A TEXTBOOK OF

Physics

FOR GRADE X

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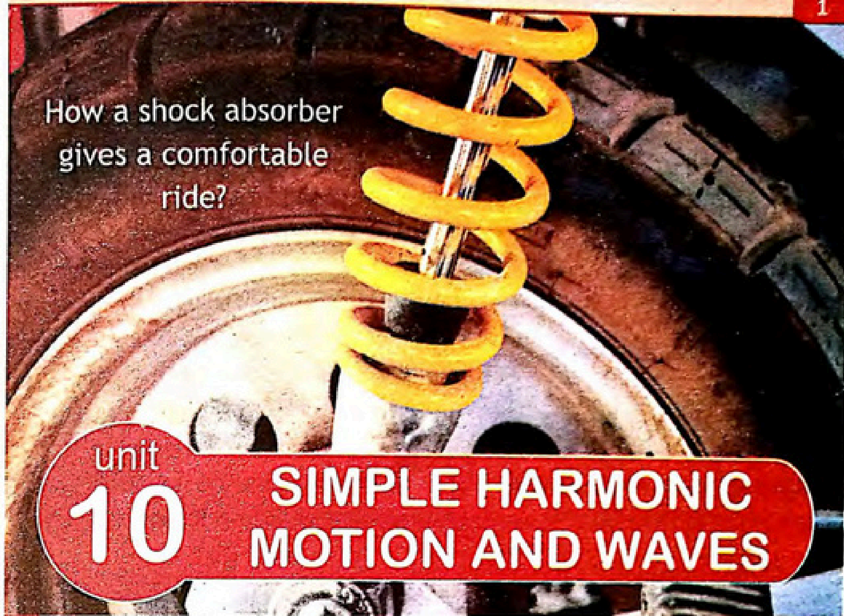
Khyber Pakhtunkhwa Textbook Board, Peshawar

Contents



unit 10 SIMPLE HARMONIC MOTION AND WAVES

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ state the conditions necessary for an object to oscillate with SHM.
- ✓ explain SHM with simple pendulum, ball and bowl examples.
- ✓ draw forces acting on a displaced pendulum.
- ✓ solve problems by using the formula $T = 2\pi\sqrt{l/g}$ for simple pendulum
- ✓ understand that damping progressively reduces the amplitude of oscillation.
- ✓ describe wave motion as illustrated by vibrations in rope, slinky spring and by experiments with water waves.
- ✓ describe that waves are means of energy transfer without transfer of matter.
- ✓ distinguish between mechanical and electromagnetic waves.
- ✓ identify transverse and longitudinal waves in mechanical media, slinky and springs.
- ✓ define the terms speed (v), frequency (f), wavelength (λ), time period (T), amplitude, crest, trough, cycle, wave front, compression and rarefaction.
- ✓ derive equation $v=f\lambda$.
- ✓ solve problems by applying the relation $f = 1/T$ and $v = f\lambda$.
- ✓ describe properties of waves such as reflection, refraction and diffraction with the help of a ripple tank.

Contents

Many objects vibrate or oscillate—an object on the end of a spring, a tuning fork, a pendulum, beating of heart, a plastic ruler held firmly over the edge of a table and gently struck, the strings of a guitar or piano, vehicles oscillate up and down when they hit a bump, buildings and bridges vibrate during an earth quake. Indeed, because most solids are elastic, they vibrate when given an impulse.

Because it is so common in everyday life and occurs in so many areas of physics, oscillatory (or vibrational) motion is of great importance. Mechanical oscillations or vibrations are fully described on the basis of Newtonian mechanics.

10.1 OSCILLATORY MOTION

The repeated back and forth motion about certain equilibrium (mean) position is termed as oscillation or oscillatory motion. The same motion repeats over and over – a particle goes back and forth over the same path in exactly the same way. Following are few terminologies associated with oscillatory motion.

A. Cycle/Vibration: One complete round trip of the vibrating body about mean position is called vibration/cycle. To complete one vibration/cycle, the particle must be at the same point and heading in the same direction as it was at the start.

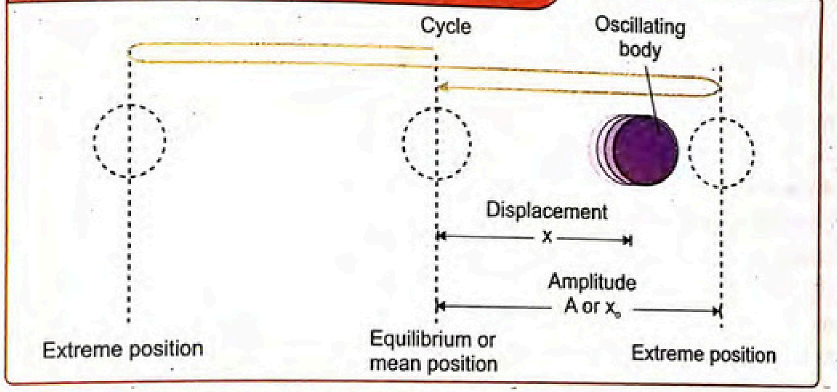
B. Time period: The time required to complete one cycle is called time period (T). The time period is measured in seconds (s).

C. Frequency: The number of cycles that the particle completes per unit time is called frequency (f). The units of frequency are cycles per second (s^{-1}), or *hertz (Hz)*.

D. Relation between time period (T) and frequency (f): Time period and frequency are reciprocal of each other.

$$T = \frac{1}{f} \qquad (10.1)$$

Figure 10.1 - Terminologies of Oscillatory Motion



E. Displacement: The distance of oscillating body from the mean position at any instant of time is called its displacement (x). Displacement is measured in metres (m).

F. Amplitude: The maximum displacement of the body from its mean position in a cycle is called amplitude (x_o). Amplitude being a length, is measured in metres (m).

EXAMPLE 10.1: FREQUENCY OF OSCILLATION

What is the frequency of oscillation if the time period is 20 ms?

GIVEN

Time period 'T' = 20 ms = 0.02 s

REQUIRED

frequency 'f' = ?

SOLUTION: Since the time period and frequency are reciprocal of each other, therefore

$$f = \frac{1}{T} \qquad \text{Putting values} \qquad f = \frac{1}{0.02\,s}$$

$$\text{Therefore} \quad f = 50\,s^{-1} = 50\,Hz \quad \text{Answer}$$

Hence, in one second the particle will vibrate 50 times for a time period of 20 ms.

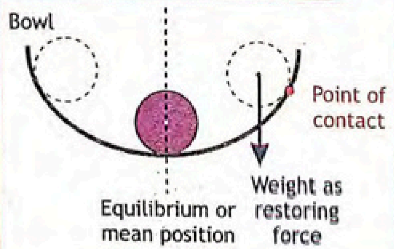
ASSIGNMENT 10.1: PERIOD OF OSCILLATION

When an object oscillates with a frequency of 0.5 Hz, what is its time period?

10.2 SIMPLE HARMONIC MOTION (SHM)

Vibration or oscillation is repeated back and forth motion along the same path. Vibrations occur in the vicinity of a point of stable equilibrium. An equilibrium point is a point at which the net force acting on the body is zero. An equilibrium point is also called stable point when at small displacements from it the net force pushes the body back to the equilibrium point. Such a force is called a restoring force since it tends to restore equilibrium.

Figure 10.2 - Harmonic Motion



Consider a bowl and ball example under stable equilibrium condition as shown in figure 10.2, when ball is displaced from its equilibrium position, it will start moving under restoring force towards equilibrium position, opposite to the displacement 'x'. After reaching equilibrium position the object will continue under inertia and will reach the other extreme position and thus it will continue to oscillate back and forth. Simple harmonic motion (SHM) is a special kind of vibratory or oscillatory motion— which occurs whenever the restoring force F_{res} is proportional to the displacement x from equilibrium. Mathematically

$$F_{res} \propto -x \qquad (10.2)$$

Where the negative sign signifies that the restoring force 'F_{res}' is directed towards the equilibrium position opposite to the displacement 'x'. We can also define simple harmonic motion in terms of acceleration as the type of motion in which the acceleration a is directly proportional to the displacement x and is directed towards the mean position. Mathematically

$$a \propto -x \qquad (10.3)$$

Equation 10.2 and equation 10.3, represent the condition for simple harmonic motion (SHM).

TIP: Harmonic Motion

Not all periodic vibrations are examples of simple harmonic motion since all restoring forces are not proportional to the displacement. Any restoring force can cause oscillatory motion. An electrocardiogram traces the periodic pattern of a beating heart, but the motion of the recorder needle is not a simple harmonic motion. As the restoring force in this case is not always proportional to the displacement from the equilibrium position.

10.3 MOTION OF MASS ATTACHED TO A SPRING

Consider a block of mass m attached to one end of elastic spring, which can move freely on a frictionless horizontal surface as shown in the figure 10.3. When the block is displaced the elastic restoring force pulls the block towards equilibrium position. For an ideal spring that obeys Hook's Law the elastic restoring force F_{res} is directly proportional to the displacement x from equilibrium position.

$$F_{res} \propto -x$$

Since F and x always have opposite directions therefore we have a negative sign in equation. Each spring is different, and so is the force required to deform it.

The stiffness of the spring, or spring constant, is represented by the letter k. The equation for Hooke's law is

$$F_{res} = -kx \qquad (1)$$

Thus motion of mass attached to spring is SHM. Restoring force produces acceleration in the body, given by newton's second law of motion as

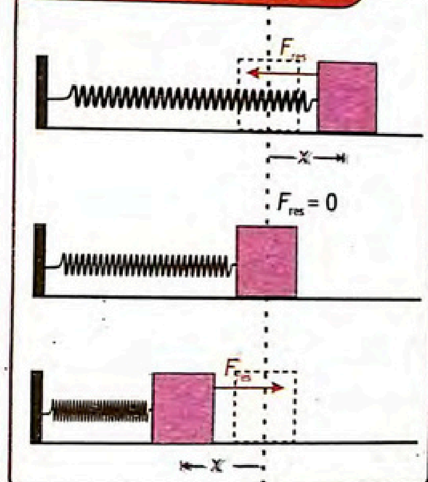
$$F_{res} = ma \qquad (2)$$

Comparing equation 1 and equation 2, we get

$$ma = -kx$$

or $$a = -\frac{k}{m}x \qquad (10.4)$$

Figure 10.3 - Mass Spring System



As spring constant k and mass m does not change during oscillation of mass attached to spring therefore they are regarded as constants

$$a \propto -x$$

If the restoring force obeys Hooks law precisely, the oscillatory motion of mass attached to spring is simple harmonic.

EXAMPLE 10.2: SPRING RESTORING FORCE

A spring has a spring constant of 48.0 N/m. This spring is pulled to a distance of 55 cm from equilibrium. What is the restoring force?

GIVEN

Displacement 'x' = 55 cm = 0.55 m

Spring constant k = 48.0 N/m

REQUIRED

Restoring force 'F_{res}' = ?

SOLUTION: Figure 10.4 shows that displacement to the right is positive, so the restoring force is negative because it is to the left, according to Hooke's law.

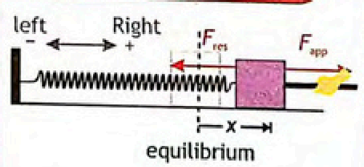
$$F_{res} = -kx$$

Putting values $F_{res} = -48\frac{N}{\cancel{m}} \times 0.55\cancel{m}$

$$F_{res} = -26.4N \quad \text{Answer}$$

The restoring force is 26.4 N [left].

Figure 10.4 - *Example 10.2*



ASSIGNMENT 10.2: SPRING RESTORING FORCE

Determine the restoring force of a spring displaced 1.5 m, with the spring constant of 30.0 N/m.

10.3.1 Time period 'T' and frequency 'f' of mass spring system: Since acceleration in SHM is

$a = -\text{constant}\,x$ Where Constant $= \frac{4\pi^2}{T^2}$

Therefore $a = -\frac{4\pi^2}{T^2}x$ —— ①

TIP: Angular Frequency

Angular frequency is the measure of angular displacement per unit time.

From equation 10.4, we have $a = -\frac{k}{m}x$ —— ②

Comparing equation 1 and 2, we get $\cancel{-}\frac{k}{m}\cancel{x} = \cancel{-}\frac{4\pi^2}{T^2}\cancel{x}$

or $\frac{k}{m} = \frac{4\pi^2}{T^2}$ re-arranging $T^2 = 4\pi^2\frac{m}{k}$

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Taking square root on both sides we have $\sqrt{\cancel{T^2}} = \sqrt{4\cancel{\pi^2}}\sqrt{\frac{m}{k}}$

Time-period 'T' is the time it takes for the mass spring system to complete one vibration, and is given by the following equation:

hence $T = 2\pi\sqrt{\frac{m}{k}}$ —— 10.5

Where 'm' is the mass in kg and 'k' is the spring constant in N/m of mass spring system. It is worth noting that time period does not depend upon amplitude of oscillation. Since frequency is the reciprocal of time period therefore the frequency of mass spring system is given as

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \text{—— 10.6}$$

EXAMPLE 10.3: MASS OF OSCILLATING MASS SPRING SYSTEM

What is the mass of a vertical mass-spring system if it oscillates with a period of 2.0 s and has a spring constant of 20.0 N/m?

GIVEN

Spring constant 'k' = 20 N/m

Time Period 'T' = 2.0 s

REQUIRED

Mass 'm' = ?

SOLUTION: The time period for mass spring system is

$T = 2\pi\sqrt{\frac{m}{k}}$ squaring $T^2 = \left[2\pi\sqrt{\frac{m}{k}}\right]^2$

or $T^2 = 4\pi^2 \times \frac{m}{k}$ isolating m $m = \frac{T^2 \times K}{4\pi^2}$

Putting values $m = \frac{(2.0\,s)^2 \times 20.0\,N/m}{4 \times (3.14)^2}$ as $N = kg\,m/s^2$

so $m = \frac{4.0\cancel{s^2} \times 20.0\frac{kg\cancel{m}}{\cancel{s^2}\cancel{m}}}{4 \times 9.86}$

Therefore $m - 2.02\,kg - 2\,kg$ —— Answer

The mass of the mass-spring oscillator is 2.0 kg.

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ASSIGNMENT 10.3: TIME PERIOD OF MASS SPRING SYSTEM

A body of mass 0.2 kg is attached to a spring placed on a frictionless horizontal surface. The spring constant of spring is 4 N/m. Find the time period of oscillating mass spring system.

10.4 SIMPLE PENDULUM

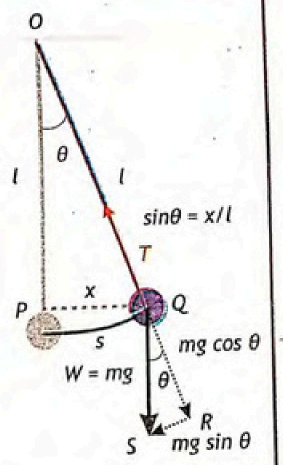
A simple pendulum is an idealized model consisting of a point mass suspended by a weightless, in-extendable string supported from a fixed frictionless support.

A simple pendulum is driven by the force of gravity due to the weight of suspended mass 'm' ($W = mg$). A real pendulum approximates a simple pendulum if

- the bob is small compared with the length l,
- mass of the string is much less than the bob's mass, and
- the cord or string remains straight and doesn't stretch.

Pull the pendulum bob aside and let it go; the pendulum then swings back and forth. Neglecting air drag and friction at the pendulum's pivot, these oscillations are periodic. We shall show that, provided the angle is small, the motion is that of a simple harmonic oscillator. As shown in figure 10.5, for ΔQRS we resolve the weight ($W = mg$) in to two components '$mg\sin\theta$' and '$mg\cos\theta$'. The component '$mg\cos\theta$' is balanced by the Tension 'T' in the string. The restoring force is only provided by component '$mg\sin\theta$'. Therefore

Figure 10.5 - Simple Pendulum



$$F_{rest} = -mg\sin\theta \quad \text{(1)}$$

Also note in the figure that only for small angles the arc length 's' is nearly the same length as *displacement* 'x'.

Therefore from ΔOPQ $\quad \sin\theta = \frac{x}{l} \quad \text{(2)}$

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Putting equation 2 in equation 1 $\quad F_{rest} = -mg\frac{x}{l} \quad \text{(3)}$

Since mass 'm', acceleration due to gravity 'g' and length 'l' are constant for simple pendulum oscillating with small angle, therefore

$$F_{res} \propto -x$$

Which is the condition for simple harmonic motion. *Thus motion of simple pendulum can be approximated as is simple harmonic motion.*

Also by Newton's second law of motion $\quad F_{rest} = ma \quad \text{(4)}$

Comparing equation 3 and equation 4 $\quad \cancel{m}a = -\cancel{m}g\frac{x}{l}$

$$\text{or} \quad a = -\frac{g}{l}x \quad \boxed{10.7}$$

Since g and l are constants for oscillating simple pendulum, therefore

$$a \propto -x$$

Hence, when released the mass will move towards the equilibrium position, will cross over it due to inertia and will execute Simple Harmonic Motion (SHM).

EXAMPLE 10.4: RESTORING FORCE OF SIMPLE PENDULUM

Determine the magnitude of the restoring force for a pendulum bob of mass 100.0 g that has been pulled to an angle of 10° from the vertical.

GIVEN

mass 'm' = 100 g = 0.1000 kg

acceleration due to gravity 'g' = 9.8 m/s^2

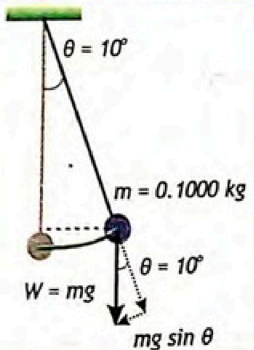
angle θ = 10°

REQUIRED

Restoring force 'F_{res}' = ?

SOLUTION: The figure 10.6 shows that the restoring force F_{res} = mg sinθ is the component of weight that is tangential to the circular path of the pendulum.

Figure 10.6 - Example 10.4



$$F_{rest} = -mg\sin\theta$$

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Putting values $F_{rest} = -0.1000kg \times 9.8ms^{-2} \sin 10^{\circ}$

or $F_{rest} = -0.98kgms^{-2} \times 0.17$

$F_{rest} = -0.167N$ —— Answer

The magnitude of the restoring force acting on the pendulum is 0.167 N.

ASSIGNMENT 10.4: CALCULATING ANGLE

At what angle must a pendulum be displaced to create a restoring force of 4.00 N on a bob with a mass of 500.0 g?

10.4.1 Time period 'T' and frequency 'f' of simple pendulum: It can be shown that the acceleration and displacement of a simple pendulum are related by its time-period T (the time it takes for the mass spring system to complete one cycle) by the following equation:

$$a = -\frac{4\pi^2}{T^2}x \quad \text{—— (1)}$$

From equation 10.7, we have $a = -\frac{g}{l}x$ —— (2)

Comparing equation 1 and 2, we get $\cancel{-}\frac{g}{l}\cancel{x} = \cancel{-}\frac{4\pi^2}{T^2}\cancel{x}$

or $\frac{g}{l} = \frac{4\pi^2}{T^2}$ re-arranging $T^2 = 4\pi^2\frac{l}{g}$

Taking square root on both sides, we have $\sqrt{T^2} = \sqrt{4\pi^2}\sqrt{\frac{l}{g}}$

Hence $T = 2\pi\sqrt{\frac{l}{g}}$ —— 10.8

Equation 10.8 shows that the time period 'T' of simple pendulum depends directly on the length 'l' of the pendulum and inversely on gravitational acceleration 'g'. The period of the pendulum does not depend on the mass of the pendulum bob. The period of a pendulum does not depend on its amplitude.

Since frequency is the reciprocal of time period therefore the frequency of simple pendulum is given as

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \quad \text{—— 10.9}$$

LAB WORK

To study the effect of the length of a simple pendulum on time, find the value of "g" by calculation.

EXAMPLE 10.5: DETERMINING GRAVITATIONAL FIELD STRENGTH

What is the gravitational field strength on planet Mercury, if a 0.500-m pendulum swings with a period of 2.30 s?

GIVEN

Time period 'T' = 2.3 s

Length 'l' = 0.500 m

REQUIRED

gravitational field strength 'g' = ?

SOLUTION: The time period for simple pendulum is

$T = 2\pi\sqrt{\frac{l}{g}}$ Squaring $T^2 = \left[2\pi\sqrt{\frac{l}{g}}\right]^2$

or $T^2 = 4\pi^2 \times \frac{l}{g}$ Isolating g $g = \frac{4\pi^2 \times l}{T^2}$

TIP: Gravitational Field

The gravitational field strength at a point is the gravitational force exerted per unit mass placed at that point.

Putting values $g = \frac{4(3.14)^2 \times 0.500m}{(2.30s)^2}$

Therefore $g = 3.73\, m/s^2 = 3.73\, N/kg$ [down]. —— Answer

The gravitational field strength at the surface of mercury is 3.73 N/kg

ASSIGNMENT 10.5: GRAVITATIONAL FIELD STRENGTH AT EVEREST

What is the gravitational field strength at the top of Mount Everest at an altitude of 8954.0 m, if a pendulum with a length of 1.00 m has a period of 2.01 s?

LAB WORK

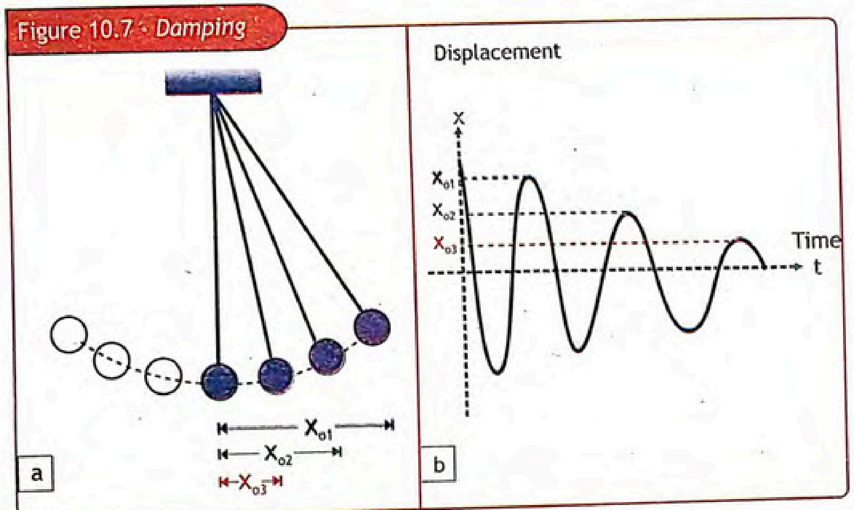
To prove that time period of a simple pendulum is independent of (i) mass of the pendulum (ii) amplitude of the vibration.

10.5 DAMPING

Any effect that tends to reduce the amplitude of vibrations is called damping.

The oscillatory motions we have considered so far have been for ideal systems that is, systems that oscillate indefinitely under the action of a linear restoring force.

Figure 10.7 : Damping



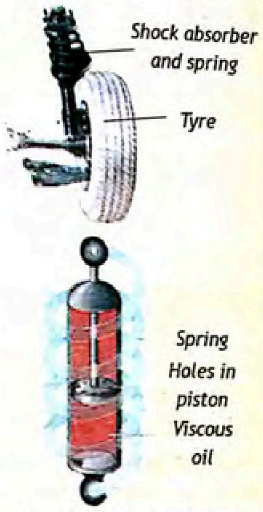
However in many real systems, resistive forces, such as friction, reduce the motion. As a result, the amplitude progressively decreases with time, and the motion is said to be damped. The motion of pendulum eventually stops if it is left untouched because the pendulum loses energy by doing work on the surrounding forces, such as air resistance and friction. The energy of the system decreases with time and eventually falls to zero and pendulum comes to rest as shown in figure 10.7.

INFO

SHOCK ABSORBERS

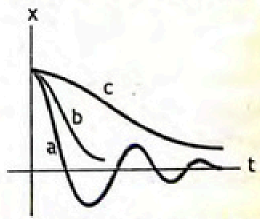
Well-designed damping is needed for certain kinds of applications. The concept of damping system is used in the car suspension system for comfortable ride.

One widely used application of damped harmonic motion is in the suspension system of an automobile. Figure shows a shock absorber attached to a main suspension spring of a car. A shock absorber is designed to introduce damping forces, which reduces the vibrations associated with a bumpy ride. As the drawing shows, a shock absorber consists of a piston in a reservoir of oil. When the piston moves in response to a bump in the road, holes in the piston head permit the piston to pass through the oil. Viscous forces that arise during this movement cause the damping.



Shock absorber and spring

The graph shows three types of damped motions, with curve (a) representing under-damped oscillation. Whereas the curve (b) shows that if the fluid viscosity is increased, the object returns rapidly to equilibrium after it's released and doesn't oscillate. In this case, the system is said to be critically damped. If the viscosity is increased further, the system is said to be over-damped. In this case the time required to reach equilibrium is greater than in critical damping, as illustrated by curve (c).



Graphs of displacement versus time for (a) an underdamped oscillator, (b) a critically damped oscillator, and (c) an overdamped oscillator.

10.6 NATURE OF WAVES AND THEIR TYPES

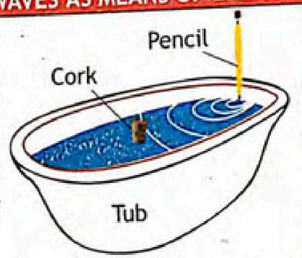
A wave is a disturbance that moves outward from its point of origin, transferring energy by means of vibrations with little or no transport of medium.

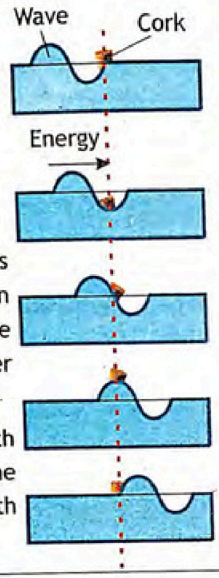
There are two common features to all waves:

1. A wave is a traveling disturbance.
2. A wave carries energy from place to place.

ACTIVITY: WATER WAVES AS MEANS OF ENERGY TRANSFER

Take a tub full of water, move a pencil up and down at one edge of the tub. Waves are produced on the water surface which move away from the point of impact of the pencil.





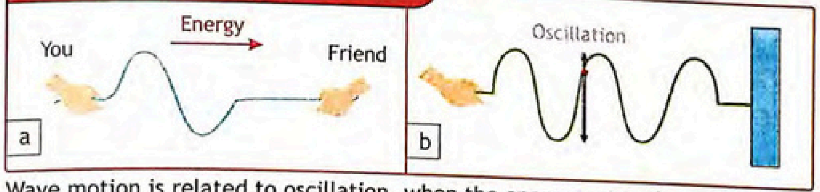
Place a cork in the middle of the tub. You can see that as the waves passes through the cork it will move up and down about its place. The energy which is spent in moving the pencil up and down reaches the cork by means of water waves due to which it is also moves up and down.

Notice that during this process the cork does not move with waves, it only moves up and down which shows that the particles of matter (water) does not move forward with waves instead they oscillate about their mean position.

A wave is a disturbance that transfers energy through a medium. While the disturbance and the energy that it carries, moves through the medium, the matter does not experience net movement. Instead, each particle in the medium vibrates about some mean (or rest) position as the wave passes.

Both particles and waves carry energy but there is an important difference in how they do this. Think of a ball as a particle. If you toss the ball to a friend, the ball moves from you to your friend and carries energy, this is not wave motion because matter is transported. However, if you and your friend hold the ends of a rope and you give your end a quick shake, the rope remains in your hand and the energy can be felt by your friend on the other end of the rope. Even though no matter is transferred, the rope still carries energy through the wave that you created as shown in figure 10.8 (a).

Figure 10.8 - *Simple Harmonic Motion*



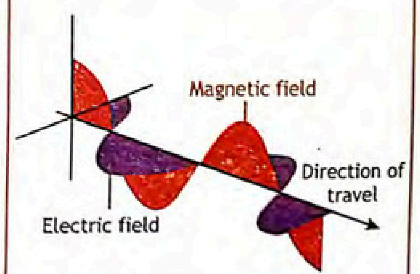
Wave motion is related to oscillation, when the energy moves through the wave the particles of the medium executes simple harmonic motion about their equilibrium position. For example, take a rope and color a part of it. Attach one end of the rope to the wall and wiggle the other end regularly and continuously. The number of waves will be produced forming a wave train. Observe the color marking, it will execute oscillations about certain mean position, as shown in figure 10.8 (b).

When a stone is dropped in a pond water, ripples (waves) are seen on the surface of water. The particles of water that absorb energy and start oscillating from the impact of the stone. These particles transfer some of its energy to the neighboring particles which also start vibrating. In this way gradually other particles on the water surface also start oscillating and energy is spread out throughout the water pond.

10.6.1 Types of waves: The waves are mainly of two kinds: mechanical waves, and electromagnetic waves.

i. Mechanical waves: *The waves produced by oscillation of material particles are called mechanical waves.* Mechanical waves are very familiar; common examples include water waves, sound waves, seismic waves, etc. These waves can exist only within a material medium.

Figure 10.9 - *Electromagnetic waves*



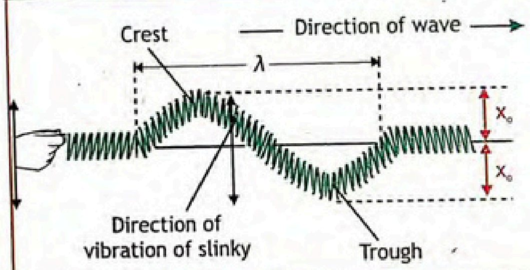
ii. Electromagnetic waves: *The waves that propagate by oscillation of electric and magnetic fields are called electromagnetic waves, they do not require material medium for their propagation.* The wave is a combination of travelling electric and magnetic fields.

The fields vary in value and are directed at right angles to each other and to the direction of travel of the wave, as shown by the representation in Figure 10.9. The common examples of electromagnetic waves are visible and ultraviolet light, radio waves, microwaves, x-rays etc.

Waves can also be classified as transverse and longitudinal in terms of the directions of disturbance or displacement in the medium and that of the propagation of wave.

i. **Transverse waves:** *A transverse wave is one in which the disturbance occurs perpendicular to the direction of motion of the wave.* Radio waves, light waves, and microwaves are transverse waves. Transverse waves also travel on the strings of instruments such as guitars and banjos.

Figure 10.10 - *Transverse wave in slinky*



Crest: *The part of wave above the equilibrium position is called crest.*

Trough: *The part of wave below the equilibrium position is called trough.*

Figure 10.10 shows transverse wave can be generated using a Slinky*(a long loosely coiled spring)*. If one end of the Slinky is jerked up and down, an upward pulse is sent traveling toward the right. If the end is then jerked down and up, a downward pulse is generated and also moves to the right.

TIP: AM and FM

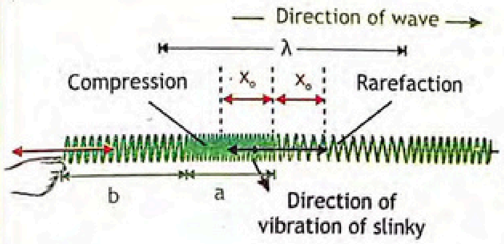
AM and FM radio waves are transverse waves consisting of electric and magnetic disturbances traveling at a speed of 3.00×10^8 m/s.

If the end is continually moved up and down in simple harmonic motion, an entire wave is produced.

ii. **Longitudinal wave:** *A longitudinal wave is one in which the disturbance occurs parallel to the line of travel of the wave.* A sound wave is a longitudinal wave.

A longitudinal wave can also be generated with a slinky, as shown in Figure 10.11. When one end of slinky is pushed forward and backward along its length (i.e., longitudinally) two regions are formed.

Figure 10.11 - *Longitudinal Waves in slinky*



Compressions: *The regions of high density and pressure relative to the equilibrium density or pressure of the medium are termed as compressions.*

Rarefactions: *The regions of low density and pressure relative to the equilibrium density or pressure of the medium are termed as rarefactions.*

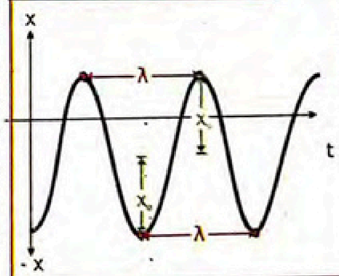
The region where the parts of slinky are compressed together (called compression) is seen moving towards the right. The region where the parts of slinky are stretched apart (called rarefaction) is also seen moving towards the right.

10.6.2 Characteristic Wave Parameters: There are many ways to describe or measure a wave. Some characteristics depend on how the wave is produced, whereas others depend on the medium through which the wave travels. Certain characteristic wave parameters and their definitions are given as under.

i. **Wavelength 'λ':** *The shortest distance between points where the wave pattern repeats itself is called the wavelength, its symbol is the Greek letter lambda 'λ'.*

The unit of wavelength is '*m*'. The wavelength is the repeated distance of the wave pattern—a shift of the wave pattern by one wavelength to the right (or the left) reproduces the original wave pattern. The wave length may be the distance between two successive crests or troughs as shown in figure 10.10 and figure 10.12, or it may be the distance between two successive compressions as shown in figure 10.11.

Figure 10.12 - *Wavelength*



Amplitude x_o or A: *The amplitude A of a wave is the magnitude of the maximum displacement of the elements of wave from their equilibrium positions as the wave passes through them.* Amplitude is represented by x_o or *A* and the unit of amplitude is *m*. As shown in figure 10.10, figure 10.11 and figure 10.12.

Wave Cycle: *As a wave passes a given point along its path, that point undergoes cyclic motion. The point is displaced first in one direction and then in the other direction. Finally, the point returns to its original equilibrium position, thereby completing one cycle.*

Frequency f: *The number of wave cycles (N) passing through a certain point (P) in unit time (t) is called frequency.* The unit of frequency is hertz (Hz).

$$f = \frac{N}{t} \quad \text{——} \quad \boxed{10.10}$$

Figure 10.13: Frequency

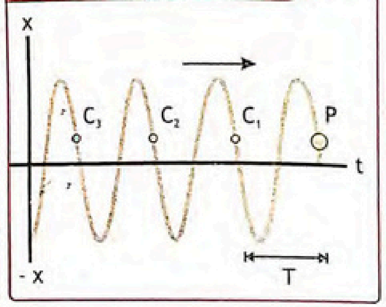


Figure 10.13 shows three cycles C_1, C_2 and C_3 approaching point P if these cycles cross point P in one second then frequency will be 3 hertz.

Time Period T: *The time required for one wave cycle to pass through a certain point is called Time Period T.* The unit of time period is seconds (s).

It is the time any vibrating element of wave takes to move through one complete oscillation as shown in figure 10.13. Time period is the reciprocal of frequency.

$$T = \frac{1}{f} \quad \text{——} \quad \boxed{10.11}$$

POINT TO PONDER

Earthquake waves under Earth's surface also have both longitudinal and transverse components (called compressional or P-waves and shear or S waves, respectively). These components propagate at different speeds. For example, earthquakes also have surface waves that are similar to surface waves on water.

Wave Speed: The distance traveled by wave in unit time is called wave speed 'v'.

$$v = \frac{\text{distance}}{\text{time}} = \frac{\Delta s}{\Delta t} \quad \text{——} \quad (1)$$

The distance traveled by wave equal to one wavelength 'λ' ($\Delta s = \lambda$) is covered in time equal to time period T ($\Delta t = T$), therefore equation 1 can be written as

$$v = \frac{\lambda}{T} \quad \text{——} \quad (2)$$

Since time period 'T' and frequency 'f' are reciprocal of each other, therefore

$$f = \frac{1}{T} \quad \text{——} \quad (3)$$

putting equation 3 in equation 2, we get

$$v = f\lambda \quad \text{——} \quad \boxed{10.12}$$

Equation 10.12 is also called universal wave equation as it applies to all waves and gives the wave speed in terms of frequency f and wavelength λ.

EXAMPLE 10.6: WAVE SPEED

A student vibrates the end of a spring at 2.6 Hz. This produces a wave with a wavelength of 0.37 m. Calculate the speed of the wave.

GIVEN

frequency 'f' = 2.6 Hz

wavelength 'λ' = 0.37 m

REQUIRED

speed 'v' = ?

SOLUTION: By universal wave equation $v = f\lambda$

putting values $v = 2.6 s^{-1} \times 0.37 m$

Hence $v = 0.962 ms^{-1}$ —— Answer

The answer validates; as reasonable speed for wave in a spring is about 1 m/s.

ASSIGNMENT 10.6: WAVELENGTH OF SOUND

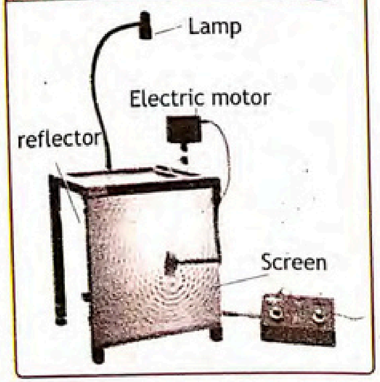
A sound wave of wavelength 1.7×10^{-2} m. Calculate the frequency of sound if its velocity is $343.4 ms^{-1}$.

10.7 PROPERTIES OF WAVES

The basic properties of two dimensional waves, such as water waves can be described with the help of ripple tank.

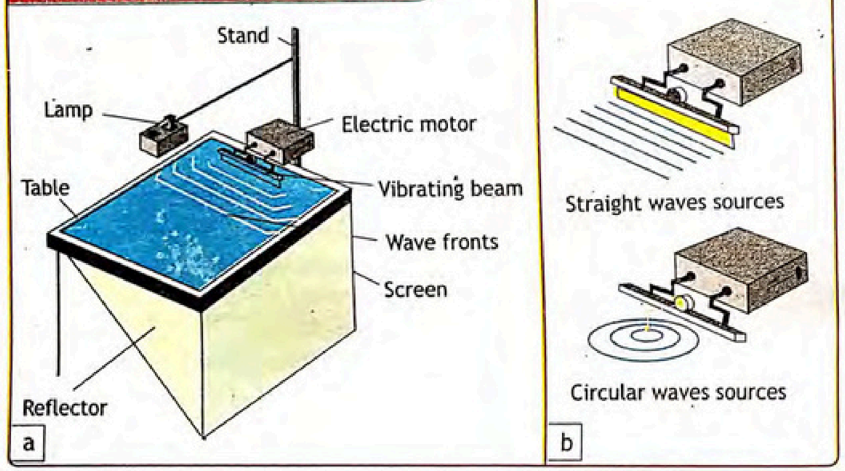
The schematic diagram and the image of ripple tank are shown in the figure 10.14. Ripple tank is an experimental setup to study the two dimensional features or characteristics of wave mechanics such as reflection, refraction and diffraction. It consist of shallow tray of water with a transparent base, usually illuminated from above, so that light shines through the water. The ripples on the water show up as shadows (bright and dark lines) on the screen underneath the tank.

Figure 10.14 - Ripple Tank



Sometimes for easy visualization, a reflector is used to project the screen on front base of the ripple tank as shown in figure 10.15 (a). Straight waves can be set up by using a straight dipper, while circular waves can be formed by using a spherical dipper. Both dipper are vibrated up and down by an electric motor as shown in figure 10.15 (b).

Figure 10.15 - Ripple Tank Illustration



NOT FOR SALE

For a two or three dimensional wave, such as a water wave, we are concerned with wave fronts, by which we mean all the points along the wave forming the wave crest (what we usually refer to simply as a "wave" at the seashore). A line drawn in the direction of wave motion, perpendicular to the wave front, is called a ray, as shown in Figure 10.16.

Figure 10.16 - Wavefront

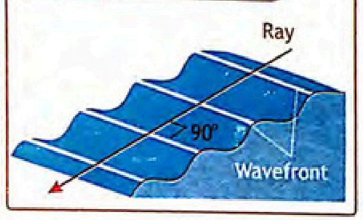
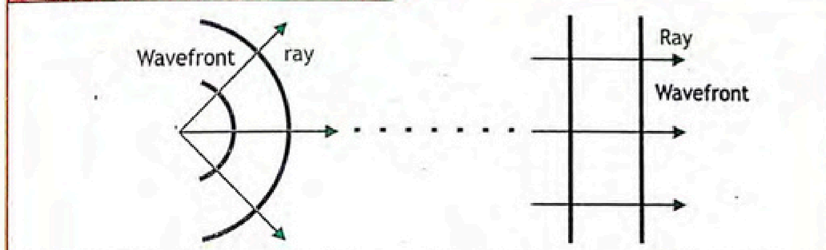


Figure 10.17 - Rays and wavefronts

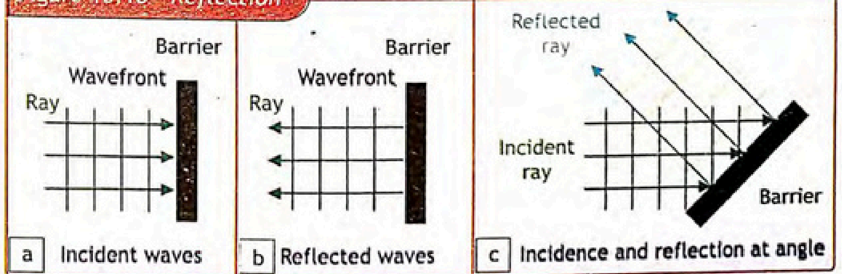


Rays, signifying the direction of wave motion, are always perpendicular to the wave fronts (wave crests). (a) Circular or spherical waves near the source. (b) Far from the source, the wave fronts are nearly straight or flat, and are called plane waves.

Wave fronts far from the source have lost almost all their curvature (Figure 10.17) and are nearly straight, as ocean waves often are. They are then called plane waves.

A. Reflection: Reflection is the change in direction of a wave-front at an interface between two different media or rigid barriers so that the wave-front returns into the medium from which it is originated.

Figure 10.18 - Reflection



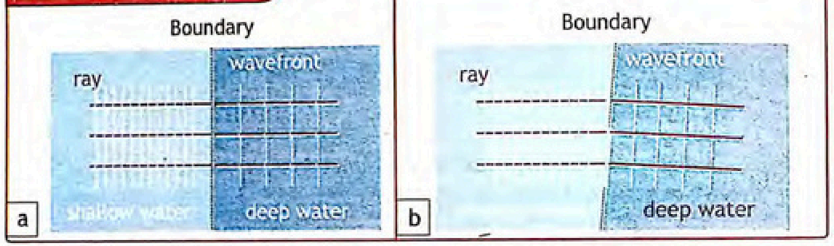
NOT FOR SALE

When waves run into a straight barrier, as shown in figure 10.18 (a), they are reflected back along their original path as shown in figure 10.18 (b). However, if a wave hits a straight barrier obliquely as shown in figure 10.18 (c), the wave-front is reflected at an angle to the barrier.

In ripple tank reflection can be demonstrated by placing an upright barrier in tray and the reflection of water can be seen.

A. Refraction: When waves travel from one medium into another, their speed changes. This phenomenon is called refraction. When a water wave enters a medium in which it moves more slowly, its wavelength decreases as well. This could have been predicted using the universal wave equation, since we can conclude that $\lambda \propto v$.

Figure 10.19 - *Refraction*



We can demonstrate this effect in water waves in ripple tank without even changing from water to another medium. Refraction occurs in water because the speed of waves in water is influenced by the depth of the water.

We can observe refraction occurring in the ripple tank if we place a thick sheet of plastic in the tray. When the wave travels from shallow to deep water, we can observe that its wavelength, and hence its speed, changes. If the wave crosses the boundary between the two depths straight on, no change in direction occurs. On the other hand, if a wave crosses the boundary at an angle, the direction of travel does change, again by equation $v = f\lambda$ as shown in figure 10.19.

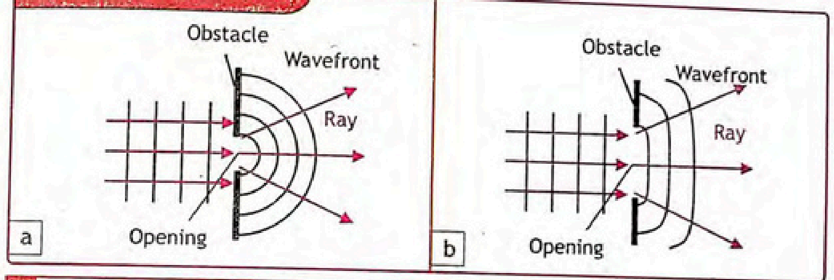
C. Diffraction: The bending of waves around corners of an obstacle is called diffraction. When waves pass through an aperture or opening it spreads out due to diffraction.

We can observe diffraction in water waves in ripple tank by generating straight waves and place two obstacles in such a way that the separation is comparable to the size of the wavelength.

After passing through the opening, waves spread out in every direction and turn into circular waves. This effect is greatest when the size of the opening is less than or equal to the size of the wavelength of generated waves. It must be noted that wavelength (or speed) of the wave is not affected by diffraction.

If the separation is large between obstacle compared to the wavelength, it can be seen that central part of the wave is not affected, only part of the wave at the edges diffract as shown in the figure 10.20.

Figure 10.20 - Diffraction



KEY POINTS

- **Oscillation:** The repeated motion back and forth about certain equilibrium (mean) position.
- **Simple Harmonic Motion:** The type of vibratory motion in which acceleration is directly proportional to displacement and is directed towards the mean position.
- **Time period:** Time required to complete one oscillation.
- **Frequency:** Number of cycles in unit time.
- **Wave:** Energy transfer mechanism without the transport of material medium.
- **Mechanical waves:** Wave that require material medium for their propagation.
- **Electromagnetic waves:** Waves which does not require material medium for its propagation.
- **Transverse waves:** The waves in which the particles of the medium oscillates perpendicular to the direction of motion of wave.
- **Longitudinal waves:** The waves in which the particles of the medium oscillates parallel to the direction of motion of wave.
- **Diffraction:** Bending of waves around the edges of an obstacle.

PRO

GROUP A 'EARTHQUAKE': Research earthquakes and different kinds of seismic waves. Also try to figure out the reason behind devastating earthquake that occurred at 08:50:39 Pakistan Standard Time on 8 October in Kashmir. Create a classroom presentation.

PROJECTS

GROUP B 'TWO SPRING-MASS SYSTEM': Design an experiment to compare the spring constant and period of oscillation of a system built with two (or more) springs connected in two ways: in series (attached end to end) and in parallel (one end of each spring anchored to a common point). If your teacher approves your plan, obtain the necessary equipment and perform the experiment, prepare a presentation to share your result with your class fellows.

GROUP C 'ANGLE IN SIMPLE PENDULUM': The rule that the period of a pendulum is determined by its length is a good approximation for amplitudes below 15°. Design an experiment to investigate how amplitudes of oscillation greater than 15° affect the motion of a pendulum. List what equipment you would need, what measurements you would perform, what data you would record, and what you would calculate. If your teacher approves your plan, obtain the necessary equipment and perform the experiment, prepare a presentation to share your result with your class fellows.

GROUP D 'TSUNAMI': Read litrature and search what are tsunamis, how they are formed. Also figure out the cause of destructing tsunami in 2004 at Indian Ocean. Write an article for school library.

GROUP E 'DEFINING TERMS': Make a chart of definitions of the terms used in oscillations and waves such as speed (v), frequency (f), wavelength (λ), time period (T), amplitude, crest, trough, cycle, wave front, compression and rarefaction and display it in your classroom.

EXERCISE

MULTIPLE CHOICE

1. A transverse wave on a string has an amplitude A. A tiny spot on the string is colored red. As one cycle of the wave passes by, what is the total distance traveled by the red spot?
   A. A B. 2A C. $\frac{1}{2}$A D. 4A
2. Which of the following does not affect the period of the mass-spring system?
   A. mass B. spring constant
   C. amplitude of vibration D. All of the above affect the period.
3. An object of mass 'm' oscillates on the end of a spring. To double the period, replace the object with one of mass:
   A. 2 m B. m/2 C. 4 m D. m/4

QUESTIONS

4. A car mounted on shock absorbers is like a mass on a spring. If we ignore damping, how will the frequency of the oscillations change if passengers (or a heavy load) are added to the car? The frequency will
   A. increase B. decrease, C. stay the same D. be zero
5. If the pendulum completes exactly 12 cycles in 2.0 min, what is the frequency of the pendulum?
   A. 0.10 Hz B. 0.17 Hz C. 6.0 Hz D. 10 Hz
6. A certain pendulum has an iron bob. When the iron bob is replaced with lead bob of the same size, its time period will
   A. stay the same B. decrease C. increase D. be zero
7. A wave transports
   A. energy but not matter B. matter but not energy
   C. both energy and matter D. air
8. The bending of waves around the edges of the obstacle is
   A. reflection B. refraction C. diffraction D. damping

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. Is every oscillatory motion simple harmonic? Give examples.
2. For a particle with simple harmonic motion, at what point of the motion does the velocity attain maximum magnitude? Minimum magnitude?
3. Is the restoring force on a mass attached to spring in simple harmonic motion ever zero? If so, where?
4. If we shorten the string of a pendulum to half its original length, what is the affect on its time period and frequency?
5. A thin rope hangs from dark high tower so that its upper end is not visible. How can the length of rope be determined?
6. Suppose you stand on a swing instead of sitting on it. Will your frequency of oscillation increase or decrease?
7. Explain the difference between the speed of a transverse wave traveling along a cord and the speed of a tiny colored part of the cord.
8. Why waves refract at the boundary of shallow and deep water?
9. What is the effect on diffraction if the opening is made small?

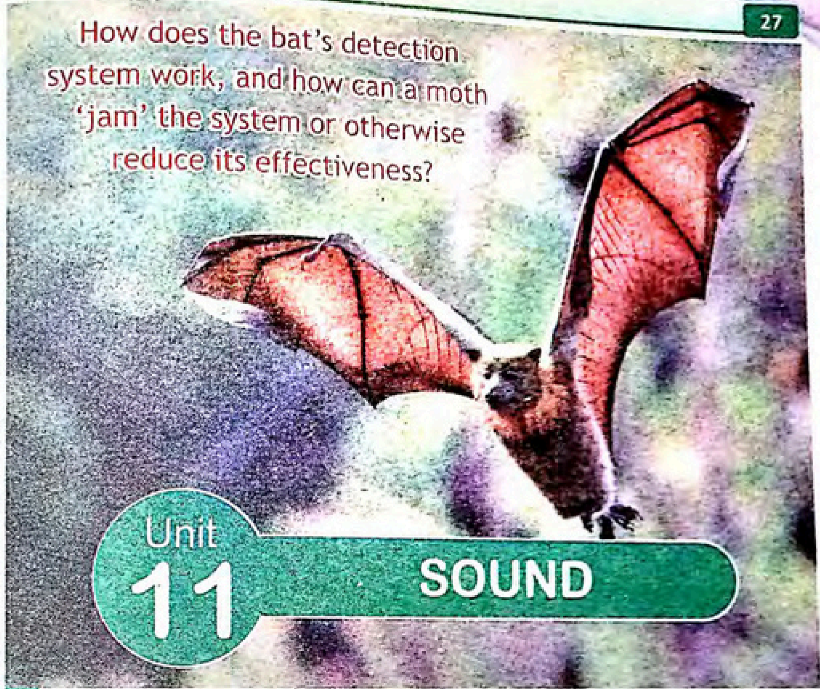
COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

1. What is Simple Harmonic Motion (SHM)? What are the conditions for an object to oscillate with SHM?
2. Show that the mass spring system executes Simple Harmonic Motion (SHM).
3. What is simple pendulum? Diagrammatically show the forces acting on simple pendulum. Also show that simple pendulum executes simple harmonic motion.
4. What is wave motion? How waves can be categorized?
5. How waves transport energy without carrying the material medium? Also describe the connection between oscillatory motion and waves.
6. Prove the relation between wave speed, wavelength and frequency of wave.
7. Using ripple tank explain reflection, refraction and diffraction of waves.

NUMERICAL QUESTIONS

1. A mass hung from a spring vibrates 15 times in 12 s. Calculate (a) the frequency and (b) the period of the vibration.
2. A spring requires a force of 100.0 N to compress it to a displacement of 4 cm. What is its spring constant?
3. A second pendulum is a pendulum with period of 2.0 s. How long must a second pendulum be on the Earth ($g = 9.81\ m/s^2$) and Moon (where $g = 1.62\ m/s^2$)? What is the frequency of second pendulum at earth and on Moon?
4. Calculate the period and frequency of a propeller on a plane if it completes 250 cycles in 5.0 s.
5. Water waves with wavelength 2.8 m, produced in a ripple tank, travel with a speed of 3.80 m/s. What is the frequency of the straight vibrator that produced them?
6. The distance between successive crests in a series of water waves is 4.0 m, and the crests travel 9.0 m in 4.5 s. What is the frequency of the waves?
7. A station broadcasts an AM radio wave whose frequency is 1230×10^3 Hz (1230 kHz on the dial) and an FM radio wave whose frequency is 91.9×10^6 Hz (91.9 MHz on the dial). Find the distance between adjacent crests in each wave.



STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ explain how sound is produced by vibrating sources and that sound waves require a material medium for their propagation.
- ✓ describe the longitudinal nature of sound waves (as a series of compressions and rarefactions).
- ✓ define the terms pitch, loudness and quality of sound.
- ✓ describe the effect of change in amplitude on loudness and the effect of change in frequency on pitch of sound.
- ✓ define intensity and state its SI unit.
- ✓ describe what is meant by intensity level and give its unit.
- ✓ explain that noise is a nuisance.
- ✓ describe how reflection of sound may produce echo.
- ✓ describe audible frequency range.
- ✓ describe the importance of acoustic protection.
- ✓ solve problem based on mathematical relations learnt in this unit.

C O N T E N T S

Hearing is perhaps the one sense we take for granted the most. We often do not realize the different sounds that goes through our ears on minute-to-minute basis. It's probably the first thing we experience when we wake up in the morning – when we hear birds chirping or our alarm clock bleeping away. Sound fills our days with excitement and meaning, when people talk to us, when we listen to music, or when we hear interesting programs on the radio and TV.

At times it may be displeasing in the form of noise, but that is the lively world around us. In this unit we will describe sound as waves, its characteristics, speed and reflection.

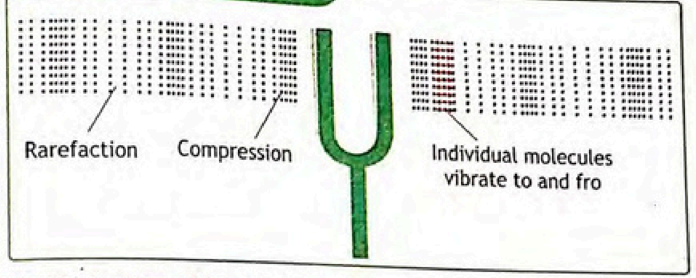
11.1 SOUND WAVES

Sound waves are longitudinal waves traveling through a medium, such as air.

Sound wave is created by a vibrating object, such as a guitar string, the human vocal cords, or the diaphragm of a loudspeaker. Moreover, sound can be transmitted only in a medium, such as a gas, liquid, or solid. As we will see, the particles of the medium must be present for the creation of disturbance and the sound wave to move from place to place. Sound cannot exist in a vacuum.

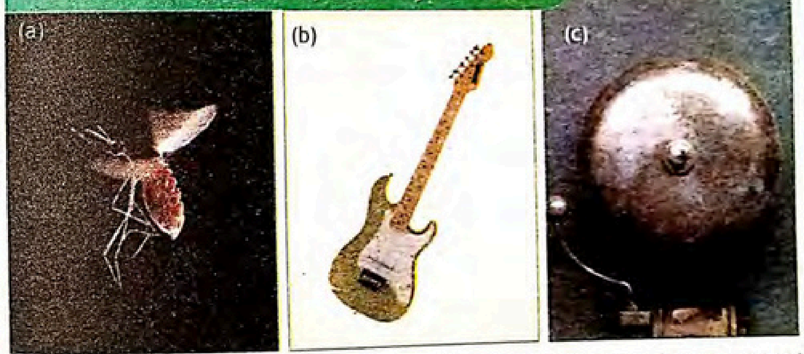
For example, consider a tuning fork, a common device for producing pure musical notes. A tuning fork consists of two metal prongs, or tines, that vibrate when struck. Their vibration disturbs the air near them, as shown in Figure 11.1. When a tine swings to the right, the molecules in an element of air are forced closer together than normal. Such a region of high molecular density and high air pressure is called a *compression*. When the tine swings to the left, the molecules in an element of air to the right of the tine spread apart, and the density and air pressure in this region are then lower than normal. Such a region of reduced density is called a *rarefaction*. The rarefaction itself therefore moves, following the previously produced compression. As the tuning fork continues to vibrate, a succession of compressions and rarefactions forms and spreads out from it.

FIGURE 11.1 - Tunning Fork



11.1.1: Production of Sound: Some disturbance and vibration is needed for the production of sound, as seen in the tunning fork experiment. As shown in figure 11.2 similar observations can be made from buzzing sound of bees or mosquitoes; the sound is produced due to rapid vibrations of their wings. Sound in sitar or guitar is produced by vibration of the stretched string. The sound of school bell is produced by vibrations in its steel gong (half-sphere) when it is struck by a spring-loaded arm.

FIGURE 11.2 - Examples of sound by vibrations

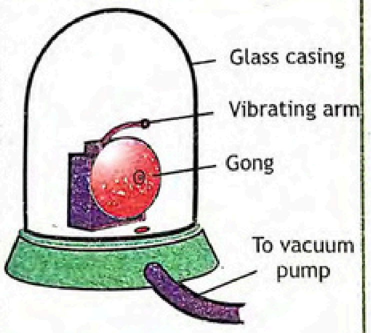


11.1.2 Transmission of sound: Since sound is a longitudinal mechanical wave it also requires the transmitting medium. In tuning fork experiment, the compressions and rarefactions that were produced in air were used to carried sound. However, sound can be transmitted through other media (such as other gases and even liquids and solids). For example, children at play may discover that sound travels very easily along a metal fence. Swimmers notice that they can hear a distant motorboat better with their ears under the water than in the air. In both these examples, sound is traveling in a material other than air.

Nevertheless sound does require a material medium for its propagation and it cannot travel through vacuum.

ACTIVITY

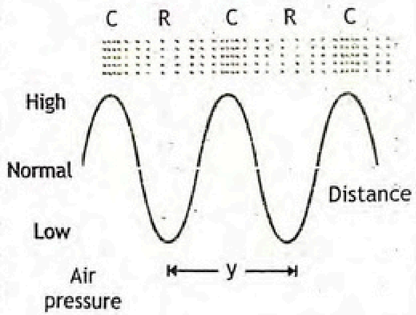
The bell in jar experiment is shown in figure, it demonstrates that sound does require a material medium for its propagation and it cannot travel through vacuum. An electric bell is sealed inside a bell jar and a vacuum pump to remove the air. When the electric bell is turned on, it produces a loud ringing sound. As the vacuum pump removes the air from the bell jar, the loudness of the ringing decreases.



If the vacuum pump is a good one, the sound of the bell will almost be eliminated.

SOUND PROPAGATION

Sound, like all waves, travels at a certain speed and has the properties of frequency 'f' and wavelength 'λ'. Figure shows a graph of air pressure as a function of distance from a source. There are crests in the sinusoidal wave at points where the sound wave has compressions and troughs where the sound wave has rarefactions.



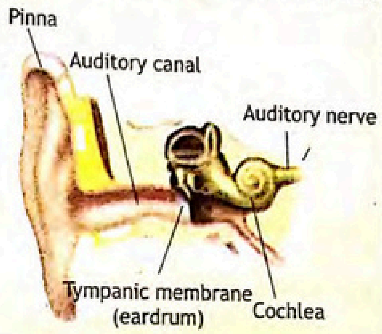
11.1.3 Detection of sound: Sound can be detected by various means, ear is one such biological organ. Ear converts sound waves into perception of hearing. Perception is commonly defined to be awareness through the senses, a typically circular definition of higher level processes in living organisms.

Microphones detect sound by converting it to electrical signals. The persons impaired of hearing detects the sound with artificial hearing devices.

PHYSICS OF HEARING

The hearing mechanism involves some interesting physics. Figure shows the anatomy of the ear with its division into three parts: the outer ear or ear canal; the middle ear, which runs from the eardrum to the cochlea; and the inner ear, which is the cochlea itself. The body part normally referred to as the ear is technically called the pinna.

The sound wave that enters our ear is a pressure wave, which sets eardrum into motion. Oscillation of ear drum causes oscillation in the fluid-filled inner ear; the motion of the fluid disturbs hair cells within the inner ear, which transmit nerve impulses to the brain with the information that a sound is present.



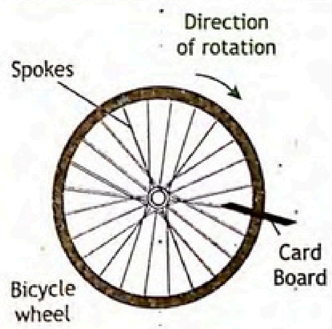
11.2 CHARACTERISTICS OF SOUND

Few characteristics on which one sound can be distinguished from another are pitch, loudness and quality (or timber).

11.2.1 Pitch: Pitch distinguishes shrill sound from grave sound. The pitch of a note depends on the frequency of the sound wave reaching the ear. A high-pitched note has a high frequency and a short wavelength. A low pitched note has a low frequency and a long wavelength.

ACTIVITY

Support a bicycle on its stand and rotate its rear wheel. Hold a piece of cardboard in your hand with its free end touching the spokes of the rotating wheel. The sound will be produced, as you increase the speed of rotation the spokes touching per unit time to the cardboard will increase, which will increase the frequency. As a result, sound produced will become shriller (of a higher pitch).



For example the sound produced by man, dogs, frogs etc are of low pitch whereas the sound produced by women, birds, cats etc are of high pitch. Pitch is like colour in light; both depend on the frequency.

11.2.2 Loudness: The greater the sound energy, the louder is the sound. The loudness depends upon the amplitude (height) of the sound wave.

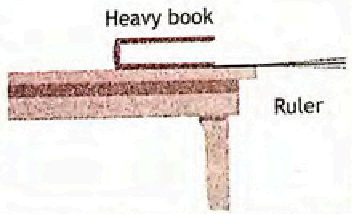
Loudness depends upon the following factors:

- The area of vibrating body: Larger the area of vibration larger will be amplitude of sound produced.
- Distance from the source of sound: The farther away, the smaller the amplitude.
- Material through which sound is traveling: Amplitude of sound wave is different in different materials such as water and air.

For example, a drum produces loud sound if its membrane is struck strongly. This is because the vibrating body starts to oscillate with larger amplitude and therefore the sound it produces also has a larger amplitude and as a result the sound is louder.

ACTIVITY

Support a ruler under a heavy load or book as shown in the figure. Twang the ruler with your hand, sound will be produced. Notice that when you gently twang the ruler, faint sound is produced and when you twang it hard, loud sound is produced. Thus by increasing the amplitude of vibration the loudness increases.



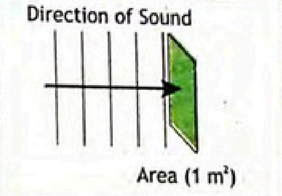
11.2.3 Quality: The property of sound by which two sounds of the same loudness and pitch are distinguished from each other. The same note on different instruments sounds different; we say the notes differ in quality or timbre.

For example, when a piano and a flute are made to produce sound of same loudness and pitch, we can easily distinguish between the overall sound from piano and flute.

11.3 SOUND INTENSITY

Intensity is a measure of the amount of sound energy reaching a unit of area in unit time (power per unit area).

FIGURE 11.3 - Intensity



In equation form, intensity I is

$$I = \frac{E}{A \times \Delta t} = \frac{P}{A} \quad \text{--- } 11.1$$

In equation 11.1, 'P' is Power (the rate at which energy 'E' is transferred by the wave per unit time 'Δt') and 'A' is the area through which sound energy is measured. Sound intensity is measured in units of **picowatts per square metre** (pW/m^2). (Note that $1.0\ pW$ is $1.0 \times 10^{-12}\ W$.)

Intensity is an objective property of the sound wave – in fact, it is related to the square of the wave amplitude, and does not depend on the particular characteristics of a person's ears. Loudness, on the other hand, is a subjective property of the sound that depends on the human ear, the sensitivity of the ear to the frequency of the sound, and the distance from the source of the sound.

10.3.1 Intensity Level: An average human ear can detect sounds with an intensity as low as $10^{-12}\ W/m^2$ and as high as $1\ W/m^2$ (and even higher, although above this, it is painful). This is an incredibly wide range of intensity, spanning a factor of 10^{12} from lowest to highest. To permit comparison of values which vary so greatly in magnitude, it is most convenient to express them in terms of their logarithms - the power to which 10 must be raised to equal the number.

Table 11.1 LOGARITHMIC INTENSITY LEVELS AND SOUND INTENSITY

Intensity level (dB)	Intensity level (B)	Intensity (pW/m^2)
0	0	1
10	1	10
20	2	100
30	3	1000
50	5	100000
100	10	10000000000

If L is the loudness and I is the sound intensity in W/m^2, then mathematically

$$L \propto \log I \qquad \text{or} \qquad L = k\log I \quad \text{—— ①}$$

Where 'k' is the constant of proportionality. If 'L_o' represents the loudness of faintest audible sound of intensity 'I_o' such that $I_o = 10^{-12}\ W/m^2$ equation 1 can be written as:

$$L_o = k\log I_o \quad \text{—— ②}$$

Subtracting equation 2 from equation 1, we get

$$L - L_o = k\log I - k\log I_o \qquad \text{or} \qquad L - L_o = k(\log I - k\log I_o)$$

$$L - L_o = k\log\frac{I}{I_o}$$

The difference between the loudness of these two loudness of sound (L - L_o) is called intensity level or intensity level (β) and is given as

$$\beta = k\log\frac{I}{I_o} \quad \text{—— ③}$$

Since β is defined in terms of a similar quantities ratio, it is unit-less. The value of k depends not only on the units of I and I_o but also on the unit of intensity level. If the intensity of any sound is ten times greater than the intensity I_o of the faintest audible sound ($I = 10\, I_o$), then intensity level of such a sound is taken as unit called bel and value of k becomes 1. Substituting k = 1, equation 3 becomes

$$\beta = \log\frac{I}{I_o} \quad (bels)$$

POINT TO PONDER

It's Zero, Not Nothing! A sound intensity level of 0 dB does not indicate that the sound wave has no intensity or amplitude. An intensity level of 0 dB corresponds to an intensity of $10^0 = 1\ pW/m^2$.

The sound intensity level scale is similar to the Celsius temperature scale — it can have negative values. A sound intensity level of −1 dB corresponds to a sound intensity of 10^{-1} or $0.1\ pW/m^2$. Similarly, an intensity level of −2 dB corresponds to an intensity of $0.01\ pW/m^2$.

- When our teacher hear us whispering with friend in class it is 20 dB, when teacher is demonstrating in the class the sound is 50 dB and when whole class is working on assignment it is 60 dB. Some values are given in table 11.2.

Table 11.2 LOGARITHMIC INTENSITY LEVELS AND SOUND INTENSITY

Source	Intensity level (dB)	Intensity (W/m^2)
threshold of hearing	0	10^{-12}
normal breathing	10	10^{-11}
average whisper at 2 m	20	10^{-10}
empty theatre	30	10^{-9}
residential area at night	40	10^{-8}
quiet restaurant	50	10^{-7}
two-person conversation	60	10^{-6}
busy street traffic	70	10^{-5}
vacuum cleaner	80	10^{-4}
loud stereo in average room	90	10^{-3}
maximum level in concert hall (13th row)	100	10^{-2}
pneumatic chisel	110	10^{-1}
maximum level at some rock concerts	120	10^{0}
propeller plane taking off	130	10
threshold of pain	140	10^{-2}
military jet taking off	150	10^{-3}
wind tunnel	160	10^{-4}
instant perforation of the eardrum	170	10^{-5}

Since bel is a large unit, **the intensity of sound is often expressed in a smaller unit called decibel (dB).** Such that

$$\beta = 10\log\frac{I}{I_o} \quad (dB) \quad \text{—— 11.2}$$

It must be remembered that 1 bel = 10 decibels.

The comparison values for different intensity levels in decibel (dB), Bel (B) and intensity in pW/m^2 is given in table 11.2.

DECIBEL SCALE

INFO

One convenient feature of the logarithmic scale is that an increase of X decibels corresponds to an increase by a particular multiplicative factor in intensity, no matter where you start from. The relative sound level, Δβ, is the difference between two sound levels:

$$\Delta\beta = \beta_2 - \beta_1$$

or $$\Delta\beta = 10\log\frac{I_2}{I_o} - 10\log\frac{I_1}{I_o}$$

or $$\Delta\beta = 10(\log I_2 - \log I_o) - 10(\log I_1 - \log I_o)$$

Hence $$\Delta\beta = 10\log I_2 - 10\log I_o - 10\log I_1 + 10\log I_o$$

or $$\Delta\beta = 10\log I_2 - 10\log I_1$$

Therefore $$\Delta\beta = 10\log\frac{I_2}{I_1} \quad \text{—— 11.3}$$

A sound level metre is a measuring instrument used to assess sound levels by measuring air pressure.

Equation 11.3 enable us to find the relative sound levels of the loudest and the quietest sounds produced by a source called dynamic range. The larger the dynamic range, the greater the range of sound intensities a device can produce or record. Manufacturers list the dynamic range for all high-end loudspeakers and headphones as well. In general, the higher the dynamic range, the better the sound quality. However, the price usually increases with the dynamic range.

EXAMPLE 11.1:

Show that if one sound is twice as intense as another. About what factor is the sound level (in dB) higher?

GIVEN

Intensity 'I_1' = I

Intensity 'I_2' = $2I$

REQUIRED

Intensity level 'Δβ' = ?

SOLUTION: the difference between two sound levels is $\Delta\beta = 10\log\frac{I_2}{I_1}$

Putting values $\Delta\beta = 10\log\frac{2I}{I}$ or $\Delta\beta = 10\log 2.0$

or $\Delta\beta = 10\times 0.301$

Hence $\Delta\beta = 3.01$ —— Answer

This means that the two sound intensity levels differ by 3.01 dB. Note that because only the ratio I_2 / I_1 is given (and not the actual intensities), this result is true for any intensities that differ by a factor of two.

For example, a 56.0 dB sound is twice as intense as a 53.0 dB sound, a 97.0 dB sound is half as intense as a 100 dB sound, and so on.

EXTENSION EXERCISE 11.1

If an increase of 3 dB means "twice as intense," what does an increase of 6 dB mean?

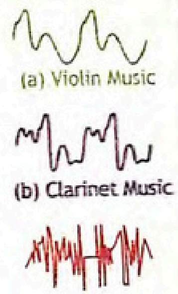
ASSIGNMENT 11.1:

Suppose that when a certain sound intensity level (in dB) triples, the sound intensity (in W/m^2) also triples. Determine this sound intensity level.

MUSIC AND NOISE

INFO

The sound that produces a pleasing sensation in the ear is called musical sound. The wave form of such sound is composed of regular and uniform vibrations as shown in figure (a) and (b), the violin and clarinet music is having regular and uniform pattern. On the other hand, the sound which produces a displeasing effect on the ear is called noise. The wave form of such sound is of irregular and disordered vibrations as shown in figure (c). The excessive displeasing sound which disrupts the balance or activity of humans or other living things is called noise pollution.



(a) Violin Music

(b) Clarinet Music

(c) Noise

11.4 SPEED OF SOUND WAVES

The speed of sound is the distance traveled per unit time by a sound wave as it propagates through a medium. Sound, like all waves, travels at a certain speed and has the properties of frequency and wavelength. At 20 °C, the speed of sound in air is 343 m/s. Sound can be transmitted through any medium—gas, liquid, or solid. The speed of sound depends on the material through which it is passing.

Children at play may discover that sound travels very easily along a metal fence. Swimmers notice that they can hear a distant motorboat better with their ears under the water than in the air.

In both examples, sound is traveling in a material other than air. You may have watched distant lightning and noticed the time lapse before the sound of thunder reaches you. This is an example of the relatively slow speed of sound compared to the speed of light. The speed of sound in water is almost five times faster than its speed in air. Sound travels most rapidly in certain solids, less rapidly in many liquids, and quite slowly in most gases. Some values are given in Table 11.3. The speed of sound 'v' can be found by dividing distance 'S' by time 't' as:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

or $$v = \frac{S}{t} \quad \text{— 11.4}$$

TABLE 11.3 THE SPEED OF SOUND

State	Material	Speed at 0°C (m/s)
Solid	aluminum	5104
	glass	5050
	steel	5050
	maple wood	4110
	bone (human)	4040
	pine wood	3320
Solid/liquid	brain	1530
Liquid	fresh water	1493 (at 25°C)
	sea water	1470
	alcohol	1241
Gas (at atmospheric pressure)	hydrogen	1270
	helium	970
	nitrogen	350 (at 20°C)
	air	332
	oxygen	317
	carbon dioxide	258

EXAMPLE 11.2:

You are standing at 1.5 km from the cannon with a stop watch. You start the stopwatch when you see the cannon flash and stop it when the sound is heard. The time recorded on your stopwatch is 4.4 s, what is the speed of sound? What is this speed in km/hr?

GIVEN

Distance 'S' = 1.5 km = 1500 m

Time 't' = 4.4 s

REQUIRED

Speed of sound 'v' = ?

SOLUTION: speed is defined as $v = \frac{S}{t}$

Putting values $v = \frac{1500\,m}{4.4\,s}$

Hence $v = 340.9090\,m/s = 341\,m/s$ — Answer

To convert m/s into km/h we apply the conversion factor

$$v = 341 \times \frac{3600}{1000}\,km/h$$

$$v = 341 \times 3.6\,km/h$$

$$v = 1227.6\,km/h = 1228\,km/h \quad \text{— Answer}$$

The speed of sound is 341 m/s or 1228 km/h.

ASSIGNMENT 11.2: LIGHTNING

If the time between seeing lightning and hearing the thunder is 5.0 s. The speed of sound is 343 m/s, how far away is the lightning?

11.4.1 The Speed of Sound in Air: The speed of sound in air depends upon the density of air and its compressibility (how easy it is to squeeze). As temperature increases, these properties change causing the speed of sound in air to increase with temperature. At a temperature of 0°C and a pressure of 101 kPa (1 atm pressure), the speed of sound in dry air is 331 m/s, and for each 1°C rise in temperature, the speed of sound increases approximately by 0.6 m/s. Mathematically

$$v = 331 + 0.6T \quad \text{— 11.5}$$

where T is the temperature in °C. Unless stated otherwise, we will assume in this Chapter that T = 20°C, so v = [331 + (0.60)(20)] ms = 343 ms.

The general wave equation also applies to sound waves as

$$v = f\lambda \quad \text{— 11.6}$$

It should be noted that wide range of frequencies observed in sound, and the speed of sound is the same for all frequencies. Thus, in the relation 11.6 the speed v remains fixed. For example, if the frequency of a wave is doubled, its wavelength is halved, so that the speed v stays the same.

EXAMPLE 11.3: WAVELENGTH CALCULATION

What is the wavelength of the sound in dry air if its frequency is 590 Hz on a hot day with temperature of 40 °C?

GIVEN

Temperature T = 40 °C

Frequency 'f' = 590 Hz

REQUIRED

Wavelength 'λ' = ?

SOLUTION: Since speed of sound at 0 °C is 331 m/s and for each one degree celsius rise in temperature, the speed of sound increases by 0.6 m/s. Therefore

$$v = 331 + 0.6T \quad \text{or} \quad v = [331 + 0.6 \times 40]\, m/s$$

$$\text{or} \quad v = [331 + 24]\, m/s \quad \text{Hence} \quad v = 355\, m/s$$

Now by general wave equation $v = f\lambda$ or $\lambda = \frac{v}{f}$

Putting values $\lambda = \frac{355\, m/s}{590\, Hz}$ or $\lambda = \frac{355\, m/s}{590\, 1/s}$

$\lambda = 0.6\, m$ —— Answer

Thus, the wavelength of wave is 0.6 m

EXTENSION EXERCISE 11.2

What is the wavelength of 590Hz frequency sound in fresh water at 25 °C, where the speed of sound is 1493 m/s.

ASSIGNMENT 11.3: FREQUENCY CALCULATION

What is the frequency of sound with wavelength 0.25 m in air with temperature of 32 °C?

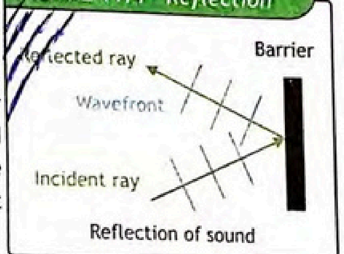
11.5 REFLECTION OF SOUND WAVES AND ECHO

When a wave front strikes a boundary that is parallel to the front, the wave may be absorbed, be transmitted, or undergo reflection, depending on the nature of the boundary medium, or the wave may be partly absorbed, partly transmitted, partly reflected, or any combination thereof. Sound wave reflect like other kind of waves.

The bouncing back of sound waves when it strikes a surface is called reflection of sound.

Just like reflection of water waves in ripple tank, sound waves can also be made to bounce back as shown in figure 11.4. Some materials, such as hard, smooth surfaces, reflect sound waves more than they absorb them. Other materials, such as soft curtains, absorb sound waves more than they reflect them. Figure shows a sound wave with a plane wave front reflecting from a flat surface.

FIGURE 11.4 - *Reflection*



Reflection of sound

Some people claim that their singing voice is better in the shower than anywhere else. This may be true as a result of the many sound reflections that occur in a small room. Sound due to multiple reflections is called a **reverberation**. The continuation of many reflections causes a tone to gain in volume. Thus reverberation adds to gain in volume of tone.

11.5.1 Echo: A reflected sound that can be distinguished from the original is called an echo. If a reflected sound arrives after 0.10 s, the human ear can distinguish the reflected sound from the original sound. ***Thus, a reflected sound that arrives before 0.10 s is perceived as an increase in volume and is called a reverberation, but a sound that arrives after 0.10 s is perceived as an echo.***

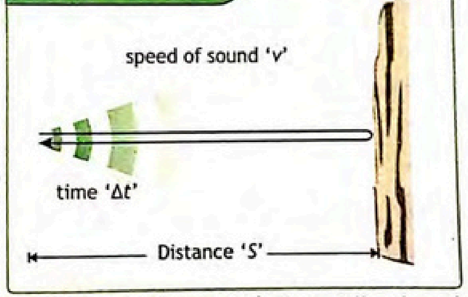
Besides the hearing of your words repeated, echoes can be used to estimate the distance of an object and the velocity of sound itself. Since the sound covers a distance 'S' twice 'S = 2S' i.e for going and receiving in time 'Δt' as shown in figure 11.5. The speed 'v' is

Energy

$$v = \frac{2S}{\Delta t}$$

$$\text{or} \quad S = \frac{v\Delta t}{2} \quad \text{—— 11.7}$$

FIGURE 11.5 - *Echo*



This means that we can calculate the minimum distance for the echo to be heard.

For example, the speed of sound at room temperature of 20 °C is v = 343 m/s and the sound reaches the ear in time Δt = 0.1s, the distance S can be calculated as

$$S=\frac{343\,m/s\times 0.1s}{2} \quad \text{or} \quad S=\frac{34.3m}{2}$$

$$S=17.15m$$

So the minimum distance required for an echo to be heard when the speed of sound is 343 m/s is 17.15 m. The change in temperature can effect this distance because the speed of sound changes with temperature.

EXAMPLE 11.4: ECHO

During a winter school camp on Pipe Line Track from Donga Gali to Ayubia, Aalia shouts at a cliff and hears her echo after 1.5 s. She record the temperature on her personal thermometer as 3 °C. How far is the cliff from her?

GIVEN

time $\Delta t = 1.5$ s

Temperature T = 3 °C

REQUIRED

distance 'S' = ?

SOLUTION: First we would calculate the speed of sound at 3 °C. Since speed of sound at 0 °C is 331 m/s and for each one degree Celsius rise in temperature, the speed of sound increases by 0.6 m/s. Therefore for increase in 4 degrees we have

$$v=331+0.6T \quad \text{or} \quad v=[331+0.6\times 3]\,m/s$$

$$\text{or} \quad v=[331+1.8]\,m/s \quad \text{so} \quad v=[331+2]\,m/s$$

$$\text{Hence} \quad v=333\,m/s$$

Now using the equation for echo $S=\frac{v\Delta t}{2}$

Putting values $S=\frac{333\,m/\cancel{s}\times 1.5\cancel{s}}{2}$

$S=249.75m=250m$ — **Answer**

The cliff is approximately 250 m far from her.

EXTENSION EXERCISE 11.3

By how much time the echo will be heard sooner in summer when temperature is 34 °C from same cliff?

ASSIGNMENT 11.4: DOUBLE CLIFF ECHO

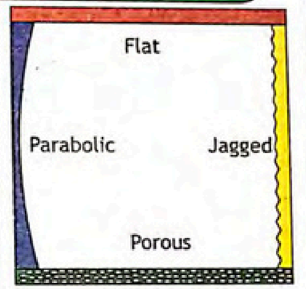
A man stands in between two parallel cliffs and fires a gun, he hears two successive echoes after 3 s and 5 s. What is the distance between cliffs?

11.6 ACOUSTICS

Acoustics is the study of waves, vibrations and sound. Echoes are easily observed in a large, empty room, but when rugs and furniture are put in the room, the acoustics change; because such materials absorbs the sound more than they reflect. If the reflective surfaces are too absorbent, the sound level will be low and the room will sound dull and lifeless.

Reflection of sound in a room makes it sound lively and full. The acoustics of a room depend on the shape of the room, the contents of the room, and the composition of the walls, ceiling, and floor. The designer of an auditorium, must find a balance between reverberation and absorption. It is often advantageous to place highly reflective surfaces behind the stage to direct sound out to an audience.

FIGURE 11.6 - *Acoustics*



Architectural acoustics is about achieving a good quality of speech in a theater, or recording studio, or suppressing noise to make offices and homes more comfortable and peaceful places to work and live. Flat surfaces reflects, parabolic surfaces focuses, porous surfaces absorbs while jagged surfaces disperses the sound as shown in figure 11.6.

It is often advantageous to place highly reflective surfaces behind the stage to direct sound out to an audience. Reflecting surfaces are suspended above the stage in some theaters.

POINT TO PONDER

A good acoustic design will provide a better and comfortable environment in the mosque in term of sound audibility and speech intelligibility. Unfortunately, architects nowadays often focus more on designing a building based on its looks or form, and the main function of space most often neglected. To ensure good listening conditions acoustical needs must be considered in the design phase of the mosque.

11.6.1 Acoustic protection: Acoustic protection is the application of soft and porous material to protect individuals against undesirable sounds and noises. Acoustic protection is employed not only for physical health, but for psychological well being as well. Animals and birds have also been reported to express discomfort due to higher noise and sound levels. Acoustic protection is also necessary to minimize stress levels generated due to high noise. Acoustic protection may also be required to protect structures against vibrations generated by objects, such as trains and earthquakes. This is also required to control the noise generated during construction and/or development activities.

TIDBITS

Noise Pollution: The excessive displeasing sound which disrupts the balance or activity of humans or other living things is called noise pollution. The first type of noise pollution involves noises that are so loud they put the sensitive parts of the ear. Prolonged exposure to sounds of about 85 dB can begin to damage hearing irreversibly. Certain sounds above 120 dB can cause immediate damage.

The sound level produced by a jet engine from a few meters away is about 140 dB. The workers working in noisy areas like an airport use 'headphones' to prevent the hearing loss brought on by damage to the inner ear.

The second kind of noise pollution involves noises that are considered annoyances, these sounds are irritating and sometimes becomes intolerable. Studies have found that long-term exposure to noise can cause potentially severe health problems in addition to hearing loss, especially for young children. Constant levels of noise (even at low levels) can be enough to cause stress, which can lead to high blood pressure, insomnia, and psychiatric problems, and can even impact memory and thinking skills in children.

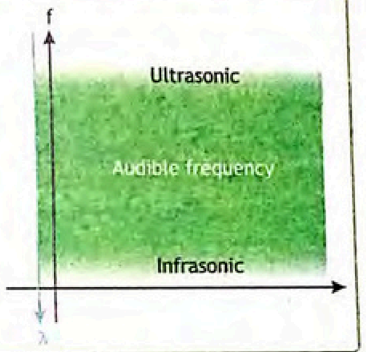
Animals and plants are also victims of noise pollution. It is observed that in animals it damages the nervous system and reproductive system. While in plants growth defects are observed. The World Health Organization has recommended that noise during sleep should be limited to a level of 35 dB.

11.7 AUDIBLE FREQUENCY RANGE

There are both upper and lower limits to the sound frequencies that humans can hear. A healthy young person can typically hear frequencies in a range from about 20 Hz (Recall that 1 Hz is 1cycle per second) to 20,000 Hz (20 kHz). The upper limit decreases with age.

Physicists have established a three-part classification of sound, based on the range of human hearing. Sound frequencies lower than 20 Hz are referred to as infrasonic, those in the 20 Hz to 20,000 Hz range are audible, and those higher than 20,000 Hz are ultrasonic as shown in figure 11.7. Different animal have varying hearing ranges. You may have experienced a dog whistle that seems to produce no sound at all when blown, but still brings your pet dog back.

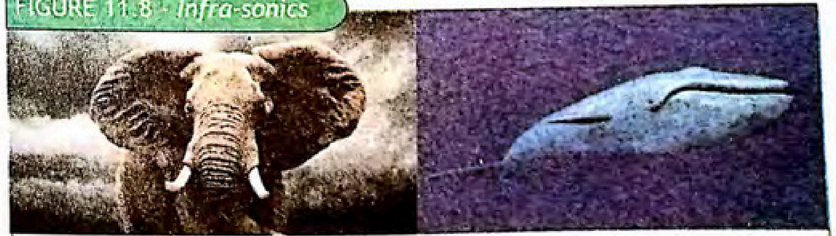
FIGURE 11.7 - Audible frequency



The frequency of the sound produced by these whistles is higher than 20 kHz. While it is outside the audible range for humans, it is obviously not outside the audible range for dogs. The top end of a dog's hearing range is about 45 kHz, while a cat's is 64 kHz.

11.7.1 Infra-sound: Whales, elephants and rhinoceroses are known to use infra-sound to communicate over long distances. The infra sounds from elephants and whales can be extremely loud (around 117 dB), allowing communication for many kilometres, with a possible maximum range of around 10 km for elephants, and potentially hundreds or thousands of kilometers for some whales.

FIGURE 11.8 - Infra-sonics



Elephants and whales use infrasounds to communicate.

Infrasounds can be generated by human processes such as explosions, or by machinery such as diesel engines, wind turbines. Certain specialized loudspeaker designs are also able to reproduce extremely low frequencies; these include large-scale rotary woofer models of subwoofer loudspeaker. Some human singers can also produce sounds in infra sonic range.

11.7.2 Ultra-sound: Bats use ultrasonic ranging (echolocation - by listening to the echoes of their calls) technique to detect their prey. They can detect frequencies beyond 100 kHz, possibly up to 200 kHz. To avoid bats, many insects have good ultrasonic listening. This includes many groups of moths, beetles, praying mantids and lacewings. Upon hearing a bat, these insects move to escape before being pray for echo-locating bat. Whales and dolphins can hear ultrasound and use such sounds in their navigational system to orient and capture prey.

FIGURE 11.9 - *Ultra-sonics*

The praying mantis and moths has a specialized ultrasound receptor on its abdomen that allows them to take cover in response to an approaching bat.

Apart from animals, humans have also used ultrasound to their advantage.

i. Automatic door opener: A common ultrasound application is an automatic door opener, where an ultrasonic sensor detects a person's approach and opens the door. Ultrasonic sensors are also used to detect intruders; the ultrasound can cover a wide area from a single point.

ii. Nondestructive Testing: Ultrasonic testing is a type of nondestructive testing commonly used to find flaws in materials and to measure the thickness of objects.

iii. SONAR: A common use of ultrasound is in underwater range finding; this use is also called SONAR (Sound Navigation and Ranging).

Sonar

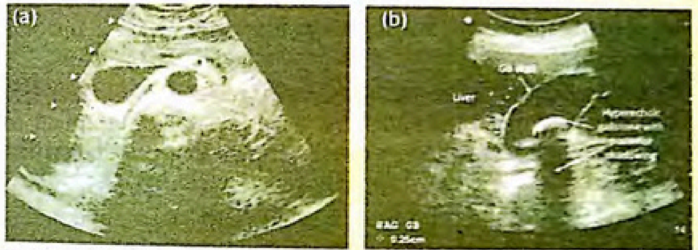
An ultrasonic pulse is generated in a particular direction. If there is an object in the path of this pulse, part or all of the pulse will be reflected back to the transmitter as an echo and can be detected through the receiver path. By measuring the difference in time between the pulse being transmitted and the echo being received, it is possible to determine the distance.

iv. Ultrasonic cleaners: Jewelry, machined parts and other objects that have odd shapes are immersed in a cleaning fluid that is agitated with ultrasound typically about 40 kHz in frequency. The intensity is great enough to cause cavitation, which is responsible for most of the cleansing action. Because cavitation-produced shock pressures are large and well transmitted in a fluid, they reach into small crevices where even a low-surface-tension cleaning fluid might not penetrate.

INFO

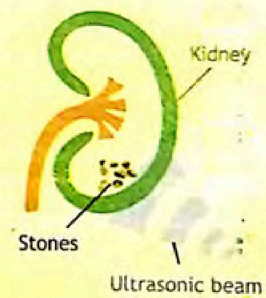
MEDICAL APPLICATIONS OF ULTRA SOUND

Perhaps the most familiar is the ultrasound scan that is used to image a particular part of the body. By sending bursts of ultrasound into the body and measuring the time delay of the resulting echoes — it is possible to map out the location of structures that lie hidden beneath the skin.



(a) Abdominal ultrasound reveals normal liver and gallbladder. There is no abnormal echo in the gallbladder. (b) A gladder stone is seen in the image.

In addition to imaging the interior of a body, ultrasound can also produce changes within the body that would otherwise require surgery. For example, in a technique called shock wave lithotripsy (SWL), an intense beam of ultrasound is concentrated onto a kidney stone that must be removed. After being hit with as many as 1000 to 3000 pulses of sound (at 23 joules per pulse), the stone is fractured into small pieces that the body can then eliminate on its own.



KEY POINTS

Sound: A disturbance of matter that is transmitted from its source outward
Loudness: The perception of sound intensity
Pitch: The perception of the frequency of a sound
Quality: Number and relative intensity of multiple sound frequencies
Musical sound: The sound that is pleasant and harmonious
Noise: Any loud, discordant, or disagreeable sound
Intensity: The power per unit area carried by a wave
Sound intensity level: A unitless quantity telling you the level of the sound relative to a fixed standard
Reflection of sound: The bouncing back of sound when it strikes a surface
Reverberation: Sound due to multiple reflections
Echo: A reflected sound that can be distinguished from the original sound
Audible frequency range: Range of frequency from 20 Hz to 20000 Hz.

PROJECTS

GROUP A 'HEARING DISABILITIES': Interview members of the medical profession to learn about human hearing. What are some types of hearing disabilities? How are hearing disabilities related to disease, age, and occupational or environmental hazards? What procedures and instruments are used to test hearing? How do hearing aids help? What are the limitations of hearing aids? Make a chart to present your findings to the class.

GROUP B 'LECTURE ROOM DESIGN': Assess your classroom acoustics, try to place different sound reflectors and experimentally determine the best design for your classroom. Write a research article to be published in school magazine.

GROUP C 'SOUND LEVEL': Obtain a sound-level metre, and measure the noise level at places where you and your friends might be during an average week. Also make some measurements at locations where sound is annoyingly loud. Be sure to hold the metre at head level and read the metre for 30s to obtain an average. Identify sources of noise in their environment and suggest how such noise can be reduced to an acceptable level. Present your findings to the class in a graphic display.

GROUP D 'ANIMALS HEARING ABILITIES': Research how animals have adopted their hearing abilities to survive and effectively communicate with each other. Prepare a chart to be displayed in the classroom.

GROUP E 'ULTRASOUND': Research how ultrasound techniques are used in medical and industry. Write an article to be published in school magazine.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. The intensity of a sound wave increases by 1000 W/m^2. What is this increase equal to in decibels?
   A. 10 B. 20 C. 30 D. 40
2. An echo occurs when a sound wave is ...
   A. absorbed B. transmitted C. refracted D. reflected
3. Compared with a sound of 60 decibels, a sound of 80 decibels has an intensity ________ times greater.
   A. 10 B. 100 C. 1000 D. 10000
4. The loudness of a sound is most closely related to its ____.
   A. frequency B. period C. wavelength D. amplitude
5. Various instruments sound different even when they play the same note due to difference in
   A. pitch B. loudness C. quality D. intensity
6. Humans can hear sound that is
   A. less than 20 Hz B. between 20 Hz and 20 kHz
   C. greater than 20 kHz D. None
7. The speed of sound on a warm day when the outdoor temperature is 38°C is
   A. 331 m/s B. 345 m/s C. 354 m/s D. 362 m/s
8. Minimum echo distance is reduced in
   A. summer B. winter C. spring D. space
9. Which of the following cannot transmit sound?
   A. solid B. liquid C. gas D. vacuum

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. Why sound produced by a simple pendulum is not heard?
2. If a ringing bicycle bell is held tightly by hand, it stops producing sound. Why?
3. Why is the intensity of an echo less than that of the original sound?
4. In which medium air or water, an echo is heard sooner? Why?
5. Why sound cannot be heard on the moon?

6. If a person places his ear on rails of railroad for determination of coming train. Why is this done, and how does it work?
7. When you watch a thunderstorm, you see the lightning first, and you hear the thunder afterward. Why is the thunder delayed?
8. If the speed of sound is dependent on frequency, would music from marching band be enjoyed?
9. Why does your voice sound fuller in the shower?
10. Why is it so quiet after a snowfall?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

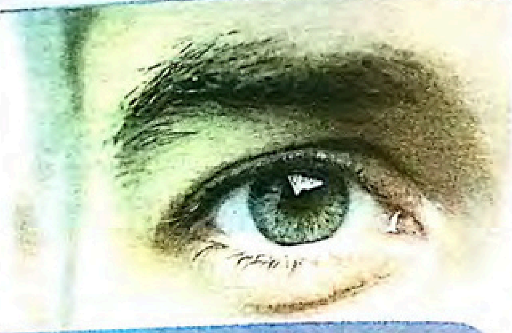
1. What is sound? How it is produced, transmitted and received?
2. What is audible frequency range?
3. What is the speed of sound?
4. Describe the terms loudness, pitch and quality. Explain each by giving an example.
5. What is intensity level? Describe the decibels scale for the intensity of different sound levels.
6. What is noise? Explain why noise is nuisance?
7. How sound is reflected? Describe the difference between echo and reverberation.
8. What is acoustic protection? Why is it important?

NUMERICAL QUESTIONS

1. The sound intensity 3 m from a jackhammer is 8.20×10^{-2} W/m^2. What is the sound intensity level in decibels? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12}$ W/m^2).
2. A ship is anchored where the depth of water is 120 m. An ultrasonic signal sent to the bottom of the lake returns in 0.16 s. What is the speed of sound in water?
3. A gunshot from a .22 rimfire rifle has an intensity of about $I = (2.5 \times 1013)I_0$. Do we need to wear ear protection? (Considering that prolonged exposure to sounds above 85 decibels can cause hearing damage or loss).
4. What sound intensity level in dB is produced by earphones that create an intensity of 4.00×10^{-2} W/m^2? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12}$ W/m^2.)

5. What is the speed of sound in air at -20 °C?
6. Army man wearing binoculars see the flash from enemy tank fire 5 s before the fire is heard, he records 26°C temperature on his personal thermometer. What is the distance of the tank from him?
7. Calculate the wavelengths of sounds at the extremes of the audible range, 20 Hz and 20,000 Hz, at normal room temperature of 20°C?
8. Ishfaq stands between two high rise buildings A and B, such that he is at 33 m distance from building A. When he blows the whistle, he hears the first echo after 0.2 s and second echo after 0.8 s. Calculate (a) the speed of sound and (b) distance of building B from him.

How a human eye works?



Unit 12 GEOMETRICAL OPTICS

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ describe the terms used in reflection including normal, angle of incidence, angle of reflection and state laws of reflection.
- ✓ solve problems of image location by spherical mirrors by using mirror formula.
- ✓ define the terminology for the angle of incidence θ_i and angle of refraction θ_r and describe the passage of light through parallel-sided transparent material.
- ✓ solve problems by using the equation $\sin\theta_i / \sin\theta_r = n$ (refractive index).
- ✓ state the conditions for total internal reflection.
- ✓ describe the passage of light through a glass prism.
- ✓ describe how total internal reflection is used in light propagation through optical fibres.
- ✓ describe how light is refracted through lenses.
- ✓ define power of a lens and its unit.
- ✓ solve problems of image location by lenses using lens formula.
- ✓ define the terms resolving power and magnifying power.
- ✓ draw ray diagram of simple microscope and mention its magnifying power.
- ✓ draw ray diagram of compound microscope and mention its magnifying power.
- ✓ draw ray diagram of a telescope and mention its magnifying power
- ✓ draw ray diagrams to show the formation of images in the normal eye, a shortsighted eye and a long-sighted eye.
- ✓ describe the correction of short-sight and long-sight.

CONTENTS

The study of light is called optics. Geometrical optics is concerned with tracing the geometrical paths of light rays. Instruments that can explore previously inaccessible domains often open new doors to understanding nature. For example, astronomy owes its progress to the invention of the telescope, and modern biology could not have been created without the microscope. In this unit we shall discuss the ideas that govern the construction of optical instruments such as these. The direction of the path in which light is traveling is represented as ray by a straight line with an arrow on it.

12.1 REFLECTION OF LIGHT

We see objects if light from it enters our eyes. Some objects such as the Sun, electric lamps and candles make their own light. We call these luminous sources. Most things that we see do not make their own light but reflect it from a luminous source. They are non-luminous objects for example this page, teaching board and the Moon.

Reflection of light is same as for other types of waves, such as reflection of water waves in ripple tank. Most objects reflect a certain portion of the light falling on them, mirrors reflect more light and in a regular manner. An ordinary mirror is made by depositing a thin layer of silver on one side of a piece of glass and protecting it with paint. The silver at the back of the glass - acts as the reflecting surface.

Suppose that a ray of light is incident on a flat, shiny surface, such as the mirror in Figure 12.1. The following terms are used in describing the reflection of light

i. **Incident ray:** the approaching ray of light.

ii. **Reflected ray:** the ray of light reflected from a reflecting surface.

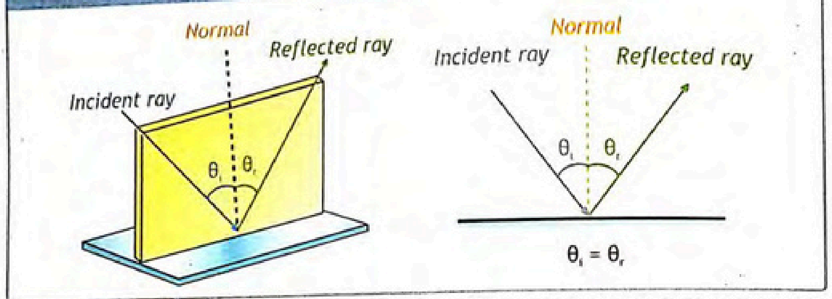
iii. Point of incidence: the point at which the incident ray strikes the reflecting surface.

iv. Normal: the line drawn at right angles to the reflecting surface at the point of incidence.

v. Angle of incidence (θ_i): the angle between the incident ray and the normal.

vi. Angle of reflection (θ_r): the angle between the reflected ray and the normal.

FIGURE 12.1 - *Laws of reflection*



12.1.1 Laws of Reflection: The laws of reflection describes the behavior of the incident and reflected rays.

- First Law: The incident ray, the reflected ray and the normal to the surface all lie in the same plane
- Second Law: the angle of reflection θ_r equals the angle of incidence θ_i:

$$\theta_i = \theta_r \qquad (12.1)$$

12.1.2 Image characteristics: We can completely describe any image by defining four characteristics.

- The **magnification** is the ratio of the image size to the object size. If the magnification is greater than one, the image is larger than the object. When it is equal to one, the object and image are the same size. If the magnification is less than one, the image is smaller than the object.
- The **attitude** of an image shows whether the image is oriented the same way as the object (upright) or upside down (inverted) with respect to the object.
- The image **location (or position)** is the distance between the image and the optical device – mirror or lens.

- The **type** of image, indicates whether the image is real or virtual. An image is real if light rays are actually converging at a point then continuing on beyond that point and diverging. In other words, if you place a screen at the image position, the image would appear on the screen (and would be perfectly in focus). If an image is not real, it is virtual. If you place a screen at the position of a virtual image, nothing would appear on the screen. There are no light rays actually converging on the image position. Light rays only appear as though they are diverging from the image location. This will become more clear as you recall and practice drawing ray diagrams you learned in grade 6, grade 7 and grade 8.

12.2 SPHERICAL MIRRORS

Reflecting surfaces can also be curved, usually spherical, which means they form a section of a sphere. As Figure 12.2 shows, a spherical mirror has the shape of a section sliced from the surface of a sphere. If the inside surface of the mirror is polished, it is a concave mirror. If the outside surface is polished, it is a convex mirror.

FIGURE 12.2 - *Spherical mirror*

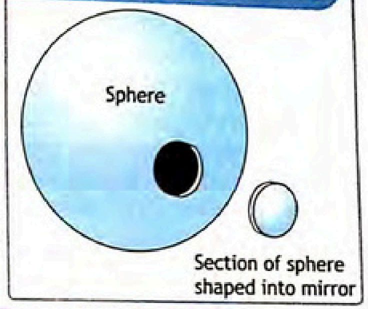
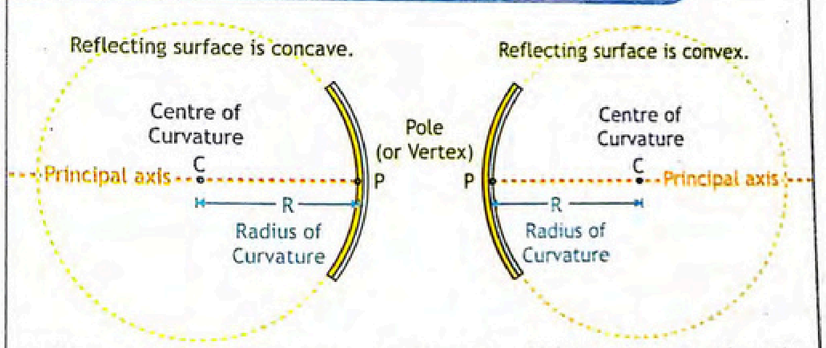


FIGURE 12.3 - *Centre of curvature and radius of curvature*

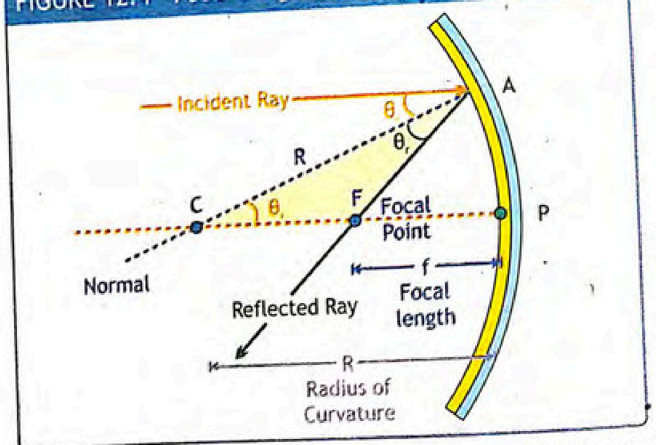


(a) A concave mirror and its centre of curvature, C, which is on the same side as the reflecting surface (light is incident from the same direction as C). (b) A convex mirror and its centre of curvature, C. In this case, C is on the opposite side of the mirror from its reflecting surface.

Centre of curvature is the centre of the sphere with radius R (radius of curvature) of which the mirror is a section, and the principal axis is a straight line drawn through the centre of curvature and the midpoint of the mirror (pole or vertex) P. Note that the principal axis intersects the mirror at right angles. Figures 12.3 shows principal axis, centre of curvature and radius of curvature for both concave and convex mirrors.

12.2.1. Focal Point and focal length of concave mirror: Consider what happens when light rays that are parallel to the principal axis, strike a concave mirror. Follow the path of the incident ray in Figure 12.4. The light incident ray strikes the mirror at point A. The line segment CA is the radius of the mirror and, therefore, is the normal to the spherical surface of the mirror at A. The Laws of Reflection tell us that the light ray reflects from the mirror such that the angle of reflection θ_r equals the angle of incidence θ_i. Furthermore, the angle ACF is also θ_i, because the radial line segment CP crosses two parallel lines. Since two of its angles are equal, the (coloured) triangle ACF is an isosceles triangle; thus, sides CF and FA are equal.

FIGURE 12.4 - Focal Length of concave mirror



When the incoming parallel light ray lies close to the principal axis, the angle of incidence, θ_i, is small, and the distance FA becomes similar in length to distance FP. Because θ_i is small, CF = AF = FP. Therefore, FP = ½ CP and so point F lies halfway between the centre of curvature and the pole P (or vertex) of the mirror. Point F is called the focal point (or principal focus). The distance from the focal point to the pole P (or vertex) is called the focal length and is symbolized, f.

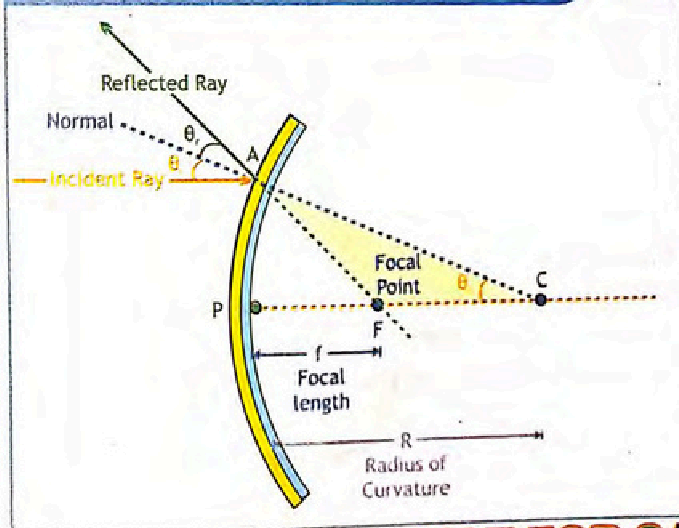
The focal length, f, is one-half of the radius of curvature, R, for the spherical mirror. Point F is called the focal point because all the incident light rays that are parallel and close to the principal axis of the mirror, reflect from the mirror and pass through that one point. such that

$$f = \frac{1}{2}R \qquad (12.2)$$

SI unit: m

12.2.2. Focal Point and focal length of convex mirror: Figure 12.5, which shows a single ray reflecting from the convex mirror. The first thing to notice about this diagram is that a straight line drawn through the centre of curvature always intersects the mirror at right angles; hence, the line through C is the normal to the surface at the point of incidence, A. Since the incoming ray is parallel to the principal axis, it follows that the angle of incidence θ_i, is equal to the angle CAF. Therefore from the laws of reflection the angle of reflection θ_r must also equal angle CAF. We see then, that ΔCAF is an isosceles triangle, with the sides CF and FA having equal length. Finally, for small angles the length CF is approximately equal to half the length CA = R; that is CF = ½ R. Therefore, to this same approximation, the distance FP (called focal length 'f') is also ½ R.

FIGURE 12.5: Focal Length of convex mirror

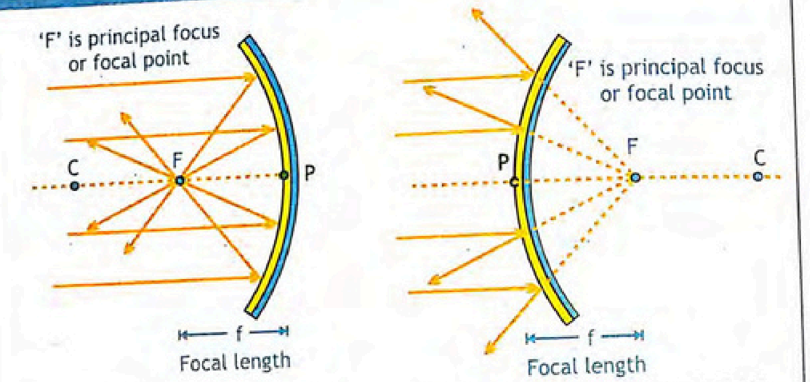


$$\boxed{f = -\frac{1}{2}R} \quad \text{12.3}$$

SI unit: m

The minus sign in this expression is used to indicate that the focal point lies behind the mirror.

FIGURE 12.6 - *Principal focus*



The concave mirror has the ability to converge the beam of light parallel to principal axis. Therefore it is also termed as converging mirror.

The convex mirror has the ability to diverge the beam of light parallel to principal axis. Therefore it is also termed as diverging mirror.

After reflecting from the mirror, the rays converge or diverge as if they originate from a single point called the focal point F (or principal focus) as shown in figure 12.6.

12.2.3. Image formation and ray tracing for spherical mirrors: Ray diagrams are used to show image formation in spherical mirrors.

1. Construct a figure showing the mirror and its principal axis. The figure should also show the focal point and the centre of curvature.

2. Draw the object at the appropriate point. One end of the object will often lie on the principal axis.

3. Draw four rays that arise from the tip of the object:

(a) The A - ray (parallel ray hitting mirror at point A) is initially parallel to the axis. After reflection, this ray (or its extrapolation) passes through the focal point.

(b) The F - ray (focal ray or its extrapolation) passes through the focal point. After reflection, this ray will be parallel to the axis.

(c) The P -ray (pole ray or its extrapolation) is incident on the mirror at its pole or vertex, reflects making an equal angle with the axis (since the axis is normal to the mirror).

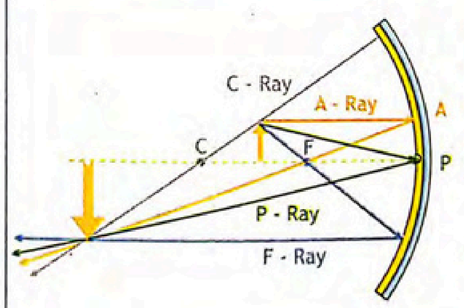
(d) The C -ray (central ray or its extrapolation) passes through the centre of curvature of the mirror. After reflection, this ray passes back through the tip of the object.

These four rays are called the principal rays. Other rays can also be drawn but we prefer the principal rays because they are easier to draw. Most of the time we draw only two of the principal rays.

4. The point where the focal, parallel, pole and central rays (or their extrapolations) intersect is the image point. This point may be in front of the mirror giving a real image, or it may be necessary to extrapolate the rays back behind the mirror to locate a virtual image.

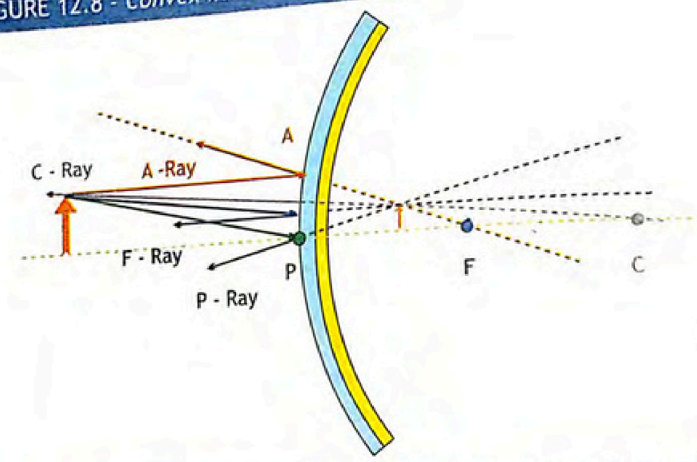
5. This ray-tracing procedure can be repeated for any desired point on the object. Thus, locating other points on the image, it is usually sufficient to consider just the tip of the image but additional points can be used if needed.

FIGURE 12.7 - *Concave mirror ray tracing*



1. A ray along the direction from the focal point to the mirror is reflected parallel to the principal axis.
2. F ray parallel to the principal axis is reflected through the focal point.
3. P ray incident on the vertex of the mirror reflects at an equal angle to the axis.
4. C ray along a radius is reflected back on itself.

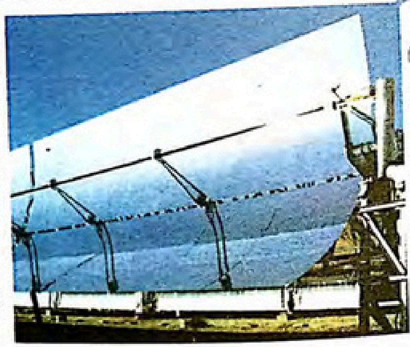
FIGURE 12.8 - Convex mirror ray tracing



1. A - ray parallel to the principal axis is reflected as if it came from a focal point.
2. F - ray directed toward the focal point is reflected parallel to the principal axis.
3. P - ray incident on the vertex of the mirror reflects at an equal angle to the axis.
4. C - ray along a radius is reflected back on itself.

TipBits

Capturing solar energy with mirrors. Parabolic mirrors are also used in one method of collecting solar energy for commercial purposes. Figure shows a long row of concave parabolic mirrors that reflect the sun's rays to the focal point. Located at the focal point and running the length of the row is an oil-filled pipe. The focused rays of the sun heat the oil.



In a solar-thermal electric plant, the heat from many such rows is used to generate steam. The steam, in turn, drives a turbine connected to an electric generator.

POINT TO PONDER

How automobile headlights produce a beam of light? Another application of parabolic mirrors is in automobile headlights. Here, however, the situation is reversed from the operation of a solar collector. In a headlight, a high-intensity light source is placed at the focal point of the mirror, and light emerges parallel to the principal axis.

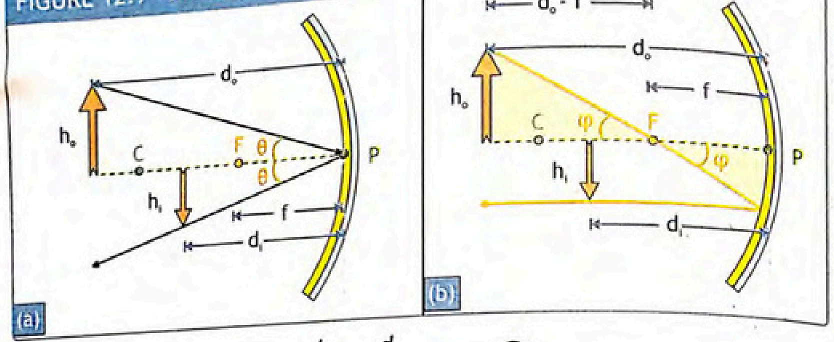
12.3 THE MIRROR EQUATION

Drawing light ray diagrams are helpful in explaining and predicting the properties of images formed in plane, concave, and convex mirrors. To determine the magnification of the image, and its position with precision, it is necessary to draw very accurate scaled diagrams. The mirror equation on the other hand is a precise **mathematical relationship between the object distance and the image distance for a given mirror.** The following quantities are included in mirror formula:

- f = the focal length of the mirror
- h_o = the height of the object
- h_i = the height of the image
- d_o = the distance of the object from the mirror
- d_i = the distance of the image from the mirror
- M = the magnification of the image

To obtain this relation, we use the ray diagrams shown in Figure 12.9. The ray in Figure 12.9 (a) hits the mirror at its midpoint, where the principal axis is the normal to the mirror. As a result, the ray reflects at an angle θ below the principal axis that is equal to its incident angle θ above the axis. Therefore, the two green triangles in this diagram are similar, from which it follows that ratios of equivalent sides of similar triangles are equal.

FIGURE 12.9 - Mirror Formula



$$\frac{h_o}{-h_i} = \frac{d_o}{d_i} \quad \text{——} (1)$$

The image height is negative because it is inverted.

From the figure 12.9 (b) it is clear that the two yellow triangles in this diagram are also similar, since they are both right triangles and share the common angle φ. Thus, by using the same rule of similar triangles we get

$$\frac{h_o}{-h_i} = \frac{d_o - f}{f} \quad \text{——} (2)$$

Comparing equation 1 and equation 2, we get $\frac{d_o}{d_i} = \frac{d_o - f}{f}$

To isolate 'f', cross multiply $d_o f = d_i(d_o - f)$

or $d_o f = d_i d_o - d_i f$ —— (3)

Divide both sides of equation 3 by $d_o d_i f$, we get $\frac{d_o f}{d_i d_o f} = \frac{d_i d_o}{d_i d_o f} - \frac{d_i f}{d_i d_o f}$

or $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$ Hence $\boxed{\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}}$ —— 12.4

The final equation 12.4 above is known as the mirror formula. It relates the distances of the object and the image to a concave mirror, in terms of the mirror's focal length. The ratio of the height of the image to the height of the object is defined as the magnification, M;

$$\boxed{M = \frac{h_i}{h_o} = \frac{d_i}{d_o}} \quad \text{——} 12.5$$

We derived the magnification and mirror equations for a concave mirror forming a real image, but the equations apply as well to convex mirrors and to virtual images if we use the sign conventions described below.

12.3.1 Convention for mirror equation and magnification equation: To include all of the possible properties of both images and objects, the following sign convention has been established for both concave and convex spherical mirrors.

a. Object distance:

- d_o is positive for objects in front of the mirror (real objects)

b. Image distance:

- d_i is positive for objects in front of the mirror (real images)
- d_i is negative for objects behind the mirror (virtual images)

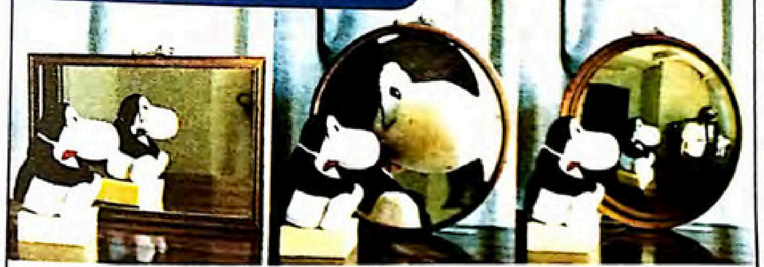
c. Image attitude:

- h_i is positive for images that are upright, compared to the object
- h_i is negative for images that are inverted, compared to the object

d. Focal length:

- f is positive for concave mirrors
- f is negative for convex mirrors

FIGURE 12.10 - Mirror comparison



(a) (b) (c)

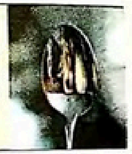
(a) Plane mirror image (no magnification). (b) Enlarged image in a concave mirror. (c) Reduced image in a convex mirror.

Table 12.1 Single-Mirror System Properties

Mirror Type	f	d_o	d_i	m
Plane	NA	$d_o > 0$	$d_i = d_o$ (negative)	Same size
Concave	+	$d_o > r$	$r > d_i > f$	Reduced, inverted
		$d_o = r$	$d_i = r$	Same size
		$r > d_o > f$	$d_i > r$	Enlarged, inverted
		$d_o = f$	$d_i = \infty$	No image
		$f > d_o > 0$	$d_i > d_o$ (negative)	Enlarged
Convex	-	$d_o > 0$	$f > d_i > 0$ (negative)	Reduced

EXAMPLE 12.1: IMAGE DISTANCE IN SPOON

The concave side of a spoon has a focal length of 5.00 cm. Find the image distance for this 'mirror' when the object distance is (a) 12.0 cm, (b) 10.0 cm, (c) 7.50 cm, (d) 5.00 cm and (e) 2.00 cm.



GIVEN

Focal length 'f' = 5.00 cm.

(a) Object Distance 'd_o' = 12.0 cm,

(b) Object Distance 'd_o' = 10.0 cm

(c) Object Distance 'd_o' = 7.50 cm

(d) Object Distance 'd_o' = 5.00 cm

(e) Object Distance 'd_o' = 2.00 cm

REQUIRED

(a) Image Distance 'd_i' = ?

(b) Image Distance 'd_i' = ?

(c) Image Distance 'd_i' = ?

(d) Image Distance 'd_i' = ?

(e) Image Distance 'd_i' = ?

SOLUTION: by mirror equation $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$ or $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

Taking LCM $\frac{1}{d_i} = \frac{d_o - f}{fd_o}$ or $d_i = \frac{fd_o}{d_o - f_o}$ —— (1)

(a) Putting values in equation 1

$$d_i = \frac{5.00\,cm \times 12.00\,cm}{12.00\,cm - 5.00\,cm}$$

or $$d_i = \frac{60.0\,cm^{\cancel{2}}}{7.00\,\cancel{cm}}$$

Therefore $d_i = 8.6\,cm$ —— **Answer**

Hence, the image is closer to the mirror, as shown in figure 12.11 (a).

(b) Putting values in equation 1

$$d_i = \frac{5.00\,cm \times 10.00\,cm}{10.00\,cm - 5.00\,cm}$$

or $$d_i = \frac{50.0\,cm^{\cancel{2}}}{5.00\,\cancel{cm}}$$

Hence $d_i = 10.0\,cm$ —— **Answer**

So the image distance is same as object distance, as shown in figure 12.11(b).

(c) Putting values in equation 1

$$d_i = \frac{5.00\,cm \times 7.50\,cm}{7.50\,cm - 5.00\,cm}$$

or $$d_i = \frac{37.5\,cm^{\cancel{2}}}{2.50\,\cancel{cm}}$$

Therefore $d_i = 15.0\,cm$ —— **Answer**

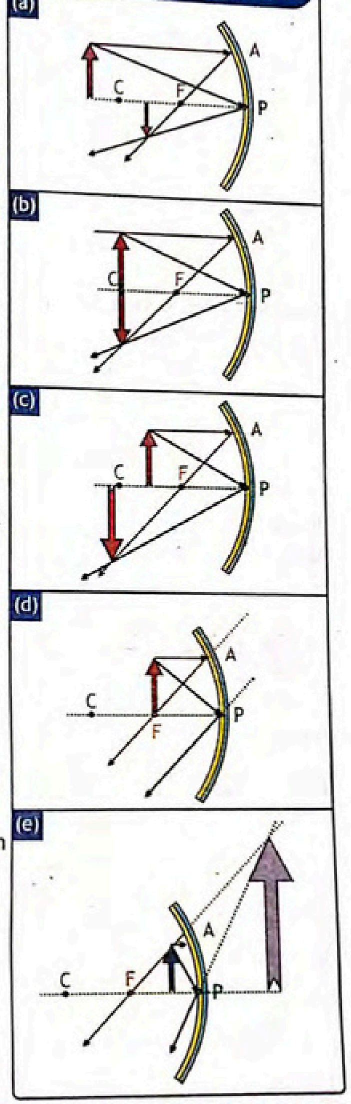
Hence, the image distance is greater than object distance, as shown in figure 12.11(c).

(d) Putting values in equation 1

$$d_i = \frac{5.00\,cm \times 5.00\,cm}{5.00\,cm - 5.00\,cm}$$

or $$d_i = \frac{25.0\,cm^{2}}{0\,\cancel{cm}}$$

FIGURE 12.11 - Example 12.1



Therefore $d_i = \infty$ — **Answer**

Hence, no image is formed, as shown in figure 12.11(d).

(e) Putting values in equation 1 $d_i = \dfrac{5.00cm \times 2.00cm}{2.00cm - 5.00cm}$ or $d_i = \dfrac{10.0cm^{\cancel{2}}}{-3.00\cancel{cm}}$

Therefore $d_i = -3.33cm$ — **Answer**

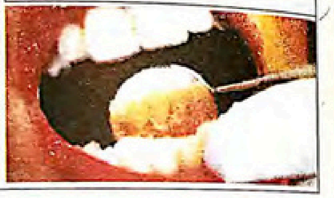
The negative sign of the image distance indicates that the image is formed on the other side of the mirror, as shown in figure 12.11(e).

EXTENSION EXERCISE 12.1

If the object height is 2 cm, what is the image height in each case? What is the magnification?

ASSIGNMENT 12.1: DENTIST MIRROR

A dentist uses a concave mirror with focal length 2.0 cm to examine some teeth. If the tooth under examination is 1.1 cm high and mirror is placed at 0.9 cm. Calculate the distance of image formed, the height of the image and magnification.



EXAMPLE 12.2: REAR VIEW MIRROR

An external rearview car mirror is convex with a radius of curvature of 16.0 m (Fig.). Determine (a) the focal length of the mirror, (b) location of the image and (c) its magnification for an object 10.0 m from the mirror.

GIVEN

Object distance 'd_o' = 10 m

Radius of curvature = R = 16.0 m

REQUIRED

(a) focal length 'f' = ?

(b) image distance 'd_o' = ?

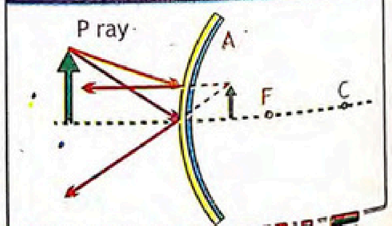
(c) magnification 'M' = ?

Solution: **(a)** radius of curvature and focal length for convex mirror are related by equation

$f = -\dfrac{1}{2}R$ Putting values $f = -\dfrac{1}{2}16m$

Therefore $f = -8.0m$ — **Answer**

FIGURE 12.12 - Example 12.2



The centre of curvature of a convex mirror is behind the mirror therefore its focal point is also negative.

(b) By mirror equation $\dfrac{1}{f} = \dfrac{1}{d_i} + \dfrac{1}{d_o}$

Solving for image distance $\dfrac{1}{d_i} = \dfrac{1}{f} - \dfrac{1}{d_o}$

Taking LCM $\dfrac{1}{d_i} = \dfrac{d_o - f}{fd_o}$ or $d_i = \dfrac{fd_o}{d_o - f_o}$ — ①

Putting values $d_i = \dfrac{-8.0m \times 10.0m}{10m - (-8.0m)}$

or $d_i = -\dfrac{80.0m^{\cancel{2}}}{18.0\cancel{m}}$

Therefore $d_i = -4.4m$ — **Answer**

The negative sign shows that the image is behind the mirror.

(c) For convex mirrors the magnification is $M = -\dfrac{d_i}{d_o}$

Putting values $M = -\dfrac{-4.4m}{10m}$ Therefore $M = +0.44$ — **Answer**

The magnification is positive so the image is upright (same orientation as object, which is useful) and about half what it would be in a plane mirror. Objects in the convex mirror are closer than they appear because the convex mirror produces an image that is reduced in size, which makes the object look as if it is farther away. Therefore, the external rearview side mirrors on most cars carry this phrase **"objects in the mirror are closer than they appear."**

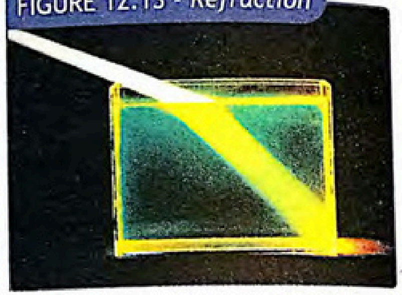
ASSIGNMENT 12.2: IMAGE IN A SECURITY MIRROR

A convex security mirror in a warehouse has a -0.50 m focal length. A 2.0 m tall forklift is 5.0 m from the mirror. What is the image position and image height?

12.4 REFRACTION OF LIGHT

Although light travels in straight lines in a transparent material, such as air, if it passes into a different material, such as water, it changes direction at the boundary of the two material i.e. it is bent.

FIGURE 12.13 - *Refraction*



Refraction of light is the change of direction of light as it moves from one material (called medium) to another. Refraction of light is same as for other types of waves, such as refraction of water waves in ripple tank.

The following terms are used describing the refraction of light

i. Incident ray: The ray of light approaching the boundary (refracting surface) between two media.

ii. Refracted ray: The ray of light moving away from the boundary between the two media.

iii. Point of incidence: The point at which the incident ray strikes the refracting surface.

iv. Normal: The line drawn at right angles to the refracting surface at the point of incidence.

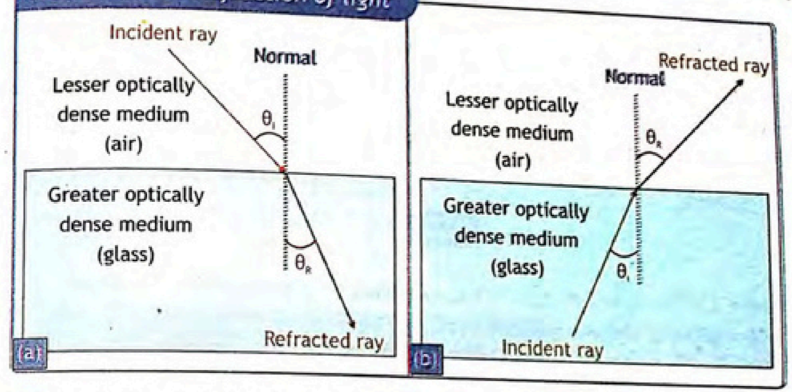
v. Angle of incidence (θ_I): The angle between the incident ray and the normal

vi. Angle of refraction (θ_R): The angle of refraction 'θ_R' is the angle between the refracted ray and the normal.

vii. Optically denser medium: Medium having a greater refraction effect (slower speed of light); the actual density may or may not be greater.

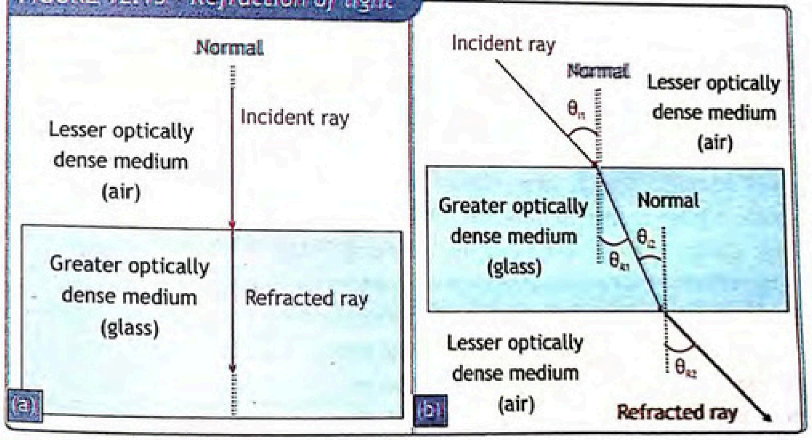
A ray of light is bent towards the normal when it enters an optically denser medium at an angle, for example from air to glass as in Figure 12.14 (a). The angle of refraction θ_R is less than the angle of incidence θ_I ($\theta_I > \theta_R$). A ray of light is bent away from the normal when it enters an optically less dense medium, for example from glass to air as in Figure 12.14 (b). The angle of refraction θ_R is greater than the angle of incidence θ_I ($\theta_I < \theta_R$).

FIGURE 12.14 - *Refraction of light*



A ray travelling along the normal direction at a boundary is not refracted as shown in figure 12.15 (a). A ray emerging from a parallel-sided block is parallel to the ray entering, but is displaced sideways, like the ray in figure 12.15 (b).

FIGURE 12.15 - *Refraction of light*



LAB WORK

To verify the laws of refraction by using a glass slab.

a. Refractive Index (n):

Light travels at different speeds in different optically transparent materials. The ratio of the speed of light in vacuum divided by the speed of light in a material is called the refractive index (or index of refraction) of the material. The index of refraction n is given by

$$n = \frac{c}{v} \quad (12.6)$$

where c is the speed of light in vacuum (about 3.00×10^8 m/s) and v is the speed of light in the medium. The speed of light in a physical medium such as glass is always less than that the speed of light in vacuum . Thus, the index of refraction of a material is always greater than or equal to 1, and by definition the index of refraction of vacuum is 1. Table 12.2 lists the indices of refraction for some common materials.

b. Snell's Law:

The amount that a light ray changes its direction depends both on the incident angle and the amount that the speed changes. For a ray at a given incident angle, a large change in speed causes a large change in direction, and thus a large change in angle. The exact mathematical relationship is the law of refraction, or 'Snell's Law,' which is stated as **'the product of the index of refraction of the first medium and the sine of the angle of incidence is equal to the product of the index of refraction of the second medium and the sine of the angle of refraction'**. Mathematically

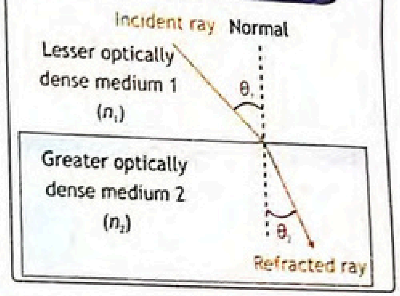
$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad (12.7)$$

Table 12.2 Indices of Refraction for Some Common Materials

Material	Index of Refraction
Gases	
Air	1.000271
Helium	1.000036
Carbon dioxide	1.00045
Liquids	
Water	1.333
Methyl alcohol	1.329
Ethyl alcohol	1.362
Glycerine	1.473
Benzene	1.501
Typical oil	1.5
Solids	
Ice	1.310
Calcium fluoride	1.434
Fused quartz	1.46
Salt	1.544
Polystyrene	1.49
Typical glass	1.5
Crown glass	1.52
Quartz	1.544
Diamond	2.417

Here n_1 and n_2 are the indices of refraction for medium 1 and 2, and θ_1 and θ_2 are the angles between the rays and the perpendicular in medium 1 and 2, as shown in Figure 12.16.

FIGURE 12.16 - Snell's Law



EXAMPLE 12.3: SPEED OF LIGHT IN WATER

What is speed of light in water having index of refraction as 1.33?

GIVEN

Speed of light in vacuum 'c' = 3.00×10^8 m/s

Index of refraction for water 'n' = 1.33

REQUIRED

Speed of light in water 'v' = ?

SOLUTION: The index of refraction is $n = \frac{c}{v}$ or $v = \frac{c}{n}$

Putting values $v = \frac{3.00 \times 10^8 \, m/s}{1.33}$

Therefore $v = 2.26 \times 10^8 \, m/s$ — Answer

Therefore the speed of light in water is 2.26×10^8 m/s

ASSIGNMENT 12.3: INDEX OF REFRACTION FOR KEROSENE OIL

If the speed of light in kerosene oil is 2.08×10^8 m/s, calculate the index of refraction.

EXAMPLE 12.4: CROWN GLASS AND WATER

Light travels from crown glass (n_g = 1.52) into water (n_w = 1.33). The angle of incidence in crown glass is 40.0°. What is the angle of refraction in water?

GIVEN

Index of refraction for crown glass 'n_g' = 1.52

Index of refraction for water 'n_w' = 1.33

Angle of incidence θ_g = 40.0°

REQUIRED

Angle of refraction θ_w = ?

SOLUTION: By Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$ or $n_g \sin\theta_g = n_w \sin\theta_w$

$$\sin\theta_w = \frac{n_g}{n_w}\sin\theta_g \quad \text{Putting values} \quad \sin\theta_w = \frac{1.52}{1.33}\sin 40^\circ$$

$$\text{or} \quad \sin\theta_w = 0.735 \quad \text{and} \quad \theta_w = \sin^{-1} 0.735$$

$$\text{Hence} \quad \theta_w = 47.3^\circ$$ **Answer**

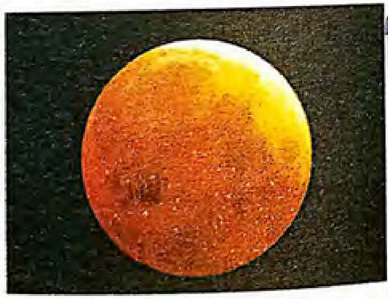
Note that $\theta_w > \theta_g$ since the light is moving to an optically lighter medium.

ASSIGNMENT 12.4: INDEX OF REFRACTION FOR UNKNOWN MEDIUM

Find the index of refraction for medium 2, if medium 1 is air with index of refraction n_a = 1.00, the incident angle is 30.0° and the angle of refraction is 22.0°. Compare the result with the table and identify the nature of medium 2.

TipBits

RED MOON: Refraction is responsible for the Moon appearing red during a lunar eclipse. A lunar eclipse occurs when Earth blocks sunlight towards the Moon. As a result, you might expect the Moon to be completely dark. Instead, the light from the sun refracts through the Earth's atmosphere and bends around Earth toward the Moon.



Since Earth's atmosphere scatters most of the blue and green light. Thus, mostly red light illuminates the Moon. Because the Moon reflects most colors of light equally well, it reflects the red light back to Earth, and therefore the Moon appears to be red.

12.5 TOTAL INTERNAL REFLECTION OF LIGHT

The angle of refraction is larger than the angle of incidence when light passes into a medium of a lower index of refraction, as shown in Figure 12.17 (a). This leads to an interesting phenomenon. As the angle of incidence increases, the angle of refraction also increases.

At a certain angle of incidence known as the critical angle, θ_c, the refracted light ray lies along the boundary of the two media, as shown in Figure 12.17 (b). When light strikes a transparent boundary, even though much of the light is transmitted, some is reflected. Total internal reflection occurs when light traveling from a region of a higher index of refraction to a region of a lower index of refraction strikes the boundary at an angle greater than the critical angle such that all light reflects back into the region of the higher index of refraction, as shown in Figure 12.17 (c).

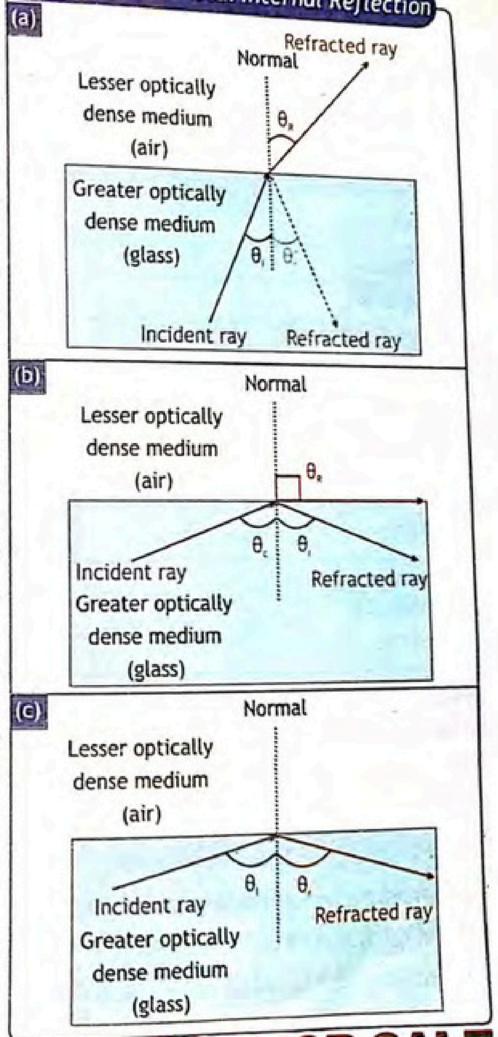
To construct an equation for the critical angle of any boundary, you can use Snell's Law and substitute $\theta_1 = \theta_c$ and $\theta_2 = 90°$.

$$n_1 \sin\theta_c = n_2 \sin 90^\circ$$

$$\text{since} \quad \sin 90^\circ = 1$$

$$\text{therefore} \quad n_1 \sin\theta_c = n_2$$

FIGURE 12.17 - *Total Internal Reflection*



Hence $\boxed{\sin\theta_c = \dfrac{n_2}{n_1}}$ —— 13.8

Thus we can define critical angle as **'the sine of the critical angle is equal to the index of refraction of the refracting medium divided by the index of refraction of the incident medium.**

No transmitted ray for $\theta_i \geq \theta_c$

The two conditions required for total internal reflection to occur are as follows.

- The light must travel from an optically more dense medium into an optically less dense medium.
- The angle of incidence must exceed the critical angle, θ_c, associated with the material.

ACTIVITY

Make a beam of light to enter a tank of water from above and place mirrors oriented at different angles to reflect this beam of light. You will observe that the beam that makes an angle of incidence greater than the critical angle will totally be reflected back.

LAB WORK

To find the refractive index of water by using concave mirror.

EXAMPLE 12.5: CRITICAL ANGLE

Find the critical angle for light traveling from glass (n = 1.502) to (a) air (n = 1.002) and (b) water (n = 1.332)

GIVEN

index of refraction for ordinary glass 'n_g' = 1.502

Index of refraction for air 'n_a' = 1.002

Index of refraction for water 'n_w' = 1.332

REQUIRED

Critical Angle θ_c = ?

SOLUTION: The critical angle is $\sin\theta_c = \dfrac{n_2}{n_1}$ or $\theta_c = \sin^{-1}\dfrac{n_2}{n_1}$

(a) When light goes from glass to air the critical angle is

$$\theta_c = \sin^{-1}\frac{n_a}{n_g} \quad \text{Putting values} \quad \theta_c = \sin^{-1}\frac{1.00}{1.50}$$

$$\theta_c = 41.8^\circ \text{ —— Answer}$$

(b) When light goes from glass to water the critical angle is

$$\theta_c = \sin^{-1}\frac{n_w}{n_g} \quad \text{Putting values} \quad \theta_c = \sin^{-1}\frac{1.33}{1.50}$$

$$\theta_c = 62.5^\circ \text{ —— Answer}$$

Note that the difference in index of refraction for glass - air is greater than glass - water. Hence light escapes from glass to air over less range of angles (00.0° to 41.8°) as compared to water (00.0° to 62.5°). In general, if the difference between indices of refraction values is large more light rays will undergo total internal reflection.

ASSIGNMENT 12.5: CRITICAL ANGLE FOR POLYSTYRENE

What is the critical angle for light traveling in a polystyrene (a type of plastic with index of refraction for polystyrene as 1.49) pipe surrounded by air (take index of refraction of air to be 1.00)?

Ans .6

a) **Optical fibres:** Light can be trapped by total internal reflection inside a bent glass rod and 'piped' along a curved path called optical fibre.

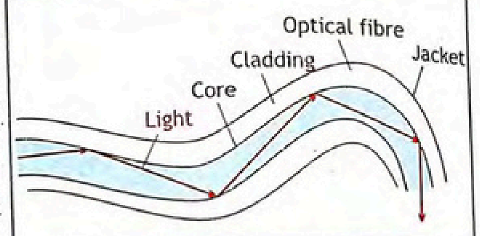
Various glasses and plastics can be used to make optical fibres. Optical fibre transmits a beam of light by means of total internal reflection. Total internal reflection can occur in any transparent medium that has a higher index of refraction than the surrounding medium.

An optical fibre cable has a cylindrical shape and consists of three concentric sections: the core, the cladding and the jacket (Figure 12.18).

The core is the innermost section and consists of one or more very thin strands, made of glass or plastic. Each strand is surrounded by its own cladding, a glass or plastic coating that has optical properties different from the core.

The boundary between the core and cladding acts as a reflector to confine light that would otherwise escape the core. The outermost layer, surrounding one or a bundle of cladded fibres, is the jacket. The jacket is made of plastic and other material layered to protect against moisture, abrasion, crushing and other environmental dangers. As shown in figure 12.18 the light traveling through the transparent fibre always hits the internal boundary of the optical fibre at an angle greater than the critical angle, so all of the light is reflected and none of the light is transmitted through the boundary. Thus, the light maintains its intensity over the distance of the fibre.

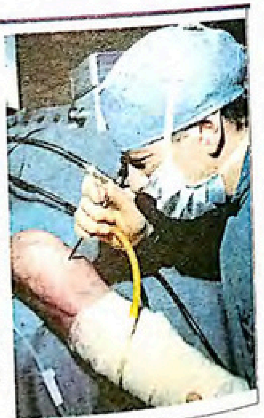
FIGURE 12.18 - *Optical fibre*



Light sent into one end of an optical fibre like those shown here is transmitted to the opposite end with little loss of light through the sides of the fibre.

POINT TO PONDER

Surgical techniques have been revolutionized by the use of optical fibres. In arthroscopic surgery, a small surgical instrument (several millimeters in diameter) is mounted at the end of an optical fibre cable which allows light to be shone on the internal area and the reflected light to be viewed by the surgeon. The surgeon can insert the instrument and cable into a joint, such as the knee, with only a tiny incision and minimal damage to the surrounding tissue. Consequently, recovery from the procedure is relatively rapid compared to recovery from traditional surgical techniques.



INFO — ENDOSCOPE

An endoscopy is a procedure where the inside of our body is examined using an instrument called an endoscope.

An endoscope is a long, thin, flexible tube that has a light source and camera at one end. Images of the inside of our body are displayed on computer monitor. Endoscopes can be inserted into the body through a natural opening, such as the mouth and down the throat, or through the bottom. An endoscope can also be inserted through a small cut (incision) made in the skin when keyhole surgery is being carried out.

Endoscopy can also be used by engineers to light up some awkward spot for inspection.

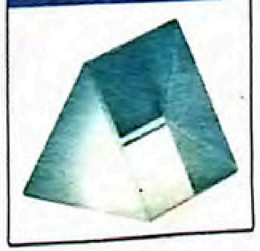
Picture shows a colonoscope revealing a benign (noncancerous) polyp attached to the wall of the colon (large intestine). Polyps that can turn cancerous or grow large enough to obstruct the colon are removed surgically.

12.6 REFRACTION OF LIGHT THROUGH PRISM

Prism is a transparent optical element with flat, polished surfaces that refract light. At least two of the flat surfaces must have an angle between them. The exact angles between the surfaces depend on the application.

The traditional geometrical shape is that of a triangular prism with a triangular base and rectangular sides as shown in figure 12.19.

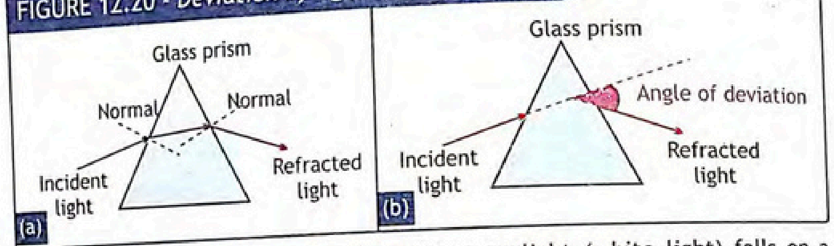
FIGURE 12.19 - *Prism*



a. Deviation of light through prism: In the prism shown in Figure 12.20(a), the incident light ray travels through the air and enters the left side of the glass. The light bends toward the normal in the glass, because glass has a higher index of refraction (optical density) than the air.

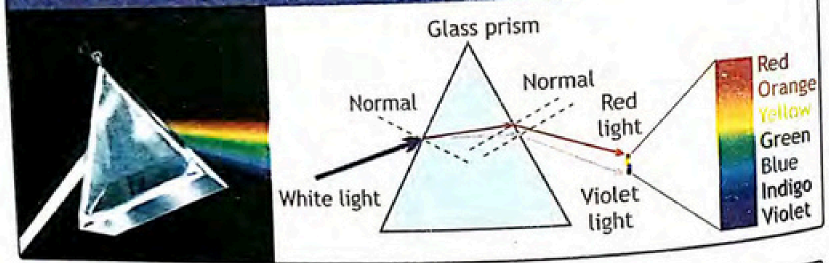
When the light leaves the glass and emerges into the air on the other side of the prism, the light is refracted away from the normal. Notice that the direction of the light leaving the glass is different from that of the light entering it. The change in direction of the light as it passes through the glass is known as its deviation. The amount of change is called the angle of deviation, θ_{dev} as shown in figure 12.20 (b). You can determine the angle of deviation for any shape of prism by applying Snell's law at each air-glass interface.

FIGURE 12.20 - *Deviation of light through prism*



b. Dispersion of light through prism: When sunlight (white light) falls on a triangular glass prism as in figure 12.21, a band of colours called a spectrum is obtained. The effect is termed dispersion. It arises because white light is a mixture of many colours; the prism separates the colours because the refractive index of glass is different for each colour (it is greatest for violet light).

FIGURE 12.21 - *Dispersion of light through prism*



LAB WORK

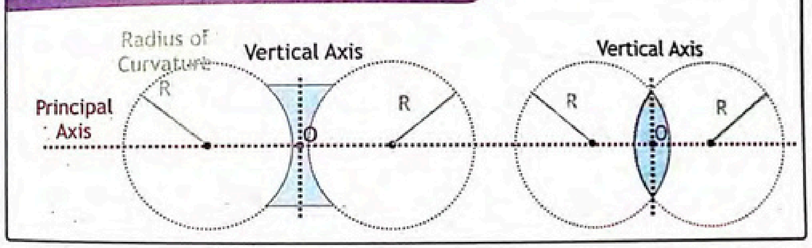
To trace the path of a ray of light through glass prism and measure the angle of deviation.

12.7 LENSES

A lens is a piece of transparent optical material that focuses or disperses a beam of light by refraction. Lenses are made from materials such as glass or plastic, and are grounded and polished or molded to a desired shape. A lens can focus light to form an image.

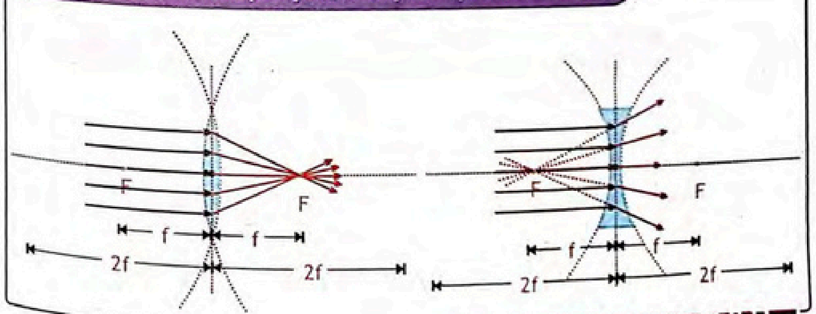
Each of a lens' two faces is part of a sphere and can be convex or concave (or one face may be flat). If a lens is thicker at the centre than the edges, it is a convex or converging lens since parallel rays will be converged to meet at the focus. A lens which is thinner in the centre than the edges is a concave or diverging lens since rays going through it will be spread out.

FIGURE 12.22 - *Concave and Convex lens*



Like mirrors, lenses have a principal axis perpendicular to their surface and passing through their midpoint as shown in figure 12.22. Lenses also have a vertical axis or principal plane through their middle. The centre point of the lense is called optical centre and denoted by O. There is no real centre of curvature, so 2F is used to denote twice the focal length.

FIGURE 12.23 - *Principal focus or focal point in lenses*



The point of convergence of the rays that enter parallel to the principal axis is called the principal focus or focal point. Since the rays of light can enter the lens from either side, there is a principal focus or focal point on the principal axis on each side of the lens. After refraction from lens, the rays converge or diverge as if they originate from a single point called the focal point F (or principal focus) as shown in figure 12.23. The distance from the vertical axis to either of the focal points is called the focal length of the lens.

12.7.1. Image formation and ray tracing for lenses: Ray diagrams are used to show image formation in lenses.

1. Construct a figure showing the lens and the principal axis of the lens. The figure should also show the focal points on both sides of the lens.

2. Draw the object at the appropriate point. One end of the object will generally lie on the axis.

3. Draw three rays that emanate from the tip of the object:

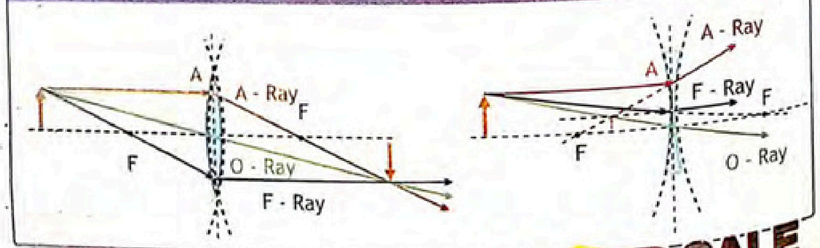
(a) The A - ray (parallel ray hitting lens at point A) is initially parallel to the axis. After passing through the lens, this ray or its extrapolation passes through one of the focal points.

(b) The F - ray (focal ray or its extrapolation) is directed at the focal point (same side for convex lens and the other side for concave lens). After passing through the lens, this ray is parallel to the axis.

(c) The O - ray (origin ray or its extrapolation) passes straight through the center of the lens called origin and is not deflected.

4. These three rays (figure 12.24) or their extrapolations intersect at the image. If the rays actually pass through the image, the image is real; if they do not, the image is virtual (just as in the case of images formed by a mirror).

FIGURE 12.24 - Image formation by concave and convex lenses



When a lens forms a real image, the object and image are on opposite sides of the lens.

12.8 THE LENS EQUATION

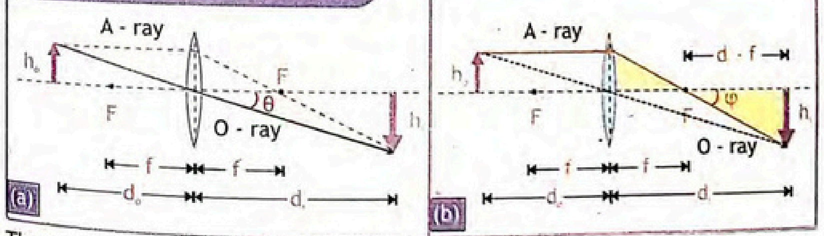
To calculate the precise location and size of the image formed by a lens, we use an equation that is analogous to the mirror equation. The lens equation is a precise mathematical relationship between the object distance and the image distance for a given lens. This formula is accurate only if the thickness of the lens is small compared to its diameter.

The following quantities are included in lens formula:

- f = the focal length of the lens
- h_o = the height of the object
- h_i = the height of the image
- d_o = the distance of the object from the lens
- d_i = the distance of the image from the lens
- M = the magnification of the image

This equation can be derived by referring to Figure 12.25, which shows the image produced by a convex lens, along with the O and A - rays that locate the image.

FIGURE 12.25 - Lens formula



The ray in Figure 12.25 (a) hits the lens at its midpoint, where the principal axis is the normal to the lens. As a result, the ray refracts at an angle θ below the principal axis that is equal to its incident angle θ above the axis. Therefore, the two green triangles in this diagram are similar, from which it follows that ratios of equivalent sides of similar triangles are equal.

$$\frac{h_o}{-h_i} = \frac{d_o}{d_i} \qquad (1)$$

The image height is taken negative because it is inverted.

From the figure 12.25 (b) it is clear that the two yellow triangles in this diagram are also similar, since they are both right triangles and share the common angle φ. Thus, by using the same rule of similar triangles, we get

$$-\frac{h_o}{h_i}=\frac{f}{d_i-f} \quad \text{——} (2)$$

Comparing equation 1 and equation 2, we get $\quad \frac{d_o}{d_i}=\frac{f}{d_i-f}$

To isolate 'f', Cross Multiply $\quad d_i f=d_o(d_i-f)$

or

$$d_i f=d_o d_i-d_o f \quad \text{——} (3)$$

Divide both sides of the equation 3 by $d_o d_i f$ $\quad \frac{\cancel{d_i}\cancel{f}}{d_o\cancel{d_i}\cancel{f}}=\frac{\cancel{d_o}\cancel{d_i}}{\cancel{d_o}\cancel{d_i}f}-\frac{\cancel{d_o}\cancel{f}}{\cancel{d_o}d_i\cancel{f}}$

$$\frac{1}{d_o}=\frac{1}{f}-\frac{1}{d_i}$$

$$\boxed{\frac{1}{f}=\frac{1}{d_i}+\frac{1}{d_o}} \quad \text{——} 12.9$$

The final equation 12.9 is known as the lens formula. You will probably recognize this equation as the mirror formula. Because the lens and mirror equations are the same, the equation is often called the mirror/lens formula.

The ratio of the height of the image to the height of the object is defined as the magnification, M. From Equation 1, we see that

$$\boxed{M=\frac{h_i}{h_o}=-\frac{d_i}{d_o}} \quad \text{——} 12.10$$

We derived the magnification and thin lens equations for a convex lens forming a real image, it can be used to calculate the image properties of both converging lenses and diverging lenses, provided we use the sign conventions described below.

12.8.1 Convention for the lens equation: To include all of the possible properties of both images and objects, the following sign convention has been established

a. Object distance:

- d_o is positive for real objects (from which light diverges).

b. Image distance:

- d_i is positive for real images (images on the opposite side of the lens from the object).
- d_i is negative for virtual images (images on the same side of the lens as the object).

c. Image attitude:

- h_i is positive for images that are upright, compared to the object
- h_i is negative for images that are inverted, compared to the object

d. Focal length:

- f is positive for converging (convex) lenses.
- f is negative for diverging (concave) lenses.

12.8.2 Power of lens: The degree of convergence or divergence of light rays falling on lens is called power of lens. Instrument makers often quote the power of a lens rather than its focal length. The power of a lens in diopters D, is given by the equation

$$\boxed{D=\frac{1}{f}} \quad \text{——} 12.11$$

where f is the focal length of the lens expressed in metres. Eyeglass lenses are typically characterized in terms of **diopters.** The power of a lens in diopters should not be confused with the familiar concept of power in watts. It is an unfortunate fact that the word "power" is used for two completely different concepts. If you examine a prescription for eyeglasses, you will note lens powers given in diopters. If you examine the label on a motor, you will note energy consumption rate given as a power in watts.

LAB WORK

To determine the critical angle of glass using a semi circular slab and a light ray box/or by prism.

To find the focal length of a convex lens by parallax method.

EXAMPLE 12.6: IMAGE DISTANCE IN CONVEX LENS

A converging lens of focal length 10.0 cm forms images of an object situated at various distances. (a) If the object is placed 30.0 cm from the lens, locate the image, state whether it's real or virtual, and find its magnification. Repeat the problem (b) when the object is at 20.0 cm and (c) when the object is 15.0 cm from the lens (d) when the object is 10.0 cm from the lens and (e) when the object is 5.00 cm from the lens.

GIVEN

Focal length 'f' = 10.00 cm.

(a) Object Distance 'd_o' = 30.0 cm,

(b) Object Distance 'd_o' = 20.0 cm

(c) Object Distance 'd_o' = 15.0 cm

(d) Object Distance 'd_o' = 10.00 cm

(e) Object Distance 'd_o' = 5.00 cm

REQUIRED

(a) Image Distance 'd_i' = ?

Magnification M = ?

(b) Image Distance 'd_i' = ?

Magnification M = ?

(c) Image Distance 'd_i' = ?

Magnification M = ?

(d) Image Distance 'd_i' = ?

Magnification M = ?

(e) Image Distance 'd_i' = ?

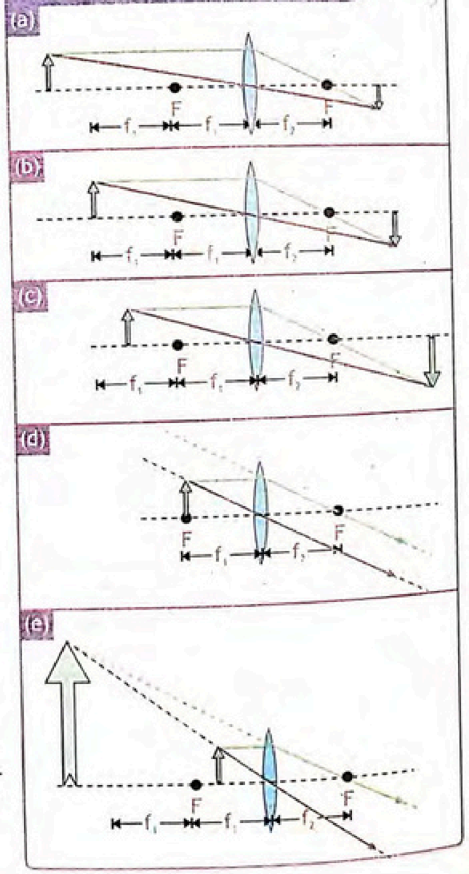
Magnification M = ?

SOLUTION: by mirror equation

$$\frac{1}{f}=\frac{1}{d_i}+\frac{1}{d_o} \quad \text{or} \quad \frac{1}{d_i}=\frac{1}{f}-\frac{1}{d_o}$$

$$\frac{1}{d_i}=\frac{d_o-f}{fd_o}$$

FIGURE 12.26 - Example 12.6



$$\text{or} \quad d_i=\frac{fd_o}{d_o-f} \quad \text{——} (1)$$

(a) to get image distance putting values in equation 1

$$d_i=\frac{10.0\,cm\times 30.0\,cm}{30.0\,cm-10.0\,cm} \quad \text{or} \quad d_i=\frac{300\,cm^{\cancel{2}}}{20\,\cancel{c}m}$$

Therefore $d_i=+15.0\,cm$ —— Answer

The magnification formula is $M=-\frac{d_i}{d_o}=-\frac{15cm}{30cm}$

Therefore $M=-0.500$ —— Answer

As shown in figure 12.26 (a) and the answers in this example it is confirmed that when the object distance is greater than twice the focal length ($d_o > 2f$), for convex lens

- the image distance is less than twice the focal length, (i.e 15cm < 20 cm)
- the image is real, (distance positive)
- the image is inverted, (magnification negative) and
- the image is smaller than the object. (magnification less than 1)

(b) to get image distance putting values in equation 1

$$d_i=\frac{10.0\,cm\times 20.0\,cm}{20.0\,cm-10.0\,cm} \quad \text{or} \quad d_i=\frac{200\,cm^{\cancel{2}}}{10.0\,\cancel{c}m}$$

Hence $d_i=+20.0\,cm$ —— Answer

The magnification formula is $M=-\frac{d_i}{d_o}=-\frac{20cm}{20cm}$

Therefore $M=-1.00$ —— Answer

Therefore, when the object distance is equal to twice the focal length ($d_o = 2f$) as shown in figure 12.26 (b) it is confirmed that for convex lens:

- the image distance is equal to twice the focal length (20 cm),
- the image is real (distance positive),
- the image is inverted (magnification negative), and
- the image is the same size as the object (magnification is equal to 1).

(c) to get image distance putting values in equation 1

$$d_i = \frac{10.0cm \times 15.0cm}{15.0cm - 10.0cm} \quad \text{or} \quad d_i = \frac{150 cm^{\cancel{2}}}{5.00 \cancel{cm}}$$

Hence $d_i = 30 cm$ — Answer

The magnification formula is $M = -\frac{d_i}{d_o} = -\frac{30cm}{15cm}$

Therefore $M = -2.00$ — Answer

Therefore, when the object distance is less than twice the focal length but greater than the focal length ($2f < d_o < f$) as shown in figure 12.26 (c), it is confirmed that for convex lens:

- the image distance is greater than twice the focal length (30 cm > 20 cm),
- the image is real (distance positive),
- the image is inverted (magnification negative), and
- the image is larger than the object (magnification is greater than 1).

(d) to get image distance putting values in equation 1

$$d_i = \frac{10.0cm \times 10.0cm}{10.0cm - 10.0cm} \quad \text{or} \quad d_i = \frac{100 cm^{\cancel{2}}}{0 \cancel{cm}}$$

Hence $d_i = \infty$ — Answer

The magnification formula is $M = -\frac{d_i}{d_o} = -\frac{\infty}{20cm}$

Therefore $M = \infty$ — Answer

Hence, the result confirms that when the object distance is equal to the focal length ($d_o = f$) as shown in figure 12.26 (d) for convex lens:

- no image exists because the refracted rays are parallel. You could say that the image lies at infinity. .

(e) to get image distance putting values in equation 1

$$d_i = \frac{10.0cm \times 5.00cm}{5.00cm - 10.0cm} \quad \text{or} \quad d_i = \frac{50 cm^{\cancel{2}}}{-5 \cancel{cm}}$$

Hence $d_i = -10 cm$ — Answer

The magnification formula is $M = -\frac{d_i}{d_o} = -\frac{-10cm}{5cm}$

Therefore $M = +2$ — Answer

Hence, the results confirms that when the object distance is less than the focal length but greater than zero ($f > d_o > 0$) as shown in figure 12.6 (e), for convex lens:

- the image distance is greater than the object distance, (10 cm > 5 cm)
- the image is virtual (distance negative),
- the image is upright (magnification positive), and
- the image is larger than the object (magnification is greater than 1).

EXTENSION EXERCISE 12.2

Repeat the problem of Example 12.6 for a diverging lens of focal length 10.0 cm.

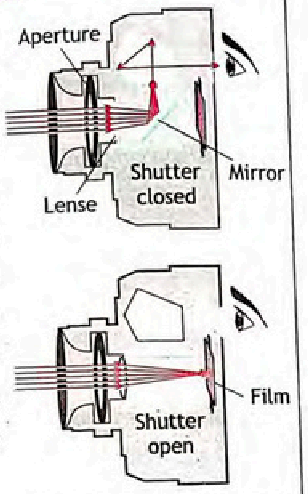
ASSIGNMENT 12.6: LENS COMPARISON

An object is placed 30.0 cm in front of a converging lens and then 12.5 cm in front of a diverging lens. Both lenses have a focal length of 10.0 cm. For both cases, find the image distance and the magnification. Describe the images.

HOW A CAMERA WORKS

INFO

One of the simplest optical instruments is the camera, which often has only one lens to produce an image, or even—in a pinhole camera—no lens. Figure shows a simple 35-mm camera. The camera uses a converging lens to form a real image on the film. The image must be real in order to expose the film (i.e., cause a chemical reaction). Light rays from a point on an object being photographed must converge to a corresponding point on the film. A digital camera has replaced film with a CCD (charge-coupled device) array.



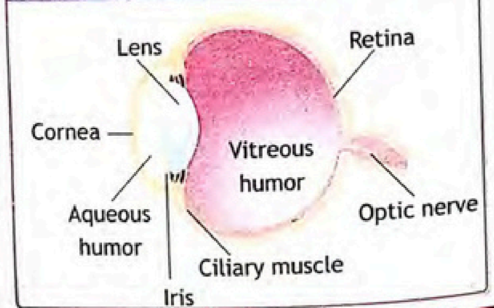
12.9 HUMAN EYE

Ans: (10)

The human eye is like a camera in its basic structure (figure 12.27), but is more complex. The interior of the eye is filled with a transparent gel-like substance called the vitreous humor with index of refraction n = 1.337. Light enters in this region through the cornea and lens. Between the cornea and lens is a watery fluid, the aqueous humor with n = 1.336. The iris adjusts automatically to control the amount of light entering the eye, similar to a camera.

The retina, which plays the role of the film or sensor in a camera, is on the curved back surface of the eye. The retina is composed of a many nerves which act to change light energy into electrical signals that travel along the nerves to brain for interpretation.

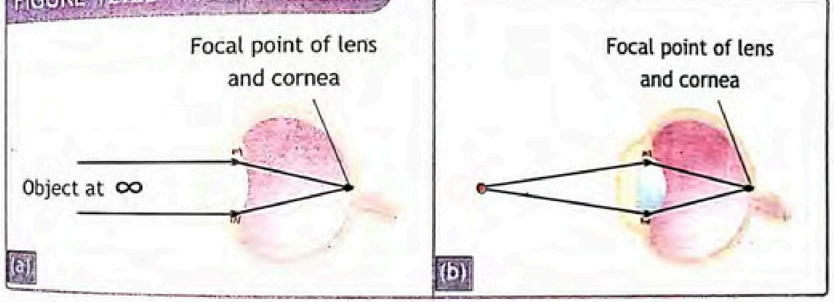
FIGURE 12.27 - Human Eye



The lens of the eye (n = 1.386 to 1.406) does little of the bending of the light rays. Most of the refraction is done at the front surface of the cornea at its interface with air. The lens acts as a fine adjustment for focusing at different distances. This is accomplished by the ciliary muscles, which change the curvature of the lens so that its focal length is changed.

To focus on a distant object, the ciliary muscles of the eye are relaxed and the lens is thin, as shown in figure 12.28 (a), and parallel rays focus at the focal point (on the retina). To focus on a nearby object, the muscles contract, causing the centre of the lens to thicken, figure 12.28(b), thus shortening the focal length so that images of nearby objects can be focused on the retina, behind the new focal point. This focusing adjustment is called **accommodation**.

FIGURE 12.28 - Accommodation



The closest distance at which the eye can focus clearly is called the near point of the eye. For young adults it is typically 25 cm, as people grow older, the ability to accommodate is reduced and the near point increases.

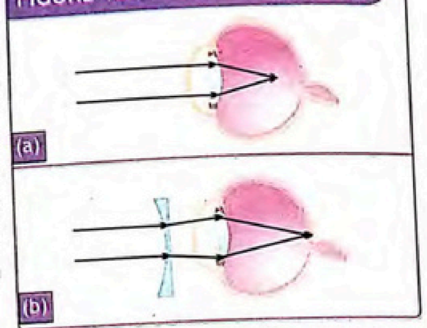
A given person's far point is the farthest distance at which an object can be seen clearly. Since we can focus on the Moon and stars, it is clear that the normal far point is essentially infinity.

Many people have eyes that do not accommodate within the normal range of 25 cm to infinity or have some other defect. Two common defects are short-sightedness and long-sightedness. Both can be corrected to a large extent with lenses—either eyeglasses or contact lenses.

12.9.1 Short-sightedness: In short-sightedness (nearsightedness or myopia), the human eye can focus only on nearby objects. The far point is not infinity but some shorter distance, so distant objects are not seen clearly.

Short-sightedness is usually caused by an eyeball that is too long, although sometimes it is the curvature of the cornea that is too great. In either case, images of distant objects are focused in front of the retina as shown in figure 12.29 (a). A diverging lens, because it causes parallel rays to diverge, allows the rays to be focused at the retina as shown in figure 12.29 (b) and thus can correct nearsightedness.

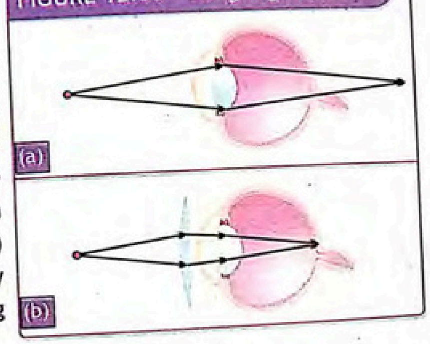
FIGURE 12.29 - Short-sightedness



12.9.2 Long-sightedness:

In long-sightedness (farsightedness or hyperopia), the eye cannot focus on nearby objects. Although distant objects are usually seen clearly, the near point is somewhat greater than the "normal" 25 cm, shown in figure 12.30 (a). This defect is caused by an eyeball that is too short or (less often) by a cornea that is not sufficiently curved. It is corrected by a converging lens, shown in figure 12.30 (b).

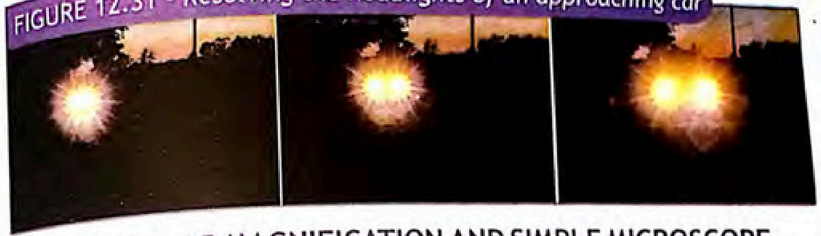
FIGURE 12.30 - Long-sightedness



12.9.3 Resolving power: Resolving power is the capacity of an instrument to distinctively separate two points which are close together. The sharpness of vision—in particular, the ability to visually separate closely spaced objects—is referred to as resolution.

For example, in the first photo we see a bright light in the distance that may be the single headlight of an approaching motorcycle or the unresolved image of two headlights on a car. As the car approaches closer, the separation between the lights will increase. As the car continues to approach, its individual headlights become increasingly distinct, as shown in the third photo. So the two points are distinctively separated.

FIGURE 12.31 - Resolving the headlights of an approaching car



12.10 ANGULAR MAGNIFICATION AND SIMPLE MICROSCOPE

An optical instrument, such as a magnifying glass, allows us to view small or distant objects because it produces a larger image on the retina than would be possible otherwise. In other words, an optical instrument magnifies the angular size of the object. **The angular magnification (or magnifying power) m_θ is the angular size θ' of the final image produced by the instrument divided by a reference angular size θ.** The reference angular size is the angular size of the object when seen without the instrument.

$$\text{Angular Magnification} = \frac{\text{Angular size of final image produced by optical instrument}}{\text{Reference angular size of object seen without optical instrument}}$$

or $$m_\theta = \frac{\theta'}{\theta} \quad \text{—— (1)}$$

Assume an object with height h_o, without a magnifier, the largest angle θ that we can attain and see the object clearly is when we place the object at the near point N as in Figure 12.32 (a). We can get a magnified image of the object by placing the object just inside the focal length of a converging lens as shown in Figure 12.32 (b). If we look through the lens at the image, we can see the enlarged, upright, virtual image.

FIGURE 12.32: SIMPLE MICROSCOPE

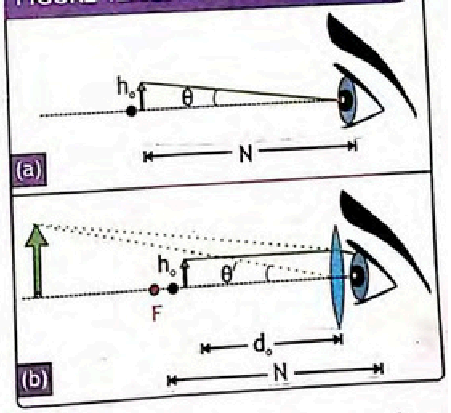


Figure 12.32 (a) shows that the angle subtended by the object without the magnifier is given by

$$\tan\theta = \frac{Perpendicular}{base} = \frac{h_o}{N} \quad \text{——— (2)}$$

Assuming that the eye is next to the magnifying glass, the angular size as seen by the eye as in figure 12.32 (b) is

$$\tan\theta' = \frac{Perpendicular}{base} = \frac{h_o}{d_o} \quad \text{——— (3)}$$

where f is the focal length of the lens. We assume that the object is placed at the focal length of the lens, so the image is at minus infinity. For small-angles $\tan\theta \approx \theta$ and $\tan\theta' \approx \theta'$. Thus, by putting values from equation 2 and equation 3 in equation 1, the angular magnification of a magnifier can be written as

$$m_\theta = \frac{\cancel{h_o}/d_o}{\cancel{h_o}/N} \quad \text{or} \quad m_\theta = \frac{N}{d_o} \quad \text{——— (4)}$$

According to the thin-lens equation, d_o is related to the image distance d_i and the focal length f of the lens by

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \text{or} \quad \frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} \quad \text{——— (5)}$$

putting values from equation 5 in equation 4, we get

$$\boxed{m_\theta = \left[\frac{1}{f} - \frac{1}{d_i}\right]N} \quad \text{——— 12.12}$$

Two special cases of this result are of interest, depending on whether the image is located as close to the eye as possible or as far away as possible.

To be seen clearly, the closest the image can be relative to the eye is at the near point, or $d_i = -N$. The minus sign indicates that the image lies to the left of the lens and is virtual. In this event, Equation 12.12 becomes

$$m_\theta = \left[\frac{1}{f} - \frac{1}{-N}\right]N \quad \text{or} \quad m_\theta = \left[\frac{1}{f} + \frac{1}{N}\right]N$$

$$\text{and} \quad m_\theta = \frac{N}{f} + \frac{\cancel{N}}{\cancel{N}} \qquad \text{Therefore} \quad \boxed{m_\theta = \frac{N}{f} + 1} \quad \text{——— 12.12 (a)}$$

The farthest the image can be from the eye is at infinity ($d_i = \infty$); this occurs when the object is placed at the focal point of the lens. When the image is at infinity, equation 12.12 can be written as

$$m_\theta = \left[\frac{1}{f} - \frac{1}{\infty}\right]N \quad \text{as} \quad \frac{1}{\infty} = 0$$

$$\text{or} \quad m_\theta = \left[\frac{1}{f} - 0\right]N \qquad \text{Hence} \quad \boxed{m_\theta = \frac{N}{f}} \quad \text{——— 12.12 (b)}$$

EXAMPLE 12.7: INSECT EXAMINATION

A biologist with a near-point distance of N = 26 cm, examines an insect wing through a magnifying glass whose focal length is 4.3 cm. Find the angular magnification when the image produced by the magnifier is (a) at the near point and (b) at infinity.

GIVEN

Focal length of magnifying glass 'f' = 4.3 cm.

Near-point distance of N = 26 cm

Object Distance 'd_o' = 1.1 cm

REQUIRED

Angular Magnification 'm_θ' = ?

SOLUTION: The magnification when the image is at near point for magnifying glass is

$$m_\theta = \frac{N}{f} + 1 \qquad \text{Putting values} \qquad m_\theta = \frac{26cm}{4.3cm} + 1$$

$$\text{Hence} \quad m_\theta = 7 \quad \text{——— Answer}$$

The magnification when the image is at infinity for magnifying glass is

$$m_\theta = \frac{N}{f} \qquad \text{Putting values} \qquad m_\theta = \frac{26cm}{4.3cm}$$

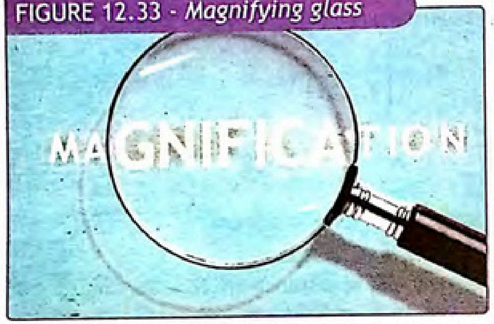
$$\text{Hence} \quad m_\theta = 6 \quad \text{——— Answer}$$

The relaxed eye results in decrease in magnification of 1.0—from 7.0 to 6.0.

ASSIGNMENT 12.7: JEWELER'S LOUPE

An 8-cm-focal-length converging lens is used as a 'jeweler's loupe,' which is a magnifying glass. Estimate the magnification (a) when the eye is relaxed, and (b) if the eye is focused at its near point

FIGURE 12.33 - *Magnifying glass*



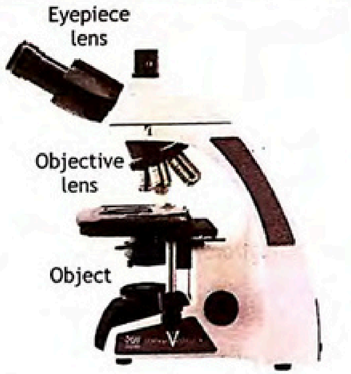
12. 11 COMPOUND MICROSCOPE

To increase the angular magnification beyond that possible with a magnifying glass, an additional converging lens can be included to "premagnify" the object before the magnifying glass comes into play.

The result is an optical instrument known as the compound microscope. The magnifying glass is called the eyepiece and the additional lens is called the objective as shown in figure 12.34.

The overall magnification of a microscope is the product of the magnifications produced by the two lenses.

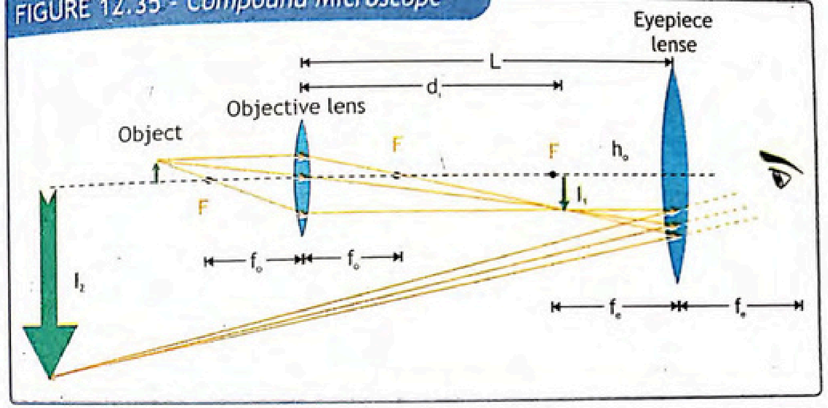
FIGURE 12.34 - *Compound Microscope*



In a typical situation shown in figure 12.35, the object to be examined is placed only a small distance beyond the focal point of the objective 'f_o', which means that $d_o \approx f_o$. The magnification 'M_o' produced by the objective is given

$$M_o = -\frac{h_i}{h_o} = -\frac{d_i}{d_o} = -\frac{d_i}{f_o} \quad \text{——①}$$

FIGURE 12.35 - *Compound Microscope*



The eyepiece acts like a simple magnifier. If we assume that the eye is relaxed, the eyepiece angular magnification m_e by equation 12.12 (b) can be written as

$$m_e = \frac{N}{f_e} \quad \text{——②}$$

Since the eyepiece enlarges the image formed by the objective, the overall magnification 'm' is the product of the magnification of the objective lens, 'M_o' times the angular magnification 'm_e' of the eyepiece lens

$$m = M_o \times m_e \quad \text{——③}$$

putting equation 1 and equation 2 in equation 3, we get

$$\boxed{m = -\frac{d_i}{f_o} \times \frac{N}{f_e}} \quad \text{—— 12.13}$$

The minus sign indicates that the image is inverted.

EXAMPLE 12.8: BIOLOGY LABORATORY

In biology class, a student with a near-point distance of N = 25 cm uses a microscope to view an amoeba. If the objective has a focal length of 1.0 cm, the eyepiece has a focal length of 2.5 cm, and the amoeba is 1.1 cm from the objective, what is the magnification produced by the microscope?

GIVEN

Focal length of eye piece 'f_e' = 2.5 cm.

Focal length of objective 'f_o' = 1.0 cm.

Near-point distance of N = 25 cm

Object distance 'd_o' = 1.1 cm

REQUIRED

Total magnification 'm' = ?

SOLUTION: The image distance d_i for the equation 12.13 is not given, therefore we will first find the image distance by using the thin-lens formula

$$\frac{1}{f_o}=\frac{1}{d_i}+\frac{1}{d_o} \quad \text{or} \quad \frac{1}{d_i}=\frac{1}{f_o}-\frac{1}{d_o} \quad \text{taking LCM} \quad \frac{1}{d_i}=\frac{d_o-f_o}{fd_o}$$

$$\text{or} \quad d_i=\frac{f_o d_o}{d_o-f_o} \quad \text{— (1)}$$

Putting values $$d_i=\frac{1.1cm\times1.0cm}{1.0cm-1.1cm_o} \quad \text{and} \quad d_i=\frac{1.1cm^2}{-0.1cm_o}$$

$$d_i=-11cm$$

The magnification formula for compound microscope is $$m=-\frac{d_i}{f_o}\times\frac{N}{f_e}$$

Putting values $$m=-\frac{11cm}{1.0cm}\times\frac{25cm}{2.5cm}$$

Therefore $m=-110$ — Answer

Thus, the amoeba appears 110 times larger and is inverted. If the amoeba is to be viewed with a relaxed eye, the image formed by the objective should be at the focal point of the eyepiece, which will then form an image at infinity. Therefore, the length of the tube containing the objective and eyepiece is L = 11 cm + 2.5 cm = 13.5 cm in this case.

ASSIGNMENT 12.8: EYE PIECE FOCAL LENGTH

If the focal length of the eyepiece is increased, does the magnitude of the magnification increase or decrease? Check your response by calculating the magnification when the focal length of the eyepiece is 3.5 cm.

12. 12 REFRACTING TELESCOPE

A telescope is an instrument for magnifying distant objects, such as stars and planets. Like a microscope, a telescope consists of an objective lens that forms a real image of the object; and an eyepiece (also called the ocular) is used to view this real image.

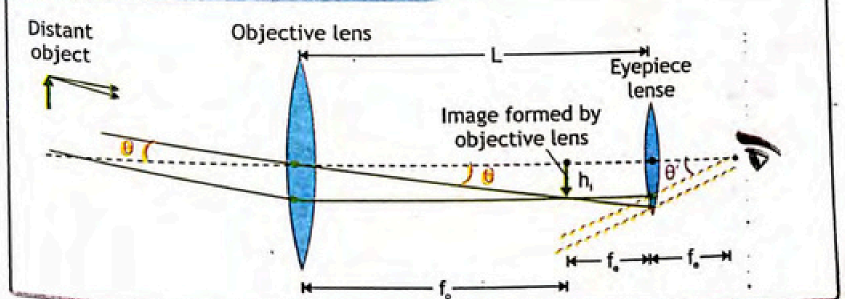
FIGURE 12.36 - Telescope

Since the object is far away, the angular size seen by the unaided eye is nearly the same as the angle θ subtended at the objective of the telescope as shown in Figure 12.37. Moreover, θ is also the angle subtended by the first image, therefore

$$\theta=-\frac{h_i}{f_o} \quad \text{— (1)}$$

Here h_i is the height of the first image and f_o is the focal length of the objective. A minus sign has been inserted into this equation because the first image is inverted relative to the object and the image height h_i is a negative number.

FIGURE 12.37 - Refracting telescope



As in the microscope, the image of the objective is the object for the eyepiece, which is basically a magnifier. Thus, if the image of the objective is placed at the focal point of the eyepiece, it will form an image that is at infinity, as indicated in Figure 12.37. In this configuration, the observer can view the final image of the telescope with a completely relaxed eye.

The angular size of the image formed by the eyepiece is approximately

$$\theta' = \frac{h_i}{f_e} \quad \text{——(2)}$$

To find the total angular magnification of the telescope, we consider the definition of angular magnification as

$$m_\theta = \frac{\theta'}{\theta} \quad \text{——(3)}$$

putting equation 1 and equation 2 in equation 3, we get

$$m_\theta = \frac{\cancel{h_i}/f_e}{-\cancel{h_i}/f_o} \qquad \text{Therefore} \qquad \boxed{m_\theta = -\frac{f_o}{f_e}} \quad \text{——12.14}$$

LAB WORK

To set up a microscope and telescope.

EXAMPLE 12.9: WORLD'S LARGEST TELESCOPE

The largest optical refracting telescope in the world is located at the Yerkes Observatory in Wisconsin. The objective lens has a focal length of 19 m, and the eyepiece has a focal length of 10 cm. (a) Calculate the total magnifying power of this telescope. (b) Estimate the length of the telescope.

GIVEN

Focal length of objective 'f_o' = 19 m.

Focal length of eye piece 'f_e' = 10 cm.

REQUIRED

(a) Angular magnification 'm_θ' = ?

(b) Approximate length 'L' = ?

SOLUTION: (a) The magnification of telescope is $m_\theta = -\frac{f_o}{f_e}$

Putting values $m_\theta = -\frac{19m}{0.10m}$ Therefore $m_\theta = -190$ —— Answer

(b) For a relaxed eye, the image is at the focal point of both the eyepiece and the objective lenses. The distance between the two lenses is thus

$$L \approx f_o + f_e \approx 19m + 0.10m$$

Therefore $L \approx 19m$ —— Answer

which is essentially the length of the telescope.

ASSIGNMENT 12.9: ASTRONOMICAL TELESCOPE

An astronomical telescope has the following specifications: f_o = 985 mm and f_e = 5.00 mm. From these data points, find (a) the angular magnification and (b) the approximate length of this telescope.

KEY POINTS

The Reflection of Light: When light reflects from a smooth surface, the reflected light obeys the law of reflection.

Spherical Mirrors: A spherical mirror has the shape of a section from the surface of a hollow sphere.

The Mirror Formula: The formula specifying the relation between the object distance d_o, the image distance d_i, and the focal length f of the mirror.

Refraction: The changing of a light ray's direction when it passes through variations in matter.

Snell's Law: The ratio of sine of angle of incidence and sine of angle of refraction is constant for a given pair of media.

Total Internal Reflection: When the angle of incidence exceeds the critical angle, all the incident light is reflected back into the material from which it came.

Lens: A transmissive optical device that focuses or disperses a light beam by means of refraction.

Thin Lens Formula: The formula specifying the relation between the object distance d_o, the image distance d_i, and the focal length f of thin lens.

Power of Lens: The degree of convergence or divergence of light rays falling on lens.

Short Sightedness: Defect of an eye so that distant object are not seen clearly.

Long Sightedness: Defect of an eye so that nearby object are not seen clearly.

Simple Microscope: A converging lens, which works by allowing an object to be viewed at a distance less than the near-point distance.

Compound Microscope: Instruments for enlarging the detail that we cannot see with the unaided eye.

Telescope: Device meant for viewing distant objects, producing an image that is larger than the image that can be seen with the unaided eye.

PROJECTS

GROUP A 'OPTICS': Interview an optometrist, optician, or ophthalmologist. Find out what equipment and tools each uses. What kinds of eye problems are curable? What training is necessary for each career? Publish the interview(s) in school magazine.

GROUP B 'MUSLIM SCIENTIST': The Egyptian scholar Alhazen (Ibn-al-Haytham) studied lenses, mirrors, rainbows, and other light phenomena early in the Middle Ages. Research his scholarly work, his life, and his relationship with the Caliph al-Hakim. How advanced were Alhazen's inventions and theories? Summarize your findings and report them to the class.

GROUP C 'OPTICAL FIBRES': Prepare a chart presentation on the use of optical fibres in telecommunications and medical field and present your chart to classroom and display it in classroom.

GROUP D 'MICROSCOPES AND TELESCOPES': Research the internet for advance microscopes and telescopes. Prepare a presentation to be presented in class.

GROUP E 'TELESCOPE OR MICROSCOPE': Buy few lenses and make your own telescope or compound microscope of simple objects and donate it to the school laboratory.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. If the angle of incidence is 30° the angle of reflection will be
   A. 30° B. 45° C. 90° D. 210°
2. When r is the radius of curvature of concave mirror. Real diminished image will be formed when the object is at
   A. $d_o > r$ B. $d_o = r$ C. $r > d_o > f$ D. $d_o = f$
3. The focal length of convex mirror with radius of curvature 10 cm is
   A. +10 cm B. +5 cm C. - 10 cm D. - 5 cm
4. An object is placed 7 cm from a concave mirror whose radius of curvature is 10 cm, the image formed will be
   A. real and upright B. virtual and upright
   C. real and inverted D. virtual and inverted
5. Which one of the following materials will refract light more
   A. water B. glass C. air D. diamond

Geometrical Method

6. A convex lense with focal length 8.00 cm has the power of lens
   A. 2.05 D B. 4.00 D C. 12.5 D D. 16.0 D
7. If the distance from your eye's lens to the retina is shorter than for a normal eye, you will struggle to see objects that are
   A. nearby B. colorful C. far away D. moving fast.
8. Who benefits more from using a magnifying glass, a person whose near point is located at a distance away from the eyes of
   A. 75 cm B. 50 cm C. 35 cm D. 25 cm
9. The human eye forms the image of an object at its
   A. iris B. retina C. pupil D. cornea

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. Which type of lens would you use to start fire from light from sun concave or convex, would work best? At what distance from the lens should the paper be held for best results?
2. If a concave mirror produces a real image, is the image necessarily inverted? Explain.
3. Are rearview mirrors used in cars concave or convex?
4. A magician during a show makes a glass lens with n = 1.47 disappear in a trough of liquid. What is the refractive index of the liquid? Could the liquid be water?
5. Suppose that you were handed a lens and a ruler and told to determine the focal length of the lens. How would you proceed?
6. Can we achieve total internal reflection from optically rare medium to optically dense medium?
7. Will a nearsighted person who wears corrective lenses in her glasses be able to see clearly underwater when wearing those glasses?
8. When you use a simple magnifying glass, does it matter whether you hold the object to be examined closer to the lens than its focal length or farther away? Explain.
9. In blind turns on hilly roads, mirrors are used to help drivers. Are these mirrors plane mirrors, concave mirrors or convex mirrors? Explain.

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

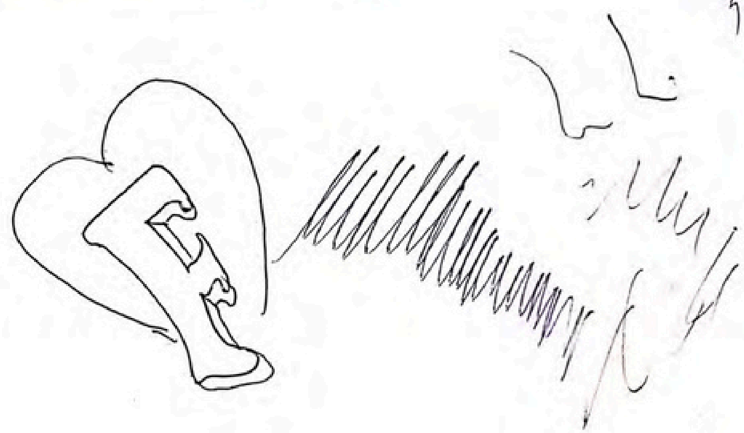
1. What is meant by reflection of light? State and explain laws of reflection with diagrams.
2. Derive spherical mirror formula.
3. What is meant by refraction of light? What is the index of refraction?
4. State and explain laws of refraction with diagrams.
5. What is total internal reflection? How we can calculate the critical angle for total internal reflection? What are the conditions for total internal reflection?
6. What are optical fibres? Give some applications of optical fibers.
7. Describe the behavior for a ray of light after passing through a prism.
8. Derive thin lens equation.
9. Describe power of lens and its resolving power. What are its units?
10. How the human eye works? How the defects in the eye like short sightedness and long sightedness be corrected by using lenses?
11. What is a simple microscope? Using a ray diagram explain its working, angular magnification and magnifying power.
12. What is a compound microscope? Using ray diagram for a compound microscope, mention its magnifying power.
13. What is a telescope? Using a ray diagram explain its working, angular magnification and magnifying power.

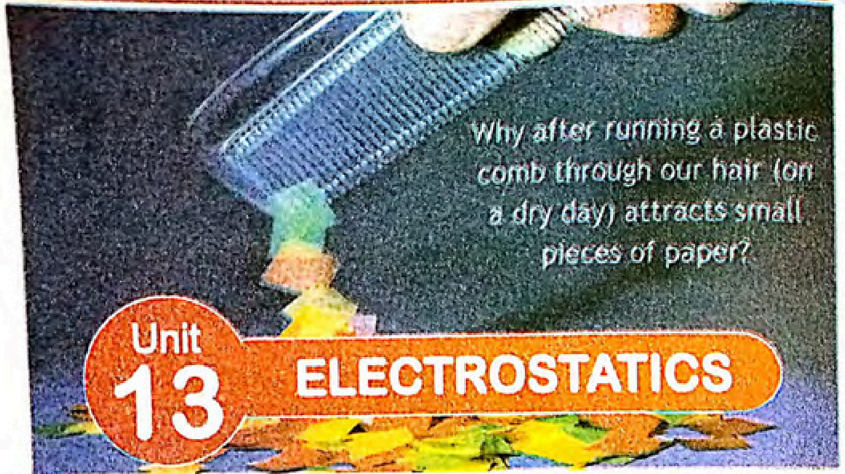
NUMERICAL QUESTIONS

1. A 1.50-cm-high object is placed 20.0 cm from a concave mirror with radius of curvature 30.0 cm. Determine (a) the position of the image, and (b) its size, also draw the ray diagrams.
2. A candle of height 8.0 cm is located at a distance of 300 mm from a convex mirror, its virtual image is formed behind the mirror at a distance of 3.0 cm from the pole (or vertex). Find the focal length of the mirror and height of the image formed.
3. Calculate the speed of light in zircon with index of refraction n = 1.923, a material used in jewelry to replicate diamond.

NUMERICAL QUESTIONS

4. A light ray strikes an air/water surface at an angle of 46° with respect to the normal. The refractive index for water is 1.33. Find the angle of refraction when the direction of the ray is (a) from air to water and (b) from water to air.
5. An optical fiber is made from flint glass with index of refraction 1.66 and is surrounded by a cladding made of crown glass with index of refraction 1.52. What is the critical angle?
6. Suppose the book page is held 7.50 cm from a Concave lens of focal length 10.0 cm and concave lens of focal length -10 cm. What magnification is produced in each case?
7. Gulalai is viewing a flea using a magnifier with f = 3.0 cm. If her near point is at N= 25 cm then calculate the maximum magnification she can get.
8. A telescope has a magnification of 40.0 and a length of 1230 mm. What are the focal lengths of the objective and eyepiece?





Unit 13 ELECTROSTATICS

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ describe simple experiments to show the production and detection of electric charge.
- ✓ describe experiments to show electrostatic charging by induction.
- ✓ state that there are positive and negative charges.
- ✓ describe the construction and working principle of electroscope.
- ✓ state and explain Coulomb's law.
- ✓ solve problems on electrostatic charges by using Coulomb's law.
- ✓ define electric field and electric field intensity.
- ✓ sketch the electric field lines for an isolated +ve and -ve point charges.
- ✓ describe the concept of electrostatic potential.
- ✓ define the unit "volt".
- ✓ describe potential difference as energy transfer per unit charge.
- ✓ describe one situation in which static electricity is dangerous and the precautions taken to ensure that static electricity is discharged safely.
- ✓ describe that the capacitor is charge storing device.
- ✓ define capacitance and its unit.
- ✓ derive the formula for the effective capacitance of a number of capacitors connected in series and in parallel.
- ✓ apply the formula for the effective capacitance of a number of capacitors connected in series and in parallel to solve related problems.

CONTENTS

Electrostatics is the study of charges at rest. The electrostatic force just like force of gravity is an action at a distance force. In the opening picture of the chapter we see that a plastic comb that is run through hair and brought near tiny pieces of paper, attracts them.

A similar effect can be observed for plastic (or amber) rod rubbed with fur, as shown in figure 13.1. Similarly, balloon rubbed against hair also attracts a falling stream of water.

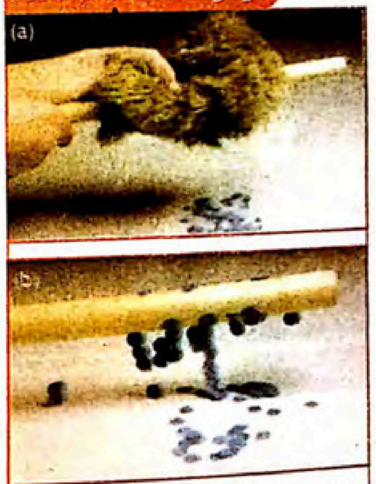
We sometime feel a shock when we touch a metal doorknob after sliding across a car seat or walking across a synthetic carpet. In all these cases electrostatic force is in action.

But the electric force plays an even deeper role in our lives. According to atomic theory, electric forces between atoms and molecules hold them together to form liquids and solids, and electric forces are also involved in the metabolic processes that occur within our bodies.

13.1 ELECTRIC CHARGE

We have learnt already that an inherent property of an object is its mass. An object with smaller mass will have less inertia as compared to an object with larger mass. Along with mass, another inherent property of an object is its electrical charge.

FIGURE 13.1 - *Charging*

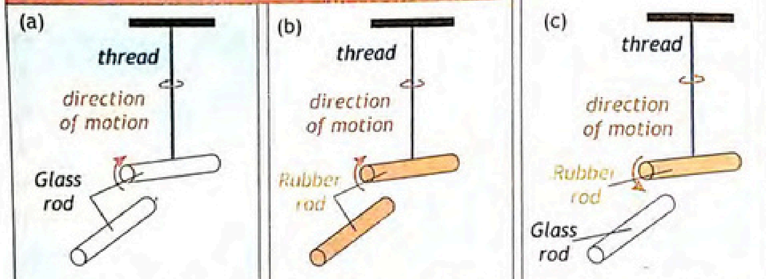


(a) When a plastic rod is rubbed with fur, the rod acquires an electric charge. (b) A charged rod attracts small bits of paper and other objects.

Charge is measured in units of coulomb (C).

There are two kinds of charges: A simple experiment as shown in the figure 13.2 can be performed to show that there are two types of charges, one type is called positive and the other negative.

FIGURE 13.2 - *Experiments in Electrostatics*



(a) Glass rod rubbed with silk cloth brought near another suspended glass rod rubbed with silk cloth repel each other.

(b) Rubber rod rubbed with fur brought near another suspended rubber rod rubbed with fur repel each other.

(c) Glass rod rubbed with silk cloth brought near a suspended rubber rod rubbed with fur attract each other.

From these observations we can conclude that

- there are two types of charges and
- similar charges repel and different charges attract.

Interestingly it is seen that after rubbing the silk cloth and animal fur also acquired the charge in opposite sense to glass rod and rubber rod respectively.

In grade 7, unit 6 'STRUCTURE OF ATOMS' we learnt that all matter is made up of atoms. Atoms have two kinds of charges: protons contained in the nucleus of atom have positive charge, whereas electrons clouding around the nucleus carry

FIGURE 13.3

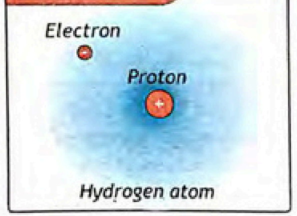


Table 13.1 BASIC CHARGES		
Particle	Charge (C)	Mass (kg)
electron	-1.6×10^{-19}	9.109×10^{-31}
proton	$+1.6 \times 10^{-19}$	1.673×10^{-27}
neutron	0	1.675×10^{-27}

negative charge, neutrons inside the nucleus have no charge, as shown in figure 13.3. The charge on an electron or proton (as shown in Table 13.1) is said to be an elementary or fundamental charge because all known charges are made up of electrons and protons and so all charges are integer multiples of the fundamental charge.

As all the matter is made of atoms, thus every material object has charges in it. We often do not notice the effects of electrical charges because most objects have the same number of electrons and protons in them (therefore we have equal and opposite charges) and as a result the net effect is zero and so these objects are electrically neutral.

Electrification: Electric charge is not created in the process of charging objects, charges are only transferred between the objects. In electrification experiments in figure 3.2, it is seen that silk cloth/animal fur also attained charge. Thus, in those experiments, charge was not produced rather it was only transferred and we can say that objects can be charged by removal or addition of charges (specifically electrons) called electrification.

ACTIVITY

Rub a balloon with your hairs for some time and attach it to the wall. It will cling to it, Why? Explain.

Since electrons can be transferred easily therefore if an object has a...

- Positive (+) charge - means it has less electrons than normal
- Negative (-) charge - means it has more electrons than normal

13.2 ELECTROSTATIC INDUCTION

A change in distribution of electrical charge in an object, caused by the influence of nearby charges is called **electrostatic induction.** This effect may be shown by bringing a negatively charged rubber strip near to an insulated metal sphere X which is touching a similar sphere Y (as shown in Figure 13.5 - a). Electrons in the spheres are repelled to the far side of Y.

If X and Y are separated, with the charged strip still in position, X is left with a positive charge (deficient of electrons) and Y with a negative charge (excess of electrons) as shown in Figure 13.5 - b. In this way electrostatic induction can be used to charge objects as in Figure 13.5 - c.

FIGURE 13.4 - *Induction*

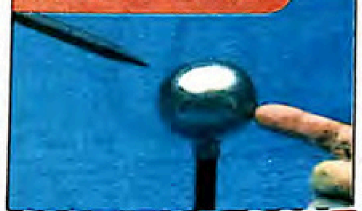
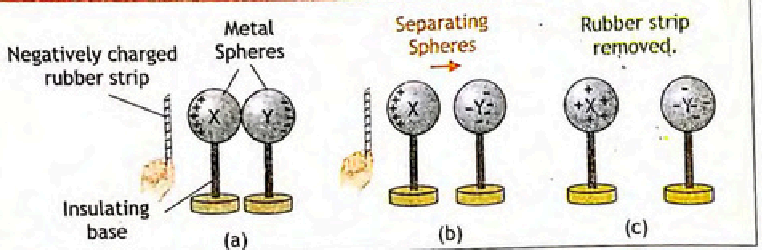


FIGURE 13.5 - Experiments in Electrostatic Induction

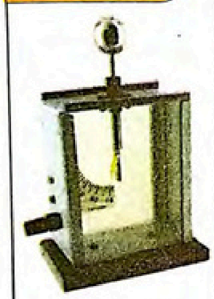


13.3 ELECTROSCOPE

Electroscope is a device used for detecting and testing the nature of charge on a body. It works on the principle that similar charges repel each other.

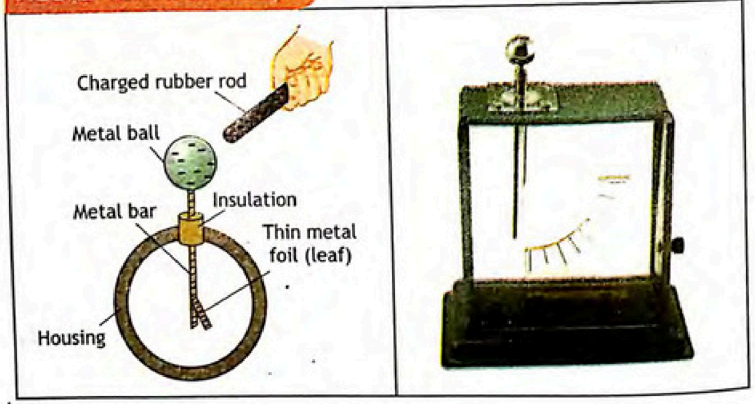
A simple form of electroscope consists of a metal bar which has a metallic sphere (ball) at its upper end. Thin flexible metal leaf (made of gold, silver, copper or any other metal) is attached to the lower end of metal bar. The lower part is enclosed in an insulated housing as shown in the figure 13.7.

FIGURE 13.6



Electroscope

FIGURE 13.7 - Electroscope



Working: In order to detect charge on a body we touch the metal ball with it. For example, if we touch it with negatively charged rubber rod some of its excess electrons will be transferred to the ball and then they will spread throughout the metal rod and the metal foil. The flexible metal leaf will be repelled by the similar charge on the metal rod and will move away from the rod by rising higher. As more electrons are transferred to the electroscope, the metal leaf will rise higher. Alternatively if the rod is positively charged it will attract electrons from the electroscope, leaving a net positive charge on it. Once again the foil will rise.

However, to test the nature of charge on the body we charge the electroscope with some known charge first. Now if the same charge is added to the metal ball, it will increase divergence of flexible metal leaf and opposite charge will decrease the divergence allowing us to identify the unknown charge on the body.

ACTIVITY

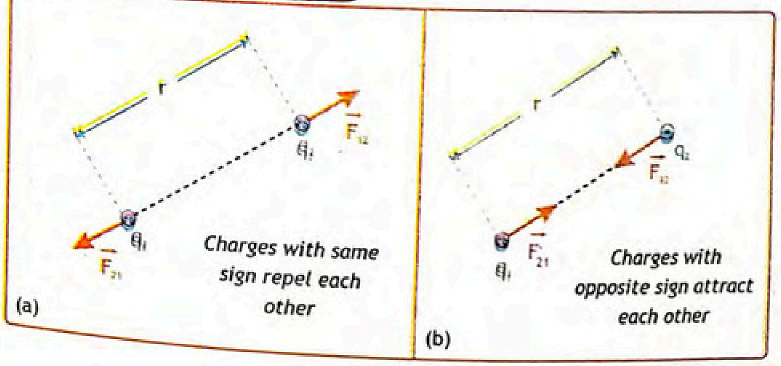
Rub a balloon with your hair for some time and turn on a water faucet just enough to have a very small but steady stream trickling out. Bring a balloon near the stream. What happens?

13.4 COULOMB'S LAW

Statement: *The electric force between two stationary point charges is*

- *directly proportional to the product of the charges;*
- *inversely proportional to the square of the distance between them and*
- *is directed along the line joining these charges.*

Figure 13.8 - Coulomb's Law



(a) *Charges with same sign repel each other*

(b) *Charges with opposite sign attract each other*

Consider two point charges q_1 and q_2 separated by distance r as shown in figure 13.8. By definition of Coulomb's law

$$F_E \propto q_1 q_2 \quad \text{——} (1)$$

and
$$F_F \propto \frac{1}{r^2} \quad \text{——} (2)$$

Combining equation 1 and equation 2, we get

$$F_E \propto \frac{q_1 q_2}{r^2}$$

Changing the sign of proportionality into equality

$$\boxed{F_E = k\frac{q_1 q_2}{r^2}} \quad \text{——} \; 13.1$$

TIP: Point Charges

Coulomb's law can only be applied to **point charges** (charges of very small size). Practically the charged objects are considered point charges if the separation between the charges is made large as compared to the size of the charged objects.

Equation 13.1 gives coulomb force, where k is a constant of proportionality and is called the Coulomb constant. Here the charges 'q_1' and 'q_2' are considered as **point charges** as distance '*r*' is considered large as compared to their size.

COULOMB'S CONSTANT

The Coulomb constant k for vacuum in SI units has the value $9 \times 10^9\ Nm^2/C^2$, this constant is also written in the form

$$k = \frac{1}{4\pi\varepsilon_0} \quad \text{——} (3)$$

Where the constant ε_0 (lowercase Greek epsilon) is known as the permittivity of free space (vacuum) and has the value $8.85 \times 10^{-12}\ C^2/Nm^2$. Putting this value in above equation 3 we get the value of coulomb's constant $k = 8.998 \times 10^9\ Nm^2/C^2$.

The value of the Coulomb constant depends on the medium between the charges. If the space in between charges has matter in it, the value of the Coulomb's constant changes and as a result coulomb force changes. For any medium other than vacuum, the coulomb's constant has the form

$$k = \frac{1}{4\pi\varepsilon}$$

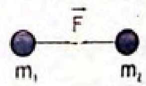
The quantity ε is called permittivity of the material. A material medium with high permittivity is a medium which reduces the coulomb force between the charges to a greater degree as compared to the case where the charges are in vacuum. The permittivity for air (ε_{air}) is slightly greater than permittivity for vacuum the ε_0, for most practical purposes they are taken as equal.

POINT TO PONDER

The attraction of an uncharged object by a charged object near it is due to electrostatic induction. For example, it is the reason for the opening question 'Why after running a plastic comb through our hair on a dry day does the comb attract small pieces of paper?'. The influence of the charge on the comb redistributes the charges in the paper due to electrostatic induction. Charges in the pieces of paper with the same sign (polarity) are pushed away while charges with opposite sign are pulled closer. This change in distance means the attractive force due to the closer opposite sign charges is greater than the repulsion due to the same sign charges which have been pushed further away. As coulomb forces decreases as distance between similar charge is increased, on the other hand it increases for dissimilar charges, as a result it overcomes inertia and lifts small pieces of paper. This creates a net attractive force which pulls the paper towards the comb.

We have noticed that Coulomb's law is similar to Newton's law of universal gravitation. Table 13.2 gives a comparison between these two laws.

TABLE 13.2 COMPARISON OF COULOMB'S LAW AND NEWTON'S LAW OF UNIVERSAL GRAVITATION

Electric Force	Comparison	Gravitational Force
Force is between charge as key quantity 	Coulomb Force is both attractive or repulsive, while the gravitational force is only attractive	Force is between mass as a key quantity 
$\vec{F}_E \propto q_1 q_2$	Force varies directly with product of key quantity (charge/mass)	$\vec{F}_G \propto m_1 m_2$
$\vec{F}_E \propto \frac{1}{r^2}$	Force varies with square of distance between the key quantities (charge/mass)	$\vec{F}_G \propto \frac{1}{r^2}$
$\vec{F}_E = k\frac{q_1 q_2}{r^2}$	Equations are similar with appropriate constant applied	$\vec{F}_G = G\frac{m_1 m_2}{r^2}$

TIPBITS

How adhesive tape work? Since the electrostatic force depends on the inverse square of the distance between the charges, it becomes larger for smaller distances, such as those involved when a strip of adhesive tape is stuck to a smooth surface. Electrons shift over the small distances between the tape and the surface. As a result, the materials become oppositely charged. Since the distance between the charges is relatively small, the electrostatic force of attraction is large enough to contribute to the adhesive bond.

EXAMPLE 13.1: FORCE BETWEEN PROTONS

The two protons and two neutrons in the nucleus of the helium atom are held together by the strong force, which is required to overcome the electrostatic repulsion between the protons. The charge of each proton is $q_p = +1.6 \times 10^{-19}$ C. A distance of approximately $r = 2 \times 10^{-15}$ m separates the two protons. Calculate the magnitude of the electrostatic force between the protons.

GIVEN

Charge on proton 'q_p' = $+1.6 \times 10^{-19}$ C.

Distance 'r' = 2×10^{-15} m

Coulomb Constant 'k' = 9×10^9 Nm²/C²

REQUIRED

Force 'F_E' = ?

SOLUTION: Using Coulomb's Law, we can find the force

$$F_E = k\frac{q_P \times q_P}{r^2}$$

Putting values $$F_E = 9\times10^9 \frac{\text{Nm}^2}{\text{C}^2}\frac{(1.6\times10^{-19}\text{ C})\times(1.6\times10^{-19}\text{ C})}{(2\times10^{-15}\text{ m})^2}$$

Hence $$F_E = 57.6N = 58N \text{ — Answer}$$

Therefore, the two protons in the atomic nucleus of a helium atom push each-other with a force of 58 N.

EXTENSION EXERCISE 13.1

Considering the small size of nuclear particles, 58N is a very large force. How are the protons kept together in the nucleus?

ASSIGNMENT 13.1: FORCE BETWEEN CHARGED METAL SPHERES

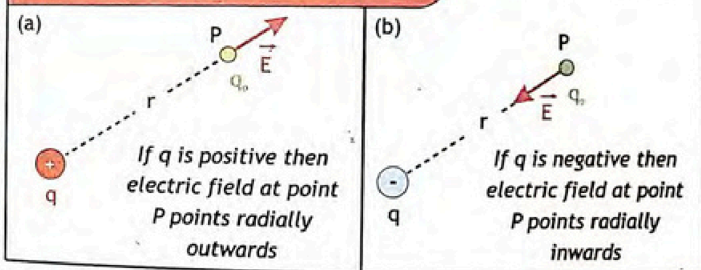
A small metal sphere with a charge of - 2.10 × 10⁻⁶ C is brought near an identical sphere with a positive charge of 1.50 × 10⁻⁶ C so that the distance between the centres of the two spheres is 3.30 cm. Calculate the magnitude of the force that each charge exerts on the other.

13.5 ELECTRIC FIELD AND ITS INTENSITY

The region around a charge in which an electric test charge would experience an electric force is called ***electric field****, and the strength of the field (equal to the force experience by a (+ 1C) test charge) at any point is called* ***electric field intensity****.*

An electric field exist in the region of space around a charged object in three dimensions. When another charged object enters this electric field, an electric force acts on it even without any physical contact between the charges.

Figure 13.9 - *Electric Field Intensity*



Consider a small positive test charge q_0 near the greater magnitude charge q as shown in figure 13.9. Now the electric field E at any point in space is defined as the force F_E acting on unit positive charge q_0, divided by the magnitude of test charge q_0, mathematically

$$\vec{E} = \frac{\vec{F}_E}{q_0} \quad (13.2)$$

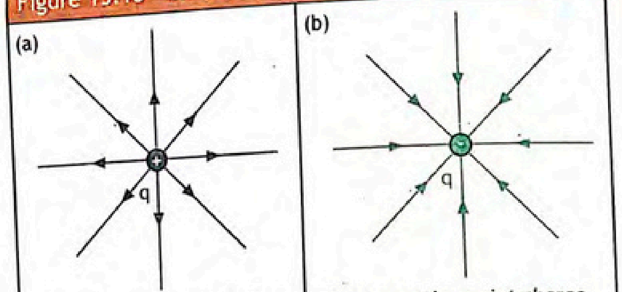
Equation 13.2 gives the mathematical form of electric field intensity. The SI unit of electric field intensity is newton per coulomb (NC⁻¹). It is a vector quantity having direction in which a positive test charge would move under the influence of force.

TIP: Test Charges

By convention, test charge is always taken as positive. The size of test charge is kept small, such that it does not effect charge distribution on object and distort the field created by source (original) charge.

An easy way to visualize an electric field is to draw lines that follow the same direction as the electric field intensity vector E at any point. These lines are called **electric field lines.**

Figure 13.10 - Electric field lines for point charges



For a positive point charge, the lines radiate radially outwards

For a negative point charge, the lines converge radially inwards

Electric field intensity vectors help to visualize the electric field. Electric field lines are a kind of "map" that gives the direction and strength of the field at various places. The direction of the lines is radially outward for a positive charge and radially inward for a negative charge as shown in figure 13.10.

EXAMPLE 13.2: ELECTRIC FIELD INTENSITY

A positive test charge of 30 μC is placed in an electric field. Force on it is 0.600 N. What is the magnitude of electric field at the location of test charge?

GIVEN

Test Charge $q_o = 30\,\mu C = 30 \times 10^{-6}$ C.

Force 'F_E' = 0.600 N

REQUIRED

Electric field intensity 'E' = ?

SOLUTION: By definition of electric field intensity $\vec{E} = \frac{\vec{F}_E}{q_0}$

Putting values $\vec{E} = \frac{0.600\,N}{30 \times 10^{-6}\,C}$

Hence $\vec{E} = 2.00 \times 10^{4}\ NC^{-1}$ Answer

Therefore, the magnitude of electric field is 2×10^4 N/C.

ASSIGNMENT 13.2: FORCE IN AN ELECTRIC FIELD

If a charge of 4 μC is placed in a uniform field of strength 2 NC^{-1}, what force will it experience?

13.6 ELECTRIC POTENTIAL

The electric potential energy 'U' per unit charge 'q' in an electric field is called electric potential V.

$$V = \frac{U}{q} = \frac{W}{q} \qquad (13.3)$$

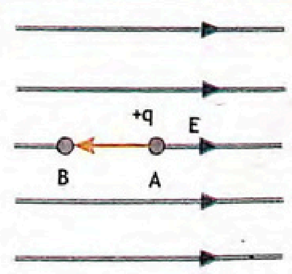
The electric potential units of joules per coulomb ($J\,C^{-1}$), or volt (V) in honor of Italian scientist Alessandro Volta. The potential at a point is one volt, when it requires one joule of work to move a positive charge of one coulomb from a point of ZERO potential to that point.

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

The concept of electric potential is closely related to electric field. Electric field is the force per unit charge, whereas the electric potential is the energy per unit charge. However electric potential is a scalar quantity. Since, it is easier to solve problems with scalars, therefore, it is simpler to solve problems with electric potential rather than electric field.

Let us consider a positive charge +q is placed in an electric field at point B as shown in the figure 13.11. If the charge is allowed to move freely, it will acquire kinetic energy and will move from B to A. Conversely, we can say that an external force is required to keep the charge at rest or to move with uniform velocity from A to B. Thus

Figure 13.11 - Electric Potential



$$V_B - V_A = \frac{W_{AB}}{q} \qquad (13.4)$$

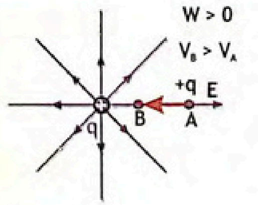
Often point A is taken to be at infinity, meaning a large distance from the charges that produce the electric field, and the electric potential at A is taken to be zero. Note that the choice of zero potential at infinity is taken arbitrarily and for simplicity, such that

$$V = \frac{W}{q} \qquad (13.5)$$

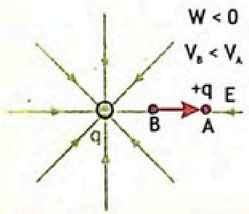
In equation 13.5, V (by definition) the Work that must be done against the Electric Field to bring a test charge q from infinity to a specific location.

INFO: POSITIVE AND NEGATIVE WORK DONE

The work done W_{AB} in moving charge $+q$ from point A to point B can be positive negative or zero, thus the potential at point B can be higher, lower or equal to potential at point A.



For example, in order for a positive test charge to be brought closer to an isolated positive charge $+q$. The work must be done by an external agent, the work done in this case is positive. In this case, the electric potential at point B is higher than electric potential at point A. Alternately, we can observe that $V_B > V_A$ by noting that the electric field would push a positive charge from B to A, which is always from high potential to low potential.



On the other hand, if the isolated charge is negative ($-q$), the positive test charge must be restrained from moving from point A to point B and the work done must be negative. In this case, the electric potential at point B is lower than electric potential at point A. Alternately, we can observe that VB < VA by noting that the electric field would pull a positive charge from A to B, which is always from high potential (A) to low potential (B).

EXAMPLE 13.3: WORK DONE

How much work must be done to increase the potential of a charge 2.5×10^{-7} C by 100 V?

GIVEN

Charge 'q' $= 2.5 \times 10^{-7}$ C

Change in potential 'ΔV' = 100 V

REQUIRED

Work Done 'W' = ?

SOLUTION: By definition of electric potential

$$V = \frac{W}{q} \quad \text{or} \quad W = qV$$

Putting values $W = 2.5 \times 10^{-7}\,C \times 100\,V$

Hence $W = 2.5 \times 10^{-5}$ J — Answer

EXTENSION EXERCISE 13.2

How the units coulomb (C) multiplied by volt (V) gives joule(J)?

ASSIGNMENT 13.3: WORK DONE IN AN ELECTRIC FIELD

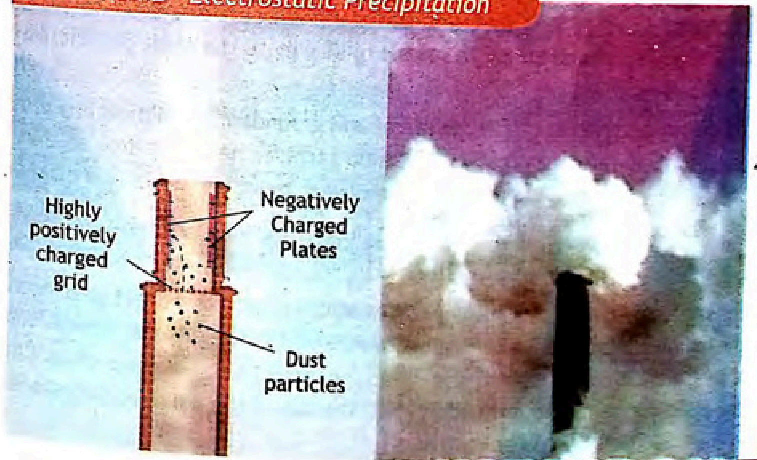
How much work is done in moving a charge of 3 C from a point at 118 V to a point at 138 V in an electric field?

13.7 PRACTICAL APPLICATIONS OF ELECTROSTATICS

Electrostatic phenomena has wide applications in daily life.

A. Electrostatic precipitator and dust extraction: Electrostatic phenomena can be used to separate dust from smoke particles. To reduce air pollution, modern day coal burning power stations extract dust from the smoke in chimneys before releasing it to the environment by a process called electrostatic precipitation.

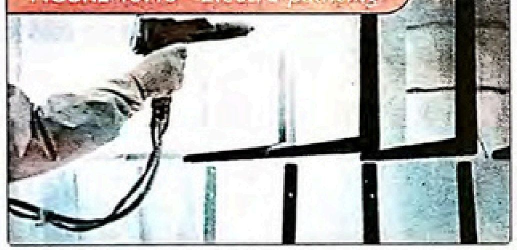
FIGURE 13.12 - Electrostatic Precipitation



For this purpose chimneys have a highly positively charged grid (usually a wire gauze) and negatively charged plates as shown in the figure 13.12. When smoke rising from chimney containing smoke and dust particles pass through the positively charged grid they acquire a positive charge. These charged particles are attracted by the negatively charged plate and are deposited on them. Thus, the smoke coming out of chimney is free from dust and other particles.

B. **Electro painting:** Electrostatic spray painting is a method in which electrostatically charged paint is applied as shown in figure 13.13. This method reduce the paint usage and uneven coating that result from using a regular spray painter, both for powder and liquid paint.

FIGURE 13.13 - *Electro painting*



One type of system applies a negative electric charge to the paint while it is in the container. Other systems apply the charge in the barrel of the spray painter gun. The paint is then pushed through the gun, rubbing against the side, and gaining a static electric charge as it moves. Since the paint particles all have the same charge, they repel each other. This helps to distribute the paint particles evenly and get uniform coverage.

Usually the object being painted is metal and grounded, but almost any product can be finished electrostatically. The paint particles have a charge so they are attracted to the opposite charge of the object being painted. This makes the particles less likely to stay in the air.

13.8 DANGERS OF STATIC CHARGE

Apart from useful applications of electrostatics - it can sometimes be dangerous. For example, lightning is the result of large scale charge separation occurring within a thundercloud. Lightning involves the dielectric breakdown of air. Charge separation occurs within a thundercloud; the top of the cloud becomes positive and the lower part becomes negative.

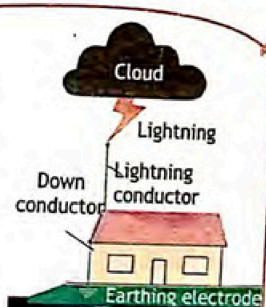
The negative charge at the bottom of the thundercloud induces positive charge on the Earth just underneath the cloud as shown in figure 13.14. When the electric field between the cloud and the earth becomes large enough, the air undergoes dielectric breakdown, meaning it momentarily becomes a good conductor of electricity allowing the negative charge to jump from the cloud to the earth. A lightning channel is completed and electrons rush to the ground making the channel glow in the process. A total of about 20 C to 25 C of electronic charge is transferred from the thundercloud to the surface.

FIGURE 13.14 - *Lightning*

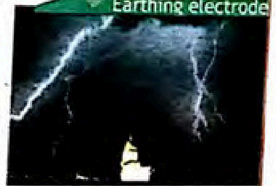
positive charge being induced on ground

TIDBITS

Lightning conductors/rods: The purpose of Lightning conductors is to protect structures against direct lightning strikes. By catching the lightning and running the discharge current to earth, they avoid damage connected with the lightning strike itself and circulation of the associated current.



How can we protect our self during a thunderstorm? We should stay indoors or in an automobile if possible. When caught in the open, we should keep low, stay away from any tall tree; if lightning strikes the tree, charge traveling down the tree and then along the surface will put us in danger.



If trapped in such situation we should try to go in a nearby ditch or low spot keeping our head low and feet as close together as possible.

13.9 CAPACITOR

***Capacitor** is a device used for storing charge, it consists of two conductors separated from (without touching) each other, carrying charges of equal magnitude but opposite sign.*

FIGURE 13.15

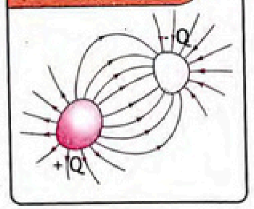
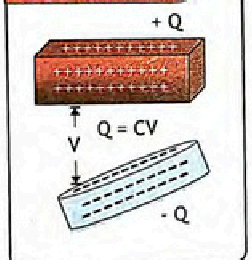


Figure 13.15 shows the basic elements of any capacitor — two isolated conductors (having charge +Q and -Q) of any shape. No matter what their geometry, flat or not, we call these conductors plates. Each capacitor plate carries a charge of the same magnitude, one positive and the other negative. Due to the charges, the electric potential of the positive plate exceeds that of the negative plate by an amount V.

The insulating medium that separates the plates of capacitor (air or some other insulating material) is referred to as dielectric.

FIGURE 13.16



Capacitance of capacitor: *The capacitance C of a capacitor, is the ratio of the magnitude of the charge on either conductor to the magnitude of the potential difference between them.*

When charge Q is increased on the plates of the capacitor the potential difference V also increases and vice versa as shown in figure 13.16 , thus we can write

$$Q \propto V \qquad \text{or} \qquad Q = CV$$

Where C is the constant of proportionality and is called the capacitance of a capacitor.

therefore $\boxed{C = \frac{Q}{V}}$ — 13.6

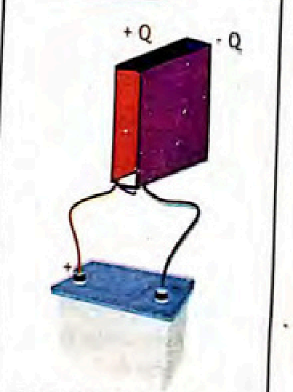
The capacitance of a capacitor is the amount of charge the capacitor can store per unit of potential difference. The capacitance of a capacitor depends upon the size and shape of the plates. It also depends upon the separation and the nature of insulating material in-between the plates.

Units of Capacitance: *The SI unit of capacitance is coulombs per volt or the farad (F)*, named in honor of Michael Faraday, such that

$$1\ F = 1\ C/V$$

The farad is a very large unit of capacitance. In practice, typical devices have capacitances ranging from microfarads (10^{-6} F) to picofarads (10^{-12} F). For practical purposes, capacitors often are labeled "μF" for microfarads and "pF" for picofarads.

FIGURE 13.17



Parallel Plate Capacitor

Capacitors can be charged by applying a potential difference across its plates by using a battery. A charging of parallel plate capacitor by using a battery, as shown in Fig. 13.17.

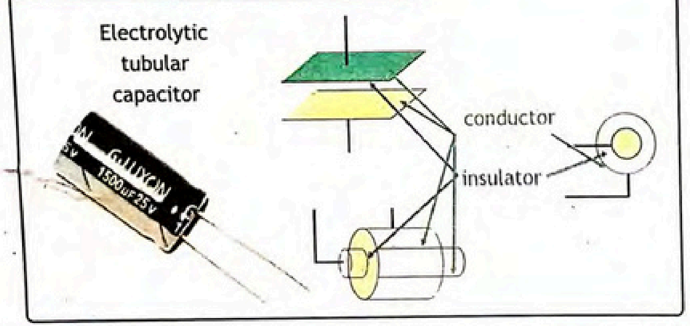
Note that if we double the voltage, we would not do anything to the capacitance. Instead, we would double the charge stored on the capacitor. However, if we try to overfill the capacitor by placing too much voltage across it, the electric field between the plates will become so strong that dielectric breakdown will occur causing current to spark between the plates, destroying the capacitor. Thus capacitors have a maximum voltage!

13.10 TYPES OF CAPACITORS

There are different types of capacitors. These capacitors are of various sizes and shapes, depending upon their construction and dielectric used between them; each one has its own set of characteristics and applications. These capacitors may have fixed or variable capacitance values.

Electrolytic tubular capacitor is the most popular for values greater than about 1 microfarad, having one of the highest levels of capacitance for a given volume. This type of capacitor is constructed by using two thin foils of aluminum, with leads for proper polarity connection. An electrolyte-soaked paper sheet is placed between them and the two plates are wound around on one another and placed in a can with emerging leads ready to use as shown in figure 13.18.

FIGURE 13.18 - Tubular capacitor

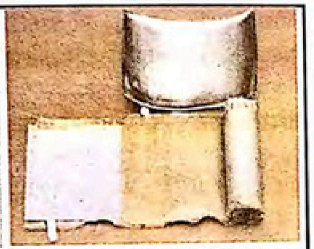


ACTIVITY

INSIDE A CAPACITOR

Tubular capacitors that are not in use can be torn apart to look how is it made from inside. They are metals foils wrapped in a tubular shaped cylinder separated by paper acting as insulating material between the conductors as dielectric.

A disassembled capacitor, showing the foil conducting plates and the thin sheet of insulating material.



The metal foil and Mylar sandwich shown can be rolled up with an insulating layer to produce a capacitor with a compact geometry.

EXAMPLE 13.4: CAPACITOR OF MP3 PLAYER

A typical capacitor in an MP3 player has C = 0.10 μF. If a charge 5.0 μC is placed on the plates, what is the voltage across the capacitor?

GIVEN

Charge q = 5 μC = 5×10^{-6} C.

Capacitance 'C' = 0.10 μF = 0.10×10^{-6} F

REQUIRED

Voltage 'V' = ?

SOLUTION: The capacitance of capacitor is $C = \dfrac{Q}{V}$

or $V = \dfrac{Q}{C}$ Putting values $V = \dfrac{5 \times 10^{-6}\,C}{0.10 \times 10^{-6}\,F}$

or $V = \dfrac{5 \times \cancel{10^{-6}}\,\cancel{C}}{0.10 \times \cancel{10^{-6}}\,\cancel{C}/V}$ Hence $V = 50\ V$ —— Answer

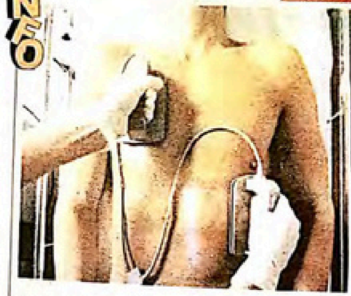
Therefore, the voltage across the capacitor in Mp3 player is 50 V.

ASSIGNMENT 13.4: CAPACITANCE

The potential difference across the plates of the capacitor is 500 V. The charge on each plate is 0.02 C. What is the capacitance of the capacitor?

INFO

HEART DEFIBRILLATOR



During a heart attack, the heart produces a rapid, unregulated pattern of beats, a condition known as cardiac fibrillation. Cardiac fibrillation can often be stopped by sending a very fast discharge of electrical energy through the heart. For this purpose, emergency medical personnel use defibrillators, such as the one being used in Figure. A paddle is connected to each plate of a large capacitor, and the paddles are placed on the chest near the heart. The capacitor is charged to a potential difference of about a thousand volts.

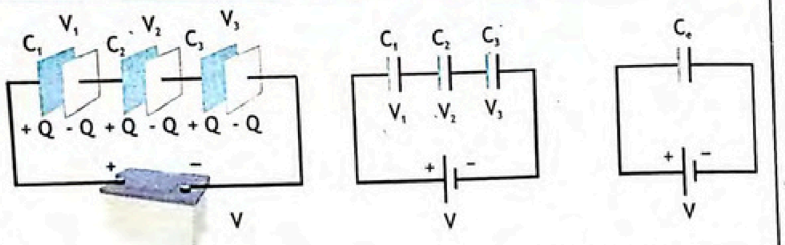
The capacitor is then discharged in a few thousandths of a second; the discharge current passes through a paddle, the heart, and the other paddle. Within a few seconds, the heart often returns to its normal beating pattern.

13.11 COMBINATION OF CAPACITORS

In practice, two or more capacitors are sometimes joined together. In studying electric circuits, we use a simplified pictorial representation called a circuit diagram. Such a diagram uses circuit symbols to represent various circuit elements. The circuit symbols are connected by straight lines that represent the wires between the circuit elements. The circuit symbol for capacitor is '| |'.

A. Series Combination of Capacitors: When the capacitors are connected plate to plate then they are said to be connected in series, three capacitors having capacitance C_1, C_2 and C_3 are shown in the figure 13.19 as series combination.

FIGURE 13.19 - *Series Combination of Capacitors*



When battery is connected to a series combination of capacitors, the same current flows through each capacitor which means charge of +Q is placed on the left plate of each capacitor and an equal charge of -Q on the right plate of each capacitor. As a result each capacitor gets an equal amount of charge Q on each of its plates.

$$Q_1 = Q_2 = Q_3 = Q \quad (1)$$

When the three capacitors in the circuit are charged, the sum of the potential drops across all three must equal the potential difference supplied by the battery.

$$V = V_1 + V_2 + V_3 \quad (2)$$

Since the capacitance of capacitor is $C = \frac{Q}{V}$ or $V = \frac{Q}{C}$

Therefore, each voltage can be written as

$$V_1 = \frac{Q_1}{C_1} \text{ and } V_2 = \frac{Q_2}{C_2} \text{ and } V_3 = \frac{Q_3}{C_3} \text{ and } V = \frac{Q}{C_e}$$

Where C_e is the equivalent capacitance of a single capacitor that has the same effect on the circuit as the series combination when it is connected to the battery. Hence equation 2 can be written as

$$\frac{Q}{C_e} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2} + \frac{Q_3}{C_3} \quad (3)$$

From equation 1 in equation 3 can be written as $\frac{Q}{C_e} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$

or $$\frac{Q}{C_e} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

Hence $$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad 13.7$$

Generally for '*n*' number of capacitors connected in series

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n} \quad 13.8$$

From equation 13.7 and equation 13.8 it is clear that in series combination, the equivalent capacitance is always smaller than any individual capacitance in combination.

EXAMPLE 13.5: SERIES COMBINATION OF CAPACITORS

Two capacitors of 5 μF and 10 μF are connected in series with the external source of voltage is 100 V. Calculate the total capacitance and the potential drop across each capacitor.

GIVEN:

Capacitor C_1 = 5 μF = 5 × 10^{-6} F

Capacitor C_2 = 10 μF = 10 × 10^{-6} F

Voltage V = 100 V

WANTED:

Equivalent capacitance C_{eq} = ?

Potential drops V_1 and V_2 = ?

SOLUTION: For Series Combination the equivalent capacitance is

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{or} \quad \frac{1}{C_e} = \frac{C_2 + C_1}{C_1 C_2}$$

or $C_e = \frac{C_1 C_2}{C_2 + C_1}$ Putting values $C_e = \frac{5\times10^{-6}F\times10\times10^{-6}F}{5\times10^{-6}F+10\times10^{-6}F}$

or $$C_e = \frac{50\times10^{-12}F^2}{15\times10^{-6}F}$$

$$C_e = 3.33\times10^{-6}F = 3.33\ \mu F$$ Answer

In series combination, the charge remains the same $q_1 = q_2 = Q$

The charge on each capacitor is $Q = C_e V$

Putting values $Q = 3.33\times10^{-6}F\times100V$

Hence $Q = 3.33 \times 10^{-4} C$

Therefore $q_1 = q_2 = Q = 3.33 \times 10^{-4}$ C

However, series combination of circuit elements the voltage splits, the voltage across capacitor C_1 and capacitor C_2 as V_1 and V_2, respectively

$V_1 = \dfrac{Q}{C_1}$ Putting values $V_1 = \dfrac{3.33 \times 10^{-4}\ C}{5 \times 10^{-6}\ F}$

$V_1 = 0.666 \times 10^2 V = 66.6V$ —— Answer

$V_2 = \dfrac{Q}{C_2}$ Putting values $V_2 = \dfrac{3.33 \times 10^{-4}\ C}{10 \times 10^{-6}\ F}$

$V_2 = 0.333 \times 10^2 V = 33.3V$ —— Answer

Note that $V_1 + V_2 = 66.6 + 33.3 = 100 = V$, that is the battery voltage is split between the two capacitors.

ASSIGNMENT 13.5: SERIES COMBINATION OF CAPACITORS

Two capacitors of capacitance 3 μF and 6 μF are connected in series to a 100 V battery. Calculate the equivalent capacitance and the voltage across each capacitor.

B. Parallel Combination of capacitors: When the capacitors are connected in different branches of the circuit, the capacitors are said to be connected in parallel. Three capacitors having capacitance C_1, C_2 and C_3 are shown in the figure 13.20 as parallel combination.

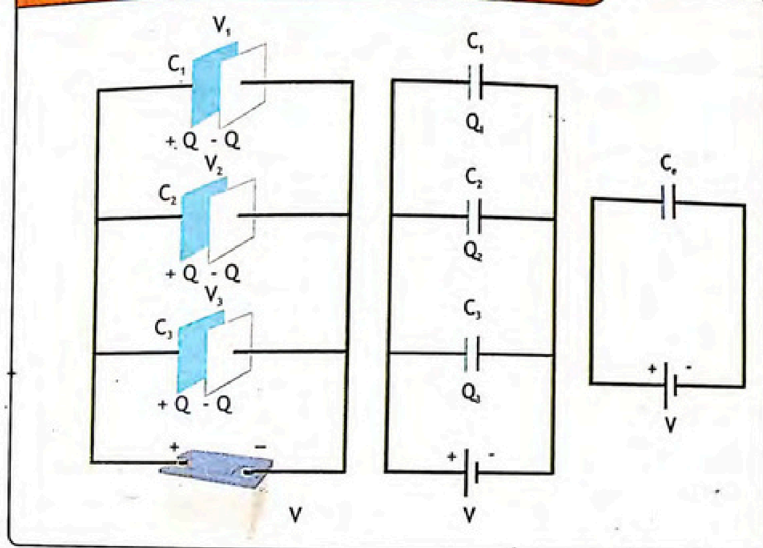
In this configuration, the potential applied across each capacitor is same and is equal to the applied potential.

$$V_1 = V_2 = V_3 = V \quad \text{——} (1)$$

Depending upon the capacitance, the capacitors acquire different amount of charges. Conservation of charge requires that the charge Q of the equivalent capacitor be equal to the sum of the charges on the individual capacitors. Such that the total charge is the sum of all the individual charges.

$$Q = Q_1 + Q_2 + Q_3 \quad \text{——} (2)$$

FIGURE 13.20 - Parallel Combination of Capacitors



How are [illegible]

physics.

Since the capacitance of capacitor is

$$C = \frac{Q}{V} \quad \text{or} \quad Q = CV$$

Therefore, each charge can be written as

$$Q_1 = C_1V_1 \quad \text{and} \quad Q_2 = C_2V_2 \quad \text{and} \quad Q_3 = C_3V_3 \quad \text{and} \quad Q = C_eV$$

Where C_e is the equivalent capacitance of a single capacitor that has the same effect on the circuit as the series combination when it is connected to the battery.

Hence equation 2 can be written as $C_eV = C_1V_1 + C_2V_2 + C_3V_3$ —— (3)

Putting equation 1 in equation 3 we get $C_eV = C_1V + C_2V + C_3V$

or $C_e\cancel{V} = \cancel{V}(C_1 + C_2 + C_3)$

Therefore $\boxed{C_e = C_1 + C_2 + C_3}$ —— 13.9

Generally for 'n' number of capacitors connected in parallel

$$C_e = C_1 + C_2 + C_3 + \cdots + C_n \quad (13.10)$$

From equation 13.9 and equation 13.10 it is clear that in parallel combination the equivalent capacitance is always greater than any individual capacitance in combination.

EXAMPLE 13.6: PARALLEL COMBINATION OF CAPACITORS

Two capacitors of 4 μF and 8 μF are in parallel. In each case the external source of voltage is 100 V. Calculate the total capacitance and the charge on each capacitor.

GIVEN:

Capacitor C_1 = 4 μF = 4 × 10^{-6} F

Capacitor C_2 = 8 μF = 8 × 10^{-6} F

Voltage V = 100 V

WANTED:

Equivalent capacitance C_{eq} = ?

Charge Q_1 and Q_2 = ?

SOLUTION: For Parallel Combination, the equivalent capacitance is

$$C_e = C_1 + C_2$$

Putting values $C_e = 4\times10^{-6}\,\text{F} + 8\times10^{-6}\,\text{F}$

Therefore $C_e = 12\times10^{-6}\,\text{F} = 12\,\mu\text{F}$ — Answer

In parallel combination the voltage remains the same $V_1 = V_2 = V$

Since the applied voltage V = 100 V, therefore $V_1 = V_2 = V$= 100 V

In parallel combination the charge splits, the charge stored in first capacitor C_1 is

$q_1 = C_1V$ Putting values $q_1 = 4\times10^{-6}\,\text{C}\times100\,\text{V}$

$q_1 = 400\times10^{-6}\,\text{C} = 400\,\mu\text{C}$ — Answer

In parallel combination the charge splits, the charge stored in second capacitor C_2 is

$q_2 = C_2V$ Putting values $q_2 = 8\times10^{-6}\,\text{C}\times100\,\text{V}$

$q_1 = 800\times10^{-6}\,\text{C} = 800\,\mu\text{C}$ — Answer

ASSIGNMENT 13.6: PARALLEL COMBINATION OF CAPACITORS

Two capacitors of capacitance 3 μF and 6 μF are connected in parallel to a 800 V battery. Find the equivalent capacitance and charge on each capacitor.

KEY POINTS

- **Electrostatics:** The study of charges at rest.
- **Electrostatic Induction:** The process of charging without physical contact.
- **Electroscope:** Instrument used for the detection and testing of electric charge.
- **Coulomb's Law:** The electric force between two stationary point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.
- **Electric field:** The region around a charge where another charge will experience an electrostatic force.
- **Electric field Intensity:** The strength of the field at any point, given as the force per unit positive test charge.
- **Electric field lines:** Representative lines for the electric field intensity.
- **Electric potential:** The electric potential energy per unit charge in an electric field.
- **Capacitor:** The device used for storing electrical energy.
- **Series combination of capacitors:** The combination of capacitors connected plate to plate.
- **Parallel combination of capacitors:** The combination of capacitors connected in different branches of circuit.

PROJECTS

GROUP A 'AIRCRAFT ENGINEERING': Research why aircrafts are always positively charged when flying. This is seen when an aircraft lands during dry conditions, huge sparks are released to Earth as soon as the aircraft touches down. What problems are faced by air craft engineers and what remedial measurements are taken. Prepare a presentation to share your research with class fellows.

GROUP B 'PETROL STATION': Research why there are warning signs in petrol pumps such as 'turn off your vehicle' or 'do not use your cell phone'. What are the chances of petrol being ignited? Prepare a chart to display the hazards of static electricity at petrol station.

GROUP C 'UNIT NAME AFTER SCIENTISTS': Choose the name of an electric unit, such as coulomb, volt, or farad and research the life and work of the scientist after whom it was named.

PROJECTS

Write a brief essay for school magazine on this person and include a discussion of the work that justified the honor of having a unit named after him.

GROUP D 'REFUELING OIL TANKERS AND AIRCRAFTS': When refueling oil tankers or aircrafts the fuel rubbing along the pipe as it flows through it can cause an electrostatic charge, if this sparks. It could ignite the fuel causing a fire or explosion. What preventive measures can be taken to reduce the risks of fire explosion? Prepare a chart to display in the classroom.

GROUP E 'ELECTROSCOPE': Make your own electroscope of simple objects and donate it to the school laboratory.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. When combing our hair, we shift electrons from our hair onto the comb. The charge on our hairs is
   A. positive B. negative C. zero D. infinite
2. The unit of charge is
   A. farad B. coulomb C. volt D. electron volt
3. Initially, sphere A has a charge of -50e and sphere B has a charge of +20e. The spheres are made of conducting material and are identical in size. If the spheres then touch, what is the resulting charge on sphere A?
   A. +15e B. -15e C. +35e D. -35e
4. If the distance between two charged particles is halved, the Coulomb force between the two charged particles becomes
   A. half B. one quarter C. double D. four times
5. The value of coulomb constant k, depends on
   A. value of charges B. material medium
   C. separation between charges D. all of these
6. An additional capacitor is added to a group of capacitors already connected in series, the equivalent capacitance
   A. increase B. stay the same C. decrease D. goes to zero
7. The unit of electric potential is
   A. farad B. coulomb C. volt D. NC^{-1}

8. Four identical 1 μF capacitors are connected together electrically. What is the least possible capacitance of the combination?
   A. 4 μF B. 1μF C. 1/4μF D. 1/8μF
9. A capacitor C 'has a charge Q'. The actual charges on its plates are:
   A. Q, Q B. Q, 0 C. Q, -Q D. Q/2, -Q/2

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. Normally, objects with large number of electrons are electrically neutral, Why?
2. How does shuffling feet across a carpet cause hair to stand on our body?
3. Why neutral objects are always attracted by charged object? Not repelled.
4. Why the pieces of paper initially attracted by charged comb fly away when they touch it?
5. Is it necessary for a charged body actually to touch the ball of the electroscope for the leaves to diverge? Defend your answer.
6. How electrostatic painting is better than conventional spray painting?
7. Why are lightning rods normally at a higher elevation than the buildings they protect?
8. What would happen if two insulating plates were used instead of conducting plates to construct a capacitor?
9. The sum of the charges on both plates of a capacitor is zero. What does a capacitor store?
10. If you wish to store a large amount of energy in a capacitor bank, would you connect capacitors in series or parallel? Explain.

COMPREHENSIVE QUESTIONS

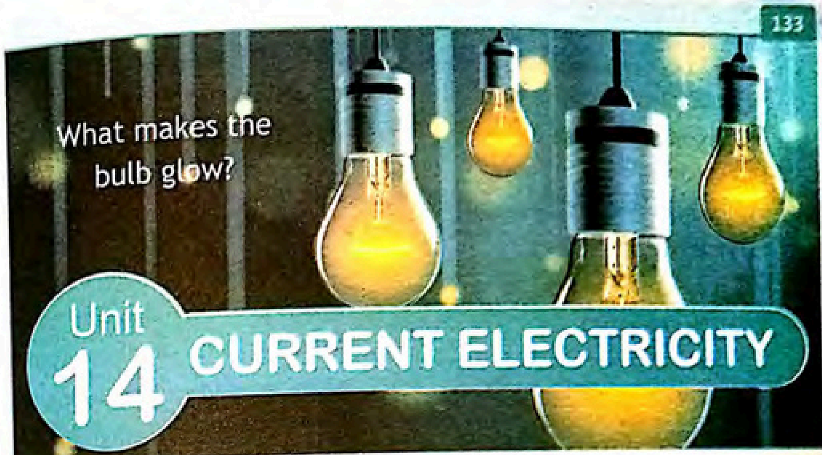
Give an extended response to the following questions

1. What is electric charge? How objects can be electrified? Describe with the help of experiments.
2. What is electrostatic induction? Explain.
3. What is the function of electroscope? How can we use electroscope to find the presence and nature of charge on a body?

4. State and explain Coulomb's Law.
5. What is meant by electric field and electric field intensity? How the field lines represent the electric field for isolated positive and negative point charges?
6. What is electric potential? In what units we measure electric potential?
7. Give some practical applications in which electric field is useful.
8. How lightning occurs? How can we safeguard ourselves from lightning hazard?
9. What is capacitor? Define capacitance and its units.
10. What is series combination of capacitors? How we can determine equivalent capacitors for different capacitors connected in series?
11. What is parallel combination of capacitors? How we can determine equivalent capacitors for different capacitors connected in parallel?

NUMERICAL QUESTIONS

1. Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the single proton that is the atom's nucleus. Assume the average distance between the electron and the proton is $r = 5.3 \times 10^{-11}$ m and charge on electrons and proton is 1.6×10^{-19} C.
2. A 5 μC point charge is placed 20 cm from a 10 μC point charge. (a) Calculate the force experienced by the 5 μC charge. (b) What is the force on the 10 μC charge? (c) What is the field strength 20 cm from the 10 μC point charge?
3. In a certain region of space, a uniform electric field has a magnitude of 4.60×10^4 N/C and points in the positive x-direction. Find the magnitude and direction of the force this field exerts on a charge of (a) +2.80 μC (b) -9.30 μC.
4. The potential difference between two points is 110 V. When an unknown charge is moved between these two points, the work done is 550 J. What is the amount of charge?
5. The capacitance of a capacitor is 3200 pF. If the potential difference between its plates is 220 V. What is the charge on each of its plates?
6. Three capacitors of capacitance 1 μF, 2 μF and 3 μF are connected in series to a 110 V battery. Calculate the equivalent capacitance and voltage across each capacitor.
7. Two capacitors of capacitance 2 pF and 3 pF are connected in parallel to a 9V battery. Calculate the equivalent capacitance and the charge on each capacitor.



Unit 14 CURRENT ELECTRICITY

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ define electric current.
- ✓ describe the concept of conventional current.
- ✓ understand the potential difference across a circuit component and name its unit.
- ✓ describe Ohm's law and its limitations.0.12
- ✓ define resistance and its unit(Ω).
- ✓ calculate the effective resistance of a number of resistances connected in series and also in parallel.
- ✓ describe the factors affecting the resistances of a metallic conductor.
- ✓ distinguish between conductors and insulators.
- ✓ sketch and interpret the V-I characteristics graph for a metallic conductor, a filament lamp and a thermistor.
- ✓ describe how energy is dissipated in a resistance and explain Joule's law.
- ✓ apply the equation $E = I.Vt = I^2Rt = V^2 t/R$ to solve numerical problem.
- ✓ calculate the cost of energy when given the cost per kWh.
- ✓ distinguish between D.C and A.C.
- ✓ identify circuit components such as switches, resistors, batteries etc.
- ✓ describe the use of electrical measuring devices like galvanometer, ammeter and voltmeter (construction and working principles not required).
- ✓ construct simple series (single path) and parallel circuits (multiple paths).
- ✓ predict the behaviour of light bulbs in series and parallel circuit such as for celebration lights.
- ✓ state the functions of the live, neutral and earth wires in the domestic main supply.
- ✓ state reason why domestic supplies are connected in parallel.
- ✓ describe hazards of electricity (damage insulation, overheating of cables, damp conditions).
- ✓ explain the use of safety measures in household electricity, (fuse, circuit breaker, earth wire).

UNIT14: CURRENT ELECTRICITY

CONTENTS

The previous chapter was concerned with static charges, current electricity deals with charges in motion. Making charges move has many advantages for example it helps us light our homes, entertain ourselves with the television and even inside the human body it carries signals to and from our brain as nerve impulses. We have harnessed electricity to improve our quality of living and understand the life within us. This unit introduces the basic concepts of electricity and will make us aware of our household electricity and safety considerations.

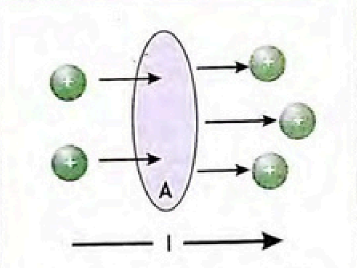
14.1 ELECTRIC CURRENT

'Time rate of flow of charge is called current'.

A charge 'ΔQ' flowing through any cross-sectional area in time 'Δt', corresponds to a current I that is defined mathematically as

$$I = \frac{\Delta Q}{\Delta t} \qquad (14.1)$$

FIGURE 14.1 - *Electric current*



The time rate at which charge flows through the area is defined as the current I.

When charges flow, they can be positive, negative, or both. For example the current in metals is due to flow of negatively charged electrons. The current in the beam of a particle accelerator is due to positively charged protons, while in some cases such as gases and electrolytes, the current is due to the flow of both positive and negative charges. Moving charges, whether positive or negative, are referred to as charge carriers. The total current is $I = I_+ + I_-$.

The SI unit of current is **ampere** and is represented by capital letter A. When one coulomb charge flows through any cross-sectional area in one second, the current is one ampere.

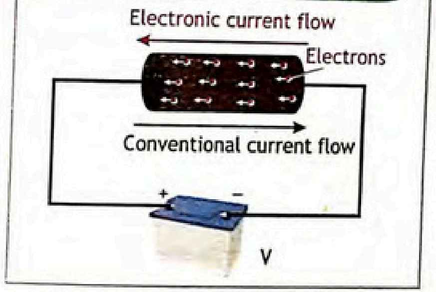
$$1\ A = 1\ C/s.$$

Since coulomb is large amount of charge, therefore ampere is also a large unit of current. In real life situations, we deal with small values of current like milli-amperes (mA $= 10^{-3}$ A) and micro-amperes (μA $= 10^{-6}$ A)

Conventional flow of current: *The direction of conventional current is the direction in which positive charges flow.*

In conductors (e.g metals), the actual flow of current is due to electrons which flow from negative terminal to the positive terminal of battery. However, before the discovery of electron, the current was assumed to flow from positive to negative terminal of the battery even for conductors.

FIGURE 14.2 - *Direction of current*



This assumed direction of current flow is now called conventional current. For practical purposes, positive charge moving in one direction is equivalent to negative charge moving in opposite direction. Both conventional current and electron flow are used by industry.

EXAMPLE 14.1: AMOUNT OF CHARGE TO BATTERY

A new battery is charged at the battery shop charging station using a current of 6.7 A for 5.0 h. How much charge passes through to the battery?

GIVEN

Current 'I' = 6.7 A

Time 'Δt' = 5 hrs = $5 \times 60 \times 60$ = 18000 s

REQUIRED

Charge 'ΔQ' = ?

SOLUTION: By definition of electric current $I = \dfrac{\Delta Q}{\Delta t}$ or $\Delta Q = I \times \Delta t$

Putting values $\Delta Q = 6.7\,A \times 18000\,s$ or $\Delta Q = 6.7\,\cancel{C}/\cancel{s} \times 18000\,\cancel{s}$

$\Delta Q = 120600\,C = 1.2 \times 10^5\,C$ — Answer

Thus, in charging battery 0.12 MC of charge was provided.

ASSIGNMENT 14.1: TRUCK STARTER CURRENT

While starting an engine of a truck, its battery sets 720 C of charge in motion for 4.00 s. How much current is flowing?

INFO

CONDUCTORS AND INSULATORS

Materials are broadly divided into two categories based on their electrical properties. They are either conductors, in which charge flows freely, or insulators that do not allow easy flow of charges.

The electronic structure of a material refers to the way in which electrons are bound to nuclei, conductors have an electronic structure that allows the free movement of some electrons. The positive charges of the atoms of a conducting material do not move, since they reside in a heavy nuclei. Metals are a typical example of solid conductors. Copper, for example, is a very good conductor used in electrical wiring.

For insulators, no free movement of electrons occurs because the material has no loosely bound electrons that can escape from its atoms and thereby move freely throughout the material. Typical insulators are glass, plastic, and cloth.

14.2 POTENTIAL DIFFERENCE AND EMF

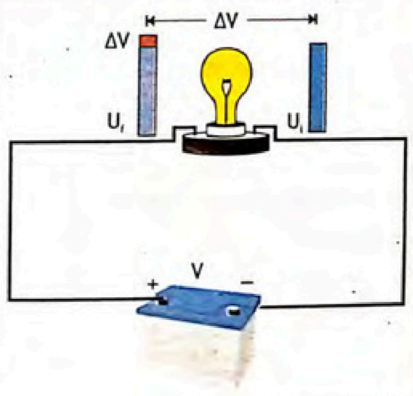
The electric potential at one point can be higher, lower or equal to the potential difference at other point. *'The difference of electric potential between two points is called potential difference'.*

Table 14.1 SOME CURRENT VALUES

Sr	Situation	Current (A)
1	Advanced technology computer chips	10^{-12} to 10^{-6}
2	Electron beam of a TV set	10^{-3}
3	Minimum current that is dangerous when it passes through the body	10^{-2} to 10^{-1}
4	Flash light bulb	0.3
5	House hold light bulb	1
6	Automobile starter	200
7	Maximum current in lightning strike	10^{4}
8	Maximum current carried by a superconducting niobium of 1 cm^2 cross-section	10^{7}

For example in an electric circuit which has an electric device (electric bulb) connected across a battery through conducting wires as shown in figure 14.3. The charge leaving the positive terminal of the battery has potential energy in device; part of this energy is lost (converted to other forms of energy). Thus, there is a difference of potential energy per coulomb of charge (q) from once side of the electric device to the other, which is termed as potential difference.

FIGURE 14.3 - *Potential difference*

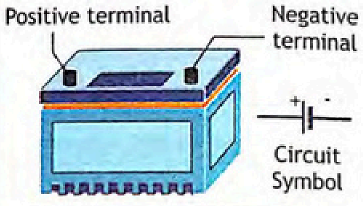


$$\Delta V = \frac{\Delta U}{q} \qquad (14.2)$$

The potential difference developed and maintained by source of electrical energy is called electromotive force (emf or ξ).

To sustain steady current in a circuit, emf source (*A device which converts a non-electrical energy into electrical energy*) is required which maintains a constant potential difference across its ends. Figure 14.4 shows battery as an emf source with positive and negative terminals.

FIGURE 14.4 - EMF



When battery is connected through conducting wires with a device. The positive charges enter the negative terminal of the battery. Therefore, work has to be done inside the battery to bring the positive charge from lower potential to higher potential. The influence that makes current flow from lower to higher potential (inside the battery) is called electromotive force (emf or E). If W is the work done by battery in taking a charge q from negative terminal to positive terminal, then electromotive force (emf or E) of the battery is:

$$E = \frac{W}{q} \qquad (14.3)$$

Equation 14.3 is the equation for emf, thus electromotive force (emf) is also defined as ***the energy spent per unit positive charge by the source to move it from negative terminal to the positive terminal within source.***

The units of electromotive force is the same as units for electric potential or potential difference as J/C = V.

$$1V = \frac{1J}{1C}$$

TIP: Arbitrary Reference

Recall that the reference point for determining the electric potential at a location is arbitrary. For example, consider a typical 9 V alkaline battery. It means that the positive terminal has an electric potential that is 9 V higher than the electric potential of the negative terminal. If we designate that the negative terminal of the battery is at zero potential, the positive terminal would have a potential of 9 V. We could just as correctly choose the potential of the negative terminal to be -4.5 V and the positive terminal to be +4.5 V.

14.3 OHM'S LAW

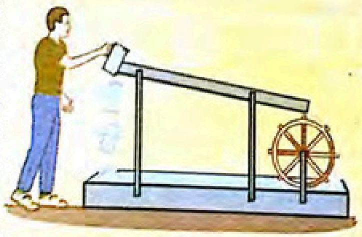
Statement: ***The current in a conductor is directly proportional to the applied voltage across the conductor as long as temperature and the physical state of the conductor is kept constant.***

Those devices which obey Ohm's law are called Ohmic devices and are commonly reffered to as "resistors".

INFO

ANALOGY BETWEEN GRAVITATIONAL POTENTIAL AND EMF

In this system, the person raising the water from a low to a high level is analogous to the battery, the paddle wheel is analogous to the lightbulb and the water is analogous to the electric charge. Notice that the person does work in raising the water; later, as the water falls to its original level, it does work on the external world by turning the paddle wheel.



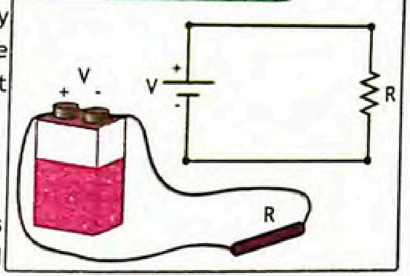
This means if we connect an ohmic device first to 1.5 V battery, and then we double the battery voltage to 3V, the current will also double. The current I flows through ohmic device when voltage V is applied across its ends, then according to Ohm's Law, we have

$$I \propto V \quad \text{or} \quad I = kV$$

Where k is the constant of proportionality and is equal to 1/R, where R is the opposition to the flow of current therefore

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

FIGURE 14.5 - Ohm's law



Here R is called resistance and is independent of the value of V and I and depends upon the nature of the conductor (its material), the dimensions of the conductor (such as length and cross-sectional area) and temperature of the conductor. All devices does not obey Ohm's Law. The devices that follow Ohm's law are called Ohmic devices and are commonly referred to as 'resistors'.

Limitations of Ohm's law: For Ohm's law to hold good, the resistance 'R' must not change. However, only metallic conductors (for example copper, silver and gold wires) show this behavior and that too only over limited range of voltages.

Many important devices do not obey Ohm's law. Even a lightbulb has resistance that depends on its temperature and does not obey Ohm's law.

EXAMPLE 14.2: CURRENT THROUGH RESISTOR

A 30.0-V battery is connected to a 10.0 Ω resistor. What is the current in the circuit?

GIVEN

Potential difference 'V' = 30.0 V

Resistance 'R' = 10.0 Ω

REQUIRED

Current 'I' = ?

SOLUTION: By Ohm's law $I = \frac{V}{R}$

Putting values $I = \frac{30.0V}{10.0\Omega}$

$I = 3.00\,A$ — Answer

EXTENSION EXERCISE 14.1

How V/Ω gives amperes? 3.00 A is a large current, is this current realistic?

ASSIGNMENT 14.2: CURRENT THROUGH ELECTRIC RANGE

A heating element on an electric range operating on 240 V has a resistance of 30.0 Ω. What current does it draw?

14.4 ELECTRICAL RESISTANCE (R)

The opposition offered to the flow of charges is called electrical resistance.

In metallic conductors, the charge is transported by free electrons. Resistance is due to collisions between these free electrons and fixed atoms inside the conductor. By Ohm's law, the resistance is the ratio of the voltage V across the conductor to the current I it carries, mathematically

$$R = \frac{V}{I} \qquad (14.4)$$

The **SI unit of resistance is ohm** and is represented by Greek letter (omega) Ω. *The resistance of wire is one ohm if potential difference of one volt applied across its ends and causes a current of one ampere to flow through it.*

$$1\Omega = \frac{1V}{1A}$$

For example, a wire or an electrical device that offers resistance to the flow of charges is called a resistor. The resistance can have a wide range of values. The copper wires in a television set, for instance, have a very small resistance. On the other hand, commercial resistors can have resistence up to many kilo-ohms (1 kΩ = 10^3 Ω) or mega-ohms (1 MΩ = 10^6 Ω).

The circuit symbol for a resistance in circuit diagrams is a zigzag line.

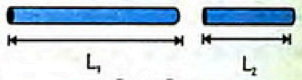
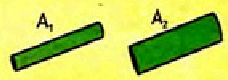
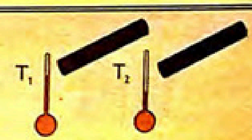
Resistance symbol

Factors on which Resistance depend: Since the resistance is provided by collisions of the free electrons with the lattice atoms, thus, any factor that affects the number of collisions will also affect a material's resistance. These factors include

A. Length B. Cross sectional Area C. Temperature D. Material

The effect of these factors is shown in table 14.2.

Table 14.2 FACTORS AFFECTING RESISTANCE OF METALLIC CONDUCTORS

Factor	How resistance changes	Example
Length	Resistance increases with increase in length $R \propto L$	 $R_{L1} > R_{L2}$
Cross sectional Area	Resistance increases by decreasing cross sectional area $R \propto \frac{1}{A}$	 $R_{A1} > R_{A2}$
Temperature	Resistance increase as temperature increases	 $R_{T1} > R_{T2}$
Material	Keeping length, cross-sectional area and temperature constant, resistance also varies by using different materials.	R Increases ↑ Platinum Iron Aluminum Gold Copper Silver

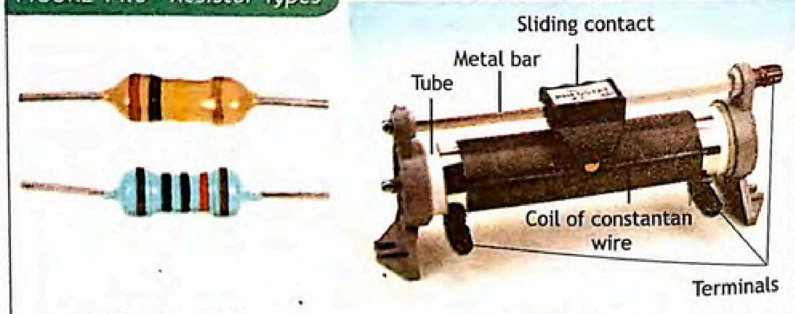
NOTE: The increases in resistance with temperature is not directly proportional.

POINT TO PONDER

Wire Resistance: Although copper wire conducts electricity extremely well, it still has some resistance, as do all conductors. The resistance of a particular wire depends on all the three physical characteristics mentioned above such as (a) type of material, (b) length of wire, and (c) cross-sectional area. In addition, temperature can also affect the resistance.

Resistors: Devices intended to have a specific value of resistance are called resistors and are made either from wires of special alloys or from carbon, a type of carbon resistor is shown in the figure 14.6 (a). Those used in radio and television sets have values from a few ohms up to millions of ohms. Variable resistors are used in electronics as volume and other controls. Variable resistors that take larger currents, like the one shown in Figure 14.6 (b) are useful in laboratory experiments. These consist of a coil of constantan wire (an alloy of 60% copper, 40% nickel) wound on a tube with a sliding contact on a metal bar above the tube.

FIGURE 14.6 - *Resistor Types*



(a) Fixed resistors

(b) Variable resistors

LAB WORK

Verify Ohm's law (using wire as conductor).

EXAMPLE 14.3: FLASHLIGHT BULB'S RESISTANCE

A small flashlight bulb draws 300 mA from its 1.5-V battery. What is the resistance of the bulb?

GIVEN

Potential difference 'V' = 1.5 V

Current 'I' = 300 mA = 0.3 A

REQUIRED

Resistance '*R*' = ?

SOLUTION: By definition of resistance $R = \frac{V}{I}$

Putting values $R = \frac{1.5V}{0.3A}$ therefore $R = 5\Omega$ —— Answer

Thus, the resistance of the bulb is 5 Ω.

ASSIGNMENT 14.3: RESISTANCE OF WIRE

Calculate the resistance of wire when the current through it is 2.0 A and the voltage across its ends is 3.0 V.

14.4 COMBINATION OF RESISTANCES

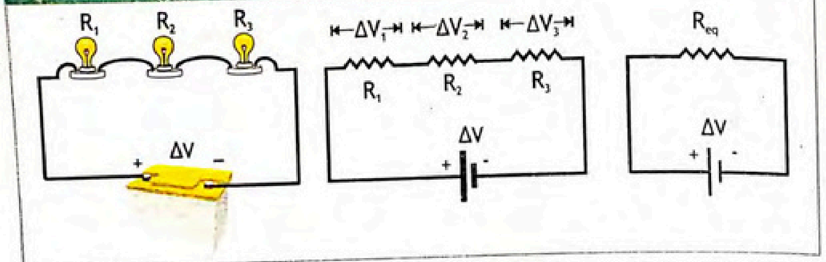
Electric circuits often contain a number of resistors connected in various ways. The connection and arrangement of resistors in a circuit affects the current and voltage drops in a circuit, therefore, they are used to control current and voltages in it. You are already familiar with series and parallel circuits from general science for grade 7, unit 11 "circuits and electric current", in which light bulbs were used. These light bulbs have resistance, therefore, they can be treated as resistors. There are two basic arrangements in which resistors can be connected.

A. Series Combination of resistors: When the resistors are connected end to end in such a way that there is a single path for the flow of current are said to be connected in series. Three resistors (e.g. light bulbs) having resistances R_1, R_2 and R_3 are shown in the figure 14.7 as series combination.

In a series connection, the same amount of charge passes through all resistors in a given time interval and therefore currents is the same in all resistors, such that

$$I_1 = I_2 = I_3 = I \quad \text{——(1)}$$

FIGURE 14.7 - Series combination of resistors



Where I is the current leaving the battery, I_1 is the current in resistor R_1, I_2 is the current in resistor R_2 and I_3 is the current in resistor R_3. The potential difference applied across the series combination of resistors divides between the resistors:

$$\Delta V = \Delta V_1 + \Delta V_2 + \Delta V_3 \quad \text{——} (2)$$

Since by Ohm's Law, the potential difference across the battery is also applied to the equivalent resistance R_{eq} in Figure 14.5

$$\Delta V = IR_{eq}$$

Where R_e is the equivalent resistance; a single resistor that has the same effect on the circuit as the series combination of all resistors when it is connected to the battery. Therefore, the voltage across each resistor by Ohm's Law can be written as

$$\Delta V_1 = I_1 R_1 \quad \text{and} \quad \Delta V_2 = I_2 R_2 \quad \text{and} \quad \Delta V_3 = I_3 R_3$$

Hence equation 2 can be written as $\quad IR_e = I_1R_1 + I_2R_2 + I_3R_3 \quad \text{——} (3)$

Putting equation 1 in equation 3, we get

$$IR_e = IR_1 + IR_2 + IR_3$$

or $\quad \cancel{I}R_e = \cancel{I}(R_1 + R_2 + R_3)$

Therefore $\quad \boxed{R_e = R_1 + R_2 + R_3} \quad \text{——} \boxed{14.5}$

Generally for 'n' number of resistors connected in series

$$\boxed{R_e = R_1 + R_2 + R_3 + \bullet\bullet\bullet\bullet\bullet + R_n} \quad \text{——} \boxed{14.6}$$

TIP: Equivalent Circuit

A resistor R_{eq} is 'equivalent' to a certain arrangement of several resistors mean that if that arrangement of resistors is replaced by R_{eq}, the current through the rest of the circuit is unchanged. This notion of equivalence applies to many types of circuit elements, including capacitors.

From equation 14.5 and equation 14.6, it is clear that in series combination the equivalent resistance is always greater than any individual resistance in combination.

EXAMPLE 14.4: RESISTORS CONNECTED IN SERIES

Four resistors $R_1 = 5\ \Omega$, $R_2 = 12\ \Omega$, $R_3 = 13\ \Omega$ and $R_4 = 96\ \Omega$ are connected in series across a 90 V battery. What is the current in the circuit?

GIVEN

Resistance $R_1 = 5\ \Omega$,

Resistance $R_2 = 12\ \Omega$,

Resistance $R_3 = 13\ \Omega$

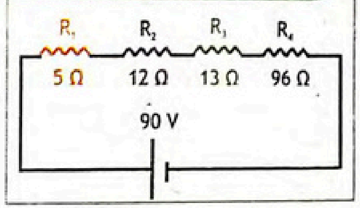
Resistance $R_4 = 96\ \Omega$

Potential difference 'V' = 90 V

REQUIRED

Circuit Current 'I' = ?

FIGURE 14.8 - Example 14.4



SOLUTION: For series combination as shown in figure 14.8, the equivalent resistance is

$$R_{eq} = R_1 + R_2 + R_3 + R_4$$

Putting values $\quad R_{eq} = 5\Omega + 12\Omega + 13\Omega + 96\Omega \quad$ therefore $\quad R_{eq} = 126\Omega$

By Ohm's law $\quad I = \dfrac{V}{R_{eq}} \qquad$ Putting values $\quad I = \dfrac{90V}{126\Omega}$

Therefore $\quad I = 0.71A$ —— Answer

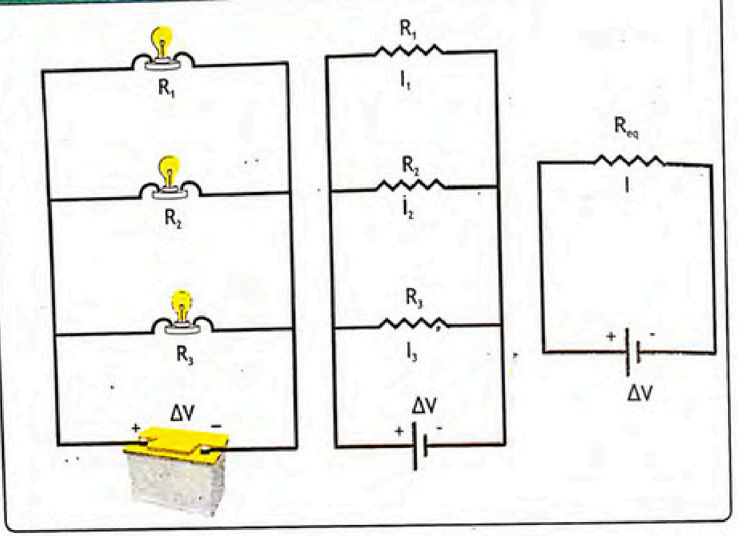
The current through the circuit is 0.71 A.

ASSIGNMENT 14.4: RESISTORS IN SERIES

Four resistors all having similar resistance of 15 Ω are connected in series across a 30 V battery. What is the current in the circuit?

B. Parallel Combination of resistors: When the resistors are connected in different branches of the circuit in such a way that there is more than one path for the flow of current, resistors are said to be connected in parallel. Consider three light bulbs as resistors having resistance R_1, R_2 and R_3 are shown in the figure 14.9 as parallel combination.

FIGURE 14.9 - *Parallel combination of resistors*



In a parallel combination of resistors the potential difference across each resistor is the same (since their ends are connected) while the current is split between them since it has multiple available paths.

$$\Delta V_1 = \Delta V_2 = \Delta V_3 = \Delta V \quad \text{——} (1)$$

Where ΔV is the terminal voltage of the battery, ΔV_1 is the voltage across resistor R_1, ΔV_2 is the voltage across resistor R_2 and ΔV_3 is the voltage across resistor R_3.

The total current I in parallel combination of resistors divides between the resistors:

$$I = I_1 + I_2 + I_3 \quad \text{——} (2)$$

Since by Ohm's Law, the current in the equivalent resistance R_{eq} in Figure 14.9 is

$$I = \frac{V}{R_{eq}}$$

Where R_e is the equivalent resistance; a single resistor that has the same effect on the circuit as the parallel combination of all resistors when it is connected to the battery. Therefore, the current through each resistor by Ohm's Law is

$$I_1 = \frac{V_1}{R_1} \quad \text{and} \quad I_2 = \frac{V_2}{R_2} \quad \text{and} \quad I_3 = \frac{V_3}{R_3}$$

Hence equation 2 can be written as $$\frac{V}{R_e} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \quad \text{——} (3)$$

Putting equation 1 in equation 3 we get $$\frac{V}{R_e} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or $$\frac{\cancel{V}}{R_e} = \cancel{V}\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

Therefore $$\boxed{\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \quad \text{——} \boxed{14.7}$$

Generally for '*n*' number of resistors connected in parallel

$$\boxed{\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \bullet\bullet\bullet\bullet\bullet + \frac{1}{R_n}} \quad \text{——} \boxed{14.8}$$

From equation 14.7 and equation 14.8 it is clear that in parallel combination the equivalent resistance is always smaller than any individual resistance in combination.

EXAMPLE 14.5: RESISTORS IN PARALLEL

Three resistors $R_1 = 5.0\ \Omega$, $R_2 = 10.0\ \Omega$ and $R_3 = 20.0\ \Omega$ are connected in parallel across a 90.0 V battery. What is the total current in the circuit?

GIVEN

Resistance $R_1 = 5.0\ \Omega$,

Resistance $R_2 = 10.0\ \Omega$,

Resistance $R_3 = 20.0\ \Omega$

Potential difference 'V' = 90 V

REQUIRED

Circuit Current 'I' = ?

SOLUTION: For parallel combination as shown in figure 14.10 the equivalent resistance is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Putting values

$$\frac{1}{R_{eq}} = \frac{1}{5.0\Omega} + \frac{1}{10.0\Omega} + \frac{1}{20.0\Omega}$$

Therefore $\frac{1}{R_{eq}} = \frac{1\times4 + 1\times2 + 1\times1}{20.0\Omega}$

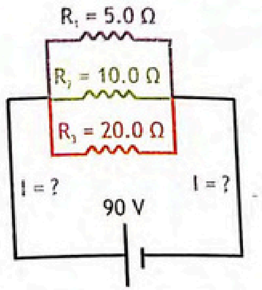
or $\frac{1}{R_{eq}} = \frac{7}{20.0\Omega}$

Hence $R_{eq} = 2.9\Omega$

By Ohm's law $I = \frac{V}{R_{eq}}$ Putting values $I = \frac{90V}{2.9\Omega}$

Therefore $I = 31.03A$ — Answer

FIGURE 14.10 - Example 14.5



The total current through the circuit is 31.0 A.

ASSIGNMENT 14.5: RESISTORS IN PARALLEL

Three resistors of 60 Ω, 30 Ω and 20 Ω are connected in parallel across a 90 V battery. Calculate the current flowing through the circuit?

LAB WORK

To study resistors in series circuit.

To study resistors in parallel circuit.

14.5 THE I-V CHARACTERISTICS FOR OHMIC AND NON OHMIC CONDUCTORS

The conductors for which Ohm's law hold are called Ohmic conductors. Thus, these conductors obey

$$I \propto \Delta V$$

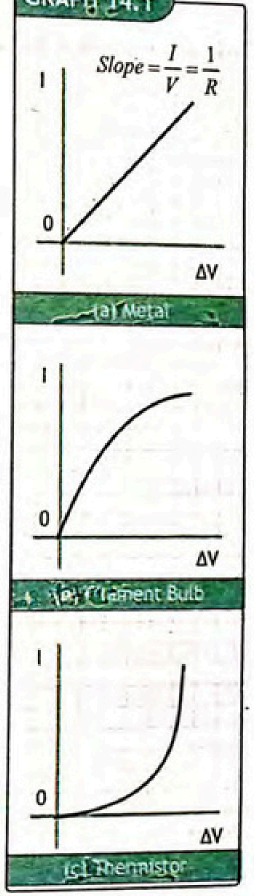
It means that if we plot a graph between current 'I' and potential difference 'ΔV' (called IV graph), we get a straight line; as for constant resistance the slope 1/R is a straight line. However, not all the materials have straight line graph as we can see from the graph 4.1, only metals show Ohmic behavior. The graphs of filament bulb and thermistor are curved, therefore, they are termed as non-ohmic conductors.

A. Metallic Conductors: For metallic conductors and some alloys the graph of 'I' verses 'V' is a straight line as shown in graph 14.1 (a). For example, when the potential difference doubled, the current through metallic conductors also doubles.

B. Filament Bulb: The graph of filament bulb shows that current saturates as it is increased and at large value even a large change in voltage V will show small change in current I as shown in graph 14.1 (b). This is because the tungsten wire in the filament of the bulb heats up with the increase in applied potential difference and free electrons collide more with lattice atoms causing the resistance to increase and consequently the rate and the rate of change in current decreases.

C. Thermistor: Thermistor is a device whose resistance changes significantly (highly) with temperature. Usually thermistor's resistance decreases with increase in temperature. The IV Graph of the thermistor shows that resistance decreases sharply. Thus, at a large value even for a small change in applied voltage ΔV, it will show a large change in current I as shown in graph 14.1 (c).

GRAPH 14.1



14.6 ELECTRICAL POWER AND JOULE'S LAW

Every appliance is rated for its power output (P) – the rate at which it can transform electrical energy to a desired form (for example light, sound, or heat). An electric clothes dryer might be rated at 5000 W and an electric shaver might be rated at 15 W.

A. Electrical Energy: The electrical energy lost or work done by a charge Q, going through a potential difference V, can be written as

$$V = \frac{W}{Q} = \frac{E}{Q} \quad \text{or} \quad E = Q \times V \quad \text{—— (1)}$$

We can use the definition of current

$$I = \frac{Q}{t} \quad \text{or} \quad Q = It \quad \text{—— (2)}$$

Putting equation 2 in equation 1, we get

$$\boxed{E = It \times V} \quad \text{—— 14.9}$$

Equation 14.9 gives the equation for electrical energy consumed in a device. Also by Ohm's law V = IR, therefore, the electrical energy E from equation 14.9 can also be written as

$$E = It \times IR \quad \text{or} \quad \boxed{E = I^2Rt} \quad \text{—— 14.10}$$

Also by Ohm's law I = V/R, therefore, electrical energy from equation 14.9 can also be written as

$$E = \frac{V}{R}t \times V \quad \text{or} \quad \boxed{E = \frac{V^2}{R}t} \quad \text{—— 14.11}$$

All the three equations 14.9, 14.10 and 14.11 are equally valid for calculation of electric energy.

EXAMPLE 14.6: ELECTRIC KETTLE

If a current of 10.0 A takes 5 minutes to boil a kettle of water requiring 3.6×10^5 J of energy, what is the potential difference (in voltage) across the kettle?

GIVEN

Energy 'E' = 3.6×10^5 J

Time 't' = 5.0 min = 300 s = 3.0×10^2 s

Current 'I' = 10.0 A

REQUIRED

Voltage 'V' = ?

SOLUTION: The electric energy is $E = It \times V$ or $V = \frac{E}{It}$

Putting values $V = \frac{3.6 \times 10^5\ \text{J}}{10.0\ \text{A} \times 3.0 \times 10^2\ \text{s}}$ or $V = \frac{3.6 \times 10^5\ \text{J}}{10.0\ \frac{C}{\cancel{s}} \times 3.0 \times 10^2\ \cancel{s}}$

Hence $V = 1.2 \times 10^2\ J/C = 1.2 \times 10^2\ V$ —— Answer

There is a potential difference of 1.2×10^2 V across the kettle.

ASSIGNMENT 14.6: CLOTHES DRYER

For how long a clothes dryer is operated, if it uses 32 kJ of energy to dry cloths at 220 V, running 16 A of current through it?

B. Joule's Law: The electrical energy lost in a device due to potential difference across it can be represented as equation called Joule's law of heating.

Statement: The amount of heat generated in resistor is proportional to the product of square of current 'I', resistance 'R' and duration of time for which the current passes through the resistor.

$$H \propto I^2Rt \quad \text{or} \quad \boxed{H = \frac{I^2Rt}{J}} \quad \text{—— 14.12}$$

Where J is called Joule's Mechanical Equivalent of heat. Its value depends upon choice of units of work and heat. This energy can be utilized for different useful purposes, for example, in light bulb we get this energy in the form of light and heat and in fan we get this energy in the form of mechanical energy and heat.

C. Electric Power: *The time rate at which the work is done in electric circuit is called electric power.* The electric power is the work done W in electric circuit divided by time t, mathematically

$$P = \frac{W}{t} \quad \text{—— (1)}$$

By definition of electric potential V $\quad V = \frac{W}{Q}$ or $W = V \times Q$ —— (2)

By definition of current $\quad I = \frac{Q}{t}$ or $Q = It$ —— (3)

Putting equation 3 in equation 2, we get $\quad W = V \times It$ —— (4)

Putting equation 4 in equation 1, we get $\quad P = \frac{V \times I\cancel{t}}{\cancel{t}}$

$$\text{or} \quad \boxed{P = IV} \quad \text{—— 14.13}$$

Equation 14.13 gives the relation for electric power. As by Ohm's law V = IR, therefore, the electrical power P from equation 14.13 can also be written as

$$P = I \times IR \quad \text{or} \quad \boxed{P = I^2R} \text{ — } 14.14$$

Also by Ohm's law I = V/R, therefore, electrical power from equation 14.13 can also be written as

$$P = \frac{V}{R} \times V \quad \text{or} \quad \boxed{P = \frac{V^2}{R}} \text{ — } 14.15$$

All the three equations 14.13 , 14.14 and 14.15 are equally valid for calculation of electric power.

Units of Power: The S.I units for electrical power is **watt (W)**. A power of 1 W is said to be consumed in an electrical circuit if potential difference of 1 V, causes a current of 1 A to flow through a circuit.

$$1W = 1A \times 1V$$

FIGURE 14.11 - *Electric Power*

The power rating (sometimes called the "wattage") of a light bulb 12 W and tube light 40 W tells us how fast it will convert electric energy into heat and light. For an incandescent bulb, only about 2 percent of the transformed energy is actually emitted as light; the rest is emitted as heat. A fluorescent bulb, on the other hand, converts about 9.5 percent of its energy into light, making it more than four times as efficient as an incandescent bulb.

It is energy, not power, that we pay for in our electricity bill. Since power is the rate at which energy is transformed, the total energy used by any device is simply its power consumption multiplied by the time for which it is operated. If the power is in watts and the time is in seconds, the energy will be in joules.

EXAMPLE 14.7: FLASHLIGHT

In the flashlight the current is 0.40 A, and the voltage of 3.0 V is delivered by cell. Find the power delivered to the bulb.

GIVEN

Current 'I' = 0.40 A

Voltage 'V' = 3.0 V

REQUIRED

Electric Power 'P' = ?

SOLUTION: The electric power is $P = I \times V$

Putting values $P = 0.40A \times 3.0V$ or $P = 0.40\,\cancel{C}/s \times 3.0\,J/\cancel{C}$

Hence $P = 1.2\,J/s = 1.2W$ — Answer

The 'wattage' rating of this bulb would, therefore, be 1.2 W.

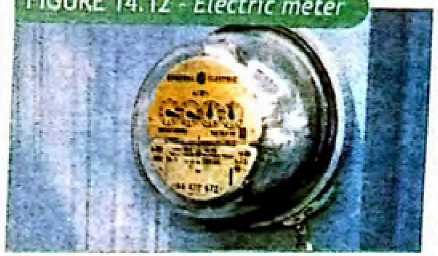
ASSIGNMENT 14.7: AUTOMOBILE HEADLIGHT

Calculate the resistance of a 40-W automobile headlight designed for 12 V.

D. Electrical energy and Kilowatt-hour (kWh): The electric metre in our homes measures how much energy (in kWh) we use, not the electrical power. Electrical energy is consumed in large quantities for which joule is a very small unit, therefore **Kilowatt-hour** (kWh) is preferred. It is the amount of energy consumed by a device of power 1 kW running continuously for one hour.

$$\begin{aligned} E &= 1 \text{ kW-hr} \\ &= 1000 \text{ W} \times 1\text{hr} \\ &= 1000 \text{ J/s} \times 3600\text{s} \\ &= 3.6 \times 10^6 \text{ J} \end{aligned}$$

FIGURE 14.12 - *Electric meter*



kWh is the unit for which the tariff (cost of electricity) is decided by electricity supply company.

EXAMPLE 14.8: COST OF ELECTRICITY FOR CRICKET TOURNAMENT

You are arranging night cricket tournament, you have arranged five 1000 W light bulbs. These bulbs will remain lit for 6 hours for 29 days. Estimate the cost of electricity consumption if the cost of electricity is 8.11 Rs/kWh.

GIVEN

Power 'P' = 5 ×1000 W = 5000 W = 5 kW

Time 't' = 29 × 6 h = 174 h

Tariff rate = 8.11 Rs/kWh

REQUIRED

Energy consumed '$E_{(kWh)}$' = ?

Cost of electricity 'C' = ?

SOLUTION: The electric power is defined as $P = \frac{E}{t}$

$E = P \times t$ Putting values $E = 5\,kW \times 174\,h$

$E = 870\,kWh$ —— Answer

The total consumed energy is 870 kWh, the cost can be calculated as

$$Cost = E \times Tariff\ Rate$$

$$Cost = 870\,\cancel{kWh} \times 8.11\,{}^{Rs}/_{\cancel{kWh}}$$

$$Cost = 7055.7\,Rs$$ —— Answer

The total cost of electricity for whole tournament is Rs. 7056.

EXTENSION EXERCISE 14.2

It is found that if eight 35 watt LED Lights are used, it will serve the same purpose. Will this reduce the cost of electricity?

ASSIGNMENT 14.8: WINTER COST

A 100-W bulb is left on, in an outdoor storage room to keep paint from freezing. The 100-W rating refers to the power dissipated in the bulb's filament, which is a resistor. If electricity costs 8.11 Rs/kWh, about how much does it cost to burn the lightbulb for three months during winter?

14.7 USE OF CIRCUIT COMPONENTS

a. **Wires and Connectors:** Wires and connectors are used to direct current from one part of the circuit to another. A blob should be drawn where wires are connected. In complex diagrams, it is sometimes necessary to draw crossed wires even when they are not connected. In such cases a bridge; joined and not joined wires are shown in figure 14.13 a.

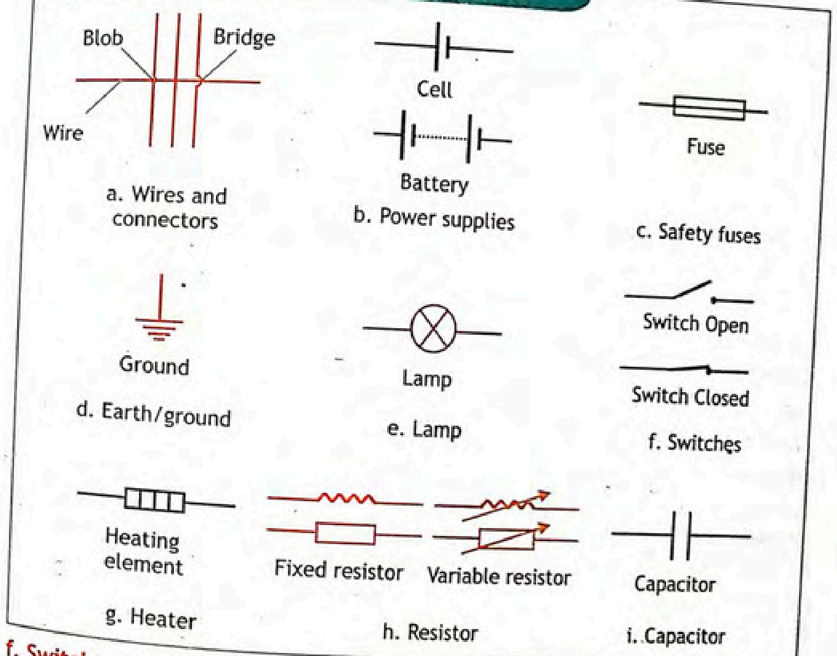
b. **Power Supply:** Source of electrical energy to the circuit, such as cells and batteries whose symbols are shown in figure 14.13 b.

c. **Fuse:** Safety device which blows (melts) if the current through it exceeds a specified value, its circuit symbol is given in figure 14.13 c.

d. **Earth (Ground):** This is the zero volt connection of a power supply. But for electricity mains and the radio circuits it really means the earth or ground. The circuit symbol is given in figure 14. 13 d.

e. **Lamp:** The device which converts electrical energy into light, its circuit symbol is shown in figure 14.13 e.

FIGURE 14.13: *Circuit components symbols*



f. **Switch:** A device that allows or blocks the flow of current. The circuit symbol is shown in figure 14.13 f.

g. **Heater:** A device that converts electrical energy into heat. The circuit symbol is shown in figure 14.13 g.

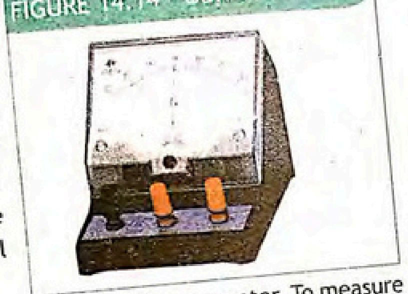
h. Resistor: The materials that provide resistance to the current in a circuit are called resistors. The variable resistors can be used to control the volume in radio and TV or regulate fan speed. The circuit symbol is shown in figure 14.11 h.

i. Capacitor: A capacitor is a device that store electric charge. A capacitor is used with resistor in a timing circuit. Capacitors can be used as block and pass filters as well. The circuit symbol is shown in figure 14.11 i.

14.8 ELECTRICAL MEASURING INSTRUMENTS

Electrical measuring instruments are devices used for measuring various electrical aspects such as the presence and amount of current, voltage, resistance and power of electrical devices.

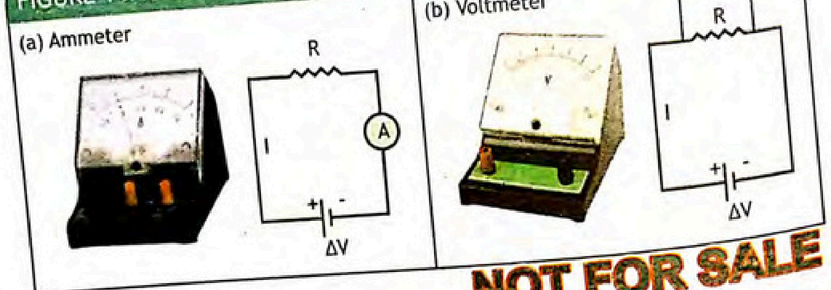
FIGURE 14.14 - Galvanometer



A. Galvanometer: Galvanometer is an instrument used to detect the presence of current or indicate potential difference between two points. It is a very sensitive device capable of detecting very small currents and voltages.

B. Ammeter: A device used to measure current is called an ammeter. To measure the current, an ammeter must be connected in a circuit in series. Figure 14.15 (a) shows an ammeter connected in a circuit. Since the ammeter must be able to make measurements by disturbing the current in the circuit as little as possible. Ammeters are designed to have as low resistance as possible (because they are connected in series), usually of the order of. 1 Ω, so they do not have an appreciable effect on the currents they measure.

FIGURE 14.15 - Ammeter and Voltmeter



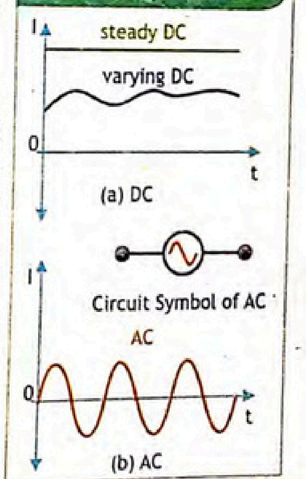
C. Voltmeter: A device used to measure potential difference is called an voltmeter. To measure the potential difference, voltmeter must be wired in parallel with the component across which the potential difference is to be measured. Figure 4.15 (b) shows a voltmeter placed in the circuit to measure the potential drop across resistor R. Since the voltmeter must be able to make measurements while disturbing the circuit as little as possible, voltmeters are designed to have as high a resistance as possible, usually of the order of 10 M Ω (10^7 Ω), so they have a negligible effect on the potential differences they are measuring.

FIGURE 14.16 - Multi-meter

D. Multimeter: In practice, measurements of current and potential difference are made with a digital multimeter that can switch between functioning as an ammeter and functioning as a voltmeter. It displays the results with an auto-ranging numerical digital display, which includes the sign of the potential difference or current. Most digital multimeters can also measure the resistance of a circuit component; that is, they can function as an ohmmeter.

14.9 DIRECT AND ALTERNATING CURRENT

FIGURE 14.17 - DC & AC



In a direct current (DC), the charge flows in one direction only. Graphs for steady DC and varying DC are shown in Figure 14.17 (a). The current from cell or battery is direct current because of fixed positive and negative terminals.

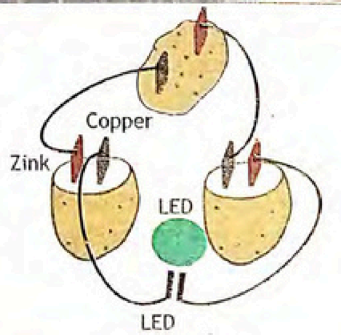
In an alternating current (AC), the direction of charge flow, reverses regularly and therefore, the current also changes direction, as shown in the graph in Figure 14.17 (b). When alternating voltage is applied, the current first flows in one direction and then in the opposite direction.

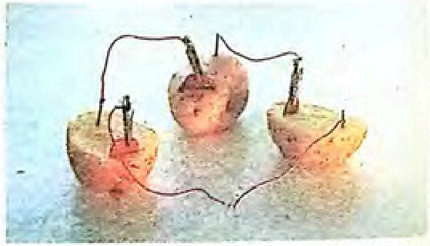
The direction of current in the circuit depends upon the changing polarity of alternating voltage source. The circuit symbol for AC is also given in figure 14.17(b). Electric generators can produce either DC or AC.

Most of the electric power in the world is AC, since it is easier to transmit it from one place to another. Therefore the electricians work with AC about 99% of the time. Digital multi-meter shown above can measure both DC and AC.

ACTIVITY: LIGHT AN LED WITH POTATOES

Take two potatoes, cut one potato in half, insert one Zink and Copper electrode deep to each piece of halved potato and single potato. Take a sensitive voltmeter you will notice some reading across each arrangement. Now connect these three arrangement (batteries) in series as shown in figure (Zink to Copper and Copper to Zink) to produce a higher voltage. An LED (Light Emitting Diode) which is a low power light bulb and uses little energy, can be lit using this arrangement. Using this energy, you can run a small clock or any other low power electronic equipment. Try to answer the following questions.





- Why LED cannot be lit by using single potato? A minimum of how many potatoes are required to lit an LED?
- What happens to the Copper and Zink electrode over time?
- Is potato a good alternate energy source? If we use large number of potatoes, can we power heavy load devices?

LAB WORK

To find the resistance of galvanometer by half deflection method.

INFO: BEHAVIOUR OF LIGHT BULBS IN SERIES AND PARALLEL CIRCUIT

When the light bulbs are connected in series and parallel combination interesting observations can be made. Celebration lights in series and parallel combination are shown in the figures.

Series Circuit: If one lamp in a series circuit burns out, the circuit is broken and all lamps cease to glow.

The brightness of light from each lamp in a series circuit decreases when more lamps are added to the circuit. Because adding more lamps in series produces a greater circuit resistance. This decreases the current in the circuit. All voltages have to add up to the same total voltage, so the voltage drop across each lamp also decreases. Since power is the product of voltage and current, both these changes act to dim the lamps.

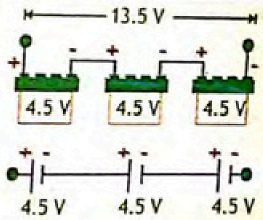
Celebration lights series circuit

Parallel Circuit: If one lamp burns out, the other lamps are unaffected. This is because current in each branch, according to Ohm's law, is equal to voltage/resistance and since neither voltage nor resistance is affected in the other branches, the current in those branches is unaffected.

The brightness of light from each lamp in a parallel circuit is not affected when more lamps are added to the circuit because the current in the battery increases by an amount that feeds the added branch(es). In the overall circuit, added paths means decreased resistance.

Celebration lights parallel circuit

A series connection adds the voltage of the two batteries but it keeps the same amperage rating (also known as Amp Hours). For example, these three 4.5-volt batteries joined in series now produce 13.5 volt but they still have a total capacity of 10 amps. To connect batteries in a series, use a jumper wire to connect the negative terminal of the first battery to the positive terminal of the second battery.



Series Combination of batteries

14.10 HOUSE CIRCUITS

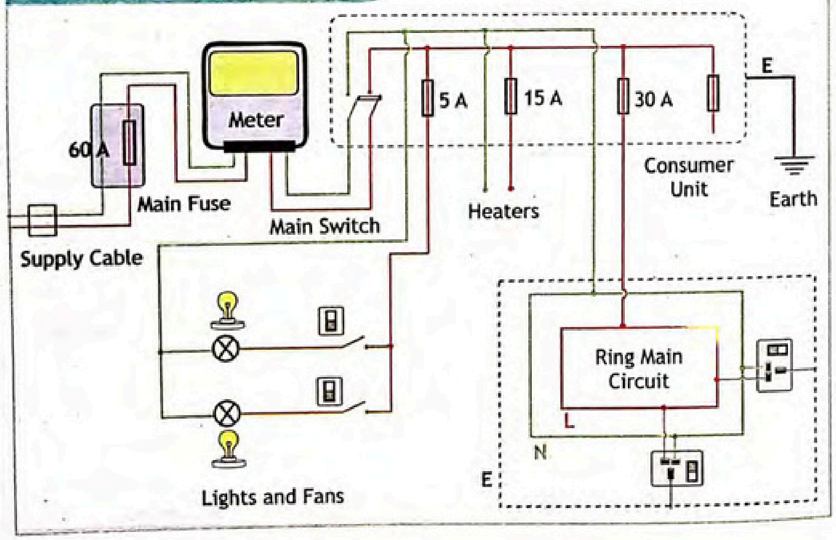
Electricity usually comes to our homes by supply cable containing two wires, the live (L) and the neutral (N). The neutral is earthed at the local sub-station and so there is no p.d. between it and earth. The supply is AC and the live (L) wire is alternately positive and negative. Typical house circuits are shown in figure 14.18.

A. Parallel Circuitry: Every circuit is connected in parallel with the supply, i.e. across the live and neutral, and receives the p.d. of 220 V from supply mains. The advantages of having appliances connected in parallel rather than in series, can be seen by studying the lighting circuit in figure 14.18.

(i) The p.d. across both lamps is fixed (same as the supply potential difference) so the lamp shines with the same brightness irrespective of how many other lamps are switched on.

(ii) Each lamp can be turned on and off independently; if one lamp fails, the others can still be operated.

FIGURE 14.18: House Circuit



B. Switches and fuses: In figure 14.18, it is seen that switches and fuses are employed only to the live wire. If they are installed to the neutral wire, electrical appliances and power sockets would be 'live' even when switches are in 'off mode' or fuses 'blown'. A fatal shock could then be obtained even in switched off condition.

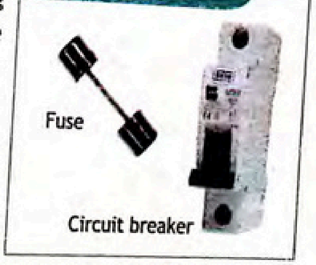
C. Ring main circuit: Most houses have live and neutral wires running in two complete rings with power sockets attached, as shown in fig. 14.18. Having a ring allows current to be split into two parts allowing heavy appliances to be powered using relatively thinner wires. The live and neutral wires each run in two complete rings around the house and the power sockets. The ring has a 30 A fuse and if it has, say, ten sockets, then all can be used as long as the total current does not exceed 30 A, otherwise the wires overheat. A house may have several ring circuits, each serving a different area.

14.11 ELECTRICAL SAFETY IN HOUSEHOLD ELECTRICITY

The devices and appliances that we operate in our home runs with 220 V of AC, which is hazardous. For safe use of electricity, fuses should be installed and earthing should be made in the household circuitry.

A. Fuses and Circuit breakers: Fuse consist, of a thin piece of metal wire, having low melting temperature. When excessive current, above fuse rating, flows through it, the wire piece inside it get hot and melts. This disconnects the current through the live wire, thus preventing any damage to the appliances they are connected. Circuit breakers (figure 14.19) are now used instead of fuses in consumer units.

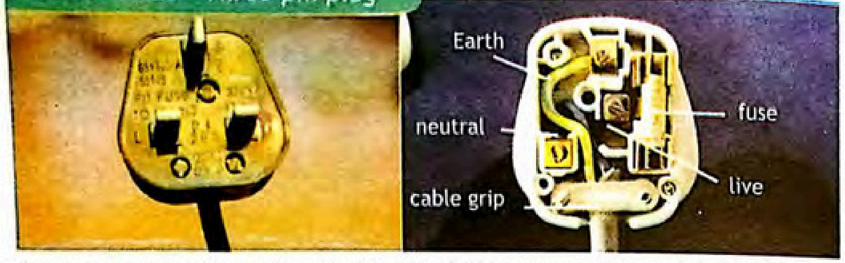
FIGURE 14.19 Fuse



When the current exceeds the rated value of the circuit breaker, it separate a contact and breaks the circuit. They operate much faster than fuses and have the advantage that they can be reset by pressing a button.

B. Earthing: A ring main has a third wire which goes to the top sockets on all power points (figure 14.18) and is earthed by being connected either to a metal water pipe entering the house or to an earth connection on the supply cable. This third wire is a safety precaution to prevent electric shock.

FIGURE 14.20 - Three-pin plug



The earth pin on a three-pin plug (figure 14.20) is connected to the metal case of the appliance which is thus joined to earth by a path of almost zero resistance. If for example, an electric device breaks or sags and touches the case, a large current flows to earth and 'blows' the fuse. Otherwise, the case would become 'live' and anyone touching it would receive a shock which might be fatal, especially if standing in a damp environment, such as on a wet concrete floor.

14.12 DANGERS OF ELECTRICITY

A. Electric shock: Electric shock occurs if current flows from an electric circuit through a person's body to earth. This can happen if there is a damaged insulation or faulty wiring. The typical resistance of dry skin is about 10,000 Ω, so if a person touches a wire carrying electricity at 240 V, an estimate of the current flowing through them to earth would be $I = V/R = 240/10\,000 = 0.024\ A = 24\ mA$. For wet skin, the resistance is lowered to about 1000 Ω (since water is a good conductor of electricity) so the current would increase to around 240 mA.

It is the size of the current (not the voltage) and the length of time for which it acts which determines the strength of an electric shock.

TIP BITS

The human body: The human body acts as a variable resistor. When dry, the skin's resistance is high enough to keep currents that are produced by small and moderate voltages low. If the skin becomes wet, however, its resistance is lower, and the electric current can rise to dangerous levels. A current as low as 1 mA can be felt as a mild shock, while currents of 15 mA can cause loss of muscle control and currents of 100 mA can cause death.

- If your body resistance is 100,000 Ω, how much current will you experience if you touch the terminals of a 12-V battery?
- If your skin is very moist, so that your resistance is only 1000 Ω and you again touch the battery terminals, how much current will you experience? Will it hurt?

The path the current takes influences the effect of the shock; some parts of the body are more vulnerable than others. A current of 100 mA through the heart is likely to be fatal. Damp conditions increase the severity of an electric shock because water lowers the resistance. Wearing rubber-soled shoes or standing on a dry insulating floor increases the resistance between a person and earth and will reduce the severity of an electric shock.

To avoid the risk of getting an electric shock:

- Switch off the electrical supply to an appliance before starting repairs.
- Use plugs that have an earth pin and a cord grip; an insulating casing (a rubber or plastic case) is preferred.
- Do not allow appliances or cables to come into contact with water. For example it is dangerous to hold a hair straightener with wet hands in a bathroom. Keep electrical appliances well away from baths tubs and wash basins.
- Do not have long cables trailing across a room, because the insulation can become damaged.

Table 14.3: EFFECT OF CURRENT ON HUMAN BODY

Current (mA)	Effect
1	Threshold of sensation
5	Maximum harmless current
10-20	Onset of sustained muscular contraction; cannot let go for duration of shock; contraction of chest muscles; may stop breathing during shock
50	Onset of pain
100-300	Ventricular fibrillation possible; often fatal
300+	Onset of burns depending on concentration of current
600	Onset of sustained ventricular contraction and respiratory paralysis; both cease when shock ends; heartbeat may return to normal; used to defibrillate the heart

B. Fire risks: If the electrical wiring in the walls of a house becomes overheated, a fire may start. Wires become hot when they carry electrical currents - the larger the current carried, the hotter a particular wire will become, as we studied in joules law. To reduce the risk of fire through overheated cables, the maximum current in a circuit should be limited by taking these precautions:

- Use plugs that have a correct fuse.
- Do not attach too many appliances to a circuit (for example an extension box).
- Don't overload circuits by using too many adapters.
- Thick wires have lower resistance, therefore appliances such as heaters requiring large amounts of power (and hence current) must not be operated with thin wires.
- Damaged insulation or faulty wiring which leads to a large current flowing to earth through flammable material can also start a fire.

KEY POINTS

Current: Time rate of flow of charge.
Conventional Current: The current conventionally considered due to flow of positive charges in conductors.
Potential Difference: The difference of electric potential between two points
EMF: The energy per unit positive charge supplied by the source to the charge to move it from negative terminal to the positive terminal within source.
Ohm's Law: The electric current through a conductor is directly proportional to the applied voltage provided the physical conditions are kept same.
Resistance: The measure of opposition to the flow of current.
Resistor: Device intended to offer resistance is called resistor.
Series combination of resistors: The combination of resistors connected end to end.
Parallel combination of resistors: The combination of resistors connected in different branches of circuit, providing alternative paths for current to flow.
Electrical Energy dissipation: Energy consumed by appliances such as light bulbs, fans, heater, cell phone, TV e.t.c.
Joule's Law: The amount of heat generated in resistor is proportional to the product of square of current 'I', resistance 'R' and duration of time for which the current passes through the resistor.
Commercial Electricity Consumption Units: kWh is the unit used for commercial electricity consumption.
Direct Current: The current in which the flow of charge is in one direction.
Alternating Current: The current in which the flow of charge reverses its direction regularly.

PROJECTS

GROUP A 'HOME CIRCUITS': Contact an electrician, builder, or contractor, and ask to see a house electrical plan. Study the diagram to identify the circuit breakers, their connections to different appliances in the home, and the limitations they impose on the circuit's design. Find out how much current, on average, is in each appliance in the house. Draw a big chart diagram to be presented in class of the house, showing which circuit breakers control which appliances. Your diagram should also keep the current in each of these appliances under the performance and safety limits.

GROUP B 'IMPROVING POTATO BATTERY - I': The chemical reaction that takes place inside the potato is responsible for creating electricity. To see if you can improve the effectiveness or speed of this reaction, try using different types of metals in various combinations. First, test what happens when you use two pieces of the same metal. Then test a series of metals in different combinations with each other. In addition to zinc and copper, you could test a nickel, an iron nail, an aluminum foil, a brass button or a paper clip.

You can also test different types of potatoes, different sizes of potatoes, you can even boil a potato, non-metallic electrodes or different types of connecting wires. Write a research presentation for your school magazine.

GROUP C 'IMPROVING POTATO BATTERY - II': Potatoes are not the only food product that produces the necessary chemical reaction to produce a flow of electrons. Citrus fruits also contain a special chemical, citric acid, that reacts with metal to produce electricity. Compare the voltage and current produced by a potato battery to that of a lemon, tomato, orange, apple, watermelon, loaf of bread or any other type of food you want to test. Hypothesize which food you think will make the best battery and compare your results, explaining how each food reacted and why? Write a research article about your findings for the school magazine.

GROUP D 'LIFE WITHOUT ELECTRICITY': Prepare a presentation to be presented in class room about the dependence of modern life on electricity. Also emphasize on how difficult life would be, without electricity?

GROUP E 'ELECTRICITY COST REDUCTION': Identify ways to reduce electricity consumption in everyday life. Calculate the total cost of electrical energy used in one month (30 day) at home. Suggest ways how it can be reduced without compromising the comforts and benefits of electricity. Prepare a presentation to share with your class fellows.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer:

1. Batteries are rated with unit 'ampere - hour', it is the unit of
   A. charge B. current C. power D. energy
2. When connected to a battery, a lightbulb glows brightly. If the battery is reversed and reconnected to the bulb, the bulb will glow
   A. brighter B. dimmer C. with the same brightness D. and fuse
3. The resistance of wire will decrease by increasing
   A. temperature B. length C. diameter D. both A & B
4. The wire made from which of the following material is a conductor
   A. glass B. rubber C. silver D. silk
5. The current which reverses direction after regular interval of time is
   A. DC B. AC C. conventional current D. both A and B
6. Electricity main supply meters measures it in units of 'kilowatt - hour'; it is the unit of
   A. charge B. current C. power D. energy
7. The device that is used to protect a circuit against overload is
   A. heater B. fuse C. lamp D. All of these
8. Which of the following represent one ohm
   A. VA^{-1} B. JS^{-1} C. WA^{-1} D. JC^{-1}
9. Two resistances of 1 ohm are connected in parallel, the equivalent resistance is
   A. 2 Ω B. 1.5 Ω C. 1 Ω D. 0.5 Ω
10. 1 kWh =
    A. 3600 W B. 1000 J C. 3.6×10^6 J D. 0.36 hrs

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. As water is made of atoms having protons (charge +e) and electrons (charge -e), does the water flowing through pipe carry an electric current? Explain.
2. A car has two headlights, when the filament in one headlight burns out, the other headlight stays on. Are the headlights connected in series or in parallel?

3. Qurat-ul-Ain needs a 100-Ω resistor for a circuit, but she only has a box of 300-Ω resistors. What can she do?
4. A number of light bulbs are connected to a single power outlet. Will they provide more illumination when connected in series or in paralel? Why?
5. Explain why light bulbs almost always burn out just as they are turned on and not after they have been on for some time.
6. Explain why is it possible for birds to perch safely on high tension wires without being electrocuted?
7. An electrician working on "live" circuits wears insulated shoes and keeps one hand behind his or her back. Why?
8. Explain why is it dangerous to turn on a lightbulb when you are in a bath tub?
9. Why circuit breaker, fuses and switches are installed to 'live wire'?

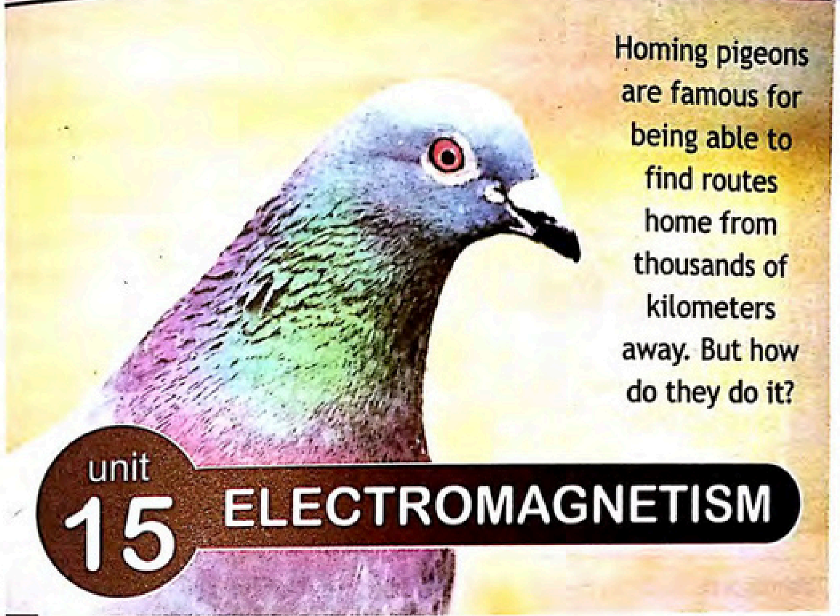
COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

1. Define electric current. In what units it is measured? Discuss briefly the direction of current through the conductor.
2. What is potential difference and emf? Differentiate between them.
3. State and explain Ohm's Law. What are its limitations?
4. What is resistance and in what units we measure resistance?
5. What is series combination of resistors? How we can determine equivalent resistance for different resistors connected in series?
6. What is parallel combination of resistors? How we can determine equivalent resistance for different resistors connected in parallel?
7. Explain the factors on which the resistance of metallic conductor depends.
8. What are ohmic and non-ohmic devices? Sketch and interpret the VI characteristic graph to justify metallic conductor, filament lamp and thermistor as ohmic or non-ohmic materials.
9. Explain the concept of electric energy and electric power. What is the commercial unit for the consumption of electric energy?
10. State the functions of live, neutral and earth wires in domestic main supply. Explain why the domestic appliances are connected in parallel?
11. Differentiate between alternating current and direct current.
12. What are the hazards of electricity? What safety measures are taken in household electricity to safeguard for these hazards?

NUMERICAL QUESTIONS

1. A small electric heater has a resistance of 15 ohms when the current in it is 2 amperes. What voltage is required to produce this current?
2. If a potential difference of 10 V is maintained across a 1 m length of the Nichrome wire having resistance of 3.1 Ω, what is the current in the wire?
3. What resistor would have a 15 mA current if connected across the terminals of a 9.0 V battery?
4. Consider a circuit with three resistors $R_1 = 250.0\,\Omega$, $R_2 = 150.0\,\Omega$, $R_3 = 350.0\,\Omega$, connected in parallel with a 24.0-V battery. Find the total current supplied by the battery.
5. An electric hair dryer is rated at 1,875 watts when operating on 120 volts. What is the current flowing through it? If the hair dryer is used for 3 minutes, how much energy does it consume?
6. A battery with an emf of 12 V is connected to a 545 Ω resistor. How much energy is dissipated in the resistor in 65 s?
7. If the unit of electricity cost 8.11 Rs/kWh, what is cost of running two 160 W fans and four 100 W light bulbs for 6 hours in school?



Homing pigeons are famous for being able to find routes home from thousands of kilometers away. But how do they do it?

unit 15 ELECTROMAGNETISM

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

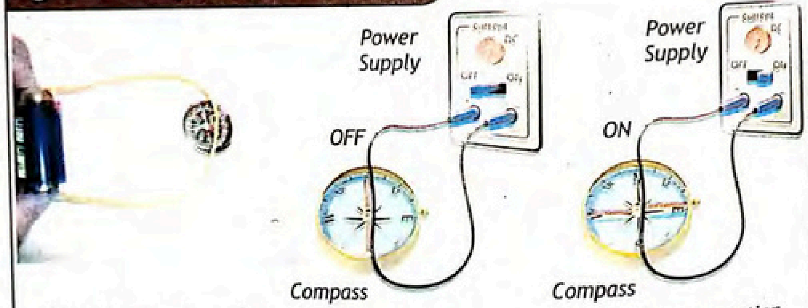
- ✓ explain by describing an experiment that an electric current in a conductor produces a magnetic field around it.
- ✓ describe that a force acts on a current carrying conductor placed in a magnetic field as long as the conductor is not parallel to the magnetic field.
- ✓ state that a current carrying coil in a magnetic field experiences a torque.
- ✓ relate the turning effect on a coil to the action of a D.C. motor.
- ✓ describe an experiment to show that a changing magnetic field can induce e.m.f. in a circuit.
- ✓ list factors affecting the magnitude of an induced e.m.f.
- ✓ explain that the direction of an induced e.m.f opposes the change causing it and relate this phenomenon to conservation of energy.
- ✓ describe a simple form of A.C generator.
- ✓ describe mutual induction and state its units.
- ✓ describe the purpose of transformers in A.C. circuits.
- ✓ identify that a transformer works on the principle of mutual induction between two coils.

CONTENTS

Just like electric field, the region or space around a magnet where magnetic effects can be observed is called the magnetic field and is represented by magnetic field vector or magnetic induction vector B and can be represented by magnetic field lines. When charges move (such as in a current carrying wire), they generate a magnetic field as well as an electric field. Thus, when charges move they also exhibit magnetic behavior, when they are at rest no such effect is seen. Magnetic effects created due to the presence of currents is the focus of study in this chapter.

This magnetic field can be detected, by bringing a compass needle close to the steady direct current carrying wire such as produced by the cell or Power Supply as shown in the figure 15.1.

Figure 15.1 - *Magnetic effect of current*



Using an apparatus similar to the one shown, we can demonstrate a connection between magnetism and electricity by applying current to the wire.

15.1 MAGNETIC EFFECT OF A STEADY CURRENT

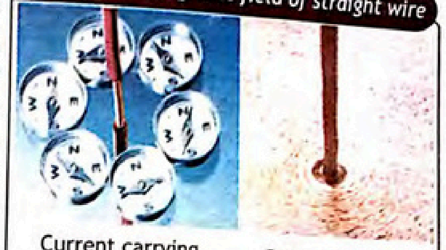
The magnetic field produced by steady current can be mapped by the following experiments.

15.1.1. Magnetic Field due to a straight steady current carrying wire:

When current is passed through a long wire with compass needles placed around it in a circle, the compass needles line up with the magnetic field in a circular pattern.

Similar observations can be made by using a cardboard on which iron filings have been placed. These iron fillings form concentric circles around the wire as shown in figure 15.2. These experiments show the orientation of a magnetic field around a current carrying wire is circular. Without any current in the wire all the compass needle will align with earth's magnetic field, pointing towards the north.

Figure 15.2 - *Magnetic field of straight wire*

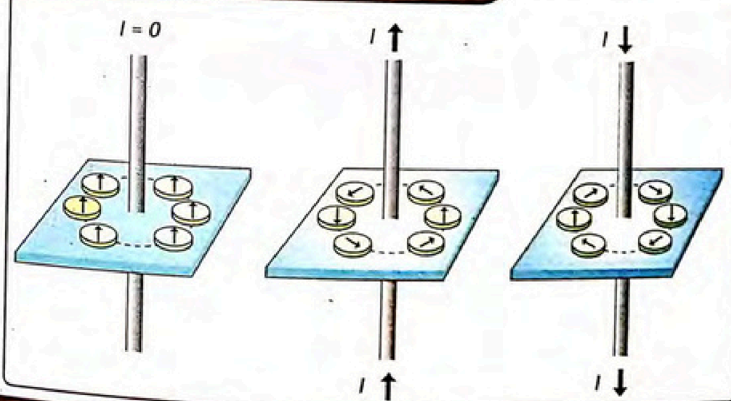


Current carrying wire, with compass needles lining up with the magnetic field in form of circular pattern.

Current carrying wire through a cardboard shows concentric circles of iron filings around the wire.

As soon as the current is passes through the wire, the compass needles will redistribute to align with magnetic field of the wire.

Figure 15.3 - *Magnetic field of straight wire*



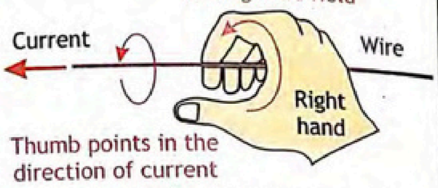
LAB WORK

Trace the magnetic field of a bar magnet.

The compass needle deflects in opposite direction when the current is reversed as shown in the figure 15.3, the direction of such field is determined by right hand rule I.

RIGHT-HAND RULE I

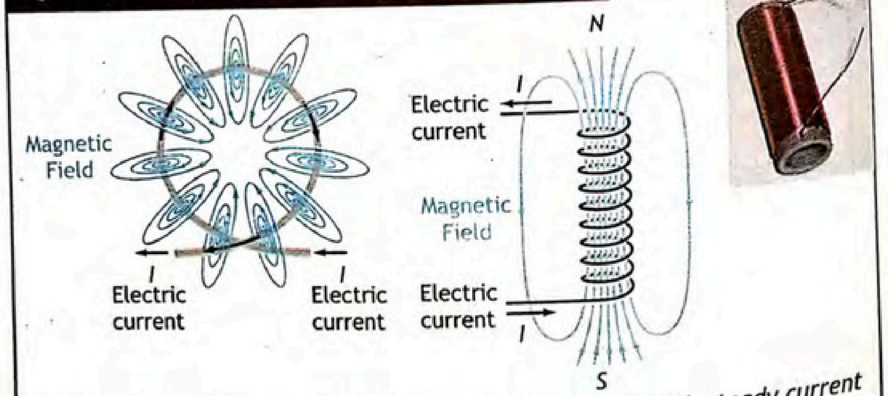
Right-hand rule for the magnetic field from a current carrying wire: Put your thumb in the direction of current and curl your fingers around the wire, the curled fingers will show the direction of magnetic field. This rule is for direction of conventional current or flow of positive charges. For electronic current flow the same rule is applied but with left hand.



Right-hand rule - I for the magnetic field from a current carrying wire.

15.1.2. Magnetic Field due to a coil or solenoid: When wire is shaped in to the loop or coil and steady current is applied through it. By applying the right hand rule around a loop of wire carrying current, we see that the magnetic field around a loop of wire carrying current is in same direction coming in and going out of coil, forming a north and south pole like bar magnet. Since the field lines cannot cross, the field lines are packed closer together inside therefore the field is stronger inside and weaker outside the coil.

Figure 15.4 - *Magnetic Field due to a Coil or Solenoid*



The magnetic field lines for a wire loop and solenoid with steady current

To make a field having resemblance with the field of a bar magnet, a coil is shaped as spiral (helix) called solenoid as shown in figure 15.4. When current is passed through a solenoid, a reasonably uniform magnetic field can be produced. This field is strong along the axis of solenoid and weaker outside. For a tightly wound solenoid, the field in the interior space is very uniform and strong. The field lines have resemblance to those of a bar magnet, meaning that the solenoid effectively has north and south poles. To determine the direction we use right hand rule II.

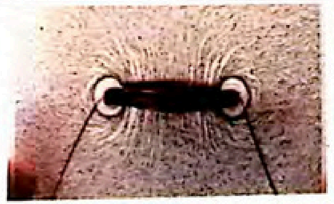
RIGHT-HAND RULE II

Right-hand rule II for a solenoid: Curl the fingers in the direction of current around the coil or solenoid and the extended thumb will point in the direction of north pole of a magnet. This rule is for direction of conventional current or flow of positive charges. For electronic current flow, the same rule is applied but with left hand.

The right-hand rule (II) for a solenoid

LAB WORK

To trace the magnetic field due to a current carrying circular coil.

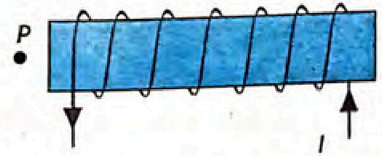


CHECK POINT

?

What is the direction of the magnetic field at point P in the figure? (P is on the axis of the coil.)

A. ? B. ?
C. ? D. ?



The compass needle deflects in opposite direction when the current is reversed as shown in the figure 15.3, the direction of such field is determined by right hand rule I.

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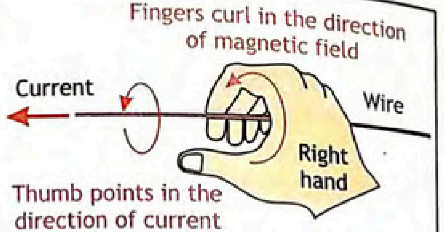

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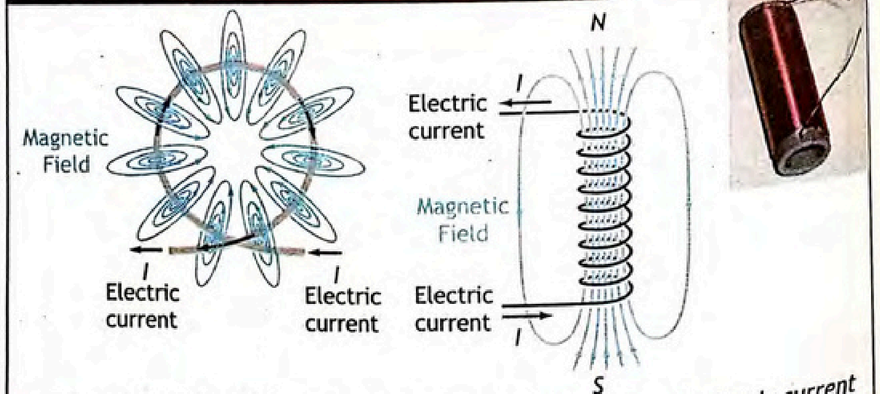
Figure 15.4 - *Magnetic Field due to a Coil or Solenoid*



The magnetic field lines for a wire loop and solenoid with steady current

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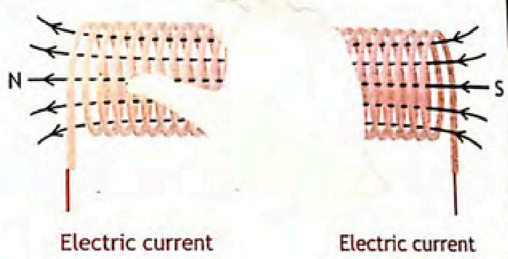
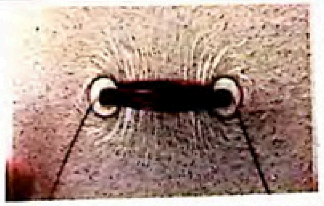
Right-hand rule II for a solenoid: Curl the fingers in the direction of current around the coil or solenoid and the extended thumb will point in the direction of north pole of a magnet. This rule is for direction of conventional current or flow of positive charges. For electronic current flow, the same rule is applied but with left hand.



The right-hand rule (II) for a solenoid

LAB WORK

To trace the magnetic field due to a current carrying circular coil.

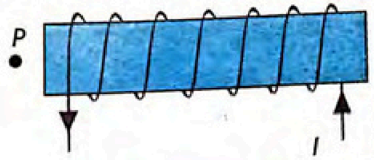


CHECK POINT

What is the direction of the magnetic field at point P in the figure? (P is on the axis of the coil.)

A. ?　　B. ?

C. ?　　D. ?



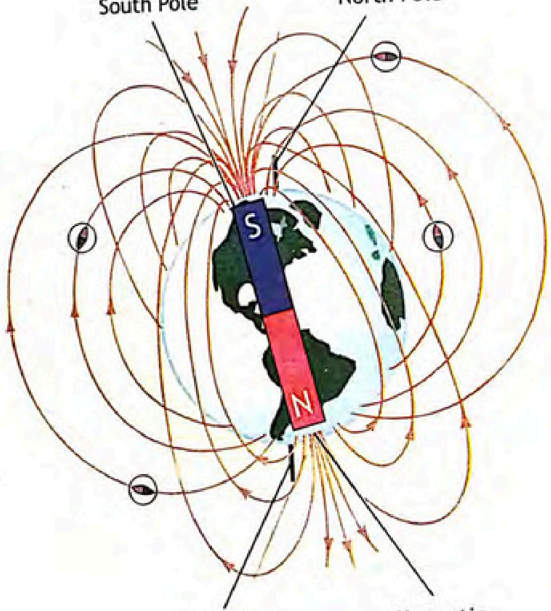
EARTH'S MAGNETIC FIELD

INFO

Origin of Earth's Magnetic Field: The magnetic field of the earth is probably caused by electric currents (electromagnetism) at its core. The Earth's core contains a liquid, which conducts electricity and the spin of the Earth about its axis causes the liquid to circulate much like the current in a conducting loop.

Jupiter rotates faster than the Earth and space probes indicate that Jupiter's magnetic field is stronger than ours. Venus, on the other hand, rotates more slowly than the Earth and its magnetic field is found to be weaker.

The north pole of a magnet is attracted toward the north geographic pole of the Earth. We conclude that the Earth's south magnetic pole is located near the north geographic pole and the Earth's north magnetic pole is located near the south geographic pole. In fact, the configuration of the Earth's magnetic field, pictured in figure, is very much like the a magnet.



POINT TO PONDER

Magnetoreception: Magnetoreception is a sense which allows an organism to detect a magnetic field to perceive direction, altitude or location. This sensory modality is used by a range of animals for orientation and navigation. Magnetoreception is present in bacteria, arthropods, molluscs and members of all major taxonomic groups of vertebrates. Humans are not thought to have magnetic sense, but there is a protein (a cryptochrome) in the eye which could serve this function.

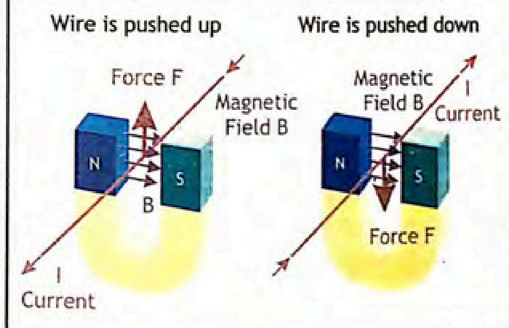
The pigeons also navigate by using Magnetoreception, evidence indicates that they sense this field at least partly by means of small magnetite crystals located in their beaks. When the area of the beak containing he crystals is anaesthetized or the nerves to it are cut, the birds lose their ability to sense the magnetic field. The pigeon shown in the opening photo has a small magnet attached to its beak; this also interferes with the bird's ability to sense the earth's magnetic fields.

15.2 FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

When current carrying wire is placed in a magnetic field, charges flowing through the wire interact with the external magnetic field and thus the wire experiences a force.

Consider a wire connected to a battery and passing through a U-shaped magnet as shown in figure 15.5. It is observed that the wire experiences a force which is perpendicular to both the direction of current I and the direction of magnetic field B. If we reverse the direction of current, the direction of force is also reversed.

Figure 15.5 - *Force on a current carrying conductor in magnetic field*



We see that this force is maximum when the current carrying wire is placed perpendicular to the magnetic field and reduces in magnitude when the angle is changed and vanishes when the current carrying wire and magnetic field are parallel, showing a sine of angle θ variation.

With this experiment we can find that this force is directly proportional to the current flowing though the wire I, the magnetic field B, length L of the wire in the magnetic field and sine of angle θ between current and magnetic field. Thus, mathematically the force is

$$F_B \propto BIL\sin\theta$$

or

$$F_B = kBIL\sin\theta$$

For SI units K = 1, therefore the equation that describes the force experienced by a current-carrying conductor in a uniform external magnetic field then becomes

$$F_B = BIL\sin\theta \qquad (15.1)$$

Where F is the magnetic force in newtons (N), B is the magnetic field strength in tesla (T), I is the current in the conductor in amperes (A), L is the length of the conductor in the magnetic field in metres (m), and θ is the angle between the conductor and the magnetic field.

15.2.1 Maximum Magnetic Force: The force will be maximum when the angle between current direction and magnetic field is $\theta = 90°$.

$F_B = BIL\sin 90^o$ Since $\sin 90^o = 1$

hence $F_B = BIL \qquad (15.2)$

also $B = \dfrac{F_B}{IL}$

15:2.2 Unit of magnetic field B: The SI unit for magnetic field strength is tesla (T). If one ampere of current in a one-metre-long wire produces a maximum force of one newton then the magnetic field is defined as one tesla (T), where

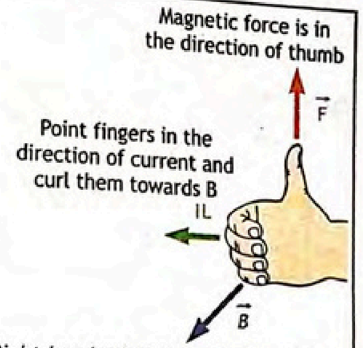
$$1T = \frac{1N}{1A \times 1m}$$

TABLE 15.1 : SOME APPROXIMATE MAGNETIC FIELDS	
At surface of neutron star	10^{8} T
Near large electromagnet	1.5 T
Near small bar magnet	10^{-2} T
At earth's surface	10^{-4} T
Interstellar space	10^{-10} T
Magnetically sheilded room	10^{-14} T

15.2.3 Direction of force: Since force is a vector quantity it must be associated with proper direction. Fleming's Left hand rule or right hand rule III is used to determine the direction of force on a current carrying wire in magnetic field.

RIGHT-HAND RULE III

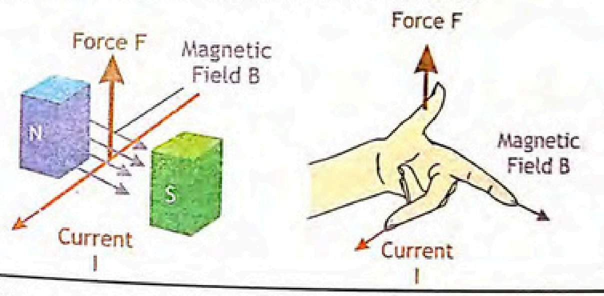
Right-hand rule for the force on a current carrying conductor: Outstretch the fingers of right hand in the direction of current then bend the fingers in the direction of magnetic field (through the shorter angle between them) then the extended thumb will give the direction of force on the current carrying wire. This rule is for direction of conventional current or flow of positive charges. For electronic current flow, the same rule is applied but with left hand.



Right-hand rule (III) for the force on a current carrying conductor

Fleming's Left hand rule

Fleming's left hand rule can also be used to represent the direction of force. The thumb and the first two fingers of the left hand are set at right angles to each other. With the first finger pointing in the direction of the field, the second finger pointing in the direction of current, the thumb will give the direction of force.

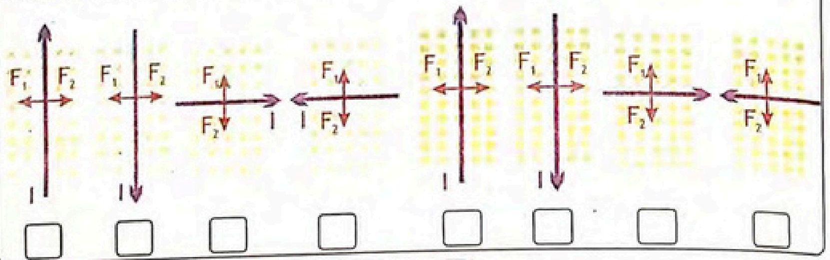


Since magnetism is inherently three-dimensional; we often need to draw vectors that are perpendicular to the page. The symbol • (or ⊙) represents a vector arrow pointing out of the page; think of the tip of an arrow coming toward you. The symbol × (or ⊗) represents a vector pointing into the page; it suggests the tail feathers of an arrow moving away from you.

- • out of the page
- × in to the page

ACTIVITY: IDENTIFY THE MAGNETIC FORCES

In each of the following different current I (blue) directions and magnetic field (green) into the page and out of the page are shown. Identify the direction of force (red) direction as either F_1 or F_2 using right hand rule III or Fleming's left hand rule and write in the box provided.



EXAMPLE 15.1: MAGNETIC LEVITATION

Can the magnetic force on a current-carrying wire be large enough to suspend the wire against gravity? Consider a wire having mass of 6.24×10^{-4} kg and length 3.5 cm placed perpendicular to a 2.4 T magnetic field. How large a current must the wire carry in order to be suspended against gravity?

GIVEN

Mass 'm' = 6.24×10^{-4} kg

Length 'L' = 3.5 cm = 0.035 m

Magnetic field 'B' = 2.4 T

Acceleration due to gravity 'g' = 9.8 m/s^2

REQUIRED

Current 'I' = ?

SOLUTION: In order to suspend a wire against gravity, the magnetic force on a wire must balance its weight W, such that

$$F_B = W \qquad \text{Here} \qquad F_B = ILB \qquad \text{and} \qquad W = mg$$

$$\text{Therefore} \qquad ILB = mg \qquad \text{or} \qquad I = \frac{mg}{LB}$$

$$\text{Putting values} \qquad I = \frac{6.24 \times 10^{-4} kg \times 9.8 ms^{-2}}{0.035 m \times 2.4 T}$$

$$\text{or} \qquad I = \frac{6.24 \times 10^{-4} \cancel{kg} \times 9.8 \cancel{m} \cancel{s^{-2}}}{0.035 \cancel{m} \times 2.4 \frac{\cancel{kg} \cancel{s^{-2}}}{A}}$$

$$\text{Hence} \qquad I = 0.073A = 73mA \text{ — Answer}$$

From Chapter 14, you know that 73 mA is a modest current for an ordinary copper wire of this size, so the suspension is easily accomplished.

EXTENSION EXERCISE 15.1

Where is this magnetic levitation is applied?

ASSIGNMENT 15.1: FORCE ON A WIRE

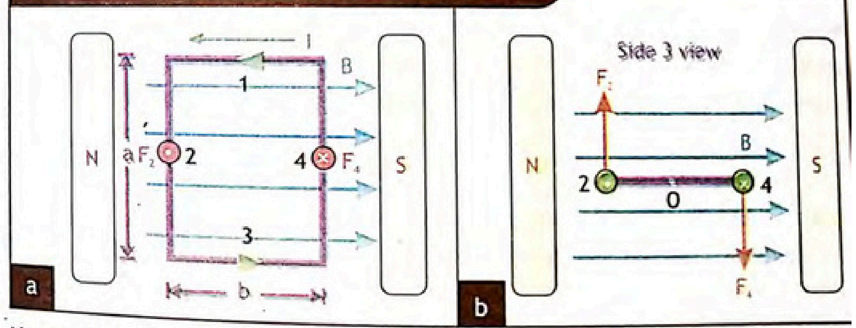
A wire carrying a steady (dc) 30 A current has a length of 0.12 m between the pole faces of a magnet. The wire is at an angle $\theta = 60°$ to the field. The magnetic field is approximately uniform at 0.90 T. Determine the magnitude of the force on the wire.

15.3 TURNING EFFECT ON A CURRENT CARRYING COIL IN A MAGNETIC FIELD

When a current carrying coil or loop is placed in uniform magnetic field it experiences a net force, this force can exert torque on the coil or loop of wire.

Consider a rectangular coil having four (1, 2, 3 and 4) sides of length a and b carrying a current I in the presence of a uniform magnetic field B directed parallel to the plane of the loop as shown in figure 15.6.

Figure 15.6 - *Torque on current carrying coil*



No magnetic forces act on sides 1 and 3 because these wires are parallel to the field $\theta = 0°$; the length of sides 1 and 3 is b, therefore magnetic force F_1 and F_3 is

$$F_1 = F_3 = BIb\sin 0° \qquad \text{since} \quad \sin 0° = 0$$

$$\text{Therefore} \qquad F_1 = F_3 = 0 \quad \text{——} (1)$$

However, maximum magnetic forces act on sides 2 and 4, because these sides are perpendicular to the field θ = 90°; the length of sides 2 and 4 is a, therefore magnetic force is

$$F_2 = F_4 = BIL\sin 90^o \quad \text{since } \sin 90^o = 1$$

$$\text{Therefore } F_2 = F_4 = BIa \quad \text{——— (2)}$$

If we view the loop from side 3 and sight along sides 2 and 4, we see the view shown in figure 15.6 (b). The two magnetic forces F_2 and F_4 point in opposite directions such that they form a couple. If the loop is pivoted so that it can rotate about point O, these two forces produce a torque that rotates the loop (in this case clockwise).

ACTIVITY: BUILD AN ELECTROMAGNET

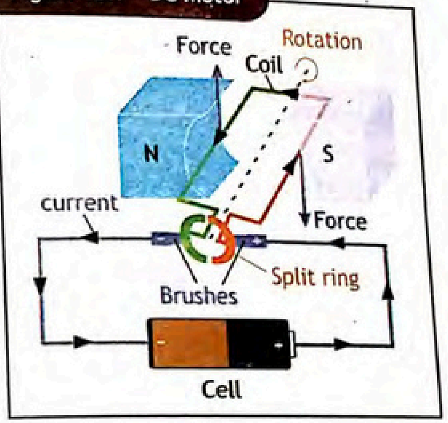
Wrap a copper wire around a nail and hold the ends of the wire with both terminals of the cell. This system will form an electromagnet and will be able to attract objects (paper pins) just like a magnet. The electromagnet that you'll construct in this experiment will become hot during use. Be prepared to drop the electromagnet if it becomes uncomfortably hot.

15.4 DC MOTOR

Electric motor is a device that converts electrical energy into mechanical energy. A DC Motor uses direct current (DC) for this purpose. It works on the principle that current carrying wire in a magnetic field experiences a torque. The electric motor is found in many devices, such as CD players, automobiles, washing machines and air conditioners.

Simplest and cheapest form of a DC motor is shown in the figure 15.7, it consists of a rectangular current carrying coil mounted on a spindle that can rotate between the poles of a permanent magnet. Practically, it is a coil of many turns wound on a soft iron cylinder (or core) which rotates with the coil to make it more powerful. The coil and core together are called the armature. Consider the motor to be initially in the position shown in fig. 15.7.(b). A clockwise torque acts on the coil causing it to turn. If the current in the coil were to continue to flow in the same direction when the green half of the coil rotates in front of the South pole, it would still experience an upward force causing the direction of the torque/couple to reverse. The coil would simply oscillate (wobble) back and forth.

Figure 15.7 - DC Motor



To make the coil continue to rotate, the ends of the coil are attached to a split ring called the commutator. The power supply is connected to the commutator using a pair of brushes which allows the ring to rotate while maintaining electrical contact. Again consider the motor starting in the position in fig. 15.7. The coil rotates clockwise. When the coil becomes vertical (green conductor on the top, red on the bottom, coil perpendicular to the magnetic field), the gaps in the commutator align with the brushes and so the current stops flowing. The inertia of the coil carries it forward and now the green half is closer to the South pole. But the rotation of the commutator now means that the green half is connected to the positive terminal of the power supply instead of the negative. This causes the direction of current in the coil to reverse and so the force on the green half points down instead of up.

The torque/couple created is still clockwise and the coil continues to rotate.

Thus the commutator allows the direction of the current in the coil to reverse every half-cycle ensuring that the torque/coil continues to rotate in the same direction as long as DC power is supplied.

ACTIVITY: BUILD A SIMPLE DC MOTOR

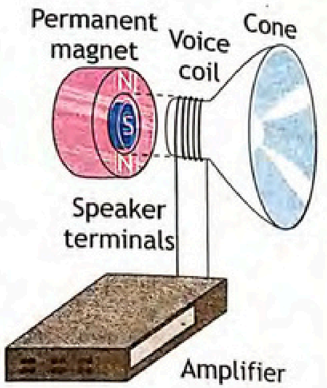
Attach the magnet on the side of the battery using a long piece of adhesive tape. Shape one end of each paper clip so as to make it longer and to make a small loop at the top. Fix these paper clips on the ends of the battery using adhesive tape. Make 10 to 15 coils of wire, scrap the insulation at the ends of the wire.

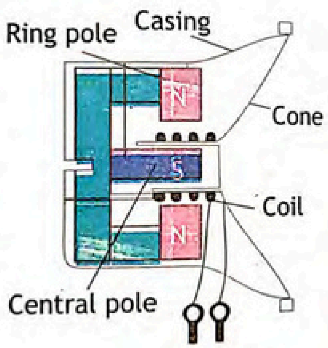
Using a permanent marker, color one side at each end in order to insulate that side. This will prevent current from flowing through the loops for half of every cycle. It has the same effect as that of a commutator. Finally, mount the coils onto the two paper clips and allow the motor to spin as shown.

MOVING-COIL LOUDSPEAKER

INFO

A common application of the magnetic forces on a current-carrying wire is found in loudspeakers. The radial magnetic field created by the permanent magnet exerts a force on the voice coil that is proportional to the current in the coil; the direction of the force is either to the left or to the right, depending on the direction of the current. The signal from the amplifier causes the current to oscillate in direction and magnitude. The coil and the speaker cone to which it is attached, responds by oscillating with an amplitude proportional to the amplitude of the current in the coil. Turning up the volume knob on the amplifier increases the current amplitude and hence the amplitudes of the cone's oscillation and of the sound wave produced by the moving cone.





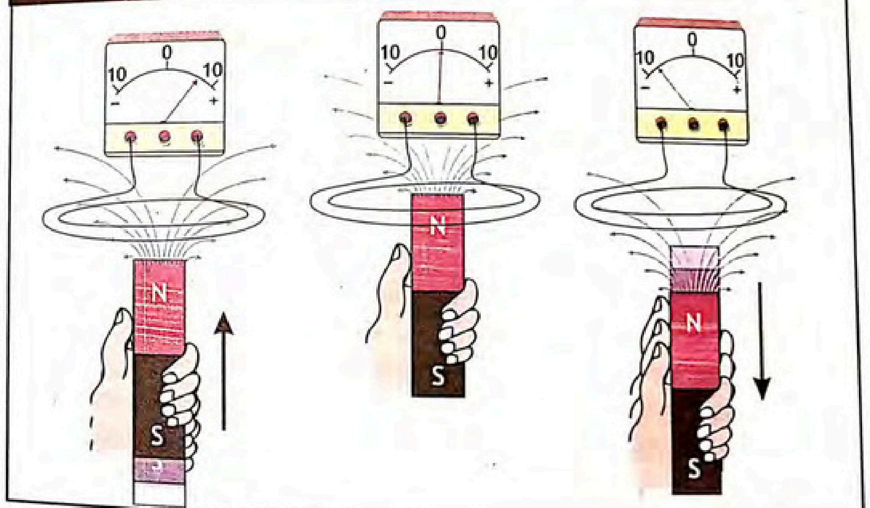
15.5 ELECTROMAGNETIC INDUCTION

When magnetic field through a wire is changed, current is found to flow in the loop, the phenomena is called Electromagnetic Induction. A changing magnetic field induces an emf. *The current in a circuit due to a changing magnetic field is called an* **induced current.** An induced current is not caused by a battery; it is a completely new way to generate a current. So there is a current in a coil of wire only if the magnetic field passing through the coil is **changing.**

Consider a coil of wire connected to a galvanometer as shown in figure 15.8. When the magnet is stationary (even inside the coil), the galvanometer shows no current. But when we move the magnet either toward or away from the coil, the galvanometer shows current in the circuit. If we keep the magnet stationary and move the coil, we again detect a current during the motion. We call this an induced current and the corresponding emf required to create this current is called an induced emf. Whenever we have a changing magnetic field, an emf is induced. If the circuit is completed, the induced emf will cause an induced current to flow. The emf is induced regardless of whether a current can flow or not.

It should be noted that when magnet and coil are moved towards each other, the galvanometer shows deflection in one direction.

Figure 15.8 - Electromagnetic induction



When the magnet and the coil are moved away from each other, the galvanometer shows deflection in the other direction. When both are fixed, no such deflection occurs.

Similar effects can be observed with two coils. When one coil is connected to a battery called primary coil (the steady current in the coil produces a steady magnetic field forming an electromagnet). While the other connected to a galvanometer is called as secondary coil.

When the primary coil is moved towards the secondary coil, the galvanometer shows a deflection. This indicates that electric current is induced in secondary coil. When the primary coil is moved away, the galvanometer shows a deflection again, but this time in the opposite direction. The deflection lasts as long as primary coil is in motion.

When the primary coil is held fixed and the secondary coil is moved, the same effects are observed. Again, it is the relative motion between the coils that induces the electric current.

If both coils are held fixed but the current in the primary coil is changed the magnetic field it produces changes and an emf is induced in the secondary coil. This is the basis of the working principle of a transformer.

15.5.1 Factors affecting magnitude of induced emf:

- When a double loop of wire is used, the deflection on the galvanometer is twice as large as before. A tripple loop induces three times the e.m.f. and so on. This shows that "the e.m.f. is proportional to the number of turns in a coil."
- The faster the wire is moved, the larger the deflection on the galvanometer. This indicates that the speed at which the conductor moves through the magnetic field also determines the magnitude of induced e.m.f.
- The longer the length of the conductor in the magnetic field, the greater is the induced e.m.f.
- The larger the magnetic field, the greater the e.m.f induced.

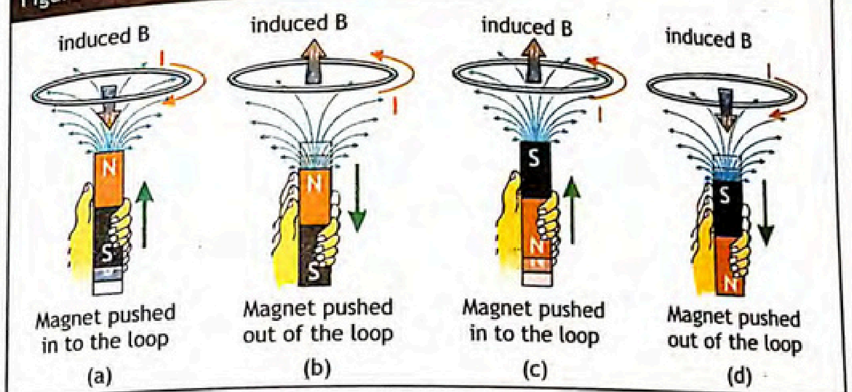
15.5.2 Direction of induced emf and conservation of energy:

Whenever there is a change of magnetic flux, there will be induced emf and current will flow in such a direction so as to oppose the cause producing it.

The induced current around a loop produces its own magnetic field. This field may be weak compared with the external magnetic field. It cannot prevent the magnetic flux through the loop from changing, but its direction is always such that it " tries " to prevent the flux from changing.

Consider pushing the bar magnet's North pole into the loop, it causes the magnetic field to increase in the upward direction. To oppose the change, the loop itself needs to generate the downward-pointing magnetic field (acting as a magnet with its North Pole at the bottom which repels the North pole of the bar magnet moving towards it) as shown in figure 15.9(a).

Figure 15.9 - Direction of induced current



The induced magnetic field at the center of the loop will point downward (using right hand rule II) only if the current is clockwise (cw) as seen from above. Now suppose the north pole of bar magnet is pulled away from the loop, as shown in figure 15.9(b). There is a upward magnetic field through the loop, but the magnetic field is decreasing as the magnet is moving away. Thus, the induced magnetic field of the loop opposes this decrease, therefore, the induced field needs to point in the upward direction, the induced current is counter clockwise (ccw) as seen from above.

Similar effects can also be observed with the south pole of a magnet pushed in and out of the loop figure 15.9(c,d). It is seen that the induced current sets up a magnetic field of its own. From the above discussion, it is clear that the motion of magnet is always opposed by the magnetic field generated from induced current. The mechanical energy spent in overcoming this opposition is converted into electrical energy.

If the induced current were in the opposite direction, the magnetic force would have accelerated it with no external energy source, even though electric energy would have been dissipated in the circuit. This would have been a clear violation of the law of conservation of energy, which doesn't happen in nature.

15.6 AC GENERATOR

Electricity generator is a device that converts mechanical energy into electrical energy. The principle of electromagnetic induction can be used to generate electricity for practical purposes.

In essence, electric generator is an electric motor operated in reverse. If the armature of DC motor is rotated we would get the DC output at the brushes which can be used. However, to produce AC (the current which changes polarity and reverses the flow of charge) some modifications needs to be made to the system.

The basic elements of an AC generator are shown in Figure 15.10. It consists of a coil mounted on a rotor shaft and placed between poles of a permanent magnet. The coil is mechanically rotated by some external means. The rotation of the coil causes the magnetic field to change through it, so an emf is induced in the coil. The ends of the coil are connected to an external circuit by means of circular rings called slip rings and brushes (usually graphite). As the coil rotates, the magnitude and direction of the induced emf changes. Therefore, this current is called alternating current and the generator is called alternating current generator.

Figure 15.10 - *AC Generator*

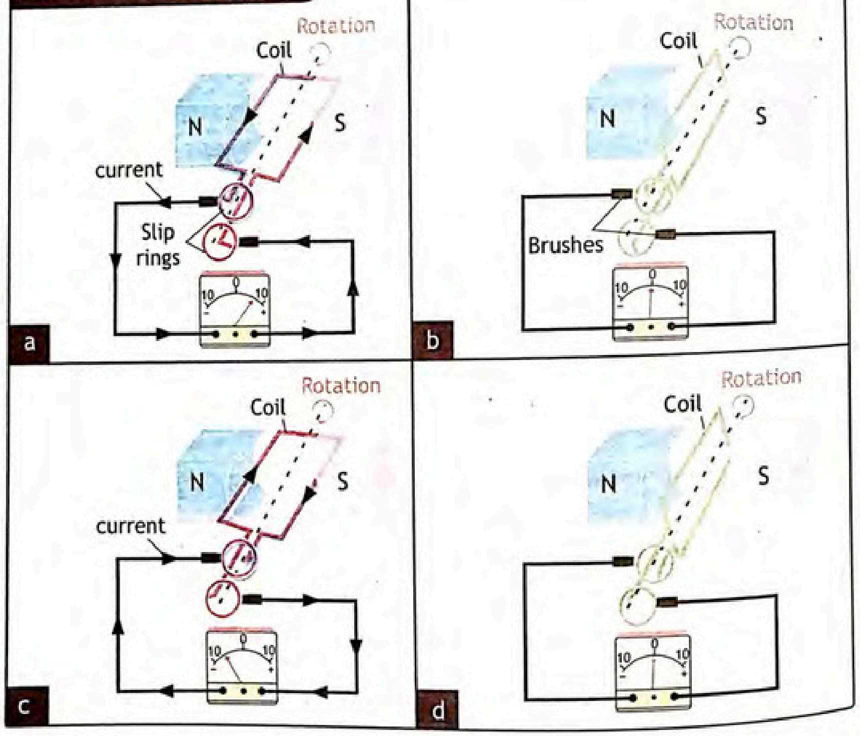


Figure 15.11 shows a coil rotated in a magnetic field of permanent magnet to light a bulb. A bicycle dynamo is also depicted. The AC generator and DC generator are the same, only the slip ring is replaced with commutator (split ring) for DC generator. The DC Generator produces current whose magnitude changes continuously but whose direction remains the same.

Figure 15.11 - *Generators*

(a) Coil rotation in magnetic field (b) Bicycle dynamo

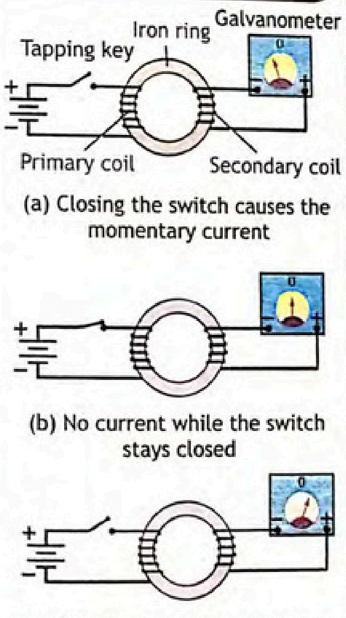
15.7 MUTUAL INDUCTION

The phenomena in which the emf induced in one circuit or coil due to the change in current in another circuit or coil is called mutual induction.

We have seen that an emf can be induced in a coil by keeping the coil stationary and moving a magnet nearby or by moving the coil near a stationary magnet. With another experiment, we can show that this relative motion is not an absolute requirement.

Consider two fixed coils placed side by side as shown in the figure 15.12, the coil that is connected to a battery is called primary coil, while the coil that has no source of emf is called secondary coil. Both are wound on an iron ring core well insulated from coils. The iron core is used only to increase the magnetic field produced.

Figure 15.12 - *Mutual Induction*



(a) Closing the switch causes the momentary current

(b) No current while the switch stays closed

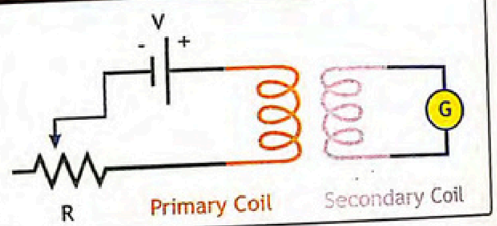
(c) Opening the switch causes a current in the opposite direction

The primary coil is connected to a battery through a tapping key, while the secondary coil is connected to galvanometer. It is observed that the galvanometer shows a momentary deflection when the tapping key is pressed. The pointer in the galvanometer returns to zero immediately. If the key is held pressed continuously, there is no deflection in the galvanometer. When the key is released, a momentary deflection is observed again but in the opposite direction.

From this experiment, we can conclude that it is not the relative motion but the change in magnetic field that is responsible for electromagnetic induction. When the tapping key was pressed the magnetic field developed by primary coil was changed due to change in current per unit time which induced an emf in secondary coil.

Such that for a constantly changing current such as AC the time rate of change of current in the primary $\Delta I_P/\Delta t$ is proportional to the emf induced in the secondary ε_S. Mathematically,

Figure 15.13 - *Mutual Induction*



$$\varepsilon_S \propto -\frac{\Delta I_P}{\Delta t} \qquad (1)$$

Where negative sign tells us that the induced current is always in opposite direction to the original current flow.

To change the sign of proportionality into equality, equation 1 can be written as

$$\varepsilon_S = -\text{Constant} \times \frac{\Delta I_P}{\Delta t} \quad \text{or} \quad \varepsilon_S = -M \times \frac{\Delta I_P}{\Delta t} \qquad (2)$$

Where M is the constant of proportionality and is called as coefficient of Mutual induction. The Coefficient of mutual induction from equation 2 can therefore be written as

$$M = \frac{\varepsilon_S}{\Delta I_P / \Delta t} \qquad \boxed{15.3}$$

The units of mutual induction is Henry (H). Mutual inductance of two coils will be one henry (H), if the current is changing at the rate of one ampere per second in the primary and causes an induced emf of one volt in the secondary.

$$1H = \frac{1V \times 1s}{1A} = \frac{Vs}{A}$$

EXAMPLE 15.2: INDUCED EMF

If the mutual inductance of two coils is 3.5 mH and the current through primary coil changes from 0 A to 10 A in 0.03 s, how much emf is induced in the secondary coil.

GIVEN

Mutual inductance 'M' = 3.5 mH = 3.5×10^{-3} H

Initial current 'I_i' = 0 A

Final current 'I_f' = 10 A

Time taken for change 'Δt' = 0.03 s

REQUIRED

Induced emf in secondary 'ε_s' = ?

SOLUTION: The emf induced in the secondary coil is given by the equation

$$\varepsilon_S = -M \times \frac{\Delta I_P}{\Delta t} \quad \text{or} \quad \varepsilon_S = -M \times \frac{I_f - I_i}{\Delta t}$$

Putting values $\varepsilon_S = -3.5 \times 10^{-3} H \times \frac{10A - 0A}{0.03s}$

or $\varepsilon_S = -3.5 \times 10^{-3} \frac{V\cancel{s}}{\cancel{A}} \times \frac{10\cancel{A}}{0.03\cancel{s}}$

Hence $\varepsilon_S = -1.17\,V$ — **Answer**

Thus the emf induced in the secondary coil is 1.17 V.

ASSIGNMENT 15.2: MUTUAL INDUCTANCE

If the current through the primary coil changes from 0 A to - 10 A in 0.02 s, such that the induced emf is 4.3 V. What is the mutual inductance?

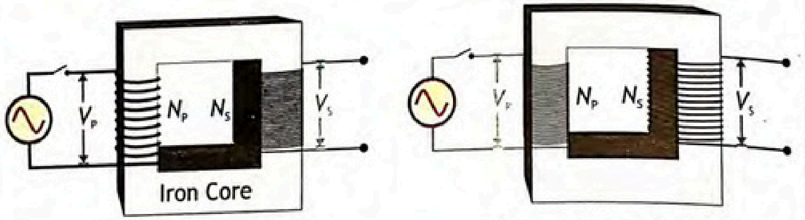
15.8 TRANSFORMER

A transformer is a device which is used to increase or decrease an AC voltage or current level. The principle of transformer is mutual induction. Changing current (alternating current) in one coil induces emf in another coil.

The key components of the transformer are two coils or windings, electrically insulated from each other but wound on the same core. The core is typically made of a material which supports magnetism, such as iron. This makes almost all of these field lines pass through to the other winding, maximizing the mutual inductance of the two windings.

The winding to which power is supplied is called the primary; the winding from which power is drawn is called the secondary.

Figure 15.14 - Step-up and step-down transformers



(a) Step-up transformer (b) Step-down transformer

Figure 15.14 shows a drawing of a transformer. The transformer consists of an iron core on which two coils are wounded: a primary coil with N_p turns and a secondary coil with N_s turns. If the voltage in the secondary is V_S and voltage in primary is V_P then

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \qquad (15.4)$$

According to the equation 15.4, if N_S is greater than N_P ($N_S > N_P$), the secondary (output) voltage is greater than the primary (input) voltage ($V_S > V_P$). In this case we have a **step-up** transformer. On the other hand, if N_S is less than N_P ($N_S < N_P$), the secondary voltage is less than the primary voltage ($V_S < V_P$), and we have a **step-down** transformer. The ratio N_S / N_P is referred to as the **turns ratio** of the transformer.

EXAMPLE 15.3: X-RAY UNIT

A portable x-ray unit has a step-up transformer, the 220 V input of which is transformed to the 100 kV output needed by the x-ray tube. The primary has 50 loops, what is the number of loops in the secondary?

GIVEN

Primary voltage 'V_p' = 220 V

Secondary voltage 'V_s' = 100 kV = 10^5 V

Number of turns in the primary 'N_p' = 50

REQUIRED

Number of turns in the secondary 'N_s' = ?

SOLUTION: By transformer equation $\frac{V_S}{V_P} = \frac{N_S}{N_P}$ or $N_S = \frac{V_S}{V_P} \times N_P$

Putting values $N_S = \frac{10^5\,V}{220\,V} \times 50\,turns$

Hence $N_S = 2.27 \times 10^4\,turns$ —— Answer

Therefore, a large number of loops in the secondary (compared with the primary) is required to produce such a large voltage.

EXTENSION EXERCISE 15.2

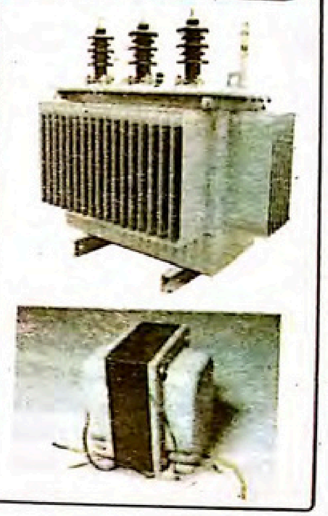
What is the turns ratio of transformer in X-ray tube?

ASSIGNMENT 15.3 : STEP UP TRANSFORMER

A step-up transformer has a primary coil consisting of 200 turns and a secondary coil consisting of 3000 turns. The primary coil is supplied with an effective AC voltage of 90.0 V. What is the voltage in the secondary circuit?

15.8.1 Purpose of Transformers: Transformers allow electricity to be efficiently transmitted over long distances. Whenever electricity is transmitted, there is always some loss of power in the transmission lines themselves due to resistive heating. To reduce the loss, power companies use transformers that step up the voltage to high levels while reducing the current. A smaller current means less power loss, since $P = I^2R$, where R is the resistance of the transmission wires. figure 15.16 shows one possible way of transmitting power.

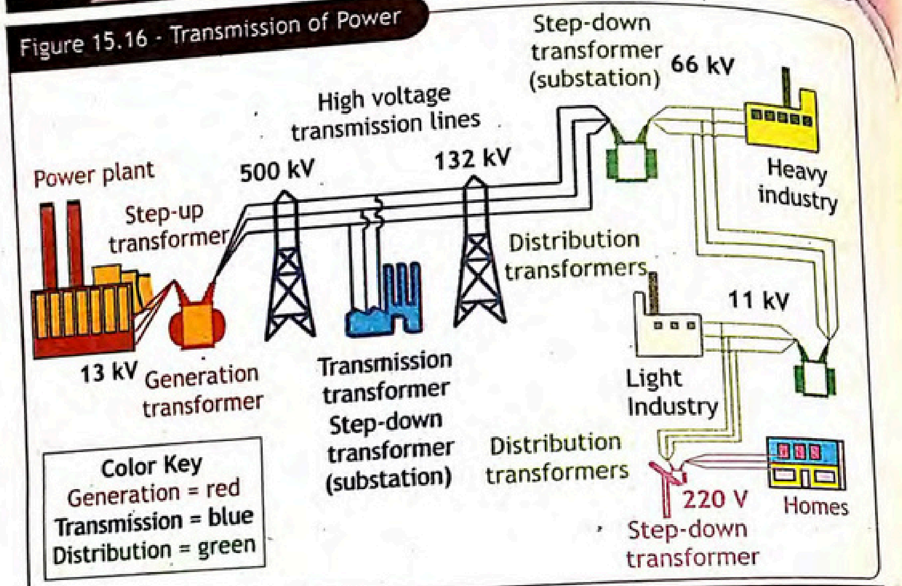
Figure 15.15 - Transformers



The power plant produces a voltage of 13,000 V. This voltage is then raised to 500,000 V by a 40: 1 step-up transformer. The high-voltage power is sent over the long-distance transmission line.

Upon arrival at the city, the voltage is reduced to about 11000 V at a substation using a step-down transformer. However, before any domestic use, the voltage is further reduced to 240 V by another step-down transformer that is often mounted on a utility pole.

Figure 15.16 - Transmission of Power



KEY POINTS

Magnetic effect of current: Electric current through a conductor produces magnetic field around it. In case of straight wire, it is in the form of concentric circles.

Force on a current carrying conductor in a magnetic field: When a current carrying conductor is placed in a magnetic field, the interaction between the moving charges in the current and the external magnetic field causes it to experience a force.

Torque on a current carrying coil in a magnetic field: When a current carrying coil is placed in a magnetic field, it experiences a couple due to which it begins to rotate.

DC Motor: Converts electrical energy into mechanical energy by principle of torque on a current carrying coil in a magnetic field.

Electromagnetic induction: *When a magnetic field through a loop of wire is changed, current is found to flow in the loop.* The direction of this induced e.m.f opposes the change causing it.

AC Generator: Simple form of AC generator consists of a coil which is made to rotate in external magnetic field and by principle of electro magnetic induction alternating voltage is induced.

Mutual induction: Emf induced in one circuit due to changing current in another circuit which is magnetically attached/coupled with it.

Transformer: A device which converts low voltage to high voltage vice versa.

PROJECTS

GROUP A 'ELECTROMAGNET': Build an electromagnet as an activity in this chapter. See how much the strength of electromagnet change by changing the current flow by using different batteries or increasing the number of turns in the coil or having other core materials (such as pencil, steel nail etc.) instead of iron nail. Summerize your findings in an article for school magazine.

GROUP B 'MAGNETIC EFFECT OF CURRENT': Research the application of the magnetic effect of an electric current in relay, door latch, loudspeaker, and circuit breaker from the internet and school library, and present your findings in classroom.

GROUP C 'MAGNETISM AND TECHNOLOGY': Identify different technologies related to magnetism such as electric motors and generators, medical equipment, loudspeakers, magnetic information storage devices. Write its historical over view relating when, how and where these devices were first formed. Write an essay for school magazine.

GROUP D 'ELECTRIC MOTOR AND GENERATOR': Read literature and search how different motors and generators can be easily made. Build a simple DC Motor or AC Generator for your school laboratory.

GROUP E 'TRANSFORMERS': Make a list of the use of transformers (step-up and step-down) for various purposes in your home. Make a chart and display it in your classroom.

EXERCISE

MULTIPLE CHOICE

1. A current carrying wire in which current flow in northward direction is deflected towards the east by a magnetic force. The direction of the magnetic field is
   A. straight up B. straight down C. south D. west.
2. Which derived unit is equivalent to tesla T?
   A. Nm/A B. NA/m C. N/Am D. Am/N
3. The unit of inductance, the henry, is equivalent to:
   A. Vs/A B. VA/m C. As/V D. V/A
4. When the speed at which a magnet is moved through a coil is increased, the induced voltage
   A. increases B. remain the same C. decreases D. goes to 0
5. Slip rings are part of
   A. DC motor B. AC generator C. transformer D. magnet

QUESTIONS

6. A transformer is used for
   A. both DC and AC B. AC voltages C. DC voltages D. farming
7. A step-up transformer increases
   A. power B. energy C. voltage D. current
8. A certain transformer has a primary winding with 500 turns and a secondary winding with 250 turns. The turns ratio is
   A. 0.5 B. 2 C. 250 D. 750
9. If the turns ratio is 5, the secondary voltage is greater than the primary voltage by a factor of
   A. 0.2 B. 0.5 C. 2.5 D. 5

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. Differentiate between electric and magnetic fields.
2. Can an electron at rest be set into motion with a magnetic field?
3. Which is more likely to show deflection in compass needle, AC current or DC current? Explain.
4. A constant magnetic field is applied to a current carrying conductor. What angle should the wire make with the field for the force to be (a) maximum, (b) minimum?
5. Why does a compass needle points North?
6. How can a magnetic field be used to generate electric current?
7. What would happen if we use a slip ring to drive a DC motor?
8. The primary coil of a transformer is connected to a DC battery. Is there an emf induced in the secondary coil? Why?

COMPREHENSIVE QUESTIONS

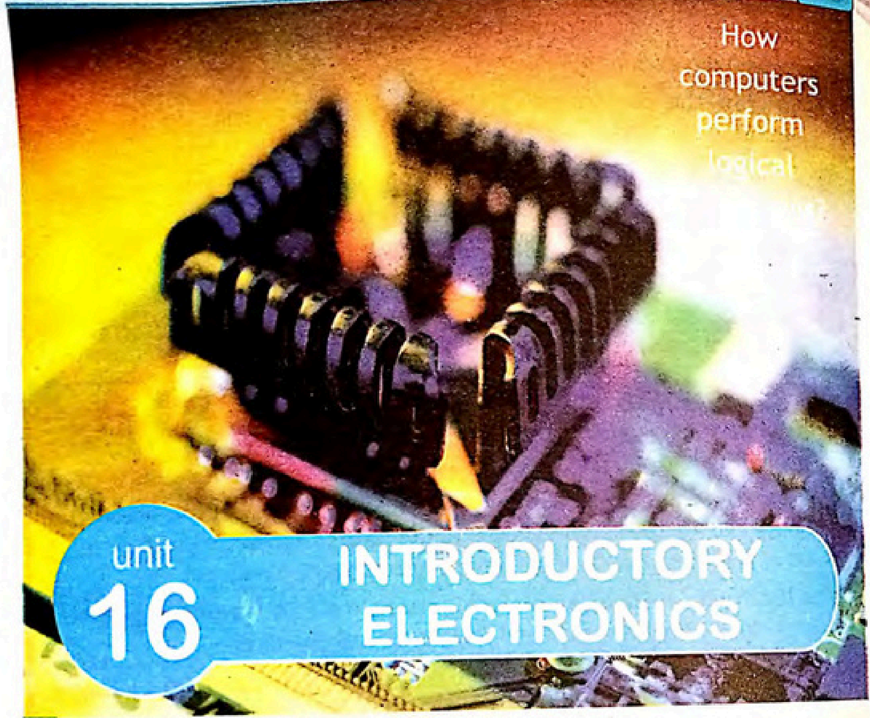
Give an extended response to the following questions

1. Describe an experiment to show that the steady current carrying wire produces a magnetic field around it. What is the direction of this magnetic field?
2. How the magnetic field of wire increases and resembles more like that from a permanent magnet, if the wire is formed in a circular coil? [Hint: Consider the magnetic field of a single coil and then a series of coils.]
3. Explain the force on a current carrying wire in a magnetic field.

4. Explain the torque on current carrying coil in a magnetic field.
5. Explain the working of DC motor.
6. Describe the phenomena of electromagnetic induction. List the factors effecting electromagnetic induction.
7. Explain the direction of induced emf and show its relation to conservation of energy.
8. Sketch and describe the construction and working of AC generator.
9. Describe the phenomena of mutual induction.
10. What are transformers? On what principle it works? Also describe the purpose of transformers in AC circuits.

NUMERICAL QUESTIONS

1. A 1.5 m long wire carries a current of 5 A, at right angle to a uniform magnetic field of 0.04 T. Determine the force exerted on the wire.
2. A wire carrying a direct current of 10.0 A is suspended 5.0 m east between a house and a garage perpendicular to the Earth's magnetic field of 5.0×10^{5} T. What is the magnitude of the force that acts on the conductor?
3. A 10 cm wire at 30° to uniform magnetic field of 0.06 T is exerted by a force of 0.024 N. What is the current flowing through the wire?
4. If the current through the primary coil changes from -5 A to +5 A in 0.05 s, such that the induced emf is 2.8 V. What is the mutual inductance?
5. A transformer connected to a 120-V AC line is to supply 9600 V for a neon sign. (a) What is the ratio of secondary to primary turns of the transformer? (b) If the transformer consisted of 275 primary windings, how many secondary windings would there be?
6. How many turns would you want in the secondary coil of a transformer having 400 turns in the primary, if it were to reduce the voltage from 220 V AC to 3.0 V AC?
7. A transformer steps down a main supply of 220 V AC to operate a 12 V AC lamp. Calculate the turns ratio of the windings.



unit 16 INTRODUCTORY ELECTRONICS

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ explain the process of thermionic emission emitted from a filament.
- ✓ describe the simple construction and use of an electron gun as a source of electron beam.
- ✓ describe the effect of an electric field on an electron beam.
- ✓ describe the effect of a magnetic field on an electron beam.
- ✓ describe the basic principle of CRO and make a list of its uses.
- ✓ differentiate between analogue and digital electronics.
- ✓ state the basic operations of digital electronics.
- ✓ identify and draw the symbols for the logic gates (NOT, OR, AND, NOR and NAND).
- ✓ state the action of the logic gates in truth

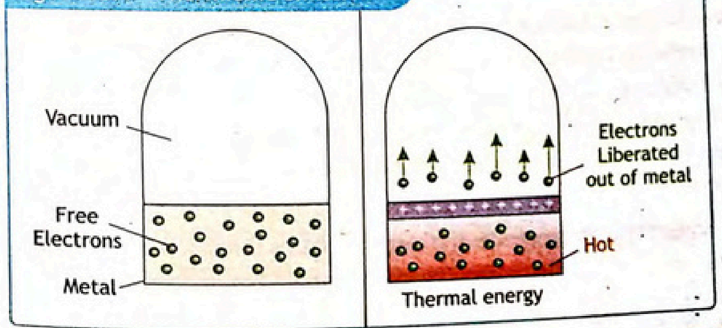
CONTENTS

We have used electronic equipment of one type or the other. Most of our homes have radio and television as standard domestic equipment. Mobile phones, personal computers and CD players provide further proof that electronics are vital to a developing economy like ours. This chapter will provide an introduction to electronics.

16.1 THERMIONIC EMISSION

Metals conducts electricity, this indicates that they contain some 'free' electrons that are not bound to a particular atom and free to move randomly through the metal as a whole. Most electrons in metals, particularly the 'core' electrons closest to the nucleus, are tightly bound to individual atoms; it is only the outermost 'valence' electrons that are somewhat 'free' and are termed as 'free electrons'. These free electrons are still bound to the material by a characteristic binding energy called the 'work function' and it represents the minimum energy that must be imparted to an electron in order to escape from the metal.

Figure 16.1 - Thermionic emission

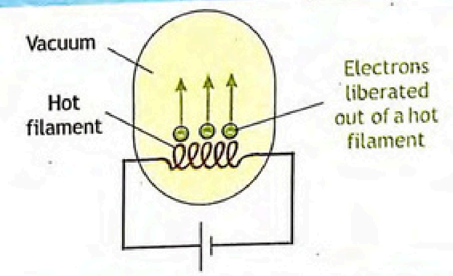


If sufficient energy is given to the metal, the electrons taking this energy will be able to overcome the work function, causing electrons to be emitted from the metal.

If we increase the temperature of the metal, electrons start to move faster and some may have enough energy to escape from the metal as shown in figure 16.1. The higher the temperature, the higher will be the number of escaping electrons. **The temperature induced electron ejection is called thermionic emission.**

Thermionic emission can also be achieved by passing electric current through tungsten filament as shown in figure 16.2. The electric current heats up the filament and electrons are emitted.

Figure 16.2 - Thermionic Emission from a filament



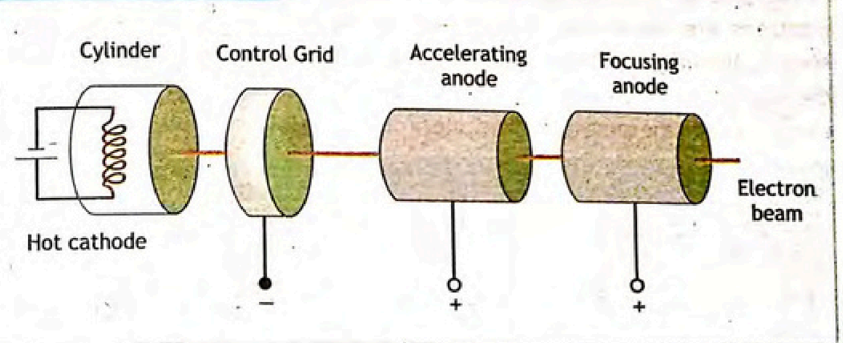
16.2 ELECTRON GUN

Electron gun is a source of focussed and accelerated electron beam. Electron gun is a versatile electrical component. It is an essential part for a number of devices, like Televisions, 3D printers, Scanning Electron Microscopes (SEM) and large synchrotrons.

Electron gun consists of a glass tube at very low pressure, with negatively charged electrode as cathode and positively charged electrode as anode as shown in figure 16.3. The electrons are emitted through the **indirectly heated cathode.** Indirectly heated cathode means the cathode surrounds the filament and emit electrons when the filament is heated up by the power applied. For getting the high emission of electrons at the moderate temperature, the layer of barium and strontium oxide is applied at the end of the cathode. The current and voltage required by the indirectly heated cathode are approximately equal to the 600 mA and 6.3V.

After exiting from the cathode, the electron passes through the control grid. The control grid is mostly made up of nickel material. The grid has negative biasing which controls the flow of electrons.

Figure 16.3 - Electron gun



By increasing the negative bias, one can decrease the number of electrons passing through and vice versa, thereby controlling the intensity (number of electrons) of the electron beam.

The electron which passes from the control grid is accelerated by the high positive potential which is applied across the accelerating anode. The electron beam is focused by the focusing anode.

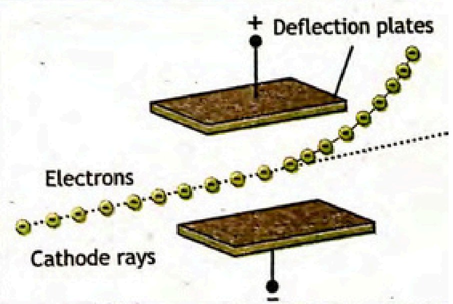
The beam after passing through the focusing anode passes through the deflection system and goes to the fluorescent screen.

16.3 CATHODE RAYS

Electron beam produced by electron gun is also called cathode rays as these rays are emitted from a negative electrode, also termed as cathode. Cathode rays can be effected by presence of an electric and magnetic field.

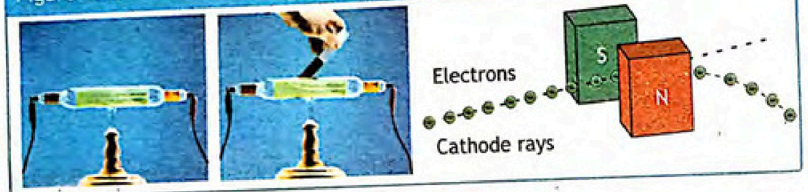
(a) Deflection by electric field: As cathode rays are composed of negatively charged electrons, therefore, the cathode ray beam is attracted by positive electrode and repelled by negative electrode as sown in figure 16.4. Thus, we can say that cathode rays are affected by presence of an electric field.

Figure 16.4 - Electric field deflection



(b) Deflection by Magnetic field: Since 'cathode rays' is stream of electrons. Electrons are negatively charged, and a magnetic field exerts forces on electrically charged particles that are in motion in any direction other than that of the magnetic field. To determine the direction of force and thus the deflection of electron beam, the same right hand rule III or fleming left hand rule can be used.

Figure 16.5 - Deflection of electron beam in magnetic field



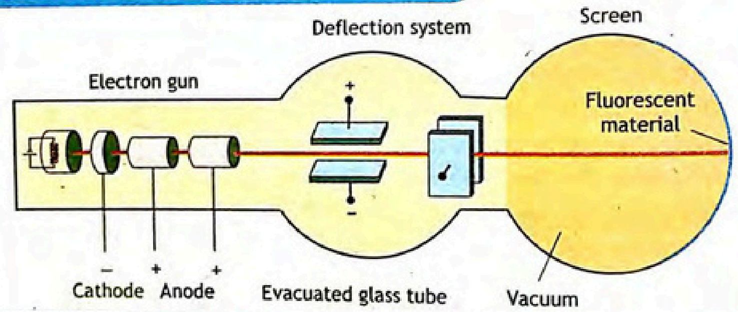
16.4 CATHODE RAY OSCILLOSCOPE (C.R.O.)

The Cathode Ray Tube (CRT) is used in computer monitors, TV sets and oscilloscope tubes. The main part of the C.R.O. is a highly evacuated glass tube, consisting of parts which generates a beam of electrons, accelerates them, shapes them into a narrow beam, and provides external connections to the sets of plates for changing the direction of the beam.

The CRO operates by firing an electron beam at a fluorescent material, which give off light as shown in figure 16.6. It consists of the following parts:

(a) Electron gun: The electron beam is generated at the cathode in the electron gun. As described earlier in electron gun, potential (voltage) is applied, which strips off and accelerates the electrons by accelerating anode.

Figure 16.6 - *Cathode Ray Oscilloscope (C.R.O.)*



The electrons then travel to the electron beam focusing anode. An electrostatic mechanism is used to focus the beam.

(b) Deflection system: After the beam exits from the electron gun, it travels to the electron beam deflector. The deflector has two mechanisms, one to change the vertical direction and one to change the horizontal direction of the beam. This allows the electron beam to sweep over the entire screen.

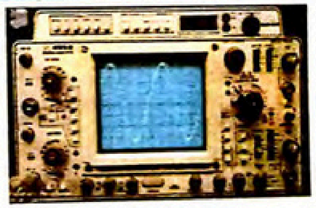
(c) Screen: When an electron in the beam strikes a phosphor (such as Zinc Sulphide ZnS), it excites an electron in the phosphor. After being excited, the electron then releases the energy it got in form of a visible light, which is always the same for that phosphor. Phosphors emitting red, blue, and green light form a color image. The Cathode Ray Oscilloscope (CRO) is an electronic test instrument, used to observe the waveform of repetitive electric signal. This signal can be amplified or attenuated as required. Which enable its user to get the useful information about the electrical component attached to its in-put terminal.

Uses of Cathode Ray Oscilloscope:

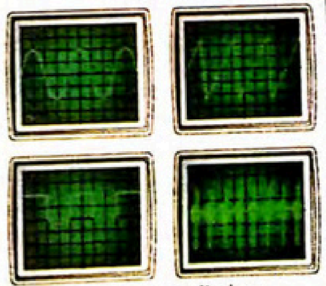
In a laboratory, a Cathode Ray Oscilloscope (CRO) can be used to

- display different types of wave form.
- measure short time interval.
- measure potential difference (as a voltmeter).

Figure 16.7 - Basic CRO



Front Panel



Few waveform displays

One of the most frequent use of oscilloscope is troubleshooting a malfunctioned electronic equipment because it has the advantage that it can graphically show signals. Using a voltmeter to study a circuit may show a totally unexpected intermediate voltage, an oscilloscope on the other hand can show the changes in the circuit voltage at various instants (showing that the circuit is oscillating). In such cases, the precise shape or timing of a pulse is important to troubleshoot the equipment.

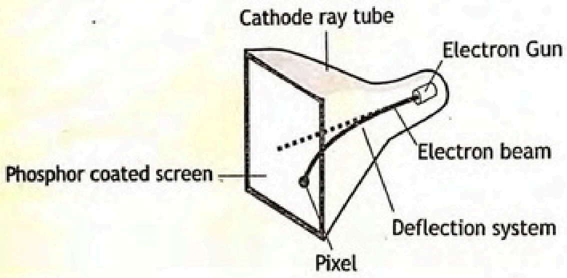
Another use of oscilloscope is to check newly designed circuitry. Very often a newly designed circuit will misbehave because of design errors, bad voltage levels, electrical noise etc.

INFO

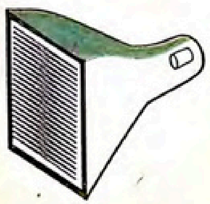
THE PHYSICS OF TELEVISION SCREENS

Some television sets and some computer display monitors have a cathode ray tube inside it. An electron gun sends a narrow beam of high-speed electrons toward the screen of the tube. The inner surface of the screen is covered with a phosphor coating, and when the electrons strike it, they generate a spot of visible light. This spot is called a pixel (a 'picture element').

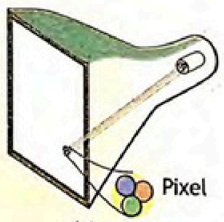
To create a black-and-white picture, the electron beam is scanned on the whole screen in sawtooth shape as shown in figure (b). As the beam scans the screen, brighter and darker spots are created by controlling electrons emitting from electron gun. A color TV operates with three electron guns i.e. red, green and blue colors as indicated in Figure b. Red, green and blue are primary colors, so virtually all other colors can be created by varying the intensities of the three beams focused on a cluster.



(a)



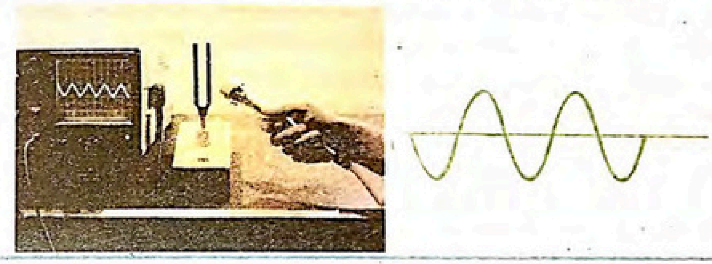
(b)



(c)

TIDBITS

'Seeing' Sound Waves: Cathode Ray Oscilloscope is used to display the form of electronic signals on a small monitor similar to a television screen. Sounds can be "seen" by using a microphone to convert them into electronic signals, an amplifier to amplify these signals, and an oscilloscope to display their form (see Figure 8.5). With an oscilloscope, you can visualize the difference between the sounds made by a variety of musical instruments. In figure below, an oscilloscope connected to a microphone can be used to display the wave form of a pure tone, created here by a tuning fork. The trace on the screen shows that the wave form is sinusoidal.



16.5 INTRODUCTION TO ELECTRONICS

The branch of physics and technology concerned with the design of circuits using transistors and microchips, and deals with the behaviour and movement of electrons in a semiconductor, conductor, vacuum, or gas is called electronics.

Electronics is widely used in information processing, telecommunication and signal processing. The ability of electronic devices to act as switches makes digital information processing possible.

Mathematical methods are integral part for the study of electronics. To become proficient in electronics, it is also necessary to become competent in the mathematics of circuit analysis. Due to the complex nature of electronics theory, laboratory experimentation is an important part of the development of electronic devices. These experiments are used to test or verify the engineer's design and detect errors. Historically, electronics labs have consisted of electronic devices and equipment located in a physical space.

16.6 ANALOGUE AND DIGITAL ELECTRONICS

Analogue quantity is the one having continuous values. Therefore analogue signal is a continuously variable electrical or physical quantity. Most of the quantities that we deal in physical world are analogue quantities. There is an infinite amount of colors to paint an object (even if the difference is indiscernible to our eye), there is an infinite number of tones we can hear, and there is an infinite number of smells we can smell. The common theme among all of these analog signals is their infinite possibilities.

Digital systems on the other hand, operate on discrete digits that represent numbers, letters, or symbols. They deal strictly with ON and OFF states, which we can represent by 0 s and 1 s. A watch and voltmeter with both analogue measurement and digital measurements are shown in figure 16.8. The analogue measurement represents infinite possibilities whereas the digital watch is restricted only in its least count.

So why do we need to use digital representations in a world that is naturally analog? The answer is that if we want an electronic machine to interpret, communicate, process and store analog information, it is much easier for the machine to handle it if we first convert the information to a digital format. The conversion from one analogue to digital is achieved through circuit known as Analogue to Digital Convertor (ADC) and converted back to analogue signals by Digital to Analogue Converter (DAC).

Figure 16.8 - *Analog Vs digital*

Analog and digital watch | *Analog and digital Multi-meter*

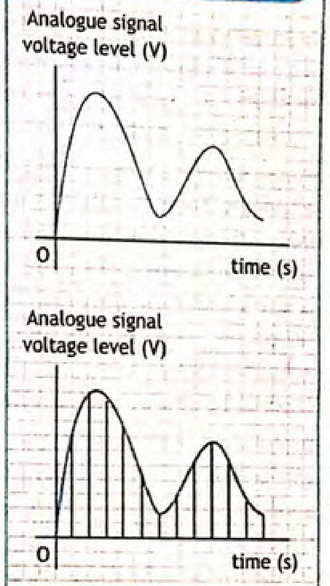
A digital value is represented by a combination of ON and OFF voltage levels that are written as a string of 1 s and 0 s.

Instead of dealing with the infinite span and intervals of analog voltage levels, all we need to use is ON or OFF voltages (usually +5 V = ON and 0 V = OFF).

A good example of the use of a digital representation of an analog quantity is the audio recording of music, Compact Disks (CDs) and Digital Versatile Disks (DVDs). Musical instruments and the human voice produce analog signals and the human ear naturally responds to these analog signals.

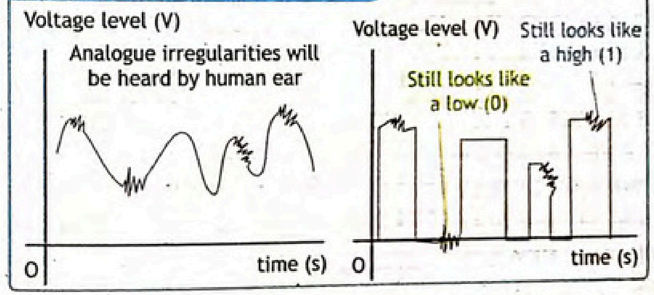
To accurately represent a complex musical signal as a digital string (a series of 1s and 0s), rather than gathering all the music on continuous basis, several samples of an analog signal must be taken, as shown in figure 16.9. It looks like an extra work but digital recordings have virtually eliminated problems such as electrostatic noise and the magnetic tape hiss associated with earlier methods of audio recording.

Figure 16.9: Analogue Wave



Digital representation of data points on an analog waveform;

Figure 16.10 - Analogue Vs Digital



These problems have been eradicated because, when imperfections are introduced to a digital signal, the slight variation in the digital level does not change an ON level (high - 1) to an OFF level (0), whereas a slight change in an analog level is easily picked up by the human ear as shown in Figure 16.10.

16.7 LOGIC GATES

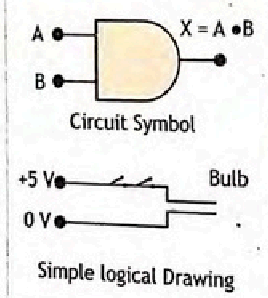
Logic gates are the basic building blocks for forming digital electronic circuitry. A logic gate has one output terminal and one or more input terminals. Its output will be HIGH (1) or LOW (0) depending on the digital level(s) at the input terminal(s). Thus having the ability to perform a logical operation.

Proper understanding of logic circuits is vital for today's electrical and computer engineers. These circuits are the key ingredients of computers and are also used in many other applications. They are found in commonly-used products like music and video players, electronic games, digital watches, cameras, televisions, printers and many household appliances, as well as in large systems, such as telephone networks, internet equipment, television broadcast equipment, industrial control units, and medical instruments. In short, logic circuits are an important part of almost all modern products.

Digital logic circuits are simple. To depict algebraically the operation of a logic gate or a combination of logic gates, a **Boolean equation** is used. The operation of a logic gate or circuit can be represented in a table which contains all possible inputs and their corresponding outputs is called a **truth table.** The circuit symbols for the five basic logic gates AND, OR, NAND, NOR, and NOT gate (or inverter) are described below, along with their boolean equation and truth table.

AND GATE: The simplified AND gate has two inputs and will give high (1) output only if both inputs are high (1). In other words, if A =1 AND B = 1, then X = 1. If either A or B or both are Low (0), the output will be Low (0). The Boolean equation for the AND function can simply be written as $X = A.B$ or just $X = AB$ (which is read as 'X equals A AND B'). AND gate performs the logical multiplication of the inputs. The circuit symbol for AND gate, its simple logical drawing and the truth table are shown in the figure 16.11.

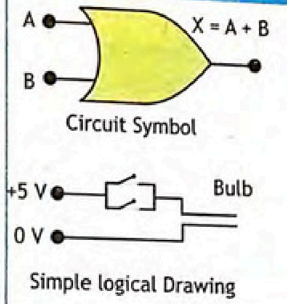
Figure 16.11 - TWO INPUT AND GATE



TRUTH TABLE		
Input		Output
A	B	X = AB
0	0	0
0	1	0
1	0	0
1	1	1

OR gate: The simplified OR gate has two inputs and will give high (1) output at X whenever input A OR input B is HIGH or both are HIGH. As a Boolean equation, this can be written as $X = A + B$ (which is read as "X equals A OR B"). Notice the use of the '+' symbol to represent the OR function. OR gate performs the logical addition of inputs, the circuit symbol for two input OR gate, its simple logical drawing and truth table are shown in the figure 16.12.

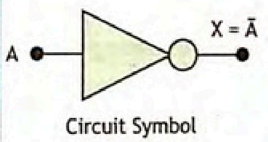
Figure 16.12 - TWO INPUT OR GATE



TRUTH TABLE		
Input		Output
A	B	X = A+B
0	0	0
0	1	1
1	0	1
1	1	1

NOT gate: NOT gate is used to complement or invert a digital signal therefore, it is also called inverter. It has a single input and a single output. If a High level (1) comes in, it produces a Low-level (0) output. If a Low level (0) comes in, it produces a High-level (1) output. The symbol and truth table for the inverter gate are shown in Figure 16.13. The Boolean equation for an inverter is written $X = \bar{A}$ (X = NOT A). The bar over the A is an inversion bar, used to signify the complement.

Figure 16.13 - NOT GATE (Inverter)



TRUTH TABLE	
Input	Output
A	$X = \bar{A}$
0	1
1	0

NAND gate: The operation of the NAND gate is the same as the AND gate except that its output is inverted. You can think of a NAND gate as an AND gate with an inverter at its output. The symbol for a NAND gate is made from an AND gate with the inversion circle (bubble) at its outputis shown in figure 16.14.

LAB WORK

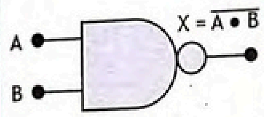
To verify the truth table of OR, AND, NOT, NOR and NAND gates.

To make a burglar alarm/fire alarm using an appropriate gate.

The Boolean equation for the NAND gate is written $X = \overline{AB}$. The inversion bar is drawn over (A and B), meaning that the output of the NAND is the complementation of inputs (A and B) [NOT (A and B)].

Because we are inverting the output, the truth table outputs will be the complement of the AND gate truth table outputs. From truth table we can see that the output is low (0) when both inputs A and B are high (1). Also, the output is high (1) whenever either input is low (0).

Figure 16.14 - TWO INPUT NAND GATE



Circuit Symbol

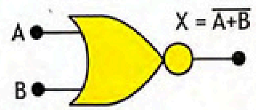
TRUTH TABLE

Input		Output
A	B	$X = \overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

NOR gate: The operation of the NOR gate is the same as that of the OR gate except that its output is inverted.

We can think of a NOR gate as an OR gate with an inverter at its output. The symbol for a NOR gate and truth table is shown in figure 16.15. The Boolean equation for the NOR function is $X = \overline{A + B}$. The equation is stated 'X equals not (A or B).'

Figure 16.15 - TWO INPUT NOR GATE



TRUTH TABLE

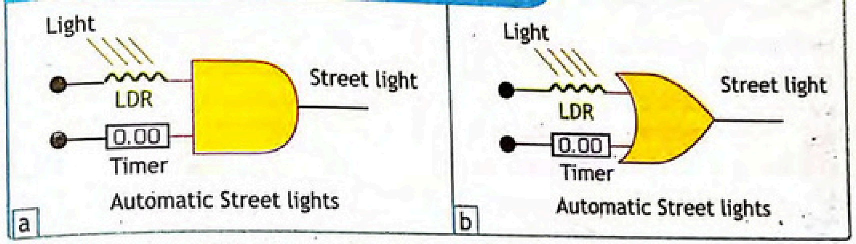
Input		Output
A	B	$X = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

In other words, X is low (0) if A or B is high (1). Notice that the output column in the truth table is the complement of the OR gate truth table output column.

16.7.1 Uses of logic gates: Equipment and devices could be turned on and off automatically by using logic gates and their combinations.

(a) Automatic light bulb switching: If you desire to automatically switch the street lights on and off, after appropriate time and light level, you can use an AND gate.

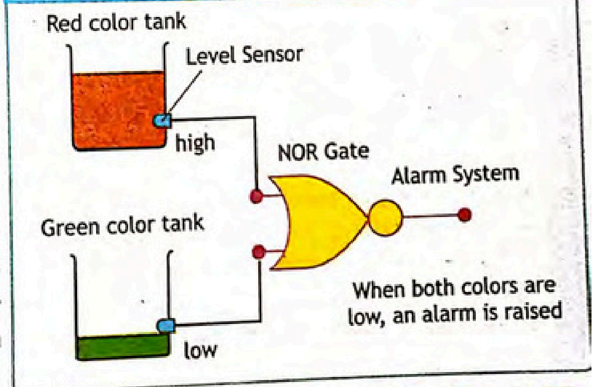
Figure 16.16 - Automatic Street light switching



During day when light shines on Light Dependent Resistor (LDR), the resistance is high and current in the wire is low (0). In the evening when light fades out, the resistance of LDR decreases and it starts conducting and turns to high (1). But the light will not glow until the timer time is not reached after which it would also turn high (1). When both the terminals are high the street light will turn up. The schematic representation is shown in the figure 16.16 (a). On the other hand if we want to turn the light on when either light is low or timer time is reached, we can use an OR gate, as shown in figure 16.16 (b).

(b) Textile coloring plant: A textile coloring plant uses two tanks to store red color and green color. Each tank has a sensor that detects when the color level drops to 25% of full. The sensors produce a high level of 5 V when the tanks are more than one-quarter full. When the volume of color in a tank drops to one-quarter full or less, the sensor puts out a low level of 0 V. Manufacturer requires that an alarm is raised when both tanks are more than one-quarter empty. A NOR gate with its two inputs connected to the tank level sensors and its output connected to the indicator alarm system is shown in figure 16.17. Such that if red color tank and green color tank are above one-quarter full, the signal is low (0 V), even if one tank reduces to less than 25 % of full.

Figure 16.17 - Color level indicator



As soon as both sensor outputs are low (0 V), indicating that both tanks are less than one-quarter full, the NOR gate output is high (5 V) and alarm is raised.

Here NAND gate circuitry can be used to indicate by a green light that both tanks are full.

KEY POINTS

Thermionic Emission: Temperature induced electron ejection.

Electron Gun: Source of focussed and accelerated electron beam (cathode rays).

Deflection of electron beam in electric and magnetic field: Electron beam is deflected in electric and magnetic field.

CRO: Cathode Ray Oscilloscope (CRO) is composed of electron gun, deflecting plates and florescent screen enclosed in an evacuated chamber. CRO works on the principle of deflection of electron beam in electric and magnetic field. CRO is used to

- estimate small intervals
- displays waveform of voltage and current

Analogue quantities and signals: Quantity having continuous values. Therefore, an analogue signal is a continuously variable electrical or physical quantity.

Digital quantities and signals: Quantity having discrete values that represent numbers, letters or symbols. Therefore digital signal deals strictly with ON and OFF states, which we can represent by 0 s and 1 s.

Logic gates: Basic building blocks for forming digital electronic circuitry.

Boolean equation: Algebraic depiction of the operation of a logic gate or a combination of logic gates.

Truth table: Table which contains all possible inputs and their corresponding outputs.

PROJECTS

GROUP A 'AUTOMATIC WATER PUMP': Design logic circuit for automatic water pump. Pump will operate if there is an insufficient amount of water in the tank on the roof of house and sufficient amount of water in the well inside the house. Prepare a chart and present your finding to the class.

GROUP B 'AUTOMATIC FRONT GATE LIGHTING SYSTEM': What types of logic gates can you use to build an automatic lighting mechanism at front gate of your house. Identify the sensors required and the logic gates when a lamp outside your home front gate comes on automatically when it is dark and someone stands on the doormat outside the front door. Prepare a chart and give a brief presentation to your class fellows.

GROUP C 'CHART MAKING': Prepare a chart of symbols and corresponding truth table for NOT, OR , AND, NOR and NAND gates to be displayed in your classroom.

GROUP D 'CRT': CRT technology is replaced with LED and LCD technology for television screens. Identify the main reason behind this shift. Also discuss where the research is still progressing in CRT technology. Document your finding in an article for your school magazine.

GROUP E 'TECHNOLOGY AND ELECTRONICS': Write an essay for your school magazine that modern world is the world of digital electronics. Identify by quoting examples that electronics is shifting from low-tech electrical appliances to high-tech electronic appliances. And that computers are the forefront of electronic technology.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. Cathode rays are beam of
   A. protons B. electrons C. ions D. neutrons
2. If electric field is applied parallel to the direction of electron beam, the electrons will
   A. speed up B. slow down C. deflect D. not change its state
3. If magnetic field is applied parallel to the direction of electron beam, the electrons will
   A. speed up B. slow down C. deflect D. not change its state
4. The electronic circuit that gives high (1) output when all its input are high (1) is called ________ gate.
   A. AND B. OR C. NAND D. NOR
5. The electronic circuit that gives high (1) output when one or more of its input are high (1) is called ________ gate.
   A. AND B. OR C. NAND D. NOR
6. The electronic circuit that gives low (0) output when all its input are high (1) is called ________ gate.
   A. AND B. OR C. NAND D. NOR
7. The electronic circuit that gives low (0) output when one or more of its input are high (1) is called ________ gate.
   A. AND B. OR C. NAND D. NOR
8. The Boolean equation for OR gate is
   A. $X = AB$ B. $X = A + B$ C. $X = \overline{AB}$ D. $X = \overline{A + B}$
9. The Boolean equation for NAND gate is
   A. $X = AB$ B. $X = A + B$ C. $X = \overline{AB}$ D. $X = \overline{A + B}$

CONCEPTUAL QUESTIONS

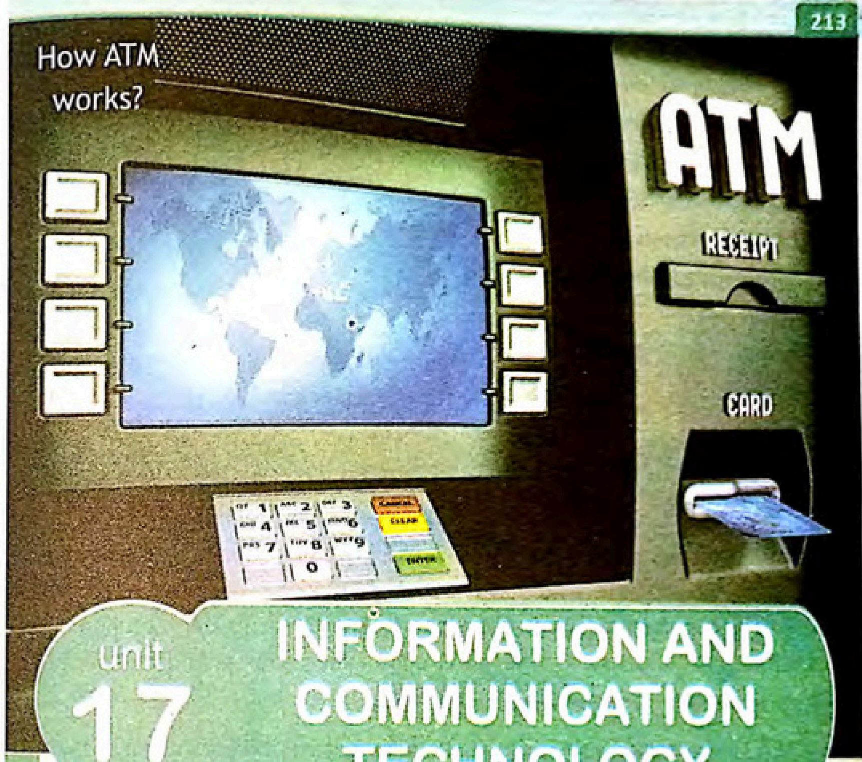
Give a brief response to the following questions

1. What are free electrons?
2. What is the function of an accelerating anode in an electron gun?
3. If the electron beam in a television tube is striking just one point on the screen at a time, how can we get a full picture? Explain.
4. Why image is distorted when a magnet is brought close to old television screens or monitors with cathode ray tube (CRT) inside?
5. Assuming that cathode rays are a beam of charged particles, how could you demonstrate that these particles are negatively charged? Explain.
6. If there are 4 inputs in any logic gate, how many combinations are possible?
7. What conditions produce a high (1) output for an AND gate and NOR gate?
8. What are the algebraic Boolean expressions to represent the output of AND, OR, NOT, NAND and NOR gates?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

1. Why electrons are emitted from an electrically heated metal filament?
2. What are cathode rays? How are cathode rays produced?
3. Describe the construction and working of electron gun?
4. What effect does an electric field and magnetic field have on the electron beam?
5. Describe the working principle of Cathode Ray Oscilloscope (CRO) and make list of its uses.
6. What is the difference between analogue and digital electronics?
7. Define logic gates. Describe the operation of AND, OR, NOT, NAND and NOR logic gates by drawing their symbols and truth tables.
8. Explain simple uses of logic gates in (a) automatic light bulb switching (b) textile coloring plant.



unit 17 INFORMATION AND COMMUNICATION TECHNOLOGY

STUDENT LEARNING OUTCOME

After studying this chapter you should be able to

- ✓ describe the components of information technology.
- ✓ explain briefly the transmission of
  1. electric signals through wires
  2. radiowaves through air
  3. light signals through optical fibres
- ✓ describe function and use of a fax machine, cell phone, photo phone and computer.
- ✓ make a list of the use of E-mail and internet.
- ✓ describe the use of information storage devices such as audio cassettes, video cassettes, hard discs, floppy, compact discs and flash drives.
- ✓ identify the functions of word processing, data managing, monitoring and controlling.

CONTENTS

This is the age of Information and Communication Technology (ICT). This field is constantly being developed, altered, and improved upon. It is evolving so rapidly that it is changing almost on a daily basis. The devices that were in use a decade ago are now outdated and some are partially replaced and some are totally replaced.

17.1 INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

Information and Communications Technology (or technologies) is the infrastructure and components that enable modern computing to create, access, analyze and communicate information. Human beings have always accessed information and communication, but what makes these present technologies special is that it has allowed more people to communicate faster and cheaper.

ICT system is made up of these components:

A. Data and information: Data is simply facts or figures – bits of information, but not information itself. When data is processed, interpreted, organized, structured or presented so as to make them meaningful or useful, they are called information. It may be in the form of text, sound, graphic or figure that has been processed in such a way as to be meaningful to the person who receives it.

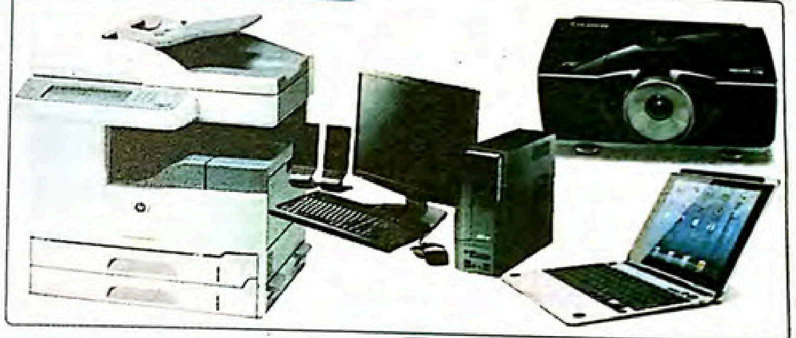
B. Hardware: In information technology, hardware is the physical aspect of computers, telecommunications, and other devices. Hardware are the physical parts or machinery that we can touch. For example mouse, key board, printer, etc.

C. Software: A computer needs to be told what to do, software is the applications and programming instructions that tell your computer what to do. Software enable you to use a computer for things such as playing games, writing an essay or listening to music. These are machine-readable instructions that direct the circuitry within the hardware parts to store, process, transmit, receive and retrieve information in a specific manner.

D. Procedures: These are set of instructions and rules to design and use information system. These are written in manuals and documents for use. These rules or methods may change from time to time. The Information System must be flexible to incorporate these changes.

E. Human resource: It is people who design and operate the software, they feed input data, build the hardware.

Figure 17.1 - Components of ICT



INFO

AUTOMATIC TELLER MACHINE (ATM)

Let us say you are withdrawing money from a nearby ATM (Automated Teller Machine). Can you make a list of all the things you need to do for that? You need your account number, ATM Card, your PIN and you need to enter the amount of money. When you put your card in the machine, it verifies your PIN, collects information about your bank account, the bank and the balance amount. The ATM machine does all of this, connects with you to the bank and allows you to withdraw the money.

So many things we do now are based on information. Many devices such as mobile phones, television, computers, tablets, cameras, scanners, collectively called ICTs, have made this possible. How we collect information, how we analyze it, how we communicate the information and how we use the information to make decisions are all very important.

17.2 FLOW OF INFORMATION

Flow of information is a particular view that focuses on the path and means followed by information entities.

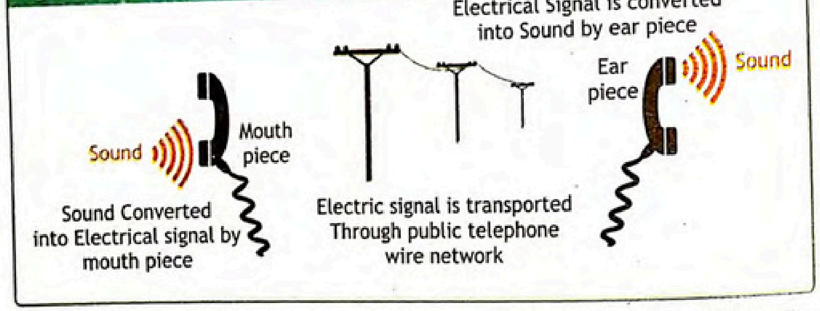
In telephone, information path is wires in which the information flows by means of electrical signals. In radio, television and cell phone, information path is either air, vacuum, and/or seawater in which the information travels in the form of electromagnet waves or through optical fibres through which information travels in the form of light.

Signals are electric or electromagnetic representations of data or information. Transmission is the communication of data/information by the propagation and processing of signals.

17.2.1 Transmission of electrical signal through wire: Data or information can be transmitted and received over a wire-based communication technology. The information is converted to electrical signals at the transmitter, which is sent through wires (twisted pair, coaxial cable etc.), and information is converted back to original form at receiver's end. Examples include telephone networks, cable television and internet access.

For example in figure 17.2, a simple telephone model sound (voice) is converted into electrical signals through mouth piece and sent through electrical wires (twisted pair) and converted back to sound (voice) through ear piece at the receiver.

Figure 17.2 - Telephone communication

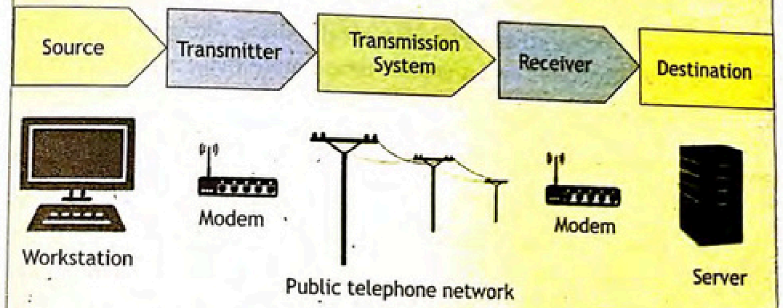


Electrical wire may be used to transmit both analog and digital transmission. For analog signals, amplifiers are required about every few kilometers and for digital transmission (using either analog or digital signals), repeaters are required every kilometer, depending upon the type of wire used.

INFO

A COMMUNICATIONS MODEL

A simple model of communications is illustrated by the block diagram and example in figure below. The fundamental purpose of a communications system is the exchange of data between two parties. Figure below presents one particular example, which is communication between a workstation and a server over a public telephone network. Another example is the exchange of voice signals between two telephones over the same network.



The key elements of the model are as follows:

A. Source: This is the device that generates the data to be transmitted; examples are telephones and personal computers.

B. Transmitter: Usually, the data generated by a source system are not transmitted directly in the form in which they were generated. Rather, a transmitter transforms and encodes the information in such a way as to produce electromagnetic signals that can be transmitted across some sort of transmission system. For example, a modem takes a digital bit stream from an attached device such as a personal computer and transforms that bit stream into an analog signal that can be handled by the telephone network.

C. Transmission system: This can be a single transmission line or a complex network connecting source and destination.

D. Receiver: The receiver accepts the signal from the transmission system and converts it into a form that can be handled by the destination device. For example, a modem will accept an analog signal coming from a network or transmission line and convert it into a digital bit stream.

E. Destination: Takes the incoming data from the receiver.

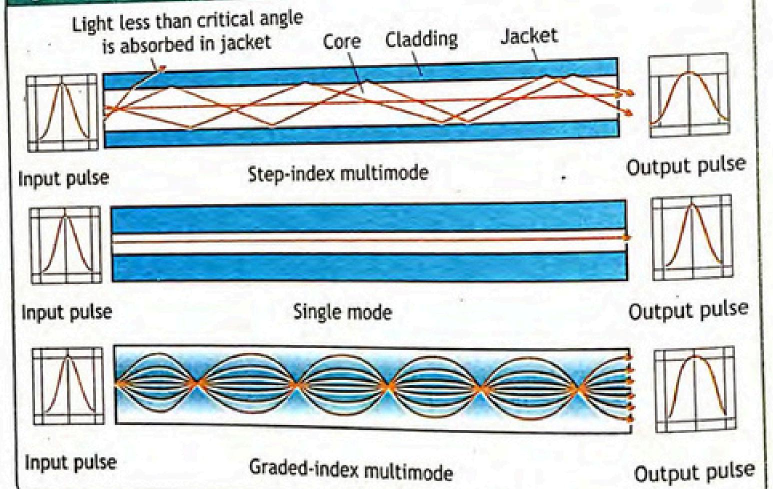
17.2.2 Transmission of electrical signal through optical fibers:

An optical fiber (discussed in chapter 12, geometrical optics) transmits a signal-encoded beam of light by means of total internal reflection. Total internal reflection can occur in any transparent medium that has a higher index of refraction than the surrounding medium.

The information is converted into electrical voltage signals, this varying voltage is used to produce light. Two different types of light source are used in fiber optic systems: the light emitting diode (LED) and the injection laser diode (ILD). Both are semiconductor devices that emit a beam of light when a voltage is applied. The LED is less costly, operates over a greater temperature range and has a longer operational life. The ILD, which operates on the laser principle, is more efficient and can sustain greater data rates. Figure 17.3 shows the principle of optical fiber transmission.

A. Step-index multimode: Light from a source enters the cylindrical glass or plastic core. Rays at low angles are reflected due to total internal reflection and travel along the fiber; other rays are absorbed by the surrounding material. This form of propagation is called step-index multimode. This type of fiber is best suited for transmission over very short distances.

Figure 17.3 - Optical Fibers



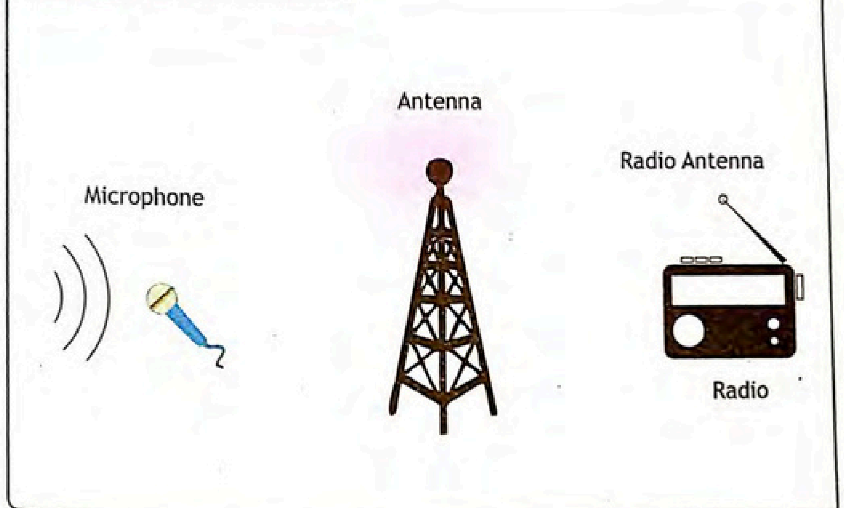
B. Single-mode: When the fiber core radius is reduced to the order of a wavelength, only a single angle or mode can pass. Single-mode is typically used for long distance applications, including telephone and cable television.

C. Graded-index multimode: When the index of refraction at the centre of the core is made is higher and reduced gradually, light in the core curves helically due to variation in the index of refraction. The shortened path and higher speed allows light at the periphery to arrive at a receiver at about the same time as the straight rays in the core axis. Graded-index fibers are often used in Local Area Networks (LAN).

C. 17.2.3 Transmission of radio-waves through air or space: Electrical signals representing information from a microphone, a TV camera, or a computer (transmitters) can be sent from one place to another place using radiowaves.

For transmission of a signal, radio-frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment (atmosphere, space, water). For reception of a signal, electromagnetic energy falling on the antenna is converted into radio-frequency electrical energy and fed into the receiver.

Figure 17.4 - Radio Broadcast



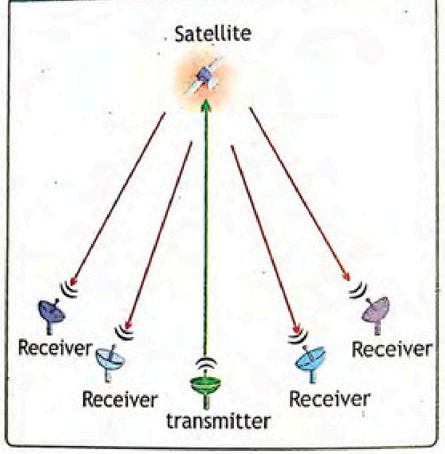
In two-way communication, the same antenna can be used for both transmission and reception.

An antenna can be defined as an electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy.

For example sound waves produced at the radio station as shown in Figure 17.4 are changed into electrical signals through microphone. These electric signals are then fed into the transmission antenna which superimposes these electric signals on electromagnetic waves and emits them, in form of radio-waves. At the receiving end, the receiver selects and amplifies this radio-wave signal. The receiver extracts the information and converts it to sound with the help of a speaker.

A communication satellite is infact a microwave relay station. It is used to link two or more ground-based microwave transmitter/ receivers, known as earth stations, or ground stations. The satellite receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink). Figure 17.5 depicts in a general way communications between one ground-based transmitter and a number of ground-based receivers.

Figure 17.5 - Satellite Broadcast



17.3 TELECOMMUNICATION DEVICES

The machines or devices used to carry information to far off places is called telecommunication. Fax machine, cell phone, photo phone and computer are few examples of telecommunication devices.

A. Fax machine: A fax machine (figure 17.6) is designed to send as well as receive documents so it has a sending part and a receiving part. The sending part is a bit like a computer scanner, that scans only one line of a document at a time, and only in black and white. A fax machine transmits one kind of electric pulse down the phone line to represent black and another to represent white.

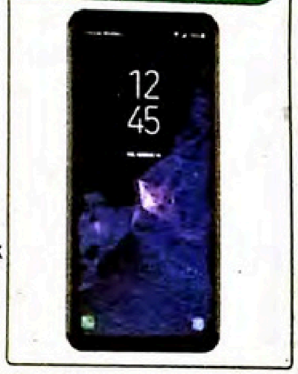
Figure 17.6 - Fax Machine

The phone line transmits this information almost instantly to a fax machine at the other end. It receives the electrical pulses and uses them to control a printer. It takes about a minute or so to transmit a single page of writing (or a complex drawing) in very systematic way.

B. Cell phone: Wireless phones which receive their signals from towers. A cell is typically the area (several miles) around a tower in which a signal can be received.

Cell phones provide an incredible array of functions. Depending on the cell-phone model, you can:

Figure 17.7 - Cell Phone



- Store contact information
- Make task or to-do lists
- Send text messages
- Keep track of appointments and set reminders
- Use the built-in calculator for simple math
- Get information (news, entertainment, stock quotes) from the internet
- Send or receive e-mail
- Customizable Operating Systems (Oss - software that allows users to interact with the computer system) - enable the user to download apps (computer program designed to run a mobile device such as phone/tablet or watch) like games, GPS, watching TV, utilities, and other tools. Android, a mobile OS developed by Google, is the first completely open-source mobile OS, meaning that any cell phone manufacturer can use it in their phones for free.

C. Photo phone: The photophone is a telecommunications device that allows transmission of speech (sound) on a beam of light. This means that the light we use will not only provide light but also act as a means of communication. Until the late 1960s, radio and radar communications were more successful than optical communications (OC). OC started to get real attention with the invention of the light amplification by stimulated emission of radiation (laser) and the laser diode (LD) in the 1960s, followed in the 1970s by the development of low-loss optical fibres (OFs) as a medium for transmitting information using light.

D. Computer: A computer is a device that can be instructed to carry out sequences of arithmetic or logical operations automatically via computer programming. Modern computers have the ability to follow generalized sets of operations, called programs. These programs enable computers to perform an extremely wide range of tasks. There are many different kinds of computer systems. Some computer systems are very big because they are used to carry out large and complex tasks. Others are small and portable - small enough to put in your pocket - even to wear around your wrist or as a pair of glasses. The table 17.1 looks at the ways in which various types of computer are used, as well as their characteristics.

POINT TO PONDER

Virtual reality (VR) is an artificial environment that is created with a software and presented to the user in such a way that the user accepts it as a real environment. The most important piece of a virtual reality kit these days is the headset, a device like a thick pair of goggles. VR devices have their own app stores, similar to smartphone app stores, where games and apps can be downloaded.

VR products are also used by many companies, often to test product designs and simulate user interaction, e.g. flight simulators and medical training.

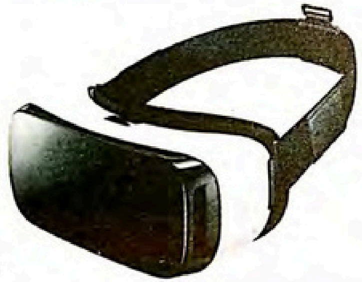


Table 17.1 TYPES OF COMPUTERS

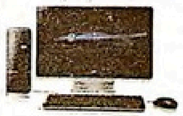
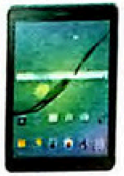
Type of computer	Description	Advantages	Disadvantages
Mainframe computer 	These are extremely large computers used in organisations (such as banks and government departments) where very large amounts of data are processed.	• Capable of processing very big jobs, which make use of their large memories and fast processor speeds. • Capable of complex problem-solving that would take smaller computers much longer to do.	• Mainframes are so large that they take up almost a whole room. • Complex to set up. • Expensive to operate and maintain and they require specialist staff to operate.
Desktop or Personal computer (PC) 	This is a general purpose computer made up of separate components: • monitor • keyboard • mouse • processor and storage.	• Spare parts are often cheap because they are standardised. • They often have faster processors than laptop computers for the same price. • There are fewer problems with overheating than laptops because of their larger size.	• Lack of portability - heavy and separate components are connected by wires. • Files have to be copied and stored on portable disks, especially if you need to take them with you.
Laptop or notebook 	This is a computer where all the components are together in a single unit. This means that they are portable; unlike desktop computers, they can be moved from one work area to another.	• Portability. • Users can work anywhere, especially if they can access Wi-Fi and link to other media.	• Loss and theft • Limited Battery life • Keyboards and pointing devices are not as flexible as those on a desktop. • Laptops are more compact, so overheating can be a problem.

Table 17.1 TYPES OF COMPUTERS

Type of computer	Description	Advantages	Disadvantages
Tablet 	Like a laptop this is a small portable computer but the biggest difference is that its user interface is all through touch.	o Portable and easy to use. o Quick to switch on. o Thousands of downloadable applications available.	o Not all have 3G/4G access. o Touch-screen typing can be difficult. o Cannot make phone calls.
Smartphones 	This is an advanced mobile phone with, features such as: web browsers, high-resolution touch screens, GPS navigation and Wi-Fi access. Smartphones are often used as media players and cameras.	o Online access to data. o Better web browsing capability than a more simple mobile phone. o Just one device can accomplish many tasks at work or at home. o Contacts' details and phone numbers can be integrated.	o Screen sizes make it difficult to read long documents and makes it difficult to enter text and numbers quickly. o Costs can be high as most providers want the user to commit to a long-term contract with internet access. o Some webpages may not display or function entirely as the web designer expected.

17.4 INTERNET AND EMAIL

The Internet is a worldwide system of computer networks - a network of networks in which users at any one computer can, if they have permission, get information from any other computer (and sometimes connect directly to users at other computers).

Electronic mail (email or e-mail) is a method of exchanging messages ("mail") between people using electronic devices.

Email has practically replaced the postal service for short written transactions. Email operates across computer networks, which today is primarily the Internet.

Table 17.2: USES OF INTERNET

Communication	• Email • Social media (face book, twitter, Instagram, etc) • Read or write blogs. • Chat-room • Forums • Internet Telephone (VOIP)
Exploring the world	• Exploring through satellite mapping applications (google earth) • Travel sites providing details of places with pictures and videos • Almanacs and encyclopedias
Keeping up with events	• Keeping up to date with news and sports events. Read newspapers and watch news channels • Watching catchup television shows from main channels
Managing your life	• Online banking (make deposits and withdrawals, order checks) • Online shopping (buying and selling) • Pay utility bills. • Investing money. • Keeping a calendar. • Finding a new job
Study and Research Information	• Find research papers and articles • Find professional services. • Take classes.
Entertaining Yourself	• Watch television and movies. • Watching online video (youtube) • Play games. • Listen to music. • Look for holidays and tickets (sports, concerts etc.)

17.5 INFORMATION STORAGE DEVICES

Information can be stored by virtually any form of energy. Handwriting (paper documents), phonographic recording, magnetic tape, DNA and RNA and optical discs are all examples of storage media. Electronic data storage requires electrical power to store and retrieve data.

Computer data storage is one of the core functions of a general purpose computer. Electronic documents can be stored in much less space than paper documents. There are two different types of electronic data storage devices:

A. Primary storage devices: Generally smaller in size, these are designed to hold data temporarily and are internal to the computer. They have the fastest data access speed, and include RAM and cache memory.

B. Secondary storage devices: These usually have large storage capacity, and they store data permanently. They can be either internal or external to the computer, and they include the hard disk, optical disk drive and USB storage device. Some secondary storage devices are explained below.

A. Audio and Video cassettes: A magnetic tape, in computer terminology, is a storage medium that allows for data archiving, collection, and backup. At first, the tapes were wound in wheel-like reels but then cassettes and cartridges came along, which offered more protection for the tape inside.

One side of the tape is coated with a magnetic material. Data on the tape is written and read sequentially. Finding a specific record takes time because the machine has to read every record in front of it. Most tapes are used for archival purposes rather than ad-hoc writing/reading.

Figure 17.8 - Audio and video cassettes

An audio cassette can store music and sounds. A video cassette on the other hand is magnetic tape used for storing video and usually sounds in addition. Audio and video cassettes are shown in the figure 17.8. Audio and video cassettes require special devices to be played and recorded.

B. Hard Disk: A hard disk drive (sometimes abbreviated as Hard drive, HD, or HDD) is a device that permanently stores and retrieves data on a computer. A hard drive is a secondary storage device that consists of one or more platters to which data is written using a magnetic head, all inside of an air-sealed casing. A typical hard disk drive is shown in figure 17.9.

Figure 17.9 - Hard Disk

TipBits

Helium Hard drives

In an attempt to build higher-capacity, energy-efficient hard drives, a few manufacturers have come up with a novel solution: filling the hard drive case with helium. Because helium is one-seventh as dense as air, the spinning platters in a helium drive encounter less resistance and experience almost no turbulence. As a result, manufacturers can put more platters into a drive and track data on those platters more precisely, greatly increasing drive density. It also decreases energy use, makes the drive quieter and improves reliability.

It took some time for helium drives to move from concept to reality because it was difficult to prevent the helium from leaking out of the drives. Now, HGST and Seagate both have helium drives currently on the market, and HGST reports that of the one million helium drives it shipped in the first year of production, none experienced seal failure in the field.

C. Floppy: A floppy disk is a magnetic storage medium for computer systems. The floppy disk is composed of a thin, flexible magnetic disk sealed in a square plasticcarrier. In order to read and write data from a floppy disk, a computer system must have a floppy disk drive (FDD).

A floppy disk is also referred to simply as a floppy. Since the early days of personal computing, floppy disks were widely used to distribute software, transfer files, and create back-up copies of data. because hard drives were very expensive, floppy disks were also used to store the operating system of a computer. The picture shown in figure 17.10 is an example of a 3.5" floppy diskette, which was one of the most commonly used floppy diskettes, capable of storing 1.44 MB of data.

Figure 17.10 - Floppy

D. CD and DVD: A Compact Disc (CD) is a portable storage medium that can be used to record, store and play back audio, video and other data in digital form.

A DVD (Digital Versatile Disc or Digital Video Disc) is an optical disc capable of storing up to 4.7 GB of data, more than six times what a CD can hold. CDs and DVDs are used to hold music, data or computer software. They have become the standard medium for distributing large quantities of information in a reliable package. If you have a computer and CD-R drive, you can create your own CDs, including any information you want. A typical 700 MB storage CD is shown in figure 17.11

Figure 17.11 - CD

E. Flash Drive: A flash drive is a small, ultra-portable storage device which, unlike an optical drive or a traditional hard drive, has no moving parts.

Flash drives connect to computers and other devices via a built-in USB (Universal Serial Bus) Type-A plug, making a flash drive a kind of combination USB device and cable.

Figure 17.12 - Flash Drive

17.6 WORD PROCESSING

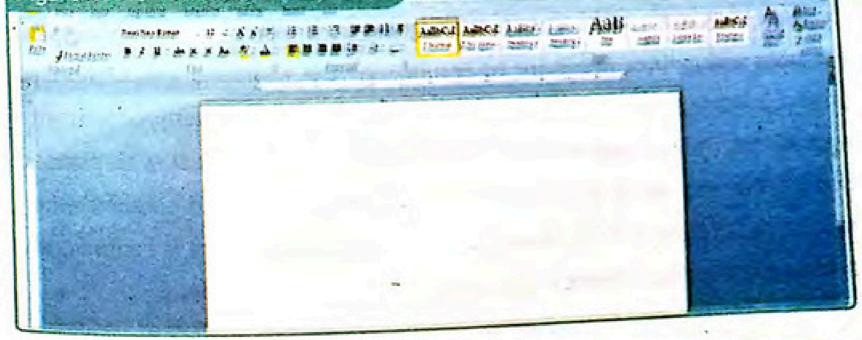
Every day we come into contact with documents, posters, letters, leaflets, books and other printed materials that were prepared using software that enables users to develop and edit text-based documents.

Word processing software is used to manipulate a text document, such as a resume or a report. We typically enter text by typing and the software provides tools for copying, deleting and various types of formatting. Some of the functions of word processing software include:

- Creating, editing, saving and printing documents.
- Copying, pasting, moving and deleting text within a document.
- Formatting text, such as font type, bolding, underlining or italicizing.
- Creating and editing tables.
- Inserting elements from other software, such as illustrations or photographs.
- Correcting spelling and grammar.

Word processing software typically also contains features to make it easier for us to perform repetitive tasks. For example, let's say we need to send a letter to all our customers regarding a new policy. The letter is the same for all customers except for the name and address at the top of the letter. Word processing software can take a database of customer information and use it to automatically create a letter for each customer.

Figure 17.13 - Microsoft (MS) Word



17.7 HANDLING INFORMATION

Handling information is the ability to use ICT for gathering, organising, storing, retrieving, modifying, interpreting and presenting information. It involves categories such as databases, spreadsheets and Internet.

A. Data management: Data management is an administrative process that includes acquiring, validating, storing, protecting, and processing required data to ensure the accessibility, reliability, and timeliness of the data for its users. Designing effective data management solutions consists of three primary activities

- An assessment of supply chain information needs should be conducted, including who needs the information, how it will be used and the potential actions that may be taken in response to the data. Secondly, the platform best suited to supporting data collection should be selected. This may range from paper-based systems to mobile phones to sophisticated software programs.
- Standard Operating Procedures (SOPs) should be developed, with staff trained on how to adhere to the SOPs. Staff need to be trained on how to use the selected tool(s) and equally importantly on how to analyze and use the results.
- The collected data should be made available in a format that enables decision making. The format will depend on the resources available and the audience but the data should be accessible and easy to use to answer key supply chain performance questions.

B. Monitoring and control: The Monitoring and Controlling process oversees all the tasks and metrics necessary to ensure that the approved and authorized project is within scope, on time and on budget so that the project proceeds with minimal risk. This process involves comparing actual performance with planned performance and taking corrective actions to yield the desired outcome when significant differences exist. Monitoring and Controlling process is continuously performed throughout the life of a project.

KEY POINTS

Information technology: The scientific method used to store information, to arrange it for proper use and to communicate it to others

Information and Communication Technology: The infrastructure and components that enable modern computing

Components of Information and Communication Technology: Five parts that must come together in order to produce an Information and Communication Technology System. These are: data and information, hardware, software, procedures and people.

Flow of information: The transfer of information from one place to another through different electronic and optical equipments

In telephone, information [illegible] wires in the form of electrical signals. In radio, television and cell phone information can be sent either through space in the form of electromagnetic waves or it can be sent through optical fibres in the form of light signals.

Telecommunication: The methods and means that are used to communicate information to distant places instantly

Information storage devices: Store the information for later use and benefits. These include audio - video cassettes, compact discs, floppy disks and hard disks.

Computer: A multipurpose electronic computing machine.

Word Processing: Software used to manipulate a text document

Data managing: To collect information for a special purpose and to store it in a computer in a file form which may help at times when needed

PROJECTS

GROUP A 'RISKS AND BENEFITS OF ICT': Assess the risks and benefits to society and the environment of introducing ICT (e.g. effects on personal privacy, criminal activities, health and transfer of information).Write an essay to be published in school magazine.

GROUP B 'ADVANTAGES OF HIGH TECH COMMUNICATION DEVICES': Compare the advantages of high-tech communication devices with the traditional system through library or internet search. Prepare a chart and give a brief presentation to your class fellows.

GROUP C 'CHART MAKING': Prepare a chart listing the use of computer technology in various fields of daily life, to be displayed in your class room.

GROUP D 'MAKING NEWSLETTER': Newsletters are usually produced for a specific audience, having words and images. Find a computer and by using a word processing software (Like Microsoft word) make a news letter including last year events of your school, make a hard copy (printed document) available for school library.

GROUP E 'VIRTUAL REALITY (VR)': Research the current state of VR technology, including virtual immersion and think about how this technology could be used, for example, in tourism. Write a research article for the school magazine.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. The components of information and communication systems are humans, hardware, software, procedures and ____
   A. computers B. fields C. data/information D. signals
2. Electric or electromagnetic representations of data or information is termed as
   A. computer B. signal C. transmission D. software
3. The phenomenon of total internal reflection is used in transmission of signal through
   A. electric wires B. optical fibers C. electromagnetic waves D. radio
4. Electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy is
   A. antenna B. satellite C. repeater D. signal
5. Software that allows users to interact with the computer system is
   A. hardware B. application C. operating system D. program
6. Which of the following information storage device has no moving parts to store and retrieve information
   A. CD/DVD B. Hard Drive C. Flash drive D. Floppy
7. Which of the following information storage device is least used these days
   A. CD/DVD B. Hard Drive C. Flash drive D. Floppy
8. Telephone communication is the example of transmission of signals through
   A. electric wires B. optical fibres C. electromagnetic waves D. All

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

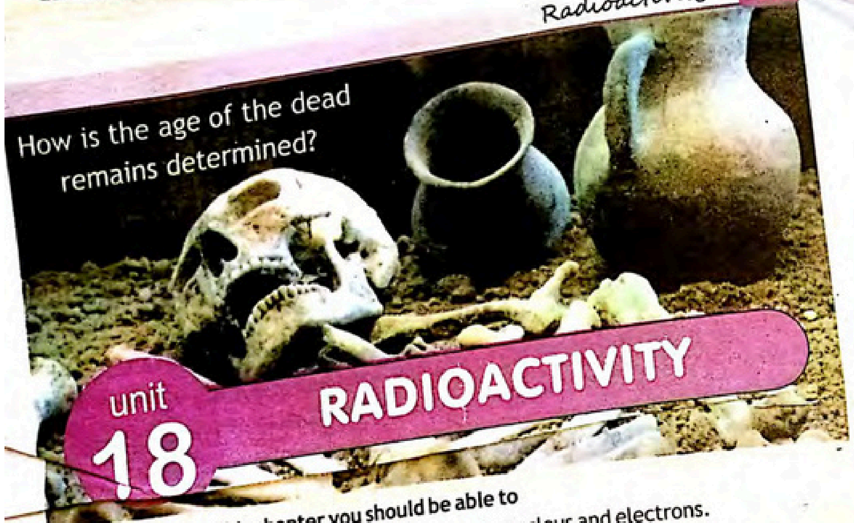
1. Identify the most reliable means of storing information?

2. How information is different from data?
3. Why frequency band for uplink and downlink is different in transmission of microwaves through space?
4. What does 'cell' in 'cell phone' refers to?
5. Can internet be used for shopping? Give an example.
6. How a flash drive is different from other storage devices?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

1. What is Information and Communication Technology (ICT)? Explain briefly its components.
2. Explain the flow of information. Describe how information is transmitted as electric signal through wires, light signals through optical fibres and radio waves through air/vacuum?
3. Describe function and use of fax machine, cell phone, photo phone and computer.
4. What is email and internet? List few uses of internet in daily life.
5. What are information storage devices? Describe the use of information storage devices such as audio cassettes, video cassettes, hard discs, floppy, compact discs and flash drive.
6. What are the functions of word processing?
7. How information is handled? Describe data management and its monitoring and control.



After studying this chapter you should be able to

STUDENT LEARNING OUTCOME

- ✓ describe the structure of an atom in terms of a nucleus and electrons.
- ✓ describe the composition of the nucleus in terms of protons and neutrons.
- ✓ explain that number of protons in a nucleus distinguishes one element from the other.
- ✓ represent various nuclides by using the symbol of proton number Z, nucleon number A and the nuclide notation X.
- ✓ explain that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive.
- ✓ describe that the three types of radiation are α, β & γ.
- ✓ state, for radioactive emissions:
  - o their nature
  - o their relative ionizing effects.
  - o their relative penetrating abilities.
- ✓ explain that an element may change into another element when radioactivity occurs.
- ✓ represent changes in the composition of the nucleus by symbolic equations when alpha or beta particles are emitted.
- ✓ describe that radioactive emissions occur randomly over space and time.
- ✓ explain the meaning of half life of a radioactive material.
- ✓ describe what are radio isotopes. What makes them useful for various applications?.
- ✓ describe briefly the processes of fission and fusion.
- ✓ show an awareness of the existence of background radiation and its sources.
- ✓ describe the process of carbon dating to estimate the age of ancient objects.
- ✓ describe hazards of radioactive materials.

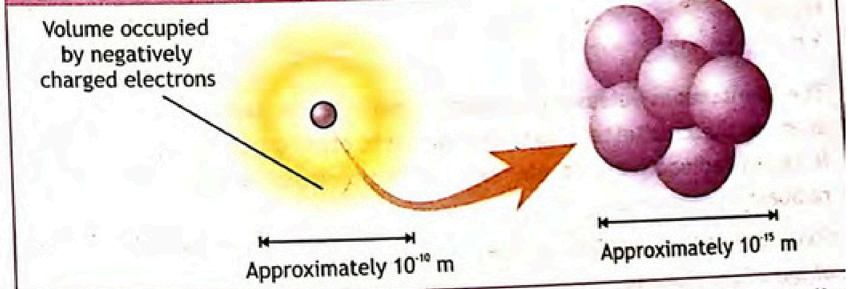
CONTENTS

In this chapter, we discuss the properties and structure of the atomic nucleus. We start by describing the phenomenon of radioactivity, nuclear transmutations and half life. We also discuss the various processes by which nuclei decay and the ways that nuclei can react with each other. In nuclear reactions, however, we will study how a nucleus breaks apart or is ... nuclei and particles combine.

18.1 ATOM AND ATOMIC NUCLEUS

All matter is composed of atoms that are in turn composed of a heavier, central, positively charged core called '**nucleus**' surrounded by a less massive negatively charged cloud of '**electrons**'. The nucleus lies at the center of the atom, occupying only 10^{-15} of its volume since the electrical force comes from both the electron and the nucleus as shown in figure 18.1. The nucleus is about 10,000 times smaller than atom. The size difference is like a ping pong ball in the center of a 2 km circle.

Figure 18.1 - *Atom and Atomic nucleus*

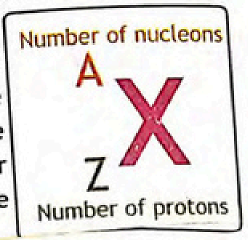


All nuclei are composed of two types of particles: protons and neutrons (called nucleons). The only exception is the ordinary hydrogen nucleus, which is a single proton. In describing the atomic nucleus, we must use the following quantities:

o The atomic number, Z (sometimes called the charge number), which equals the number of protons in the nucleus.

o The nucleon (or mass) number, A, which equals the number of nucleons (neutrons plus protons) in the nucleus.

o The neutron number, N, which equals the number of neutrons in the nucleus (N = A - Z).



In representing nuclei, it is convenient to have a system of symbols to show how many protons and neutrons are present. The symbol used is $^{A}_{Z}X$, where X represents the chemical symbol for the element, Z represents the number of protons and A represents the number of nucleons (i.e number of protons and neutrons)

For example, $^{56}_{26}$Fe (iron) has a nucleon number of 56 and an atomic number of 26; it therefore contains 26 protons and (56 -26) 30 neutrons. **The subscript Z is thus sometimes dropped.** For example for nitrogen $^{15}_{7}$N, we already know that Z = 7 for nitrogen and we simply write ^{15}N, call it as 'nitrogen fifteen' (or may write as nitrogen - 15).

The nuclei of all atoms of a particular element contain the same number of protons (and consequently electrons in a neutral atom) but often contain different numbers of neutrons. **The nuclei of atoms which have the same number of neutrons and protons are termed as nuclides.**

Within the nucleus there are Z positive charges. To keep these charges from flying apart, the nuclear force must supply an attraction that overcomes their electrical repulsion.

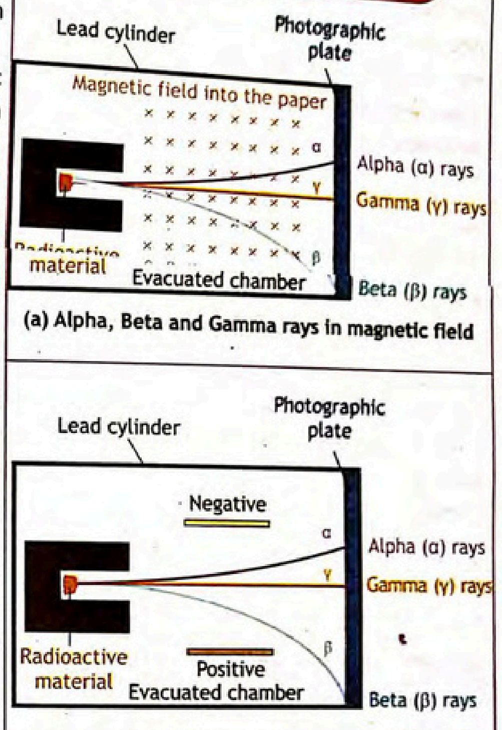
18.2 RADIOACTIVITY

The spontaneous release of subatomic particles or gamma rays by unstable atoms as their nuclei tend to break apart into other particles to attain stability is called radioactivity. An element which possesses such property is called radioactive element.

Some nuclides are unstable, in order to attain stability, elements emit three types of radiation: alpha (α), in which the emitted particles are ^{4}He nuclei; beta (β), in which the emitted particles are either electrons or positrons (positive electrons); and gamma (γ), in which the emitted "rays" are high-energy electromagnetic radiations . Nuclei which do not emit radiations are termed as 'stable nuclei'.

It is possible to distinguish these three forms of radiation using the scheme shown in Figure 18.2 (a). The radiation from a radioactive sample (e.g Radium) is directed into an evacuated chamber (region from which air is pumped out) in which there is a magnetic field.

Figure 18.2 - *Radioactivity in force fields*



(a) Alpha, Beta and Gamma rays in magnetic field

(b) Alpha, Beta and Gamma rays in electric field

The image on photographic plate shows that the beam splits into three components, two bending in opposite directions and the third experiencing no change in direction. By using the force on charged particles in magnetic field, we can conclude that the radiation of the un-deflected beam carries no charge (the gamma 'γ' ray), the component deflected upward consists of positively charged particles (alpha 'α' particles), and the component deflected downward consists of negatively charged particles (beta 'β' particles).

Similar observations can be made by passing a beam emitted from radium through an electric field placed perpendicular to the beam as shown in the figure 18.2 (b).

Radioactivity occurs without apparent external cause and cannot be speeded up or slowed down by physical or chemical means. Radioactivity is a process without defined pattern, rule or method and occur randomly. Radioactivity cannot be predicted because the precise moment of disintegration is not known for a particular nuclei. **Individual disintegrations occur randomly.**

18.2.1 Nature of emissions: It is found that all the three kinds of radiation have different nature.

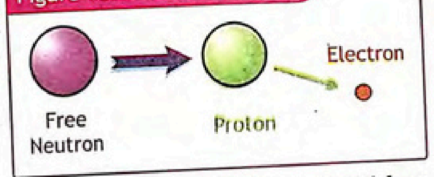
i. Alpha (α) emissions: Alpha particles are infact helium nuclei (i.e two protons and two neutrons bound together) emitted from the nucleus. When the ratio of neutrons to protons in the nucleus is too low, certain atoms restore the balance by emitting alpha particles.

Alpha emissions occur in very large atoms (that is, they have high atomic numbers).

ii. Beta (β) emissions: Beta particles consist of electrons emitted from the nucleus. Beta particle emission occurs when the ratio of neutrons to protons in the nucleus is too high. In this case, an excess neutron transforms into a proton and an [illegible] the electron is ejected energetically. electron. The proton stays in th[illegible]

A neutron by itself is unstable; the lone neutron on average of about 12 minutes will decay into a proton and an electron.

Figure 18.3 - *Beta Emission*



The spontaneous decay of free protons has never been observed and the proton is therefore, considered a stable particle. A neutron with a proton is stable.

iii. Gamma emissions: Gamma rays are electromagnetic radiation emitted from the nucleus. Gamma ray emission occurs when the nucleus of a radioactive atom has too much energy.

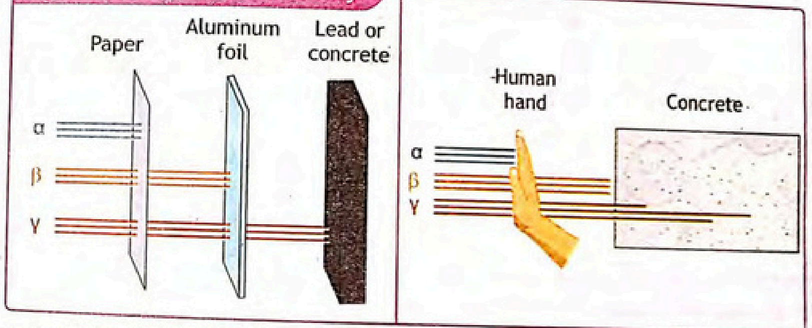
TABLE 18.1 ALPHA, BETA, AND GAMMA RADIATION

Particle	Symbols	Composition	Charge	Effect on parent nucleus
alpha	α	2 protons and 2 neutrons	+2	Mass loss: new element produced
beta	β	electron	-1	No change in mass: new element produced
gamma	γ	high energy electromagnetic radiations	0	energy loss

18.2.2 Relative ionizing abilities: The phenomena by which radiation can split matter into positive and negative ions is called ionization. All the three types of radiation (alpha 'α', beta 'β' and gamma 'γ') have quite different ionizing abilities in air. Alpha (α) particles ionizes air much strongly due to its large mass and charge than beta (β) and gamma (γ) radiations. Gamma radiation has the least ionizing ability as compared to alpha 'α' and beta 'β' radiations.

18.2.3 Relative Penetration abilities: Penetrating ability is how deeply a radiation can go into a material. All the three types of radiation (alpha 'α', beta 'β' and gamma 'γ') have quite different penetrating abilities as well. Alpha particles barely penetrate a sheet of paper and has range of no more than a few centimeters in air; beta particles can penetrate a few millimeters of aluminum has range in air of about 1 m; and gamma rays can penetrate several centimeters of lead and has an infinite range in air as shown in figure 18.4 (a).

Figure 18.4 - *Penetration ability*



In figure 18.4 (b), it is shown that α-particles can be easily absorbed by our hand, where as beta and gamma will pass through. Beta radiations on the other hand will be easily stopped by concrete block. Whereas gamma will travel few centimeters before being absorbed in concrete.

18.3 NUCLEAR TRANSMUTATIONS

In radioactivity, an unstable nucleus emits radiations to become more stable. Among 3000 known nuclides, only 257 are stable. **The process through which an unstable nucleus (parent nucleus) transforms (or changes) in to a more stable nuclide (daughter nucleus) is called nuclear transmutation (or nuclear decay).**

In these nuclear transmutations, the original element is called parent and newly formed element is termed as daughter.

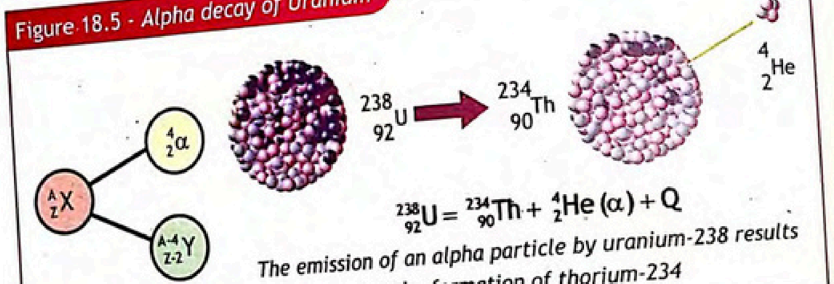
18.3.1 Alpha decay: In alpha decay, the original 'parent' nuclide is converted to a 'daughter' by the emission of an α particle. Balancing the reaction shows that the daughter nuclide has a nucleon number reduced by four and a charge reduced by two. Mathematically

$$\boxed{{}^{A}_{Z}X = {}^{A-4}_{Z-2}Y + \alpha + Q} \quad \boxed{18.1}$$

Where '*Q*' is the energy released in the process. Nuclide '*X*' changes into nuclide '*Y*' with the emission of alpha 'α' particle and the release of energy '*Q*'.

Example: ${}^{263}_{106}Sg = {}^{259}_{104}Rf + {}^{4}_{2}He\,(\alpha) + Q$

Figure 18.5 - *Alpha decay of Uranium*



$${}^{238}_{92}U = {}^{234}_{90}Th + {}^{4}_{2}He\,(\alpha) + Q$$

The emission of an alpha particle by uranium-238 results in the formation of thorium-234

EXAMPLE 18.1: ALPHA DECAY OF POLONIUM

An unstable polonium - 218 (${}^{218}_{84}Po$) atom spontaneously emits an alpha (α) particle and transmutes into an atom of some other element. Show the process, including the new element, in standard nuclear-reaction notation.

SOLUTION: Alpha decay is given by the relation ${}^{A}_{Z}X = {}^{A-4}_{Z-2}Y + \alpha + Q$

From the periodic table, we find that polonium chemical symbol is Po and atomic number is 84. Therefore:

Putting values ${}^{218}_{84}Po \rightarrow {}^{218-4}_{82-2}X + {}^{4}_{2}He(\alpha) + Q$

or ${}^{218}_{84}Po \rightarrow {}^{214}_{82}X + {}^{4}_{2}He(\alpha) + Q$

Every element has a unique atomic number. The periodic table shows the new element to be lead (Pb) with Z = 82. The finalized equation can now be written as

$${}^{218}_{84}Po \rightarrow {}^{214}_{82}Pb + {}^{4}_{2}He(\alpha) + Q \quad \boxed{\text{Answer}}$$

When polonium - 218 undergoes α- decay it converts into lead - 214.

ASSIGNMENT 18.1: ALPHA DECAY OF RADIUM

Find the daughter nucleus when radium - 224 undergoes alpha decay.

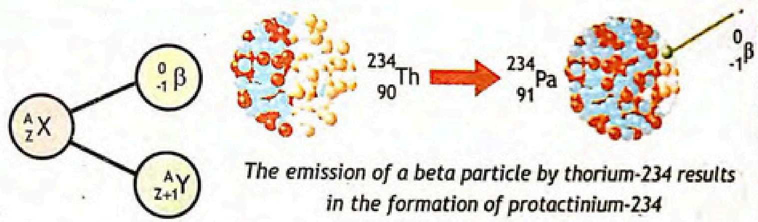
18.3.2 Beta decay: Unlike α-decay, β (or electron) decay of a nuclei does not change the number of nucleons. In essence, β- decay changes a neutron into a proton.

$$\boxed{{}^{A}_{Z}X = {}^{A}_{Z+1}Y + \beta^{-} + Q} \quad \boxed{18.2}$$

Where '*Q*' is the energy released in the process. Nuclide '*X*' changes into nuclide '*Y*' with the emission of alpha 'α' particle and the release of energy '*Q*'.

Example: ${}^{14}_{6}C = {}^{14}_{7}N + \beta^{-} + Q$

Figure 18.6 - *Beta decay of Thorium*



The emission of a beta particle by thorium-234 results in the formation of protactinium-234

EXAMPLE 18.2: BETA DECAY OF IODINE

The isotope iodine-131 undergoes beta decay. Write the reaction equation, and determine the identity of the daughter nucleus.

SOLUTION: Beta decay is given by the relation ${}^{A}_{Z}X = {}^{A}_{Z+1}Y + \beta^{-} + Q$

From the periodic table, we find that iodine's chemical symbol and atomic number are I and 53. Therefore:

Putting values $^{131}_{53}I \rightarrow {}^{131}_{53+1}X + {}^{0}_{-1}e\ (\beta) + Q$

or $^{131}_{53}I \rightarrow {}^{131}_{54}X + {}^{0}_{-1}e\,(\beta) + Q$

The mass number stays the same, and the atomic number is increased by 1 to 54. From the periodic table we find that this is the element xenon (Xe). The daughter nucleus is xenon-131.

$$^{131}_{53}I \rightarrow {}^{131}_{54}X + {}^{0}_{-1}e(\beta) + Q$$ Answer

When iodine - 131 undergoes β - decay it converts into xenon - 131.

ASSIGNMENT 18.2: BETA DECAY OF SODIUM

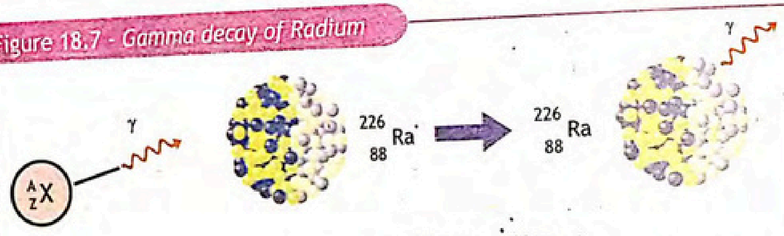
An atom of Sodium-24 can transmute into an atom of some other element by emitting a beta particle. Represent this reaction in symbols, and identify the daughter element.

C. Gamma decay: In most cases the α or β emission from the nucleus leave it in excited state such nuclei achieve further stability by emitting gamma rays.

$$^{A}_{Z}X^{*} = {}^{A}_{Z}X + \gamma \qquad (18.3)$$

Example: $^{60}_{27}Co^{*} = {}^{60}_{27}Co + \gamma$

Figure 18.7 - Gamma decay of Radium



$$^{226}_{88}Ra^{*} = {}^{226}_{88}Ra + \gamma$$

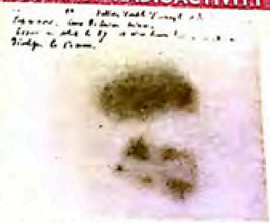
The emission of a gamma ray by radium-226 results radium-226 with gamma

Units of Activity: A common unit of activity is the curie, abbreviated Ci, which is defined to be 3.70×10^{10} decays per second. This is approximately equal to the activity of one gram of radium. The SI unit of activity is the becquerel, abbreviated Bq. *One* **becquerel** *is one decay per second.*

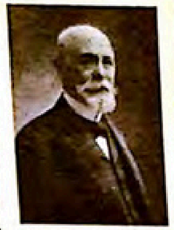
$$1\ Ci = 3.70 \times 10^{10}\ Bq = 3.70 \times 10^{10}\ decays/s$$

A SHORT HISTORY OF RADIOACTIVITY

In 1896 Henri Becquerel (French physicist) accidentally discovered Radioactivity. Becquerel discovered that uranyl potassium sulfate crystals emitted an invisible radiation that could darken a photographic plate even when the plate was covered to exclude light.



Becquerel's photographic plate. The bottom of the image shows shadow cast due to absorbed radiation.



Henri Becquerel (1852-1908)

Marie (1867-1934) and Pierre Curie (1859-1906) conducted the most significant investigations of this type. Curies reported the discovery of two unknown elements, both radioactive, which they named polonium and radium.

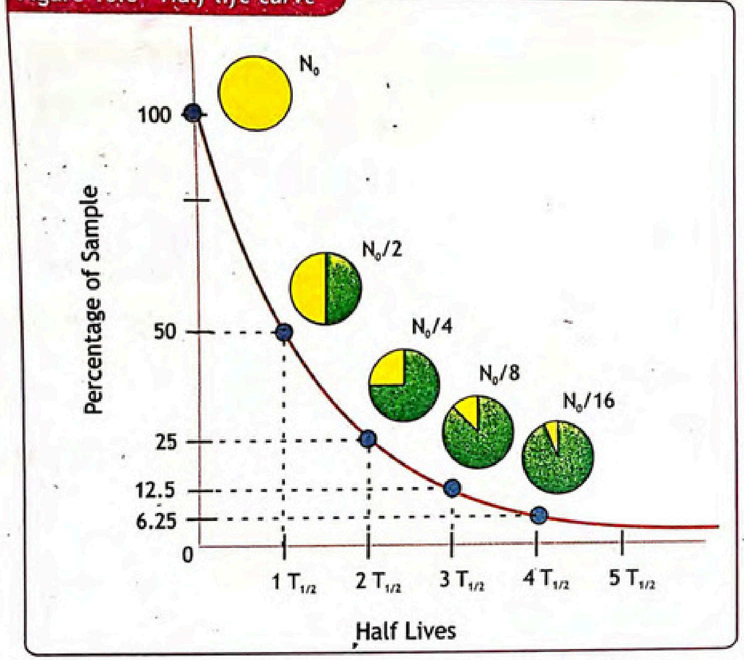
18.4 HALF LIFE

'The time it takes for half of the radioactive nuclei in a sample to decay is called half life'.

Individual disintegrations of nuclei are random, but the probability that any given nucleus will decay in a given interval of time is constant and is a characteristic of that particular nuclide.

The amount of radioactive isotope in the sample decreases with time as shown in the Half life curve shown in Figure 18.8. The number of nuclei present at time $t = 0$ s is $N = N_0$, and the number present at $t = T_{1/2}$ is $N = N_0/2$. The number present at $t = 2\,T_{1/2}$ is $N = N_0/4$, and so on. The value of the half-life depends on the nature of the radioactive nucleus. For example, radium has a half-life of 1600 years, because it takes this amount of time for one-half of a given quantity of this isotope to disintegrate.

Figure 18.8 - *Half life curve*



In another 1600 years, one-half of the remaining radium atoms will have disintegrated, leaving only one-fourth of the original number intact. Let N represent the amount of the original sample remaining after any given time interval 'Δt' and 'N_o' represent the original amount in the sample; given in the same units as 'N'. Then

After 1 half-life $\quad N = \frac{1}{2} N_o$

After 2 half-lives $\quad N = \frac{1}{2} \times \frac{1}{2} N_o = \left(\frac{1}{2}\right)^2 N_o$

After 3 half-lives $\quad N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} N_o = \left(\frac{1}{2}\right)^3 N_o$

Generally
$$N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \ldots\ldots N_o = \left(\frac{1}{2}\right)^n N_o \qquad (18.4)$$

Where, the number, n, of half-lives is equal to the time interval (Δt) divided by the time for one half-life ($T_{1/2}$).

$$n = \frac{\Delta t}{T_{1/2}} \qquad (18.5)$$

Different materials have different half lives which ranges from 10^{10} years to a fraction of second. Half lives of some common radioisotopes are shown in table 18.2.

TABLE 18.2 HALF LIVES OF SOME COMMON RADIOISOTOPES

Radioisotope	Decay	Half Life
berylium-8	α	2.0×10^{-16} s
polonium	α	1.64×10^{-4} s
iodine-131	β^-	8.04 d
cobalt-60	β^-	5.3 y
radium-226	α	1.62×10^3 y
carbon-14	β^-	5.73×10^3 y
uranium-235	α	7.04×10^8 y
uranium-238	α	4.45×10^9 y

EXAMPLE 18.3: HALF LIFE OF POLONIUM -218

You have a 160.0 μg sample of polonium-218. It decays by alpha emission with a half-life of 3.0 min. How much of the pure sample is left after 9.0 min?

GIVEN

Total quantity of pure polonium-218 'N_o' = 160 μg

Half life of polonium-218 '$T_{1/2}$' = 3.0 min

Total elapsed 'Δt' = 9 min

REQUIRED

Quantity left 'N' = ?

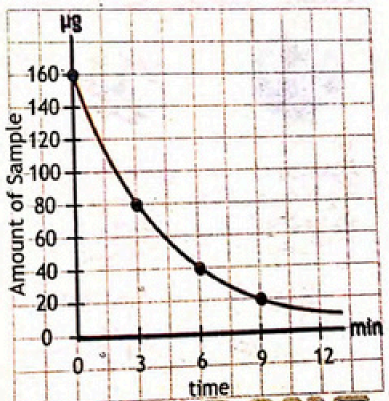
SOLUTION: The number of half lives 'n' past are

$$n = \frac{\Delta t}{T_{1/2}}$$

Putting values $\quad n = \frac{9.0\cancel{min}}{3.0\cancel{min}} = 3$

Original sample remaining after any given time interval is

$$N = \left(\frac{1}{2}\right)^n N_o$$



Putting values $N=\left(\frac{1}{2}\right)^3 \times 160\,\mu g$

or $N=\frac{1}{8}\times 160\,\mu g$ Hence $N = 20\,\mu g$ —— Answer

The graphical representation confirms that 20 μg of polonium-218 with half life of 3.0 min will be present after 9.0 min.

ASSIGNMENT 18.3: HALF LIFE OF LEAD - 210

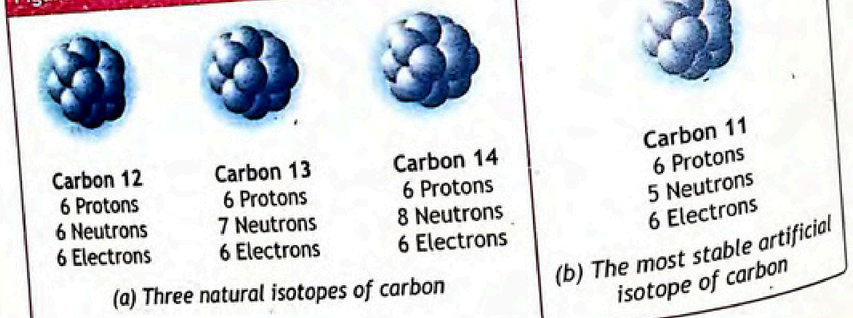
Lead - 210 has a half life of 22.3 years. How much of the 80 mg of lead will be left after 66.9 years?

18.5 RADIOISOTOPES

One of two or more forms of a chemical element having the same number of protons, or the same atomic number, but having different numbers of neutrons, or different atomic weights is called an isotope. **The isotope that are unstable and emit radiations are called radioactive isotopes or simply radioisotopes.**

Isotopes of elements that occur naturally are somewhat stable. But the isotopes, manufactured in nuclear laboratories by bombarding of subatomic particles, usually have a short life span, mostly due to their unstable nature and radioactivity. Among about 3000 known nuclides, only 257 are stable. The time scale of these decay processes ranges from a small fraction of a microsecond to billions of years.

Figure 18.9 - Isotopes of Carbon



(a) Three natural isotopes of carbon

(b) The most stable artificial isotope of carbon

The element carbon (figure 18.9) as we find it in nature consists 98.89% of ^{12}C atoms and only about 1.11% ^{13}C atoms. Whereas ^{14}C isotopes of carbon is in trace amounts, with a half life of 5,700 years. Carbon as a whole has 15 known isotopes, from ^{8}C to ^{22}C, of which the most stable artificial radioisotope is ^{11}C, which has a half-life of 20.334 minutes. All other radioisotopes have half-lives under 20 seconds, most less than 200 milliseconds.

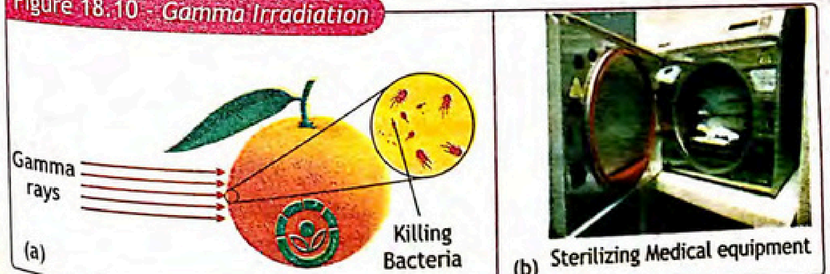
Most elements have between two and six stable isotopes (as opposed to unstable, or radioactive ones). Twenty elements, including fluorine, sodium, aluminum, phosphorus, and gold consist of only one stable isotope each. Tin, however, has ten—more than any other element.

18.5.1 Uses of radioisotopes: A radioactive isotope behaves in just the same way as the normal isotope chemically, which make it useful in wide variety of applications. Over 2,000 radioisotopes – radioactive isotopes – either exist in nature or have been made artificially by bombarding stable isotopes in particle accelerators. They are useful in so many applications that the word isotope is commonly used to mean radioisotope, as if stable isotopes did not exist. Few of the uses of radioisotopes are discussed below.

i. Food Preservation: Food irradiation is a method of treating food in order to make it safer to eat and have a longer shelf life. Even after it has been packaged, gamma rays can penetrate the packing and be used to kill bacteria, mould and insects in food as shown in figure 18.10 (a). This process prolongs the shelf-life of the food, but sometimes changes the taste.

ii. Sterilising: Gamma rays are also used to sterilise hospital equipment by irradiation, especially plastic syringes that would be damaged if heated as shown in figure 18.10 (b).

Figure 18.10 - Gamma Irradiation

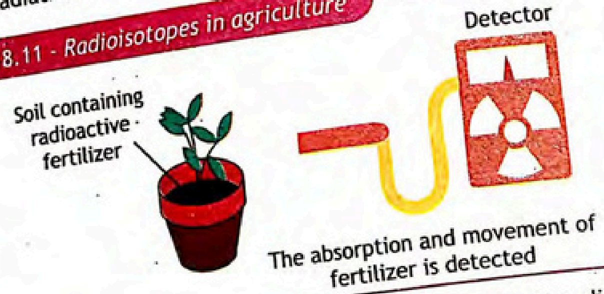


(a)

(b) Sterilizing Medical equipment

iii. Agriculture: If a plant is given fertilizer tagged with radioactive carbon-14 then the plant releases "beta radiation" and thus by measuring radioactivity in different parts of the plant, the uptake of fertilizer by plant can be determined. This technique has helped in elaborating the complex process of photosynthesis as well. Higher yield varieties of seeds have also been developed after mutation through radiation.

Figure 18.11 - *Radioisotopes in agriculture*



iv. Medical Uses: Radiopharmaceuticals – drugs that contain radioactive material – are important in the diagnosis and treatment of many diseases. They can be injected into the body, inhaled, or taken orally as medicines or to enable imaging of internal organs and bodily processes. Ionizing radiation has two very different uses in medicine – for diagnosis and therapy.

a. Medical diagnostics: Every organ in our bodies acts differently from a chemical point of view. Doctors and chemists have identified a number of chemicals which are absorbed by specific organs. The thyroid, for example, takes up iodine, the brain consumes quantities of glucose, and so on. With this knowledge, radiopharmacists are able to attach various radioisotopes to biologically active substances. Images are then obtained via gamma camera or a PET scan in nuclear diagnostics which enables to accurately detect disease progression and staging in vital organs.

A radioisotope used for diagnosis must emit gamma rays of sufficient energy to escape from the body and it must have a half-life short enough for it to decay away soon after imaging is completed.

b. Radiation therapy: High energy radiations can be used to destroy selected tissues, such as cancerous tumor.

TIP BITS

Why ^{99m}Tc is the most preferred radioisotope for nuclear diagnostics?

A technetium-99m generator

The radioisotope most widely used in medicine is technetium-99m. It is an isotope of the artificially-produced element technetium and it has almost ideal characteristics for a diagnostic scan. These are:

- It has a half-life of six hours which is long enough to examine metabolic processes yet short enough to minimise the radiation dose to the patient.
- The low energy gamma rays it emits, easily escapes the human body and are accurately detected.
- The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances to ensure that it concentrates in the tissue or organ of interest.
- Its logistics also favor its use. Technetium generators, a lead pot enclosing a glass tube containing the radioisotope, are supplied to hospitals from the nuclear reactor where the isotopes are made. They contain molybdenum-99, with a half-life of 66 hours, which progressively decays to technetium-99.

Cobalt 60 which emit beta particle and high energy gamma ray can be used to treat various cancers. Some radioisotopes are made to absorb by selected organ and radiation is concentrated on the infected tissue. For example cancerous thyroid can be treated with iodine-131.

v. Radioactive Dating: Archaeologists and geologists use radioactive dating to estimate the age of ancient objects. One common procedure uses carbon-14 which has a half-life of 5730 years. As long as the creature is alive, it will continue to absorb and collect carbon - 14. Once the creature dies, no further carbon-14 will be ingested, and the proportion of carbon-14 will start to decline.

The proportion of the total amount of carbon that is carbon-14 is very small. Nevertheless the amount is measurable. A measurement of the activity present can therefore be used to estimate the age of the specimen. Carbon-14 dating can be used for biological tissues as old as 50 or 60 thousand years, but is most accurate for younger samples, since the abundance of ^{14}C nuclei in them is greater. Very old biological materials contain no ^{14}C at all.

Materials with relatively longer half-lives can be used to determine the age of geologic formations. Uranium-238, for example, with a half-life of 4.53×10^9 years, can be used to date even the oldest deposits on Earth.

EXAMPLE 18.4: CARBON-14 DATING

Suppose you found a frozen dead animal remains in the Himalays. You took a sample from it and found that carbon-14 (half life '$T_{1/2}$'= 5730 years) activity is reduced 1/8 per gram from original value. How old are the dead animal remains?

GIVEN

Quantity left of carbon-14 'N' = $1/8\,N_o$

half life of carbon-14 '$T_{1/2}$' = 5730 years

REQUIRED

Total elapsed 'Δt' = ?

SOLUTION: Original sample remaining after any given time interval is

$$N = \left(\frac{1}{2}\right)^n N_o \quad \text{——} (1)$$

Putting values $N = \frac{1}{8}N_o$ or $N = \frac{1}{(2)^3}N_o$ or $N = \left(\frac{1}{2}\right)^3 N_o$ —— (2)

Comparing equation 1 and equation 2 $\quad n = 3$

Thus in three half lives the quantity left of carbon 14, will be $1/8\,N_o$

The number of half lives 'n' past is given by relation $\quad n = \frac{\Delta t}{T_{1/2}}$

or $\Delta t = nT_{1/2}$ Putting values $\Delta t = 3 \times 5730\ years$

Therefore $\Delta t = 17{,}190\ years$ —— Answer

The remains of the dead animal are 17,000 years old.

ASSIGNMENT 18.4: CARBON- 14 DATING

Suppose the fossil of bone you are examining has 1/4 of the carbon -14 deposits as compared to bone of the living animal per gram. The half life of ^{14}C is 5730 years, what is the approximate age of the fossil?

POINT TO PONDER

NUCLEAR REACTIONS: *A nuclear reaction is said to occur whenever an incident nucleus, particle, or photon causes a change to occur in a target nucleus.*

Such a structural change can be brought about in the nucleus by bombarding the target with sufficiently energetic particle such as neutrons, alpha particles etc. As a result the nucleons are added, removed or rearranged within a target nucleus. When Nucleus X is bombarded with some light particle *a*, the product nucleus Y and light particle b will be obtained by nuclear reaction. Mathematically

$$a + X \rightarrow Y + b$$

In 1919, Ernest Rutherford observed that when an α particle strikes a nitrogen nucleus, an oxygen nucleus and a proton are produced. This nuclear reaction is written as

$$^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}H + Q$$

In such nuclear processes the conservation laws must be followed. And in nuclear reaction the sum of number of protons and neutrons should remain constant.

Number of nucleons on LHS = Number of nucleons on RHS

For example in the reaction $\quad ^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}H + Q$

We can see that on both sides, there are 18 nucleons each.

18.6 NUCLEAR FISSION

The process of splitting of nuclei into intermediate size nuclei is called nuclear fission. The fission process often produces free neutrons and gamma rays, and releases a large amount of energy.

18.6.1 Discovery: Nuclear fission was discovered in December 17, 1938 by Otto Hahn and his assistant Fritz Strassmann, and explained theoretically in January 1939 by Lise Meitner and her nephew Otto Robert Frisch.

They found that a uranium nucleus, after absorbing a low energy neutron (thermal neutron), splits into two fragments of intermediate size. The splitting of a massive nucleus into two less massive fragments was termed as nuclear fission. It can be represented by the following nuclear reaction

$$ {}_0^1n + {}_{92}^{235}U \rightarrow {}_{92}^{236}U^* \rightarrow X + Y + \text{neutrons} \qquad (18.6)$$

Where ${}^{236}U^*$ is an intermediate excited state that lasts for only about 10^{-12} s before splitting into X and Y. The resulting nuclei X and Y are called **fission fragments**. Many combinations of X and Y are possible as fission fragments in the above nuclear reaction.

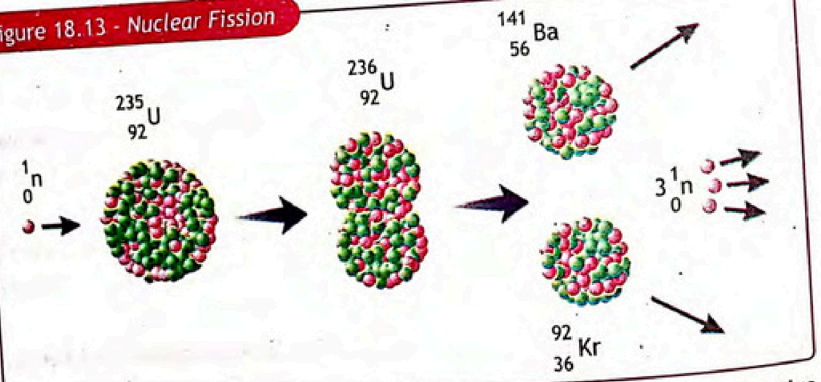
Figure 18.12 - *Lise Meitner*

Figure 18.13 shows the actual mass distribution of fragments in the fission of ${}^{235}U$. The process results in the production of several neutrons, typically two or three. On the average, about 2.5 neutrons are released per event. A typical reaction of this type is

$$ {}_0^1n + {}_{92}^{235}U \rightarrow {}_{92}^{236}U^* \rightarrow {}_{56}^{141}Ba + {}_{36}^{92}Kr + 3\,{}_0^1n + Q$$

where Q is the nuclear reaction energy.

Figure 18.13 - *Nuclear Fission*



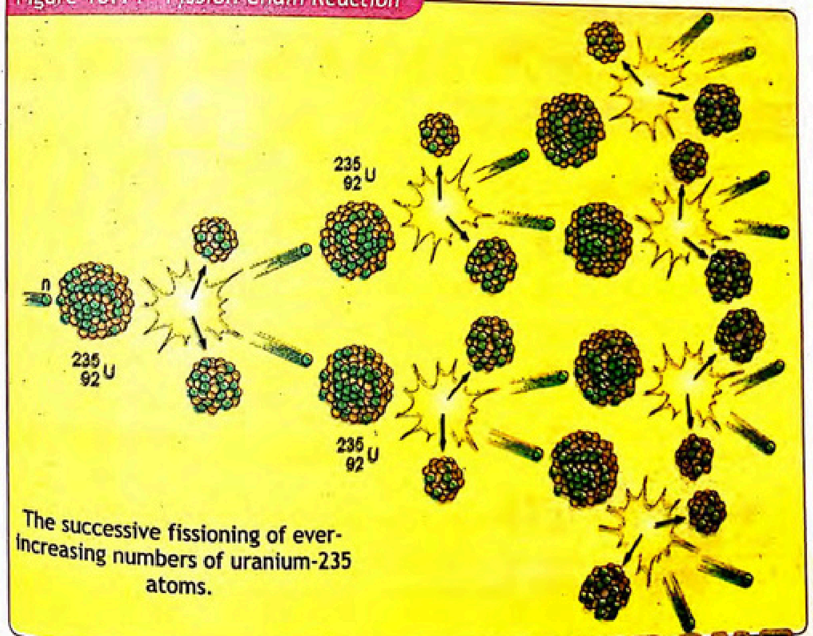
Measurement show that large amount of energy is released in this process relative to the amount of energy released in chemical processes. Thus, energy released is very high. It is found that 1 kg of uranium delivers as much energy as 3000 tons of coal.

18.6.2 Fission Chain Reaction: When one nuclear reaction causes an average of one or more nuclear reactions, thus a self-propagating series of these reactions is achieved and is called ***Fission Chain Reaction.***

The fact that fission reactions of uranium - 235 give off more than one neutron on average has significant implications. As the fission of uranium - 235 is initiated by the absorption of a neutron. So the neutrons given off by one fission reaction may cause additional fission reactions in other nuclei. If each of the neutrons emitted in fission of uranium - 235 is absorbed by another nucleus of ${}^{235}U$ and thus induce another fission process, it will result in the emission of still more neutrons, followed by more fissions, and so forth. As long as the average number of neutrons available to produce new fissions is greater than 1 per reaction, the number of fissions grows with time as shown in figure 18.14. If we have such an event in uncontrolled way, it may produce huge amount of energy is very short time. In explosion of atomic bomb we produce such an uncontrolled fission chain reaction.

The nuclear reactors on the other hand release the energy from nuclear fission in a controlled manner.

Figure 18.14 - *Fission Chain Reaction*



The successive fissioning of ever-increasing numbers of uranium-235 atoms.

18.7 NUCLEAR FUSION

When two light nuclei combine to form a heavy nucleus, the process is called nuclear fusion.

When two nuclei form a large nucleus, the mass of larger nucleus is less then the mass of nuclei that formed it. This loss in mass appears in the form of energy. A self sustaining fusion reaction is also possible but the energy required is possible only in the environments of stars including sun. One such cycle is:

A. Proton-proton cycle: In this process the direct collision of protons result in the formation of heavier nuclei whose collision in turn produces helium nuclei as shown in figure 18.15. The initial reaction in proton- proton cycle is

$$^1_1H + ^1_1H \rightarrow ^2_1H + \beta^+$$

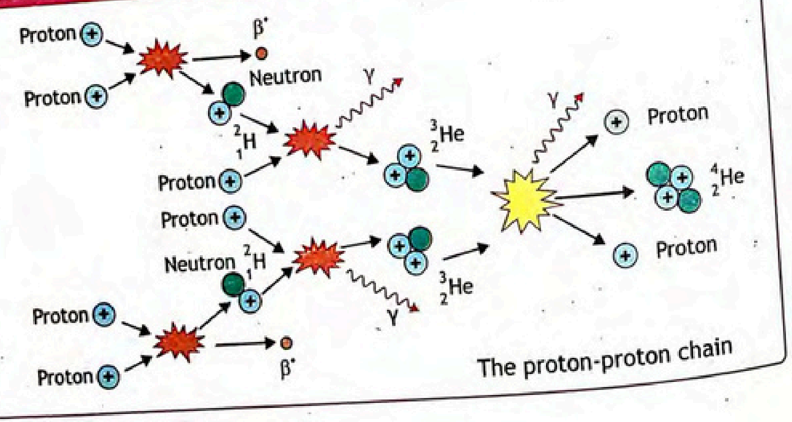
A deuteron produced in the above reaction may combine with other proton as

$$^1_1H + ^2_1H \rightarrow ^3_2He + \gamma$$

Finally, two such reactions can combine to form helium-4 with the release of two protons as

$$^3_2He + ^3_2He \rightarrow ^4_2He + ^1_1H + ^1_1H + \gamma$$

Figure 18.15 - Nuclear Fusion (Chain)



18.8 BACKGROUND RADIATION

All living creatures, from the beginning of time, have been and are still being exposed to radiation. When a radiation detector is used it will record these radiations called **natural background radiation**, it comes from three sources:

Cosmic Radiation: The earth, and all living things on it, are constantly bombarded by radiations from space. The dose from cosmic radiation varies in different parts of the world due to differences in elevation and to the effects of the earth's magnetic field.

Terrestrial Radiation: Radioactive material is also found throughout nature. It is in the soil, water and vegetation. Low levels of uranium, thorium, and their decay products are found everywhere. The dose from terrestrial sources also varies in different parts of the world.

Internal Radiation: All people also have radioactive potassium-40, carbon-14, lead-210, and other isotopes inside their bodies from birth.

18.9 HAZARDS AND SAFETY FROM RADIOACTIVE MATERIALS

Nuclear radiation is potentially harmful to humans because the ionization it produces can significantly alter the structure of molecules within a living cell. The alterations can lead to the death of the cell and even of the organism itself. The amount of biological damage produced by ionizing radiation is different for different kinds of radiation.

Everyone is continually exposed to background radiation from natural sources, such as cosmic rays (high-energy particles that come from outside the solar system), radioactive materials in the environment, radioactive nuclei (primarily carbon and potassium $^{40}_{19}K$) within our own bodies, and radon.

The effects of radiation on humans can be grouped into two categories, according to the time span between initial exposure and the appearance of physiological symptoms: (1) short-term or acute effects that appear within a matter of minutes, days, or weeks, and (2) long-term or latent effects that appear years, decades, or even generations later.

The radiation from the material can damage the cells of the person directly. This is damage by irradiation. Some of the radioactive material can be swallowed or breathed in. While inside the body, the radiation it emits can produce damage. This is damage by contamination.

18.9.1 Radiation sickness is the general term applied to the acute effects of radiation. Depending on the severity of the dose, a person with radiation sickness can exhibit nausea, vomiting, fever, diarrhea and loss of hair. Ultimately, death can occur. The severity of radiation sickness is related to the dose received, and in the following discussion, the biologically equivalent doses quoted are whole-body, single doses.

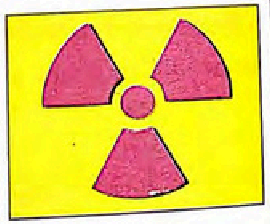
Long-term or latent effects of radiation may appear as a result of high-level, brief exposure or low-level exposure over a long period of time. Some long-term effects are hair loss, eye cataracts, and various kinds of cancer. In addition, genetic defects caused by mutated genes may be passed on from one generation to the next.

18.9.2 Safety Measures: There are three general guidelines for controlling exposure to ionizing radiation: minimizing exposure **time**, maximizing **distance** from the radiation source and **shielding** yourself from the radiation source.

While working with radiation Lab coats, shoes and safety glasses must be worn in the laboratory. Materials/equipment which are not required must not be brought into the laboratory or stored inside. An inventory of radioactive sources used in the laboratory must be maintained and updated.

POINT TO PONDER

International **(trefoil)** symbol of radiation. This sign must be posted where radioactive materials are handled or where radiation-producing equipment is used. Sign is used as a warning to protect people from being exposed to radioactivity.



International Atomic Energy Agency (IAEA) in 2007 has launched a new symbol for 'Ionizing-Radiation Warning – Supplementary Symbol'. New symbol is intended to supplement the existing, well recognized, radiation trefoil symbol. The new symbol has been designed to convey the message "Danger – Stay Away" to anyone who sees it, regardless of their age, education or cultural background.

Food items must not be stored or consumed inside the laboratory. Radiation symbols must be displayed wherever active sources are being manipulated or stored.

KEY POINTS

- **Nucleus:** a region consisting of protons and neutrons at the center of an atom
- **Nucleons:** the particles found inside nuclei
- **Nuclide:** a type of atom whose nucleus has specific numbers of protons and neutrons
- **Decay:** the process by which an atomic nucleus of an unstable atom loses mass and energy by emitting ionizing particles
- **Alpha Decay:** type of radioactive decay in which an atomic nucleus emits an alpha particle (Helium nuclei)
- **Beta Decay:** type of radioactive decay in which an atomic nucleus emits a beta particle (electrons)
- **Gamma Decay:** type of radioactive decay in which an atomic nucleus emits gamma rays (electromagnetic rays of high frequency and short wavelength)
- **Half life:** the time needed for half of the original nuclei of a sample of a radioactive substance to undergo radioactive decay
- **Radioactive:** a substance or object that emits nuclear radiation
- **Radioactive Dating:** an application of radioactive decay in which the age of a material is determined by the amount of radioactivity of a particular type that occurs
- **Carbon - 14 Dating:** a radioactive dating technique based on the radioactivity of carbon-14
- **Nuclear Radiation:** rays that originate in the nuclei of atoms
- **Nuclear Fission:** reaction in which a nucleus splits
- **Nuclear Fusion:** a reaction in which two nuclei are combined, or fused to form a larger nucleus
- **Shielding:** a technique to limit radiation exposure

PROJECTS

GROUP A 'MARIE CURIE': It is said that Marie Curie died of aplastic anemia from exposure to radiation in the course of her scientific research and radiological work at field hospitals during World War I. What is meant by the damaging effects of ionizing radiation? How much was known about damaging effects of radiation at curies time? Research her life and give a presentation about her achievements.

GROUP B 'ATOMIC BOMBS': During the final stage of World War II, the United States detonated two nuclear weapons over the Japanese cities of Hiroshima and Nagasaki on August 6 and 9, 1945, respectively. Explain the destruction from these bombs in a classroom presentation.

PROJECTS

GROUP C 'PNRA': Pakistan Nuclear Regulatory Authority (PNRA) control, regulates and supervises all matters related to nuclear safety in Pakistan. Search the internet and other materials to find out the activities, targets and performance of this organization. Prepare a report to be published in school magazine.

GROUP D 'NUCLEAR MEDICINE': Investigate careers in nuclear medicine. Interview people who work with radiation or with isotopic tracers in a hospital. Find out what kind of patients they treat or test and the technology they use. What training is necessary for this type of career? Make a presentation and discuss it with your classmates.

GROUP E 'HARMFUL EFFECTS OF RADIATION': Design a questionnaire to investigate what people in your community know about harmful effects of radiation. Give the questionnaire to your classmates for their comments and if your teacher approves, conduct a study with people in your community. Present your results in the form of a class presentation and discussion.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. What is the number of neutrons in the plutonium $^{242}_{92}Pu$
   A. 92 B. 142 C. 150 D. 242
2. Which one or more of the three decay processes (α, β, or γ) results in a new element?
   A. Only α B. Only β C. Only γ D. α and β
3. What type of nuclear decay leaves the number of protons and neutrons unchanged?
   A. alpha decay B. beta decay C. gamma decay D. both A & B
4. What type of nuclear decay most often produces the greatest mass and charge loss?
   A. alpha decay B. beta decay C. gamma decay D. both B & C
5. $^{214}_{84}Po$ undergoes α-decay to produce a daughter nucleus that itself undergoes β- decay. Which one of the following nuclei is the one that ultimately results?
   A. $^{211}_{82}Pb$ B. $^{215}_{80}Hg$ C. $^{211}_{81}Tl$ D. $^{212}_{83}Bi$
6. Radium-226 decays by emitting an alpha particle. What is the daughter nucleus?
   A. Rd B. Rn C. Bi D. Pb

7. ^{39}Ar is an isotope with a half-life of 269 yr. It will reduce to half in
   A. 134.5 min B. 134.5 Years C. 269 min D. 269 Years
8. A sample starts with 1000 radioactive atoms. How many halflives have elapsed when 750 atoms have decayed?
   A. 0.25 B. 1.5 C. 2.0 D. 2.5
9. Origin of energy from the sun and stars is
   A. fission B. fusion C. Carbon dating D. radioactivity

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

1. The atomic number of one particular isotope is equal to its mass number. Which isotope is it?
2. Which is more likely to expose, a film kept in a cardboard box, α-particles or β-particles? Explain
3. Is it possible for a form of heavy hydrogen to decay by emitting an alpha particle? Explain.
4. Different isotopes of a given element have different masses but they have the same chemical properties. Explain why chemical properties are unaffected by a change of isotope.
5. What fraction of a radioactive sample has decayed after two half-lives have elapsed?
6. Can carbon-14 dating give the age of fossil dinosaur skeletons? Explain.
7. Some food is treated with gamma radiation to kill bacteria. Why is there not a concern that people who eat such food might be consuming food containing gamma radiation?
8. Radioactive a-emitters are relatively harmless outside the body, but can be dangerous if ingested or inhaled. Explain.
9. If nuclear radiation is harmful. How it can be used for treatment of diseases?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

1. What is nucleus? How a nuclide is represented symbolically?
2. What is radioactivity? Give the nature, ionizing and penetration abilities of the three types of radioactive emissions.

3. What are nuclear transmutations? What changes in the composition of the nucleus is observed when alpha or beta particles are emitted? Explain by symbolic equations.
4. Radioactive sources are said to have half life. What is the meaning of half life?
5. What are radioisotopes? Explain their uses for various applications?
6. How is carbon-14 used to determine the ages of wood, bones and other artifacts?
7. What are fission and fusion?
9. What are background radiations? What are its major sources?
10. What are radiation hazards? How can we safeguard ourselves from radiation?

NUMERICAL QUESTIONS

1. How many neutrons are contained in a gold nucleus $^{197}_{79}Au$?
2. $^{220}_{86}Rn$ decays via alpha decay. Identify the daughter nuclide.
3. Write the nuclear equations for the beta decay of $^{210}_{82}Pb$ and $^{234}_{90}Th$
4. Iodine - 131 is an important radioisotope for medical diagnostic and treatment procedures. The half life of ^{131}I is 8.02 days. Out of 100 g of the sample how much will be left after 24 days?
5. Phosphorus-32 is used in plant sciences for tracking a plant's uptake of fertiliser from the roots to the leaves. The half life of ^{32}P is 15 days. Out of 800 μg of the activity given as fertilizer how much will be left after one month?
6. ^{12}C to ^{14}C ratio in an animal fossil is found to be one fourth of the ratio in the bone of living animal. The half life of ^{14}C is 5730 years, how old is the fossil?

Glossary

Alternating current: The current which changes its direction a number of times in one second is called alternating current.

Ammeter: A current measuring instrument is called ammeter.

Analogue electronics: The branch of electronics which deals with variable quantities is called analogue electronics.

Antinode: The points of maximum amplitude of stationary waves are called antinodes.

Atomic mass number: Total numbers of protons and neutrons present in the nucleus.

Atomic number: Number of p otons present in the nucleus.

Audio cassette: Device for collecting sound.

Capacitance: Capacitance is the ability of a capacitor to store an electrical charge.

Centre of curvature: The centre of that spherical surface whose part is the mirror.

Chromatic aberration: Defect of any lens produced due to dispersion of light.

Compressional waves: Waves in which particles of the medium vibrate parallel to the direction of the wave.

Computer: A machine which can communicate and analyse information efficiently and has a vast and long last memory.

Concave mirror: A spherical mirror whose inner polished surface reflects.

Conventional current: The current due to positive charge equivalent to negative charge flowing in the opposite direction.

Convex mirror: A spherical mirror whose external surface reflects.

Crest: In case of transverse waves, the portion of the displacement above the equilibrium position.

Critical angle: The angle in the denser medium whose respective angle of refraction in the rare medium is 90°.

Compact disc or CD: A device used to store data with the help of digital technology.

Diffraction: Bending of waves round an obstacle.

Digital electronics: Name of processing data provided in the form of digits.

Direct current: Current which always flows in one direction.

Electric current: The rate of flow of electric charge through any cross sectional area.

Electric field: The space around a charged body in which another charge experiences its effect in the form of a force.

Electric intensity: The influence of a force acting on a unit positive charge at any place.

Electric lines of force: Lines drawn in the direction of electric intensity in an electric field.

Electric potential: Potential energy of a unit charge in any electric field.

Electric power: Amount of energy obtained from electric current in unit time.

Electromagnetic field: Production of magnetic field due to passage of electric current through a conductor.

Electromagnetic induction: The phenomenon in which e.m.f. is produced due to relative motion of coil and magnet.

Electromagnetic waves: Such waves, which do not require any material medium for their propagation.

Electromotive force: The energy needed to move a charge through the whole circuit including the battery.

Electronics: The branch of physics in which the flow of electrons is controlled and used according to the need in semiconductor devices.

Electroscope: An instrument used for measuring the nature and presence of charge on a body.

Far sightedness: A defect of eyes due to which near objects are not clearly visible.

Fixed capacitor: The capacitor whose parts are fixed by design.

Floppy: A device used for storing computer data.

Focal length: The distance between the pole and principal focus of any mirror or the distance between optical centre and principal focus of any lens.

Fusion reaction: The phenomenon in which small nuclei diffuse each other to form a larger nucleus.

Galvanometer: An instrument which indicates the current in a circuit.

Half life: The time in which the number of atoms of a radioactive element becomes half.

Information technology: Scientific method of collecting, arranging processing and arranging information.

Infrasonics: Sound of frequency less than 20 hertz, which are inaudible to human ears.

Intensity of sound: Energy transmitting per second through a unit area placed perpendicular to the direction of sound waves.

Interference: Resultant displacement of two or more waves in a medium by combining the two coherent waves.

Internet: Important source of global contact.

Isotopes: Atoms of an element whose atomic number is same but mass number is different.

Kilowatt hour: Quantity of that energy which is obtained from one kilowatt power in one hour.

Magnetic flux: The number of magnetic lines of forces passing through any surface.

Magnification: The ratio of the height of the image to the height of the object.

Mechanical waves: Such waves which require a material medium for their propagation.

Music: Pleasant and musical sound.

Mutual induction: The current induced in the coil by the change of flux in the nearby coil.

Natural radioactivity: The natural, spontaneous emission of radiation from radioactive element.

Noise: Unpleasant sound.

N-type Semi-conductor: A semi-conductor in which pentavalent impurity is doped.

Nuclear fission reaction: The splitting of heavy nucleus into two parts in which huge amount of energy is released.

Pitch: Characteristic of sound due to which shrill and grave sound is distinguished.

P-N junction: A semi-conductor diode.

Pole: Centre of the mirror.

Power of lens: Inverse value of focal length (in metre).

Principal focus: Point from where rays parallel to the principal axis pass after reflection from a concave mirror.

P-type semi-conductor: A semi-conductor in which trivalent impurity is doped.

Quality of sound: Characteristic of sound due to which different sounds are distinguished.

Radio isotopes: Isotopes which emits different radiation.

Radio: An instrument which imparts sounds to us.

Rectification: Conversion of alternating current into direct current.

Reflection: Bouncing of waves after striking from the other medium.

Refractive index: Ratio of speed of light in air to the speed of light into any other medium.

Remote control: An instrument which controls television or electronic equipments by sitting at a place in line with a device.

Self induction: The e.m.f. induced in a coil due to change in the current of that coil.

Semi-conductor: Elements of the 4^{th} group silicon and germanium.

Short sightedness: A defect of eyes due to which distant objects are not seen clearly.

Simple harmonic motion: Vibratory motion in which the acceleration of the body is directly proportional to its displacement.

Solenoid: Cylindrical coil of the wire having more than one turn.

Sound: A form of energy which is transferred from one place another due to compressional waves.

Specific resistance: Resistance of unit length and unit cross sectional area of a conductor.

Spherical aberration: Defect of thick and large aperture of a lens.

Stationary waves: Waves in which the amplitude of all particles of the medium remains constant.

Tele communication: To impart information quickly to far off areas.

Total internal reflection: The reflection of light in the same denser medium from the surface of a rare medium.

Transformer: An electric instrument which increases or decreases the value of alternating voltage.

Transverse waves: Waves in which particles of the medium vibrate perpendicular to the direction of motion of the wave.

Trough: In case of transverse waves, portion of the displacement below the equilibrium position.

Ultrasonics: Sound of frequency more than 20000 hertz, which are inaudible t human ears.

Variable capacitor: A capacitor whose area of plates can be changed and desire capacitance can be achieved.

Video cassette: A device used to store sound and pictures.

Voltmeter: An instrument used for the measurement of potential difference between the ends of a circuit.

3050
150
00000
152500
30500
457500

Answers

Answer Chapter 10

Assignment 10.1 :	2 s
Assignment 10.2 :	- 45 N
Assignment 10.3 :	1.4 s
Assignment 10.4 :	54.6°
Assignment 10.5 :	9.77 N/kg
Assignment 10.6 :	2.02×10^4 Hz
Numerical problem 10.1:	1.25 Hz, 0.8 s
Numerical problem 10.2:	2.5×10^3 N/m
Numerical problem 10.3:	0.99 m, 0.16 m, 0.5 s and 0.5 s
Numerical problem 10.4:	50 Hz, 0.02 s
Numerical problem 10.5:	1.4 Hz
Numerical problem 10.6:	0.5 Hz
Numerical problem 10.7:	244 m, 3.26 m

Answer Chapter 11

Assignment 11.1 :	2.39 dB
Assignment 11.2 :	1.7 km or 1 mile
Assignment 11.3 :	Speed = 350 m/s and Frequency 1400 Hz
Assignment 11.4 :	1320 m
Numerical problem 11.1:	109.14 dB
Numerical problem 11.2:	1.5×10^3 m/s or 1500 m/s
Numerical problem 11.3:	134 decibels
Numerical problem 11.4	106.02
Numerical problem 11.5:	319.2 m/s.
Numerical problem 11.6:	1.7 km or mile
Numerical problem 11.7:	17 m and 1.7 cm
Numerical problem 11.8:	330 m/s, 32 m

Answer Chapter 12

Assignment 12.1 :	- 1.64
Assignment 12.2 :	-0.45 m (virtual image, behind the mirror) 0.18 m (upright, smaller image)
Assignment 12.3 :	1.44
Assignment 12.4 :	1.33, water
Assignment 12.5 :	42.2°
Assignment 12.6 :	15.0 cm, - 0.500 - 5.56 cm, 0.445
Assignment 12.7 :	3 times, 4 times
Assignment 12.8 :	The magnification is reduced in magnitude. Its new value is -79
Assignment 12.9 :	-197, 990 mm

NOT FOR SALE

Numerical problem 12.1:	60 cm, - 4.5 cm
Numerical problem 12.2:	- 3.33 cm, - 0.8 cm
Numerical problem 12.3:	1.56×10^8 m/s
Numerical problem 12.4:	33°, 74°
Numerical problem 12.5:	66.3°
Numerical problem 12.6:	0.571,+4
Numerical problem 12.7:	9.3
Numerical problem 12.8:	30 mm, 1200 mm

Answer Chapter 13

Assignment 13.1 :	26.0 N
Assignment 13.2 :	8 µN
Assignment 13.3 :	60 J
Assignment 13.4 :	4 µF
Assignment 13.5 :	2×10^{-6} F or 2 µF, 33.3 V and 66.6 V
Assignment 13.6 :	9×10^{-6} F or 9 µF, 2400 µC and 4800 µC
Numerical problem 13.1:	8.22×10^{-8} N and
Numerical problem 13.2:	(a) 11.25 N (b) force on 10 µC charge is same as force on 5 µC charge (c) 2.25×10^6 N/C or) 2.25 M N/C
Numerical problem 13.3:	(a) 0.129 N positive x-direction (b) 0.428N negative x-direction
Numerical problem 13.4:	5 C
Numerical problem 13.5:	0.704 µC or 7.04×10^{-7} C
Numerical problem 13.6:	0.54 µF, 60 V, 30 V and 20 V
Numerical problem 13.7:	5 pF, 18 pC, 27 pC

Answer Chapter 14

Assignment 14.1 :	180 A
Assignment 14.2 :	8.0 A
Assignment 14.3 :	1.5 Ω
Assignment 14.4 :	0.5 A
Assignment 14.5 :	9.09 s
Assignment 14.6 :	4.54 s
Assignment 14.7 :	3.6 Ω
Assignment 14.8 :	Rs. 1784.2
Numerical problem 14.1:	30 V
Numerical problem 14.2:	3.2 A
Numerical problem 14.3:	600 Ω
Numerical problem 14.4:	0.3 A
Numerical problem 14.5:	15.6 A, 34000 J (34 kJ)
Numerical problem 14.6:	17 J
Numerical problem 14.7:	Rs. 5.84

NOT FOR SALE

Answer Chapter 15	
Assignment 15.1 :	2.8 N
Assignment 15.2 :	8.6 mH
Assignment 15.3 :	1350 V
Numerical problem 15.1:	0.3 N
Numerical problem 15.2:	2.5×10^{-3} N
Numerical problem 15.3:	8 A
Numerical problem 15.4:	14 mH
Numerical problem 15.5:	80, 22000
Numerical problem 15.6:	5.45
Numerical problem 15.7:	0.06
Answer Chapter 18	
Assignment 18.1 :	Radon - 220 , $^{220}_{86}Rn$
Assignment 18.2 :	Magnesium - 24, $^{24}_{12}Mg$
Assignment 18.3 :	10 mg
Assignment 18.4 :	11,460 years
Numerical problem 18.1:	118
Numerical problem 18.2:	$^{220}_{86}Rn \rightarrow ^{216}_{82}Pb + ^{4}_{2}He$ (Bismuth)
Numerical problem 18.3:	$^{210}_{82}Pb \rightarrow ^{210}_{83}Bi + \beta^{-}$ (Bismuth)
	$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + \beta^{-}$ (Protactinium)
Numerical problem 18.4:	12.5 g
Numerical problem 18.5:	200 μg
Numerical problem 18.6:	22,920 years

Author's Profile

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مومن تو آپس میں بھائی بھائی ہیں

پس اپنے دو بھائیوں میں صلح کرا دیا کرو

اور اللہ سے ڈرتے رہو

تا کہ تم پر رحمت کی جائے۔

(سورۃ الحجرات: ۱۰)