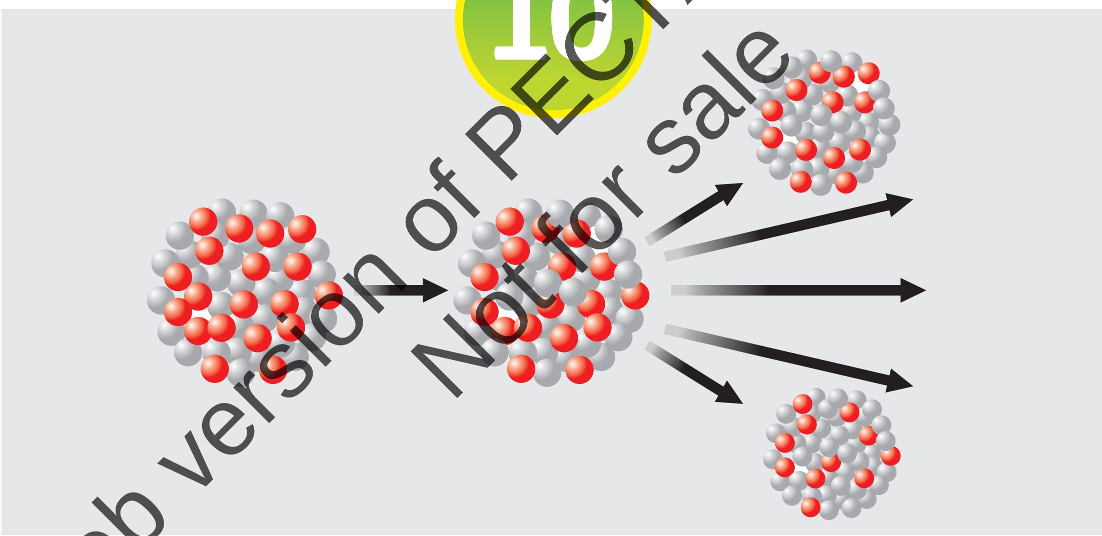
بِسۡمِ اللّٰہِ الرَّحۡمٰنِ الرَّحِیۡمِ

(In the Name of Allah, the Most Merciful, the Most Compassionate.)

PHYSICS (Tech)

10



PECTAA
Transformation, Innovation and Excellence

PUNJAB EDUCATION, CURRICULUM, TRAINING AND ASSESSMENT AUTHORITY

AUTHORS

- **Dr. Naveed Afzal**
  Ph.D (Physics), Universiti Sains Malaysia
  Associate Professor
  Centre for Advanced Studies in Physics,
  Government College University, Lahore
- **Dr. Mohsin Rafique**
  Ph.D (Physics), Hanyang University, South Korea
  Assistant Professor
  Centre for Advanced Studies in Physics,
  Government College University, Lahore

Editor

- **Ghulam Ullah**

Table of Contents

CHAPTER 10

THERMAL PHYSICS

Student's learning outcomes (SLOs)

After studying this unit, student will be able to:

- describe qualitatively the thermal expansion of solids (linear and volumetric expansion).
- explain the thermal expansion of liquids (real and apparent expansion) and gases.
- discuss the pressure and the changes in pressure of a gas in terms of particles [the forces exerted by particles colliding with surfaces, creating a force per unit area.]
- define and calculate specific heat for solids and liquids.
- discuss everyday effects due to the large specific heat of water.
- define latent heat of fusion and latent heat of vaporization of ice and water. How these can be determined Experimentally? [including illustrating the analysis of data by sketching temperature-time graph on heating ice.]

Heat and temperature play a vital role in our daily life, from feeling the warmth of the Sun to enjoying a cold drink on a hot day. Thermal physics helps us to understand how heat flows, how the temperature of substances change , and how heat energy is transferred. This field explains important concepts such as temperature, heat transfer, specific heat capacity and latent heat. Thermal physics is not just about daily life, it also helps scientists to explore space, develop efficient energy systems, and emendate modern technology.

10.1 Thermal Expansion

Thermal expansion is the change in length, area, or volume of a substance when it is heated. As the temperature rises, the particles within a substance gain more kinetic energy. This causes them to move faster and spread out, leading to expansion of the material (Fig. 10.1-b).

Conversely, when a substance is cooled, its particles lose energy and move closer together, causing the material to contract (Fig. 10.1-a). This phenomenon is known as thermal contraction.

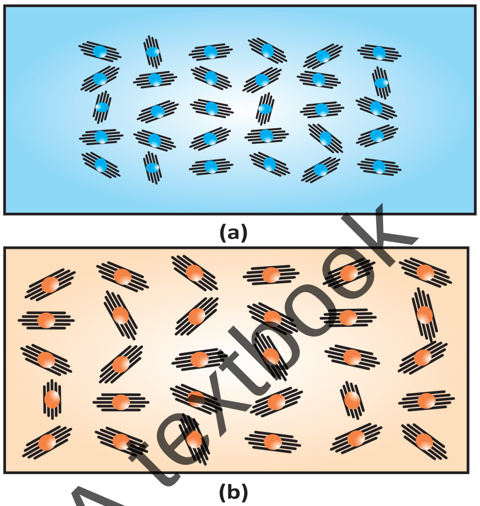


Fig. 10.1: Molecules of an object moving with (a) smaller amplitude at low temperature (b) larger amplitude at higher temperature

Thermal Expansion in Solids

When solids are heated, they expand, and this expansion remains almost consistent over a broad temperature range. Change in temperature may cause respective change in length or volume of the solids. If length of a solid changes upon heating, then it is called linear thermal expansion. For example, consider a metal rod in Fig. 10.2 with an initial length L_o at a temperature T_o. When heated to a temperature T, its new length becomes L. Thus, the increase in length of the rod is:

$$\Delta L = L - L_o$$

and the rise in temperature is:

$$\Delta T = T - T_o$$

It has been observed that the change in length ΔL of a solid is directly proportional to its original length L_o and the temperature change ΔT. Thus,

$$\Delta L \propto L_o \Delta T$$

or $$\Delta L = \alpha L_o \Delta T$$

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

or $$L - L_o = \alpha L_o \Delta T$$

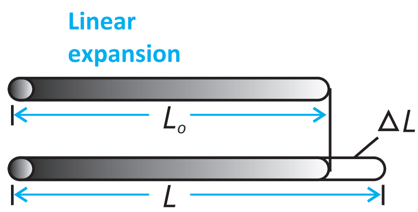


Fig. 10.2: Linear expansion in a metal rod

or $L = L_o(1 + \alpha \Delta T)$ ....(10.1)

Here α is called the coefficient of linear thermal expansion of the material. Table 10.1 shows the value of 'α' of different solid materials.

Table 10.1: Values of some coefficient of linear expansion (α) of different solid materials

Substance	α (K^{-1})
Aluminium	2.4×10^{-5}
Brass	1.9×10^{-5}
Copper	1.7×10^{-5}
Steel	1.2×10^{-5}
Silver	1.93×10^{-5}
Gold	1.3×10^{-5}
Platinum	8.6×10^{-5}
Tungsten	0.4×10^{-5}
Glass (pyrex)	0.4×10^{-5}
Glass (Ordinary)	0.9×10^{-5}
Concrete	1.2×10^{-5}

The volume of a solid also increases when its temperature rises. This is known as volume thermal expansion. Suppose a solid has an initial volume V_o at a temperature T_o. When heated to a temperature T, its new volume becomes; $\Delta V = V - V_o$.

and the rise in temperature is: $\Delta T = T - T_o$

Similar to linear expansion, the increase in volume ΔV is directly proportional to its original volume V_o and the temperature change ΔT, thus

$$\Delta V \propto V_o \Delta T$$

$$\text{or} \quad \Delta V = \beta V_o \Delta T$$

$$\text{or} \quad V - V_o = \beta V_o \Delta T$$

$$\text{or} \quad V = V_o(1 + \beta \Delta T) \quad \text{................ (10.2)}$$

Here β is called coefficient of volume expansion which determines how much a material expands with temperature. Different solids have different values of β, meaning some expand more than others when heated.

Mathematically,

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

In solids, atoms are arranged in a tight, regular pattern. As the temperature rises, each atom pushes slightly harder against its neighbours due to increased vibration. Since there is no room to move inwards, the structure expands outward instead.

Thermal Expansion in Liquids

When a liquid is heated, its volume increases. This happens because the heat energy makes the liquid molecules move faster, causing them to spread apart and take up more space. Unlike solids, which have a fixed shape and expand in a limited way, liquids do not have a definite shape, so they expand freely in all directions when their temperature rises.

The degree to which a liquid expands depends on its specific coefficient of volumetric expansion, a property unique to each substance. This expansion is quantified by the formula:

$$\Delta V = \beta V_o \Delta T \quad \text{................} \quad (10.3)$$

where ΔV is the change in volume, β is the volume expansion coefficient, V_o is the initial volume, and ΔT is the temperature change.

A common example of thermal expansion in liquid as seen in a flask (Fig 10.3). When the flask is heated, the glass expands leading to decrease in liquid level from A to B which is known as expansion of flask (AB). As the liquid heats up, it expands and the level rises from B to C which is known as real expansion (BC). Where AC is an apparent expansion. Remember that real expansion is always greater than apparent expansion.

BC = AC+AB

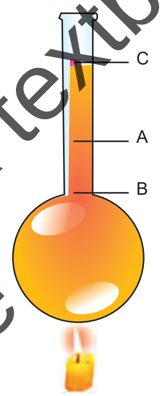


Fig. 10.3 : Thermal expansion of a liquid

Tidbit

Liquids do not have a fixed shape, so they expand more freely than solids. That is why we should not fill a bottle of water to the top before freezing it, it might crack.

Thermal Expansion in Gases

When temperature of a gas increases, its volume increases as long as the pressure remains same. This is called thermal expansion of the gas. As the temperature of a gas increases, the kinetic energy of its particles also increases. This causes the gas molecules to move faster and collide more frequently and forcefully with the walls of the container. Thus, collisions exert pressure, on the container walls.

If a gas is in a non flexible container, the increased collisions lead to a rise in pressure. However, in a flexible container, the volume can expand instead, allowing pressure to remain constant. This behaviour aligns with Charles' law, which states that the volume of a gas is directly proportional to its temperature at constant pressure.

The expansion of gases plays an important role in daily life and various industries. For example, in a hot air balloon, the air inside is heated, causing it to expand and become lighter than the cooler air outside. This makes the balloon to rise (Fig. 10.4). Similarly, in car engines, fuel burns and produces hot gases that expand quickly, pushing the pistons and making the vehicle move. In weather patterns, warm air expands and rises, affecting air pressure and causing winds and weather changes. However, the uncontrolled expansion of gases can be dangerous. For instance, aerosol cans and gas cylinders can explode if exposed to high temperatures because the gas inside expands beyond what the container can withstand.

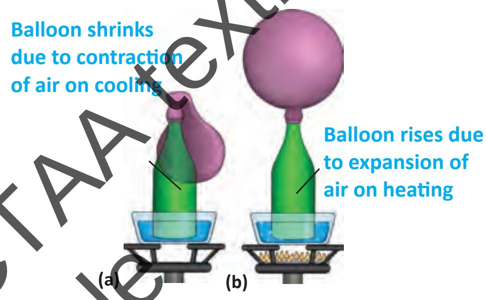


Fig. 10.4: Thermal expansion of gas in a balloon (a) Before heating (b) After heating

Example 10.1: A metal rod of length 1.5 m expands by 0.025 m when heated from 30 °C to 180 °C. Calculate its coefficient of linear expansion.

Solution:

Given that;

L_o = Initial length = 1.5 m

ΔL = Change in length = 0.025 m

ΔT = Change in temperature = 180 °C - 30 °C = 150 °C or 150 K

To find; α = Coefficient of linear expansion = ?

The formula for linear expansion is:

$$\Delta L = \alpha L_o \Delta T$$

or

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

Substituting the values

$$\alpha = 0.025 \text{ m} / 1.5 \text{ m} \times 150 \text{ K}$$

$$\alpha = \frac{0.025}{225} = 1.11 \times 10^{-4} \text{ K}^{-1}$$

10.2 Specific Heat Capacity

The energy required to heat a material depends on three factors:

1. Mass of the substance
2. Change of temperature
3. Nature of the material

Some substances absorb heat more easily than others. For example, heating 1 kg of water by 1 °C requires more energy than heating 1 kg of alcohol by the same amount. This relationship is expressed using the formula:

$$Q = m\, c\, \Delta T \quad \text{................(10.4)}$$

where

Q = heat energy

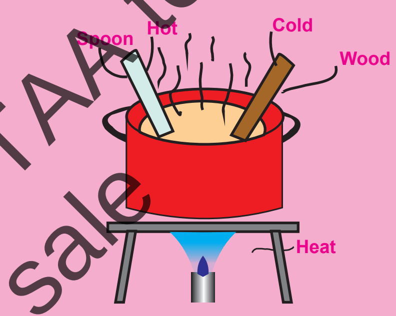
m = mass of the substance

ΔT = change in temperature

c = specific heat capacity

Specific heat capacity (c) is the amount of heat energy needed to increase the temperature of 1 kg of a substance by 1 °C (or 1 K). The SI unit of specific heat capacity is $\text{J kg}^{-1}\text{K}^{-1}$.

For Your Information



Metal heats up quickly due to its low specific heat capacity, while wood stays normal because of its higher specific heat capacity.

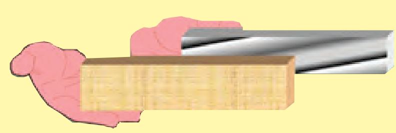
Specific Heat Capacity of Solids

The specific heat capacity of solids is the heat energy needed to raise the temperature of 1 kg of a solid by 1 °C. Materials with a high specific heat capacity, such as wood and rubber require more heat to increase their temperature, making them useful in applications like cooking utensils and thermal insulation. On the other hand, metals like steel and copper have low specific heat capacities, i.e; they heat up and cool down quickly, so they are used in making cooking items, kettles, radiators, and heat engines.

Do You Know?

Why does metal feel colder than wood when touched, if they are both at the same temperature?

Metal is a conductor, wood is an insulator. The metal conducts the heat away from our hands, the wood does not conduct the heat away from our hands as well as the metal, so the wood feels warmer than the metal.



Specific Heat Capacity of Liquids

The specific heat capacity of a liquid is the amount of heat energy needed to raise the temperature of 1 kg of the liquid by 1 °C or 1 K. Different liquids have different specific heat capacities based on their molecular structure and ability to store heat. One of the most important liquids in this regard is water, which has a high specific heat capacity of 4,200 J kg^{-1} K^{-1}. This means water can absorb and store a large amount of heat with only a small temperature increase. Because of this property, water is widely used in cooling systems, heating systems, and as a natural temperature stabilizer. Other liquids, such as alcohol and mercury, have lower specific heat capacities, meaning they heat up and cool down more quickly than water.

Effects of Large Specific Heat Capacity of Water

Large water bodies like oceans and lakes absorb heat during the day and release it slowly at night, preventing drastic temperature changes. This is why coastal areas have milder climates compared to inland regions. Since water has a specific heat capacity of 4200 J kg^{-1} K^{-1}, while dry soil has only 810 J $kg^{-1}K^{-1}$, soil heats up five times faster than the same mass of water under the same heat. As a result, land temperatures rise and fall more quickly than sea temperatures, making seasonal temperature changes less extreme in coastal areas.

Water's high specific heat capacity also makes it useful for storing and transferring heat. In an automobile engine, the cooling system uses water to absorb and carry away the heat produced during the engine operation. The pump circulates water through jackets around the engine cylinders, where it absorbs heat (Fig. 10.5). This heated water then flows through the thermostat, which regulates its movement based on temperature. If the water is too hot, the thermostat opens, allowing it to enter the radiator. In the radiator, a fan draws in outside air, which cools the water passing through it. The cooled water then returns to the engine to absorb more heat, and this

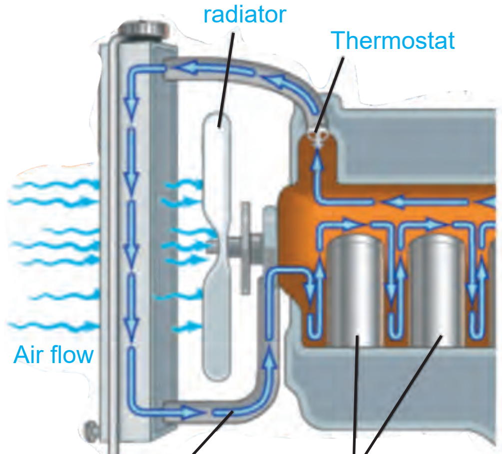


Fig. 10.5: Cooling system of automobile

cycle is repeated. A pressure release cap ensures that the system remains safe by releasing excess pressure. This property helps water to carry away engine heat efficiently, preventing overheating and ensuring smooth engine performance.

10.3 Latent Heat

Latent heat is the heat energy required to change the state of a substance without changing its temperature.

This heat is used to break or form bonds between particles instead of increasing their movement.

Latent Heat of Fusion

Latent heat of fusion is the heat energy required to convert 1 kg of a solid into a liquid at its melting point while keeping the temperature constant. When a solid melts into a liquid, it absorbs heat without rise in temperature. This heat is used to break the strong bonds between solid particles, allowing them to move more freely as a liquid. The temperature remains constant until the entire solid has melted. The latent heat of fusion is calculated using the formula:

Tidbit

When ice melts or water boils, energy is working hard behind the scenes to break bonds between molecules but the thermometer does not show any rise in temperature.

$$Q = m\,L_f \quad \text{............(10.5)}$$

where

L_f = Latent heat of fusion

Q = Heat energy

m = Mass of the substance

Example: Ice at 0 °C absorbs heat but remains at 0 °C until it completely melts into water.

The latent heat of fusion of ice is 3.36×10^5 J kg^{-1}, meaning 3.36×10^5 joules of heat is needed to melt 1 kg of ice into water at 0 °C.

Example 10.2: How much heat is required to melt 600 g of ice at 0 °C into water at 0 °C? Latent heat of fusion of ice is 3.36×10^5 J kg^{-1}.

Solution:

Given that;

Mass of ice m = 600 g

= 0.600 kg

Latent heat of fusion of ice L_f = 3.36×10^5 J kg^{-1}

To find;

Heat required Q = ?

Using the formula: $Q = m \times L_f$

Substituting the values $Q = 0.600 \text{ kg} \times 3.36 \times 10^5 \text{ J kg}^{-1}$

Q = 201,600 J

Q = 201.6 kJ

Experiment 1: This involves placing small ice pieces in a beaker over a stand, suspending a thermometer to measure temperature. Heating the beaker causes the ice to melt, keeping the mixture at 0 °C until all ice melts. Note the time taken for complete melting. Further heating causes water temperature to rise from 0 °C to 100 °C. Record the time for this increase. Plot a temperature-time graph (Fig. 10.6) and calculate the latent heat of fusion of ice using collected data.

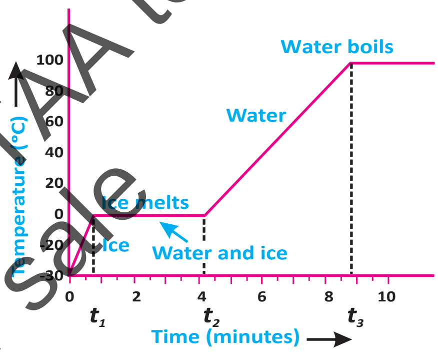


Fig. 10.6: Temperature-time graph as ice changes into water that boils as heating continues

Latent Heat of Vaporization

Latent heat of vaporization is the heat energy needed to change 1 kg of a liquid into gas at its boiling point without changing the temperature.

When a liquid changes into gas, it absorbs heat, but its temperature remains constant until the entire liquid has evaporated. This heat is used to break the bonds between liquid molecules, allowing them to escape as gas. The latent heat of vaporization of water is 2.26×10^6 J kg^{-1}. This means 2.26×10^6 J of heat energy is needed to convert 1 kg of water into steam at 100 °C. The latent heat of vaporization is expressed as:

$$Q = m\,L_V \quad \text{............} \quad (10.6)$$

where L_V is latent heat of vaporization, Q is heat energy and m is the mass of the substance

Table 10.2 shows the melting point, boiling point, latent heat of fusion, and latent heat of vaporization of some common substances.

Experiment 2: At the end of experiment 1, the beaker contains boiling water. Continue heating water until all the water changes into steam. Note the time which the water in the beaker takes to change completely into steam at its boiling point 100 °C.

Table 10.2: Melting point, boiling point, latent heat of fusion, and latent heat of vaporization of some common substances

Substance	Melting point (°C)	Boiling point (°C)	Heat of fusion ($J g^{-1}$)	Heat of vaporization ($J g^{-1}$)
Aluminium	660	2250	39.7	10500
Copper	1083	2595	205.0	4810
Gold	1063	2660	64.0	1580
Helium	-270	-269	5.5	21
Lead	327	1750	23.0	858
Mercury	-39	357	11.7	270
Nitrogen	-210	-196	25.5	200
Oxygen	-219	-183	13.8	210
Water	0	100	336.0	2260

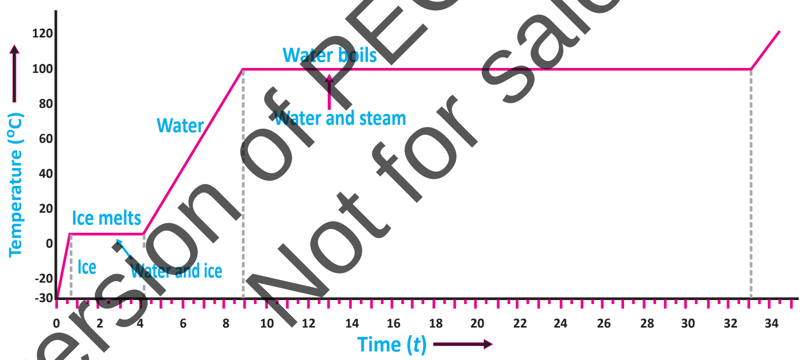


Fig. 10.7: Temperature-time graph as ice changes into water and water into steam on heating

Extend the temperature-time graph as shown in Fig. 10.7. Calculate the latent heat of fusion of ice from the data.

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

10.1 When the temperature of a rod of copper is increased, its length:
(a) remains the same (b) increases (c) decreases (d) becomes double

10.2 The amount by which unit length of a material increases when the temperature is raised to 1 °C, is called the coefficient of:
(a) cubic expansion (b) volume expansion
(c) linear expansion (d) none of these

10.3 Gas pressure inside a container increases if gas particles:
(a) collide less frequently with walls of the container
(b) lose kinetic energy
(c) strike the container walls more frequently and forcefully
(d) decrease in number

10.4 Which property determines how much heat a solid can absorb before its temperature changes significantly?
(a) Density (b) Specific heat capacity (c) Colour (d) Hardness

10.5 Water's high specific heat capacity helps to moderate climates because water:
(a) freezes quickly (b) heats and cools slowly
(c) evaporates instantly (d) boils at lower temperatures

B. Short Answer Questions

10.1 What factors influence the thermal expansion of solids?

10.2 What is latent heat of fusion?

10.3 How do different materials exhibit varying thermal expansion behaviours?

10.4 What do you understand by specific heat capacity?

10.5 What is latent heat of vaporization, and how is it calculated?

C. Constructed Response Questions

10.1 If two liquids are heated under identical conditions but one heats up more quickly, what does this reveal about their specific heat capacities?

10.2 Which one is bigger, real expansion or apparent expansion?

10.3 Whose specific heat capacity is large, liquids or solids, and why?

10.4 Why do elective transmission wires sag in summer and tighten in winter?

D. Comprehensive Questions

10.1 How does thermal expansion differ between solids, liquids, and gases? Provide examples to illustrate these differences.

10.2 What is the difference between latent heat of fusion and latent heat of vaporization? Explain.

10.3 What is specific heat capacity? Describe the effects of large specific heat capacity of water.

10.4 Why do solids, liquids, and gases expand when heated? Explain with examples.

E. Numerical Problems

10.1 A metal rod of length 1 m expands by 0.02 m when heated from 20 °C to 120 °C. Calculate its coefficient of linear expansion. **[Ans: 2.0×10^{-4} K^{-1}]**

10.2 A container holds 1 litre of water at 20 °C. What will be its volume at 80 °C, assuming water's coefficient of volume expansion is 2.1×10^{-4} per °C? **[Ans: 1012.6 cm^3]**

10.3 A steel rod initially measures 2 m at 20 °C. If its coefficient of linear expansion is 1.2×10^{-5} $°C^{-1}$, what will be its length at 100 °C? **[Ans: 2.002 m]**

10.4 How much heat is required to raise the temperature of a 2 kg iron bar from 20 °C to 100 °C, given that the specific heat capacity of iron is 450 J kg^{-1} K^{-1}? **[Ans: 72 kJ]**

10.5 How much heat is required to melt 500 g of ice at 0 °C into water at 0 °C? (Latent heat of fusion of ice = 3.36×10^{5} J kg^{-1}) **[Ans: 168 kJ]**

10.6 Calculate the heat required to completely vaporize 1 kg of water at 100 °C. (Latent heat of vaporization of water = 2.26×10^{6} J kg^{-1}) **[Ans: 2.26 MJ]**

CHAPTER 11

TRANSFER OF THERMAL ENERGY

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- explain thermal conduction in all solids (in terms of atomic or molecular lattice vibrations and also in terms of the movement of free (delocalized) electrons in metallic conductors).
- analyze everyday applications of conduction, convection, and radiation. (a) Heating objects such as kitchen pans (b) Using thermal insulation to maintain the temperature of a liquid and to reduce thermal energy transfer in buildings .
- explain convection in liquids and gases [in terms of density changes]. Justify experiments to illustrate convection.
- explain convection in seawater to support marine life.
- describe the role of land breezes and sea breezes in maintaining moderate coastal climates.
- explain how birds are able to fly for hours without flapping their wings and gliders are able to rise by riding on thermal currents.
- describe the process of thermal energy transfer by radiation [and know that it does not require a medium].
- describe the effect of surface colour and texture on the emission, absorption, and reflection of infrared radiation.
- justify qualitatively how the rate of emission of radiation depends on the surface temperature and surface area of an object.
- analyze the consequence of heat radiation in the greenhouse effect and its effect on global warming.

Heat is an important form of energy that is essential for life. It plays a pivotal role in cooking, maintaining our body temperature, and supporting various industrial processes. Understanding how heat flow is important for protecting ourselves from extreme temperatures. In this chapter, we will look into the different methods of heat transfer. When two objects with different temperatures come into contact, thermal energy flows from the hotter object to the cooler one, a process known as heat transfer. This is a natural occurrence that continues as long as there is a temperature difference between the objects. Thermal energy constantly transfers from one object to another until thermal equilibrium is reached. Whether it is the Sun warming the Earth, a hot cup of coffee, or a metal rod heating when placed in a flame, heat transfer is a fundamental part of daily life. This chapter focuses on the three primary types of heat transfer conduction, convection, and radiation. Understanding of these processes is important not just in nature, but also in the fields like engineering, meteorology, and technology.

11.1 Conduction

Conduction is the process by which heat is transferred through direct contact between particles in a material, without any actual movement of the material. It happens when fast-moving (hotter) particles collide with slow-moving (cooler) particles, transferring their kinetic energy (Fig. 11.1). This method of heat transfer is most efficient in solids, especially in metals, as their particles are densely packed, and freely moving electrons facilitate the quick transfer of energy.

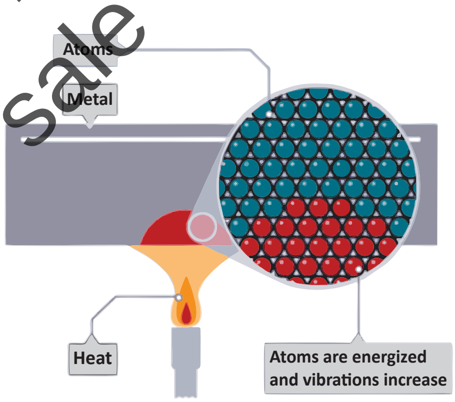


Fig. 11.1: Heat transfer in metals through conduction

Thermal Conduction in Solids

When the handle of a metal spoon is placed in hot water, it quickly becomes warm, whereas the handle of a wooden spoon does not heat up. This difference highlights how materials transfer heat in different ways. Both metals and non-metals can conduct heat, but metals are typically much better at it. In solids, the atoms and molecules are tightly packed and constantly vibrate around their mean positions as shown in Fig. 11.1. When one end of the solid is heated, the particles at that end begin to vibrate more vigorously. These vibrating particles collide with nearby atoms or molecules, transferring some of their energy. This process causes the neighbouring particles to vibrate more rapidly and, in turn, pass some of their energy to other surrounding particles. Gradually, heat spreads throughout the solid, but the transfer is slow, with only a small amount of heat moving from the hotter to the cooler parts. In conduction, heat transfers through a solid medium due to a temperature difference.

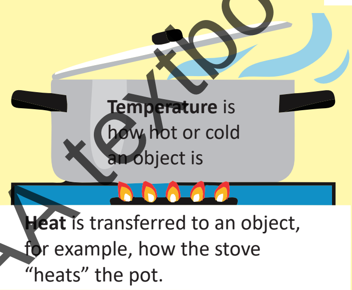
why does heat travel more quickly in metals than in non-metals?

Metals have free electrons that can move freely within the material. These fast-moving electrons carry energy quickly from the hot areas to the cooler areas of the metal. This is why heat moves more rapidly through metals than non-metals.

Tidbit

Diamonds are the best heat conductors, far better than metals. A high quality diamond can conduct heat 4-5 times better than copper.

Do You Know?



11.2 Convection in liquids and Gases

Liquids and gases are not very efficient in conducting heat. However, heat can still be transferred through these fluids (liquids or gases) by a process called convection.

When a liquid or gas is heated, it becomes less dense (lighter) and expands. The heated liquid or gas rises above the heat source, and cooler fluid from the surrounding area moves in to take its place. This colder fluid then gets heated as well. In this way, heat is transferred through fluids by the movement of heated molecules from the hotter parts to the colder parts of the fluid.

Convection is the transfer of heat through the actual movement of molecules from a hot area to a cold area.

Experiment: (For Liquid Convection)

Fill a beaker two-thirds with water and heat it by placing a burner underneath. Now drop two or three potassium permanganate crystals into the water. We will notice coloured streaks moving upward above the flame, then flowing downward along the sides, as shown in Fig. 11.2. These coloured streaks reveal the movement of currents within the liquid. But why do these currents stop when the burner is removed? As the water at the bottom of the beaker heats up, it expands, becoming lighter and rising. Meanwhile, the cooler, denser water sinks to replace it.

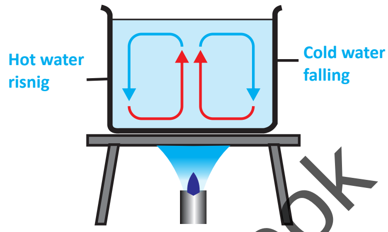


Fig. 11.2: Convection currents circulate heat as hot water rises and cold water sinks

Convection Currents in Air

When gases get heated, they expand, and this creates convection currents due to the differences in air density at various points in the atmosphere. This can be demonstrated with a simple experiment, as shown in Fig. 11.3. Can you explain the process?

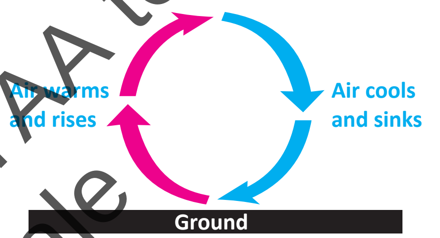


Fig. 11.3: Convection currents drive air circulation as warm air rises and cool air sinks

This process begins when the Sun heats the Earth's surface, warming the air close to the ground. As the air warms up, it becomes lighter and less dense, causing it to rise. As it rises, it cools down, becomes denser, and sinks back toward the surface. The cooler air then gets heated, and the cycle repeats. This movement of air creates convection currents, which are responsible for various natural phenomena such as winds, sea breezes, and weather patterns. These currents help to distribute heat throughout the atmosphere, playing a vital role in regulating Earth's climate and weather.

Applications of Convection Currents

Convection currents created by electric, gas, or coal heaters are used to warm our homes and offices. Central heating systems also rely on convection to distribute heat throughout the buildings. On a larger scale, convection currents occur naturally in the environment. The daily changes in temperature in the atmosphere are caused by the movement of warm or cool air. Land and sea breezes are examples of convection currents in nature.

Land and Sea Breezes

Why does a sea breeze blow during the day, and why does a land breeze occur at night?

Land and sea breezes are caused by convection. During the day, the land heats up faster than the sea due to the land's lower specific heat capacity. The warm air above the land rises, and cooler air from the sea moves in to replace it, creating a sea breeze, as shown in Fig.11.4.

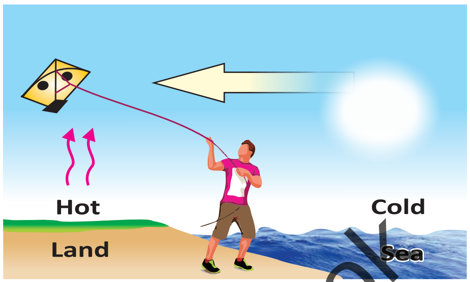


Fig. 11.4: Sea breeze blows from sea to land as warm air rises over heated land (day time)

At night, the land cools down more quickly than the sea. As a result, the air above the sea becomes warmer and rises, while cooler air from the land moves towards the sea, creating a land breeze, as illustrated in Fig. 11.5.

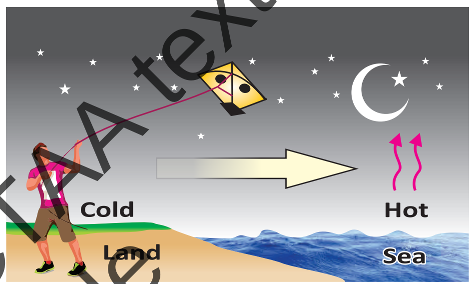


Fig. 11.5: Land breeze blows from land to sea as warm air rises over heated water (night time)

Gliding

What keeps a glider in the air?

A glider, which is like a small plane without an engine, relies on the upward movement of warm air currents, or thermals, created by convection (Fig. 11.6).

Fig. 11.6: A glider

Gliders take advantage of these rising currents of warm air to stay in the air for extended periods. Similarly, birds use thermals to stay aloft for hours without flapping their wings. They stretch their wings and circle in the thermals, allowing them to gain altitude as the warm air rises. Birds such as eagles, hawks, and vultures are especially skilled at using thermals to glide over long distances with little effort, barely needing to flap their wings (Fig. 11.7).

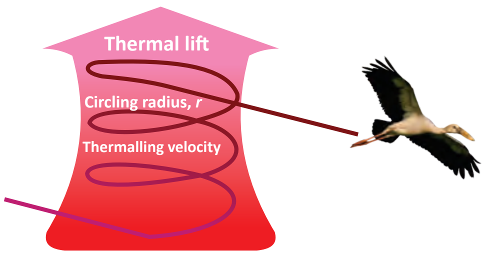


Fig. 11.7: Birds flying taking the advantage of thermal air currents

Convection in Seawater and Marine Life

Convection plays an important role in seawater and is important for supporting marine life. When sunlight heats the surface of the ocean, the warm water becomes lighter and stays at the top, while the cooler, denser water sinks to the bottom. This difference in temperature causes convection currents in the ocean. These currents continuously move water up and down, helping to mix oxygen from the surface into deeper layers and bringing nutrients from the ocean floor to the surface. This process is very important for the survival of marine animals and plants because it ensures that there is enough oxygen and food available at different depths. Without convection, the deep ocean would lack oxygen, and surface waters would lack nutrients, making it difficult for marine ecosystems to thrive.

Brain Teaser

Why do we feel a nice breeze coming from the sea during the day time at the beach?

Brain Teaser

How can birds fly for hours without moving their wings much in sunny weather?

11.3 Heat Transfer through Radiation

The Sun serves as the main source of heat for our planet. However, this heat does not reach the Earth through conduction or convection, as there is no medium between the Sun and Earth's atmosphere. Instead, heat is transferred via radiation, a process in which energy travels across space in the form of electromagnetic waves. This is the mechanism through which the Sun's heat reaches the Earth.

In radiation, heat transfer occurs through electromagnetic waves without requiring a medium.

Radiation from a Fireplace

How does heat travel from a fireplace to us (Fig. 11.8)?

Heat does not reach us via conduction through the air because air neither conducts heat efficiently nor transfers heat but radiation emitted is influenced by various factors, including:

- the colour and texture of the surface
- the temperature of the surface
- the surface area

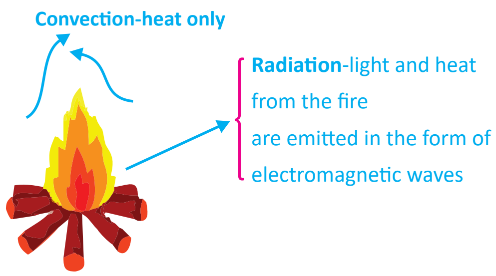


Fig. 11.8: Thermal radiations transform in form of E.M waves

Why Objects Cool or Warm Over Time?

Why does a hot cup of tea cool down over time, and why does a cold glass of water warm up? All objects in a room, including the walls, ceiling, and floor radiate heat while simultaneously absorbing it. If temperature of an object is higher than that of its surroundings, it radiates more heat than it absorbs. Consequently, its temperature decreases until it matches the temperature of the surrounding environment. On the other hand, if the temperature of the object is lower than its surroundings, it absorbs more heat than it radiates, causing its temperature to rise until it reaches equilibrium with the environment. The rate at which different surfaces emit heat depends on their characteristics. This phenomenon can be illustrated with Leslie's cube (Fig. 11.9).

Do You Know?

- Convection is when liquid or gases get heated.
- Conduction is when something is hot and it touches another object and it becomes hot.
- Radiation is when energy travels through E.M. waves to heat something up.

Leslie's Cube – Emission and Absorption of Radiation

Leslie's cube is a metal box with faces of different materials, such as:

- a shiny silver surface
- a dull black surface
- a white surface
- a coloured surface

When the cube is filled with hot water and one face is directed towards a radiation detector, it is found that the dull black surface is the most effective emitter of heat (Fig. 11.9). The rate at which different surfaces absorb heat also varies based on their nature. For example, when comparing a dull black surface with a polished silver one, the dull black surface absorbs heat more rapidly, causing its temperature to rise quickly, while the polished silver surface absorbs heat more slowly and warms up at a much slower rate. These observations are recorded and compared for clarity (Fig.11.10).

Do You Know?

Dull black surfaces absorb and emit more heat than shiny surfaces that is why solar panels are black.

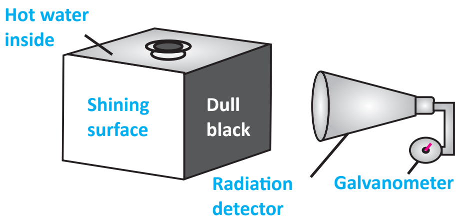


Fig. 11.9: Radiations from Leslie's cube

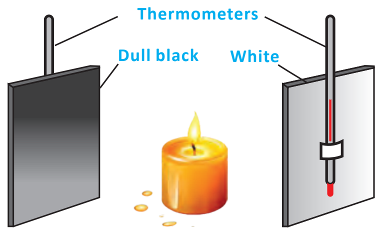


Fig. 11.10: A comparison of absorption of radiations

Effect of Surface Colour and Texture on Infrared Radiation

The colour and texture of a surface have a strong effect on how it emits, absorbs, and reflects infrared radiation. Dull and dark-coloured surfaces are very good at absorbing and emitting infrared radiation. That is why a dull black surface heats up quickly and cools down faster by giving off more heat. On the other hand, shiny and light-coloured surfaces are poor absorbers and emitters of radiation. Instead, they reflect most of the infrared radiation away. This is why shiny surfaces, like polished metals, stay cooler under the Sun compared to dark surfaces. The texture also matters. Rough surfaces absorb and emit radiation better, while smooth surfaces tend to reflect more radiation.

Tidbit

Heat from the Sun reaches us through radiation, no air needed, just pure energy travelling across space.

Impact of Surface Temperature and Surface Area on Heat Transfer

The rate of radiation emitted by an object depends greatly on two important factors: the surface temperature and the surface area. When the surface temperature of an object increases, it radiates more energy because hotter objects emit more heat compared to cooler ones. For example, a hot iron rod glows and emits more heat than a warm one.

Similarly, the surface area also plays a major role. If an object has a larger surface area, it can emit or absorb more heat at a faster rate. This is why radiators used for heating rooms are made with lots of thin slots or fins to increase the surface area without taking up too much space. A larger area means more radiation can happen at the same time, making heat transfer more efficient. Thus, both a higher surface temperature and a larger surface area help an object emit thermal energy more quickly through radiation.

Applications of Heat Transfer

1. Heating Objects such as Kitchen Pans

One everyday application of heat transfer is when we cook food using kitchen pans. When a pan is placed on a stove, heat from the flame or heating element transfers to the pan mainly by conduction. The metal of the pan, being a

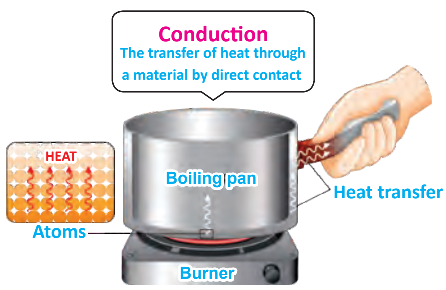


Fig. 11.11: Heat transfer through conduction in a boiling pan

good conductor, quickly absorbs the heat and passes it through the surface. This causes the entire pan to become hot, allowing food placed inside to cook evenly (Fig.11.11).

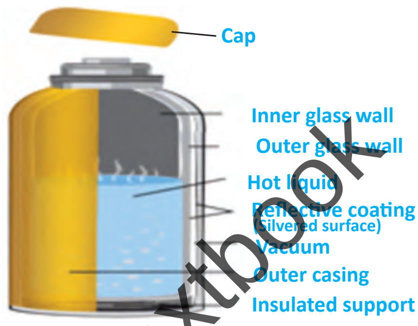


Fig. 11.12: Thermos flask

2. Using Thermal Insulation to Maintain the Temperature of a Liquid

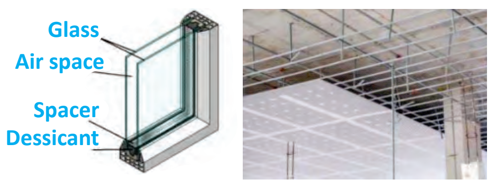
Thermal insulation helps to keep hot things hot and cold things cold. For example, a thermos flask (vacuum flask) has double walls with a vacuum between them (Fig. 11.12). The vacuum stops heat transfer by conduction and convection because there is no air or material to move heat. The inside walls of the flask are coated with a reflective layer (silvered coating) that bounces back radiation to keep the liquid warm. The outer casing and lid are made of insulating materials like plastic or stainless steel to prevent heat loss. This smart design helps liquids like tea, coffee, or soup to stay at the right temperature for many hours.

3. Reducing Thermal Energy Transfer in Buildings

Thermal insulation in buildings helps to keep them warm in winter and cool in summer. By adding things like thick curtains, foam in the walls, double-glazed windows (Fig. 11.13-a), or false ceilings (Fig. 11.13-b). We can reduce heat loss through conduction, convection, and radiation. In cold weather, insulation stops warm indoor air from escaping. In hot weather, it prevents heat from entering from outside. This reduces the need for heaters and air conditioners, saving energy and lowering costs. Even simple ideas like using proper shading outside the windows or ensuring good ventilation can make a big difference in controlling indoor temperature.

Tidbit

The handle of a cooking pan stays cool because it is made of poor conductors like wood or plastic.



(a) Doubled-glazed window **(b)** False cieling

Fig. 11.13: Reducing thermal energy transfer

11.4 Greenhouse Effect

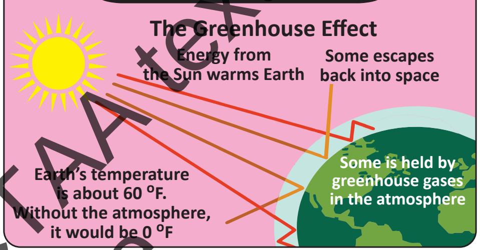
The greenhouse effect refers to the process by which the Earth's atmosphere traps some of the Sun's heat, maintaining a temperature that is suitable for life.

Without this effect, the planet would be too cold to support life as we know it.

Temperature Regulation in a Greenhouse

How is the temperature controlled inside a greenhouse? The Sun emits both short-wavelength light and ultraviolet radiations and long-wavelength thermal radiations (infrared). Transparent materials such as glass and plastic allow short-wavelength radiations to pass through but block long-wavelength infrared radiation. This creates a heat trap inside the greenhouse. The rays from the Sun warm the objects inside the greenhouse, and these objects emit radiations with longer wavelengths. However, the glass or plastic sheets prevent this longer-wavelength radiations from escaping, reflecting it back into the greenhouse and maintaining a warm environment that benefits plant growth.

For Your Information



Tidbit

The increased carbon dioxide from human activities in causing a green house effect that is heating the planet. But carbon dioxide comprises only 0.035% of our atmosphere and is a very week green-house gas.

Greenhouse Effect on Earth

The Earth's atmosphere functions in a similar way to a greenhouse, trapping heat from the Sun with gases such as carbon dioxide and water vapours (Fig. 11.14). This helps to maintain the Earth's temperature. In recent years, the amount of carbon dioxide in the atmosphere has increased significantly, strengthening the greenhouse effect. As a result, more heat is trapped, leading to a rise in the Earth's average temperature, a phenomenon known as global warming. This increase in temperature has serious implications for global climate patterns.

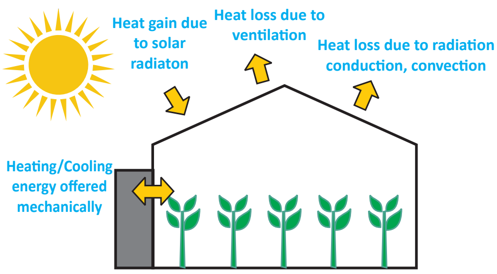


Fig. 11.14: Heat transfer mechanisms in a greenhouse

Do You Know?

- Greenhouse gases absorb solar energy and trap it in the atmosphere.
- Without greenhouse gases creating what is known as the "Greenhouse Effect" the Earth would not be warm enough for human to live.

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

11.1 Which method of heat transfer requires direct contact between particles?
(a) Convection
(b) Radiation
(c) Conduction
(d) Evaporation

11.2 What causes convection currents in liquids and gases?
(a) The continuous movement of particles in all directions
(b) The rising of warm regions and sinking of cooler regions
(c) The conduction of heat through the medium
(d) The reflection of heat waves

11.3 The natural phenomenon caused by convection currents is:
(a) earthquakes
(b) land and sea breezes
(c) magnetic fields
(d) solar eclipses

11.4 How does heat transfer occur through radiation?
(a) Through direct contact between objects
(b) Through the movement of heated fluid
(c) Through electromagnetic waves without needing a medium
(d) Through the absorption of water molecules

11.5 The surface which absorbs and emits the most radiation is:
(a) smooth and shiny surfaces
(b) dark and rough surfaces
(c) transparent and thin surfaces
(d) polished and white surfaces

11.6 What is the role of the greenhouse effect in Earth's temperature regulation?
(a) It allows all heat to escape into space
(b) It blocks heat from entering the atmosphere
(c) It traps heat to maintain a stable temperature
(d) It causes immediate cooling of Earth's surface

11.7 The Sun's heat reaches the Earth:
(a) through conduction between air particles
(b) through convection in space
(c) through radiation via electromagnetic waves
(d) through reflection by the moon

B. Short Answer Questions

11.1 What are the three primary types of heat transfer?
11.2 Why does heat travel faster in metals compared to non-metals?
11.3 How does convection transfer heat in liquids and gases?
11.4 What natural phenomenon causes land and sea breezes?
11.5 How do birds and gliders take advantage of convection currents?
11.6 What is radiation, and how does it transfer heat?
11.7 Why does a dull black surface emit and absorb more radiation than a shiny silver surface?
11.8 How does the greenhouse effect help regulate Earth's temperature?

C. Constructed Response Questions

11.1 During the Leslie's Cube experiment, why does the dull black surface radiate more heat than the shiny silver one, even though they are at the same temperature?
11.2 Why is convection not possible in solids, and how do convection currents in liquids and gases compensate for their poor thermal conductivity?
11.3 How do birds like eagles and gliders manage to stay aloft without flapping their wings for hours? Explain the scientific principle involved.
11.4 Why does a hot metal object placed in a cooler room eventually cool down? Explain using the concepts of radiation and thermal equilibrium.

D. Comprehensive Questions

11.1 Describe how convection occurs in fluids. How do convection currents contribute to natural phenomena such as sea breezes and wind patterns?
11.2 How does radiation differ from conduction and convection in terms of heat transfer? Give examples of radiation in everyday life and explain how different surfaces affect radiation absorption and emission.
11.3 Discuss the role of the greenhouse effect in regulating Earth's temperature. What are the potential consequences of an enhanced greenhouse effect due to human activities?
11.4 Compare the absorption and emission of heat by different surfaces. How does the colour and texture of a surface affect its ability to absorb and emit heat?
11.5 How heat energy is transferred by convection in liquids and gases? Explain how the whole room is heated by placing a stove or heater at one place in the room.

CHAPTER 12

WAVES

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- prove that waves transfer energy without transferring matter.
- describe what is meant by wave motion [as illustrated by vibrations in ropes and springs and by experiments using water waves].
- state the types of waves:
  - (i) transverse waves
  - (ii) longitudinal waves
- describe the features of a wave [in terms of wave front, wavelength, frequency, time period, crest (peak), trough, compression, rarefaction, amplitude and wave speed].
- define the terms frequency, wavelength and amplitude.
- recall and apply the equation wave speed = frequency × wavelength; $v = f\lambda$
- illustrate that for a transverse wave the direction of vibration is at right angles to the direction of the energy transfer [including giving examples such as electromagnetic radiation, waves on the surface of water, and seismic waves].
- illustrate that for a longitudinal wave, the direction of vibration is parallel to the direction of the energy transfer [including giving examples such as sound waves and seismic P-waves (primary)].

The concept of waves demonstrates the transfer of energy from one place to another without the transfer of the matter. Waves play a vital role in understanding various phenomena of our everyday life. Waves are all around us from small ripples on a quiet lake to the loud sound of thunder in the sky. In this chapter, we will explore various types of waves, and the principles that govern their behaviour. We will uncover the main concepts such as amplitude, wavelength, frequency, and speed of waves. Through experiments and real life examples, we will also see how waves influence our daily lives and contribute to various fields, including communication, medicine, and technology.

12.1 Waves and Nature of Waves

As waves travel through a medium, they cause the particles within it to vibrate. These vibrations allow energy to be transferred from one particle to the next, as shown in Fig. 12.1. However, the particles themselves do not move along with the wave. They simply oscillate around their original positions. For example, when a twig is dropped into still water, ripples spread across the surface, as shown in Fig. 12.2. These ripples carry energy outward, yet the water and the twig remain mostly in place.

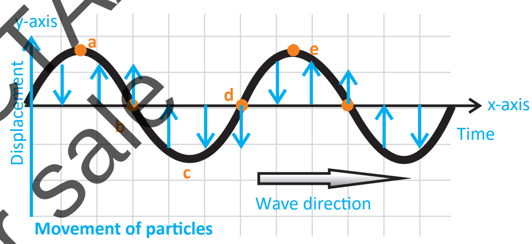


Fig 12.1: Vibration of particles in a wave perpendicular to the wave direction

A similar effect occurs with sound waves. When a guitar string is plucked, it creates vibrations that travel through the air as sound waves (Fig. 12.3). The air particles do not move toward our ears; instead, they vibrate in place to pass the energy forward.

Fig 12.2: Ripples in water showing energy transfer without transfer of matter

Waves can transfer energy from one place to another without transferring matter.

The same principle is illustrated by vibrations in a spring. When one end of a stretched spring is pushed and released, longitudinal waves move through the spring. As shown in

Fig. 12.4, the spring develops regions of compression (where the coils are close together) and rarefaction (where the coils are spread out). These compressions and rarefactions travel along the spring, showing how energy is transmitted without the entire spring moving forward. This experiment visually demonstrates wave motion and how longitudinal waves (such as sound) travel through matter.

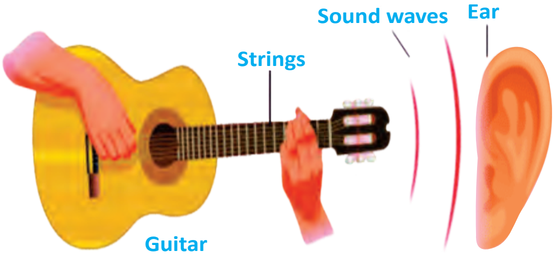


Fig 12.3: Vibrations from a guitar string producing sound waves that transfer energy through air to the ear

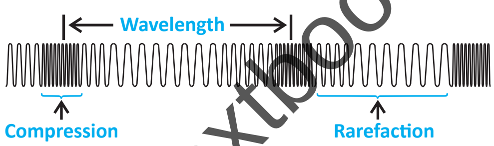


Fig 12.4: Longitudinal wave (Stretched spring)

Water Wave Experiment to Demonstrate Wave Motion

A simple and effective way to understand wave motion is through an experiment using a ripple tank, as shown in Fig. 12.5. In this setup, a shallow tray is filled with water to a uniform depth. A bar, connected to a motor, vibrates up and down gently on the water's surface. This disturbance generates ripples or wave crests that spread outward across the water surface.

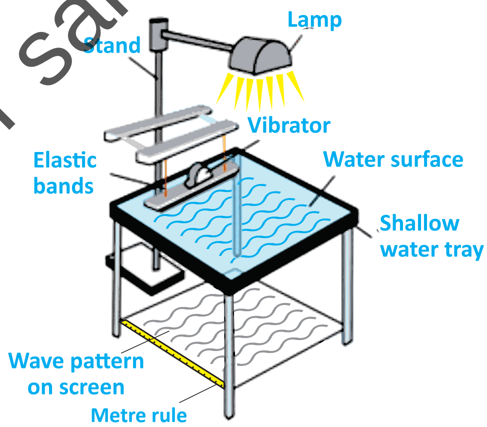


Fig. 12.5: Ripple tank

12.2 Types of Waves

There are two main types of waves:

1. Mechanical Waves

Mechanical waves are waves that require a material medium such as air, water, or a solid material to travel. These waves cannot pass through vacuum because they rely on the vibration of particles in the medium to transfer energy. The particles of the medium vibrate

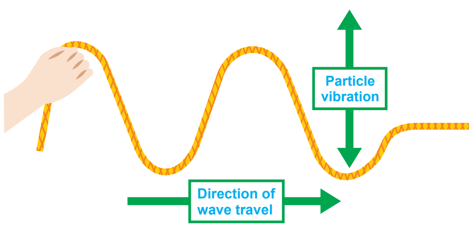


Fig. 12.6: A transverse wave on a rope showing particle vibration perpendicular to the direction of wave travel

and pass the energy along, even though the particles themselves do not move with the wave.

A simple way to observe this is by moving one end of a rope up and down. The wave travels along the rope, but each part of the rope only moves vertically while the wave itself moves forward, as shown in Fig. 12.6.

Examples of mechanical waves include sound waves, water waves, vibrations on a rope or spring, and seismic waves produced by earthquakes.

> **Tidbit**
>
> Waves carry energy across oceans, air, and even empty space without dragging particles along with them.

2. Electromagnetic Waves

Electromagnetic waves are different from mechanical waves because they do not require a material medium to travel. These waves can move through empty space (vacuum), that is why sunlight and other types of radiation from the Sun are able to reach the Earth through space.

Examples of electromagnetic waves include radiowaves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays.

These waves differ in their wavelengths and frequencies, but they all travel at the same speed in vacuum approximately 3,00,000 km per second (3×10^8 m s^{-1}), known as the speed of light.

> **Do You Know?**
>
> 
>
> ***Radiowaves*** are electromagnetic waves that travel at the speed of 3,00,000 kilometre per second through air.

> **Tidbit**
>
> Infra means below; infrared waves have a lower frequency than red waves. Warm objects radiate light in the infrared region of the spectrum.

The range of all these electromagnetic waves is called the electromagnetic spectrum, as illustrated in Fig. 12.7.

The Electromagnetic Spectrum

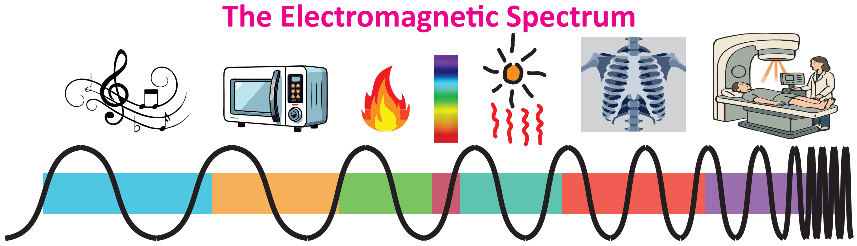


Fig. 12.7: Types of electromagnetic waves arranged by wavelength

Types of Mechanical Waves

Mechanical waves are divided into two main types, depending on how the particles of the medium vibrate in relation to the direction the wave travels. These are:

1. Transverse Waves

2. Longitudinal Waves

Transverse Waves

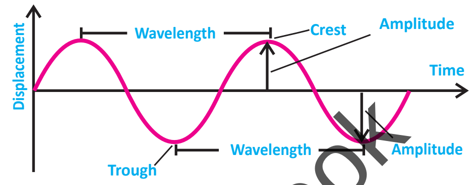


Fig. 12.8: A transverse wave labelled with crest, trough, wavelength, and amplitude

Brain Teaser

When we shake a stretched slinky spring side-to-side and then push it back and forth. What two types of waves did we just create?

In transverse waves, the particles of the medium vibrate at right angles to the direction in which the wave is travelling. This perpendicular vibration causes the energy to transfer through the medium without any significant forward movement of the particles themselves. A simple way to observe a transverse wave is by holding one end of a rope and moving it up and down. While the wave travels horizontally along the rope, the rope segments move vertically. This motion results in the formation of the highest points known as crests and the lowest points called troughs, as shown in Fig. 12.8.

An excellent example of a transverse wave is a water wave. As the wave moves forward across the water surface, the water molecules move up and down rather than along with the wave. Another important example is electromagnetic radiation (such as light, radiowaves, and X-rays), where the electric and magnetic fields oscillate perpendicular to the direction of energy propagation.

Longitudinal Waves

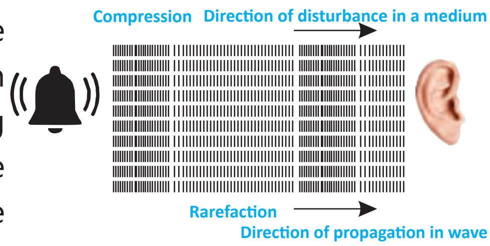


Fig. 12.9: A longitudinal sound wave showing compressions and rarefactions

In longitudinal waves, the particles of the medium vibrate parallel to the direction in which the wave is travelling. Instead of moving up and down like in transverse waves, where the particles move back and forth along the same path as the energy flow. This creates regions where particles are close together, known as compressions, and regions where particles are spread apart, known as rarefactions (Fig. 12.9).

A common and important example of a longitudinal wave is a sound wave. When a sound is produced, such as when someone claps his hands, the air molecules near the hands are first pushed together, forming a compression. Immediately after, they spread apart into a rarefaction as the wave continues to move forward through the air. This sequence of compressions and rarefactions allows sound to travel to our ears without the air itself moving permanently from the source to the listener.

12.3 Terms and Parameters of Waves

A transverse wave is shown in Fig. 12.8, labelled with crest, trough, wavelength, and amplitude. The definitions of these key terms are given below:

> **Tidbit**
>
> Frequency tells us how many waves pass a point in one second. That is why FM radio station is called "88.0 MHz". It is sending 88 million wave cycles per second.

Crest

The crest is the region of a transverse wave, above the mean position.
It is the upper part of a wave.

Trough

The trough is the region of a transverse wave, below the mean position.
It is the lower part of a wave.

Compression

A compression is a region in a longitudinal wave where the particles of the medium are close together, resulting in high pressure.

Rarefaction

A rarefaction is a region in a longitudinal wave where the particles are spread apart, resulting in low pressure.

Amplitude

The amplitude of a wave is the maximum displacement of a point on the wave from its undisturbed (rest) position. It indicates the energy carried by the wave.

> **Tidbit**
>
> The time period tells how long one complete wave takes to pass a point like the rhythm heartbeat of the wave.

> **Brain Teaser**
>
> Two waves travel at the same speed, but one has a higher frequency. Which has the shorter wavelength?

Wavelength (λ)

The wavelength is the distance between two corresponding points on adjacent waves (e.g., crest to crest or trough to trough in transverse waves, or compression to compression in longitudinal waves).
Its SI unit is metre (m).

Frequency (f)

The frequency of a wave is the number of complete wave cycles that pass a fixed point in one second.

It is measured in hertz (Hz), where; 1 Hz = 1 wave per second

Wave Period (T)

Time required to complete one wave to pass a fixed point is called wave period.

It is the inverse of frequency:

i.e; $T = 1 / f$

It is measured in seconds (s).

Wave Front

A wave front is an imaginary surface on which all the points have same phase of vibration (i.e., have the same displacement and direction of motion).

It represents the leading edge of the wave as it travels through a medium.

Wave Speed (v) / Wave Equation

The wave speed is the rate at which the wave propagates through a medium.

As, Speed = Distance travelled / Time taken

Let us consider a wave:

Distance travelled = λ (wavelength)

Time taken = T (time period)

Then

$$v = S / t$$

Since $S = \lambda$ *and* $t = T$

Therefore $v = \lambda / T$ .... (12.1)

Now $1 / T = f$ (where f is frequency)

So $v = f \times \lambda$ .... (12.2)

Equation (12.2) is known as wave equation. This is used to calculate wave speed. where v is the wave speed (in metres per second), f is the frequency (in hertz), and λ is the wavelength (in metres).

Example: A wave takes 5 seconds to complete 10 cycles. If the wavelength of the wave is 1.2 metres, calculate:

(a) frequency of the wave (b) speed of the wave

Solution:

Given that;

Number of cycles = 1

Time $t = 5$ s

Wavelength $\lambda = 1.2$ m

To find;

(a) Frequency f =?

(b) Speed of wave v = ?

We know that;

$$f = \text{Number of cycles / Time}$$

$$f = 10 / 5 = 2 \text{ Hz}$$

$$v = f \times \lambda$$

Substituting the values

As

$$v = 2 \times 1.2 = 2.4 \text{ m s}^{-1}$$

12.4 Seismic Waves

Seismic waves are natural waves produced by disturbances in the Earth's crust. Understanding them is important for safety and readiness since they have the potential to do a great deal of harm.

Seismic waves are those that pass through the Earth and are typically created by earthquakes, volcanic eruptions, or explosions. Seismometers detect these waves, which aid scientists in their investigations of the Earth's insides.

Primary Waves (P-Waves)

These are the fastest seismic waves and the first to be detected during an earthquake. P-waves can travel through solids, liquids, and gases. They move by compressing and expanding the material in the same direction as the wave travels, similar to a slinky toy being pushed and pulled. This compressional movement is shown in Fig. 12.10, where alternating regions of high and low density represent compressions and rarefactions.

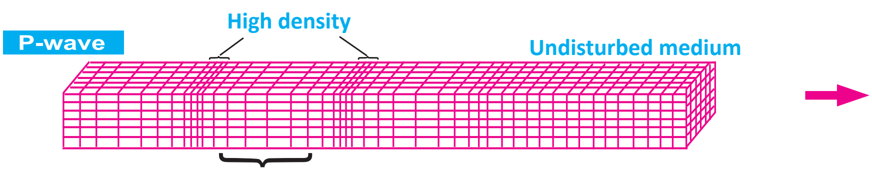


Fig. 12.10: P-wave showing longitudinal motion

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

12.1 The direction of vibration in a longitudinal wave is:
(a) at right angles to the wave direction
(b) in circular motion
(c) opposite to the wave direction
(d) in the same direction as the wave travels

12.2 Which part of a transverse wave carry the lowest point?
(a) Crest (b) Compression
(c) Rarefaction (d) Trough

12.3 Which of the following wave type requires a medium to travel?
(a) X-rays (b) Light waves
(c) Radiowaves (d) Sound waves

12.4 The property of a wave which indicates how much energy it carries is:
(a) crest (b) amplitude (c) wavelength (d) speed

12.5 A wave front is:
(a) the distance between two crests
(b) a region of high pressure in a wave
(c) a line joining points that vibrate in phase
(d) the outer edge of a wave medium

12.6 A wave generator produces 600 waves in 3 minutes, and each wave travels at 2 metres per second. What is the wavelength of the wave?
(a) 0.60 m (b) 0.10 m (c) 1.0 m (d) 0.30 m

B. Shorts Answer Questions

12.1 What do waves transfer from one place to another?
12.2 Name any two examples of mechanical waves.
12.3 Which type of wave can travel through vacuum?
12.4 What is the difference between transverse and longitudinal waves?
12.5 What is meant by wavelength?
12.6 Write the definition of frequency.

C. Constructed Response Questions

12.1 Why sound cannot travel through space, but light can? Explain using the concept of wave types.
12.2 A student shakes one end of a rope and observes waves move along it. What kind of wave is this, and how do the particles move?

12.3 How does the amplitude of a wave relate to the energy it carries? Give an example to support your answer.

12.4 A person wants to generate both an electromagnetic wave and a mechanical wave, each with a frequency of 100 Hz. How can he achieve this?

D. Comprehensive Questions

12.1 Explain how waves transfer energy without transferring matter. Give examples from daily life.

12.2 Describe the difference between mechanical and electromagnetic waves with suitable examples.

12.3 What are transverse and longitudinal waves? Explain each with the help of diagrams and examples.

12.4 Discuss the relationship between wave speed, wavelength, and frequency. Derive the wave equation and explain each term with appropriate SI units.

E. Numerical Problems

12.1 The wavelength of a wave is 2 metres and its frequency is 5 Hz. What is the speed of the wave? **[Ans: 10 m s^{-1}]**

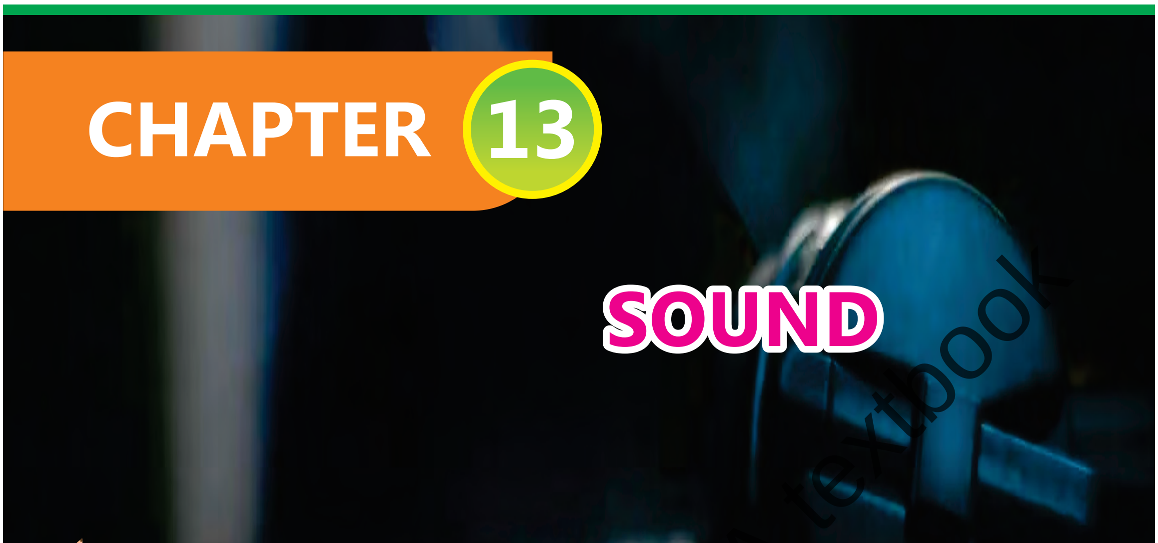
12.2 A wave travels at a speed of 300 m s^{-1} and has a wavelength of 3 metres. Calculate its frequency. **[Ans: 100 Hz]**

12.3 A sound wave has a frequency of 250 Hz and a speed of 340 m s^{-1}. Find its wavelength. **[Ans: 1.36 m]**

12.4 A wave has a frequency of 50 Hz. How much time does it take to complete one wave? **[Ans: 0.02 s]**

12.5 A wave has a wavelength of 0.5 m and frequency of 200 Hz. Calculate the speed of the wave. **[Ans: 100 m s^{-1}]**

12.6 The time period of a wave is 0.02 seconds. Calculate the frequency of the wave. **[Ans: 50 Hz]**



CHAPTER 13

SOUND

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- describe the production of sound.
- describe the longitudinal nature of sound waves.
- state the approximate range of frequencies audible to humans as 20 Hz to 20,000 Hz.
- justify why sound waves cannot travel in vacuum (including experiments to demonstrate this).
- describe how changes in amplitude and frequency affect the loudness and pitch of sound waves.
- describe an echo as the reflection of sound waves.
- justify simple experiments to show the reflection of sound waves.
- state that the speed of sound in air is approximately 330-350 m s^{-1}.
- describe that, in general, sound travels faster in solids than in liquids and faster in liquids than in gases.
- define ultrasound as sound with a frequency higher than 20 kHz.
- illustrate and analyze the uses of ultrasound (in cleaning, parental and other medical scanning, and in sonar, including calculation of depth or distance from time and wave speed).
- analyze the effects of noise pollution on the environment.
- justify the importance of acoustic protection.
- describe how knowledge of the properties of sound waves is applied in the design of buildings with respect to acoustics.
- explain the use of soft materials to reduce echo sounding (such as in classroom studies and other public gathering buildings).

Sound waves are simple to generate. When we speak, our vocal cords vibrate, producing sound waves. Any object that vibrates in the air causes nearby air layers to vibrate as well, which in turn affects adjacent layers. This continuous vibration pushes and pulls the air, creating waves of compression and rarefaction. When these waves reach our ears, they cause our eardrums to vibrate, allowing us to perceive sound. As these vibrations move through the air, they form sound waves. These waves are longitudinal, meaning air particles oscillate back and forth in the same direction as the wave's energy transfer. The speed at which sound waves travel through the air is approximatly 330-350 $m\ s^{-1}$. In this chapter, we will explore the fascinating world of sound; how it moves, reflects, and helps us understand both nature and technology.

13.1 Production and Propagation of Sound

Production of Sound

Sound is produced by vibrating objects. When an object vibrates, it makes the air around it to vibrate as well. These air vibrations travel to our ears and create the sensation of sound.

For example, in a guitar, the sound is produced when its strings vibrate (Fig. 13.1). Similarly, our voice is produced by the vibrations of our vocal cords. The human heart and other organs like the lungs also create sound waves when they vibrate. Doctors use a stethoscope to listen to these sounds.

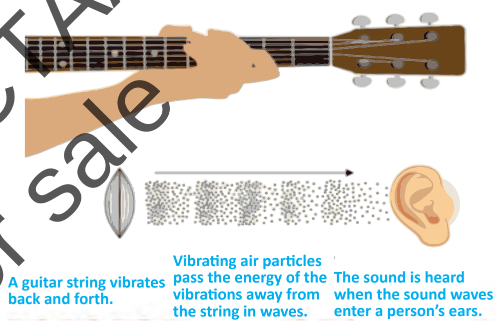


Fig. 13.1: Vibrations of guitar strings produce sound waves

Tidbit

Sound needs a medium (like air, water, or solids) to travel through. In vacuum, there are no particles to vibrate, which is why sound cannot travel there.

Activity 13.1: In school laboratories, tuning fork is used to produce a specific sound. When a rubber hammer is struck with the tuning fork, it begins to vibrate (Fig. 13.2). By bringing it close to our ear, we can hear the sound produced by these vibrations.

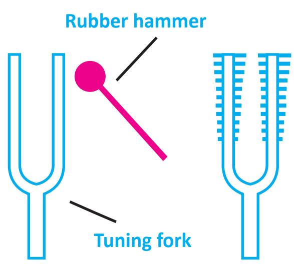


Fig. 13.2: Strike a rubber hammer on a tuning fork to produce vibrations

We can also observe the vibrations of a tuning fork by bringing one of its prongs in contact with a small table tennis ball hanging from a thread (Fig. 13.3). When the vibrating prong touches the ball, the ball moves, showing the presence of vibrations. Similarly, if we place the vibrating tuning fork into a glass of water, we will notice water splashing. But what causes this splash? This simple activity demonstrates that vibrations are responsible for producing sound.

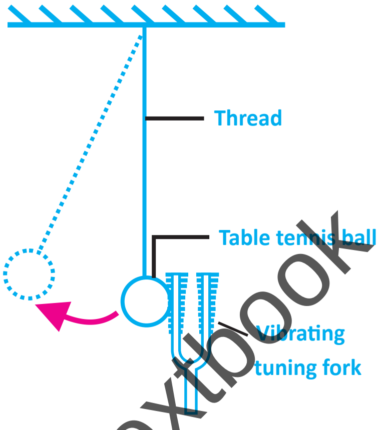


Fig. 13.3: The production of sound waves from a vibrating tuning fork

Propagation of Sound

Sound needs a medium, such as air, water, or a solid, to travel from one place to another. When a tuning fork vibrates, it creates compressions (high pressure) and rarefactions (low pressure) in the air, allowing sound to travel. As the prong moves forward, it pushes air molecules together, forming a compression that moves outward. When it moves back, it creates a rarefaction, where air molecules spread apart. This continuous cycle of compressions and rarefactions propagates sound as a longitudinal wave, meaning air molecules move in the same direction as the wave (Fig. 13.4). The wavelength of a sound wave is the distance between two successive compressions or rarefactions.

Do You Know?

Sound is a
MECHANICAL WAVE

- Sound requires a medium
- Sound can travel in a solid, liquid or gas

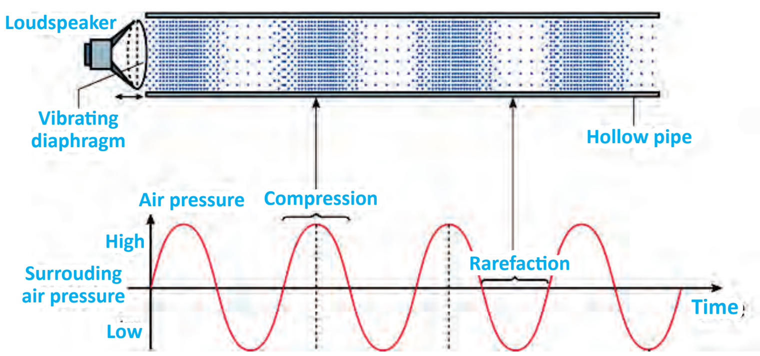


Fig. 13.4: Longitudinal waves showing compression and rarefaction in sound propagation

Activity 13.2: Unlike light waves, which are electromagnetic and can travel through vacuum, sound waves need a material medium to propagate. This can be demonstrated using a bell jar setup (Fig. 13.5).

Brain Teaser

If sound is created by vibrations, how do particles move when sound waves pass through the air?

The bell jar is placed on the base of a vacuum pump, with an electric bell suspended inside using two wires connected to a power supply. When the power supply is turned ON, the electric bell rings, and we can hear the sound. Next, air is pumped out of the jar using the vacuum pump. As the air is removed, the sound of the bell becomes weaker and eventually fades, even though the bell continues ringing. When air is reintroduced into the jar, the sound becomes audible again. This demonstrates that sound waves require a medium, such as air, to propagate.

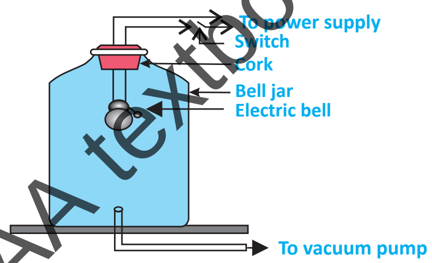


Fig.13.5: Bell jar apparatus

Longitudinal Nature of Sound Waves

The propagation of sound waves can be understood through the example of a slinky (Fig. 13.6). Sound travels in the form of a longitudinal wave. This means the particles of air move back and forth in the same direction as the sound wave. If we push and pull one end of the slinky, we will see some parts where the coils come close together (called compression) and some parts where they spread apart (called rarefaction).In the same way, when sound moves in air, it creates compressions (where air particles are closer) and rarefactions (where particles are far apart).The distance between two compressions or two rarefactions is called the wavelength. So, just like the slinky, sound moves by making compressions and rarefactions, showing that it is a longitudinal wave.

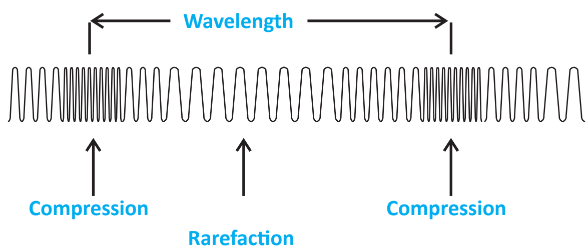


Fig. 13.6: Propagation of longitudinal sound waves in a slinky, showing compressions and rarefactions

13.2 Speed of Sound

Sound waves require a medium with vibrating particles to travel and cannot propagate through vacuum. The speed of sound varies with the type of medium. It moves 5 times faster in liquids and 15 times faster in solids than in gases. In air, factors like temperature, and humidity affect its speed. At room temperature (21°C), sound travels at 343 m s^{-1} in air, increasing with higher temperature and humidity. Since solids and liquids transmit sound faster than gases, the material of the medium plays a key role in determining sound speed. The speed of sound v is calculated using a specific equation:

$$v = f\lambda \text{ .... (13.1)}$$

where v is the speed of sound, f is the frequency, and λ is the wavelength of the sound wave. The speed of sound in various media is shown in Table 13.1.

Example 13.1: Calculate the frequency of a sound wave of speed 340 m s^{-1} and wavelength 2.0 m.

Solution:

Given that;

Speed of wave v = 340 m s^{-1}

Wavelength λ = 2.0 m

To find; f=?

Using the formula; $v = f\lambda$

or $f = v/\lambda$

Substituting the values

f = 340 m s^{-1}/2 m = 170 Hz

Table 13.1: Speed of sound in various media

Medium	Speed (m s^{-1})
Gases	
Air(0 °C)	330
Air (25 °C)	346
Air (100 °C)	391
Hydrogen (0 °C)	1290
Oxygen (0 °C)	317
Helium (0 °C)	972
Liquids at 25 °C	
Distilled water	1498
Sea water	1531
Solids at 25 °C	
wood	200
Aluminium	6420
Brass	4700
Nickel	6040
Iron	5950
Steel	5960
Flint Glass	3980

13.3 Characteristics of Sound

Sounds from different objects can be identified based on their distinct characteristics, as explained below:

Loudness

Loudness is a property of sound that allows us to differentiate between loud and faint sounds.

For example, when speaking with friends, our voice is soft, but while addressing a large audience, we speak louder. The loudness of a sound depends on several factors, which influence how we perceive its intensity. Some of these factors are discussed below:

Brain Teaser

Does the loudness of a sound affect the time it takes for an echo to return?

(a) Amplitude of the vibrating body

The loudness of sound depends on the amplitude of the vibrating object (Fig. 13.7). If we pluck the strings of a guitar with more force, the vibrations will have greater amplitude, producing a louder sound. Likewise, striking a drum harder causes its membrane to vibrate more intensely, resulting in a louder noise.

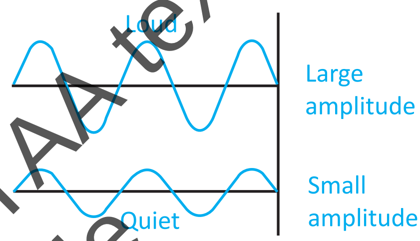


Fig. 13.7: Variation of loudness with amplitude

(b) Area of the vibrating body

The loudness of sound is also influenced by the size of the vibrating surface. A large drum produces a louder sound than a smaller one because its greater surface area allows more air to vibrate. Similarly, striking a tuning fork alone creates a faint sound, but placing it on a solid surface, like a bench, amplifies the sound. This demonstrates that a larger vibrating area increases loudness, while a smaller area produces a weaker sound.

(c) Distance from the vibrating source

The loudness of a sound decreases as the distance between the vibrating source and the listener increases. This occurs because the amplitude of the sound wave diminishes with distance. Additionally, the perception of loudness varies based on the listener's hearing ability. A person with sensitive ears perceives sound as louder compared to someone with hearing impairment. However, there is a physical characteristic of sound that remains independent of the listener's hearing ability. This is known as the intensity of sound, which is a measurable quantity and does not rely on human perception.

Pitch

Pitch is the characteristic of sound that allows us to differentiate between a shrill and a deep (grave) sound.

It is directly related to frequency, higher frequency results in higher pitch, while lower frequency produces lower pitch.

For example, the voices of women and children have a higher frequency, making them shrill and high-pitched, whereas the voices of men have a lower frequency, giving them a deeper and lower-pitched sound.

The relationship between pitch and frequency is represented in Fig. 13.8.

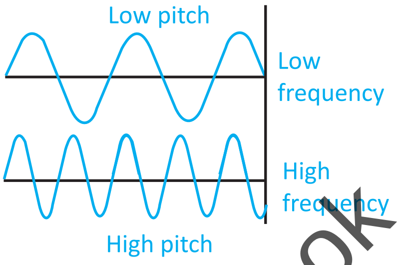
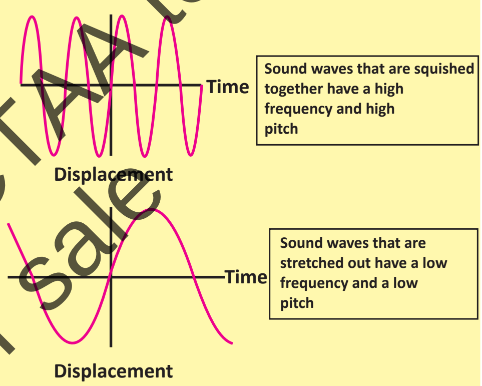


Fig 13.8: Variation of pitch with frequency

Do You Know?



13.4 Musical Sounds and Noise

In daily life, we hear sounds of different qualities. Musical instruments like the guitar, violin, recorder, and drum produce sounds with controlled pitch and quality, which are pleasant to hear. Such sounds are called musical sounds. However, some sounds, like traffic noise, door slamming, and machinery, are harsh and unpleasant. These are classified as noise. Noise results from irregular and sudden vibrations and is considered a form of pollution that affects both humans and animals.

Effects of Noise Pollution

Excessive noise from industrial machinery, vehicle horns, alarms, and construction work can lead to stress, lack of concentration, hearing loss, sleep disturbances, aggression, and hypertension.

Controlling Noise Pollution

The recommended safe noise level is 85 – 90 dB for a maximum of eight-hour workday. Noise pollution can be reduced by

1. using quieter, eco-friendly machinery.

2. installing sound barriers.

3. wearing hearing protection devices.

By controlling noise pollution, we can create a healthier environment.

Brain Teaser

Why can we hear our voice echoing back to us when we shout? How do the particles in the air play a role in this?

13.5 Reflection of Sound (Echo)

When we clap or shout near a tall building or mountain, we hear the sound return after a brief delay (Fig. 13.9). This repeated sound is called an echo, caused by the reflection of sound waves from a surface.

When sound waves hit a surface and bounce back into the same medium, the phenomenon is called an echo or reflection of sound.

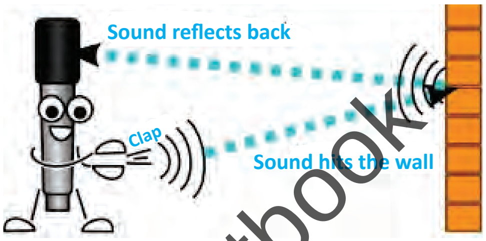


Fig. 13.9: Reflection of sound

The human brain retains sound for about 0.1 seconds, so to hear a distinct echo, the reflected sound must reach us after at least 0.1 seconds. Given the speed of sound in air (340 m s^{-1}), the minimum distance for an echo to form is 34 metres (total distance travelled by sound), meaning the reflecting surface must be at least 17 metres away. Echoes can also repeat multiple times due to successive reflections.

Do You Know?

How bats use echo to find food?

Bats send out sound waves using their mouth or nose. When the sound hits an object, an echo comes back.

The bat can identify an object by the sound of the echo. They can even tell the size, shape and texture of a tiny insect from its echo.

Example 13.2: Flash of lightning is seen 2 seconds earlier than the thunder. How far away is the cloud in which the flash has occurred? (Speed of sound = 332 m s^{-1})

Solution:

Given that; Time $t = 2$ s

Speed of sound $v = 332$ m s^{-1}

To find; Distance $S = ?$

As distance of the cloud; $S = vt = 332$ m s^{-1} x 2s ; $S = 664$ m

13.6 Audible Frequency

The human ear can detect sounds within the 20 Hz to 20,000 Hz range, known as the audible frequency range. Sounds below 20 Hz or above 20,000 Hz are inaudible to humans (Fig. 13.10). Hearing ability declines with age. Young children can hear up to 20,000 Hz, while older individuals may struggle with sounds above 15,000 Hz.

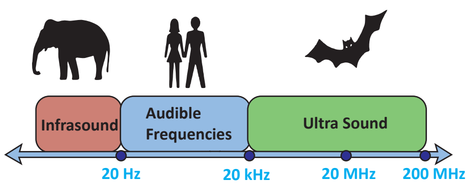


Fig.13.10: Frequency of sound

Infrasound

Infrasound refers to waves below 20 Hz, which humans cannot hear but may feel as vibrations.

Many animals, like elephants and whales, use infrasound for communication. It is produced by natural events (earthquakes, volcanoes), industrial processes, and human activities (machinery, explosions). Due to its ability to travel long distances, infrasound is used for monitoring natural disasters.

Tidbit

Infrasound sensors are used to monitor volcanic eruptions, earthquakes, and even tsunamis before they strike. The low-frequency waves from these natural events travel great distances and help scientists issue early warnings!

Uses of Infrasound

- **Elephant Communication:** Elephants use infrasound to communicate over long distances. Their deep rumbles travel far through air and ground, helping them stay connected. They can sense these vibrations not just with their ears but also through their feet and trunks.
- **Earthquake Detection:** Scientists use infrasound to detect earthquakes before the strong shaking starts. These low-frequency waves act as an early warning system.
- **Volcano Monitoring:** When a volcano erupts, it creates unique infrasound waves. Scientists study these waves to predict eruptions and assess risks.
- **Nuclear Explosion Detection:** Special sensors track infrasound waves from nuclear explosions.

Do You Know?

Blue whales, the largest animals on the Earth, sing in infrasound that can travel across entire oceans! These deep calls help them communicate with others even when they are hundreds of kilometres apart.

Ultrasound

Sounds with frequencies above 20,000 Hz, which are inaudible to humans, are called ultrasound or ultrasonics.

Uses of Ultrasound

- **Medical Applications**

Ultrasound is widely used in medical diagnostics and treatments. When ultrasonic waves pass through the body, they reflect differently from various tissues and organs. These reflected waves are then captured and converted into images on a screen, a process known as ultrasonography. This helps in visualizing organs such as the heart, liver, and kidneys, as well as in monitoring pregnancies.

For example, parental scanning uses ultrasound to observe the fetus inside the womb, assess its development, and detect any potential issues. Additionally, ultrasound aids in thyroid gland imaging for diagnosis, providing clear visual representations that help doctors evaluate thyroid health.

Do You Know?

Doctors use ultrasound waves to "see" inside the body without cutting it open! These waves are completely non-invasive and safe, making them ideal for monitoring babies during pregnancy or detecting organ problems.

Underwater Exploration (SONAR)

Ultrasound is used to measure ocean depth and locate objects on the seabed. SONAR (Sound Navigation and Ranging) works by sending ultrasonic waves into water; the reflected waves help to determine the distance and shape of an object (Fig. 13.11).

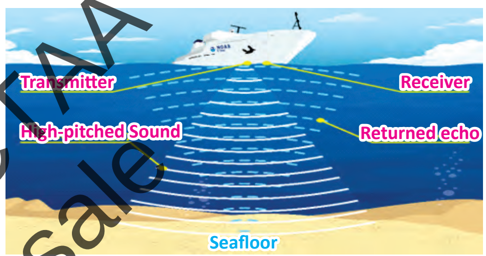


Fig. 13.11: Illustration of sonar used by a ship

Calculating Distance in SONAR

The formula used to calculate distance (or depth) in sonar systems is:

Distance = (Speed of Sound in Water × Time) / 2 .... (13.2)

where speed of sound in water is approximately 1500 m s^{-1} at room temperature. Time is the duration it takes for the ultrasound pulse to travel to the object and return to the source. The distance is divided by 2 because the pulse travels to the object and then returns to the source.

Industrial Applications

Ultrasound helps to detect cracks in machines like turbines, ship engines, and airplane parts. Ultrasound waves reflect from damaged areas, revealing hidden defects. It is also used to destroy bacteria in liquids through high-intensity waves.

Example 13.3: A sonar device on a ship sends out a sound pulse that returns after 3.2 seconds. If the speed of sound in water is 1600 m s^{-1}, what is the distance from the ship to the seafloor?

Solution:

Given that;

Time for the sound pulse to return t = 3.2 seconds

Speed of sound in water $v = 1600\ m\ s^{-1}$

To find; Distance $d = ?$

The sound pulse travels to the seafloor and back, so the total distance covered is twice the distance from the ship to the seafloor.

Using the formula; $d = v \times t$

Substituting the values

$$d = 1600\ m\ s^{-1} \times 3.2\ s = 5120\ m$$

Since the distance covered is twice the actual distance to the seafloor, we divide by 2 to find the distance.

$d = 5120\ m / 2 = 2560\ m$

13.7 Acoustic Protection of Buildings

Acoustic protection reduces unwanted sound using soft, porous materials like carpets and curtains, which absorb sound and minimize echoes. Hard, smooth surfaces reflect more sound, while excessive absorption can weaken audibility in classrooms and halls (Fig. 13.12-a). Multiple reflections, known as reverberation, can distort sound, so a balance between reflection and absorption is essential in auditoriums, lecture halls, and theatres. Reflective surfaces behind the stage help direct sound to the audience. Additionally, curved ceilings and sound boards are often used to ensure even sound distribution throughout the hall (Fig. 13.12-b).

Tidbit

In concert halls and theatres, curved ceilings and soft walls do not just look stylish. They are engineered to shape sound! While carpets and curtains absorb echoes, curved panels and reflectors bounce the music toward the audience so that even the person in the last row hears every note clearly. That is the science of acoustic protection—a perfect harmony of silence and sound!

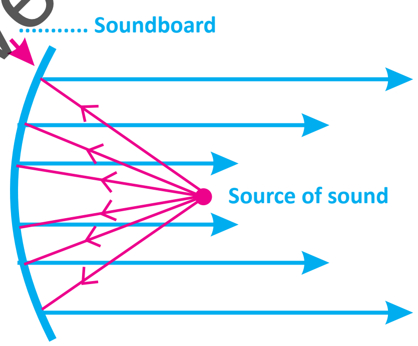


Fig. 13.12(a): Soundboard used in a big hall

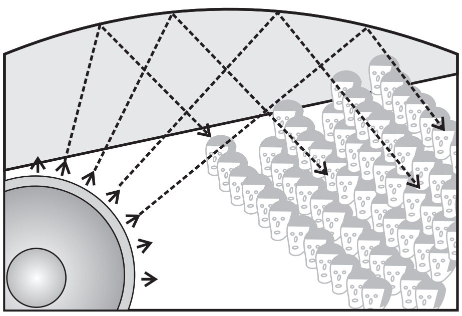


Fig. 13.12(b): Curved ceiling of a conference hall

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

13.1 What is required for the production of sound?
(a) A vacuum (b) Vibrations of a medium (c) Only air (d) Light waves

13.2 An echo is produced due to:
(a) refraction of sound waves (b) reflection of sound waves
(c) diffraction of sound waves (d) absorption of sound waves

13.3 An example of a longitudinal wave is:
(a) light wave (b) water wave (c) sound wave (d) radiowave

13.4 In which medium does sound travel the fastest?
(a) Gases (b) Liquids (c) Solids (d) Vacuum

13.5 What is the approximate speed of sound in air?
(a) 150 $m\ s^{-1}$ (b) 330-350 $m\ s^{-1}$ (c) 500 $m\ s^{-1}$ (d) 1,000 $m\ s^{-1}$

13.6 Why is acoustic protection important in building design?
(a) To increase noise pollution (b) To reduce echo and improve sound quality
(c) To amplify sound (d) To increase the speed of sound

B. Short Answer Questions

13.1 How does the medium affect the speed of sound?
13.2 Does sound waves show reflection?
13.3 What factors influence the loudness of sound?
13.4 Why do we hear an echo when we clap near a building?
13.5 What is ultrasound, how is it used in medicine?

C. Constructed Response Questions

13.1 Why does a tuning fork placed on a wooden table produce a louder sound than when held in the air? What does this tell us about the role of surface area in sound propagation?

13.2 If sound needs a medium to travel, how does the bell jar experiment prove this requirement? What happens when air is removed, and why?

13.3 A person hears his echo when shouting near a tall building. Why must the building be at least 17 metres away for the echo to be heard clearly?

13.4 Why do voices of men sound deeper than those of women or children, even when they are speaking at the same intensity? Explain using the relationship between frequency and pitch.

13.5 In what ways do soft materials like carpets or curtains improve the acoustics of a room? How do they affect echoes and sound quality?

D. Comprehensive Questions

13.1 What is the approximate speed of sound in air, and what factors affect it?
13.2 Why does sound travel faster in solids than in liquids and gases? Explain.
13.3 How do amplitude and frequency affect the quality of sound? Explain.
13.4 How does echo occur? Explain.
13.5 What are infrasound and ultrasound, and how are they used in different applications?

E. Numerical Problems

13.1 At a particular temperature, the speed of sound in air is 333 m s^{-1}. If the wavelength of a sound wave is 3 cm, calculate the frequency of the sound wave. Is this frequency in the audible range of the human ear?
[Ans: 11 kHz, yes audible]

13.2 A clock chimes 48 times in 1 minute. Calculate the frequency and period of the chimes. **[Ans: 0.8 Hz, 1.25 s]**

13.3 A car horn emits a sound with a wavelength of 0.5 m. If the speed of sound in air is 340 m s^{-1}, calculate the frequency of the sound produced by the car's horn. **[Ans: 680 Hz]**

13.4 A research boat sends a sound wave straight to the seabed and receives the echo 2 seconds later. The speed of sound in seawater is 1600 m s^{-1}. Find the depth of the sea at this position. **[Ans: 1600 m]**

13.5 A person claps his hands near a mountain and hears the echo after 6 seconds. If the speed of sound is 343 m s^{-1}, what is the distance of the mountain from the person? **[Ans: 1029 m]**

CHAPTER 14

LIGHT

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- define and use the terms normal, angle of incidence, and angle of reflection.
- describe an experiment to find the position and characteristics of an optical image formed by a plane mirror (same size, same distance from mirror as object, and virtual).
- use the law of reflection to solve simple optical problems.
- apply the qualitative principle that a wave refracts towards the normal when it slows down while entering a medium and that it refracts away from the normal if it speeds up when it enters a new medium (in the case the angle of incidence is zero, then the waves continue parallel to the normal).
- define and use the refractive index from vacuum to a medium for light as *c/v*.
- define refractive index n as; n = sin i / sin r. Apply Snell's law; n = sin i / sin r, to solve simple problems.
- define the terms critical angle *C* and total internal reflection.
- derive the equation; n = 1 / sin *C*.
- apply the equation; n = 1 / sin *C* to solve simple problems.
- describe experiments to show internal reflection and total internal reflection.
- explain the dispersion of light by a prism [including the detection of non-visible spectra by a thermometer].
- draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye, and a long-sighted eye.
- describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness.

Light is a form of energy that travels in the form of waves and allows us to see the world around us. In this chapter, we will explore how light reflects, bends (refracts) when passing through different materials. Key topics include the angles of incidence, reflection, and refraction. We will also learn how the human eye detects light and colour, and how lenses help to correct vision problems.

14.1 Reflection of Light

Reflection of light takes place when light hits a surface and bounces back instead of passing through it. This usually occurs on smooth and shiny surfaces, such as mirrors. The angle at which light strikes the surface (angle of incidence) is always equal to the angle at which it reflects (angle of reflection) (Fig. 14.1).

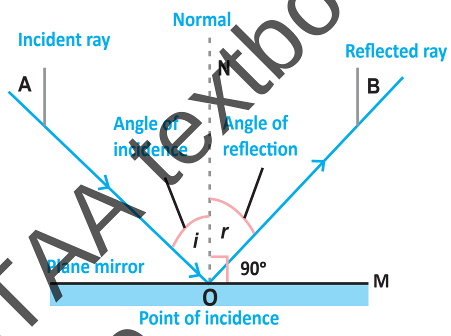


Fig. 14.1: Reflection of light

There are two types of reflection:

Regular/Specular Reflection : It takes place on smooth surfaces (like mirrors) where light reflects in one direction, forming a clear image.

Diffused/Irregular Reflection: It occurs on rough surfaces (like paper), where light scatters in different directions, so no clear image is seen.

Reflection is important for mirrors, periscopes, and optical devices, allowing us to see objects and form images.

Laws of Reflection

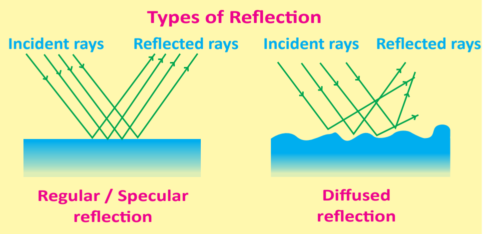
The reflection of light follows two basic laws:

First Law: The incident ray, the reflected ray, and the normal (a line drawn perpendicular to the surface at the point of reflection) all lie in the same plane.

Second Law: The angle of incidence *(i)* is always equal to the angle of reflection *(r)*.

$$\angle i = \angle r \qquad \text{............ (14.1)}$$

Do You Know?



These laws apply to all reflective surfaces, such as mirrors and water, and help us to understand how light bounces back to form images.

Activity 14.1: Finding the Image Position in a Plane Mirror

Objective: To observe and understand the position and characteristics of the image formed by a plane mirror.

Materials Needed: A plane mirror, an object, a measuring tape, a light source, and a white paper.

Procedure: Place the plane mirror in an upright (vertical) position. Position the object in front of the mirror. Ensure the object is not taller than the mirror. Shine light onto the object, so it is clearly visible (Fig. 14.2).

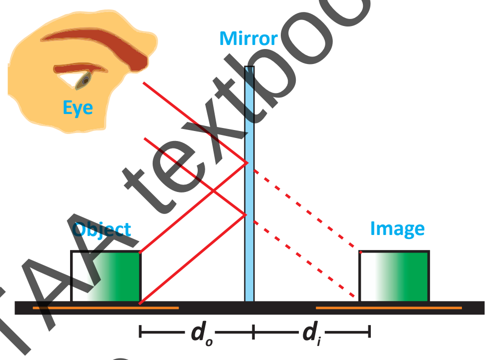


Fig. 14.2: Image formation by a plane mirror

Look at the mirror and observe the rays of light reflecting from the object. When two rays reflect off the mirror and reach the observer's eye, they appear to be coming from behind the mirror. By using a ruler and the law of reflection, we can draw the reflected rays on paper. Extend these reflected rays backward with dotted lines where they meet behind the mirror is the position of the image. This method shows the virtual image location.

There are four properties of an image formed by a plane mirror :

1. The image is erect – It appears upright, just like the object.
2. The image is of the same size – The size of the image is exactly equal to the size of the object. It can be written as: $d_i = d_o$
3. The image is laterally inverted – The left and right sides of the object appear reversed in the image as shown in Fig. 14.3.

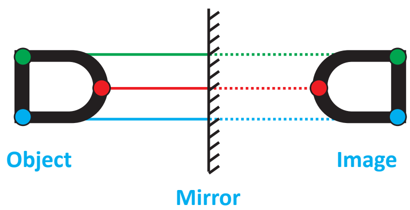


Fig. 14.3: Letter 'D' showing lateral inversion in a mirror

4. The image is virtual – It cannot be captured on a screen because it is formed behind the mirror where light rays do not actually meet.

14.2 Refraction of Light

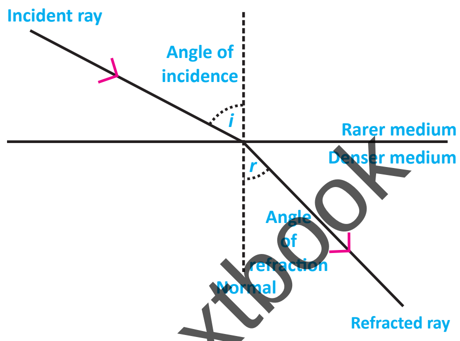


Fig. 14.4: Refraction of light

Refraction of light occurs when light changes direction as it passes from one medium to another, such as from air to water or glass (Fig. 14.4). This happens because light travels at different speeds in different materials. When light moves from a rarer medium (air) to a denser medium (glass or water), it bends towards the normal. When it moves from a denser medium to a rarer medium, it bends away from the normal. The amount of bending depends on the refractive index of the medium. Refraction explains many everyday phenomena, such as a pencil appearing bent in water, the working of lenses in glasses and cameras, and the formation of rainbows.

Laws of Refraction of Light

The bending of light during refraction follows two essential principles:

1. **First Law:** The incident ray, refracted ray, and the normal at the point where light enters a new medium all lie in the same plane.

2. **Second Law (Snell's Law):** The ratio of the sine of the angle of incidence i to the sine of the angle of refraction r remains constant for a specific pair of media.

$$\frac{\sin i}{\sin r} = n \quad \text{......... (14.2)}$$

Here, n is the refractive index of the second medium relative to the first. The refractive index indicates how much light bends when entering a different medium.

Speed of Light in a Medium

The speed of light varies depending on the medium through which it travels. In vacuum, light moves at its maximum speed of 3×10^8 m s^{-1}. However, when light passes through materials like air, water, or glass, it slows down due to interactions with medium particles. The denser the medium, the slower the speed of light. This change in speed is measured using the refractive index n, which is the ratio of the speed of light in vacuum to its speed in a given medium. The variation in the speed of light, when it moves between different material, is what causes refraction, or the bending of light.

Refractive Index

The refractive index *n* of a medium is a measure of how much the speed of light changes when it enters that medium.

It is defined as the ratio of the speed of light in air or vacuum *c* to the speed of light in the given medium *v*:

$$\text{Refractive index} = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}}$$

or $$n = \frac{c}{v} \quad \text{.......... (14.3)}$$

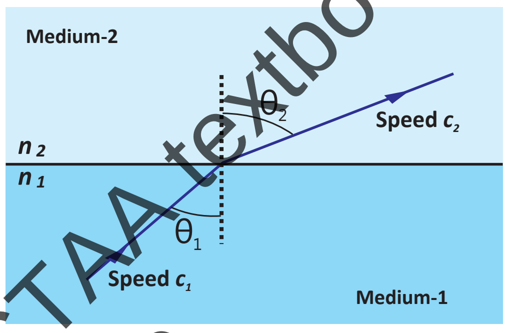


Fig. 14.5: Refraction of light at a boundary between two media

Figure 14.5 illustrates how a light ray changes direction when passing from medium-1 (with refractive index n_1 and speed c_1) to medium-2 (with refractive index n_2 and speed c_2). The angles θ_1 (angle of incidence) and θ_2 (angle of refraction) demonstrate how the light bends according to Snell's law due to the difference in refractive indices.

Example 14.1: A ray of light enters from air into water. The angle of incidence is 40° and the refractive index of water is 1.33. Find the angle of refraction.

Solution:

Given that; Angle of incidence $i = 40°$

Refractive index of water $n = 1.33$

Using Snell's law: $\frac{\sin i}{\sin r} = n$

Substituting the values: $1.33 \times \sin r = \sin 40°$

$\sin r = \sin 40° / 1.33$

$\sin r = 0.483$

$r = \sin^{-1}(0.483)$

or $r = 28.9°$

Hence, the angle of refraction is 28.9°.

Example 14.2: The refractive index of water is 1.33. What is the speed of light in water?

Solution:

Given that;

Refractive index of water $n = 1.33$

Speed of light in vacuum $c = 3 \times 10^8$ m s^{-1}

To find; Speed of light in water $v = ?$

Using the formula: $n = c / v$

or $v = c / n$

Substituting the values

$v = (3 \times 10^8 \text{ m s}^{-1}) / 1.33$

$v = 2.26 \times 10^8 \text{ m s}^{-1}$

The speed of light in water is 2.26×10^8 m s^{-1}.

Refraction Through Prism

A prism is a transparent optical object with at least two polished plane surfaces inclined towards each other. It is usually made of optical glass and is used to refract (bend) light. In the case of a triangular prism (Fig. 14.6), 60° angle each, the light passing through it does not emerge parallel to its original path but instead changes direction. When an incident ray (PE) strikes the prism at point E, it bends towards the normal N and travels inside the prism as refracted ray (EF). Inside the prism, the ray makes an angle of refraction r before reaching the second surface at point F. As it exits the prism, it bends again, forming an emergent ray (FS)

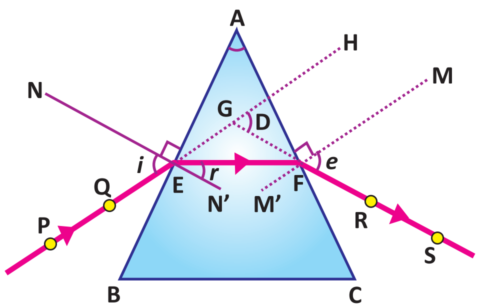


Fig. 14.6: Refraction through a triangular glass prism

at an angle e. The emergent ray (FS) is not parallel to the incident ray (PE) but is instead deviated by an angle D, known as the angle of deviation. This bending effect of light through a prism is widely used in optical instruments, spectrometry, and light dispersion experiments.

Total Internal Reflection

When a light ray is incident at a boundary between two different media, it splits into two parts: one part reflects back into the original medium (reflected ray), and the other part passes into the second medium (transmitted or refracted ray), as shown in Fig. 14.7(a).

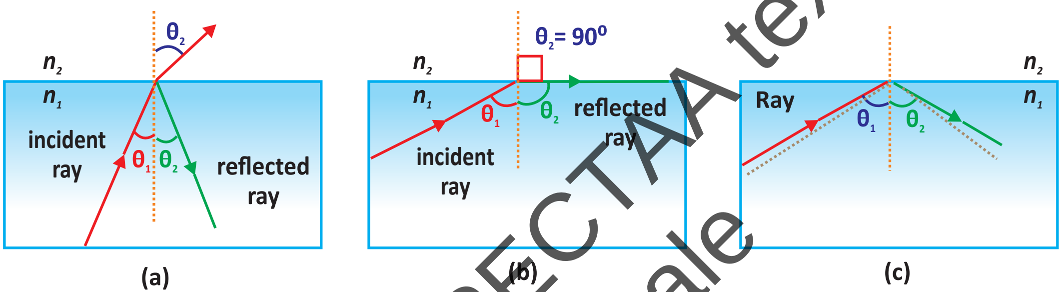


Fig. 14.7: Total internal reflection

If the angle of incidence increases then refraction angle also increases. The more the angle of incidence increases, the greater the angle of refraction becomes. At a particular angle, the refracted ray no longer enters the second medium but travels along the boundary. This angle is called the critical angle (Fig. 14.7-b), and is defined as:

The angle of incidence for which the angle of refraction is 90° is called the critical angle.

Now, if the angle of incidence is increased beyond the critical angle, the light ray does not refract at all. Instead, it reflects entirely back into the same medium. This phenomenon is called total internal reflection, as shown in Fig. 14.7(c).

Total internal reflection is the phenomenon of reflection of light ray back to the same medium when passing from denser medium to rarer medium in such a way that angle of incidence is greater than its critical angle.

The values of the refractive index, speed of light, and critical angle for different media are given in Table 14.1.

Table 14.1: Refractive index, speed of light, and critical angle for different media

Medium	Refractive Index	Speed of Light ($\times 10^8$ m s^{-1})	Critical Angle
Diamond	2.42	1.25	24.4°
Glass (flint)	1.66	1.81	37.0°
Glass (crown)	1.52	2.01	41.2°
Perspex	1.49	2.00	42.0°
Water	1.33	2.25	48.8°
Ice	1.31	2.30	49.8°
Air	1.00	2.99	88.6°
Vacuum	1.00	3.00	90.0°

Derivation of the formula for Total Internal Reflection

To derive a formula for total internal reflection, we start with Snell's law:

$$n_1 \sin i = n_2 \sin r \quad \text{.............. (14.4)}$$

When total internal reflection occurs, the refracted angle becomes 90°. So, the equation becomes:

$$n_1 \sin i = n_2, \text{ because } \sin(90°) = 1$$

Now, if *'i'* is the critical angle C, the formula becomes:

$$\sin C = n_2 / n_1 \quad \text{................. (14.5)}$$

To find the critical angle C, we rearrange it as:

$$C = \sin^{-1}(n_2 / n_1) \quad \text{............. (14.6)}$$

This only works when $n_1 > n_2$, meaning the light must travel from a denser medium to a rarer medium. If the second medium is air (where $n_2 = 1$), the equation becomes:

$$\sin C = 1 / n$$

From the above equation, the refractive index of the first material (denser medium) can be found as:

$$n = 1 / \sin C \quad \text{.................. (14.7)}$$

This relation only holds true if the light is moving from a denser medium with refractive index n into air.

Experiment to Study Refraction

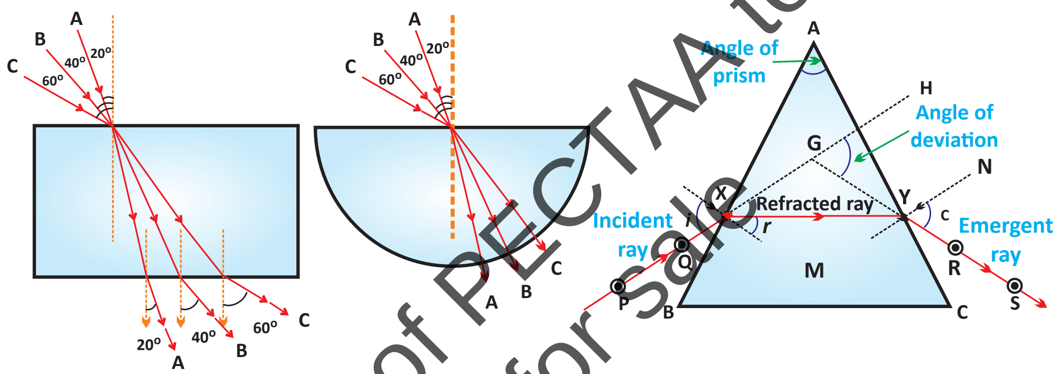
To understand how light bends (refracts) when it passes through different transparent materials, we can perform a simple experiment using blocks of different shapes right in our classroom or school laboratory (Fig. 14.8).

Aim of the Experiment

To observe how light refracts (bends) when it passes through a rectangular block, semi-circular block, and glass prism.

Materials Needed

Laser light, protractor, paper sheet, pencil, ruler, and Perspex blocks (rectangular, semi-circular, and prism-shaped).



(a) Rectangular block (b) Semi-circular block (c) Prism

Fig.14.8: Experiment for refraction of light

Method of Experiment

Place the rectangular glass block on a sheet of paper and observe its result.

- Draw a straight line at one edge where the light will enter.
- Draw a normal (a straight perpendicular line) at the point where light will hit the block.
- Shine the laser light at an angle on the block along the drawn line.

Tidbit

Diamonds sparkle because they have a very high refractive index, causing multiple total internal reflections inside.

Experiment to Study Total Internal Reflection

Aim of the Experiment

To study how total internal reflection of light occurs using a semi-circular glass block (Fig. 14.9).

Materials Needed

Light ray, protractor, paper, pencil, ruler, and a

Brain Teaser

Place a pencil in a glass of water, it appears bent. What does this tell about the speed of light in water compared to air?

semi-circular Perspex (glass) block.

Figure 14.9 (a) demonstrates the refraction, while Fig. 14.9 (b) and Fig. 14.9 (c) illustrate the critical angle and total internal reflection respectively.

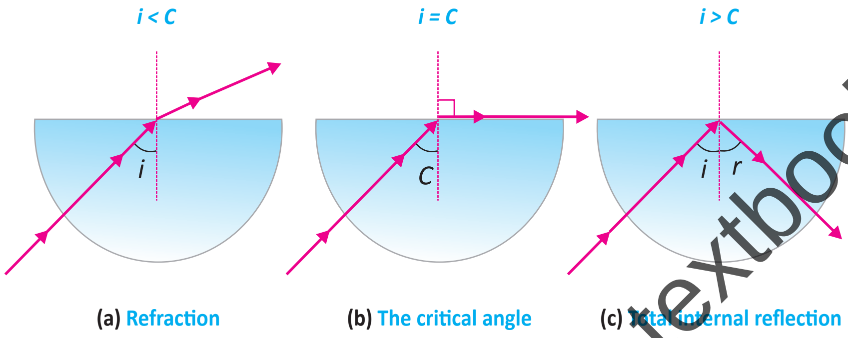


Fig. 14.9: Experiment for total internal reflection

Example 14.3: Find the value of critical angle for water (refracted angle = 90°). The refractive index of water is 1.33 and that of air is 1.

Solution:

Using Snell's law:

$$n_1 \sin i = n_2 \sin r$$

For the critical angle, the refracted angle $r = 90°$ and $i = C$, so $\sin(90°) = 1$

$$n \sin C = 1$$

Rearranging for C:

$$C = \sin^{-1}(1 / n)$$

Substituting the values

$$C = \sin^{-1}(1 / 1.33)$$

$$C = \sin^{-1}(0.752)$$

$$C = 48.8°$$

The critical angle for water is 48.8°.

14.3 Image Formation in a Normal Eye

In a healthy eye, light rays from an object pass through the cornea and lens, and are focused directly onto the retina, forming a sharp and clear image. As shown in Fig. 14.10, rays from

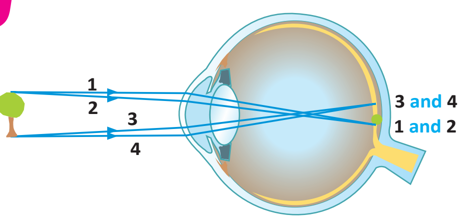


Fig. 14.10: Image formation by eye

the top and bottom of the object converge at specific points on the retina, allowing us to see a clear image. This process is similar to how a convex lens forms a real image.

Short-Sightedness (Myopia) and Its Correction

The closest distance from the eye where we can see things clearly is called near point. For a normal person, it is about 25 cm.

Short-sightedness is a condition where a person can clearly see nearby objects but struggles to see distant ones.

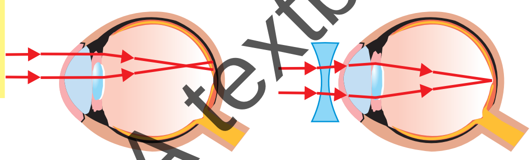


Fig. 14.11: Short-sightedness or myopia

This occurs when the eye lens bends light rays too strongly, causing the image to form in front of the retina instead of on it (Fig. 14.11-a). As a result, distant objects look blurry. To correct this, concave lenses are used in glasses or contact lenses. A concave lens spreads out the light rays before they enter the eye, helping the eye's natural lens to focus them correctly on the retina (Fig. 14.11-b).

Causes of Short-Sightedness (Myopia)

There are two main causes of short-sightedness:

1. Lens too strong: The eye lens becomes too curved, focusing light in front of the retina.

2. Eyeball too large: The distance between the cornea and retina increases, so the focused image falls short of the retina.

Long-Sightedness (Hypermetropia) and Its Correction

In a normal eye, light rays from nearby objects focus directly on the retina, creating a clear image (Fig. 14.12-a). However, in long-sightedness a person can see distant objects clearly, but nearby objects appear blurry. This happens when the eye lens is too weak or the eyeball is too small, so the light rays from near objects are not bent enough. As a result, the rays focus behind the retina instead of on it (Fig. 14.12-b).

To correct this, convex lenses are used in glasses or contact lenses. A convex lens bends the light rays more before they enter the eye, helping them focus directly on the retina (Fig. 14.12-c).

Causes of Long-Sightedness

There are two main causes:

1. Lens too weak: The lens does not bend the light rays enough.

2. Eyeball too small: The retina is too close to the lens.

In both cases, the image is formed behind the retina, making close-up vision blurry.

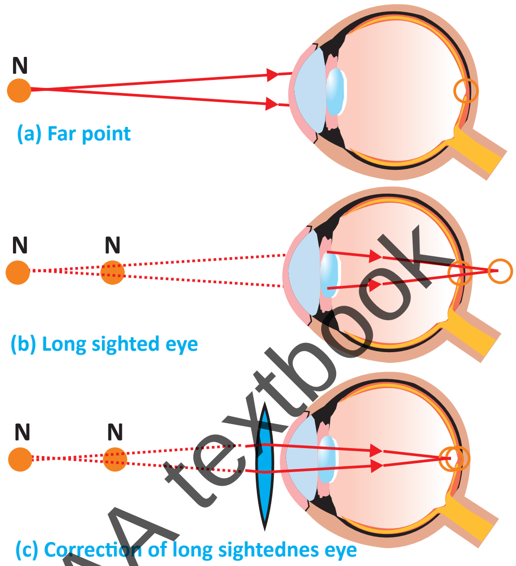


Fig. 14.12: Long-sightedness

14.4 Dispersion of Light by Prism

A prism is an optical object typically made of glass with triangular and rectangular sides. It bends light passing through it due to refraction. Since visible light consists of a range of wavelengths, and refraction depends on wavelength, different wavelengths bend at different angles, causing dispersion.

The splitting of white light into its seven constituent colours when passing through a prism is called dispersion of light.

When white light enters a prism, it slows down and bends toward the normal. Each colour has a unique wavelength, and as light travels through the prism, each wavelength refracts at a different angle. Shorter wavelengths (violet, blue) bend more than longer wavelengths (red, orange). As a result, the light exiting the prism separates into seven distinct colours red, orange, yellow, green, blue, indigo, and violet forming the visible light spectrum (Fig. 14.13).

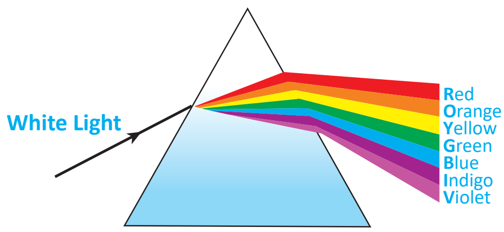


Fig. 14. 13: Dispersion of light by prism

Beyond the visible spectrum, prisms can also disperse infrared (IR) and ultraviolet (UV) light, though these wavelengths are invisible to the human eye. Special detection methods, such as infrared thermometers with sensors, are used to measure these wavelengths.

Infrared Thermometers

These devices detect IR radiation emitted by objects, which correlates with their temperature. When dispersed light from a prism reaches an IR thermometer, it can measure both visible and infrared light. By analyzing the intensity of IR radiation, the thermometer determines the temperature of the emitting object. This technology allows for non-contact temperature measurement, such as checking human body temperature (Fig. 14.14).

Fig. 14. 14: Infrared thermometer

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

14.1 What is the critical angle for a medium with refractive index 1.7?
(a) 55.1° (b) 40.5° (c) 60° (d) 36°

14.2 What occurs if incidence angle goes beyond the critical angle?
(a) Refraction (b) Absorption (c) Total reflection (d) Light vanishes

14.3 When refractive index of a material increases, then increases:
(a) speed of light (b) refraction angle
(c) bending of light (d) wavelength

14.4 Which statement best describes the phenomenon of total internal reflection?
(a) Light bends when it enters a new medium
(b) Light is completely reflected at the boundary of two media
(c) Light slows down as it enters a denser medium
(d) Light passes through a medium without changing direction

14.5 A ray of light travelling from water to air bends:
(a) toward the normal
(b) away from the normal
(c) at 90° to the normal
(d) parallel to the normal

B. Short Answer Questions

14.1 What happens when light passes from air to water?
14.2 Define refractive index. What is the refractive index of air and water?
14.3 Write Snell's law and define the terms used in the equation.
14.4 Define total internal reflection. What conditions are required for it to occur?

C. Constructed Response Questions

14.1 When a pencil is partially dipped in water, it appears bent or broken. What principle of light explains this phenomenon, and how does it relate to changes in speed?

14.2 Why can a prism separate white light into its component colours while a plane glass slab cannot, even though both cause refraction?

14.3 Why does light undergo total internal reflection when travelling from water to air at a certain angle but not the other way around?

14.4 What is meant by the critical angle, and how is it related to total internal reflection?

14.5 A diver sees a fish underwater closer than it really is. Why does this happen?

D. Comprehensive Questions

14.1 Explain the terms; normal, angle of incidence and angle of reflection in the context of light reflection. Provide a diagram to illustrate these terms.

14.2 Define the terms critical angle and total internal reflection. Explain the conditions required for total internal reflection to occur.

14.3 Derive the equation; ($n = 1/\sin C$) for the refractive index in terms of the critical angle C. Include all steps and assumptions.

14.4 Explain the phenomenon of total internal reflection. Also give its two practical applications.

14.5 What is long-sightedness? Discuss its causes.

E. Numerical Problems

14.1 The speed of light in water is 2.25×10^8 m s^{-1}. Calculate the refractive index of water. **[Ans: 1.33]**

14.2 A light ray in air (n_1=1.0) strikes a glass surface (n_2=1.5) at an angle of incidence 30°. Find the angle of refraction inside the glass. **[Ans: 19.5°]**

14.3 A ray of light travels from air into an unknown liquid. The angle of incidence in air is 45°, and the angle of refraction in the liquid is 30°.Calculate the refractive index of the liquid. **[Ans: 1.41]**

14.4 A ray of light passes from air into a liquid. The angle of incidence in air is 50°, and the angle of refraction inside the liquid is 32°.The speed of sound in air is 340 m s^{-1} and in the same liquid is 1500 m s^{-1}.Calculate:(a) the refractive index of the liquid(b) the speed of light in the liquid.

[Ans: (a) 1.45,(b) 2.08×10^8 m s^{-1}]

14.5 Light travels inside a glass block of refractive index n = 1.6. It strikes the glass–air boundary. Calculate the critical angle for total internal reflection.

[Ans: 38.68°]

CHAPTER 15

ELECTROSTATICS

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- state that there are positive and negative charges [and charge is measured in coulombs].
- state that unlike charges attract and like charges repel.
- describe experiments to show electrostatic charging by friction.
- explain that charging of solids by friction involves only a transfer of negative charge (electrons).
- explain how a conductor can be charged by electrostatic induction and then "earthing."
- describe an electric field as a region in which an electric charge experiences a force.
- state that the direction of an electric field line at a point is the direction of the force on a positive charge at that point.
- discuss and illustrate simple electric field patterns (including the direction of the field):
  - (a) around a point charge
  - (b) around a charged conducting sphere
  - (c) between two oppositely charged parallel conducting plates (end effects will not be examined).
- state examples of electrical conductors and insulators.

Electrostatics is a branch of physics which deals with the study of charges at rest. It focuses on understanding the interaction between charges and electric field they create. Electrostatics plays an important role in everyday life. In this chapter, we will cover topics such as electric charge and its properties, electrostatic induction, Coulomb's law and electric field.

15.1 Electric Charge

When a plastic comb (or rod) is rubbed through dry hair and is brought near small pieces of paper, it attracts them (Fig. 15.1). Similarly, amber rod when rubbed with silk attracts small pieces of paper. We often experience a shock when we touch a metal doorknob, after sliding across a car seat or walking on a synthetic carpet. In each of these cases, the electrostatic force, resulting from electric charges, is in action. This phenomenon of attraction or repulsion between objects is due to a property called electric charge. We have already learnt that an object's mass is an inherent property. Objects with smaller mass have less inertia than those with larger mass. Similarly, another intrinsic property of an object is its electrical charge. There are two types of electric charges, known as positive and negative, which can be demonstrated through a simple experiment (Fig. 15.2). The SI unit of charge is the coulomb (C).

Fig. 15.1: Comb rubbed with dry hair attracts small pieces of paper

Figure. 15.2 shows electrostatic interactions between glass and plastic rods after being charged by friction. In scenario (a), two glass rods that have been rubbed with silk cloth are brought close to each other. Since both rods acquire a positive charge, they repel

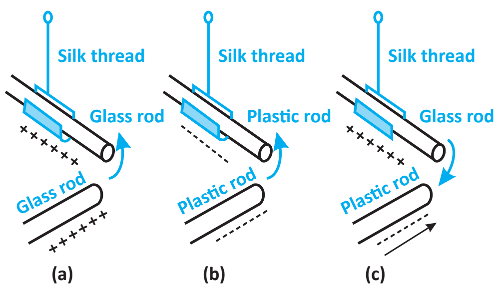


Fig. 15.2: Electrostatic interactions between glass and plastic rods after being charged by friction

each other due to the fundamental principle that like charges repel. In scenario (b), two plastic rods, likely rubbed with wool or fur, are placed near each other. Both rods gain a negative charge, leading to repulsion, as similar charges push away from each other. Lastly, in scenario (c), a positively charged glass rod (rubbed with silk) is brought near a negatively charged plastic rod (rubbed with fur or wool). Unlike the previous cases, attraction is observed because opposite charges attract. This set of experiments clearly demonstrates the basic electrostatic rule that like charges repel while opposite charges attract.

Properties of Charges

Matter is composed of atoms, which consist of subatomic particles. Among these, protons are positively charged particles located in the nucleus, while electrons are negatively charged particles that orbit around the nucleus (Fig.15.3). Since everything is composed of atoms, every material carries either a positive charge, a negative charge, or neutral. Charge is an essential property of materials that causes them to either attract or repel . Charge can be transferred between objects through various processes, including rubbing, direct contact, or induction. The total amount of charge in an isolated system remains constant.

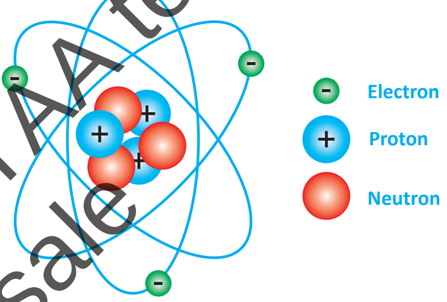


Fig. 15.3: Structure of an atom

15.2 Electrostatic induction

Activity 15.1: When a charged plastic rod is brought near a suspended neutral aluminium rod, both rods are drawn toward each other, as shown in Fig. 15.4. At first glance, this attraction suggests that the rods have opposite charges. However, this is not the case. The charged plastic rod causes a redistribution of positive and negative charges within the neutral aluminium rod, leading to the

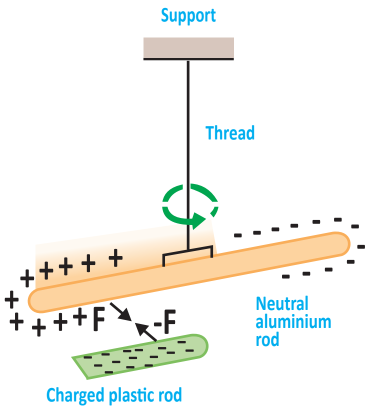


Fig. 15.4: Charged plastic rod attracts neutral aluminium rod

attraction. Despite this, the total charge on the aluminium rod remains zero. This indicates that attraction alone is not a reliable method to determine if an object is charged. The observed behaviour is an example of a phenomenon known as electrostatic induction.

Do You Know?

When a charged rod is brought near a conductor without touching it, the conductor still gets charged. That is the amazing effect of electrostatic induction.

Activity 15.2: Take two metal spheres, A and B, and place them on insulated stands so that they are in contact with each other, as shown in Fig. 15.5(a). Now bring a positively charged rod close to sphere A, as shown in Fig. 15.5(b). The charged rod will attract the negative charges towards it and repel the positive charges away from it. This clearly shows that unlike charges attract each other, while like charges repel each other. As a result, negative charge accumulates on the left surface of sphere A, which is closer to the rod, while positive charge appears on the right surface of sphere B.

Now separate the spheres while keeping the charged rod near sphere A. Upon testing the two spheres, we will find that they are oppositely charged, as shown in Fig. 15.5(c). After removing the rod, the charges are evenly distributed across the surfaces of the spheres, as seen in Fig. 15.5(d). In this process, equal and opposite charges appear on each sphere. This phenomenon is known as charging by induction.

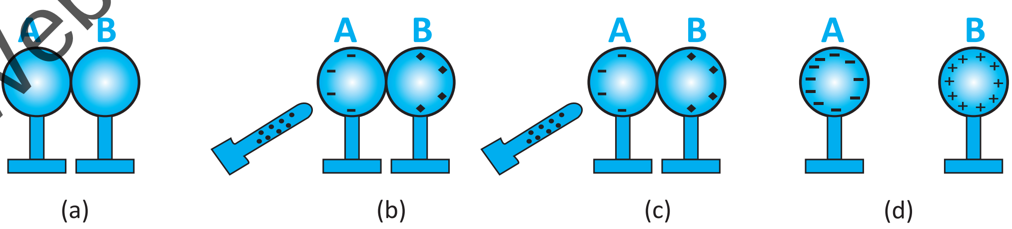


Fig. 15.5: Charging two spheres by electrostatic induction

In the presence of a charged object, an insulated conductor develops a positive charge at one end and a negative charge at the other end. This process is known as electrostatic induction.

Charging by Induction and Earthing

Charging by induction is a method of charging a conductor without directly touching it with a charged object. It involves the redistribution of electric charges within a conductor when exposed to a nearby electric field. Suppose we bring a negatively charged rod near a neutral metal sphere (conductor). The presence of the negatively charged rod causes free electrons in the conductor to move away due to repulsion, leaving the side near the rod positively charged and the far side negatively charged. This separation of charges is called electrostatic induction.

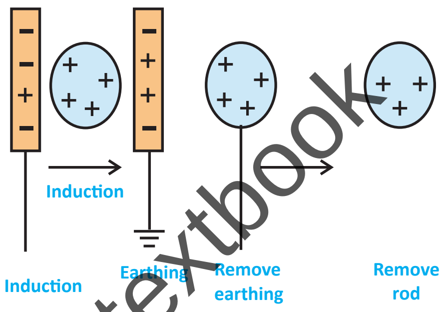


Fig. 15.6: Charging a conductor by induction and earthing

Earthing is the process of connecting a conductor to the Earth using a conducting wire. While the charged rod is still in place, the conductor is connected to the Earth using a wire (Fig. 15.6). Since the far side of the sphere is negatively charged, electrons flow from the sphere to the Earth, neutralizing the negative charge. After the unwanted charges have flowed away, the grounding connection is removed. The excess positive charge remains near the rod because the negative charges have left. Finally, the charged rod is taken away. The conductor now has a net positive charge, even though it was never touched by the rod.

Electroscope

The gold leaf electroscope is a sensitive device which is used to detect electric charges. It consists of a brass rod with a brass disk at the top and two thin gold leaves suspended at the bottom, as shown in Fig. 15.7. The rod passes through an insulating material, which holds it in place. Charges can move freely from the disk to the leaves via rod. Additionally, a thin aluminum foil is attached to the lower part of the inside of the jar. This aluminum foil is typically grounded by connecting it to a copper wire, which helps in protecting the gold leaves from external electrical interference. To detect the presence of charge on an object, bring the object near the disk of an

Brain Teaser

Rub a balloon on your dry hair and then hold it close to a wall. The balloon sticks to the wall. But why does this happen when the wall is not charged?

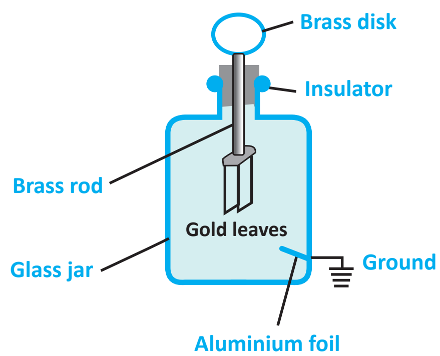


Fig. 15.7: Uncharged electroscope

uncharged electroscope. If the object is neutral, there will be no deflection of the leaves, as shown in Fig. 15.8(a). However, if the object is charged either positively or negatively the leaves of the electroscope will diverge. For example, if the object is negatively charged, electrostatic induction will cause a positive charge to appear on the disk and a negative charge to accumulate on the leaves, as shown in Fig. 15.8(b). Since both leaves carry the same charge, they will repel each other and move apart. The extent of the divergence depends on the amount of charge present on the object. An electroscope can also serve to distinguish between conductors and insulators. To perform this test, bring a charged object near the disk of the electroscope without allowing contact. If the leaves collapse from their previously diverged position, it indicates that the material is a good conductor as charge can flow.

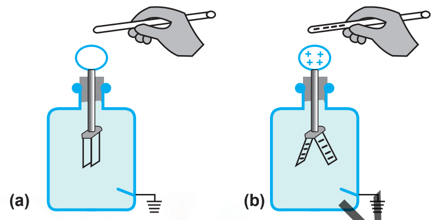


Fig. 15.8: Detecting charge using a gold leaf electroscope

Brain Teaser

Why do the leaves of an electroscope diverge when a charged object is brought near, even if the object does not touch the electroscope?

15.3 Coulomb's Law

Charges can repel and attract each other with a force called electrostatic force. Charles Coulomb in 1785, provided an experimental law to explain the nature and magnitude of electrostatic force between the charges. Coulomb's law states that;

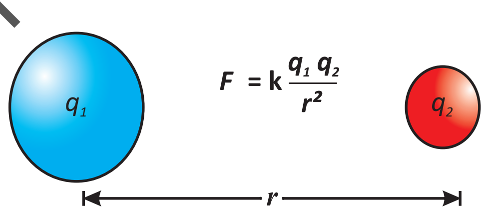


Fig. 15.9: Coulomb's law

The magnitude of the electrostatic force between two point charges is directly proportional to the product of magnitude of these charges and inversely proportional to the square of the distance between them.

Consider two charges q_1 and q_2, seperated by distance r (Fig.15.9).

Mathematically;

$$F \propto q_1 q_2 \quad \text{.............} \quad (15.1)$$

and

$$F \propto \frac{1}{r^2} \quad \text{.............} \quad (15.2)$$

or

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

or

$$F = k\frac{q_1 q_2}{r^2} \quad \text{.............} \quad (15.3)$$

where k is a constant of proportionality which quantifies the strength of the electrostatic force between two point charges. The value of k is determined by the medium between the charges. In vacuum or air, k is approximately 9×10^9 N m^2 C^{-2}. Coulomb's law is applicable primarily to point charges whose sizes are negligible compared to the distance separating them.

Do You Know?

Newton Vs. Coulomb

- **Similar formulae inverse square laws**
- **Gravitaional forces are only attractive**
- **Are important when dealing with large masses and distances**
- **Electrical forces are attractive and repulsive**
- **Are important when dealing with small masses and distances**

15.4 Electric Field

One charge exerts a force on another charge. This force is present everywhere around the charge, theoretically extending to infinity. However, the strength of the force decreases with distance.

An electric field is the region around a charge where it exerts a force on other charges.

Tidbit

If the charges are opposite in sign (one positive and one negative), they will attract each other. If the signs are reversed, making both charges positive or both negative, they will repel each other. The magnitude of the force will remain the same, but the direction of the force will change. This is an example of how Coulomb's law works with both attraction and repulsion.

The electric field strength decreases with distance from the charge, following an inverse square law for point charges.

Mathematically;

$$E = k\frac{q}{r^2} \quad .... \quad (15.4)$$

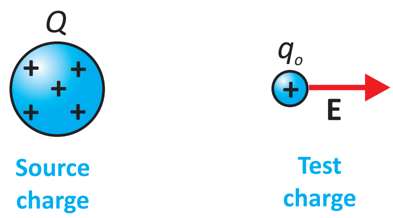


Fig. 15.10: Electric field intensity

Consider a test charge q_o is brought into the electric field of a source charge Q as shown in Fig. 15.10. The source charge will exert an electrostatic force **F** on the test charge.

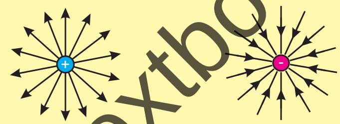
The electrostatic force per test charge (unit positive charge) when it is brought to the electric field of a source charge is called electric field intensity.

Mathematically;

$$\mathbf{E} = \mathbf{F}/ q_o \quad .... \quad (15.5)$$

The SI unit of electric field intensity is newton per coulomb ($N\,C^{-1}$).

Electric field intensity (electric field strength) is a vector quantity having both magnitude and direction. The direction of electric field intensity at a point is same as that of electric force.

> **Do You Know?**
>
> **Electric Fields**
>
> - Electric fields are represented by electric field lines. (imaginary) and show the direction of the force at that point.
> - Electric field direction is from a positive charge to a nagative charge.
> - Electric field lines (also known as electric flux) do not cross each other.
> - Electric field lines represent the path that a small positive test charge would follow in an electric field.
>
> 
>

Electric Field Lines

The concept of an electric field demonstrates how a charged object affects other nearby charged objects. The electric field is a vector field, which means it has both magnitude and direction. The direction of the electric field at any point is the direction in which a positive test charge would move if placed at that location. Here, we will explain and show the electric field patterns for three common situations:

(a) Around a Point Charge

Around a point charge, the electric field is radial, extending outward in all directions. For a positive point charge (Fig. 15.11-a), the electric field lines radiate outward, indicating that a positive test charge placed nearby would be repelled. In contrast, for a negative point charge (Fig. 15.11-b), the electric field lines point inward, showing that a positive test charge would be attracted towards it. This reflects the repulsive force around positive charges and the attractive force around negative charges.

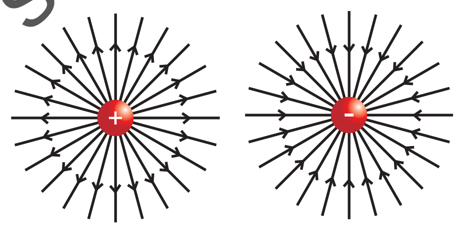


Fig. 15.11: Electric field lines for isolated positive and negative point charges

(b) Around a Charged Conducting Sphere

A charged conducting sphere distributes its charge evenly on its surface, and the electric field around it behaves similar to that of a point charge, but only outside the sphere. Outside, the electric field lines are radial, radiating outward for a positively charged

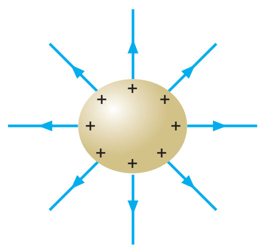


Fig. 15.12: Charge distribution on a positively charged sphere

sphere and inward for a negatively charged one (Fig. 15.12). Inside the sphere, the electric field is zero because the charges on the surface rearrange to cancel any internal electric field.

(c) Between Two Oppositely Charged Parallel Conducting Plates

When two large parallel conducting plates are given equal and opposite charges, a uniform electric field is created between them, commonly used in capacitors (Fig. 15.13). The electric field lines point from the positively charged plate to the negatively charged plate, and they are parallel and equally spaced, showing a uniform electric field. This uniformity means the electric field has the same magnitude and direction at all points between the plates, which is due to the plates being large and close together, minimizing edge effects.

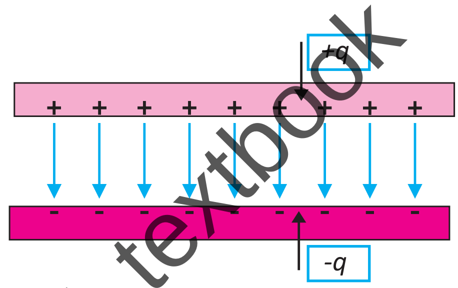


Fig. 15.13: Electric field between two oppositely charged parallel plates

Example: A point charge q = 10 μC is placed in air. Calculate the electric field at a distance of 0.5 m from the charge.

Solution:

Given that;

$k = 9.0 \times 10^9\ N\,m^2\,C^{-2}$

$q = 10 \times 10^{-6}\ C$

and $r = 0.5\ m$

To find; $E = ?$

Using the formula:

$E = kq / r^2$

Substituting the values

$E = (9.0 \times 10^9 \times 10 \times 10^{-6}) / (0.5)^2$

$E = 3.6 \times 10^5\ N\,C^{-1}$

Do You Know?

The electric field inside a charged conducting sphere is always zero, that is why people inside metal cars or airplanes are safe during lightning strikes.

15.5 Conduction of Electric Charges

Electrical Conductors

Electrical conductors are materials that allow electric charge to flow freely through them. They have loosely bound electrons in their atomic structure, which can flow easily when a voltage is applied, creating an electric current.

Examples of electrical conductors include metals, such as copper, aluminum, and silver, as well as materials like graphite and electrolytes .

Electrical Insulators

Electrical insulators are materials that resist or prevent the flow of electric charge. In insulators, electrons are tightly bound to their atoms and cannot move freely. As a result, they do not allow electric current to pass through them. Examples of electrical insulators include rubber, plastic, glass, wood, and ceramics . These materials are used to block the flow of electricity and provide safety in electrical systems.

Experiment: To explore this concept, we can conduct a simple experiment: Build a circuit with a battery, a bulb, and a gap to test materials. Insert objects like a metal key, a plastic spoon, or a wooden stick into the gap. If the bulb lights up, the material is a conductor; if it stays OFF, it is an insulator. This hands-on activity turns us into an electricity detective, revealing the hidden properties of everyday items.

EXCERISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

15.1 A charged balloon sticks to a wooden wall after you rub the balloon on your hair. Which phenomenon explains why the balloon sticks to the wall?
(a) Electrostatic induction (b) Conduction
(c) Friction (d) Magnetism

15.2 What happens when two unlike charges are brought close to each other?
(a) They attract (b) They repel
(c) They neutralize each other (d) Nothing happens

15.3 According to Coulomb's law, what happens to the attraction of two oppositely charged objects as their distance of separation increases?
(a) Decreases (b) Increases
(c) Remains unchanged (d) Cannot be determined

15.4 What is true about the electric field in the region between two oppositely charged parallel metal plates?
(a) The field is approximately uniform between the plates
(b) The field is stronger near the positive plate
(c) The field is weaker near the negative plate
(d) The field is stronger at the centre of the plates

B. Short Answer Questions

15.1 State Coulomb's law of electrostatics and write its mathematical form.

15.2 What is an electric field?

15.3 Give two examples each of electrical conductors and electrical insulators.

15.4 What is meant by electrostatic induction?

15.5 What happens when like charges and unlike charges are brought close to each other?

15.6 Why do metals conduct electric current but plastic do not?

C. Constructed Response Questions

15.1 Why do some materials gain electrons while others lose electrons when rubbed together? What property of the materials determines this behaviour?

15.2 A charged comb attracts small pieces of paper, but after some time, the paper pieces fall off. Why does this happen?

15.3 If we rub a balloon on our dry hair and place it near a thin stream of water, the water bends toward the balloon. What does this tell us about the nature of water molecules?

15.4 A conductor and an insulator are both placed in an electric field. How will their behaviour differ, and why?

15.5 In dry weather, why do we feel a current shock when we touch a metal doorknob?

D. Comprehensive Questions

15.1 How is a conductor charged by the process of electrostatic induction? Explain.

15.2 Describe how object are charged by friction?

15.3 Discuss the working of a gold leaf electroscope. How can it be used to determine the nature and magnitude of charge on a body?

15.4 How does Coulomb's law help in understanding the interaction between charged particles? What factors affect the force between them?

15.5 Explain the concept of electric field intensity. How can the electric field of a point charge and a parallel plate capacitor be represented using field lines?

E. Numerical Problems

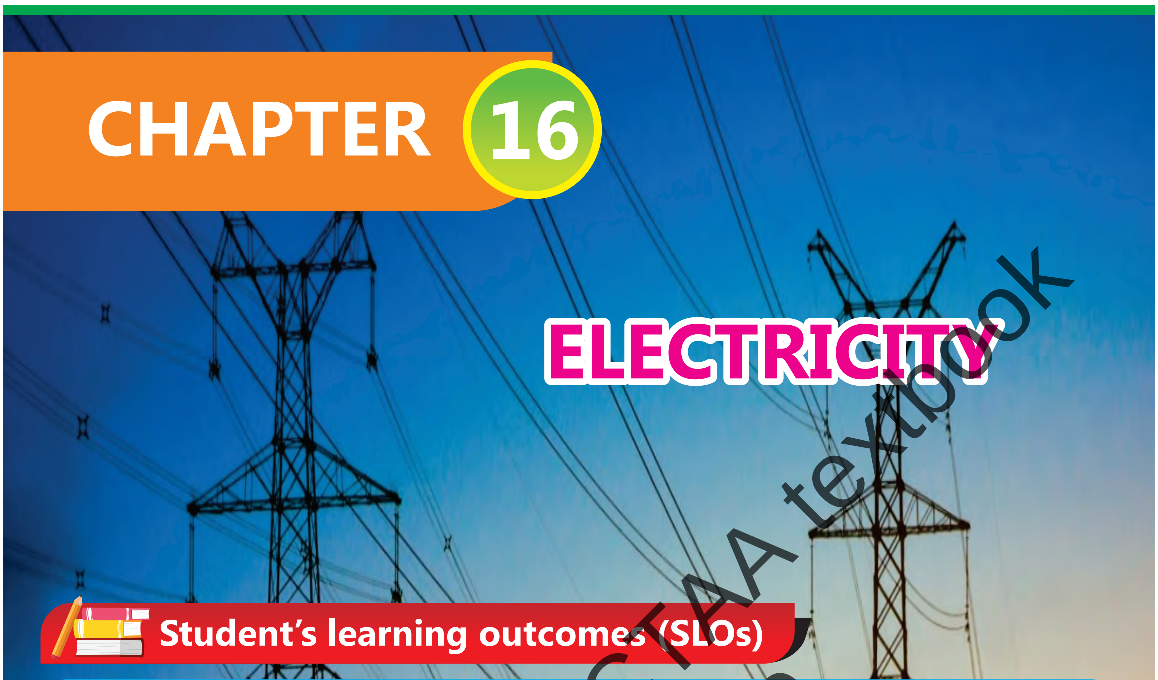
15.1 A positive test charge of 25 µC is placed in an electric field. The force on it is 0.500 N. What is the magnitude of the electric field at the location of the test charge? **[Ans: 2.0×10^4 N C^{-1}]**

15.2 Two point charges, q_1 = 8 µC and q_2 = 4 µC, are placed at a distance of 120 cm. What will be the Coulomb's force between them? Also, find the nature of the force. **[Ans: 0.2 N, the direction of repulsion]**

15.3 A point charge q=10 µC is placed in air. Calculate the electric field strength at a distance of 0.5 metres from the charge. **[Ans: 3.6×10^5 N C^{-1}]**

15.4 Two small equally charged metal spheres repel each other with a force of 0.5 N when placed 3 cm apart in the air. Calculate the charge on each sphere. **[Ans: 224 µC]**

15.5 A force of 85 N acts between two charges placed 3.2 cm apart. If one charge is 25 µC, determine the other charge. **[Ans: 3.87µC]**



CHAPTER 16

ELECTRICITY

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- define and calculate electric current, using the equation; *I* = *Q/t*.
- explain electrical conduction in metals in terms of the movement of free electrons.
- state that current is measured in amperes and that one ampere is equal to one coulomb per second ($C\ s^{-1}$).
- differentiate between direct current D.C and alternating current A.C.
- differentiate between conventional and electronic current.
- justify and illustrate the use of ammeters (analog and digital) with different ranges.
- define e.m.f. as the electrical work done by a source in moving a unit charge around a complete circuit, using the equation; *E* = *W/Q*.
- define potential difference (p.d.) as the work done by a unit charge passing through a component, using the equation; *V* = *W/Q*.
- state that e.m.f. and p.d. are measured in volts and that one volt is equal to one joule per coulomb ($J\ C^{-1}$).
- illustrate the use of voltmeters (analog and digital) with different ranges.
- calculate the total e.m.f when multiple sources are arranged in series.
- state that the e.m.f of identical sources connected in parallel is equal to the e.m.f. of one of the sources.

- define and apply Ohm's law using the equation; $R = V/I$.
- describe the effect of temperature increase on the resistance of a resistor, such as in a filament lamp.
- calculate the combined resistance of resistors in series.
- calculate the combined resistance of resistors in parallel.
- analyze the function of variable potential dividers in circuits, using the equation; $R_1/R_2 = V_1/V_2$.
- use the equation; power = current × voltage ($P = IV$) to solve simple problems.
- use the equation energy = current × voltage × time ($E = IVt$) to solve simple problems.
- define the kilowatt-hour (kWh).
- explain the need to choose components with suitable power ratings.
- calculate the cost of using electrical appliances where the energy unit is the kWh.
- explain the use and operation of trip switches and fuses and choose appropriate fuse ratings and trip switch settings.
- explain what happens when a live wire touches a metal case that is earthed.
- explain why the outer casing of an electrical appliance must be either non-conducting (double-insulated) or earthed.
- state that a mains circuit consists of a live wire (line wire), a neutral wire, and an earth wire.
- explain why fuses and circuit breakers are connected into the live wire for the circuit to be switched OFF safely.
- explain why domestic supplies are connected in parallel.

Electricity is a branch of physics which deals with the flow of charges. The movement of charges results in the flow of electric current which plays an important role in our daily lives. The electricity illuminates our homes, fuels our industries, and connects us across vast distances. In this chapter, we will learn the basic concepts of electricity, including electric current, potential difference, Ohm's law, and common uses of electricity, benefits and its hazards. These contents will help in building up basic knowledge about electricity.

16.1 Electric Current

In an atom, the electrons and positively charged nucleus are held together by strong force. However, in metals some electrons can move freely as these are not tightly bonded with the nucleus. These electrons move randomly within a metallic conductor. However, when an external electric field is applied, these electrons move in a specific direction (Fig. 16.1). This flow of charges is called an electric current. The electric current can be caused due to movement of both positive and negative charges.

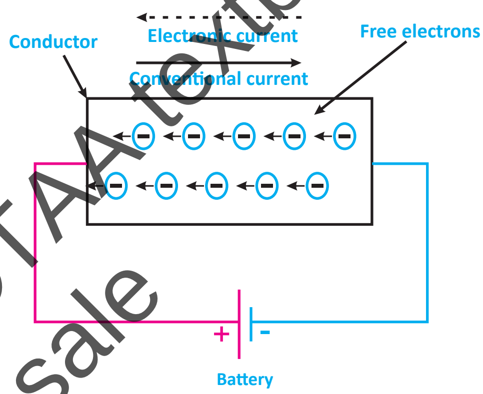


Fig. 16.1: Flow of electrons in a circuit

Amount of charge passing through any cross section of a conductor per unit time is called electric current.

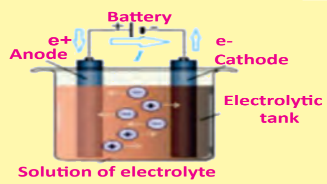
If Q charge flows in time t, then current I can be expressed as:

$$I = \frac{Q}{t} \qquad \text{............ (16.1)}$$

The SI unit of electric current is ampere (A). One ampere is defined as the flow of one coulomb of electric charge per second, which can be written as; $1\ A = 1\ C\ s^{-1}$.

Before the discovery of electrons, the electric current was considered to be due to flow of positive charges, named as Conventional Current. These charges move from positive terminal to the negative terminal of the power source. Later, after the discovery of electrons, the electric current was described due to the movement of electrons which was named

Do You Know?



In electrolysis, current is produced due to flow of both positive and negative ions. In the electrolyte, negative ions are attracted to the anode. This movement of ions within the electrolyte constitutes an electric current within the internal circuit.

as electronic current. The movement of electrons in one direction corresponds to the movement of positive charges in opposite direction. Despite this difference, both concepts are used in practice, with conventional current being the standard in circuit analysis.

Types of Electric Current

1. Direct Current (DC)
2. Alternating Current (AC)

Direct Current (D.C) is an electrical current where the electric charge flows in one direction only (Fig.16.2-a). In a D.C circuit, the voltage remains constant over time, and the strength of the current does not change. The current provided by a battery is an example of direct current.

Alternating Current (A.C) is a type of current that periodically reverses its direction (Fig. 16.2-b). Most power stations in our country produce alternating current. A.C changes direction every 1/50 second, and its frequency is 50 hertz (Hz). One advantage of A.C over D.C is that it can be transmitted over long distances with low power loss.

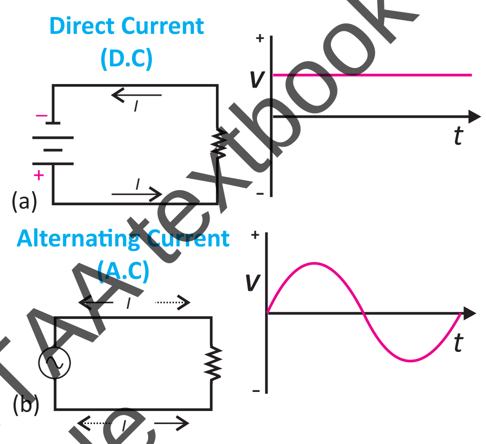


Fig. 16.2: Types of current (a) D.C (b) A.C

Tidbit

In any circuit, electric current prefers the path of least resistance, just like water flowing downhill.

Ammeter

An ammeter is a device used to measure the current flowing through a circuit. It must be connected in series with the component whose current is to be measured. There are two main types of ammeters: analog ammeters and digital ammeters. Both types are available in different current ranges to measure both small and large currents. In Fig. 16.3, we can see the digital ammeter (left) and analog ammeter (right) side by side, illustrating the difference in display type and range options. Both types are connected in series with the load to measure current, but the display method and

Fig. 16.3: Comparison of digital and analog ammeters

ease of reading differ significantly.

Types of Ammeters

Analog Ammeter: An analog ammeter uses a needle and scale to indicate the current. The current flowing through the circuit generates a magnetic field that moves the needle on the scale. The scale usually has multiple ranges, and the correct range must be selected depending on the expected current. Analog ammeters typically have multiple selectable ranges, such as 0-100 mA, 0-10mA, etc. The correct range must be selected to avoid damage to the device and to ensure accurate readings.

Use: Ideal for visual indication of current flow in basic experiments, and often used in educational settings due to its simplicity.

Digital Ammeter: A digital ammeter provides a numerical reading of the current on a digital display. It offers more precision compared to an analog ammeter. Digital ammeters also come with various ranges, and some automatically adjust the range depending on the detected current. They are typically more accurate and easier to read than analog meters. Digital ammeters are widely used in scientific, industrial, and electrical applications where precise measurements are critical.

> **Do You Know?**
>
> **A.C is More Dangerous than D.C**
>
> Direct Current (D.C) is a current that travels from negative to the positive terminal. It does not change its direction. It is the current, we can get from a battery. It can cause burning if the positive and negative wires can come into contact.

Range Selection

Ammeters are equipped with multiple ranges to accommodate different magnitudes of current. Selecting the correct range is important to ensure that ammeter is not damaged and to provide an accurate measurement. Low-range ammeters (e.g. 0–1 A) are used to measure small currents, typically in laboratory experiments.

High-range ammeters (e.g. 0–10 A) are used to measure larger currents, such as those in power systems or industrial circuits.

16.2 Electromotive Force and Potential Difference

Electromotive force (e.m.f.) and potential difference (p.d.) are two important concepts, both measured in volts (V). One volt is defined as one joule of energy per coulomb of charge ($1\ V = 1\ J\ C^{-1}$). This means that if 1 joule of energy is used to move 1 coulomb of charge, the voltage is 1 volt.

Electromotive Force (e.m.f.)

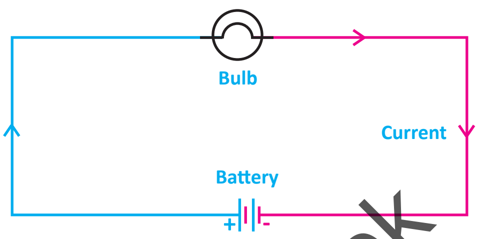


Fig. 16.4: Electromotive force

A source of electromotive force (e.m.f.) converts non-electrical energy, like chemical, thermal, or mechanical energy, into electrical energy. Examples of such sources include batteries (which convert chemical energy), thermocouples (which convert thermal energy), and generators (which convert mechanical energy). When a conductor is connected to a battery, current flows due to the potential difference between the battery's terminals. The battery provides energy to move positive charges from the positive terminal through the conductor to the negative terminal (Fig. 16.4). Once the charge reaches the negative terminal (lower potential), the battery does work to push it back to the positive terminal (higher potential). This cycle keeps the current flowing continuously. In short, the e.m.f. supplies the energy needed to keep the charges in motion.

Electromotive force is the electric potential energy supplied by a battery to a unit positive charge when it flows through the closed circuit.

Mathematically;

$$\text{e.m.f} = \frac{\text{Energy}}{\text{Charge}} \quad \text{..........} \quad (16.2)$$

or

$$E = \frac{W}{Q} \quad \text{...........} \quad (16.3)$$

E is the e.m.f., *W* is energy converted from non-electrical forms to electrical form and *Q* is the charge. Emf of a battery can be measured directly by connecting its terminal to a voltmeter as shown in Fig. 16.5.

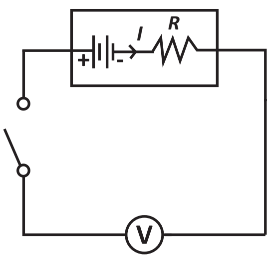


Fig. 16.5: Schematic diagram for measuring e.m.f. of the battery

Potential Difference

A battery converts chemical energy into electrical energy. Inside the battery, a chemical reaction causes a buildup of electrons at the negative terminal and a shortage of electrons at the positive terminal. This imbalance creates a potential difference between the terminals, which allows electrons to flow through a connected circuit, generating an electric current. The battery continues to drive this flow as long as the chemical reaction is active, providing a steady supply of energy. In short, the chemical action inside the battery creates a potential difference that allows the current in the circuit.

Electric potential (*V*) is the amount of electric potential energy (*W*) per unit charge (*Q*) at a specific point in an electric field.

$$\text{i.e;} \qquad V = \frac{W}{Q} \qquad \text{..............} \quad (16.4)$$

The potential difference is the difference in the values of electric potential between two points in the electric field (Fig. 16.6). The unit of electric potential is volt (V). One volt is equals to one joule per coulomb ($V = J\ C^{-1}$). Potential difference is also called voltage which is the energy used by a component in the circuit. Voltage can also be referred to e.m.f. which is the energy supplied by a source like a battery. Both potential difference and e.m.f. are measured in volts.

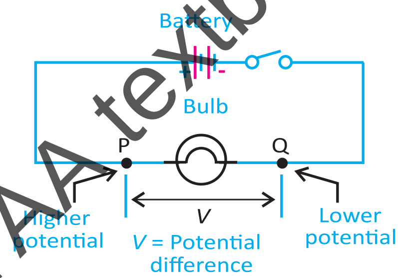
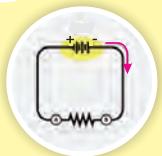


Fig. 16.6: Potential difference across a battery

Voltmeter

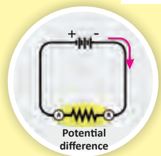
Voltage can be measured using a device called voltmeter. Voltmeter can also be of analog and digital types. Both types are available with different ranges, allowing them to measure voltages of varying magnitudes. Analog voltmeters use a needle and a scale to display the voltage, making them useful for observing changes or trends over time. Digital voltmeters, on the other hand, show the voltage as a numerical value on a screen, offering greater precision and ease of reading. For example, a low-range voltmeter might measure millivolts (mV),

Do You Know?



EMF

The electromotive force is the type of energy which forces a unit positive charge to move from the positive to the negative terminal of the source. It separates the two charges from each other.



VOLTAGE

Voltage is the difference in electric potential between two points. The voltage between two points is equal to the work done per unit of charge against a static electric field to move a test charge between two points.

Analog voltmeter

Digital voltmeter

Fig. 16.7: Types of voltmeters

while a high-range voltmeter could measure hundreds or even thousands of volts. Choosing the right range is important, using a low-range voltmeter for a high voltage could damage the device, while using a high-range voltmeter for a small voltage, might not provide accurate readings. Analog and digital voltmeters are shown in Fig. 16.7.

Example 16.1: A battery does 120 J of work to move a charge of 20 C through a circuit. What is the potential difference across the circuit?

Solution:

Given that; $W = 120\text{ J}$, $Q = 20\text{ C}$

To find; $V = ?$

Using the formula; $V = W / Q$

Substituting the values; $V = 120\text{ J} / 20\text{ C} = 6\text{ V}$

Total E.M.F. of Series Connected Sources

When multiple voltage sources (e.g., batteries) are connected in series (Fig. 16.8), their total electromotive force (e.m.f.) is simply the sum of their individual e.m.f. This is because the voltage sources add energy to the charges one after the other.

Formula: $E_{total} = E_1 + E_2 + ... + E_n$

where

E_{total} = total e.m.f.

$E_1, E_2, ..., E_n$ = e.m.f. of the individual sources

Example: If four batteries, each with an e.m.f. of 1.5 V (Fig. 16.8), are connected in series, the total e.m.f. would be 6 V.

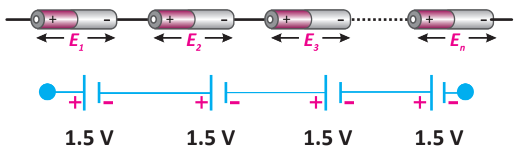


Fig. 16.8: Series combination of batteries

E.M.F. of Identical Sources Connected In Parallel

When multiple identical sources (such as batteries with the same voltage) are connected in parallel (Fig. 16.9), the total e.m.f. across all of them remains equal to the e.m.f. of a single source. This is because, in parallel connections, each battery is connected directly across the same two points, meaning the voltage (e.m.f.) does not change. However, the total current supplied by the sources will increase due to the additional paths available for current to flow.

For Your Information

In a series combination, the total e.m.f. increases, making it easier to push electric charges through the circuit. However, the total current depends on the overall resistance in the circuit.

Explanation: In a parallel connection, each source contributes current independently while maintaining the same voltage across each of them. This results in the total e.m.f. remaining equal to the e.m.f. of one of the individual sources, but the total current becomes the sum of the individual currents provided by each source.

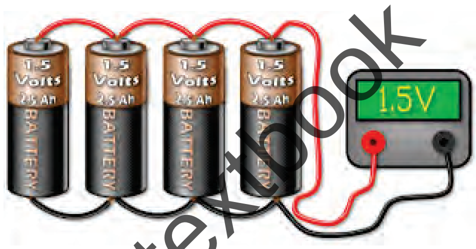


Fig. 16.9: Four 1.5 V batteries connected in parallel

Brain Teaser

Three identical 5 V cells are connected in parallel. What is the total e.m.f. of the combination?

Formula: For identical sources in parallel:

$$E_{total} = E_1 = E_2 = ... = E_n$$

where

E_{total} is the total e.m.f. across the parallel sources.

E_1, E_2, ..., E_n are the e.m.f's of the individual sources (which are identical for each source in the parallel connection).

Example: In Fig. 16.9, four 1.5 V batteries are connected in parallel. The total e.m.f. across the combination will still be 1.5 V, just as it is for a single battery.

16.3 Ohm's Law

In 1826, George Simon Ohm made an investigation of the relationship between electric potential difference across a conductor and the current flowing through it. The current in a conductor was increased by increasing the potential difference across its ends. According to Ohm's law:

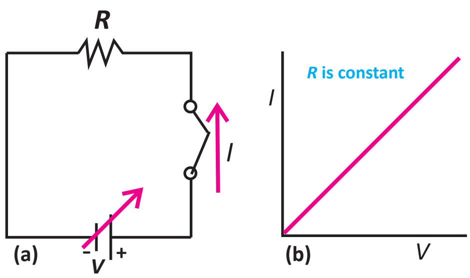


Fig.16.10: (a) Ohm's law circuit (b) *I-V* graph for ohmic conductor

The current flowing through a conductor is directly proportional to the potential difference *V* across its two ends of a conductor, provided the physical state (dimension, temperature, etc.) of the conductor remains same.

Mathematically;

$$I \propto V$$

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

$$V = IR \quad \text{.................... (16.5)}$$

where R is constant of proportionality called resistance of a conductor. The SI unit of resistance is ohm (Ω) and 1 Ω = V A^{-1}.

16.4 Combination of Resistances

A number of resistors can be connected in a circuit to increase or decrease the net resistance of the circuit. The resistors are connected either in series or in parallel and the equivalent resistance of the circuit depends upon the type of combination.

Series Combination of Resistors

When resistors are connected in such a way that there is only one path for the current to flow, then it is called series combination of resistors. For example, consider three resistors R_1, R_2 and R_3 connected in series as shown in Fig. 16.11. When this combination is connected to a battery of V volts, it draws current I from the battery. Let R_e be a single resistor representing the total resistance of the circuit, also called equivalent resistance.

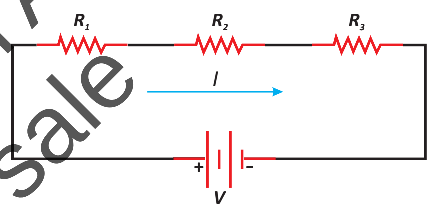


Fig.16.11: Resistors in series

The total voltage in the circuit will be the sum of voltage across the three resistors.

i.e; $V = V_1 + V_2 + V_3$

Applying Ohm's law:

$$V_1 = IR_1,\ V_2 = IR_2 \text{ and } V_3 = IR_3$$

or $IR_e = IR_1 + IR_2 + IR_3$

$IR_e = I(R_1 + R_2 + R_3)$

$R_e = R_1 + R_2 + R_3$ .... (16.6)

Thus, equivalent resistance is equal to the sum of individual resistances.

Parallel Combination of Resistors

When there are multiple paths for current flow in a circuit (as indicated in the diagram), the combination of resistances is referred to as parallel combination. The electric potential across each resistance is the same and equal to the applied potential. Each resistor has a steady current flowing through it. Consider three resistors R_1, R_2 and R_3 connected in parallel (Fig. 16.12). When these are connected to a battery of V volts, it draws a current I from the battery. R_e is a single resistor. This resistor is such that when it is connected to the same battery of V volts, it also draws current I from the battery. This resistor is therefore called equivalent resistor and its resistance is called equivalent resistance. The total current in the circuit will be the sum of currents flowing through the resistors;

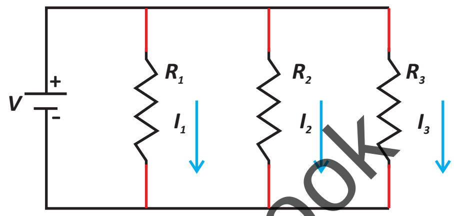


Fig.16.12: Resistors in parallel

$$I = I_1 + I_2 + I_3$$

Applying Ohm's Law:

$$V = I_1R_1,\ V = I_2R_2,\ V = I_3R_3$$

or $$I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$$

or $$\frac{V}{R_e} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or $$\frac{V}{R_e} = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{..............} \quad (16.7)$$

Tidbit

Birds are safe because both their feet touch the same potential wire. There is no voltage difference, so no current flows through their bodies.

Thus, the reciprocal of equivalent resistance is equal to the sum of reciprocals of individual resistances.

Example 16.2: Two resistors of 8 Ω and 24 Ω are connected in parallel across a 30 V power supply. Calculate the total resistance and the current drawn from the power supply.

Solution:

Given that; R_1 = 8 Ω, R_2 = 24 Ω and V = 30 V

To find; R_e = ? and I = ?

Using the formula for parallel resistance: $1/R_e = 1/R_1 + 1/R_2$

Substituting the values; $1/R_e = (1/8) + (1/24)$

$$1/R_e = (3/24) + (1/24)$$

$$1/R_e = 4/24 \text{ or } R_e = 24/4 = 6\ \Omega$$

Now, we calculate total current by using Ohm's Law:

$$I = V / R_e = 30\ V / 6\ \Omega = 5\ A$$

16.5 Effect of Temperature on Resistance of a Conductor

The resistance of a conductor can change with temperature. In most conductors such as metals, the electrical resistance increases with temperature because atomic vibrations resist electron flow.

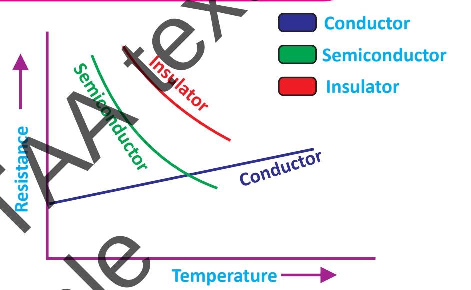


Fig.16.13: Temperature effect on materials

For example, in a filament lamp, when the temperature of the filament (resistor) increases, its resistance also increases. This occurs because the filament is made of metal, and metals have free electrons that causes the flow of electric current. The increase in the temperature of a resistor increases the vibration of its atoms. These vibrations make it harder for the electrons to move. As a result, the flow of current becomes more difficult, and the resistance goes up. So, a hot filament has more resistance than a cold one.

In the case of semiconductors and insulators, resistance may decrease with temperature due to increase in the mobility of free charge carriers. For example, thermistor, which is made up of a semiconductor material, is a type of resistor whose resistance decreases as its temperature increases. At low temperatures, the semiconductor material has fewer free charge carriers (electrons or holes), resulting in high resistance. As the temperature rises, more charge carriers are released, increasing conductivity and reducing resistance.

16.6 Potential Divider Circuit

A potential or voltage divider is a circuit that divides a voltage into smaller parts using resistors. It consists of two or more resistors connected in series across a voltage source (Fig. 16.14). The voltage across each resistor is proportional to its resistance relative to the total resistance of the circuit.

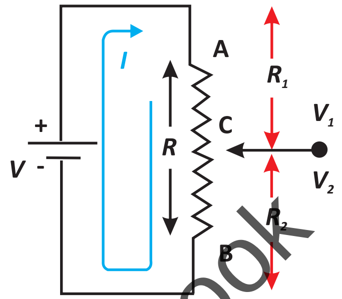


Fig.16.14: Potential divider circuit

Consider two resistors R_1 and R_2 connected in series. The voltage across each resistor is given by

$$\frac{R_1}{R_2} = \frac{V_1}{V_2} \quad \text{............} \quad (16.8)$$

where V_1 = voltage across R_1

and V_2 = voltage across R_2

The total voltage (V_{total}) is the sum of V_1 and V_2:

$$V_{total} = V_1 + V_2 \quad \text{............} \quad (16.9)$$

The voltage across each resistor can also be calculated using the formulae:

$$V_1 = IR_1 = \frac{V_{total}}{R_e} \times R_1$$

$$V_1 = V_{total} \times \frac{R_1}{R_1 + R_2} \quad \text{................} \quad (16.10)$$

$$V_2 = V_{total} \times \frac{R_2}{R_1 + R_2} \quad \text{................} \quad (16.11)$$

16.7 Electric Power

Electric power is the rate at which electrical energy is transferred or consumed in a circuit.

It measures how quickly work is done or energy is used. The SI unit of power is watt (W). $P = W/t$

$1\ W = J\ s^{-1}$

Electric power P is commonly written as product of current I and voltage V.

$$P = IV \quad \text{............} \quad (16.12)$$

As $V = IR$

So $P = I^2R$

or $P = V^2/R$ .... (16.13)

Tidbit

Power bills measure energy, not electricity. Our electricity bills show kilowatt-hours (kWh), a measure of energy used, not electricity consumed.

Kilowatt-hour

Electrical energy is commonly consumed in very large quantity. The unit which is used to measure large amount of electrical energy is called kilowatt-hour. It is defined as:

The amount of energy delivered by a power of one kilowatt in one hour is called kilowatt-hour.

One kilowatt-hour (1 kWh) = 1,000 W × 1 hour .... (16.14)

$= 1,000 \text{ W} \times (3600 \text{ s})$

$= 3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ}$

The energy in kilowatt-hour can be obtained by the formula:

$$\text{The amount of electrical energy in kilowatt-hour} = \frac{\text{Power in watts x time of use in hours}}{1,000}$$

The electric meter installed in our houses measures the consumption of electrical energy in the units of kilowatt-hour according to which we pay our electricity bills. If the cost of one kilowatt-hour i.e., one unit is known, we can calculate the amount of electricity bill by the formula:

Cost of electricity = Number of units consumed × Cost of one unit

$$= \frac{\text{Power in watts x time of use in hours}}{1,000} \times \text{Cost of one unit}$$

When designing circuits, it is important to choose components with suitable power ratings. Selecting components with the right power ratings ensures safety, reliability, and efficiency.

Brain Teaser

If two appliances are rated 100 W and 1,000 W, both used for 1 hour. Do they consume equal energy or different? Why?

Example 16.3: Calculate the one-month cost of using a 100 W ceiling fan for 10 hours daily in your room. Assume that the price of one unit is Rs.25.

Solution:

Given that; Power P = 100 W = 0.1 kW

Time t = 10 hour per day

Number of days = 30

To find; One month cost of electricity = ?

Number of units consumed = Power × Time × Days

= 0.1 × 10 × 30 = 30 units

Total cost = Units consumed × Price per unit

= 30 × 25 = Rs. 750

16.8 Household Circuits and Safety Measures

Household circuits safely distribute electricity through different pathways in a home. Safety measures protect against electrical hazards.

Household Circuits

In a parallel circuit, every appliance like our refrigerator, bulbs, or TV gets its own direct connection to the power supply. In the parallel circuits, each appliance works independently. We can turn OFF the lights in the kitchen without shutting down the TV in the living room. The parallel circuits are safer and more reliable. If one appliance breaks or a fuse blows, the rest of our home's power stays ON. In short, connecting our home's electrical system in parallel is like giving every appliance its own superpower consistent voltage, independent operation, and reliable performance. It is the smartest way to keep our home running smoothly and efficiently. Figure 16.15 demonstrates a household circuit.

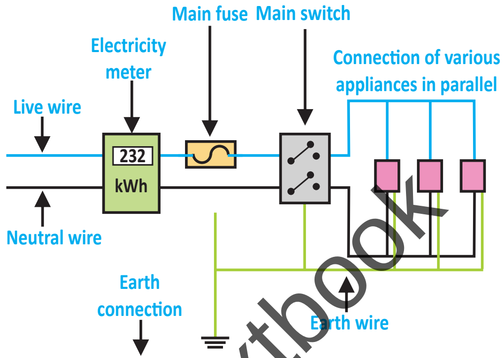


Fig. 16.15: Household circuit

Hazards of Electricity and Safety Measures

Common electric hazards occur due to:

1. Malpractice (incorrect use) or lack of maintenance, and they can lead to serious accidents like shocks, fires, or even fatalities.

2. One major hazard is damaged insulation, where the protective covering on wires wears out or gets cut, and exposing live wires. This can cause electric shocks or short circuits.

3. Another danger is overheating cables, which happens when wires carry more current than they are designed for, causing them to heat up and potentially start a fire.

4. Overloading is a common issue plugging too many devices into a single socket, extension lead, or power strip can draw excess current, overheating the circuit and causing fires.

Fuses and trip switches (circuit breakers) are essential safety devices to avoid these hazards. Fuses contain a thin wire that melts due to flow of high current. As a result, breaking of the circuit stops the flow of electricity. Different types of fuses are shown in Fig. 16.16. Trip switches, on the other hand, automatically cut OFF power

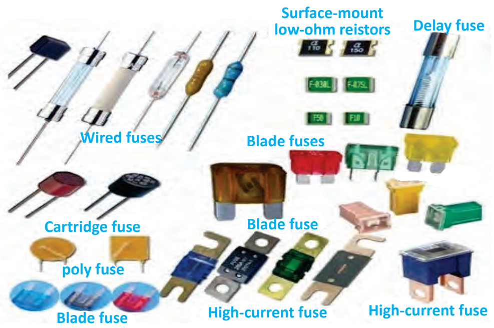


Fig. 16.16: Different types of fuses

when they detect a fault, like an overload or short circuit (Fig. 16.17). Both devices are connected to the live wire of the circuit, ensuring that the entire circuit is switched OFF safely in case of a problem. One of the most critical safety features in a circuit is the earth wire. If a fault occurs such as a live wire touching a metal casing, the earth wire provides a low-resistance path for the current to flow safely into the ground. This prevents the casing from becoming live and triggers the fuse or trip switch to cut OFF the power. This is why the outer casing of an electrical appliance must be either non-conducting (double-insulated) or earthed. Double-insulated appliances, like many power tools, have casings made of plastic, which cannot conduct electricity. Appliances with metal casings, like washing machines, are connected to the earth wire for safety.

A typical main circuit consists of three wires:

The live wire (line wire), which carries the current from the power supply; the neutral wire, which completes the circuit; and the earth wire, which provides a safety path for fault currents (Fig. 16.18). Despite these safety measures, electric shocks can still occur, and they can be extremely dangerous. When electricity passes through the human body, it can cause burns at the entry and exit points. More seriously, it can disrupt the body's electrical signals, leading to cardiorespiratory failure (where the heart and lungs stop working) or seizures. This is why proper safety mechanisms like fuses, circuit breakers, and earthing are so important which help to prevent accidents and protect lives. The symbols of various electrical components are shown in Fig. 16.19.

Fig. 16.17: A trip switch

> **Brain Teaser**
>
> Why can a tiny device like a smartphone charger trip the main switch if something goes wrong?

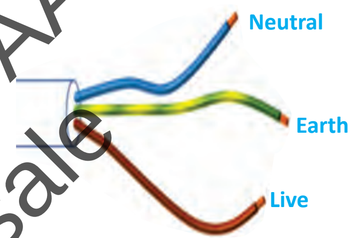


Fig. 16.18: Main circuit wires

> **Brain Teaser**
>
> Imagine your home has no Earth wire. What could happen if the live wire touches the metal body of an appliance?

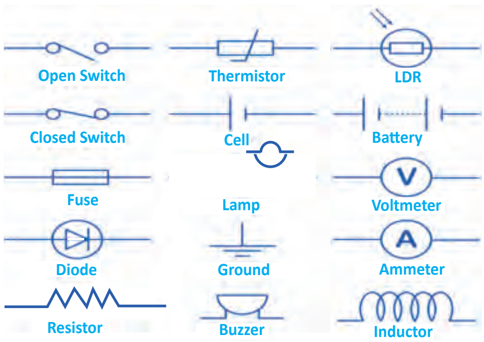


Fig. 16.19: Symbols of various electrical components

EXERSICE

A. Multiple Choice Questions

Tick (✓) the correct answer

16.1 The direction of conventional current is:
(a) from negative to positive terminal
(b) from positive to negative terminal
(c) in both directions at the same time
(d) it does not have a fixed direction

16.2 What type of electric current flows in one direction only?
(a) Alternating current (b) Direct current
(c) Induced current (d) None of these

16.3 The device used to measure electric current:
(a) voltmeter (b) ammeter (c) ohmmeter (d) wattmeter

16.4 What is the function of an electromotive force (e.m.f.) source in a circuit?
(a) To reduce resistance in the circuit
(b) To provide energy to drive charges through the circuit
(c) To store electrical energy for later use
(d) To convert electrical energy into mechanical energy

16.5 The relationship between voltage, current, and resistance is:
(a) $V = IR$ (b) $V = I/R$ (c) $V = I^2 R$ (d) $V = R/I$

16.6 What happens to the resistance of a metal conductor when its temperature increases?
(a) It decreases (b) It remains constant
(c) It increases (d) It becomes zero

B. Short Answer Questions

16.1 How does an ammeter measure electric current?
16.2 What is the main difference between direct current and alternating current ?
16.3 Define electromotive force (e.m.f.).
16.4 State Ohm's law and define resistivity.
16.5 What is the formula for calculating the equivalent resistance of resistors connected in series?
16.6 How does temperature affect the resistance of a conductor?

C. Constructed Response Questions

16.1 Why is it important that an ammeter has very low resistance and is connected in series, while a voltmeter has very high resistance and is connected in parallel? What would happen if they were connected incorrectly?

16.2 In a household lighting circuit, what practical problems might arise if the bulbs were connected in series instead of parallel?

16.3 You are tasked with designing a fuse for a device that operates at 230 V and 5 A. What rating would you choose for the fuse and why? What could go wrong if the rating is too low or too high?

16.4 Explain why A.C is more suitable for power transmission across cities, even though D.C is used in batteries and portable electronic devices.

16.5 You are given two wires; one is thin and the other is thick. For high-power appliances, which wire would you prefer and why?

D. Comprehensive Questions

16.1 Explain the concept of electric current. How is it related to the movement of charges, and how is it measured in a circuit?

16.2 Define electromotive force (e.m.f.) and potential difference. How does a battery create a potential difference, and what is the role of e.m.f. in maintaining the flow of current?

16.3 State and explain Ohm's law. How does the resistance of a conductor affect the flow of current, and how can Ohm's law be applied in practical electrical circuits?

16.4 Differentiate between series and parallel combinations of resistors. Provide mathematical expressions for calculating the total resistance in both types of circuits.

16.5 Define electric energy and electric power, and state their SI units. How is electrical energy related mathematically to power and time?

E. Numerical Problems

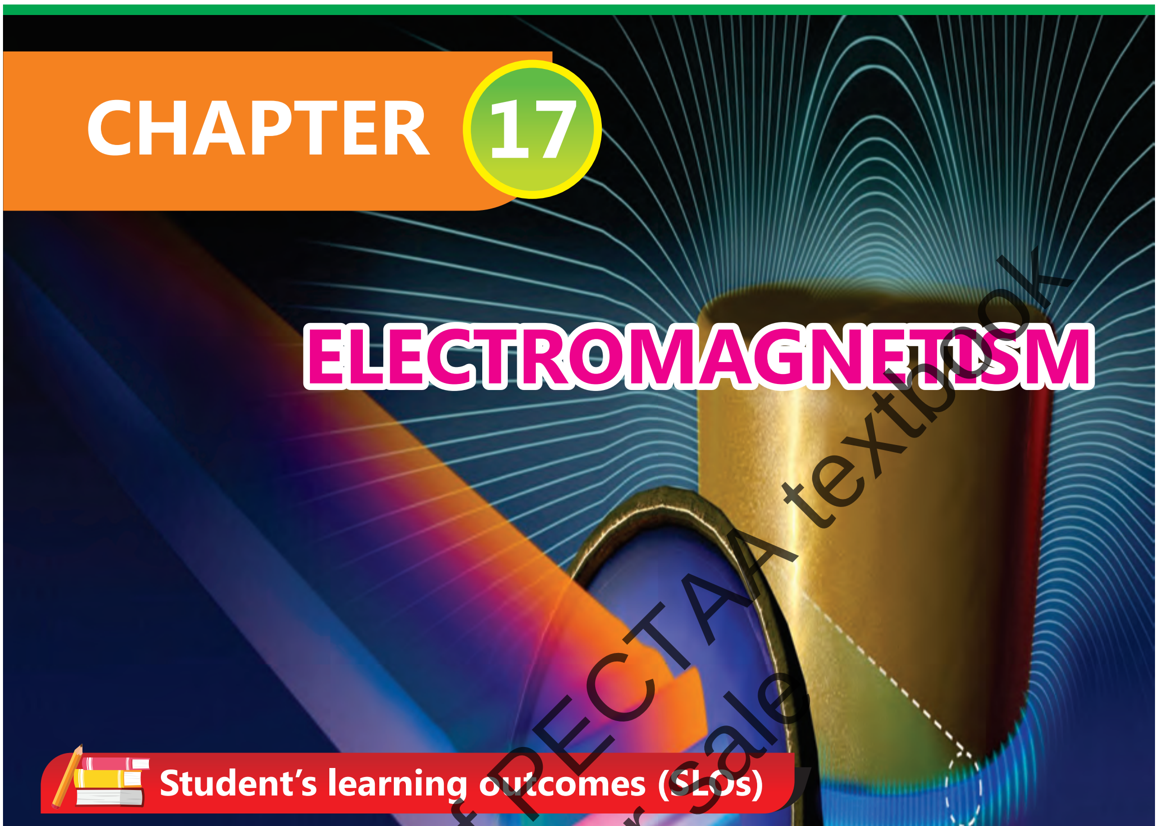
16.1 A charge of 25 coulombs passes through a circuit in 10 seconds. Calculate the current flowing through the circuit. **[Ans: 2.5 A]**

16.2 Three resistors of 4 Ω, 6 Ω, and 8 Ω are connected in series to a 24 V battery. Find the total resistance and the current flowing through the circuit. **[Ans: 18 Ω, 1.33 A]**

16.3 Two resistors of 10 Ω and 30 Ω are connected in parallel across a 20 V power supply. Calculate the total resistance and the current drawn from the power supply. **[Ans: 7.5 Ω, 2.67 A]**

16.4 Four 1.5 V batteries are connected in series in a flashlight. Determine the total electromotive force (e.m.f.) supplied to the circuit. **[Ans: 6 V]**

16.5 A circuit has a 5 A current passing through a 7 Ω resistor. Calculate the power dissipated in the resistor and the energy consumed in 10 minutes. **[Ans: 175 W, 105 kJ]**



CHAPTER 17

ELECTROMAGNETISM

Student’s learning outcomes (SLOs)

After studying this chapter, students will be able to:

- describe the pattern and direction of the magnetic field due to currents in straight wires and in solenoids.
- describe an experiment to show that a force acts on a current-carrying conductor in a magnetic field (including the effect of reversing:
  (a) the current
  (b) the direction of the field
- state and use the relative directions of force, magnetic field, and current.
- describe the magnetic field patterns between currents in parallel conductors and relate these to the forces on the conductors (excluding the Earth's field).
- state that a current-carrying coil in a magnetic field may experience a turning effect and that the turning effect is increased by increasing:
  (a) the number of turns on the coil
  (b) the current
  (c) the strength of the magnetic field
- describe the operation of an electric motor, including the action of a split-ring commutator and brushes.

Electromagnetism is the branch of physics that deals with the interactions between electric and magnetic fields. It explains how electric charges produce electric fields, and how moving charges, like an electric current, create magnetic fields. This connection helps us to understand how modern devices work. Electromagnetism is an essential part of everyday life, powering electric circuits, communication systems and generators. Even light is an electromagnetic wave, showing how important this force is in science and technology. Learning about electromagnetism gives us the knowledge to build useful machines and to understand the science behind today's technology.

17.1 Magnetic Effects of Steady Current

The magnetic effects of a steady current can be demonstrated through experiments involving a current-carrying conductor.

Magnetic Field B Due to Current in a Straight Wire

Hans Christian Orested stated that, a steady electric current in a conductor generates a magnetic field **B** around it. This can be demonstrated by passing a current-carrying wire through a vertical cardboard sheet and connecting it to a battery. When current flows, magnetic field is produced around

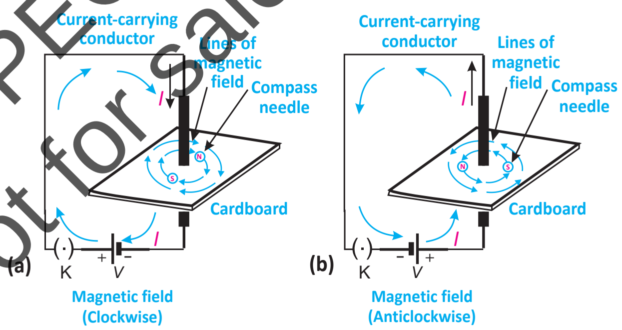


Fig. 17.1: Magnetic effects of a current

it whose direction can be determined using right hand grip rule. Concentric circles are formed by the magnetic field around the conductor. This can be observed by placing small compasses or sprinkling iron filings on the cardboard. The compass needles align themselves along the direction of the magnetic field, pointing tangentially to the circular lines of force (Fig. 17.1-a). If the direction of the current is reversed by switching the battery terminals, the compass needles and iron filings also reverse their alignment, indicating that the magnetic field direction depends on the current flow (Fig. 17.1-b). In the dot and cross convention, a dot (**.**) represents current flowing out of the paper, while a cross (**×**) indicates into the paper. The magnetic field is strongest near the conductor and weakens with distance. This concept is essential in electrical engineering, particularly with alternating currents.

Direction of the Magnetic Field of a Current-Carrying Wire

The direction of the magnetic field **B** around a current-carrying straight wire can be found using the right-hand grip rule, as shown in Fig. 17.2 .

According to the right-hand grip rule:

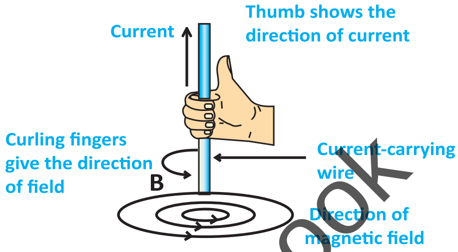


Fig. 17.2: Current-carrying conductor

If you hold the wire in your right hand with your thumb pointing in the direction of the current, then your fingers curl around the wire in the direction of the magnetic field.

This simple method helps us to quickly find the magnetic field direction around any straight current-carrying wire. The magnetic field forms circular loops around the wire, and its direction depends on the direction of the current. If the current changes direction, the direction of magnetic field also changes.

Magnetic Field Due to Current in a Solenoid

A solenoid is a coil of wire wounded in the shape of a cylinder that generates a magnetic field when current flows through it. The combined effect of all loops of the wire of solenoid makes the field strong and uniform, like a bar magnet with north and south poles. A solenoid acts as a magnet and can attract or repel a bar magnet. This temporary magnet, powered by electricity, is called an electromagnet (Fig. 17.3). The right-hand rule helps to find out the direction of the magnetic field produced by the solenoid (Fig. 17.4). According to this rule:

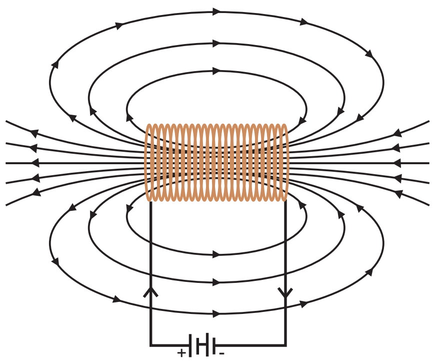


Fig. 17.3: Magnetic field due to solenoid

If you grip the solenoid with your right hand such that the curled fingers point in the direction of the conventional current, then the thumb will point towards the north pole of the solenoid.

Electromagnets are useful in motors, relays, and magnetic locks because their magnetic strength can be controlled by adjusting the current.

Fig. 17.4: Right hand rule for a solenoid

Properties of Magnetic Field Lines

Magnetic field lines, just like electric field lines, are imaginary. They do not physically exist but are a way to visualize the magnetic field. These lines have important properties:

1. Magnetic field lines always start from the north pole and end at the south pole.
2. Magnetic field lines always form closed loops.
3. At any point, the tangent to a magnetic field line shows the direction of the magnetic field.
4. Magnetic field lines never cross (intersect) each other.
5. Where magnetic field lines are closer together, the magnetic field is stronger; where they are spread apart, the magnetic field is weaker.

Understanding these properties helps us to visualize how magnetic fields behave around magnets, current-carrying wires, and in devices like motors and generators. These ideas are very important in real-world technologies.

17.2 Force on a Current-Carrying Conductor in a Magnetic Field

It is known that an electric current generates a magnetic field, much like a permanent magnet does. Since a magnetic field exertes a force on a permanent magnet, it follows that a current-carrying conductor should also experience a force when placed in a magnetic field.

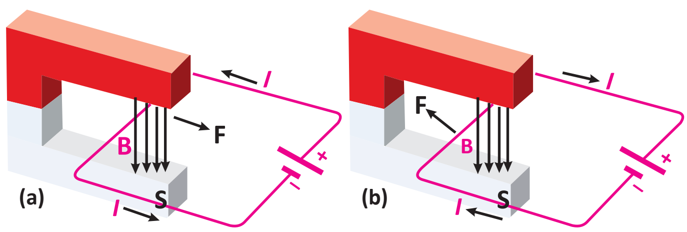


Fig. 17.5: Force on a current-carrying wire in magnetic field

The effect of a magnetic field on a wire carrying current can be illustrated using the setup in Fig. 17.5. A battery creates an electric current in the wire positioned inside the magnetic field of a permanent magnet. This wire then generates its own magnetic field, which interacts with the magnetic field of the magnet. As a result, a force acts on the wire. Based on the direction of the current, the wire is either pushed to the right (Fig. 17.5-a) or pulled to the left (Fig. 17.5-b).

The magnitude of this force is given as:

$$F = ILB\sin$$

Michael Faraday found that this force is always at right angles to both the direction of the magnetic field and the direction of the current. The force becomes stronger if:

1. The electric current (I) in the wire increases

2. The magnetic field (B) becomes stronger

3. Length (L) of the wire inside the magnetic field

The direction of this force can be determined using **Fleming's left-hand rule**, which states:

Extend the thumb, forefinger, and middle finger of the left hand so that they are at right angles to one another. If the forefinger represents the magnetic field direction and the middle finger shows the current direction, then the thumb will point in the direction of the force acting on the conductor.

As illustrated in Fig. 17.6, the force on the conductor is perpendicular to both the current and the magnetic field, in accordance with Fleming's left-hand rule.

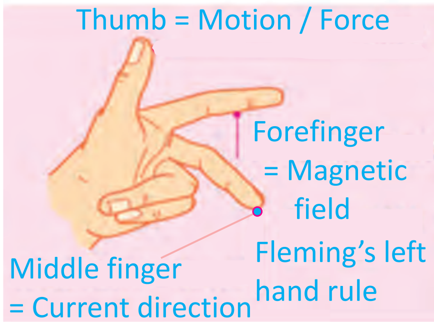


Fig 17.6: Direction of force on a current-carrying conductor placed in a magnetic field

The SI unit of magnetic field (also called magnetic flux density) is the tesla (T).

1 tesla (T) is defined as:

The magnetic field strength one tesla which causes a force of 1 N on a 1 metre length of wire carrying a current of 1 A perpendicular to the magnetic field.

i.e; $1T = 1\ N\ A^{-1}\ m^{-1}$

17.3 Turning Effect on a Current-Carrying Coil in Magnetic Field

Let us imagine a rectangular coil PQRS that is carrying a current and is placed in a magnetic field, as shown in Fig. 17.7. The coil is positioned in such a way that it is perpendicular to the magnetic field of a permanent magnet. Now, if we connect the ends of the coil to a battery, electric current starts flowing through the coil. When this happens, we can apply Fleming's Left Hand Rule to understand what force acts on the different parts of the coil. According to the rule:

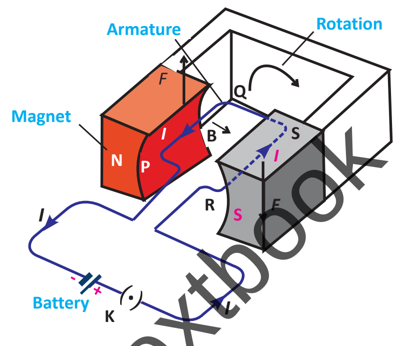


Fig. 17.7: A current-carrying coil in a magnetic field

On the side PQ of the coil, the force acts outward. On the side RS, the force acts inward. This happens because the current flows in opposite directions on the two sides of the coil. As a result, two forces are produced that are equal in magnitude but opposite in direction. These opposite forces form a couple. A couple produces a rotational effect or torque, which causes the coil to start rotating.

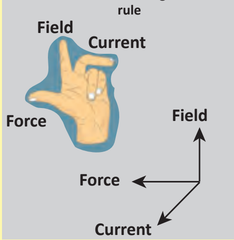
Thus, we can say that:

When a current-carrying coil is placed in a magnetic field, it experiences a couple of forces that makes the coil rotate, as shown in Fig.17.7. This is the working principle of electric motors, which are used everywhere around us from fans to cars.

Do You Know?

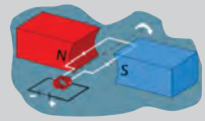
Force on current-carrying conductor in Magnetic field

Direction of force - Fleming's Left hand rule



Electric Motor

- Convert electrical energy into mechanical energy
- As current passes through the coil in a magnetic field, force acting on the coil turns the coil.



The turning effect on the coil can be made stronger by

1. increasing the number of turns of the coil. More loops mean a stronger turning effect of force.

2. increasing the current flowing through the coil. More current creates a stronger torque.

3. increasing the strength of the magnetic field. A stronger magnet makes the coil to rotate with more torque.

These factors help to make electric motors more powerful and efficient.

17.4 Electric Motor

An electric motor is a device that converts electrical energy into mechanical energy. There are two types of electric motors, one is Alternating Current (A.C) motor and the other is Direct Current (D.C) motor. A D.C motor operates using the interaction between a current-carrying coil (armature) and a magnetic field. When a coil is placed in a magnetic field, it experiences forces that cause it to rotate (Fig. 17.8).

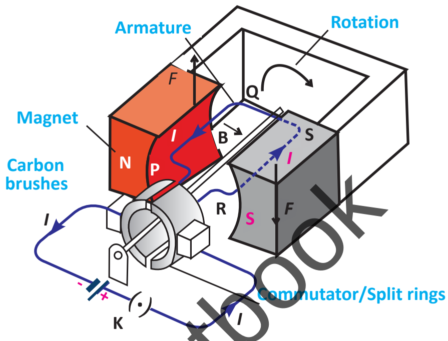


Fig. 17.8: Working principle of D.C motor

Tidbit

What is the special role of a split ring commutator in D.C motor?

However, without any external help, the coil would stop rotating after 90°, as the forces acting on its sides (such as PQ and RS) push it into a vertical position, making the coil perpendicular to the magnetic field. At this point, the net force becomes zero, preventing further rotation. To keep the coil rotating, the current direction must be reversed just as the coil reaches the vertical position. This is achieved using a split ring commutator, which is a metal ring divided into two halves, each connected to one end of the coil. Carbon brushes maintain contact with the commutator, allowing current to flow. As the coil rotates, the commutator also rotates, and when the coil reaches the vertical position, each half of the commutator switches brushes, reversing the current direction. As a result, direction of the current changes the direction of the forces which allows continuous rotation of the coil. The speed of the motor can be adjusted by controlling the current flowing through it.

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

17.1 Which statement is true about the magnetic poles?
(a) Unlike poles repel
(b) Like poles attract
(c) Magnetic poles do not affect each other
(d) A single magnetic pole does not exist

17.2 A D.C motor converts:
(a) mechanical energy into electrical energy
(b) mechanical energy into chemical energy
(c) electrical energy into mechanical energy
(d) electrical energy into chemical energy

17.3 The part of a D.C motor that reverses the direction of current through the coil every half-cycle:
(a) the armature
(b) the commutator
(c) the brushes
(d) the split rings

17.4 What does a steady electric current in a conductor generate around it?
(a) Electric field
(b) Light
(c) Magnetic field
(d) Sound waves

17.5 What happens to the magnetic field direction when the direction of the current is reversed?
(a) The magnetic field remains unchanged
(b) The magnetic field also reverses direction
(c) The magnetic field becomes stronger
(d) The magnetic field disappears

17.6 In a solenoid, the magnetic field pattern is most likely to:
(a) a current-carrying straight wire (b) a bar magnet
(c) a U-shaped magnet (d) a current-carrying coil

B. Short Answer Questions

17.1 What is the direction of the magnetic field around a straight current carrying wire?

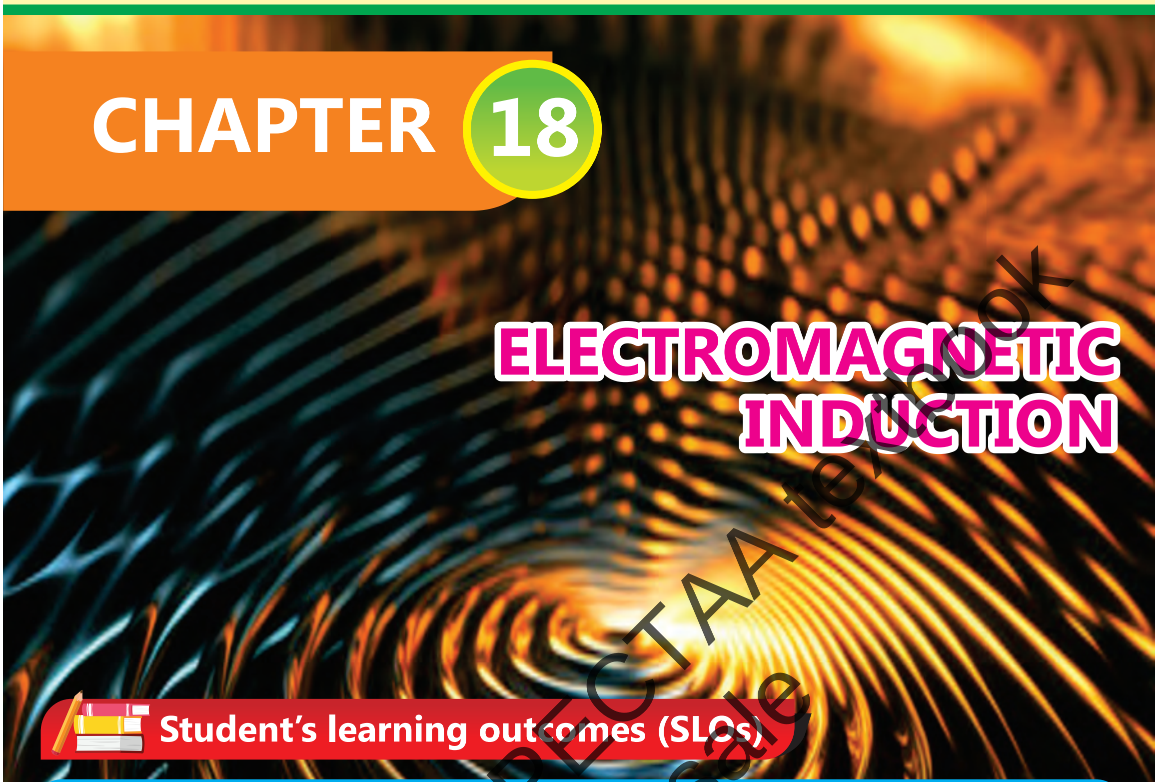
17.2 What happens to the magnetic field if the magnitude of the current in a wire is increased?
17.3 What rule determines the direction of force on a current-carrying conductor placed in a magnetic field? Explain briefly.
17.4 What role does the commutator play in a D.C motor?
17.5 State the principle of D.C motor.

C. Constructed Response Questions

17.1 Why does a magnetic field form around a conductor when current flows through it, but not when the current is OFF? What does this reveal about the nature of electricity and magnetism?
17.2 In a D.C motor, why does the coil stop turning after 90° if the direction of the current is not reversed? What mechanical feature solves this issue?
17.3 How does placing a wire at different angles to a magnetic field affect the magnetic force it experiences, and why is this important in designing motors?

D. Comprehensive Questions

17.1 How is a magnetic field created around a current-carrying wire, and what factors affect its strength?
17.2 Explain the concept of the right-hand grip rule and how it helps determine the direction of the magnetic field around a current-carrying conductor.
17.3 Describe how the turning effect is produced when a current-carrying coil is placed in a magnetic field.
17.4 In a D.C motor, discuss the functions of the commutator and brushes and how they enable the coil to rotate continuously.



CHAPTER 18

ELECTROMAGNETIC INDUCTION

Student's learning outcomes (SLOs)

After studying this chapter, student will be able to:

- describe an experiment to demonstrate electromagnetic induction.
- use the fact that the magnitude of an induced e.m.f. is affected by the rate of change of the magnetic field or the rate of cutting of magnetic field lines, and the number of turns in a coil, to solve simple electromagnetic problems.
- use the fact that the effect of the current produced by an induced e.m.f. is to oppose the change producing it (Lenz's law).
- describe how a.c. generators work (rotating coil or rotating magnet setup) and the use of slip rings and brushes where needed.
- sketch and interpret graphs of e.m.f. against time for simple A.C. generators (including relating the position of the generator coil to the peaks, troughs and zeros of the e.m.f.).
- explain the principle of operation of a simple iron-cored transformer.
- use the terms primary, secondary coils and step-up and step-down transformer.
- use the equation $V_P / V_S = N_P / N_S$ (where P and S refer to primary and secondary) to solve problems.

Have you ever wondered how electricity can be created without a battery? When a magnet moves near a wire, it produces electricity, a fascinating process called electromagnetic induction. This simple idea powers huge machines like generators and even charges our phone wirelessly. But the story does not end there. These changing electric and magnetic fields can travel through space as electromagnetic (E.M) waves bringing us light, radio signals, Wi-Fi, and even microwaves that heat our food. From lighting up cities to connecting people across the world, electromagnetic induction and E.M waves are the hidden forces shaping our everyday lives. Let us dive into the science behind these amazing wonders.

18.1 Electromagnetic Induction

Electromagnetic induction is the process by which a changing magnetic field produces an electric current in a conductor.

This principle, first discovered by Michael Faraday and at the same time Joseph Henry in 1831, is fundamental to the operation of many devices such as generators, transformers, and inductors. To understand the phenomena of electromagnetic induction let us perform experiments.

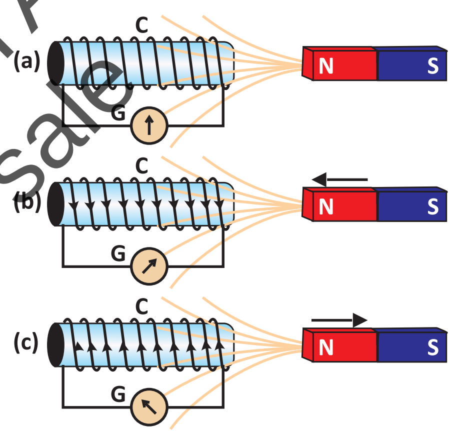


Fig. 18.1: Induced current in a coil by moving a magnet

Take a coil of conducting wire, labelled C, and connect it to a galvanometer G, as shown in Fig. 18.1. First, keep the magnet still near the coil. We will notice that the galvanometer needle does not move, no electricity is produced because there is no change happening in the magnetic field (Fig 18.1-a)

Now, move the magnet towards the coil. The galvanometer needle deflects in one direction, meaning that current is being produced (Fig. 18.1-b).

Move the magnet away from the coil. This time, the galvanometer needle deflects in the opposite direction, showing the current has reversed (Fig.18.1-c).

There are different ways to produce induced e.m.f. Imagine a straight wire of length (ℓ) placed in the magnetic field of a permanent magnet as shown in Fig. 18.2. This wire is connected to a sensitive galvanometer, forming a closed circuit or loop without using any battery. When the loop is still in the magnetic field, no current flows, and the galvanometer shows no deflection. But when the loop is moved from left to right, the wire cuts through the magnetic field lines, and current starts to flow through the loop. The galvanometer shows this current. When the motion stops, the current also stops. If the loop is moved in the opposite direction, the current also changes direction, which is shown by the galvanometer deflecting in the opposite direction. The amount of the induced current depends on how fast the wire is moved and the resistance in the loop. If we change the resistance of the loop by connecting different resistors and move the loop at the same speed each time, we notice that the product of the current I and resistance R always remains constant.

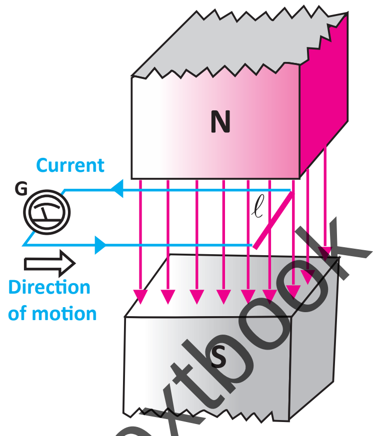


Fig. 18.2: Induction of current by moving a wire through a magnetic field

i.e; $I \times R$ = constant

This constant value is the induced e.m.f. When the circuit is complete, this induced e.m.f. causes a current to flow. The induced current can be increased in the following ways:

(i) using a stronger magnetic field

(ii) moving the loop more quickly

(iii) using a coil with many turns instead of a single loop

We can also do the experiment in another way: instead of moving the loop through the magnetic field, we can keep the loop still and move the magnet. The result is the same in both cases. This shows that it is the relative motion between the loop and the magnet that creates the induced e.m.f. In simple terms, this movement changes

Magnetic flux is the number of magnetic field lines passing through a certain area.

The magnetic flux (ϕ) is given by

$$\phi = B\,A\cos\theta \quad .... \quad (18.1)$$

B = Magnetic field strength

A = Area of the coil

θ = Angle between magnetic field and normal to the coil

The unit of magnetic flux is weber (Wb).

When a magnetic field of 1 tesla passes perpendicularly through an area of one square metre, the magnetic flux is equal to one weber.

Mathematically; 1 Wb =1 T m^2. The magnetic flux is maximum when the angle between **B** and **A** is 0° (Fig. 18.3-a). However, when the angle between **B** and **A** is 90°, flux will be zero (Fig. 18.3-b).

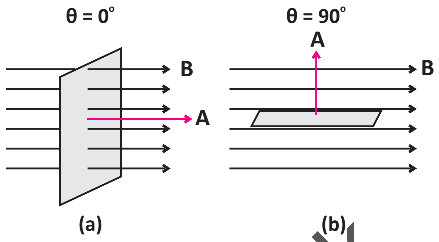


Fig. 18.3: Magnetic flux through a surface (a) Maximum (b) Zero

Faraday's Law of Electromagnetic Induction

The average e.m.f. induced in a conducting coil of *N* loops is equal to the negative of the rate at which the magnetic flux is changing with time.

Mathematically; it is expressed as:

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t} \quad \text{.........} \quad (18.2)$$

Where:

ε = induced e.m.f. (in volts, V)

N = number of turns in the coil

$\frac{\Delta\phi}{\Delta t}$ = rate of change of magnetic flux

Negative sign indicates that the induced emf opposes the change of magnetic flux that produce it.

Example 18.1: A coil with 25 turns experiences an induced emf of 2.5 V for 0.20 s. Assuming the emf is constant during this interval, calculate the total change in magnetic flux (Δϕ) through the coil.

Solution:

Given that;

Number of turns N = 25

Induced emf ε = 2.5 V

Time interval Δt = 0.20 s

To find; Change in flux Δϕ = ?

Using the formula: $\varepsilon = (N \times \Delta\phi) / \Delta t$

Rearranging to solve for Δϕ :

$$\Delta\phi = (\varepsilon \times \Delta t) / N$$

Substituting the values

$$\Delta\phi = (2.5\ \text{V} \times 0.20\ \text{s}) / 25$$

$$\Delta\phi = 0.5 / 25 = 0.02\ \text{Wb}$$

Magnitude and Direction of Induced e.m.f (Lenz's Law)

Lenz's Law is a fundamental principle in electromagnetism that describes the direction of the induced current resulting from a changing magnetic flux. It states that:

The direction of induced current is always such that it opposes the cause which produces it.

This law is a direct consequence of the conservation of energy. If the induced current were to reinforce the change instead of opposing it, it would lead to a perpetual increase in energy, which is impossible.

When a magnetic field near a conductor changes whether due to a moving magnet, a varying current, or a changing coil orientation an electromotive force (e.m.f.) is induced, driving a current. The direction of this current is not arbitrary; it must generate its own magnetic field that counteracts the original change in flux. For example, if a magnet is pushed toward a coil, the coil's induced current will produce a magnetic field that repels the magnet, resisting its motion (Fig. 18.4-a). Conversely, if the magnet is pulled away, the induced current will create a field that attracts the magnet, again opposing the movement (Fig.18.4-b).

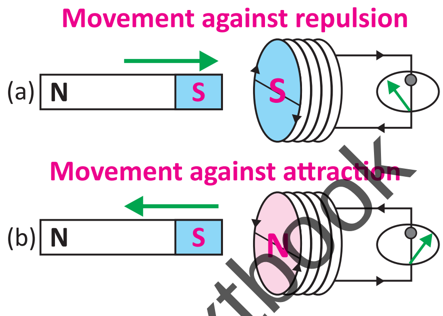


Fig. 18.4: Lenz's law

Do You Know?

- Simply moving a magnet through a coil can generate current. This is the same principle used in wind turbines and bicycle dynamos.
- The faster you change the magnetic field in a coil, the greater the current it produces, this is why fast-rotating generators make strong current.

Brain Teaser

If we stop moving a magnet near a coil, what happens to the induced current?

Tidbit

The faster we move a magnet through a coil, the greater the voltage (e.m.f.) is induced.

18.2 A.C. Generator

An alternating current (A.C) generator is a device that converts mechanical energy into electrical energy using electromagnetic induction. The most basic type includes a rectangular coil placed between the poles of a permanent magnet, as shown in Fig. 18.5(a). The coil is connected to two slip rings, which rotate along with the coil, while carbon brushes remain fixed and maintain contact with the slip rings to transfer the generated current.

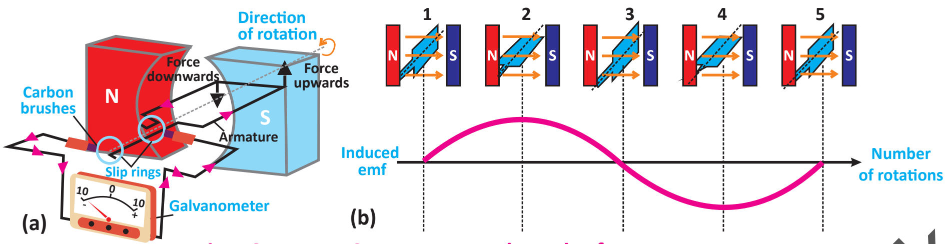


Fig. 18.5: An A.C generator and graph of current

As the coil rotates, it moves through the magnetic field, cutting the magnetic lines of force. This motion induces a voltage across the ends of the coil. The faster the coil rotates, the faster it cuts the magnetic field, resulting in a larger induced voltage. The induced voltage (or e.m.f.) changes throughout the rotation, as shown in Fig. 18.5(b).

Tidbit

A generator works by spinning a coil in a magnetic field, creating electricity powering cities.

When the coil is vertical, it moves along the field lines, and no magnetic flux is cut. So, the induced voltage is zero. As the coil rotates and becomes horizontal, it cuts the magnetic field lines at the maximum rate, producing the maximum voltage. After a half-turn, the direction of the coil's movement through the field reverses, causing the polarity of the voltage to switch, resulting in an alternating voltage. This continuous change in direction creates an alternating current (A.C), which flows back and forth in the external circuit. The shape of the voltage graph is a sine wave, completing one full cycle in each full rotation of the coil. The number of such cycles per second is called the frequency, measured in hertz (Hz).

For example; if the coil rotates once per second, the frequency is 1 Hz, and if it rotates 50 times per second, the frequency is 50 Hz (which is the frequency of A.C mains in many countries like Pakistan). According to Faraday's law of electromagnetic induction, an e.m.f. is produced in a coil when there is a change in magnetic flux through it. The amount of e.m.f. generated depends on how fast the magnetic field is being cut by the coil.

Do You Know?

In an A.C. generator, the voltage reverses direction with every half-turn of the coil that is why it is called alternating current. Slip rings in an A.C. generator help to maintain continuous electrical contact with the rotating coil while allowing current to alternate naturally.

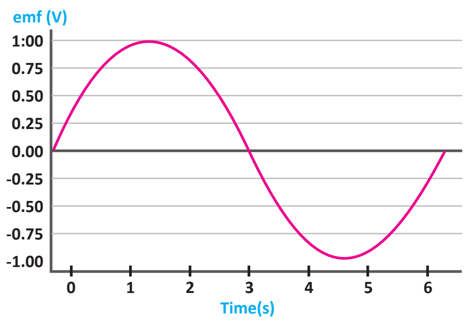


Fig. 18.6: Graph of e.m.f. against time for simple A.C generator

Figure 18.6 shows how the e.m.f. varies with time during the rotation of a coil in a simple A.C generator. The graph clearly displays a sinusoidal pattern, which represents the alternating nature of the generated voltage.

The e.m.f. reaches its maximum value when the coil is horizontal, as this is when it cuts the magnetic field lines at the highest rate. The e.m.f. becomes zero when the coil is vertical, since no magnetic flux is being cut at that position. As the coil continues to rotate, the direction of the e.m.f. reverses every half-turn, producing alternating current.

- At 0 and π radians (or 0° and 180°), the coil is vertical, and the e.m.f. is zero.
- At $\pi/2$ and $3\pi/2$ radians (or 90° and 270°), the coil is horizontal.
- At $\pi/2$, the e.m.f. is positive maximum.
- At $3\pi/2$, it reaches the negative maximum due to the reversal in direction of motion.

This repeating cycle creates the familiar A.C waveform, which alternates between positive and negative values over time.

18.3 Transformer

A transformer is a device used to increase or decrease the voltage in an alternating current (A.C) circuit. It works without any electrical connection between its input and output coils. Figure 18.7 shows a simple transformer. It has two coils of wire: the primary coil with N_P turns and the secondary coil with N_S turns. Both coils are wound on a soft iron core, which helps carry the magnetic field from one coil to the other.

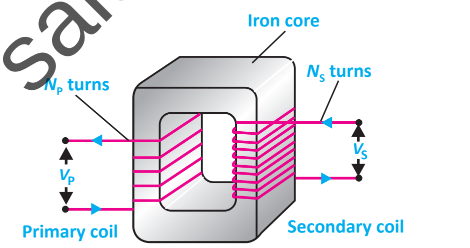


Fig. 18.7: Structure of a simple transformer showing primary and secondary coils wound around an iron core

When an alternating voltage V_P is applied to the primary coil, it causes an alternating current I_P to flow. This current produces a changing magnetic field in the iron core. The magnetic field passes through the secondary coil, where it induces an alternating voltage V_S. This causes an alternating current I_S to flow in the secondary circuit. There is no direct electrical connection between the two coils. Energy is transferred from the primary coil to the secondary coil through the magnetic field in the core.

Do You Know?

The buzzing sound in transformers is due to the iron core vibrating at 50 or 60 Hz This vibration is caused by varying magnetic field and not by electricity directly.

Step-up and Step-down Transformers

Transformers are used to either increase or decrease voltage in A.C circuits. When the secondary coil has more turns than the primary coil, the transformer increases the output voltage, it is called a step-up transformer (Fig. 18.8-a). Conversely, when the secondary coil has fewer turns than the primary, the output voltage is reduced, and it is known as a step-down transformer (Fig. 18.8-b).

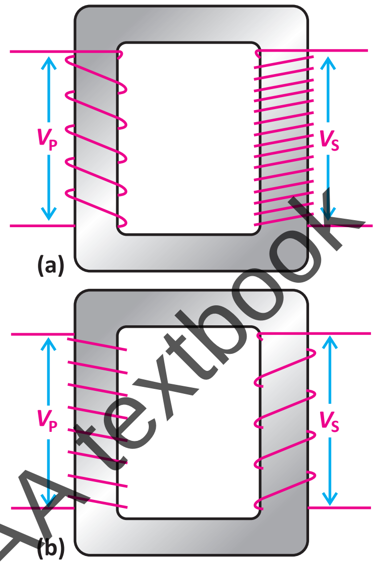


Fig. 18.8: (a) Step-up transformer (b) Step-down transformer

This relationship between coil turns and voltages is described by the equation:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \quad \text{..............} \quad (18.3)$$

This equation is known as the turns-ratio equation for a transformer.

Tidbit

Step-up transformers increase voltage for long-distance transmission, while step-down transformers reduce it to safe levels in our homes.

where

V_p is the voltage across the primary coil ; V_s is the voltage across the secondary coil

N_p is the number of turns in the primary coil ; N_s is the number of turns in the secondary coil

This equation shows that the voltage ratio is directly proportional to the number of turns in the coils. For example, if the primary has 5 turns and the secondary has 10 turns, the output voltage will be twice the input voltage.

Example 18.2: Electricity is transmitted at a voltage of 20,000 V with a current of 5 A through power cables that have a resistance of 10 Ω. Calculate the power loss in the cables?

Solution:

Given that;

Voltage V = 20,000 V ; Current I = 5 A ; Resistance R = 10 Ω

To find; Power loss P =?

We know that; Power loss $P = I^2 R$

Substituting the values ; $P = (5)^2 \times 10$

$$P = 25 \times 10 \;;\; P = 250 \text{ W}$$

The power loss in the cables is 250 W.

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

18.1 What does the waveform of an alternating current look like?
(a) A straight horizontal line (b) A square wave
(c) A sine wave (d) A triangular pulse

18.2 What happens to the induced e.m.f. in a coil if the rate of change of the magnetic field increases?
(a) Decreases
(b) Remains the same
(c) Increases
(d) Becomes zero

18.3 In an A.C generator, slip rings are used to:
(a) reverse current direction periodically
(b) convert A.C to D.C
(c) prevent induced current
(d) increase magnetic flux

18.4 In a step-down transformer, the number of turns in the secondary coil is:
(a) greater than the primary coil (b) equal to the primary coil
(c) less than the primary coil (d) always zero

18.5 In a transformer, energy is transferred from the primary coil to the secondary coil through:
(a) direct electrical connection (b) a magnetic field in the iron core
(c) electrons flowing through the core (d) heat conduction

B. Short Answer Questions

18.1 How does the speed at which a magnet move through a coil affect the size of the induced voltage?
18.2 What is the direction of induced current in Lenz's law?
18.3 Why are slip rings used in an A.C generator?
18.4 When is induced e.m.f. zero in an A.C generator?
18.5 What is a transformer and on what principle does it work?
18.6 What is the role of iron core in a transformer?

C. Constructed Response questions

18.1 If a magnet is moved quickly into a coil, a larger e.m.f. is induced. Why does speed affect the magnitude of the induced current?

18.2 Why is an iron core used in transformers instead of wood or plastic? Explain briefly.

18.3 Why can a transformer work only on alternating current and not on direct current ?

18.4 Does a transformer transform electrical energy from one coil to another? Describe briefly.

D. Comprehensive Questions

18.1 Describe how Lenz's Law supports the law of conservation of energy. Give one real-life example to support your explanation.

18.2 Describe the working principle of an A.C generator. Explain the parts involved, the role of electromagnetic induction, and how the device produces a current that alternates direction.

18.3 Compare step-up and step-down transformers. Include the difference in number of turns, output voltage, and where is each used.

D. Numerical Problems

18.1 A coil consisting of 50 tightly wound turns experiences a change in magnetic flux from 0.3 Wb to 0.8 Wb over a time interval of 0.4 s. Determine the average induced electromotive force (e.m.f.) generated in the coil during this time. **[Ans: -62.5 V]**

18.2 A circular loop of radius 0.2 m and resistance 5 Ω is placed perpendicular to a magnetic field of 0.5 T. If the field drops to zero in 0.1 s, calculate:
(a) the induced emf
(b) the induced current and its direction (assuming the field points into the page) **[Ans: 0.63 V, 0.126 A]**

18.3 A transformer has 500 primary turns and 100 secondary turns. If the primary voltage is 220 V, find: (a) secondary voltage (b) is this a step-up or step-down transformer? **[Ans: 44V, Step-down ($V_s < V_p$)]**

18.4 A step-up transformer has a turns ratio of 2:100. If an alternating voltage of 25 V is applied to the primary coil, what will be the secondary voltage? **[Ans: 1250 V]**

18.5 A step-down transformer has a turns ratio of 100:5. If an A.C voltage of 190 V is applied to the primary coil, what is the voltage across the secondary coil? **[Ans: 9.5 V]**

CHAPTER 19

NUCLEAR PHYSICS

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- define the terms proton number (atomic number) Z and nucleon number (mass number) A and be able to calculate the number of neutrons in a nucleus.
- recall the term nuclide and use the nuclide notation $^{A}_{Z}X$.
- explain what is meant by an isotope and state that an element may have more than one isotope.
- describe the emission of radiation from a nucleus as spontaneous and random.
- describe alpha-particles, beta-particles, and gamma-radiation.
- justify qualitatively the order of strength for alpha-particles, beta-particles, and gamma-radiation in terms of their (a) relative ionizing effects and (b) relative penetrating powers.
- describe the deflection of alpha-particles, beta-particles, and gamma-radiation in electric fields and magnetic fields.
- explain that radioactive decay is a change in an unstable nucleus that can result, most commonly, in the emission of alpha-particles or beta-particles and/or gamma-radiation. (Other types exist but are not required at this level.)
- use decay equations, using nuclide notation, to show the emission of alpha-particles, beta-particles, and gamma-radiation.
- describe nuclear reactions (fission and fusion) with examples.
- recognize that matter can be converted into energy and vice versa.
- apply the equation; $E = mc^2$ to calculate the energy released in the process of nuclear reactions.
- describe the activity of a radioactive material in terms of counts per unit time.
- define and infer the half-life of materials.
- explain and apply the concept of Carbon dating to solve problems.
- explain how the type of radiation emitted and the half-life of the isotope determine which isotope is used for applications.
- state the effects of ionizing nuclear radiations on living things, including cell death, mutations, and cancer.
- explain what is meant by background radiation.

Nuclear physics is a branch of science that help us to understand the smallest building blocks of matter. Nuclear physics, focuses on the nucleus of the atom, which contains protons and neutrons. It explains important concepts like radioactivity, nuclear reactions, and how energy is released in nuclear power plants. Researches in these fields have led to important applications in medicine, energy, and technology. In this chapter, we will explore these basic ideas and understand how they have shaped the world around us.

19.1 Atomic Nucleus

Atomic nucleus is the central part of an atom which holds most of its mass (Fig. 19.1). It is made up of protons and neutrons, which together known as nucleons. Protons and neutrons are held together by the strong nuclear force. The size of the nucleus is very small in comparison to the entire size of the atom.

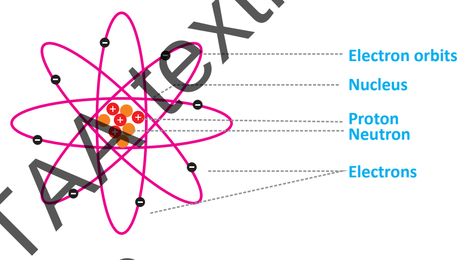


Fig. 19.1: Diagram of an atom showing the nucleus, protons, neutrons, and electron orbits

Charge Number and Mass Number

Atoms are made up of protons, neutrons, and electrons. The charge number Z tells us how many protons an atom has, which is unique for each element. It is also called atomic number. This number also determines an element's position in the periodic table and its chemical properties. The mass number A is the total count of protons and neutrons in an atom's nucleus. Since electrons have very little mass, they are not included in the mass number. Scientists use the mass number to understand an atom's size, stability, and structure. A nuclide is represented by ${}^{A}_{Z}X$, where X is its chemical symbol, the superscript is mass number A and subscript is charge number Z.

To determine the number of neutrons in the nucleus of an atom, we use the formula:

$$N = A - Z$$

Do You Know?

The number of protons in the nucleus is what defines an element. Change the number of protons, and we change the element itself!

Tidbit

Electrons are nearly 1,836 times lighter than protons, yet they move extremely fast—almost at the speed of light in their orbitals.

Brain Teaser

If protons repel each other, how can so many of them stay packed in a tiny nucleus without flying apart? What holds them together?

Example 19.1: Find the number of protons and neutrons in the nuclide defined by $^{15}_{7}X$.

Solution: From the symbol, we have atomic number Z = number of protons = 7
Mass number A = number of protons + number of neutrons = 15
But number of protons are 7, so number of neutrons will be 8. So, the element is an isotope of nitrogen-7, and is written as $^{15}_{7}N$.

19.2 Isotopes

Isotopes are atoms of an element that have the same number of protons but different numbers of neutrons.

Atoms are electrically neutral, meaning they have equal number of protons and electrons. If an atom gains or loses electrons, it becomes an ion and carries an electric charge. The number of protons and electrons determines an atom's chemical properties, while the number of neutrons affects its nuclear properties, like stability and radioactivity. A common example of isotopes is hydrogen, which has three isotopes as shown in Fig. 19.2.

$^{1}_{1}H$ contains 1 proton and 0 neutrons

$^{2}_{1}H$ contains 1 proton and 1 neutron.

$^{3}_{1}H$ contains 1 proton, 2 neutrons

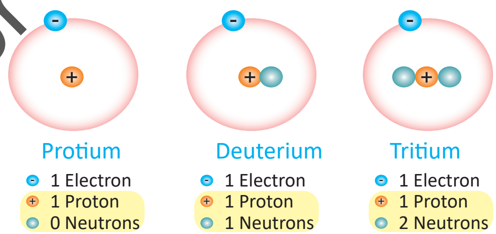


Fig. 19.2: Isotopes of hydrogen

Even though these hydrogen isotopes have different masses, they still behave chemically in the same way. Similarly, carbon has three isotopes $^{12}_{6}C$, $^{13}_{6}C$, $^{14}_{6}C$ containing 6,7 and 8 neutrons, respectively.

19.3 Radioactivity

Radioactivity is the process in which unstable atoms release energy to become stable. This energy is given off as radiation, which can be in the form of particles or waves. Some elements are naturally radioactive, while others can be made radioactive in laboratories. Henri Becquerel

Do You Know?

Marie Sklodowska-Curie, a French Physicist and chemist, was the first woman to receive a Nobel Prize and the only woman to receive two Nobel Prizes, while studying uranium's rays, she discovered new elements and named them polonium and radium.

discovered radioactivity in 1896, and later, Marie Curie and Ernest Rutherford studied it further. Atoms have a nucleus made of protons and neutrons, surrounded by electrons. Some nuclei become unstable due to an imbalance of protons and neutrons or excess energy inside. To become stable, the nucleus breaks down and gives off radiation in a process called radioactive decay. This happens naturally and cannot be controlled. It is spontaneous and random. While we cannot predict when a single atom will decay, but in a large group of atoms, the decay follows a pattern.

Emission of α, β and γ Radiations

Radioactive decay releases three types of radiation: Alpha (α), Beta (β), and Gamma (γ) radiation, each with different properties.

Alpha particles (α) are helium nuclei, consisting of 2 protons and 2 neutrons each (Fig. 19.3). They carry a +2e charge ($e = 1.6 \times 10^{-19}$ C), and are relatively large and heavy [4 atomic mass units(u)]. Due to their size, alpha particles have low penetration power and can be stopped by a sheet of paper or a few centimetres of air. However, they have high ionizing power, meaning they strongly affect other atoms they come in contact with.

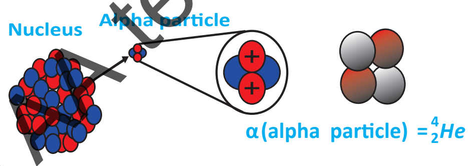


Fig. 19.3: Representing alpha particle

Beta particles (β) are high-energy electrons ($_{-1}^{0}e$) or positrons ($_{+1}^{0}e$) emitted from the nucleus (Fig.19.4) They carry a -1e charge (electrons) or +1e charge (positrons) and have a very small mass. Beta radiation has moderate penetration power. It can pass through paper but is stopped by a few millimetre of aluminum. Their ionizing power is moderate, meaning they cause less ionization than alpha particles but more than gamma rays.

Tidbit

Alpha particles are the heaviest and slowest of the three common radiation types. They can not penetrate a sheet of paper but can cause severe damage if inhaled or ingested.

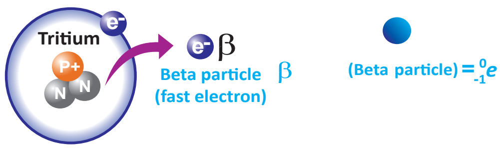


Fig. 19.4: Representing beta particles

Gamma radiation (γ) consists of high-energy electromagnetic waves (photons), making them massless and neutral (0 charge). Gamma rays are emitted out due to de-excitation of nucleus (Fig. 19.5).

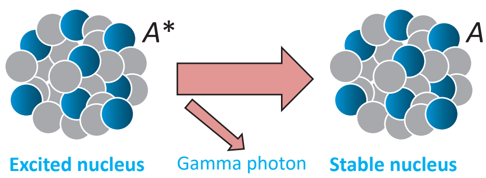


Fig. 19.5: Representing gamma radiation

Gamma rays have very high penetration power, allowing them to pass through thick materials like lead or concrete. However, they have low ionizing power, meaning they cause much less ionization compared to alpha and beta particles.

Ionizing Effects and Penetrating Powers

Ionizing Effects

Ionization occurs when radiation removes electrons from atoms, turning them into ions. The ability of radiation to ionize atoms depends on its energy and charge.

Alpha (α) particles: Strongest ionizing power due to their large size and charge.

Beta (β) particles: Moderate ionizing power, as they are smaller and faster than alpha particles.

Gamma (γ) rays: Weakest ionizing power, as they have no charge and no mass.

Do You Know?

Gamma rays are pure electromagnetic energy with no mass or charge. They are the most penetrating and require thick lead or concrete to shield against.

Penetrating Powers

Penetration power refers to how far radiation can travel through materials before being absorbed. Penetration power of (α), (β) and (γ) rays are shown in Fig. 19.6.

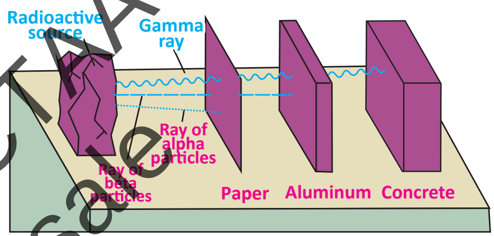


Fig. 19.6: Penetrating power of three types of radiations

Alpha (α) particles: Lowest penetration – stopped by a sheet of paper or a few centimetres of air.

Beta (β) particles: Moderate penetration – can pass through a sheet of paper but stopped by a few millimetres of aluminum.

Gamma (γ) rays: Highest penetration – can pass through paper, aluminum, and even thick lead or concrete slabs.

The other properties like composition, charge, mass, ionizing power, penetrating power and deflection in fields of these rays are shown in the table given below.

Comparison of alpha, beta, and gamma radiation

Property	Alpha particles (α)	Beta particles (β)	Gamma rays (γ)
Composition	Helium nuclei ($^{4}_{2}He$)	Electrons ($^{0}_{-1}e$) or positrons ($^{0}_{+1}e$)	Electromagnetic waves (photons)
Charge	+2e	-1e or +1e	0
Mass	4 atomic mass units	Very small	0
Ionizing power	High	Moderate	Low
Penetrating power	Low	Moderate	High
Deflection in fields	Slight both electric and magnetic fields	Significant in electric and magnetic fields	No deflection

19.4 Radioactive Decay

Radioactive decay is the process in which unstable atoms release radiation to become stable. This radiation can be in the form of particles (alpha and beta) or waves (gamma rays). Some atoms have too many or too few neutrons in their nucleus, making them unstable. To become stable, they release energy in the form of radiation.

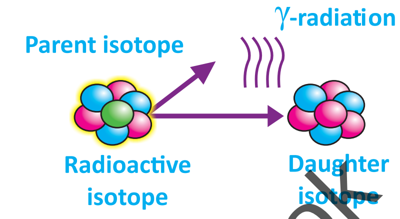


Fig. 19.7: Transformation of a parent isotope into a daughter isotope

Figure. 19.7 demonstrates a radioactive process in which transformation of parent isotope into daughter isotope takes place through the emission of radiations.

1. Alpha (α) Decay Equation

In alpha decay, an unstable nucleus emits an alpha particle ($^{4}_{2}He$), reducing its atomic number by 2 and mass number by 4 (Fig. 19.8)

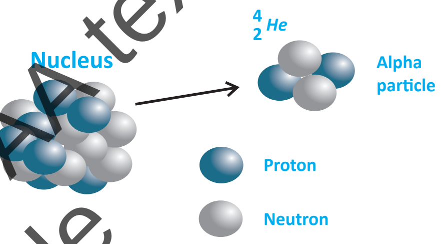


Fig. 19.8: Representing alpha decay

General Equation: $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$ .... (19.1)

Example (Decay of Uranium-238): $^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$ +Energy

2. Beta (β) Decay Equations

In beta decay, a neutron converts into a proton and emits a beta particle (electron).

General Equation: $^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta$ +Energy .... (19.2)

Example (Decay of Carbon-14): $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}\beta$ + energy

3. Gamma (γ) Decay Equation

In gamma decay, the nucleus releases excess energy as a gamma ray (γ) without changing the number of protons or neutrons (Fig. 19.9).

General Equation: $^{A}_{Z}X^{*} \rightarrow ^{A}_{Z}X + \gamma$ ....(19.3)

Example (Decay of Cobalt-60):

$$^{60}_{27}Co^{*} \rightarrow ^{60}_{27}Co + \gamma$$

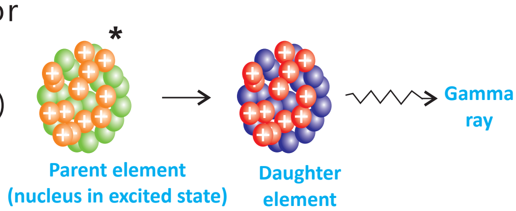


Fig. 19.9: Representing gamma decay

These equations represent the fundamental processes of radioactive decay, helping us to understand how unstable atoms transform into stable ones.

Example 19.2: Find the atomic mass and atomic number of the nuclei that come after alpha decay of Uranium (U-238).

Solution:

Alpha decay nuclear reaction is given by: $^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha$ + Energy

For Uranium -238, the nuclear reaction will come: $^{238}_{92}U \rightarrow {}^{238-4}_{92-2}Y + {}^{4}_{2}He(\alpha)$ + Energy

or $^{238}_{92}U \rightarrow {}^{234}_{90}Y + {}^{4}_{2}He(\alpha)$ + Energy

So, atomic number of the required nucleus is 90 and mass number is 234.
Every element has a unique atomic number. From periodic table, the new element is to be Thorium (Th) with Z =90.
The finalized nuclear reaction can now be witten as: $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He(a)$ + Energy

19.5 Nuclear Reactions

Nuclear reactions involve changes in the nucleus of an atom, leading to the transformation of elements and the release or absorption of energy. These reactions are different from chemical reactions, which only involve electrons.

We will discuss here two types of nuclear reactions:

1. Fission Reaction 2. Fusion Reaction

Fission Reaction

In fission reaction, a heavy nucleus (like Uranium-235) splits into two smaller nuclei when bombarded by a neutron. This process releases a large amount of energy and additional neutrons, which can cause a chain reaction. The fission reaction is the foundation of both nuclear power generation and atomic weapons. In fission, a tiny fraction of mass transforms into an enormous amount of energy. Nuclear fission was first discovered in 1939 by Otto Hahn and Fritz Strassman. They observed that a uranium nucleus splits into two nearly equal fragments after absorbing a slow-moving neutron (Fig. 19.10). This process also releases extra neutrons, typically two or three per fission event, with an average of 2.5 neutrons per reaction. This chain reaction plays an important role in nuclear power generation and atomic bombs.

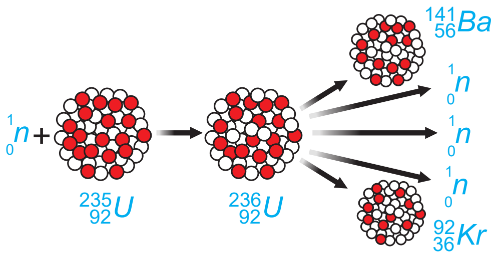


Fig. 19.10: Nuclear fission reaction

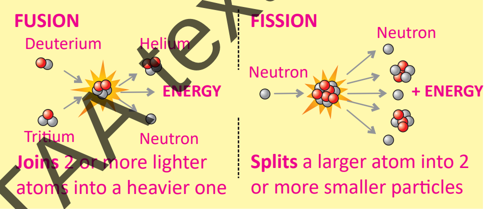
$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{236}_{92}U^{*} \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n + \text{Energy} \quad \text{.......... (19.4)}$$

In nuclear fission reaction, the total mass of the products is slightly less than the original heavy nucleus. This lost mass is converted into energy, releasing about 200 MeV (1 eV = 1.6 x 10^{-19}J) per fission event, which is far greater than energy from chemical reactions. For instance, burning 1 ton of coal releases 3.6 × 10^9 J, while fission of 1 kg of *U*-235 produces around 6.7 × 10^{13} J. During fission, released neutrons can trigger further reactions, leading to a chain reaction. If uncontrolled, this can cause a rapid energy release, resulting in an explosion. However, in nuclear reactors, this reaction is carefully controlled by absorbing extra neutrons, allowing the energy to be used safely for power generation.

Do You Know?

Fusion vs fission

Nuclear reactions that produce massive amounts of energy, but have different processes



Nuclear Fusion

Nuclear fusion is a process where two or more light nuclei (like hydrogen isotopes) combine to form a heavier nucleus, releasing huge amount of energy (Fig. 19.11). This occurs at extremely high temperatures and speeds, where some mass is converted into energy. The final nucleus is always lighter than the total mass of the original nuclei, and the lost mass turns into energy.

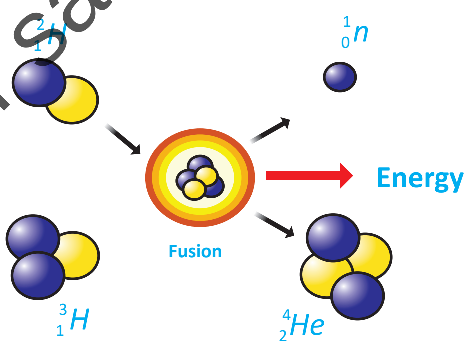


Fig. 19.11: Nuclear fusion reaction

For example, when deuterium and tritium fuse, they form helium (alpha particle) and release energy.

$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n + \text{Energy} \quad .... \quad (19.5)$$

The Sun and stars shine because of fusion reactions, where four hydrogen nuclei fuse into one helium nucleus, releasing about 25.7 MeV of energy. The Sun's core, at nearly 20 million kelvin, provides the perfect conditions for fusion to occur.

19.6 Interconversion of Matter and Energy

Matter and energy can be converted into each other (Fig. 19.12), a concept explained by Einstein's equation *($E=mc^2$)*. This means that a small amount of mass can turn into a huge amount of energy, as seen in nuclear fission and fusion, which power nuclear reactors and the Sun. Similarly, energy can also transform into matter under extreme conditions, such as in particle accelerators, where high-energy photons create particle-antiparticle pairs (pair production). This process follows the law of conservation of energy, which states that total energy, including mass-energy, remains constant in an isolated system. The ability to convert matter into energy and vice versa is key to understanding the universe, stars, and atomic particles. Theoretically a single gram of matter can be converted into enough energy to power a city for days.

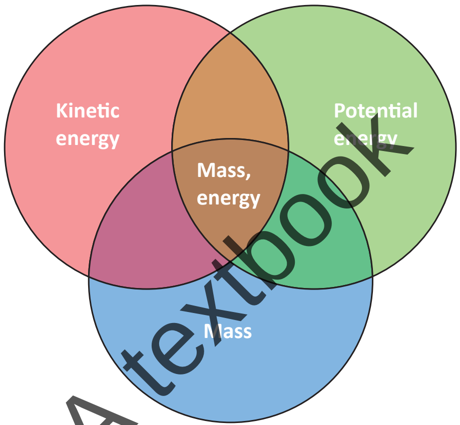


Fig. 19.12: Interconversion of different energies

Einstein's Equation and Energy Calculation

Einstein's equation $E = mc^2$ helps to calculate the energy released in nuclear reactions like fission and fusion. It states that a small amount of mass (m) converts into a large amount of energy (E), where: E = Energy (joules or MeV), m = Mass, c = Speed of light (3×10^8 m s^{-1}). In nuclear reactions, the total mass of the products is slightly less than the mass of the reactants. This missing mass is called mass defect (Δm). Using $E = mc^2$, we can find the energy released:

If $\Delta m = 1 \times 10^{-4}$ kg, then using $E = mc^2$:

$$E = (1\times10^{-4}\ \text{kg}) \times (3\times10^{8}\ \text{m s}^{-1})^2\ ;\ E = 9\times10^{12}\ \text{J}$$

Uniform Mass Scale (u)

The term uniform mass scale (u) refers to atomic mass unit (u) being used as a standardized unit to measure the mass of atoms and molecules.

1u = 1/12 the mass of carbon-12 atom ≈ 1.66605×10^{-27} kg

Example 19.3: Energy Released in Nuclear Fission Reaction:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{Energy}$$

Solution:

Consider the fission of uranium-235:

where,

- Mass of ($^{235}_{92}U$)= 235.0439 u
- Mass of neutron($^{1}_{0}n$) = 1.0087 u
- Mass of ($^{141}_{56}Ba$) = 140.9144 u
- Mass of ($^{92}_{36}Kr$) = 91.9262 u
- Mass of 3 neutrons = 3×1.0087=3.0261 u

Mass defect will be:

$$\Delta m = (\text{Mass of reactants}) - (\text{Mass of products})$$

$$\Delta m = (235.0439 + 1.0087) - (140.9144 + 91.9262 + 3.0261)$$

$$\Delta m = 236.0526 - 235.8667 = 0.1859 \text{ u}$$

Energy released will be:

$$E = \Delta m \times 931.5 \text{ MeV/ u}$$

$$E = 0.1859 \times 931.5 = 173.2 \text{ MeV}$$

Tidbit

Nuclear power plants use fission, where heavy nuclei like uranium split into smaller parts, releasing energy. Fusion is safer and cleaner, but hard to control.

19.7 Half-Life

Brain Teaser

What happens when a uranium nucleus splits during nuclear fission? Does it just break into two pieces, or is something else released?

The activity of a radioactive material is the rate at which its atoms decay, releasing radiation in the form of alpha, beta, or gamma particles. It tells us how many atoms break down in a given period and is measured in Becquerels (Bq), where 1 Bq = 1 disintegration per second, or in Curies (Ci), where 1 Ci = 3.7 × 10^{10} disintegration per second (dps). The activity of a substance depends on the number of radioactive atoms present and the decay constant (λ), which is linked to its half-life. A material with a shorter half-life decays faster and has higher activity, while one with a longer half-life decays slower and has lower activity. Scientists measure radioactivity using tools like Geiger counters and scintillation detectors, which help in monitoring radiation levels, ensuring safety, and studying radioactive decay in fields like medicine, archaeology, and nuclear physics.

The half-life of a radioactive isotope is the time it takes for half of the radioactive atoms in a sample to decay into a more stable form.

This concept helps scientists predict how long a radioactive substance remains active and is essential for its use in nuclear power, medical treatments, and radiocarbon dating.

The amount of radioactive isotope in the given sample decreases with time as shown in Fig. 19.13. .The number of nuclei present at time t=0 is $N = N_o$, and the number present at time $t = T_{½}$ is $N = N_o/2$. The number present at time $t = 2T_{½}$ is $N = N_o/4$ and so on. In this example the amount N of the radioactive substance left after sometime t is given by

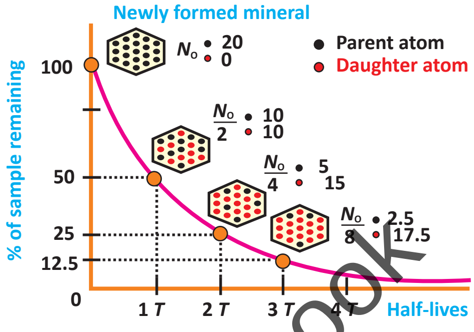


Fig. 19.13: Conversion of $^{99}_{43}Tc$ to $^{99}_{44}Ru$ by beta decay

After 1 half-Life: $N_1 = \frac{1}{2}N_0$

After 2 half-Life: $N_2 = \frac{1}{2} \times \frac{1}{2}N_0 = \left(\frac{1}{2}\right)^2 N_0$

After 3 half-Life: $N_3 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}N_0 = \left(\frac{1}{2}\right)^3 N_0$

After 4 half-Life: $N_4 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}N_0 = \left(\frac{1}{2}\right)^4 N_0$

Number of half-lives (n) can be found by the following relation:

$$\text{Number of half-lives} = \frac{\text{Total time passed}}{\text{Half-life}}$$

Therefore $$n = \frac{\Delta t}{T_{1/2}} \quad \text{............} \quad (19.6)$$

Half-Life of Radioactive Isotopes

The half-life of a radioactive isotope is the time it takes for half of its atoms to decay into a more stable form. Each isotope has a unique half-life that never changes, no matter how much of the substance is present or what ever may be the surrounding conditions.

For example, carbon-14, used in radiocarbon dating, has a half-life of 5,730 years, while U-238 takes 4.5 billion years to decay by half. Radioactive decay follows an exponential pattern, meaning that after each half-life, only half of the remaining material is left.

The concept of half-life is important in many fields, including archaeology (dating ancient artifacts), medicine (using radioactive isotopes for diagnosis and treatment), and nuclear energy (handling radioactive waste). By knowing the half-life of a substance, scientists can predict how long it will stay radioactive and how fast it will decay.

Carbon Dating

Carbon dating is a scientific method used to determine the age of ancient organic materials like wood, bones, and shells, up to 50,000 years old. This technique is based on the radioactive decay of carbon-14, a type of carbon found in the atmosphere. Living organisms constantly absorb carbon-14 while they are alive, maintaining a steady balance with carbon-12. However, when an organism dies, it stops absorbing carbon, and the carbon-14 starts to decay at a fixed rate, with a half-life of about 5,730 years. By measuring the remaining carbon-14 in a sample and comparing it to its original amount, scientists can estimate how long ago the organism died. Carbon dating is an essential tool in archaeology, geology, and anthropology, helping researchers determine the age of artifacts, fossils, and ancient remains, giving important insights into human history and environmental changes. The radioactive decay of carbon-14 shown in Fig. 19.14.

Brain Teaser

If two fossils found in the same layer of rock have nearly the same amount of carbon-14 left, but one belong to a fast-living animal and the other to a slow-living one, which one is older or are they the same age?

Tidbit

Carbon-14 is constantly created in the upper atmosphere when cosmic rays hit nitrogen atoms — meaning the clock "starts ticking" the moment an organism dies.

Fun Fact

Carbon-14 is constantly being created in Earth's atmosphere!

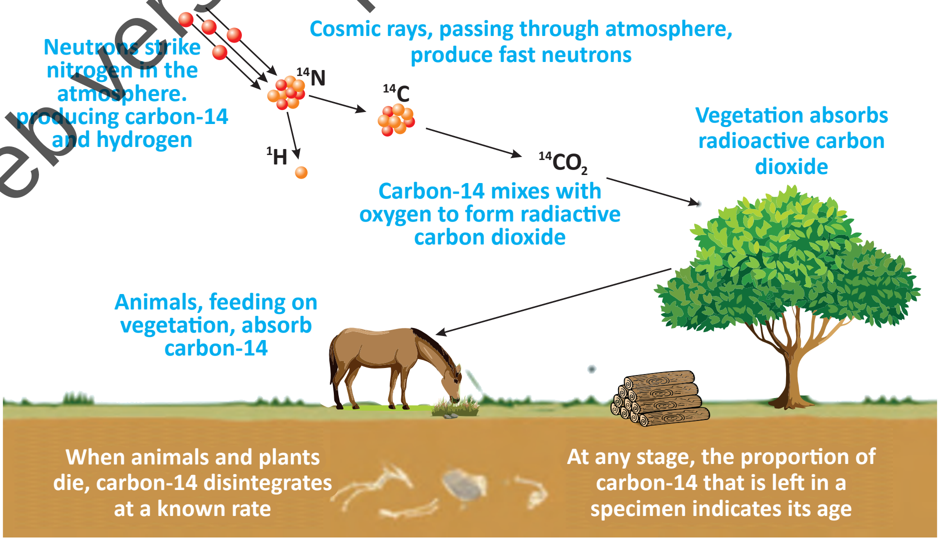


Fig. 19.14: Carbon dating

Example 19.4: We have a 50 mg sample of lead-212. it decays by beta and gamma emission with a half-life of 10.6 hours. How much of the pure sample is left after 53 hours?

Solution:

Given that;

initial quality of pure lead-212 $N_o = 50$ mg

Half-life of lead - 212 T - 10.6h

Total elapsed time $\Delta t = 53$ hours

To find; Quantity to be left $N = ?$

The number of half-lives n is given by $n = \frac{\Delta t}{T_{1/2}}$

Substituting the values $n = \frac{53\text{ h}}{10.6\text{h}}$

Therefore $n = 5$

Original sample remaining after n number of half-lives: $N = \left[\frac{1}{2}\right]^n N_o$

Substituting the values: $N = \left[\frac{1}{2}\right]^5 \times 50$ mg

Therefore $N = 1.56$ mg

So, 1.56 mg of lead -212 will be present after 53 hours of 5 half-lives.

19.8 Effects and Uses of Nuclear Radiation

Ionizing radiation (such as alpha, beta, and gamma rays) can affect living organisms because it can alter or damage atoms and molecules, including DNA. The impact of radiation depends on the dose, exposure time, and type of radiation.

Effects of Nuclear Radiation

1. High doses can kill cells by damaging their DNA, which is why radiation is used in cancer treatment (radiotherapy) to destroy cancer cells.
2. Radiation can cause DNA mutations, breaking chemical bonds and altering genetic codes, which may lead to genetic disorders or hereditary diseases if reproductive cells are affected.
3. Long-term exposure to low doses increases the risk of cancer by mutating normal body cells. For example, too much UV radiation from the Sun can lead to skin cancer.

Do You Know?

High-energy gamma rays are used to target and destroy cancer cells in radiotherapy. Precision is key to avoid harming healthy cells.

4. Severe exposure over a short time can cause radiation sickness, leading to nausea, vomiting, organ failure, and even death in extreme cases.

Uses of Nuclear Radiation

The selection of a radioactive isotope depends on its type of radiation and half-life:

1. **Medical Uses:** Short-lived isotopes are used in radiotherapy and imaging to minimize long-term radiation risks.
2. **Industrial Uses:** Isotopes with long half-lives are used in power generation, radiation detectors, and material testing, where long-term stability is important.

   Nuclear radiation plays a major role in medicine, industry, and scientific research, but it must be handled carefully to avoid harmful effects.

3. **Cobalt-60 and Cesium-137 in Food Preservation:** Gamma rays from these isotopes kill bacteria in food, increasing shelf life without affecting quality. Cobalt-60, with a moderate half-life (5.27 years), is commonly used in the food industry.
4. **Cobalt-60 in Sterilization:** Gamma radiation is used to sterilize medical equipments, killing bacteria and viruses without damaging the materials.

Radiation Source

1. **Americium-241 ($^{241}_{95}Am$) in Smoke Detectors:** Used in fire alarms, where alpha particles ionize air molecules, creating an electric current. When smoke enters, the current is disrupted, triggering the alarm. Its long half-life (432 years) makes it ideal for long-term use.
2. **Cobalt-60 and Iodine-131 in Medicine:**

   Gamma rays from Cobalt-60 are used in radiotherapy to destroy cancer cells, while Iodine-131, with a short half-life (8 days), is used in thyroid diagnosis and treatment to minimize long-term radiation exposure.

Do You Know?

Even without nuclear power or medical scans, we are exposed to radiation from cosmic rays, rocks, and even bananas (which contain potassium-40).

19.9 Radiation Exposure

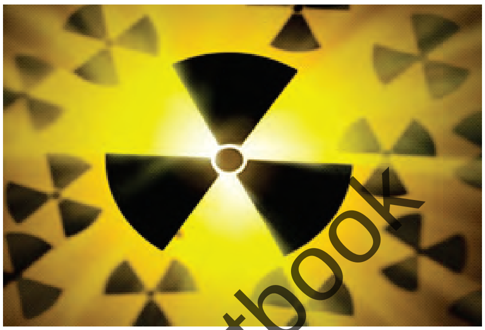


Fig. 19.15: Radiation exposure warning

Radiation exposure happens when someone comes into contact with radiation, which is a type of energy (Fig. 19.15). This energy can come from natural sources like the Sun and the ground or from man-made sources like X-ray machines and nuclear power plants. A small amount of radiation is usually safe. But too much exposure can harm our bodies by damaging cells. That is why we use safety measures, like protective wear and limited exposure, to stay safe while using radiation for useful purposes.

Background Radiation

The radiation that exists around us all the time is known as background radiation.

It is the constant, low-level ionizing radiation present in the environment from both natural and human-made sources. It includes cosmic rays from space, radioactive materials in the Earth's crust (like uranium and radon), and even tiny amounts of radiation in our food and bodies. Human activities, such as medical procedures (X-rays, CT scans), nuclear power plants, and past nuclear testing, also contribute to it. Background radiation is usually harmless at normal levels, but it is an ever-present part of our world, reminding us of the natural and human influences that shape our environment (Fig. 19.16).

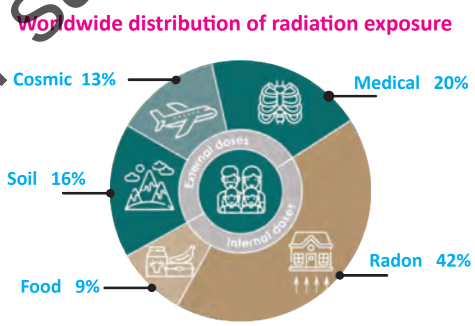


Fig. 19.16: Sources of radiation

Sources of Radiation

(a) Radon gas (in the air)

1. Radon gas is an alpha emitter.
2. Radon gas is particularly dangerous if it is inhaled into the lungs in large quantities.
3. The gas is tasteless, colourless and odourless, but it is not generally a health issue unless levels are significantly high.

Tidbit

Radon gas from the ground can seep into homes especially basements and contribute to natural background radiation. It is invisible, odourless, and radioactive.

(b) Rocks and buildings

1. Natural radioactivity can be found in building materials, including decorative rocks, stones and bricks.
2. Heavy radioactive elements, such as uranium and thorium, occur naturally in rocks in the ground.
3. Uranium decays into radon gas.

(c) Food and Drink

1. Food and water contain small amounts of naturally occurring radioactive isotopes, such as potassium-40 and carbon-14.
2. These isotopes are absorbed by plants and animals and enter the human body through consumption.
3. The contribution from food and drink is generally small but consistent.

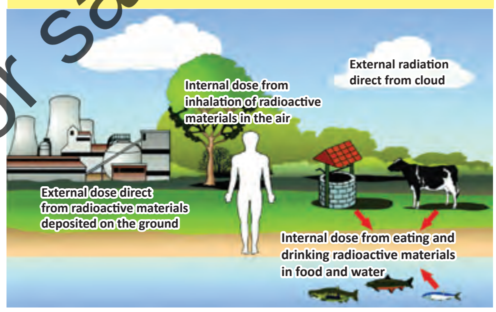
Do You Know?

Some cosmic rays that hit the Earth have travelled for millions of years from distant galaxies before colliding with atoms in our atmosphere to produce background radiation.

(d) Cosmic rays from space

1. The Sun and other stars emit an enormous number of cosmic rays including protons every second.
2. Some of these enter the Earth's atmosphere at high speeds.
3. When they collide with molecules in the air, they lead to the production of gamma radiation.

For Your Information



Exposure pathways to humans from environmental release of radioactive materials

4. High exposure to radiation in a short time can cause radiation sickness, with symptoms like nausea, vomiting, fatigue, and organ damage.
5. Long-term exposure to low levels of radiation increases the risk of cancer, especially in organs like the lungs, thyroid, and bones.
6. Radiation can damage DNA, leading to genetic mutations that may affect future generations.
7. Radioactive materials can contaminate air, water, soil, and food, spreading radiation to the environment.
8. Inhaling radioactive dust or drinking contaminated water can cause internal exposure, where radioactive particles stay in the body and keep emitting radiation.

9. Accidents, such as leaks, spills, or explosions, can occur if radioactive materials are not stored or handled safely.

10. Nuclear power plant accidents or improper waste management can lead to large-scale disasters, harming communities and ecosystems.

Brain Teaser

Which type of radiation comes from space and can affect airline pilots, but never passes through walls?

11. Radioactive materials can be misused in nuclear bombs, which spread radiation using conventional explosives, causing panic and long-term contamination.

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

19.1 The atomic number of an element represents:
(a) number of neutrons in the nucleus
(b) number of protons in the nucleus
(c) total number of protons and neutrons
(d) number of electrons and neutrons

19.2 Which type of radiation is positively charged and consists of two protons and two neutrons?
(a) Alpha (α) (b) Beta (β)
(c) Gamma (γ) (d) Neutron emission

19.3 The process by which an unstable nucleus emits radiation and transforms into a more stable nucleus is called:
(a) nuclear fusion (b) nuclear fission
(c) radioactive decay (d) isotopic exchange

19.4 Nuclear fission involves:
(a) combining light nuclei to form heavier ones
(b) splitting heavy atomic nuclei into smaller ones
(c) absorbing gamma radiation to increase stability
(d) none of the above

19.5 What does Einstein's equation; $E=mc^2$; explain?
(a) The energy released in chemical reactions
(b) The equivalence of mass and energy
(c) The rate of radioactive decay
(d) The conversion of mass into momentum

19.6 Which of the following is a practical application of nuclear radiations?
(a) Cooking food in microwave ovens

(b) Medical imaging and cancer treatments
(c) Solar energy generation
(d) Airplane navigation systems

19.7 A significant source of background radiation is:
(a) oxygen in the air
(b) cosmic rays from space
(c) sound waves in the atmosphere
(d) light from the Sun

B. Short Answer Questions

19.1 What are two main elements that make up the Sun?
19.2 Define the atomic nucleus. What are its two main characteristics?
19.3 How does alpha radiation differ from beta radiation?
19.4 What is the primary energy source of the Sun and other stars?
19.5 Name the equation proposed by Einstein that relates energy and mass.
19.6 What is the principle behind carbon dating and its applications?
19.7 Define nuclear fusion with an example.
19.8 What is background radiation, and what are its natural sources?

C. Constructed Response Questions

19.1 If an atom is mostly empty space, why do not we fall through solid objects or pass through walls?
19.2 Imagine a new radioactive element is discovered. How could scientists estimate its half-life without waiting thousands of years?
19.3 If gamma rays do not change the number of protons or neutrons in a nucleus, why are they still considered dangerous?
19.4 If carbon-14 stopped forming in the atmosphere today, how would that affect the use of carbon dating in the future?
19.5 Explain why background radiation is always present in our environment and how cosmic and terrestrial sources balance each other despite fluctuations in human activity.

D. Comprehensive Questions

19.1 How does the structure of an atom determine its chemical properties? Explain with reference to the arrangement of protons, neutrons, and electrons?

19.2 What are the major sources of background radiation, and how does human activities contribute to it?

19.3 Describe the process of radioactive decay and how it leads to the emission of alpha, beta, and gamma radiation?

19.4 Why do different isotopes of the same element have similar chemical properties but different physical properties? Explain.

19.5 Explain how carbon dating uses carbon-14 to estimate the age of artifacts. Discuss its reliability, considering the influence of carbon-14's half-life.

E. Numerical Problems

19.1 Find the number of protons and neutrons in the nuclide defined by ${}^{21}_{9}X$.

[Ans: 9 protons and 12 neutrons]

19.2 A fossil is found to have 25% of the carbon-14 compared to a living sample. How old is the fossil? **[Ans: ≈ 11460 years]**

19.3 A sample initially contains 400 g of a radioactive isotope with a half-life of 10 years. How much remains after 30 years? **[Ans: 50 g]**

19.4 In a nuclear reaction, 4 μg of mass is converted into energy. Find the energy. **[Ans. 360 MJ]**

19.5 In 420 days, one-eighth of polonium (Po) remains un-decayed. Calculate the half-life of polonium? **[Ans: 140 days]**

Pairing Scheme / Instructions for Preparation of Examination Paper

The paper of Physics (Tech) for class-10 will consist of 40 marks. Timing of the paper will be two (02) hours (Objective 15 minutes and Subjective 1: 45 hours). The paper will be made as per following details:

Objective	**Q-1:** 10 Multiple Choice Questions (MCQs) will be developed from the entire content of the textbook. One MCQ will be asked from each chapter.	$(1 \times 10) = 10$
Subjective Part-I	This section will contain two short answer questions. Each short answer question will be asked from the content of the textbook. The detail is as follows: **Q-2:** 4 short answer questions have to be answered out of 6. The detail is as follows: • One short answer question will be asked from chapters; 10, 11, 12 and 13 each, and two short answer questions will be asked from chapter 14.	$(2 \times 4) = 8$
	Q-3: 4 short answer questions have to be answered out of 6. The detail is as follows: • One short answer question will be asked from chapters; 15, 16, 17 and 18 each, and two short answer questions will be asked from chapter 19.	$(2 \times 4) = 8$
Part-II	This section will contain three detailed questions and students have to attempt any two (02) questions carrying 7 marks each. Each detailed question will be asked form the content of the textbook. The detail is as follows: **Q-4:** One detailed question will be asked from chapters; 10, 11, 12 and 13. **Q-5:** One detailed question will be asked from chapters; 14, 15 and 16. **Q-6:** One detailed question will be asked from chapters; 17, 18 and 19.	$(2 \times 7) = 14$

Note:	In this section, each question will consist of two parts. Part (a) may be asked form any chapter. Part (b) will be asked from any different chapter (not from the same chapter as Part (a). Part (a) will carry 3 marks, while Part (b) will carry 4 marks.

MODEL PAPER

Objective Type

Max. Marks: 10 — کل نمبر: 10

Time allowed: 15 Min. — وقت: 15 منٹ

نوٹ: ہر سوال کے چار ممکنہ جوابات A، B، C اور D دیے گئے ہیں۔ جو انتخاب آپ کے خیال میں درست ہے، اس سوال کے سامنے والے دائرے کو مارکر یا پین کی سیاہی سے بھریں۔ دو یا دو سے زیادہ دائروں کو کاٹنے یا بھرنے کی صورت میں جواب غلط تصوّر ہو گا۔

Note: Four possible answers A, B, C and D to each question are given. The choice which you think is correct, fill that circle in front of that question with marker or pen ink in the answer-book. Cutting or filling two or more circles will result in zero mark in that question.

1. Select the correct answer. **(1x10=10)** — 1- درست جواب کا انتخاب کریں۔

(i) مادّہ کی کون سی خصوصیت یہ بتاتی ہے کہ کوئی ٹھوس جسم اپنے ٹمپریچر میں تبدیلی سے پہلے کتنی حرارت جذب کر سکتا ہے؟

(i) Which property of matter determines how much heat a solid can absorb before its temperature changes significantly?

- (a) Density ڈینسٹی
- (b) Specific heat capacity حرارت مخصوصہ
- (c) Colour رنگ
- (d) Hardness مضبوطی

(ii) انتقالِ حرارت کے کون سے طریقے میں میڈیم کی ضرورت نہیں ہوتی؟

(ii) Which method of heat transfer does not require a medium?

- (a) Conduction کنڈکشن
- (b) Convection کنویکشن
- (c) Radiation ریڈی ایشن
- (d) Both (b) and (c) (b) اور (c) دونوں

(iii) ٹرانسورس ویو کے نچلے ترین مقام کو کیا کہتے ہیں؟

(iii) Which part of a transverse wave carry the lowest point?

(a) Crest کرسٹ (b) Trough ٹرف (c) Compression کمپریشن (d) Rarefaction ریرفیکشن

(iv) An example of a longitudinal wave is: — (iv) لونگیٹیوڈنل ویو کی مثال ہے:

(a) Light wave روشنی کی ویو (b) Water wave پانی کی ویو (c) Sound wave ساؤنڈ ویو (d) Radiowave ریڈیو ویو

(v) روشنی کی ایک رے پانی سے ہوا میں داخل ہوتے ہوئے جھک جاتی ہے:

(v) A ray of light travelling from water to air bends:

- (a) Towards the normal نارمل کی طرف
- (b) Away from the normal نارمل سے پرے
- (c) At 90° to the normal نارمل پر 90° پر
- (d) Parallel to the normal نارمل کے متوازی

(vi) جب دو مخالف چارجز کو ایک دوسرے کے قریب لایا جاتا ہے تو کیا ہوتا ہے؟

(vi) What happens when two unlike charges are brought close to each other?

- (a) They attract وہ ایک دوسرے کو کشش کرتے ہیں
- (b) They repel وہ ایک دوسرے کو دفع کرتے ہیں
- (c) They neutralize each other وہ ایک دوسرے کے اثر کو زائل کر دیتے ہیں
- (d) Nothing happens کچھ بھی نہیں ہوتا

(vii) Electromotive force is equal to: — (vii) الیکٹرو موٹیو فورس برابر ہے:

(a) $Q = W/E$ (b) $Q = E/W$ (c) $E = W/Q$ (d) $E = Q/W$

(viii) One tesla (T) is equal to: ایک ٹیسلا(T)برابر ہے: (viii)

(a) $1T=1N\,A\,m^{-1}$ (b) $1T=1N\,A^{-1}\,m^{-1}$ (c) $1T=1N\,A\,m$ (d) $1T=1N^{-1}A^{-1}\,m$

(ix) سٹیپ ڈاؤن ٹرانسفارمر میں سیکنڈری کوائل میں ٹرنز کی تعداد ہوتی ہے:

(ix) In a step-down transformer, the number of turns in the secondary coil is:

(a) Greater than the primary coil پرائمری کوائل سے زیادہ (b) Equal to the primary coil پرائمری کوائل کے برابر

(c) Less than the primary coil پرائمری کوائل سے کم (d) Always zero ہمیشہ صفر

(x) کون سی ریڈی ایشن پوزیٹیو چارج رکھتی ہے اور دو پروٹون اور دو نیوٹران پر مشتمل ہوتی ہے؟

(x) Which type of radiation in positively charged and consists of two protons and two neutrons?

(a) Alpha الفا (b) Beta بیٹا (c) Gamma گیما (d) Neutron emission نیوٹران ایمشن

Subjective Type
(Part-I)

Max. Marks: 30 **کل نمبر: 30**

Time allowed: 1.45 Hours **وقت: 1:45 گھنٹے**

.2 کوئی سے چار (04) سوالات کے مختصر جوابات لکھیے۔

2. Write short answers to any four (04) questions: (2x4=8)

(i) ویپورائزیشن کی مخفی حرارت سے کیا مراد ہے اور اسے کیسے معلوم کیا جاتا ہے؟

(i) What is latent heat of vaporization, and how is it calculated?

(ii) Enlist some applications of conduction. کنڈکشن کے چند اطلاقات کے نام لکھیں۔ (ii)

(iii) Wat is meant by wave front? ویوفرنٹ سے کیا مُراد ہے؟ (iii)

(iv) How can noise pollution be controlled? شور کی آلودگی کو کیسے کنٹرول کیا جاسکتا ہے؟ (iv)

(v) ٹوٹل انٹرنل ریفلیکشن کی تعریف کریں۔ اس کے لیے کن شرائط کا ہونا ضروری ہے؟

(v) Define total internal reflection. What conditions are required for it to occur?

(vi) کریٹیکل اینگل کی تعریف کریں۔ خلاء کے لیے کریٹیکل اینگل کی قیمت کیا ہے؟

(vi) Define critical angle. What is the value of critical angle for vacuum?

.3 کوئی سے چار(04)سوالات کے مختصر جوابات لکھیے:

3. Write short answers to any four (04) questions: (2x4=8)

(i) روزمرہ زندگی میں الیکٹروسٹیٹکس کے چند اطلاقات کے نام لکھیں۔

(i) List some applications of electrostatics in daily life.

(ii) الیکٹرک پاور کی تعریف کریں اور اس کا فارمولا لکھیں۔

(ii) Define electric power and write its formula.

(iii) State the principle of D.C motor. ڈی۔سی موٹر کا اصول بیان کریں۔ (iii)

(iv) Define magnetic flux. میگنیٹک فلکس کی تعریف کریں۔ (iv)

(v) بیک گراؤنڈ ریڈی ایشن کے چند ذرائع کے نام لکھیں۔

(v) Enlist some sources of background radiation.

(vi) الفا ریڈی ایشن بیٹا ریڈی ایشن سے کس طرح مختلف ہے؟

(vi) How does alpha radiation differ from beta radiation?

(Part-II)

4. Write detailed answers of any two (02) questions. **.4 کوئی سے دو (02) سوالات کے تفصیلاً جوابات لکھیے:**

(2x7=14)

(الف) مائعات اور گیسز میں کنویکشن کے عمل کے ذریعے حرارتی انرجی کیسے منتقل ہوتی ہے؟ وضاحت کریں کہ کمرے میں ہیٹر کے ایک ہی جگہ پر پڑے رہنے سے سارا کمرہ کیسے گرم ہو جاتا ہے۔ (3)

(a) How heat energy is transferred by convection in liquids and gases? Explain how the whole room is heated by placing a heater at one place in the room. (3)

(ب) ایک آدمی ایک پہاڑی کے نزدیک اپنے ہاتھوں سے تالی بجاتا ہے اور 6 s کے بعد اس کی ایکو کو سنتا ہے۔ اگر ساؤنڈ کی سپیڈ $343\ m\ s^{-1}$ ہو تو آدمی کا پہاڑی سے فاصلہ کتنا ہوگا؟ (4)

(b) A person claps his hands near a mountain and hears the echo after 6 s. If the speed of sound is $343\ m\,s^{-1}$, what is the distance of the mountain from the person? (4)

.5 (الف) دُور نظری سے کیا مُراد ہے؟ اس کی وجوہات بیان کریں۔ (3)

5. (a) What is long sightedness? Discuss its causes. (3)

(ب) اپنے کمرے میں 100 W کا سیلینگ فین روزانہ 10 گھنٹے چلانے کی لاگت معلوم کریں۔ فرض کریں کہ ایک یونٹ کی قیمت 25 روپے ہے۔ (4)

(b) Calculate the one-month cost of using a 100 W ceiling fan for 10 hours dail in your room. Assume that the price of one unit is Rs. 25. (4)

.6 (الف) وضاحت کریں کہ کاربن ڈیٹنگ کس طرح کاربن-14 کا استعمال کرتے ہوئے نوادرات کی عمر کا اندازہ لگاتے ہے۔ اس کی قابل اعتمادیت پر بحث کریں، خصوصاً کاربن-14 کی ہاف-لائف کے اثر کو مدِّنظر رکھتے ہوئے۔ (3)

6. (a) Explain how carbon dating uses carbon-14 to estimate the age of artifacts. Discuss its reliability, considering the influence of carbon-14's half-life. (3)

(ب) ایک سٹیپ اپ ٹرانسفارمر میں ٹرنز کا تناسب 2:100 ہے۔ اگر پرائمری کوائل پر 25 V اے۔ سی وولٹیج لگائی جائے تو سیکنڈری وولٹیج کیا ہوگی؟ (4)

(b) A step-up transformer has a turn ratio of 2:100. If an alternating voltage of 25 V is applied to the primary coil, what will be the secondary voltage? (4)