Textbook of

Physics

Grade

10

Based on National Curriculum 2022-23

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A Textbook of Physics for Grade 10
Based on National Curriculum of Pakistan (NCP) 2022-23

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PREFACE

This Grade 10 Physics textbook, developed by the National Book Foundation (NBF) in alignment with the National Curriculum of Pakistan 2022-2023, aims to deepen students' understanding of physics by building on concepts learned in earlier grades. Our goal is to foster logical thinking and higher-order reasoning by presenting physics concepts in a way that connects them to real-world applications, enabling students to relate their knowledge to daily life and prepare them for more advanced studies.

With contributions from dedicated experts and experienced authors, this textbook has undergone extensive review and refinement by professional educators. We focused on making the material engaging and accessible for students by introducing interactive concepts and real-life activities.

The National Book Foundation remains committed to enhancing the quality of its educational materials, and this edition features an improved design, clear illustrations, and meaningful activities that capture students' curiosity. We welcome suggestions from students, teachers, and the community to further enrich future editions of this textbook.

May Allah guide and help us (Ameen).

Murad Ali Mohmand
Managing Director

Practical applications for physics grade 10

Physics is more than a school subject; it's a gateway to understanding the mechanics of the world around us, from the minuscule particles within an atom to the vast networks of galaxies. As you dive into this Grade 10 textbook, you'll see that physics isn't just about memorizing equations or facts—it's about building a mindset for discovery and innovation. This subject provides the tools you need to solve real-world problems, and the skills developed here will open doors to fields as varied as engineering, medicine, and technology.

Every concept you'll study has a direct impact on everyday life and future career opportunities. Whether it's understanding the forces that hold buildings steady or the mechanics of electric circuits, each chapter will prepare you for roles that are essential in fields shaping Pakistan's future.

Chapter 10: HEAT CAPACITY AND MODES OF HEAT TRANSFER

This chapter delves into the science of how heat is stored and transferred. Understanding concepts like thermal conduction, convection, and radiation is essential in fields such as energy efficiency, HVAC (heating, ventilation, and air conditioning) design, and renewable energy. Careers in environmental engineering, energy conservation, and climate science rely heavily on the principles discussed here.

Chapter 11: THERMAL EXPANSION AND CHANGE OF STATE

In this chapter, you'll explore the kinetic theory of matter, thermal expansion, and latent heat, which are fundamental in materials science, engineering, and environmental studies. Concepts like thermal expansion of solids and liquids are particularly useful in civil and mechanical engineering, where they are used to design buildings, bridges, and machinery that withstand temperature changes.

Chapter 12: WAVES

Studying wave theory, reflection, refraction, and diffraction lays the foundation for work in telecommunications, sound engineering, and medical imaging. Professionals in fields like broadcasting, audio engineering, and seismology rely on a solid understanding of wave behavior to analyze sound waves, light waves, and seismic activity.

Chapter 13: SOUND

In this chapter, you'll learn about the production and propagation of sound, pitch, loudness, and applications of ultrasonic waves. This knowledge is essential in areas like acoustical engineering, medical ultrasonography, and environmental science. Careers in audio technology, noise pollution control, and even entertainment are built upon these principles.

Chapter 14: OPTICS

Here, you will study laws of reflection and refraction, lenses, and applications like gravitational and acoustic lensing. These topics are fundamental in fields such as optical engineering, vision sciences, and photography. Professionals in fields like ophthalmology, camera design, and fiber optics use these principles to create and refine imaging technologies.

Chapter 15: ELECTROSTATICS

Understanding electrostatics, electric fields, and electrical discharges is crucial for careers in electronics, telecommunications, and safety engineering. Applications of electrostatics are found in devices like photocopiers, air purifiers, and touch screens, opening paths to jobs in electronics design, environmental control systems, and industrial safety.

Chapter 16: CURRENT ELECTRICITY

This chapter covers current flow, potential difference, Ohm's law, and resistance—the backbone of electrical and electronic engineering. Knowledge in current electricity is vital for careers in power distribution, electrical engineering, and electronics. Whether working with power grids, household appliances, or complex electronic circuits, these concepts are widely applied.

Chapter 17: ELECTRIC CIRCUITS

In this chapter, you'll study the components and design of electric circuits, including resistors, potential dividers, and power applications. This knowledge is essential for careers in circuit design, computer engineering, and electrical safety. In Pakistan, the demand for skilled circuit designers and power engineers is growing in areas like renewable energy systems, automation, and telecommunications.

Chapter 18: ELECTRONICS

This chapter introduces students to the world of diodes, transistors, and Boolean logic, the building blocks of modern electronics. Careers in electronics, telecommunications, and even quantum computing are within reach for students who master the concepts of analogue and digital electronics.

Chapter 19: ELECTROMAGNETISM

This chapter explores magnetic fields, electromagnetic induction, and the operation of generators and motors. Understanding electromagnetism is crucial for careers in power generation, robotics, and transportation engineering. Applications in electric vehicles, magnetic storage devices, and energy systems make this field rich in opportunities for engineers and technicians alike.

Chapter 20: ELECTROMAGNETIC WAVES

The study of electromagnetic waves, spectrum applications, and light scattering is essential in fields like satellite communications, radiology, and space exploration. With Pakistan advancing in areas such as remote sensing and medical imaging, this chapter lays a solid foundation for careers in telecommunications, medical technology, and atmospheric sciences.

Chapter 21: NUCLEAR PHYSICS

The study of atoms, isotopes, and nuclear reactions offers a gateway to careers in energy production, medical imaging, and scientific research. By understanding radioactivity, students can contribute to fields like nuclear energy, healthcare, and space exploration, where the manipulation and safe handling of nuclear materials are essential.

In conclusion, the journey through Grade 10 physics prepares students not only for higher academic pursuits but also for impactful careers in diverse fields. Whether you're interested in energy solutions, medical technologies, or cutting-edge electronics, physics equips you with the tools to shape the future

بِسۡمِ اللّٰہِ الرَّحۡمٰنِ الرَّحِیۡمِ

اللہ کے نام سے شروع جو بڑا مہربان، نہایت رحم والا ہے

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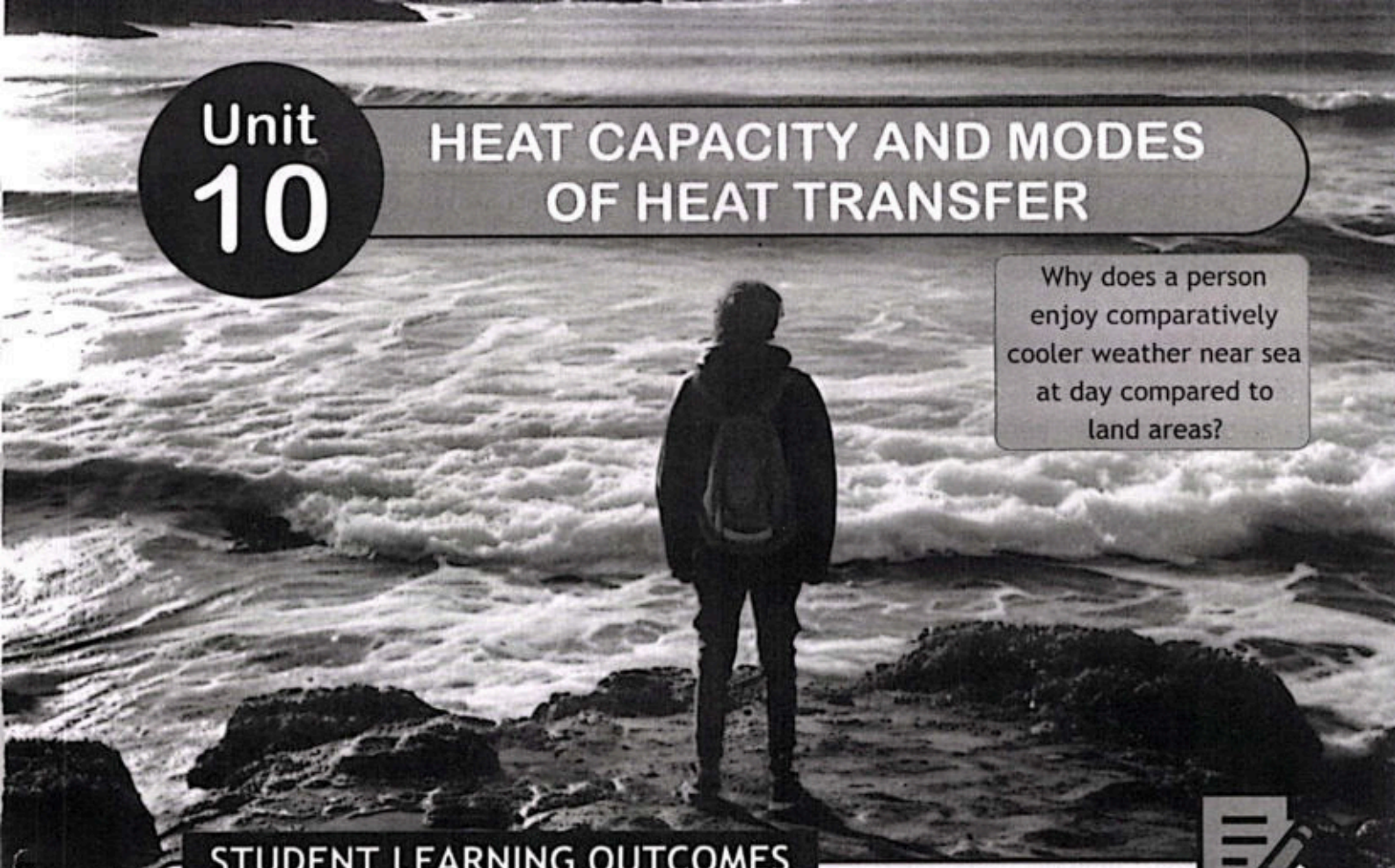
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Unit 10

HEAT CAPACITY AND MODES OF HEAT TRANSFER

Why does a person enjoy comparatively cooler weather near sea at day compared to land areas?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-C-01] Define and calculate specific heat.
- ✓ [SLO: P-10-C-02] Suggest experiments to measure the specific heat capacity.
- ✓ [SLO: P-10-C-03] Analyse everyday effects due to the large specific heat of water.
- ✓ [SLO: P-10-C-30] Justify experiments to distinguish between good and bad thermal conductors.
- ✓ [SLO: P-10-C-31] Explain thermal conduction in all solids.
- ✓ [SLO: P-10-C-32] Explain convection in liquids and gasses.
- ✓ [SLO: P-10-C-33] Explain convection in seawater to support marine life.
- ✓ [SLO: P-10-C-34] Describe the role of land breezes and sea breezes in maintaining moderate coastal climates.
- ✓ [SLO: P-10-C-35] Explain how birds are able to fly for hours without flapping their wings and gliders are able to rise by riding on thermal currents.
- ✓ [SLO: P-10-C-36] Describe the process of thermal energy transfer by radiation.
- ✓ [SLO: P-10-C-37] Describe the effect of surface color and texture on the emission, absorption and reflection of infrared radiation.
- ✓ [SLO: P-10-C-38] Justify qualitatively how the rate of emission of radiation depends on the surface temperature and surface area of an object.
- ✓ [SLO: P-10-C-39] Justify experiments to distinguish between good and bad emitters and absorbers of infrared radiation.
- ✓ [SLO: P-10-C-40] Analyze the consequence of heat radiation in the greenhouse effect and its effect in global warming.

- ✓ [SLO: P-10-C-41] Analyze everyday applications of conduction, convection and radiation.
- ✓ [SLO: P-10-F-23] Use ideas of convection to explain how cyclones are formed.
- ✓ [SLO: P-10-F-24] Explain how global warming contributes to extreme weather events.
- ✓ [SLO: P-10-F-25] Explain the phenomena of geothermal activity on the basis of conduction, convection and radiation.

Have you ever wondered why water takes time to boil or why metal feels colder than wood at the same temperature? These questions lead us to explore heat, specifically specific heat capacity and heat transfer methods.

We will start with specific heat capacity, which is the heat needed to raise a substance's temperature. Water, with its high specific heat capacity, heats slowly but retains warmth longer, linking kitchen mysteries to broader climate issues. We will conduct experiments to measure the specific heat capacities of various materials. Next, we will look at the three main heat transfer methods: conduction, convection, and radiation. These principles explain why hot coffee cools, why upper floors feel warmer, and how the sun's energy reaches us. Understanding these concepts is crucial for grasping their roles in greenhouse effects and global warming. Finally, we'll explore geothermal phenomena, where the Earth's hot core drives magma movements and tectonic shifts, leading to earthquakes and volcanic eruptions. Throughout this chapter, consider how heat and its movement impact your daily life and the world around you.

10.1 SPECIFIC HEAT CAPACITY

Specific heat capacity or specific heat of a material is the amount of heat absorbed or lost to change the temperature of 1 kg of its substance by 1 kelvin or 1 degree celsius.

$$c = \frac{Q}{m\Delta T} \quad \text{10.1}$$

Where 'c' is the specific heat of the material, 'Q' is the amount of heat absorbed or lost, 'm' is the mass of the substance and 'ΔT' i.e. $(T_{Final} - T_{Initial})$ is the change in temperature of the substance.

Its SI unit is joule per kilogram per kelvin ($J\,kg^{-1}\,K^{-1}$). Its other units in use are $J\,kg^{-1}\,°C^{-1}$ and $Jg^{-1}\,°C^{-1}$. For example, specific heat of aluminum is $900\ J\,kg^{-1}K^{-1}$. Its value in other units can be written as $900\ J\,kg^{-1}\,°C^{-1}$ and $0.9\ J\,g^{-1}\,°C^{-1}$.

Some materials require small amount of heat like metals (for example aluminium, copper, iron and diamond etc) . These materials have low value of specific heat. Such materials are good conductor of heat. We can say that these materials cannot retain heat for longer time with them. These materials heat up and cool down quickly. Therefore, such materials are used in heat sinks.

Some substances require large amount of heat like water to raise its temperature by one kelvin. They have large specific heat. These materials absorb or loose large amount of heat for small change in their temperature. They cannot be easily heated up or cooled down. It means that these materials can retain heat in them. These materials are used for controlling the temperature

UNIT OPENER?



Why does a person enjoy comparatively cooler weather near sea at day compared to land areas?

The cooler daytime temperatures experienced in coastal areas, compared to inland regions, result from the interplay between the high specific heat capacity of water and the moderating effects of sea breezes. Coastal areas tend to be cooler during the day than areas further inland due to the differing heat capacities of water and land. Water's higher specific heat capacity means it takes more energy to raise its temperature compared to land. Therefore, the water temperature rises much more gradually. This results in cooler air temperatures near coastal areas, influenced by the slower-warming water bodies.



The temperature difference between land and sea creates a pressure gradient that drives sea breezes. As the land absorbs solar radiation and heats up, the air above it warms, becomes less dense, and rises, forming a low-pressure zone. In contrast, the cooler sea surface maintains a cooler, denser air mass above it, establishing a high-pressure area. This pressure difference propels the cooler air from the sea towards the land, generating a sea breeze. This influx of cooler, more humid air from the ocean moderates coastal temperatures, keeping them lower than inland areas.

in different devices. For example, water has large specific heat therefore it is used in cars as engine coolant.

10.1.1 USES OF LARGE SPECIFIC HEAT OF WATER

Water has large specific heat (4200 J kg^{-1} K^{-1}). Due to it, it has significant uses in our daily life.

A. Temperature Variation in Land and Coastal Areas: The specific heat of dry soil (800 J kg^{-1} K^{-1}) is smaller than that of water. It is about five times smaller than that of water. It is why land area quickly heats up in summer and temperature rises from about 45 °C to 50 °C, and also because land quickly cools down in winter, leading to low temperatures from 5 °C to 0 °C. But in coastal areas, temperature variation is small. In Karachi, average temperature variation is from 19 °C to 32°C. So, oceans and large lakes absorb a lot of heat from the sun during the summer and keep the heat stored in them. On the other hand, in winters, oceans and lakes release heat into the atmosphere. This phenomenon keeps the temperature moderates between summer and winter in coastal areas.

Table 10.1: SPECIFIC HEATS OF SELECTED SUBSTANCES

Materials	Specific heat J /kg K
Aluminum	910
Copper	387
Glass	840
Gold	129
Iron/ steel	452
Lead	128
Silver	235
Ethanol	2450
Glycerin	2410
Mercury	139
Water	4190
Air	721
Carbon dioxide	638
Oxygen	651
Steam (100°C)	1520

B. Maintaining stability of Ocean and Lake Temperatures: Lakes and oceans heat up and cool down slowly due to high specific heat of water. This prevents changes in the temperature of the lake and oceans and thus provides a suitable environment for aquatic life.

C. Human Body Temperature Regulation: The human body contains approximately 60 % water. A healthy body maintains its temperature about 37 °C. Now, we can relate how can our body maintain its temperature due to high specific heat of water.

D. Cooling system and Heat Exchangers: Water is used as coolant in power plants, different industrial process and cooling system of automobiles (radiators) as shown in figure 10.1. Water takes large amount of excess heat from the machines and effectively transfer heat using heat exchanger. It prevents overheating in the machinery and maintain their high efficiency.

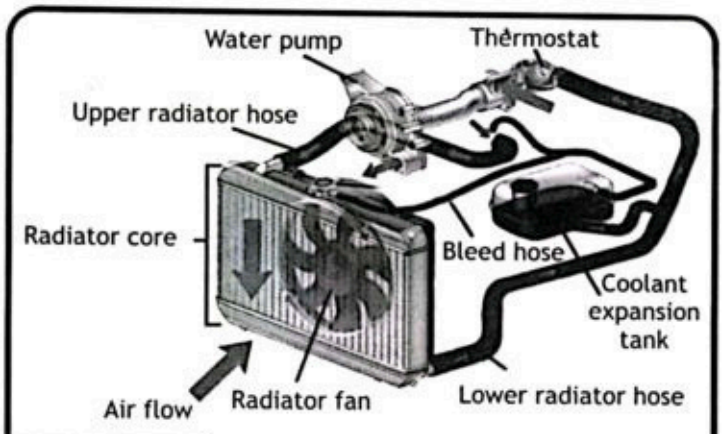


FIGURE 10.1 Cooling system of vehicles

E. Cooking Process: Water is good for cooking because of its high specific heat. It heats up slowly and distributes heat evenly. It ensures food cooking without burning. Hot drinks like tea and coffee stay hot for long time. Can you explain it?

Example 10.1

A 200 g sample of a solid metal is heated from 25 °C to 75 °C. If 3,500 joules of heat energy is required to raise the temperature of the metal, what is the specific heat of the metal?

GIVEN:
Mass 'm' = 200 g = 0.2 kg
Change in temperature 'ΔT' = 75 °C - 25 °C = 50 °C = 50 K
(Change in temperature in celsius and kelvin scales is same)
Heat energy 'Q' = 3,500 J

REQUIRED:
Specific heat of metal 'c' = ?

SOLUTION:
Specific heat capacity is given by: $c = \frac{Q}{m\Delta T}$ putting values $c = \frac{3{,}500\,J}{(0.2\,kg)(50\,K)}$

Therefore $c = \frac{3{,}500\,J}{(0.2\,kg)(50\,K)}$ ANSWER

Therefore, the specific heat of the metal is 350 J kg^{-1} K^{-1}.

Example 10.2

A half kilogram sample of aluminum (specific heat capacity c = 900 J kg^{-1} K^{-1}) is heated from room temperature of 25 °C to 100 °C. How much heat is absorbed by the aluminum to raise its temperature?

GIVEN:
Mass 'm' = 0.5 kg, Specific heat 'c' = 900 J kg^{-1} K^{-1}
Initial temperature '$T_{initial}$' = 25 °C
Final temperature 'T_{final}' = 100 °C
Change in temperature 'ΔT' = 100 °C - 25 °C = 75 °C = 75 K

REQUIRED:
Heat absorbed 'Q' = ?

SOLUTION:
Specific heat capacity is given by: $c = \frac{Q}{m\Delta T}$ or $Q = mc\Delta T$

putting values $Q = (0.5\ kg) \times (900\ Jkg^{-1}\ K^{-1}) \times (75\ K)$

Therefore $Q = 33{,}750\ J = 33.75\ kJ$ — ANSWER

The amount heat required by sample of aluminum is 33.75 kJ.

10.1.2 MEASUREMENT OF SPECIFIC HEAT OF SOLIDS AND LIQUIDS

There are different experiments which can be used to determine specific heat of solids and liquids. The most common methods are "method of mixtures" and "electrical heating method".

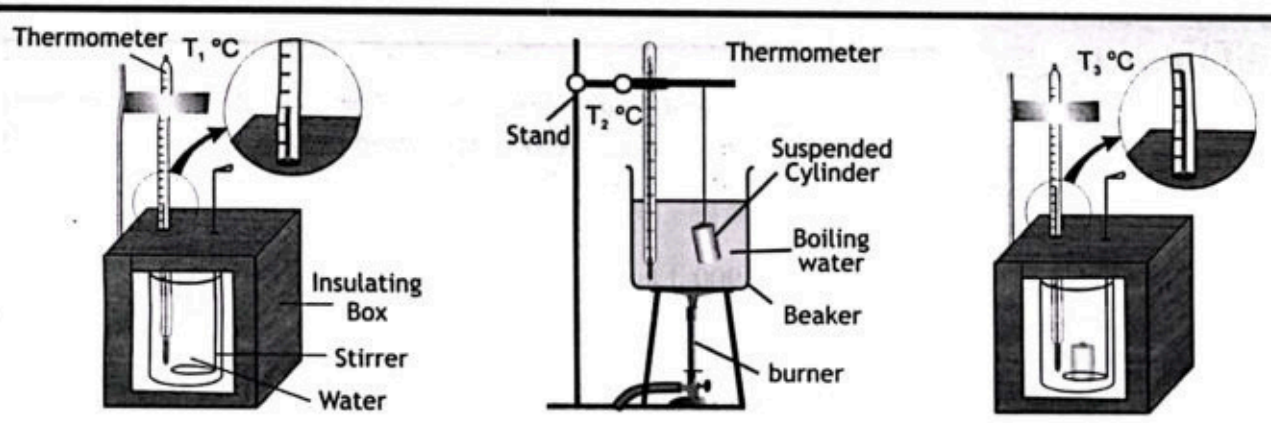
A. Method of mixtures: The experiments for measurement of unknown specific heat capacity of solids and liquids by method of mixtures are discussed below:

i. Measurement of unknown specific heat capacity of solids: This method uses a calorimeter to determine the heat capacity of a substance. In this method, when the hot sample e.g. a solid is added to water in the calorimeter, heat is exchanged between them as well as the calorimeter. From the law of conservation of energy, the heat lost by hot bodies will be equal to the heat gained by cold bodies. Then we form the equation after measuring the change in temperature of the water in calorimeter and masses of substances. After careful analysis, we can calculate the specific heat capacity of the sample.

Apparatus: A Bunsen burner or hot plate, copper calorimeter with lid stirrer and insulating cover, a metallic solid cylinder (e.g. brass or copper cylinders), weighing machine, water, beaker, laboratory stand and two thermometers

Key Variables:

- Independent Variable is the temperature of the metal block.
- Dependent Variable is the energy supplied to the metal block by heating.



(a) Initial temperature of water in calorimeter

(b) Temperature of boiling water and solid cylinder

(c) Final temperature of the mixture in calorimeter

FIGURE 10.2 Measurement of specific heat capacity of a solid with mixture method.

Procedure:

1. Take an empty calorimeter of known heat capacity C_c. Measure the mass of calorimeter m_c with the stirrer and lid.

2. Fill the calorimeter with enough water to completely submerge the solid later. Weigh (m) the calorimeter with water. Difference of masses ($m - m_c$) is equal to the mass of water (m_w) in the calorimeter.

3. Place the calorimeter in its insulating cover and insert thermometer in it. Measure the temperature of water T_1 °C (equal to the temperature of the surroundings) as shown in figure 10.2 (a).

4. Measure the mass of the given solid using a weighing machine and note down its mass as m_s.

5. Boil water in a beaker with the solid submerged. Measure the boiling water temperature (T_2 °C). In this step, ensure that the solid attains the same temperature as the boiling water on heating as shown in figure 10.2 (b).

6. Remove the solid from boiling water, shake off excess water, and quickly place it in the calorimeter. Cover the calorimeter immediately.

7. Stir the water continuously with the stirrer for uniform distribution of heat (and temperature).

8. Measure the final temperature of the mixture once it becomes constant on attaining equilibrium, record this temperature as T_3 °C as shown in figure 10.2 (c).

9. Now we calculate the increase in temperature of water and calorimeter that is equal to ($T_3 - T_1$) and decrease in temperature of solid is equal to ($T_2 - T_3$).

10. From principle of calorimetry i.e. law of conservation of energy, heat given by solid in cooling *from* T_2 to T_3 is equal to heat gained by the water and calorimeter in raising their temperature

from T_1 to T_3. Such that:

Heat loss by solid = Heat gained by water in calorimeter + Heat gained by calorimeter

$$Q_S = Q_W + Q_C$$

or $$m_S c_S (T_2 - T_3) = m_W c_W (T_3 - T_1) + m_C c_C (T_3 - T_1)$$

By rearranging the above equation, we can find the specific heat capacity of solid.

$$c_S = \frac{m_W c_W (T_3 - T_1) + m_C c_C (T_3 - T_1)}{m_S (T_2 - T_3)}$$

Hence, $$c_S = \frac{(m_W c_W + m_C c_C)(T_3 - T_1)}{m_S (T_2 - T_3)} \quad \text{— 10.2}$$

Result: Equation 10.2 is used to find specific heat of a solid (c_s). By putting the measured masses of solid, water and calorimeter, specific heat capacities of water and calorimeter, and temperatures T_1, T_2 and T_3 in equation 10.2, we can calculate the specific heat capacity of the solid.

ii. Measurement of unknown specific heat capacity of a liquid: To measure the unknown specific heat capacity of a liquid, we follow the same procedure. But in this experiment, we take solid of known specific heat capacity but liqui of unknown specific heat capacity c_l is taken. Same experiment is performed to measure the unknown specific heat capacity of a liquid. fro this experiment, law of conservation of energy can be written as:

$$m_S c_S (T_2 - T_3) = m_l c_l (T_3 - T_1) + m_C c_C (T_3 - T_1)$$

By rearranging the above equation, we get: $$m_l c_l (T_3 - T_1) = m_S c_S (T_2 - T_3) - m_C c_C (T_3 - T_1)$$

Hence, $$c_l = \frac{m_S c_S (T_2 - T_3) - m_C c_C (T_3 - T_1)}{m_l (T_3 - T_1)} \quad \text{— 10.3}$$

Example 10.3

A 150 g piece of an unknown solid cylinder is heated to 100 °C and then placed into a calorimeter containing 200 g of water at 25 °C. The calorimeter has a mass of 50 g and a specific heat capacity of 0.9 J/g°C. The final temperature of the system (solid, water, and calorimeter) is 30 °C. Assume no heat is lost to the surroundings. Calculate the specific heat capacity of the solid.

GIVEN:

Mass of solid cylinder 'm_s' = 150 g
Mass of water in calorimeter 'm_w' = 200 g
Mass of calorimeter 'm_c' = 50 g
Initial temperature 'T_1' = 25 *°C*
Temperature of solid cylinder 'T_2' = 100 *°C*
Final temperature 'T_3' = 30 *°C*
Specific heat of water 'c_w' = 4.18 *J/g °C*
Specific heat of calorimeter 'c_c' = 0.9 *J/g °C*

REQUIRED:

Specific heat capacity 'c_s' = ? (in *J/g °C*)

SOLUTION:

From principle of calorimetry, we have: $c_s = \dfrac{(m_w c_w + m_c c_c)(T_3 - T_1)}{m_s(T_2 - T_3)}$

putting values $c_s = \dfrac{\{(200\,g)(4.18\,J/g^0C) + (50\,g)(0.9\,J/g^0C\} \times (30\,^0C - 25\,^0C)}{(150\,g) \times (100\,^0C - 30\,^0C)}$

Therefore $c_s = 0.42\,J/g^0C$ — ANSWER

The specific heat capacity of solids is 0.42 $J/g^\circ C$

B. Electrical **Heating Method:** The experiments for measurement of unknown specific heat capacity of a solid and liquids are discussed below:

i. Measurement **of unknown specific heat capacity of solids:** In this method, we measure the mount of heat transferred to a material and measure its temperature change.

Apparatus: A solid block or cylinder e.g. aluminium with a hole in it for a heater and a smaller hole for a thermometer, an immersion heater, voltmeter, ammeter, thermometer.

Procedure:

1. Calculate the mass of the solid block.

2. Place an electrical immersion heater into the central hole at the top of the weighed metal block. Connect the heater with an ammeter to measure current and with a voltmeter to measure voltage (potential difference) applied on the heater as shown in figure 10.3.

3. Place the thermometer into the smaller hole. Add few drops of oil into the hole to make sure the thermometer is surrounded by hot material.

4. Insulate the block by wrapping it with cotton wool.

5. Record the initial temperature of the block.

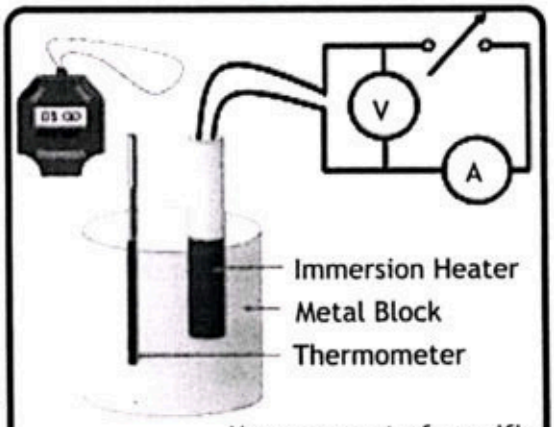


FIGURE 10.3 Measurement of specific heat capacity of a solid by electrical method

6. Connect the heater to the power supply and turn it on for ten minutes. Record the current and potential difference.

7. After ten minutes, turn the heater off. Record the highest temperature that it reaches (temperature readings will rise even after the heater is turned off).

8. Calculate the heat energy generated by water.

Result: Calculate the specific heat capacity of the solid block using the formula:

$$c = \frac{Q}{m\Delta T} \qquad \text{— 10.4}$$

ii. Measurement of unknown specific heat capacity of liquids:

Apparatus: An immersion heater, voltmeter, ammeter, thermometer, water and calorimeter.

Procedure:

1. Calculate the mass of empty calorimeter (m_c).
2. Add some liquid e.g. water in calorimeter and measure the mass of calorimeter plus liquid (m). Difference of the masses ($m - m_c$) gives the mass of liquid (m_w).
3. Measure the initial temperature of the calorimeter plus liquid using thermometer.

INFORMATION

Heat generated by heater is calculated by:

Heat energy = electrical energy supplied to heater

Heat energy = Voltage × current × time

You will study this formula in detail in unit 16: Current electricity

4. Place electrical heater inside the liquid, and connect ammeter and voltmeter with it. Switch it ON. Measure the voltage and current passing through the heater as shown in figure 10.4.
5. Temperature will start to rise. When temperature rises for 10 °C, switch off the heat and stir the liquid well and measure the highest temperature of the liquid. Then find the temperature difference between highest temperature and initial temperature of liquid.
6. From law of conservation of energy:

Energy Supplied = Heat gained by liquid + Heat gained by calorimeter

$$Q_{Heater} = Q_W + Q_C$$

$$Q_{Heater} = m_l c_l (T_f - T_i) + m_c c_c (T_f - T_i)$$

Result: By rearranging the above equation, we get:

$$c_l = \frac{Q_{Heater} - m_c c_c (T_f - T_i)}{m_l (T_f - T_i)} \quad \boxed{10.5}$$

By putting the measured values of heat energy produced by heater, masses of liquid and calorimeter and initial and final temperatures, we can measure the specific heat capacity of liquid.

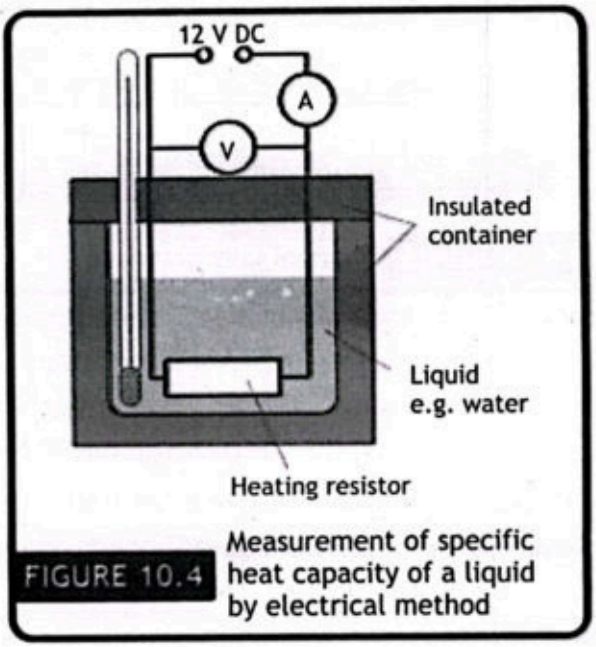


FIGURE 10.4 Measurement of specific heat capacity of a liquid by electrical method

10.2 TRANSFER OF HEAT

Heat transfer occurs when thermal energy is transferred from one object to another because of a difference in temperature. This process continues until both objects reach the same temperature, which is known as thermal equilibrium. There are three methods of heat transfer i.e. conduction, convection and radiation.

10.2.1 THERMAL CONDUCTION

A cooking pot's top edges get extremely hot when we touch them after it has been on the stove for a while, even if they are not getting heat directly. It happens because heat is transferred to these top edges due to the phenomenon of conduction. Similarly, when frying vegetables in a pan as shown in figure 10.5. Heat transfer takes place from the flame to the pan and then to the vegetables due to conduction.

This method of heat transfer takes place in solids. In conduction, heat is transferred from atoms to atoms. Metals are good conductors of heat because they have a large number of free electrons that travel faster across the metal when metal is heated. That's why heat energy is transferred quickly in metals. We can define thermal conduction as: **'It is method of transfer of heat due to collisions of atoms or molecules and motion of free electrons in solids from its hot part to cold part'.**



FIGURE 10.5 Thermal Conduction

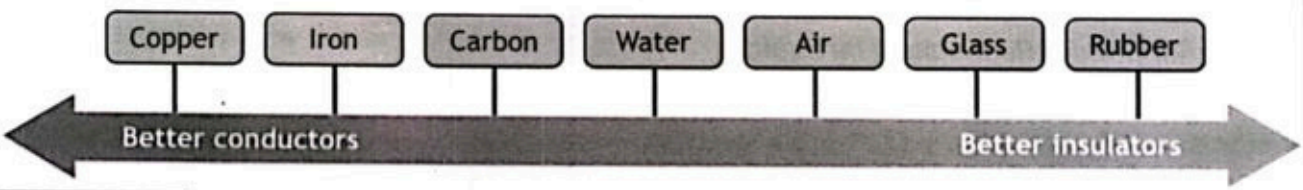


FIGURE 10.6 Thermal Conductors

When one of the ends of a rod is heated, atoms at this end start vibrating with larger amplitude. These atoms hit their neighbouring atoms and transfer them heat energy as shown in figure 10.7. Now, these atoms vibrate with larger amplitude and hit their nearby atoms, and process continues. Heat energy is transferred between the two ends in this manner.

When a copper rod and a wooden stick are heated simultaneously, we find that the copper rod's other end heats up more quickly than the wooden stick's other end.

This is due to the fact that metallic rods, such as copper rods, have a lot of free electrons. In comparison to vibrating atoms, these free electrons get energy from the hot end and transfer energy fast from one end of the rod to its second end.

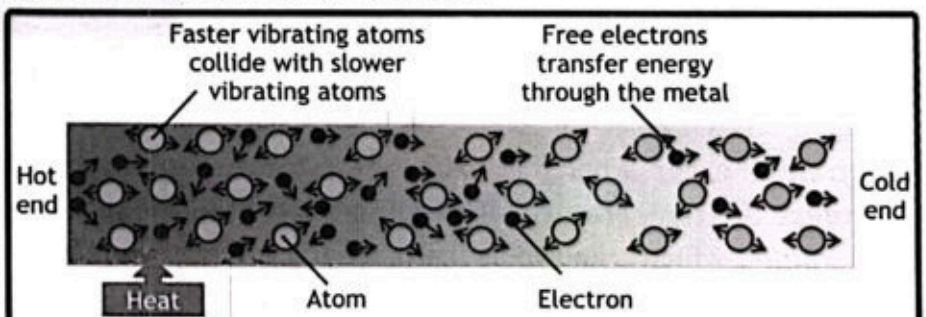


FIGURE 10.7 Mechanism for thermal Conductors

We can say that metals transfer heat energy quickly than other solids like wood, glass etc.

Experiment: Let's discuss an experiment to differentiate between good and bad conductors (figure 10.8).

Apparatus: Three long thin strips of different metals (for example copper, iron, and aluminium rods), Vaseline or wax, drawing pins and a Bunsen burner.

Control variables: length of metal rod, diameter of rods, position in the Bunsen flame.

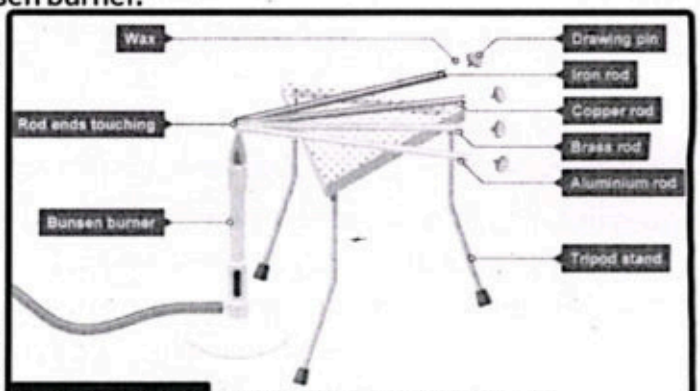


FIGURE 10.8 Good and bad conductors

Method: The following procedure is adopted.

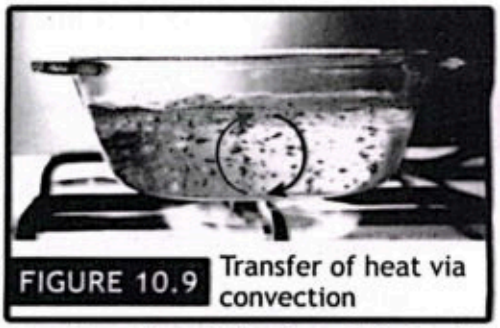
1. Apply small dots of wax at the ends of metal rods and fix the drawing pins in them.
2. Position the other end of the metal rods into a Bunsen flame. Make sure that heat can reach every metal rods in the same amount.
3. As the heat flows through metal rods, wax will melt and pin will drop. Record the time taken for the wax to melt and the drawing pin to drop off. The fastest time shows the best conductor of heat. It happens because good conductors allow heat to flow fast through them and cause Vaseline to melt soon.

Result: The drawing pin falls off the copper rod first followed by the aluminium.

Conclusion: From this we can conclude that copper conducts better than aluminium, while aluminium conducts better than iron and brass.

10.2.2 CONVECTION

When we heat water on the stove, we can see the movement of water. Water molecules at the bottom receive heat immediately. According to KMT, intermolecular forces between these water molecules decrease as temperature rises, and the distance between molecules increases. This makes the water less dense at bottom. This less dense water moves from bottom to top after taking heat energy. The dense cold water at the top sinks to fill the gap and gains heat energy. In this way, the molecules of the water move themselves to transfer heat energy due to differences in densities in two parts of the fluid.


FIGURE 10.9 Transfer of heat via convection

'The method of transfer of heat due to bulk movement of molecules in fluids is called convection'. We can also define it as "convection is the transfer of heat energy due to the transfer of fluid itself." Convection only takes place in liquids and gases. It cannot take place in solids.

Experiments: As illustrated in the figure 10.10, put some potassium permanganate crystals in the bottom of a beaker filled with water. A stream of potassium per manganate travels upward and produces a convectional current when the beaker is heated.

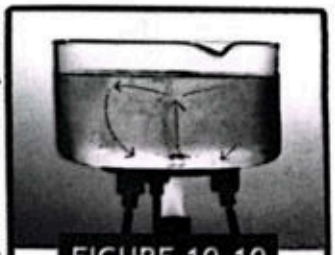


FIGURE 10.10 Formation of convectional current

Water at bottom of beaker heats up, it expands and becomes less dense. This less dense water rises up and transfer heat energy from the bottom to the top of the container. Then cold water (denser water) flows downward from the sides and replaces the hot water. This process continues and heat continuously transfers due to the continuous flow of fluid.

You can perform another experiment at home to understand the convection process as shown in figure 10.11. Take blue and red food colours. Use blue food colour to make blue colour ice cubes. Now take the water in a transparent bowl or box and put blue ice cubes on one of its sides. Add warm water on the other side. Place the ink pot filled with red food colour on the warm water side at the bottom of the container. You will see that red food colour on the warmer side will rise first and then it will move towards the cooler blue ice side. And cold water, being denser, sinks, and its left place is filled by the red colour water. This process continues and shows the transfer of heat due to the motion of molecules.

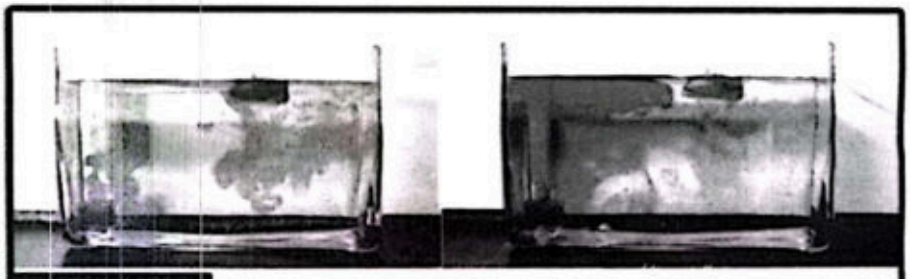


FIGURE 10.11 Colours showing flow of fluid from hot to cold regions

A. Convection and Marine Life: Convection is a crucial process that helps support marine life in the oceans. It involves the movement of seawater driven by differences in temperature and salinity across the globe as shown in figure 10.12. Salty water is denser than fresh water. In some areas, seawater becomes saltier and denser, especially where a lot of water evaporates due to hot weather.

Warm water is less dense than cold water. When the sun heats the surface of the ocean, the water at the surface becomes warmer and less dense. This warm water rises and spreads out across the surface. Cold water is denser than warm water.

While in polar regions, the seawater cools down and becomes denser, causing it to sink to ocean depths. These movements of water

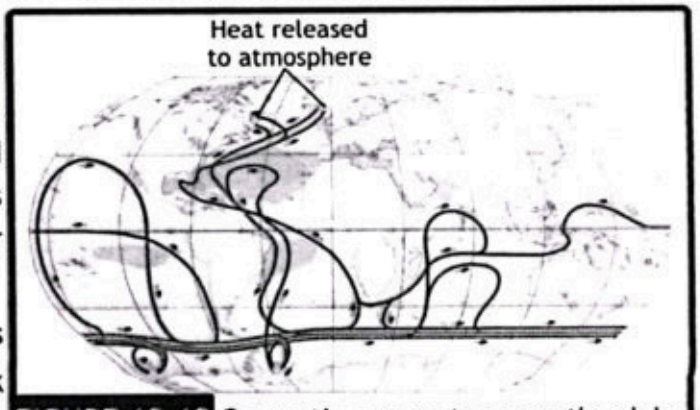


FIGURE 10.12 Convection currents across the globe

cause convectional currents. Upward movement of sea water is called upwelling and downward movement of sea water is called downwelling as shown in figure 10.13.

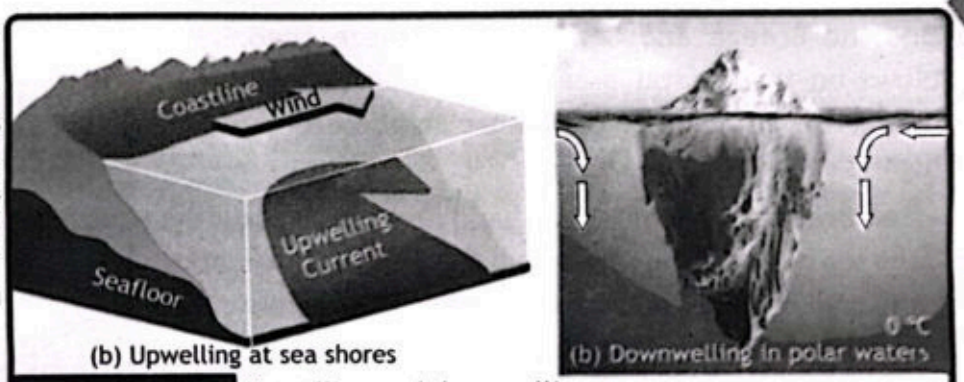


FIGURE 10.13 Upwelling and downwelling

Distribution of food: Upwelling typically occurs along coastlines where winds blow parallel to the shore. As surface water is pushed away from the coast, it is replaced by water rising from below. This deeper water is usually colder and richer in nutrients (containing nitrogen, phosphate and organic materials) as compared to the surface water. Phytoplankton (a tiny plant like organism) uses these nutrients an sunlight to grow and multiply shown in figure 10.14. Phytoplankton is food source for many marine creatures from small (zooplankton) to large (whales).

Distribution of oxygen: Marine animals, like fish nee oxygen to live. Most oxygen is dissolved in top water exposed to air. Convection causes this water to go deep into the ocean floor. Without convection, deep waters would lack oxygen, making it difficult for marine life to survive.

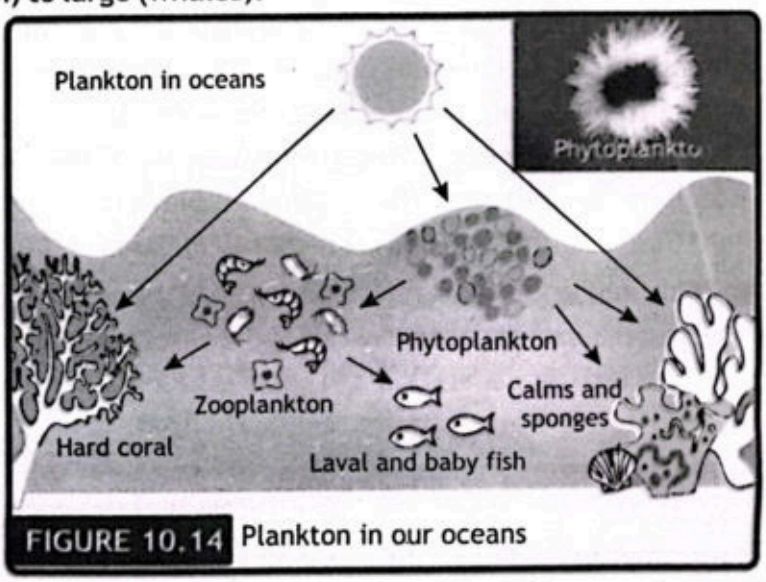
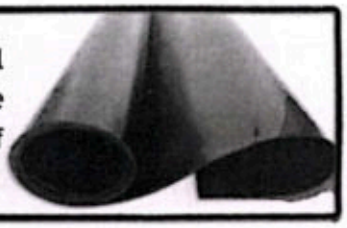


FIGURE 10.14 Plankton in our oceans

Distribution of heat: Due to upwelling warm water rises up and takes heat to top. Convection distribute heat throughout the ocean. This helps to stabilize the temperature. Also, the movement of warm and cold water around the globe effects climate patterns, which can affect the habitats of marine life.

INFORMATION

Rubber is generally a better insulator than air. Rubber has a lower thermal conductivity than air, meaning it can reduce the transfer of heat energy more effectively. Rubber has tightly bound electrons which helps to resist transfer of heat. Rubber can resist the flow of heat energy about 4-8 times better than air.



B. Land Breeze and Sea Breeze: Breeze continuously blows on the coastal areas due to convection. Breeze during the day is called sea breeze and breeze during the night is called land breeze.

- **Sea Breeze:** During the day, land heats up quickly than the sea due to its low specific heat. Therefore, air above the land becomes hot, expands and becomes less dense. This hot air above land rises up and cool air above sea moves towards the land to fill the gap.
- **Land Breeze:** At night, temperature of land quickly falls than the water (water can maintain its temperature for long time due to its high specific heat capacity). Due to this, air above the sea is hotter than the air above the land. Therefore, hot air above the water rises up and cool air from the land moves towards the sea to fill the gap.

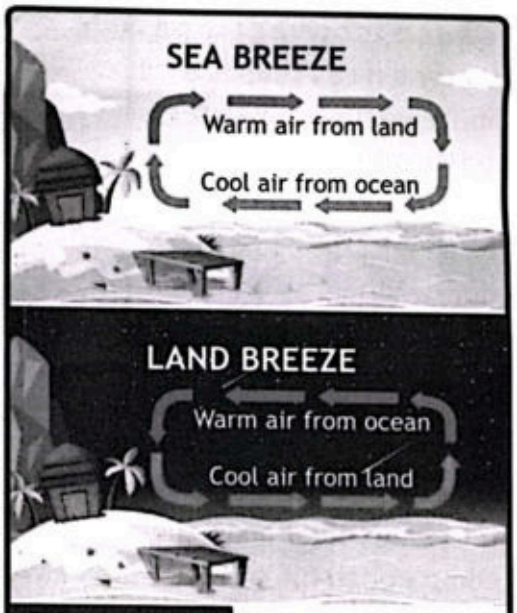


FIGURE 10.15 Sea and land breeze

These breezes continuously blow across the coastal areas and help to maintain the moderate climate there as shown in figure 10.15. These natural wind patterns help to cool coastal areas during the day and moderate temperatures at night, resulting in a more temperate and stable climate. Sea breeze carries moisture from the ocean, influencing coastal humidity and precipitation patterns. This continuous blowing of breezes exchanges gases from land to sea and sea to land (and prevents the stagnancy of gases in the region).

C. Thermal and Bird's Flight: During the day, Sun heats the land unevenly, dark and concrete structures absorb more heat than other areas like grass or water. Therefore, air above hot areas become less dense and rises from the ground. This rising hot air surrounded by the cooler air around it, forms an air column called thermal.

Birds like eagles, hawks, vultures, etc are expert thermal riders. These birds have large and wide wings. By spreading their wings and tilting them slightly upwards, they ride on this rising air (thermals) as shown in figure 10.16. To stay within the thermal in this rising air, they fly in circles. They glide between thermals and maintain their high altitude without flapping their wings for a long period of time.

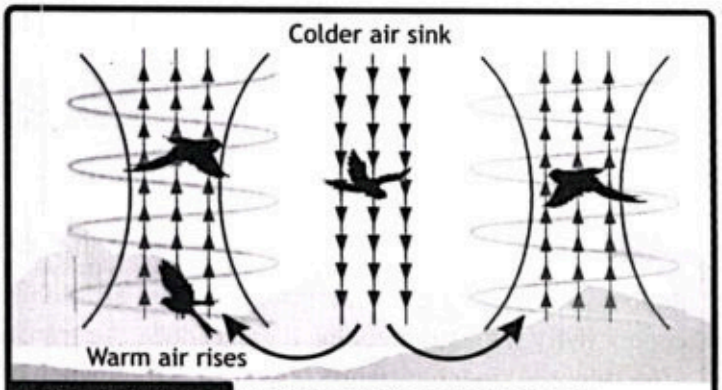


FIGURE 10.16 Motion of birds on thermals

D. Hurricanes and Cyclones: Hurricanes form over warm ocean waters. The warm water causes evaporation and this moist air rises due to convection. As it rises, it cools and forms clouds through condensation. This condensation releases latent heat which warms the surrounding atmosphere, making the air there lighter. As a result, the air continues to rise, lowering the atmospheric pressure at its surface. This decrease in pressure increases the rate of evaporation and causes more warm, moist air from oceans to move up. The Earth's rotation causes this rising air to spin, forming a cyclonic system. As the system gathers strength, it can develop into a hurricane with high wind speeds.

10.2.3 THERMAL RADIATIONS

Heat transfer through electromagnetic waves doesn't require any physical contact. For example the sun heats the Earth through radiation, and you feel warmth from a fireplace even at a distance (figure 10.17). **'The process of transfer of heat in the form of electromagnetic radiation (infra-red radiation) is called radiation'.**

Heat transfer through conduction and convection requires a medium, however heat transfer through radiation does not require a material medium. There is vacuum between the Earth and the Sun but still heat (infra-red radiation also known as IR radiation) and light reaches the Earth.

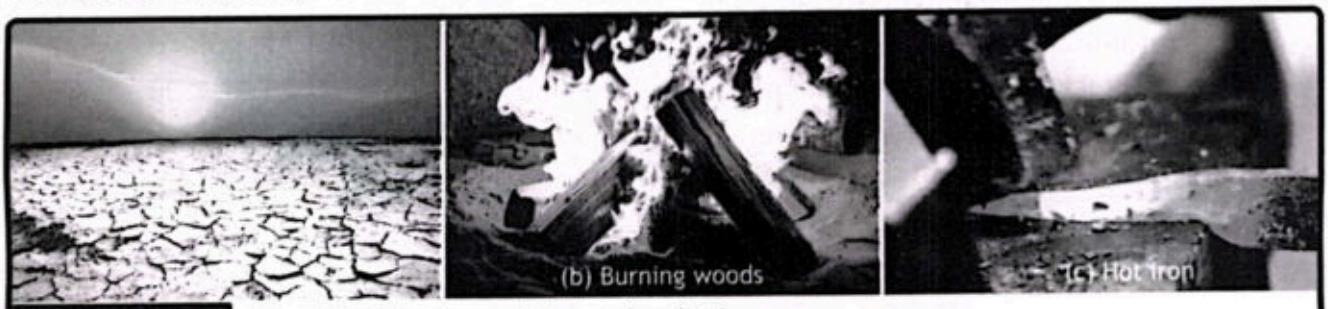


FIGURE 10.17 Examples of sources of thermal radiations

Light is the fastest entity in nature. All forms of electromagnetic radiation (figure 10.18), including heat, move at the speed of light. Therefore, radiation is the fastest method for transferring heat. Every object emits infrared radiation, but hotter objects emit a greater amount of it. For example, Sun emits large amount of radiation whereas less hot objects like human body emits small amount of radiation.

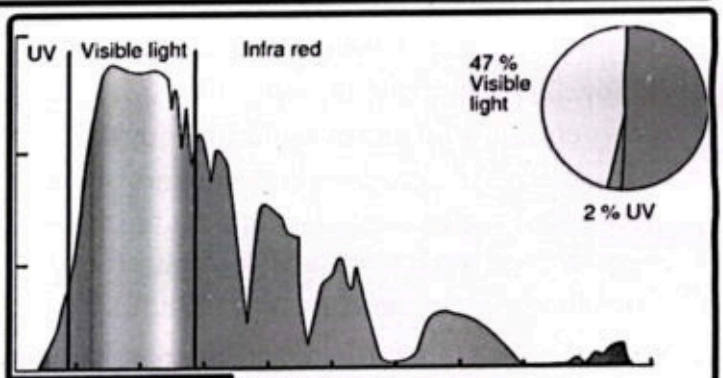


FIGURE 10.18 Solar spectra

A. Effect of Different Surfaces: All the objects absorb as well as radiate heat energy in the form of infra-red radiations. The amount of thermal radiation emitted by an object depends on different factors:

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Materials: Three identical hot water bottles, three different insulating materials (e.g., bubble wrap, foam sheet, and newspaper etc), Thermometers, Hot water

Procedure:

1. Fill the three hot water bottles with hot water (around 80°C to 90°C).
2. Wrap each bottle with a different insulating material:
   - Bubble wrap (conduction insulation)
   - Foam sheet (convection insulation)
   - Newspaper (radiation insulation)
3. Measure and record the initial temperature of the water in each bottle using a thermometer.
4. Place the bottles in a room with a consistent temperature (around 20°C to 25°C).
5. Measure and record the temperature of the water in each bottle every 15 minutes for an hour.
6. Compare the temperature changes in each bottle to see which insulating material performed best.

- **Surface colour of the object:** Different coloured surfaces have different absorption and emission abilities as shown in table 10.2. A good absorber is a good emitter, but it is a bad reflector. For example, wearing black clothes on a sunny day absorbs more heat and warms us. Black-coloured surfaces are good emitters; that's why laptop chargers are made up of black-coloured surfaces. It helps to cool it quickly. Similarly, the worst absorber is also the worst emitter, but it is a good reflector. Shiny silver surfaces are good reflectors; that's why car windscreen shades are made from silver-coloured surfaces.

Table 10.2: EFFECTS OF RADIATION ON DIFFERENT SURFACE COLOURS

Colour	Absorbing	Emitting	Reflecting
Black	Best	Best	Worst
Dull/Dark	Good	Good	Bad
White	Bad	Bad	Good
Shiny silver	Worst	Worst	Best

- **Texture of the surface:** Texture is the quality of something that can be known by touch, or the degree to which something is rough or smooth or soft or hard. Texture of a surface can be rough, bumpy, slick, scratchy, smooth, silky, soft, prickly etc. Rough, dull, and dark surfaces are good absorbers and emitters of radiation, but they are the worst reflectors. While smooth and shiny surfaces are bad absorbers and emitters of radiation, they are good reflectors. Before painting the walls of the houses, they are made smooth and usually painted white. So that they could become good reflectors and less absorbers. It helps controlling the temperature of the houses.
- **Surface area of the object:** At the same temperature, a hot body with a big surface area emits more radiation than a body with a small surface area. Therefore, heat radiators installed in houses, car radiators etc have large surface area, which helps them to radiate quickly.

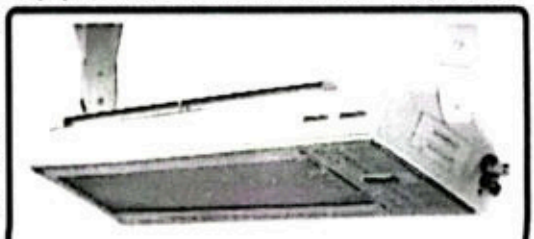


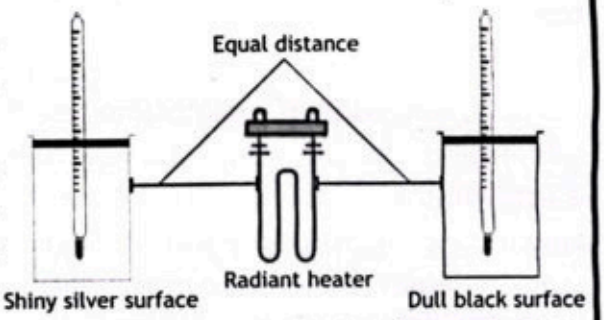
FIGURE 10.19 Infra-red heater

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Materials: Two similar cans (one can have shiny silver surface and the other is painted dull black) with lid, thermometer and radiant heater.

Procedure: Pour an equal amount of water into two cans. Place both cans at the same distance from an electric heat source. Insert thermometers into the cans as shown in the figure. There are two experiments that can be conducted with this setup:

1. Turn on the heater and after ten minutes, the water in the can with the dull black surface will be significantly hotter than the water in the other can.
2. Keep the heater off and pour boiled water into the cans. After ten minutes, the water in the can with the dull black surface will be much cooler than the water in the other can.



What can you conclude from these experiments, that which surface is a good absorber and which surface is a good reflector of heat?

For example, infrared heater (figure 10.19) that primarily emits infrared waves have large plate area so that it could radiate more heat.

B. Effect of temperature on the rate of radiation: As we know that all objects absorb as well as radiate heat. Rate of radiation emitted by an object is directly proportional to temperature of the object. High temperature objects radiate more than low temperature body. Sun has high temperature and large surface area, it emits large amount of radiation while a cooking stove has low temperature and small surface area than the Sun, it emits less amount of radiation.

When an object is absorbing more heat than radiating, its temperature will rise. When the object is emitting more radiation than absorbing, its temperature will drop i.e. it will cool down. An object will remain at same temperature if it is absorbing and radiating heat at equal rate. This state is called thermal equilibrium. A hot cup of tea is placed on table, initially its temperature is higher than its surroundings. It will be emitting radiations at faster rate. Its temperature will decrease. After a while, its temperature will reach the temperature of surroundings (i.e. it will reach thermal equilibrium).

C. Leslie cube: The Leslie cube is used to demonstrate how different surface textures affect the emission of thermal radiation. It consists of four sides having different surfaces usually they are black and white painted surfaces, a matte black or dark coloured surface and shiny metal surface. It is hollow cube with lid at its top. Hot water is used usually to heat the interior of the cube. An 'infrared (IR) thermometer' as detector is used to measure the amount of IR radiation emitted from each surface of the cube.

The experiment on the Leslie cube (figure 10.20) follows the following procedure.

1. Boiling water is added to the Leslie cube for heating it.

2. Wait until the cube reaches the desirable temperature.

3. Measure the quantity of radiation emitted from each surface by placing the IR thermometer at the same distance from each one in turn. (The infrared thermometer detects the infrared radiation emitted by each surface. Higher radiation translates to a higher temperature reading.)

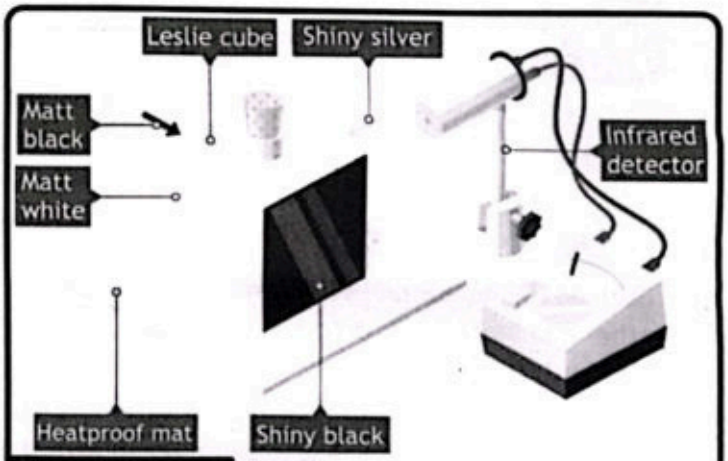


FIGURE 10.20 Different surfaces of Leslie cube

The surfaces which is better at emitting radiation show a higher temperature reading on the infrared thermometer, while the surfaces which are bad at emitting radiations have a lower reading. After performing the experiment, we can have the following conclusions:

- Black surface is the best absorber and emitter but worst reflectors.
- Dark coloured surface is good absorber and emitter but bad reflector.
- White surface is good reflector while bad absorber and emitter.
- Shiny metal (shiny silver) surface is the best reflector while worst absorber and emitter.

10.3 APPLICATIONS OF HEAT TRANSFER

A. Cooking in kitchen pan using conduction, convection and radiation: When you place a kitchen pan on a stove burner, heat from the burner conducts through the base of the pan as shown in figure 10.21. The metal of the pan absorbs the heat energy due to direct contact with the hot surface. Hot metal surface transfers the heat energy to food in contact with it by conduction. Also, this heat travels to whole surface of the pot and handle. This explains why the handles are composed of materials that are poor heat conductors, such plastic or wood.

When heating water in a pan or pot on the stove, convection currents occur. As the water near the bottom of the pan heats up, it becomes less dense and rises, while cooler water from the top sinks. This circulation helps distribute heat evenly and speeds up the boiling process.

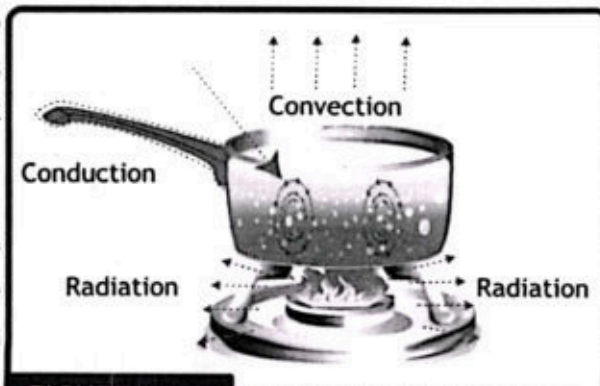


FIGURE 10.21 Heat transfer in kitchen pan

Heat from the flame also reaches the pot through radiation process. In outdoor grilling or broiling in an oven, heat radiates from the hot charcoal or heating element directly onto the surface of the metal pan through radiation. The pan absorbs the radiant heat, which then transfers to the food inside the pan. So the kitchen pans can use all heat transfer methods for cooking as shown in figure 10.22.

B. Heating a room by convection: In winter, gas heaters are commonly used in Pakistan to keep rooms warm. When a gas heater is ignited, it heats the air surrounding it. The heated air becomes less dense and rises, generating convection currents. As the hot air rises, cooler air moves in to take its place near the heater. This cooler air then gets heated by the heater, rises. The air that has risen eventually cools down becomes denser and sinks back towards the heater. This continuous cycle of hot air rising and cool air sinking creates a convection current that helps distribute heat throughout the room, gradually raising the overall temperature.

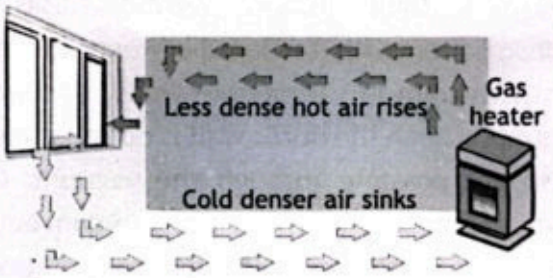


FIGURE 10.22 Heating room by convection

C. Mechanism of a household hot-water system: The most common hot water system is the storage tank water heater as shown in figure 10.23. Cold water enters your house and splits into hot and cold lines. The storage tank holds this cold water and heats it with an electric element or gas burner controlled by a thermostat. Hot water naturally rises to the top of the tank. When you turn on a hot water tap, the hot water from the top flows out. As hot water is used, cooler water from the bottom refills the tank and is reheated. This cycle keeps a steady supply of hot water available.

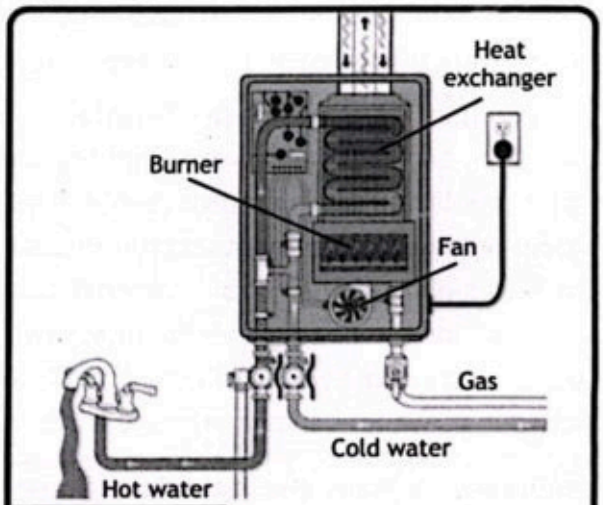


FIGURE 10.23 Household Hot-Water System

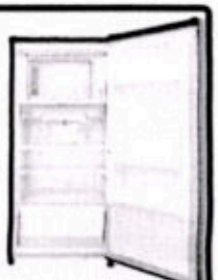
POINT TO PONDER



Why are freezer compartment at the top of refrigerator?

The freezer is located at the top of a refrigerator to take advantage of convection, the cold air from the freezer travels down and cools the bottom of the refrigerator. The warm air from the bottom rises and gets cooled again in the freezer.

Also the freezer is placed above the hot compressor, which is usually located near the bottom of the refrigerator.



D. Maintaining Liquid Temperature: Wrapping an insulator around a hot object or around a hot/cold liquid containing object can reduce the flow of heat. This property of insulators helps to maintain the temperature of liquids. This property of insulators is used in thermos flasks (also called vacuum flask) as shown in figure 10.24. Thermos flasks has double walled construction with vacuum between its inner and outer walls. With vacuum in the double walls, conduction of heat of the liquid through the outer wall is not possible. Transfer of heat is also not possible through the vacuum. Convection requires movement of air for heat flow, so convection currents cannot produce. Some heat is lost due to radiation. To minimize heat loss due to radiation, inner walls of the flasks are silvered. This reflects a significant portion of the radiant heat back towards the liquid inside, minimizing heat loss. Some of the heat can flow out due to conduction from the material of the flask and from the lid. Therefore, interior of the thermos flasks are now made up stainless steel which has low conductivity and lids are made up of plastic which usually trap air for better insulation.

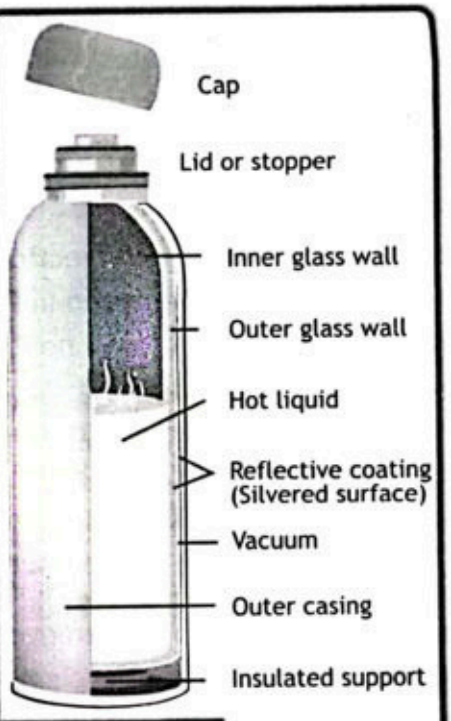
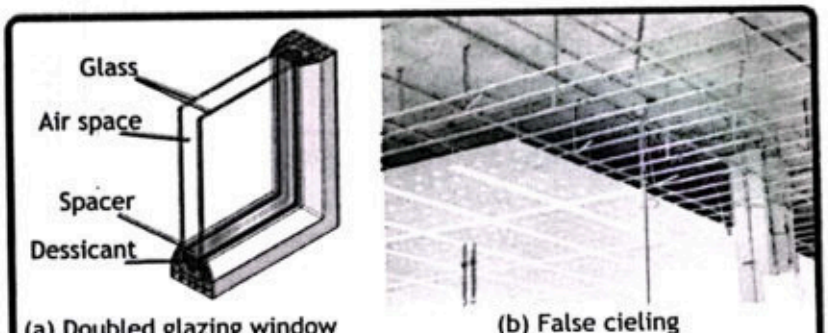


FIGURE 10.24 Thermos flask

E. Reducing Thermal Energy Transfer in Buildings: We can maintain comfort improve energy efficiency and reducing heating and cooling costs by proper thermal insulation in our homes and other buildings. Thermal insulation in winters, slows down the heat loss from warm interior to colder outside environment and it reduces the need of heating systems. In summer, it slows down the heat gain from the hot outside environment to the cooler interior, keeping the building cooler and reducing the need for air conditioning. Thermal insulation can be achieved in many ways. To reduce the conduction and convection, use double wall glazing windows with vacuum or air between its walls as shown in figure 10.25 (a), use foam etc in the gaps on the walls or doors. False ceiling which traps the air acts as insulation between the roof and the ground as shown in figure 10.25 (b), using thick curtains etc. Proper orientation of the home and shading during the summer reduce the heat entering the home. Proper ventilation also help to reduce temperature inside the home during summer.



(a) Doubled glazing window (b) False cieling

FIGURE 10.25 Reducing thermal energy transfer

F. Measuring Temperature with Infrared thermometers: In this chapter, we have studied that all objects emit heat radiations in the form of infrared radiation. These are not visible but we can sense them because they carry heat. Heat coming from the Sun, heaters or hot plates etc have infrared radiations in large amount. It is this heat that the infrared thermometers detect to measure the temperature of objects.

When it is unsafe or impracticable to make direct physical touch, infrared thermometers are used. For example, during the Corona Pandemic, infrared thermometers were routinely used. They are also used to determine the temperatures of highly hot surfaces, such as those found in furnaces, industries, food storage facilities, and hazardous places, such as those containing radioactive materials etc. Infrared thermometers can be utilized as:

1. Carefully read the instructions on the device manual.
2. Power on infrared thermometer and adjust its scale (degree Celsius or degree Fahrenheit).
3. Point the thermometer sensor to the target surface. Hold the thermometer steadily at a suitable distance mentioned in the manual as shown in figure 10.26.
4. Press and hold the trigger (a button) until the reading on the display screen stabilizes.
5. Once you hear a beep or see a stable reading on the display screen, release the trigger and note down the temperature.



FIGURE 10.26 Infrared thermometer

The following precautions should be maintained while using infrared thermometer.

1. Each infrared thermometer has a distance-to-spot (D:S) ratio. This ratio tells you the diameter of the target area (whose temperature is to be measured) relative to the distance from the target. For example, a D:S ratio of 12:1 means that for every 12 units of distance from the object, the thermometer will measure a spot with a diameter of 1 unit. So, if you hold the thermometer 12 inches away from the surface, it will measure temperature of the circle roughly 1 inch in diameter.
2. Avoid taking measurement of the small objects, moving objects, wet objects, reflective surfaces and rough surfaces.
3. Keep comparing its accuracy, off and on, with the mercury thermometer.

10.4 GREEN HOUSE EFFECT AND GLOBAL WARMING

Just like all objects, Earth also absorbs and emits radiations. Earth absorbs theses high energy radiations and emits low energy radiations back in the atmosphere. But water vapours, carbon dioxide, methane and other greenhouse gases forming atmosphere absorb these heat radiations emitted by the Earth and re-emit back to the Earth. Due to this, Earth warms which is necessary

for life to sustain on it. This is called greenhouse effect. If Earth had no atmosphere, it would have emitted all the absorbed radiations and its temperature would have drop to -180 °C at night (equal to temperature of Moon at night). At such low temperature, life would not have existed at the Earth.

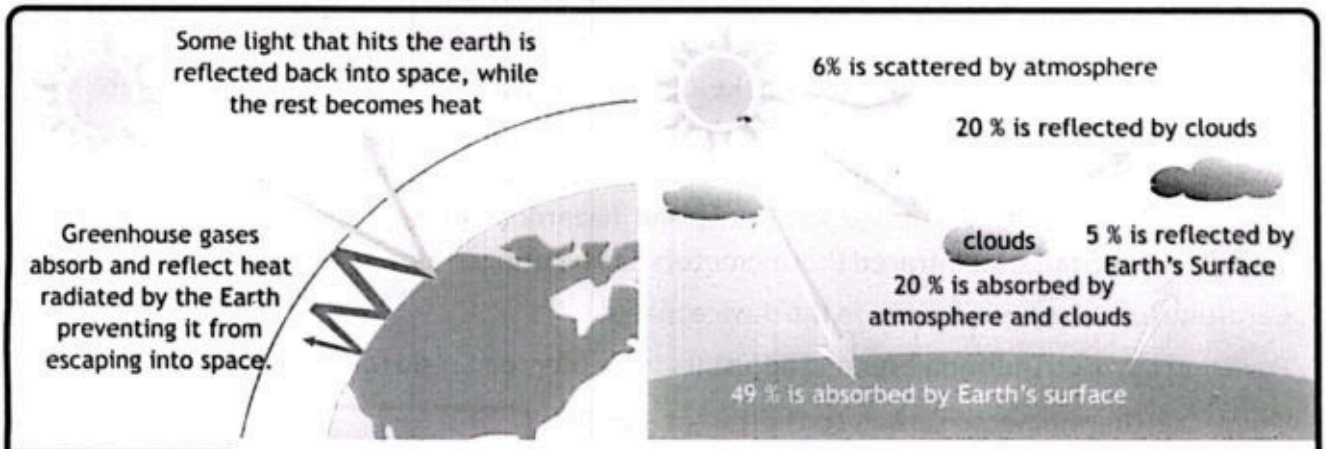


FIGURE 10.27 Trapping heat by greenhouse gases in the atmosphere

Human activities like burning of fossil fuels (coal, wood, oil and natural gas), large number of vehicles on roads generating smoke, many industrial and agricultural activities (producing methane and nitrogen oxide) and deforestations (which reduces the number of trees that can absorb carbon dioxide) have increased the concentration of greenhouse gases in the atmosphere.

Due to this amount of thermal radiation, trapped by the greenhouse gases, have increased. This has increased the Earth's average temperature. This gradual increase in the temperature of Earth's atmosphere and oceans is called **global warming**. This higher temperature is affecting our ecosystem, weather pattern (e.g. duration of season is changing) and human health. Due to global warming, we are facing effects like flooding, hurricanes, extreme rainfall, droughts etc. Let's discuss their causes:

A. Flooding: This increased temperature of the Earth is causing fast melting of glacier, which is increasing the sea levels. Rising sea levels is a threat to coastal area life as it is increasing flooding and erosion of land.

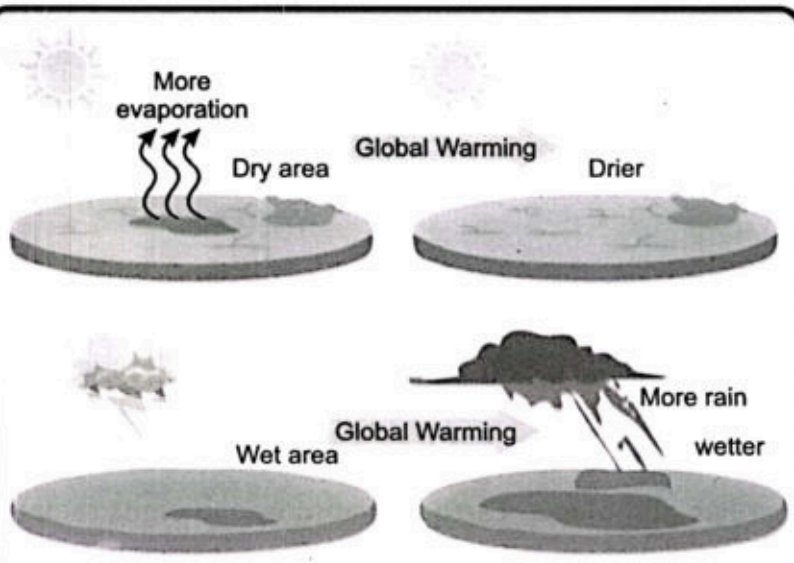


FIGURE 10.28 Droughts and extreme rainfalls

POINT TO PONDER



Climate models predict that by 2050, global fires could increase by 19% compared to 2015. Why is this happening?

There are three main reasons for increase in global fires:

1. Hotter, Drier Conditions: A key factor is rising temperatures. A warmer climate means more evaporation, leading to drier soil and vegetation. This creates more flammable fuel for fires to spread quickly.

2. Longer Fire Seasons: As temperatures rise, the window for hot and dry weather - prime fire season - gets longer. This extends the period when wildfires are most likely to ignite and spread.



3. Changes in Precipitation Patterns: Rainfall patterns are also predicted to shift due to climate change. Some areas may experience less rain, further exacerbating drought conditions and increasing fire risk.

B. Hurricanes: Global warming heats up the oceans, giving hurricanes more energy. This makes them stronger with faster winds and heavier rain. Warm air can hold more moisture, so hurricanes can drop even more rain.

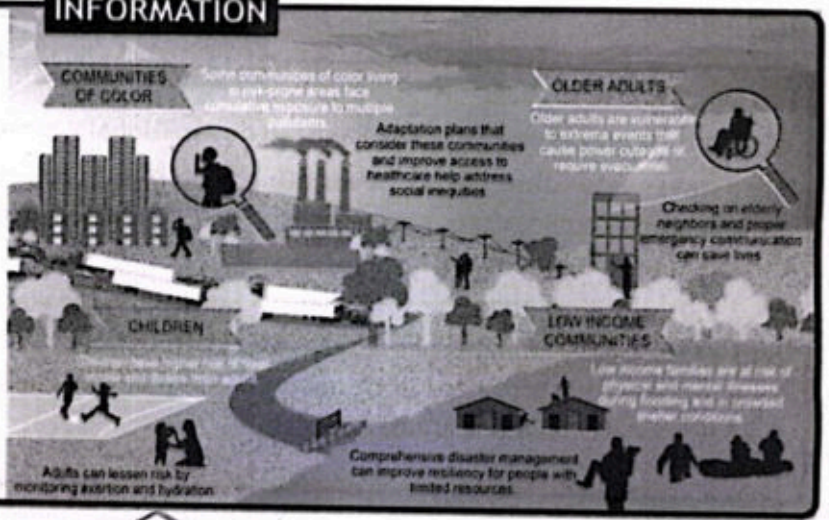
C. Rainfall: Rising temperature due to global warming have increased evaporation, causing greater moisture in the atmosphere and resulting in more intense rainfall in the area that already experience significant rainfall.

D. Droughts: Due to greater evaporation rate, water in soil and plants is decreasing. It is causing the land to get drier and making it harder for plants to acquire enough water to grow healthily.

E. Wildfires: Increased temperatures due to global warming are drying out more trees, vegetation, and bushes, increasing the amount of fuel available for fires. If a fire starts due to lightning or human activity, it can quickly spread over a large area, becoming uncontrollable. This results in huge amounts of smoke, significantly decreasing air quality.

INFORMATION

The image shows communities at higher risk to health issues related to climate change and Possible remedies. Dark text shows steps that can be made to reduce the dangers that those communities face, while white text highlights such risks.

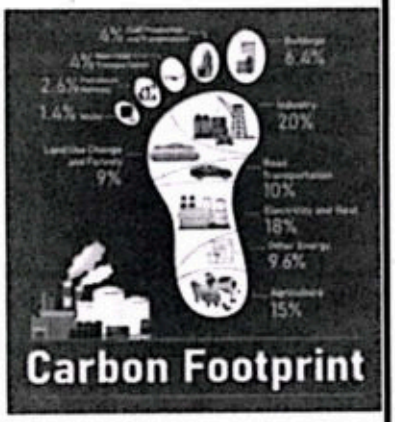


MINI LAB

Activity: Carbon Footprint of Daily Transportation

Carbon Footprint: A carbon footprint measures greenhouse gas emissions from activities like fossil fuel burning, deforestation, and industrial processes. It can be reduced by unplugging devices, using energy-efficient technologies, and adopting renewable energy sources.

Ecological Footprint: The ecological footprint measures the resources needed to support a lifestyle, including land, water, and waste absorption. A larger footprint means higher environmental impact, so reducing it helps protect the planet.



Activity: We can estimate carbon footprints using simple calculations. For example, a car emits approximately 0.2 kg of CO_2 per kilometre travelled. If a student travels 5 km to school every day by car, he can calculate his daily carbon emissions from transportation as:

Daily CO_2 emission = 5 km × 0.2 kg CO_2/km = 1kg CO_2/day

Then, calculate for a week (assuming 5 days per week of school):

Weekly CO_2 emission = 1 kg/day × 5 days = 5 kg CO_2/week

Class Activity: All students of the class are asked to calculate the carbon footprint of their own daily transportation and compare results with classmate. Discuss actions to lower your carbon footprint?

F. Winter Storms: Winter storms are events like snow, sleets and freezing rains with strong winds. Due to increased moisture in atmosphere results in heavier snowfall in winters.

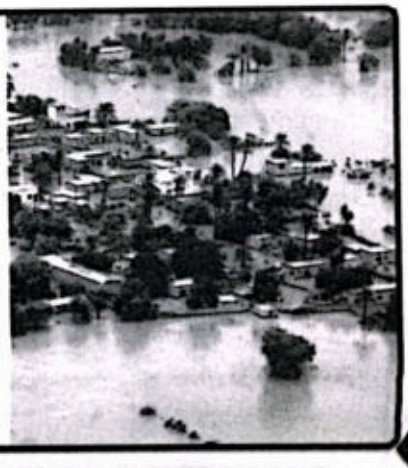
We have to take steps to fight the effects of this global warming. We have to stop deforestation and increase forestation on the globe which are natural carbon dioxide absorbing source. This can reduce the about of carbon dioxide in the atmosphere. We have to find such energy efficient sources which releases no or minimum greenhouse gases. Beside this, we have to adapt with this global warming conditions as well. Make resilient infrastructure which could sustain the extreme weather events.

INFORMATION

Recent Heat waves and Floods in Pakistan due to Global Warming

Heat-waves May- June 2022: Devastating heatwave gripped Pakistan and India with temperatures exceeding 51°C (123.8°F). Scientists linked this event to global warming.

Devastating Floods 2022: Severe monsoon rains and rapid glacial melt, both influenced by climate change, caused disastrous floods in the whole country, especially provinces Sindh, major areas of Khyber Pakhtunkhwa and Balochistan, and some areas of Punjab.



10.5 FLOW OF HEAT IN GEOTHERMAL ACTIVITIES

The structure of the earth is divided into three parts; core, mantle, and crust as shown in figure 10.29. The **core** is the central part of the earth. It is the hottest part. Its temperature is about 6000 °C. It is mainly composed of iron and nickel. The core is so hot due to different factors, involving left-over heat during the formation of the earth, radioactive decay of elements like uranium and thorium inside the core, and extra pressure applied by the earth's gravity. The inner core is the portion of the core that is solid. The core's solid form is maintained by the extreme pressure. The molten portion of the core is referred to as "the outer core". It is molten because the core's pressure has dropped. Temperature of the outer core is about 4000 °C. The mantle lies between core and crust. It is the thickest part. It floats on the outer core. It is composed of the silicate minerals mainly containing iron and magnesium. It is solid but shows plasticity (permanent change in shape of solid material) under high pressure due to gravity. The **crust** is the outer part of the earth's structure. It is composed of silicate materials. It is divided into continental crust and oceanic crust. The **lithosphere** is the layer between the crust and the upper mantle. The **asthenosphere** lies just beneath the lithosphere and plays a critical role in plate tectonics. **Magma** is molten or partially molten rock located beneath the Earth's crust. It forms from the partial melting of the mantle and crust due to various geological processes.

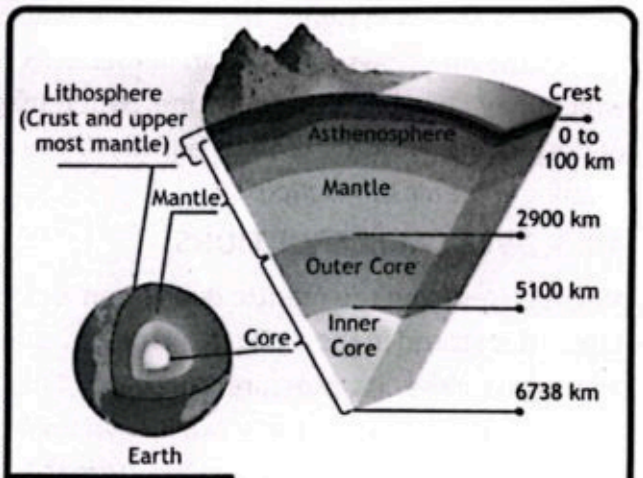


FIGURE 10.29 Earth's structure

10.5.1 FLOW OF MAGMA BENEATH THE EARTH

There is extremely high temperature around 2,000 °C to 6,000 °C between core to crest. This intense heat within the mantle can cause some solid rock to partially melt, forming magma. This molten material i.e. magma is less dense than the surrounding solid rock. Heat is transferred from core to mantle through conduction as there is temperature difference between core and mantle. In

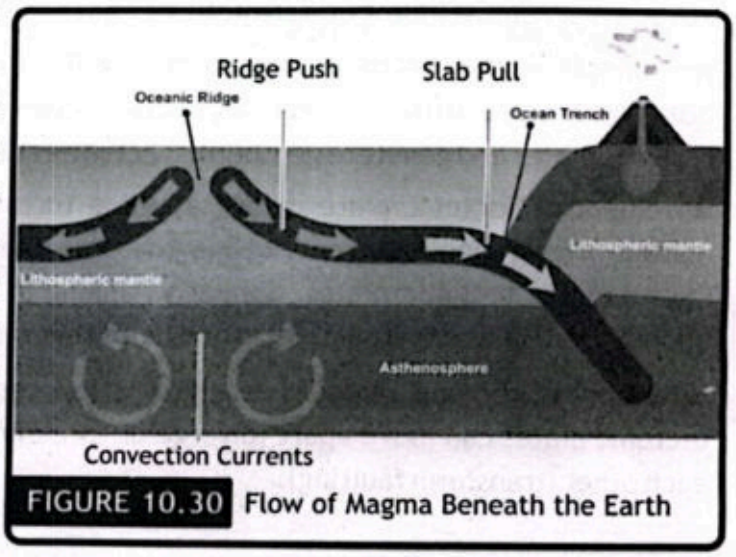


FIGURE 10.30 Flow of Magma Beneath the Earth

the mantle, magma gets heat, becomes less dense and rises up i.e. it transfers heat through convection. Hot magma rises up and cold magma sinks. This process develops convectional current as shown in figure 10.30. In this way, magma flows from bottom of mantle towards crust. Hotter magma flows easily than colder one. When magma flows, it melts the rocks on the way which may change its composition. When magma cools down, it solidifies and forms rocks deep underground. If magma finds a path to the surface through vents or fissures, it erupts as lava, shaping volcanic landscapes.

10.5.2 VOLCANIC ERUPTIONS

Magma rises from the mantle due to convectional currents and pressure difference in mantle and crust. It is stored in the crust at the place, called magma chamber.

As magma rises, its pressure decrease. This allows the dissolved gases such water vapor, carbon dioxide, and other volatiles to release and it increases the internal pressure of the magma chamber. When this pressure exceeds the strength of the covering rock, magma fractures it and creates pathways (main and secondary vents) for itself to reach the crust. This leads to a forceful volcanic eruption through crater (main opening), driven by high-pressure gases and magma as shown in figure 10.31. The hot magma that flows out during an eruption is called lava. Volcanic eruption depends upon factors like magma composition, temperature, amount of gas and interaction with water etc.

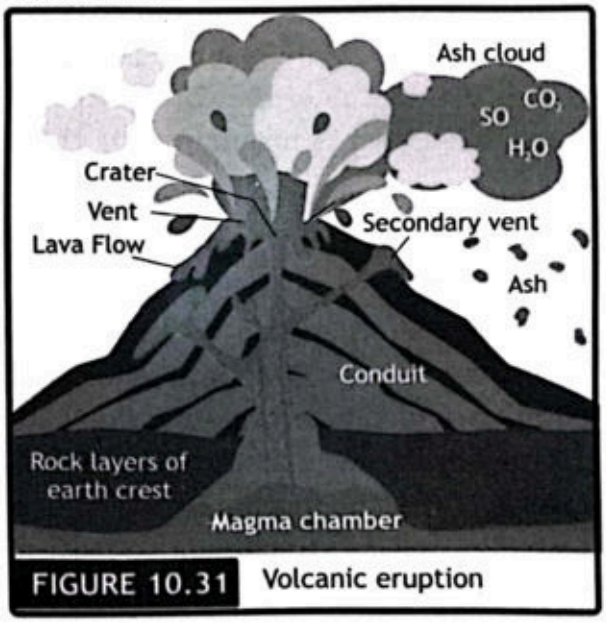


FIGURE 10.31 Volcanic eruption

10.5.3 MOVEMENT OF TECTONIC PLATES

Tectonic plates are very large, rigid parts of the Earth's crust and upper most mantle. These plates float on the molten mantle (semi-fluid asthenosphere). These tectonic plates interact with other tectonic plates and generate geothermal activities like earthquakes, volcanic eruptions etc.

Movement of Tectonic plate is basically due to the process of magma convection current in mantle. Convectional currents of magma drag the plates along with it and cause horizontal movement in tectonic plates. Similarly, sinking of dense and cold magma due to convection applies a pull on the tectonic plates and helps them to move as shown in figure 10.32.

Movement of tectonic plates is very slowly, few centimeters per year. Due to their movement, tectonic plates can move apart (diverge or spreading), come together (converge), or slide past each other (transform faulting).

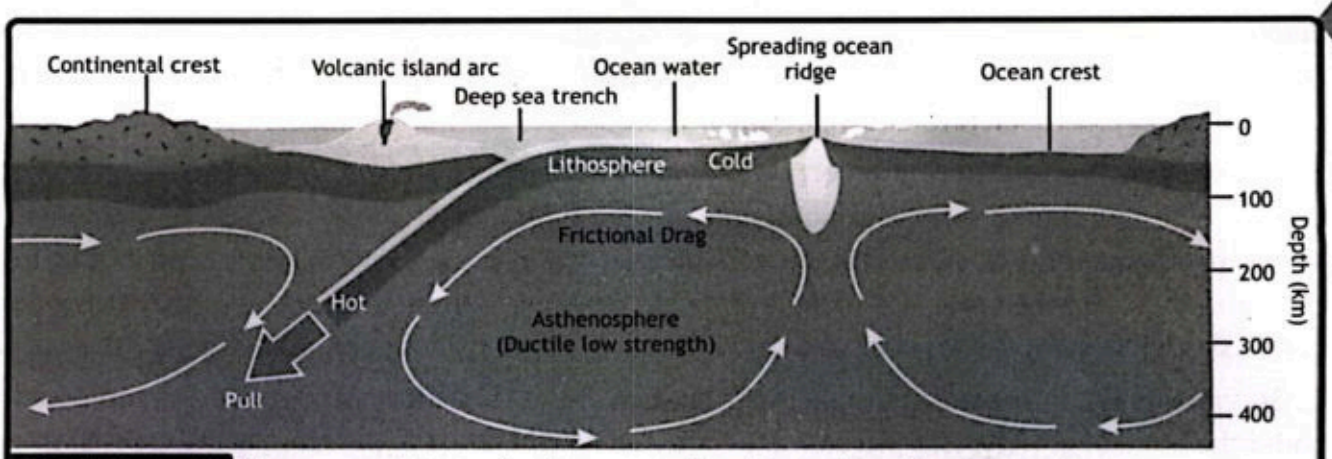
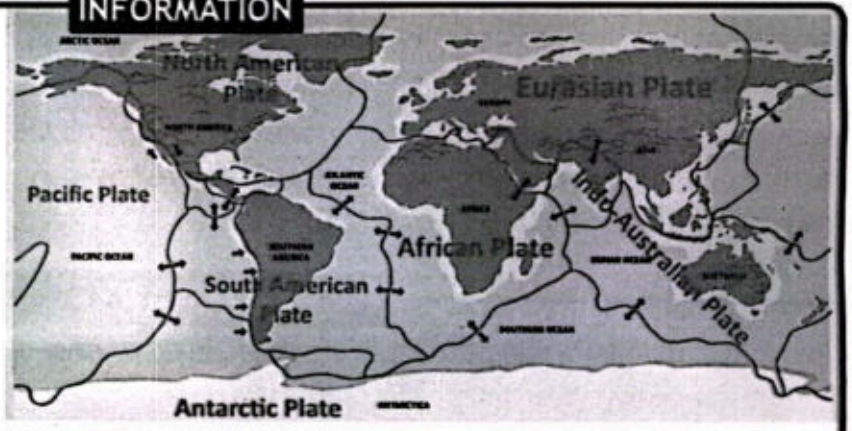


FIGURE 10.32 Movement of tectonic plates caused by the motion of magma

INFORMATION

There are seven major tectonic plates:



1. Pacific Plate
2. North American Plate
3. South American Plate
4. Eurasian Plate
5. African Plate
6. Indo-Australian Plate (It is considered as two separate tectonic plates i.e. Indian plate and Australian plate)
7. Antarctic Plate

Apart from these there are eight minor plates (Arabian plate, Caribbean plate, Indian plate etc.) and many micro plates (Rivera Plate, Somali Plate etc.) as well.

10.5.4 EARTH'S CORE MAINTAINING ITS TEMPERATURE

Scientists believe that Earth's formation involved accretion, where gravity pulls matter together to create celestial bodies. After the Sun formed, gravity combined dust, rocks, ice, and gases to form massive objects like Earth. According to the Giant Impact Hypothesis, a planet named Theia collided with Earth about 4.4 billion years ago, resulting in the destruction of Theia. the partial melting of Earth and the scattering debris into space. The early atmosphere was mainly hydrogen and helium, and as the crust solidified, volcanic eruptions and asteroid impacts introduced water, water vapour, ammonia, and carbon dioxide. Over time, Earth evolved to support life. Today, the Earth's core remains extremely hot, around 6000 °C. Lets discuss different factors due to which Earth's core is maintaining its temperature.

A. Residual Heat from Formation: During the formation of the Earth (accretion process), large

number of massive objects e.g. planetesimal objects, asteroids and other massive objects collided with it. The kinetic energy from these collisions was converted into heat, large amount this heat energy has been retained in the Earth's core.

B. Radioactive Decay: There are certain radioactive elements present in the Earth's core like uranium-238 and thorium-232 and potassium-40. During decay of these radioactive elements, large amount of energy is released in the form of heat. This process is continuously contributing to the temperature of the core. Due to decay process, amount of these radioactive elements is also decreasing, that's why rate of heat generation from radioactivity has decreased slightly.

C. Gravitational Compression: During the formation of the Earth, its materials were compressed under the force of gravity. This increased the pressure and hence, temperature in the core. In this way, gravitational compression becomes a constant source of heat to the core.

D. Crust as Insulator: The Earth's outer layers act as a thick layer of insulation. This slows down the rate at which heat escapes from the core into space. So, crust helps maintain the high temperature of the core for a longer period.

Mechanisms that generate heat are gradually slowing down, allowing heat to escape from the Earth. However, this process is so slow that the core has managed to maintain its temperature for the past 4 billion years.

SUMMARY

- **Heat Capacity** is the amount of heat required to raise the temperature of any amount of substance by 1 °C or 1 K.
- **Specific Heat Capacity** is the amount of heat required to raise the temperature of one gram of a substance by 1 °C or 1 K.
- **Conduction** is the mode of transfer of heat due to direct contact of medium particles, which do not change their positions. It occurs in solids because of difference in temperatures.
- **Convection** is the mode of transfer of heat due to the motion of particles. It occurs in liquids and gases because of the density difference between different regions.
- **Radiation** is the mode of transfer of heat due to electromagnetic waves. It does not require material medium for its motion.
- **Land Breeze** is the breeze that blows from the land. It normally occurs during the night and early morning.
- **Sea Breeze** is the breeze that blows from the massive water bodies. It normally occurs during the summer and spring season.
- **Greenhouse Effect** is the process through which heat is trapped near Earth's surface by substances known as greenhouse gases.

- **Global Warming** is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning.
- **Cyclones** are large revolving tropical storms caused by winds blowing around a central area of low atmospheric pressure.
- **Hurricane** is a tropical system with winds that have reached a constant speed of 74 miles per hour or more.
- **Heat Wave** is a period of abnormally hot weather generally lasting more than two days and can occur with or without high humidity.
- **Flooding** is an overflow of water onto normally dry land.
- **Drought** is a prolonged dry period (deficiency of precipitation) in the natural climate cycle that can occur anywhere in the world.
- **Accretion** is a process in which particles of matter, such as dust and gas, gradually come together due to gravitational attraction to form large objects, like planets, moons etc.
- Debris refer to the fragments rock, dust and other material that were scatteredd into space as a result of collision between Theia an Earth.
- **Geothermal Activity** is a group of natural heat transfer processes, caused by the presence of excess heat in the subsurface of the affected area, occurring on Earth's surface.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. Why is water used in radiators of automobile as coolant?
   A. It is easily available
   B. It is low cost or free
   C. It has large specific heat
   D. It has oxygen
2. Which of the following situations is the best example of conduction?
   A. A metal spoon becomes hot when placed in boiling water
   B. Warm air rising near a heater
   C. Sunlight warming the surface of the Earth
   D. A microwave oven heating food
3. Which combination of heat transfer methods would be dominant when you place your hand near, but not touching, a fire?
   A. Conduction and radiation
   B. Convection and conduction
   C. Radiation and convection
   D. Conduction and insulation
4. What is symbol and what is unit for the heat capacity of an object?
   A. $J\,°C^{-1}$
   B. $J\,kg^{-1}\,K^{-1}$
   C. $J\,kg\,K^{-1}$
   D. $J\,kg^{-1}\,K$
5. If the same amount of heat energy is supplied to equal masses of water and copper, why does the temperature of copper increase faster?
   A. Copper has a lower specific heat capacity
   B. Water is a poor conductor of heat
   C. Convection in water dissipates heat energy quickly
   D. Radiation from water is stronger
6. The transfer of heat that takes place because of density difference in fluids is
   A. Conduction
   B. Radiation
   C. Convection
   D. Insulation
7. Which of the following statements best explains why the Earth experiences more heat from the Sun than the Moon, despite being almost the same distance away?
   A. Earth is better conductor than the moon
   B. The Earth has greenhouse gases
   C. The Moon reflects most of the Sun's radiation
   D. Moon traps heat effectively
8. Dull black colour on a surface is the best absorber of radiation, which of the followings is the best radiator?
   A. Dull black surface
   B. Shining silver surface
   C. Red Coloured Surface
   D. White surface

9. How does the enhanced greenhouse effect contribute to global warming?
   A. It increases the Earth's ability to reflect solar radiation
   B. It traps more heat in the Earth's atmosphere, raising global temperatures
   C. It blocks ultraviolet rays from entering the atmosphere
   D. It increases the Earth's rotation speed, causing heat buildup
10. What is the primary driving force behind the movement of tectonic plates?
   A. Gravitational pull of the Moon B. Solar radiation
   C. Mantle convection currents D. Magnetic field of the Earth
11. Which layer of the Earth is composed of partially molten rock that can flow slowly?
   A. Lithosphere B. Asthenosphere C. Mesosphere D. Outer core
12. Which of the following extreme weather events is most directly associated with rising sea levels?
   A. Tornadoes B. Wildfires C. Hurricanes D. Earthquakes

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. This AI-generated image illustrates global warming caused by the greenhouse effect and its impact on climate change. It shows how rising temperatures due to the greenhouse effect led to more frequent and intense heatwaves and hurricanes.

It shows how rising temperatures due to the greenhouse effect led to more frequent and intense heatwaves and hurricanes.Answer the following questions, considering the concepts mentioned above:



a. How do increased temperatures lead to more frequent heatwaves in cities?

b. How might the intensity of future hurricanes change if global temperatures continue to rise?

c. Explain what the glass roof of a greenhouse and carbon dioxide in Earth's atmosphere have in common in terms of heat and temperature.

2.This table shows the temperature of 10 g of water and 10 g of iron after being in direct sunlight for up to 60 minutes.

Time (minutes)	0	15	30	45	60
Temperature of water (°C)	25	26.2	27.5	28.8	30
Temperature of iron (°C)	25	35	45	55	65

a. Create line graphs of temperature (on the y-axis) and time (on the x-axis) for both water and iron on a graph sheet. Be sure to label the substances.

b. Based on the data in the table, which heats up quickly: water or metal?

c. Which do you think will cool more slowly: water or iron? Elaborate your answer.

d. When you boil water in an iron pot on the stove, which heats up faster: the iron pot or the water? Provide a reason for your response.

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Why should we wear dark-coloured clothes in winter and white-coloured clothes in summer?
2. In a house, geysers or water boilers are fitted on the ground floor, and still, we get warm water on the top floor without using a pump. How is it possible?
3. Where will you get more heat from the wood fire, 1 meter above the woods or 1 meter from the front of the woods?
4. Why do crowded city areas feel hotter compared to the outskirts on a hot summer day? State the reasons for this difference.
5. Why is the is the metallic handle of a door colder than the wood of the same door when touched?
6. How do trees help reduce the effects of climate change, and what could happen if forests are depleted?
7. How does gravity contribute to the Earth's core temperature?
8. Why do certain gases in the atmosphere trap more heat than others?
9. What are the potential environmental impacts of extraction of geothermal energy?
10. How does the specific heat capacity of different materials affect their use in cookware?

11. Water at 20°C is sent deep underground into heated layers, where it turns into a mix of steam and hot water at 100°C. As the steam and hot water cool back down to 20°C, why does 1 kg of steam release more energy than 1 kg of hot water?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Explain the concept of specific heat capacity in matter. Discuss various applications of water based on its high specific heat capacity.
2. What is conduction, and how is it explained by the kinetic theory of solids? What makes metals better conductors than other solid substances.
3. Analyze how heat is transferred through convection. Provide at least three practical examples of how convection is used in daily life.
4. Analyze the process of heat transfer through radiation, explaining why it is the fastest method of heat transfer. What factors influence the rate of heat transfer by radiation?
5. Analyze the role of greenhouse gases in global warming. How does global warming contribute to the increased severity of hurricanes, heat waves, flooding, and droughts?
6. Why Earth's core has extreme high temperature even after 4 billion years? Explain in detail.
7. How are tectonic plates formed, and what factors cause them to move? Explain these causes in detail and discuss the effects of plate movements.

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Convert specific heat of water 4180 J kg^{-1} K^{-1} into units of J g^{-1} $°C^{-1}$.

(Ans. 4.18 J g^{-1} $°C^{-1}$)

2. Calculate amount of heat given to 25 kg of water to increase its temperature by 50 °C.

(Ans. 5.25 MJ)

3.. A half kg block of an unknown metal is heated from 30 °C to 80 °C, requiring 19 kJ of heat energy. (a) Calculate the specific heat capacity of the metal. (b) If the same metal block is heated from 80 °C to 125 °C, how much additional heat energy would be needed?

(Ans. 760 J $kg^{-1}K^{-1}$, 17.1 kJ)

4. Calculate the change in temperature of 5 litre of water if it absorbs 8.4 MJ of heat energy? (Use Specific heat of water = 4200 J kg^{-1} K^{-1})

(Ans. 400 °C)

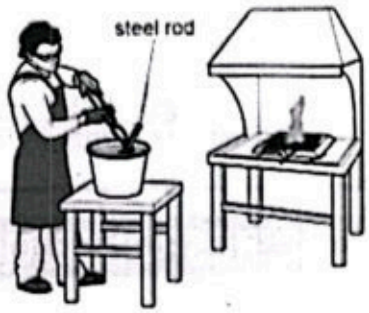
5. In a container, 100 g of water at 80 °C is mixed with 200 g of water at 20 °C. What will be the final temperature of the mixture, assuming no heat loss to the surroundings (and container)? (Use specific heat capacity of water is 4200 J kg^{-1} K^{-1} or 4.2 J g^{-1} K^{-1}).

(Ans. 40 °C)

6. A 200 g piece of an unknown solid cylinder is heated to 110 °C and then placed into a calorimeter containing 200 g of water at 20 °C. The calorimeter has a mass of 60 g and specific heat capacity of 0.9 J/g °C. The final temperature of the system (solid, water, and calorimeter) is 35 °C. Assume no heat is lost to the surroundings. Calculate the specific heat capacity of the solid.

(Ans. 890 J kg^{-1} K^{-1} or 0.89 J$g^{-1}K^{-1}$)

6. A hot steel rod is cooled by plunging it into cold water, as shown in Fig. The steel rod has a mass of 3 kg and is initially at a temperature of 450°C. It cools to 50°C when placed in the water. The specific heat capacity of steel is 460 J kg-1°C-1. Calculate the thermal energy (heat) lost by the steel rod as it cools to 50°C.



(Ans. 552 kJ)

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-C-04] Use the terms for the changes in state between solids, liquids and gasses.
- ✓ [SLO: P-10-C-05] Explain thermal expansion in terms of kinetic theory.
- ✓ [SLO: P-10-C-06] Analyze the applications and consequences of thermal expansion in real life.
- ✓ [SLO: P-10-C-07] Analyze melting, solidification, boiling and condensation in terms of energy transfer without a change in temperature.
- ✓ [SLO: P-10-C-08] State the melting and boiling temperatures for water at standard atmospheric pressure.
- ✓ [SLO: P-10-C-09] Describe qualitatively the thermal expansion of solids.
- ✓ [SLO: P-10-C-10] Explain the thermal expansion of liquids.
- ✓ [SLO: P-10-C-11] Analyse the pressure and the changes in pressure of a gas in terms of particles.
- ✓ [SLO: P-10-C-12] Differentiate between boiling and evaporation.
- ✓ [SLO: P-10-C-22] Describe evaporation in terms of particles.
- ✓ [SLO: P-10-C-23] Analyze how temperature, humidity, surface area and air movement over a surface affect evaporation.
- ✓ [SLO: P-10-C-24] Explain how evaporation causes cooling.
- ✓ [SLO: P-10-C-25] Describe the use of cooling caused by evaporation in the refrigeration process without using harmful CFCs.
- ✓ [SLO: P-10-C-26] Explain latent heat.
- ✓ [SLO: P-10-C-27] Justify experiments to determine latent heat of fusion and latent heat of vaporization of ice and water.
- ✓ [SLO: P-10-C-28] State that certain materials, when cooled to near absolute zero, can exhibit superconductivity.
- ✓ [SLO: P-10-C-29] Describe superconductivity.

Have you ever wondered why there are gaps in train tracks or why a cold bottle sweats? The answer lies in the relationship between temperature and matter. This chapter explores how heat affects particle movement, leading to phenomena like expansion, evaporation, and superconductivity.

We will begin with the kinetic theory of matter, examining how temperature influences particle motion and material properties. Then, we will look at thermal expansion, noting how solids and liquids expand with heat. Next, we will discuss state changes, including condensation, sublimation, and evaporation, along with latent heat. Finally, we will explore superconductivity, where certain materials lose no energy at very low temperatures. Let's explore these interesting thermal properties of matter!

11.1 KINETIC THEORY OF MATTER

In the previous class, we studied matter and its properties with help of kinetic molecular theory of matter. Let's revise some of their properties. Matter exists in three fundamental states: solid, liquid, and gas. Matter consists of particles (atoms and molecules). Gaps between these particles are the main reason that divides the matter into three states as shown in figure 11.1. Particles of matter apply attractive forces to each other. The difference in strength of this force is the reason for smaller or larger gaps between particles. The greater the strength of the attractive force between particles, the smaller the distance between them and vice versa.

Solids: In solids, particles are close to each other, and they have a high density. There is a strong, attractive force between particles, which keeps them closely packed. Particles in solids can only vibrate about their mean position. When a solid absorbs heat, the vibrational kinetic energy and amplitude of the vibration of its particles increase. These particles push each other away and increase the gap between them. This is how solids expand upon heating.

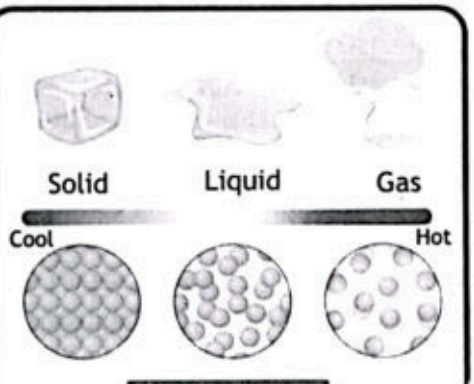


FIGURE 11.1
Effect of temperature on distance between particles of matter

Liquids: A liquid has intermediate density (smaller than a solid and higher than a gas). The attractive force between its particles is stronger than that of gases but weaker than that of solids. Due to it, the distance between particles in liquids is greater than that in solids. Liquid particles keep changing their position. Liquid particles flow. When a liquid is heated, attractive force between particles decreases and particles start moving.

Gases: In gases, there is negligibly weak attractive force between gas particles. Due to weak attractive force, distance between particles is larger as compared to the size of the particles. Particles are in constant random motion and they constantly colliding with each other and with

the walls of the container. Due to collisions of gas particles with container, they exert pressure. Gases are less dense than liquids and gases. When gases are heated, kinetic energy of gas molecules increases. They move faster and expand quicky. Figure 11.1 shows the change in distances between the particles of different states of matter due to change in their temperature.

11.1.1 CHANGING STATES OF MATTER

Figures 11.2 shows the change in state of ice (solid) into water (liquid) and then into water vapours (gas) with increase in its temperature. Attractive forces among particles of matter usually decrease with increase in temperature.

As we now know that temperature of matter effects the attractive forces between its particles. Pressure on matter also effects the phase changes of matter. Particles of liquids and gases come close to each other on increasing the pressure on them and vice versa.

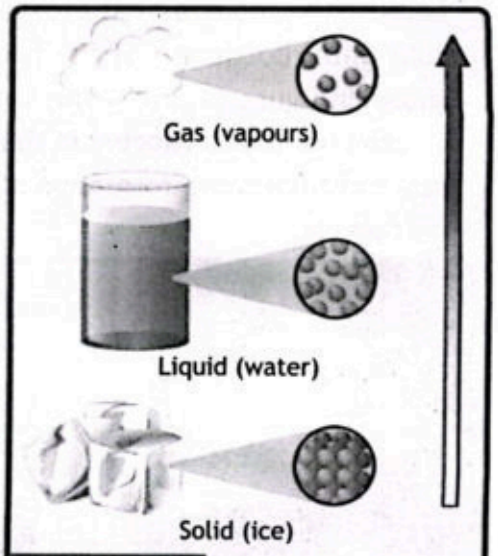


FIGURE 11.2 Phases of matter

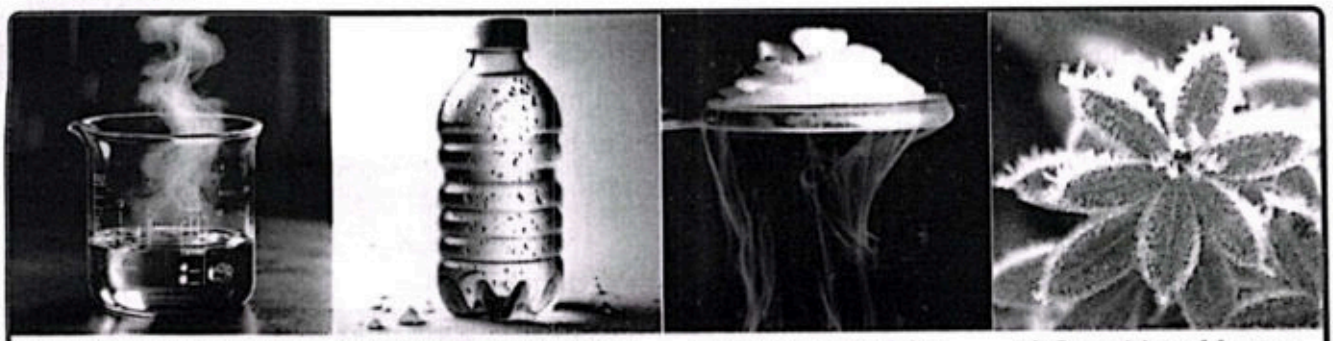
A. Changes Between Liquids and Solids: Let's discuss various phenomena involved in phase changes of matter.

- **Freezing:** It is the phenomenon in which any liquid changes into solid. When a liquid is placed at a place where its surroundings have low temperature then it loses heat to its surroundings. Its particles come close to each other and become solid at temperature called freezing point. For example, water changes into ice at 0 °C (freezing point of water).
- **Melting:** It is the phenomenon in which solid changes into liquid. When a solid is placed at a place where temperature of its surroundings is high then it absorbs heat from its surroundings. When its temperature reaches melting point, its particles overcome their bonding attractive forces and start flowing. For example, ice placed in warm surroundings melts at 0 °C. Freezing point and melting points are same.

B. Changes Between Liquids and Gases:

- **Vaporisation:** It is the phenomenon in which a liquid is converted into gas (vapours) upon boiling. When a liquid is heated, its particles gain kinetic energy. On continuous heating, their kinetic energy becomes sufficiently high that they overcome the attractive forces between them and escape from the liquid. Vaporisation is shown in figure 11.3 (a) this happens at a certain temperature of the liquid called its boiling point.

- **Evaporation:** It is phenomenon of conversion liquid into vapours at any temperature. We will discuss it in detail later in the chapter.
- **Condensation:** It is a phenomenon in which gases (vapours) change into liquids. Condensation happens in vapours where the temperature and pressure are low. Warm air can hold more moisture than cool air. When the warm, moist air cools down, the water vapours condense because the cooler air has a lower capacity to hold water vapour. For example, when you take a cold water bottle out of the fridge, you often see water droplets forming on the outside as shown in figure 11.3 (b). This happens because the cold-water bottle cools the air around it, causing the water vapours in the air to condense into liquid water on the bottles surface. Its other examples are formation of dew drops on grass, Foggy car wind screen, foggy bathroom mirrors etc.



(a) Boiling water changing into vapours | (b) Condensation of water vapours on cold bottle | (c) Sublimation of dry ice | (d) Deposition of frost on leaves

FIGURE 11.3 Changing states of matter

C. Changes Between Solid and Gases:

- **Sublimation:** It is a phenomenon in which solids change directly into gases. Its most common example is converting dry ice (solid carbon dioxide) into smoke (carbon dioxide gas) as shown in figure 11.3 (c). Dry ice is solid at extremely low temperature (-78.5 °C). When it is exposed to room temperature and pressure, its molecules overcome all the attractive forces and convert directly into gas without going into the liquid phase.

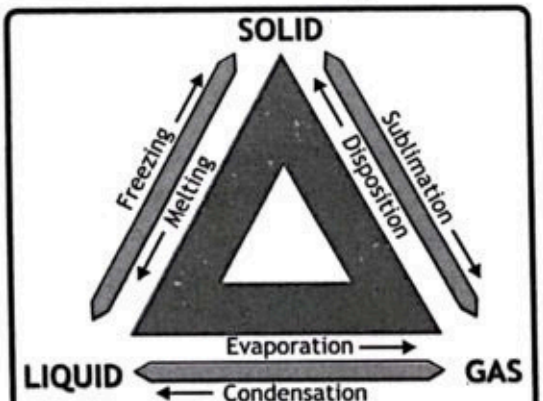
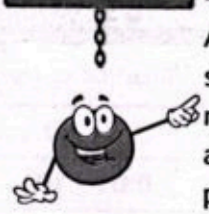


FIGURE 11.4
Change of states of matter with relating processes

- **Deposition:** It is a phenomenon in which gas changes directly to solid. Gas does not go into liquid phase during this phenomenon. It is reverse process of sublimation. Formation of frost is example of deposition. On a cold night, water vapour in the air comes in contact with surfaces like leaves or windowpanes that are much cooler than the surrounding air. The water vapor loses heat to

POINT TO PONDER



How food is preserved using deposition and sublimation?

A food preservation technique relies on deposition and sublimation to remove moisture from food or other materials. The product is frozen or frosted using deposition an then it is and placed in a vacuum chamber with very low pressure. The water in the frozen or frosted material sublimates directly into the vacuum, leaving the dehydrated product behind.



these cold surfaces, condenses directly into ice crystals forming the frost as shown in figure 11.3.

11.2 THERMAL EXPANSION

Thermal expansion means "increase in size of matter on heating". On heating, particles of matter gain energy and they start to vibrate or move around fast. They hit each other and increase the gap between them. Thus, matter expands on heating. Thermal expansion of matter depends upon nature of its material, increase in temperature and its original size (original amount of matter in it before heating). For the same increase in temperature, solid expands the least and gases expands the most.

Table 11.1: DIFFERENCE IN RELATIVE EXPANSION FOR SOLID LIQUID AND GAS

State	Expansion
Solids	Expand slightly because the low energy molecules cannot over intermolecular forces of attraction holding them together.
Liquids	Expands more than solids because the molecules have enough energy to partially overcome the intermolecular forces of attraction holding them together.
Gases	Expands significantly because the molecules have enough energy to completely overcome the intermolecular forces of attraction holding them together.

11.2.1 THERMAL EXPANSION IN SOLIDS

There are three types of thermal expansions in solids, linear thermal expansion (one dimensional thermal expansion), surface area thermal expansion (two dimensional thermal expansion) and volumetric thermal expansion (three dimensional thermal expansion). Here we will discuss linear and volumetric thermal expansions.

A. Linear Thermal Expansion of Solids: It is change in length of a solid on heating. Change in one dimension of a solid object on heating is called linear thermal expansion in solids.

Linear thermal expansion of solids depends upon three factors:

I. Increase in temperature of the rod: When a solid rod is heated, its atoms gain kinetic energy and vibrate with greater amplitude about their mean position. This increased vibrations causes the atoms to move slightly further apart resulting in an increase in the length of the rod. If we continue to increase the temperature, their kinetic energy and amplitude of vibration will further

increase. This will further increase the length of the rod. Therefore, thermal expansion in length of the rod is directly proportional to the increase in temperature of the rod.

ii. Original length of the rod: On heating the rod the increase in length of the rod is directly proportional to the original length of the rod. This is because longer rod has more atoms, each atom contribute to overall thermal expansion. So, a longer rod will expand more than a shorter rod when heated to the same temperature.

iii. Nature of material of the rod: Different materials expand differently on heating. Thermal expansion depends on the atomic structure an the strength of attractive force between its atoms. For example, aluminum rod expands more than steel rod of same length for same rise in temperature.

Table 11.2 COEFFICIENTS OF LINEAR THERMAL EXPANSION

Material	Value of α (K^{-1})
Steel	1.2×10^{-5}
Quartz	0.04×10^{-5}
Invar	0.09×10^{-5}
Glass	0.4×10^{-5}
Copper	1.7×10^{-5}
Brass	2×10^{-5}
Aluminum	2.4×10^{-5}

Consider a metal rod of original length 'L_o' at initial temperature 'T_o' as shown in figure 11.5. This rod is heated to final temperature 'T' and its final length becomes 'L'. Increase in length of the rod is 'ΔL' ($\Delta L = L - L_o$) for increase in temperature 'ΔT' ($\Delta T = T - T_o$).

From our previous discussion, we know that change in length is directly proportional to original length 'L_o' and change in temperature 'ΔT'. Mathematically

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

$$\Rightarrow \Delta L = \alpha L_o \Delta T \quad \text{— 11.1}$$

Where 'α' is the constant of proportionality and it is called coefficient of linear thermal expansion. From equation 11.1, we have

$$\alpha = \frac{\Delta L}{L_o \Delta T} \quad \text{— 11.2}$$

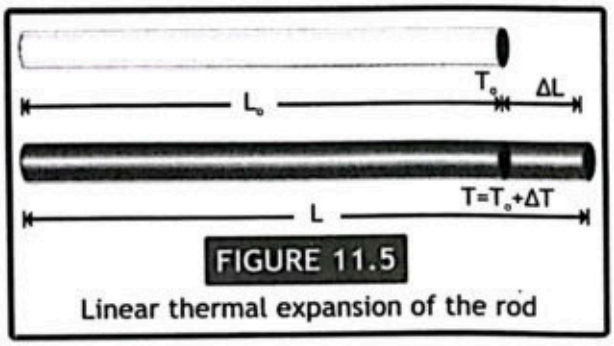


FIGURE 11.5
Linear thermal expansion of the rod

$$\text{or} \quad \alpha = \frac{\Delta L / L_o}{\Delta T} = \frac{\text{Change in length} / \text{Original length}}{\text{Change in temperature}} \quad \Rightarrow \quad \alpha = \frac{\text{Fractional change in length}}{\text{Change in temperature}}$$

The coefficient of linear expansion is defined as the fractional change in length per kelvin change in temperature. It tells how much length of the rod will change with respect to its original length when its temperature rises by 1 kelvin.

The linear expansion coefficient is an intrinsic property of every material. Hence it varies from one material to another. SI unit of coefficient of linear thermal expansion is K^{-1}.

B. Volumetric Thermal Expansion of Solids: It is change in volume of a solid on heating. Change in three dimensions of a solid object on heating is called volumetric thermal expansion in solids. Volumetric thermal expansion of solids also depends upon three factors:

i. Increase in temperature of the object: When a three-dimensional object (like a cube shaped object) is heated, kinetic energy of its particles increases, their vibrations become more vigorous and they spread out further apart. As a result, particles of the object occupy more volume. its atoms push each other and increase the volume of the object. Therefore, thermal expansion in volume of is directly proportional to the increase in its temperature.

ii. Original volume of the object: For the similar reason that we discussed in the case of linear thermal expansion, increase in volume of the solid object is directly proportional to its original volume.

Table 11.3: COEFFICIENTS OF VOLUMETRIC THERMAL EXPANSION

Material	Value of β (K^{-1})
Methanol	113×10^{-5}
Glycerin	49×10^{-5}
Mercury	18×10^{-5}
Turpentine	90×10^{-5}
Acetone	132×10^{-5}

iii. Nature of material of the object: Different materials expand differently on heating. Therefore, increase in volume of an object will be different for different materials on heating.Let original volume of solid cube is 'V_o' at temperature 'T_o' as shown in figure 11.6. It final volume becomes 'V' when its final temperature becomes 'T' ($T = T_o + \Delta T$). Let increase in its volume is 'ΔV' ($\Delta V = V - V_o$) for increase in temperature ΔT ($\Delta T = T - T_o$).

From our discussion, we can write increase in volume of the object as:

$$\Delta V = \beta V_0 \Delta T \quad \text{— 11.3}$$

Where 'β' is the constant of proportionality and it is called coefficient of volume expansion. From equation 11.3, we have:

$$\beta = \frac{\Delta V}{V_0 \Delta T} \quad \text{— 11.4}$$

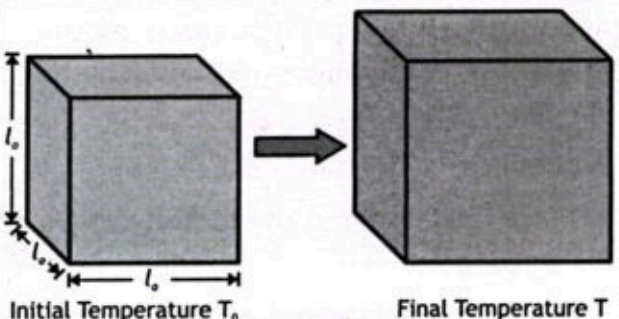


FIGURE 11.6
Volumetric thermal expansion of the solid cube

$$\text{or} \quad \beta = \frac{\Delta V / V_0}{\Delta T} = \frac{\text{Change in volume} / \text{Original volume}}{\text{Change in temperature}} \quad \Rightarrow \quad \beta = \frac{\text{Fractional change in volume}}{\text{Change in temperature}}$$

The coefficient of volumetric thermal expansion of solids is defined as the fractional change in volume per kelvin change in temperature. It tells how much volume of the solid object will change with respect to its original volume when its temperature rises by 1 kelvin. Its value is different for different materials. SI unit of β is K^{-1}. As we know that solid expands on heating and

contract on cooling. We can use the same relations for contraction of solids on cooling.

Example 11.1

An old steel bridge has original length of 1.5 km (1500 meters). The average daily temperature change in the region is 15 °C (from mid night to noon). Steel has a coefficient of linear expansion of $12 \times 10^{-6}\ K^{-1}$. How much will the bridge length change due to this daily temperature swing?

GIVEN:

Original length 'L_o' = 1.5 km = 1500 m

Coefficient of linear thermal expansion 'α' = $12 \times 10^{-6}\ K^{-1}$

Change in temperature 'ΔT' = 15 °C = 15 K

REQUIRED:

Change in length 'ΔL' = ?



Old steel bridge at Jhang

SOLUTION:

Increase in length of the bridge is calculated by the formula: $\Delta L = \alpha L_o \Delta T$

putting values $\Delta L = (12 \times 10^{-6} K^{-1})(1500\,m)(15\,K)$

Therefore $\Delta L = 0.27\,m$ — ANSWER

So, Increase in the length of the bridge is 0.27 m.

C. Experimental demonstration of thermal expansion of solids: A metal bolt snap bounded by a heated metal rod as shown in figure 11.7.

Apparatus: Metal rod (e.g., steel), metal bolt and nut (e.g., brass or aluminum), a Bunsen burner, stand and clamps

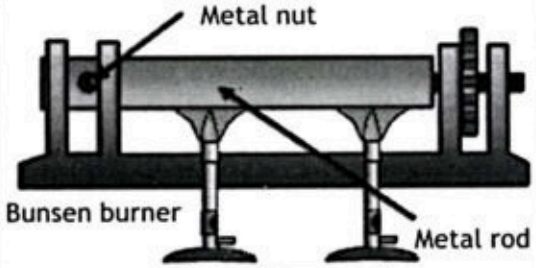


FIGURE 11.7

Experimental demonstration of thermal expansion in solids

Procedure:

1. Place the metal rod horizontally with a bolt tightly fastened to it.
2. Gradually heat the rod using a heat source.
3. As the rod heats up, it will expand due to thermal expansion.
4. The expansion will cause the rod to exert pressure on the bolt.
5. If the expansion is significant enough, the bolt will eventually snap.

Conclusion: Different metals expand at different rates when heated. The rod expands and exerts pressure on the bolt. If this pressure exceeds the bolt's strength, it snaps. This experiment shows that we should consider thermal expansion in engineering applications to prevent damage in structures.

D. Relation between coefficients of linear and volume expansions: The coefficient of linear expansion and volume expansion are related by:

$$\beta = 3\alpha \quad \text{— 11.5}$$

Example 11.2

You are designing a hot air balloon. The balloon's fabric has a volume of 500 cubic meters at room temperature of 20 °C. You need to know how much the volume will increase when hot air of 80 °C fills the balloon. The fabric material has a coefficient of volumetric expansion of $3.5 \times 10^{-5}\ K^{-1}$. Calculate the volume increase of the balloon fabric when filled with hot air.

GIVEN:

Original volume 'V_o' = 500 m^3

Coefficient of volume thermal expansion 'β' = $3.5 \times 10^{-5}\ K^{-1}$

Change in temperature 'ΔT' = 80 °C - 20 °C = 60 °C = 60 K

REQUIRED:

Change in volume 'ΔV' = ?

SOLUTION:

Increase in volume of the balloon is calculated by the formula:

$$\Delta V = \beta V_0 \Delta T$$

putting values $\Delta V = (3.5 \times 10^{-5} K^{-1})(500\, m^3)(60\, K)$

Therefore $\Delta V = 1.05\, m^3$ — ANSWER



Hot Air Balloon

After raising temperature by filling air at 80 °C, the increase in volume of the hot air balloon is 1.05 m^3.

11.2.2 THERMAL EXPANSION IN LIQUIDS

We have discussed earlier that liquids expand on heating. Liquids have intermediate attractive forces between its particles (molecules) and their particles can move relatively free as compared to solid particles. When we heat the liquid, kinetic energy of the particles increases, they push each other and increase their occupied space. This is the reason behind liquid expansion on heating. The thermal expansion in liquids is greater than solids due to the weak attractive forces between their particles.

To study the increase in volume of the liquid, we have to heat it in a container because it cannot be heated directly for this purpose. Therefore, we consider change in volume of the liquid and change in volume of the container as well during heating. There are two types of thermal volume expansion for liquid.

i. Real volume expansion ii. Apparent volume expansion

A. Real Volume Expansion: When heat is applied directly to a liquid, causing it to expand, the increase in its volume is called real volume expansion.

Generally, this expansion is similar to volume thermal expansion of solids. We can use the same

formula for coefficient of real volume expansion of liquids 'γ_r' as we do for solids. It is defined as **'fractional increase in real volume of the liquid for 1 kelvin rise in temperature'.**

$$\gamma_r = \beta = \frac{\Delta V}{V_0 \Delta T} \quad \text{— 11.6}$$

B. Apparent Volume Expansion: When we heat the liquid in a container then increase in its volume from its initial to final position is called apparent expansion of the liquid. We can also define it as: **The expansion of liquid apparently observed without considering the expansion of the container or vessel is called the apparent expansion of the liquid.** The coefficient of apparent expansion of liquid 'γ_a' defined as **'fractional increase in apparent volume of the liquid for 1 kelvin rise in temperature'.**

$$\gamma_a = \frac{\Delta V_{apparent}}{V_0 \Delta T} \quad \text{— 11.7}$$

Its SI unit is also per kelvin (or K^{-1}).

Experiment: Take a coloured liquid in a neck glass flask as shown in figure 11.8. Note initial level of liquid before heating it as 'V_1'. Now start heating the flask form its bottom. The liquid level first falls to 'V_2' and then rises to 'V_3'. Why does this happen?

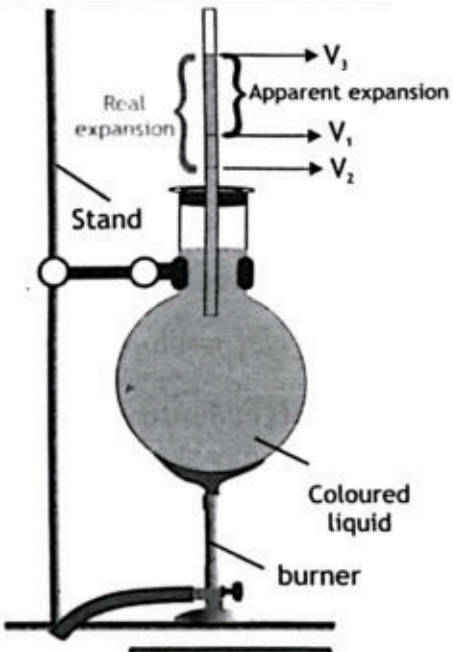


FIGURE 11.8
Real and apparent expansion of liquids

The heat first reaches the glass flask which expands first and its volume increases. As a result, liquid volume falls in the flask to level 'V_2'. After this, heat conducts to the liquid and the liquid begins to rise above 'V_2' on getting hot. At certain temperature it reaches at level 'V_3'. The increase in volume of liquid from 'V_1' to 'V_2' is called the apparent expansion in the volume of the liquid. But actually heat is transferred to liquid when it is at level 'V_2'. Therefore, rise in the level of liquid from 'V_2' to 'V_3' is called real expansion of liquid.

Actual expansion of the liquid is greater than its apparent expansion. While, fall level of liquid from 'V_1' to 'V_2' represents expansion in glass flask. Hence,

Real expansion of the liquid = Apparent expansion of the liquid + Expansion of the flask

$$\text{or} \quad V_2 V_3 = V_1 V_3 + V_1 V_2 \quad \text{— 11.8}$$

The Coefficient of real rate of volume expansion (γ_r) is always greater than the apparent rate of volume expansion (γ_a) by an amount equal to the rate of volume expansion of the container (γ_g). Thus:

$$\gamma_r = \gamma_a + \gamma_g \quad \text{— 11.9}$$

It should be noted that different liquids have different coefficients of volume expansion.

SCIENCE TIDBITS



All liquids expand on heating and contract on cooling except water. When water cools down from 4°C to 0°C, it actually expands. This strange property is called the anomalous expansion of water. When water freezes at 0°C, the hydrogen bonds become more stable and cause the water molecules to arrange themselves into a crystalline lattice structure. This structure casuses the expansion of water upon freezing. At 4°C water has highest density. It's why ice (0°C) floats in liquid water, a property crucial for life in aquatic ecosystems. As water in lakes and rivers freezes, the ice floats on top, insulating the lower water layers and preventing them from freezing completely. This allows life to survive harsh winters.

Example 11.3

A laboratory flask is filled with 250 ml of glycerine at a temperature of 20 °C. Calculate the volume of glycerine at 70 °C. The coefficient of volumetric thermal expansion for glycerine is $500 \times 10^{-6} K^{-1}$.

GIVEN:

Original volume 'V_o' = 250 ml = 250×10^{-6} m^3

Coefficient of real expansion 'γ_r'= 500×10^{-6} K^{-1}

Change in temperature 'ΔT' = 70 °C - 20 °C = 50 °C = 50 K

REQUIRED:

Change in volume 'ΔV' = ?

SOLUTION:

Increase in in volume of the glycerine is calculated by the formula: $\Delta V = \gamma_r V_0 \Delta T$

putting values $\Delta V = (500 \times 10^{-6} K^{-1})(250 \times 10^{-6} m^3)(50 K)$

Therefore $\Delta V = 6.25 \times 10^{-6} m^3 = 6.25 ml$ — ANSWER

Increase in the volume of glycerine is 6.25 ml when its temperature rises by 50 °C.

11.2.3 APPLICATIONS AND CONSEQUENCES OF THERMAL EXPANSION IN REAL LIFE

There are many applications of thermal expansions in our daily life. Let's discuss some of these applications.

A. Thermometers (Mercury and Alcohol Thermometers): Expansion of liquids (mercury or alcohol) is used to measure temperature in mercury and alcohol thermometers. As the temperature increases, the liquid expands and rises in the calibrated capillary tube. From which we read temperature.

B. Bimetallic Strips (Thermostats and switches): A bimetal strip consists of two thin strips of different metals such as brass and iron joined together as shown in figure 11.9. On heating the strip, one metal strip expands more than the other metal strip. This unequal expansion causes bending of the strip. Bimetal strips are used as switches and thermostats. For example in an electric iron, a bimetal thermostat switch controls the temperature of the heating coil.

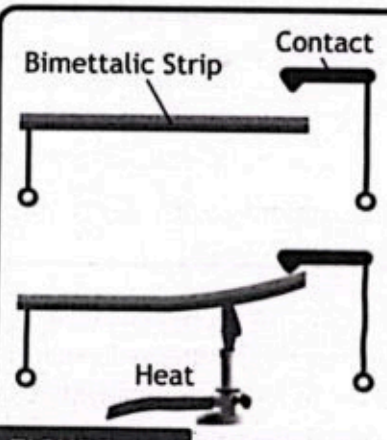


FIGURE 11.9 Bimetallic strips

C. Expansion Joints: The purpose of expansion joints is to accommodate the expansion and contraction of materials resulting from changes in temperature. This prevents structural damage in bridges, railways, pipelines, and buildings.

D. Opening Cap of A Bottle: To open the cap of a bottle that is tight enough, immerse it in hot water for a minute or so. Metal cap expands and becomes loose. It would now be easy to turn it to open.

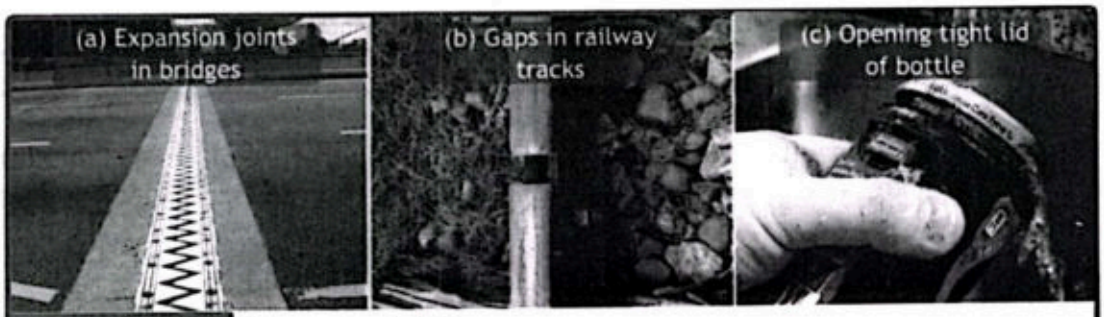


FIGURE 11.10 Expansion Joints

E. Power Lines: Overhead transmission lines are also given a certain amount of sag so that they can contract in winter without snapping (figure 11.11).

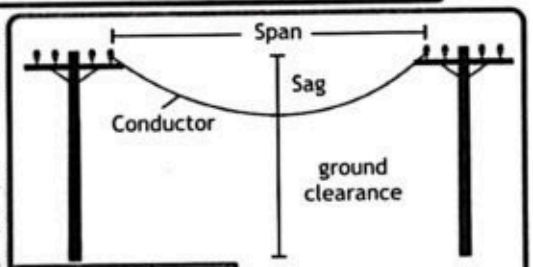


FIGURE 11.11 Sagging in power lines

F. Designing Instruments and Machinery: Different materials expand differently. Understanding thermal expansion is crucial for designing reliable and safe infrastructure, instruments, and machinery.

G. Consequences of thermal Expansions: If we ignore thermal expansion during construction, designing machines and instruments etc., we will face different problems. Some of them are:

- Temperature changes can cause materials like concrete and asphalt to expand and contract. Without proper joints or gaps, this can lead to cracks and structural damage.
- Overheated power lines might sag excessively, causing short circuits or power outages.
- In hot weather, railway tracks can expand and buckle if there are no expansion gaps.
- Pipes carrying fluids can burst if the liquid inside expands due to heating and there's no room for expansion, causing leaks and significant damage.
- Instruments with parts that expand when heated may give wrong readings if they are not

DO YOU KNOW?

The Eiffel Tower is made up of iron. It can grow up to 6 inches (15 cm) taller in summer due to thermal expansion. As iron heats up, it expands, causing the tower to increase in height. Engineers account for such thermal expansion this in their designs to ensure structural strength and safety.



properly calibrated.

- Metals get weaker when they expand and contact many times, which can damage items like airplanes, machines and buildings.

11.3 EVAPORATION

Have you ever thought how wet clothing dry on a clothesline or why puddles disappear on a hot summer day? This happens by a process known as evaporation. Evaporation is the process by which liquid changes into vapours (gas) at any temperature. This occurs at the surface of the liquid.

11.3.1 CAUSE OF EVAPORATION

In a liquid, Molecules in a liquid have different kinetic energies due to collision with each other and with walls of container. High energy molecules moving near the surface of the liquid escape from the surface in the form of vapours as shown in figure 11.12. This is how evaporation takes place.

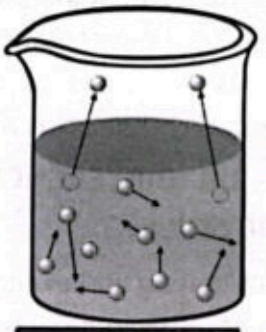


FIGURE 11.12
Molecules escaping from the surface of liquid in evaporation

11.3.2 EVAPORATION CAUSES COOLING

During evaporation, fast moving molecules escape from the surface of the liquid. Molecules that have lower kinetic energies are left behind. This lowers the average kinetic energy of the liquid molecules and, hence, the temperature of the liquid.

The temperature of a substance relates to the average kinetic energy of its molecules. A decrease in temperature causes a cooling sensation. For example when we sweat the evaporation of moisture from the skin cools the body. Similarly, when a liquid evaporates from the surface of a solid, it lowers its temperature. This principle is used in refrigerators and air conditioning systems.

11.3.3 FACTORS AFFECTING RATE OF EVAPORATION

The rate of evaporation indicates how quickly molecules at the surface of a liquid escape and become a gas. Higher rate of evaporation means the liquid will evaporate faster. Rate of evaporation depends upon different factors, such as:

A. Temperature: Rate of evaporation is directly proportional to temperature. Higher temperature of the liquid increases kinetic energy of its molecules and increase the rate of evaporation. Water in sunshine (high temperature area) evaporates faster than water in shade (low temperature area).

B. Surface Area: A larger surface area allows more molecules to escape, speeding up evaporation. Larger is the surface area of a liquid, greater number of molecules has the chance to escape from its surface. It is why wet clothes are stretched out to dry quickly.

C. Humidity: Dry air is less humid air (It has low value of moisture in it). It has ability to store more moisture. Therefore, lower humidity levels increase the rate of evaporation as dry air can allow more water vapours to be absorbed. You now understand that room air coolers function most efficiently in the dry air months of June and less efficiently in the humid months of August.

D. Wind Speed: Increased wind speed blows away the moist air near the surface, which speeds up the rate of evaporation. It is why wet clothes dry quickly in windy day than on a calm day.

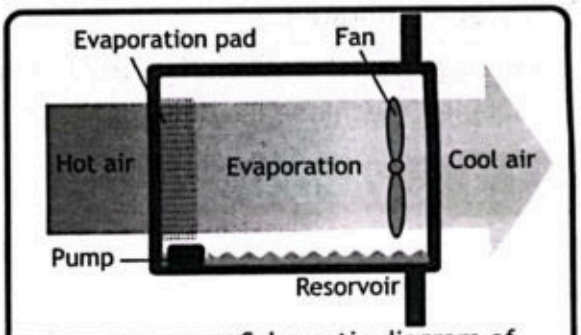


FIGURE 11.13 Schematic diagram of room air cooler



11.3.4 DIFFERENCE BETWEEN EVAPORATION AND BOILING

Both boiling and evaporation represent the change of liquid into vapours. But there are some differences in both processes, as shown in table 11.4.

Table 11.4: DIFFERENCE BETWEEN EVAPORATION AND BOILING

Properties	Evaporation	Boiling
Occurs	at the surface of liquid	Throughout the liquid
Temperature	at any temperature	only at boiling point of liquid
Energy Source	Uses surrounding energy	uses continuous external heat source
Rate/speed	Generally slower and depends on many factors	Fast process (after reaching boiling point)
Process Completion Time	It takes longer to be completed	It is quick process than evaporation
Effect of pressure	Less effected by external pressure	Highly effected by external pressure
Formation of Bubble	No bubble formation	Bubbles are formed throughout the liquid and rise from the surface
Dependence on surface area	Depends on surface area	Does not depend on surface area
Effect on temperature of surrounding	Causes cooling in surrounding	Increases temperature of surrounding

11.3.5 APPLICATIONS OF EVAPORATION

A: Refrigeration using evaporation (without CFCs): Cooling is produced in the fridge/refrigerators by evaporation of refrigerant (a liquefied gas), which absorbs heat and creates a cooling effect.

Freons, or chlorofluorocarbons (CFCs), were the type of refrigerant gas used in fridge. However, since it was found that CFCs are depleting the ozone in the upper atmosphere which increases the amount of UV rays from the sun. All living things are harmed by ultraviolet radiation. Therefore, CFCs use has been prohibited. CFCs are replaced by the environment friendly substances like water, ammonia and hydrocarbons (propane, butane) etc.

The refrigerator contains a coil (called evaporation coil) filled with refrigerant at low pressure. When the warm air inside the fridge comes into contact with the evaporator coil, the refrigerant absorbs heat and changes from liquid to gas, which cools the inside of the fridge. This gas is then compressed, releasing heat outside, and is condensed back into a liquid by the condenser. This cycle continues to maintain a cool temperature inside the fridge.

DO YOU KNOW?

The density and viscosity of a liquid determine how quickly it evaporates. Liquids that are less viscous and dense, such as those found in perfume bottles, evaporate more quickly.

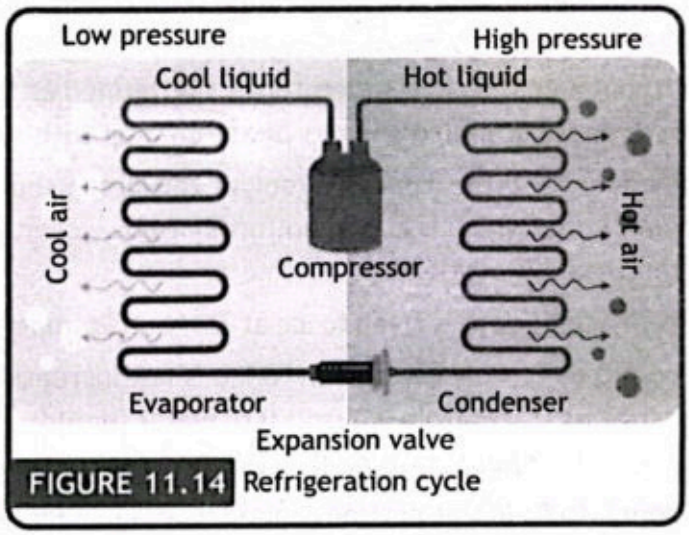


FIGURE 11.14 Refrigeration cycle

B. Food preservation: Many food items are preserved by removing the water content through evaporation. This concentrates the flavours and prevents spoilage. Examples include dried fruits, jerky (dried meat), as shown in figure 11.5 (a).

C. Production of salt: Sea water is stored in large pools. As the water evaporates, the salt is left behind as shown in figure 11.5 (b).

D. Air conditioning: Air conditioners use evaporation to cool air. They work by passing warm air over a coil that is filled with a cool liquid. As the liquid evaporates, it takes heat from the air, cooling it down.



(a) Fruits dried using evaporation



(b) Sea salt obtained from evaporation of sea water

FIGURE 11.15 Uses of evaporation

E. Fever control: *When* someone has a high fever, they apply a wet cloth to their forehead. The reason behind this is that heat from the head is removed when the water evaporates. As a result, the patient's brain temperature stays within acceptable bounds and no brain injury occurs.

11.4 LATENT HEAT

Consider you are boiling a pot of water. The temperature of the water increases gradually as you turn up the heat. But then, something interesting happens. The water reaches 100°C. Even when you apply more heat, the temperature does not change! Where is all that energy going?

The answer lies in a concept called latent heat. It is the hidden heat absorbed or released by a substance during a phase change (like melting, freezing (solidification), boiling or condensation) without a change in temperature. It is defined as **'It is the amount of heat energy absorbed or lost by a substance during its phase change without change in its temperature'.**

To understand this concept, look at this graph shown in figure 11.16 between temperature and heat energy which is added uniformly to the ice at -20 °C to 110 °C (after its boiling points). This graph has five portions.

From A to B: Heat is given to ice at -20 °C. Its temperature rises and but it is still ice at 0 °C.

From B to C: Now heat given to ice is not increasing its temperature. This heat is being used to change its states from ice (solid) to water (liquid) at its melting point 0 °C. This amount of heat is called latent heat of fusion (L_f). This process continues till all the ice is converted into water.

From C to D: In this portion, added heat again increases the temperature of the water uniformly till it reaches its boiling point.

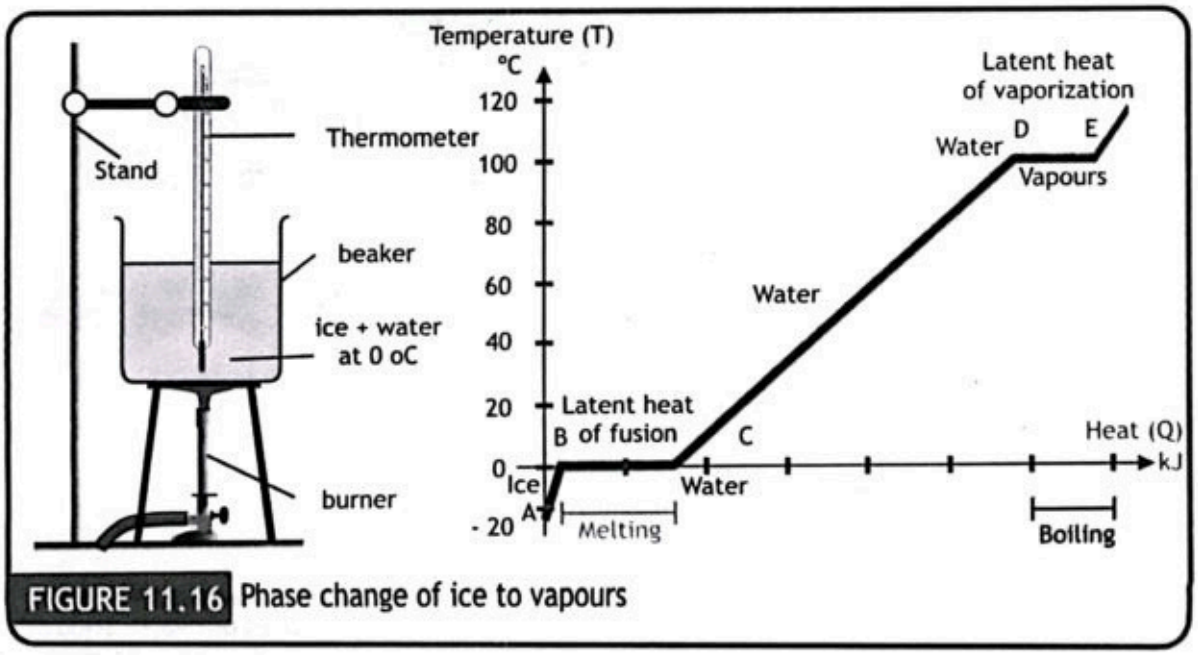


FIGURE 11.16 Phase change of ice to vapours

From D to E: In this portion, added heat again is not used to increase the temperature of water. It is used to change the state of water (liquid) into vapours (gas) at its boiling point 100 °C. Heat added at this stage to water is called latent heat of vaporization (L_v).

From E to F: After complete change of water into vapours at its melting point, added heat increases the temperature of the vapours (steam).

Temperature of a substance is related with the average kinetic energy of the particles. Therefore, whenever added heat increases the average kinetic energy of particles of the substance, it will increase the temperature of the substance. But when added heat is used to change the state of substance, it does not change its temperature. Here, heat is used to weaken the attractive forces between its particles, instead of increasing their average kinetic energy. This happens at meting point and boiling point of the substance.

During melting, the amount of heat is absorbed by the substance to change its state from solid to liquid at its melting point without the change in its temperature. Similarly, the same amount of heat is released by the same substance at its freezing point during solidification (from liquid to solid). The same happens for boiling of a liquid and its condensation from vapour to solids at boiling point. Heat energy absorbed during boiling is equal to heat energy released during condensation. In all these processes, heat absorbed or released by the substance is used to accommodate the attractive forces between its particles.

11.4.1 LATENT HEAT OF FUSION

The amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state without change in its temperature is called its latent heat of fusion. During freezing, liquids release same amount of heat to change state to solids.

If 'ΔQ' is the amount of heat energy needed to melt mass 'm' of a solid to liquid (or freeze liquid to solid), then mathematically:

$$\Delta Q = m L_f \quad \text{—(11.10)}$$

Where 'L_f' is the specific latent heat of fusion of substance. It is defined as: The amount of heat energy required to convert unit mass (one kilogram) of the solid at its melting point to liquid, (or liquid into solid) without any change in temperature is called its specific latent heat of fusion (L_f) of the solid.

$$L_f = \frac{\Delta Q}{m} \quad \text{—(11.11)}$$

The SI unit of specific latent heat of fusion is joule per kilogram which is expressed as J kg^{-1}. Different substances have different specific latent heat of fusion. Latent heat of fusion of ice is 3.33×10^5 J kg^{-1}.

Table 11.5: LATENT HEATS OF FUSION AND VAPORISATION OF SELECTED MATERIALS

Material	Melting Point (°C)	Latent Heat of fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporisation (J/kg)
Helium	- 269.65	5.23×10^3	- 269	2.09×10^4
Oxygen	- 218.79	1.38×10^4	-183	2.13×10^5
Water	0	3.33×10^5	100	2.26×10^6
Mercury	-39	1.13×10^4	357	2.93×10^5
Sulphur	119	3.81×10^4	445	3.26×10^5
Lead	327	2.45×10^4	1750	8.70×10^5
Aluminum	660	3.97×10^5	2450	1.14×10^7
Copper	1083	1.34×10^5	1187	5.06×10^6
Silver	961	8.82×10^4	2193	2.33×10^6
Gold	1063	6.44×10^4	2660	1.58×10^6

11.4.2 LATENT HEAT OF VAPORISATION

The amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state without any change in its temperature is called its latent heat of vaporization. During condensation same amount of heat is released by the gases to change its state to liquids. If 'ΔQ' is the amount of heat energy needed to vaporize mass 'm' of a liquid to gas (or condense gas to liquid), then mathematically:

$$\Delta Q = mL_v \quad \text{— 11.12}$$

Where 'L_v' is the latent heat of vaporization of substance. It is defined as: The amount of heat energy required to convert unit mass (one kilogram) of the liquid at its melting point to gas, (or gas into liquid) without any change in temperature is called its specific latent heat of vaporization of the solid.

$$L_v = \frac{\Delta Q}{m} \quad \text{— 11.13}$$

The SI unit of specific latent heat of vaporisation is joule per kilogram (Jkg^{-1}). Different substances have different specific latent heat of vaporisation. Latent heat of vaporisation of water is $2.26 \times 10^6\ Jkg^{-1}$.

11.4.3 EXPERIMENT TO FIND LATENT HEAT OF FUSION OF ICE

1. Place a beaker over a stand as shown in figure 11.17.
2. Add small pieces of ice to the beaker.

3. To find out the ice's temperature, hang a thermometer inside the beaker.

4. Set a burner below the beaker.

5. Start calculating the time by stopwatch.

6. The ice will begin to melt.

7. Now, it will have mixture of ice and water but its temperature will not rise above 0°C until all the ice melts.

8. Note the time which the ice takes to melt completely into water at 0°C.

9. When all the ice converts to water, its temperature will begin to rise. Continue heating the water at 0°C in the beaker. Its temperature will begin to increase.

10. Note the time which the water in the beaker takes to reach its boiling point at 100 °C from 0 °C.

11. Darw a temperature-time graph such as shown in figure 11.18.

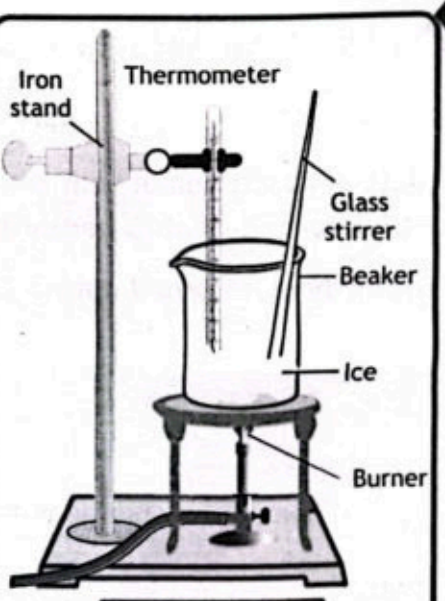


FIGURE 11.17

Experimental arrangement to find latent heat fusion of ice

Let's do some calculations to find the latent heat of fusion of ice from the graph data as follows:

Let, mass of ice = m

Finding the time from the graph:

I. Time taken by ice to melt completely at 0 °C (time for fusion) = $t_f = t_2 - t_1 = 3.7$ minutes

ii. Time taken by water for its temperature rise from 0 °C to 100 °C = $t_R = t_3 - t_2 = 4.6$ minutes

Specific heat of water = c = 4200 J kg^{-1} K^{-1}

Increase in the temperature of water from 0 °C to 100 °C = ΔT = 100 °C = 100 K

Heat required by water to raise its temperature from 0 °C to 100 °C is given by:

$$\Delta Q = mc\Delta T \cdot$$

putting values $\Delta Q = m(4{,}200\ J\,kg^{-1}K^{-1})(100\ K)$

$$\Delta Q = m(4.2\times10^5\ J\,kg^{-1})$$

This is the heat absorbed by water to raise its temperature from 0 °C to 100 °C. This heat is absorbed by the water in time t_R (4.6 minutes). Heat is absorbed at uniform rate. So, Rate of absorption of

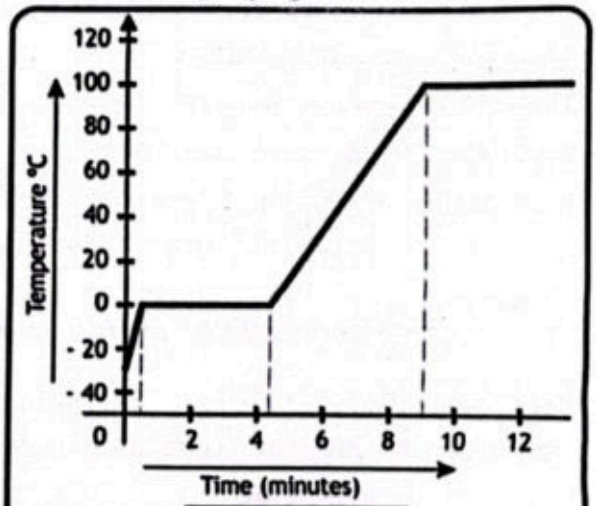


FIGURE 11.18

Temperature time graph for ice and water

heat (heat absorbed by the water in unit time) is given by:

$$Rate\ of\ absorption\ of\ heat = \frac{\Delta Q}{t_R}$$

Rate of absorption of heat is same during fusion process time 't_f' and raising temperature time 't_R'. Hence, Heat absorbed by the water in time 't_F' during fusion process is:

Total heat absorbed during fusion of ice = Rate of absorption of heat × Total time of fusion

$$\Delta Q_F = \frac{\Delta Q}{t_R} \times t_F = \Delta Q \times \frac{t_F}{t_R} \quad \text{— (1)}$$

as: $\Delta Q_F = m \times L_f$ — (2)

Comparing equations 1 and 2: $m \times L_f = \Delta Q \times \frac{t_F}{t_R}$

Putting values in above equation and simplifying it: $m \times L_f = m \times (4.2 \times 10^5\ J\,kg^{-1}) \times \frac{3.7\,min}{4.6\,min}$

Therefore, $L_f = 3.9 \times 10^5\ J\,kg^{-1}$

The latent heat of fusion of ice found by the above experiment is 3.37×10^5 J kg^{-1} while its actual value is 3.36×10^5 J kg^{-1}.

11.4.4 EXPERIMENT TO FIND LATENT HEAT OF VAPORISATION OF WATER

To find latent heat of vaporisation of water, we keep on heating beaker contains boiling water as shown in figure 11.18. Continue heating water till all the water changes into steam. Note the time taken by water to change completely into steam at its boiling point 100 °C. Extend the temperature-time graph such as shown in figure 11.19. Let's calculate the latent heat of fusion of ice from the data as follows:

Time taken by water at 100 °C to change it into steam (time of vaporization) = $t_v = t_4 - t_3 = 24.4$ min.

In experiment to find latent heat of fusion L_f, we have calculated the rate of absorption of heat by water.

$$Rate\ of\ absorption\ of\ heat\ by\ water = \frac{\Delta Q}{t_R}$$

Total heat absorbed during vaporization of water = Rate of absorption of heat × total time of vaporization:

$$\Delta Q_v = \frac{\Delta Q}{t_R} \times t_v = \Delta Q \times \frac{t_v}{t_R} \quad \text{— (1)}$$

as: $\Delta Q_v = m \times L_v$ — (2)

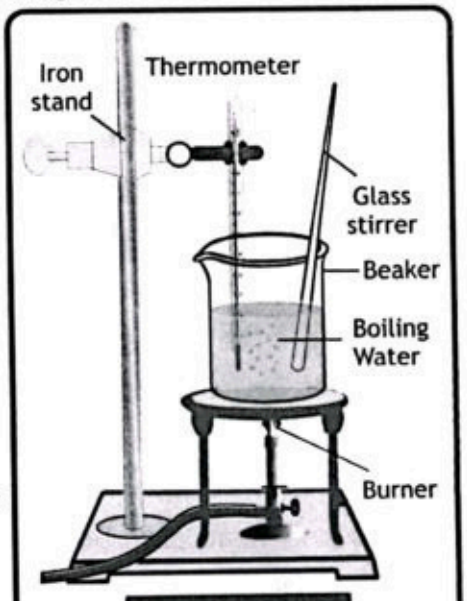


FIGURE 11.19

Experimental arrangement to find latent heat vaporization of water

Comparing equations 1 and 2: $m \times L_v = \Delta Q \times \frac{t_v}{t_R}$

Putting values in above equation and simplifying it:

$$m \times L_v = m \times (4.2 \times 10^5\ J\,kg^{-1}) \times \frac{24.4\,min}{4.6\,min}$$

Therefore, $L_v = 2.23 \times 10^6\ J\,kg^{-1}$

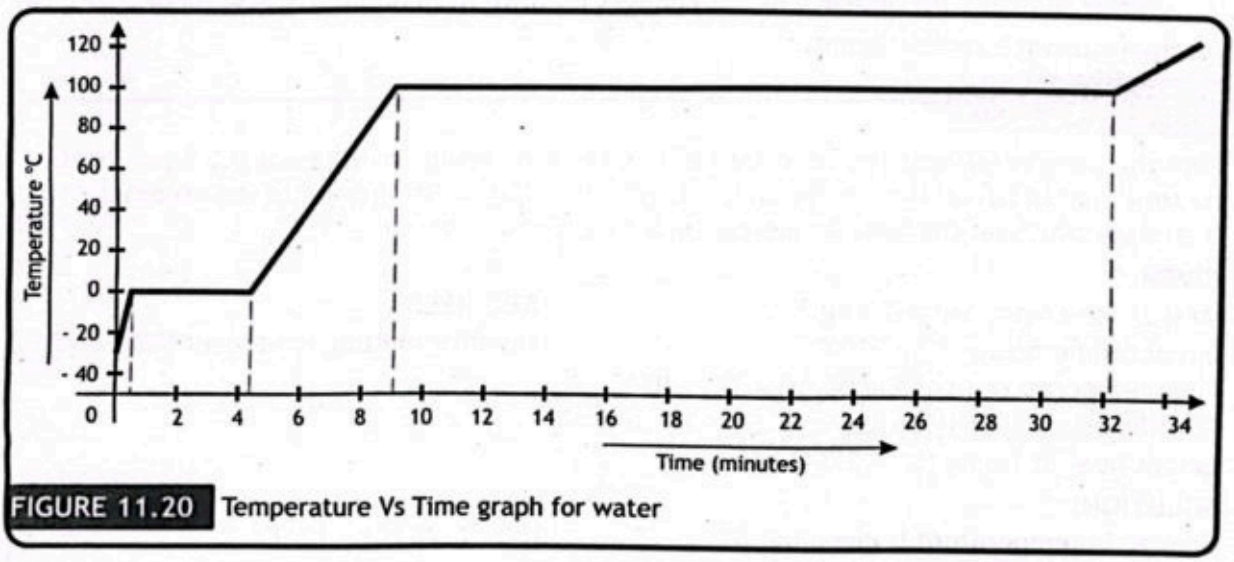


FIGURE 11.20 Temperature Vs Time graph for water

The latent heat of vaporization of water found by the above experiment is 2.23×10^6 J kg^{-1} while its actual value is 2.26×10^6 J kg^{-1}.

From these two experiments we outline the following general procedural steps for calculating latent heat of fusion and vaporisation.

1. Take the solid at its melting point in a beaker and heat it at uniform rate.
2. Note the following time taken by the substance.
   a. Time in which it completely melts without any change in its temperature at melting point (fusion process)
   b. Time in which its temperature rises from melting point to boiling point
   c. Time in which it changes its state from liquid to gas without change in its temperature at its boiling point (boiling process)
3. Calculate the heat absorbed by the substance during the time its temperature rises from melting point to boiling point.
4. Calculate the rate of absorption of heat by dividing above calculated heat in point 3 by the time in which its temperature rises.

$$Rate\ of\ absorption\ of\ heat = \frac{\Delta Q}{t_R}$$

5. Latent heat of fusion: To calculate late of fusion of substance, multiply this rate of absorption of heat with time in which it completely melts without any change in its temperature at melting point

6. Latent heat of vaporisation: To calculate late of vaporisation of substance, multiply this rate of absorption of heat with time in which it changes its state from liquid to gas without change in its temperature at its boiling point.

Example 11.4

Find the amount of heat required for melting the ice-cream having mass 0.5 kg at 20 °C? (Latent heat of fusion for ice-cream $L_f = 3.347 \times 10^5$ J/kg, melting point of ice-cream is - 10 °C and specific heat capacity for ice-cream is $c = 2.1 \times 10^3$ J/kg °C).

GIVEN:

Mass of ice-cream 'm' = 0.5 kg
Initial temperature 'T_o' = 20 °C
Final temperature (melting point) = T = - 10 °C
Specific heat capacity of ice 'c' = 2.1×10^3 J/kg °C
Latent heat of fusion 'L_f' = 3.347×10^5 J/kg

REQUIRED:

Heat for melting ice-cream 'ΔQ' = ?

SOLUTION:

Change in temperature is given by: $\Delta T = T - T_o = -10\ °C - (-20\ °C) = 10\ °C$

First, we will provide heat to increase the temperature of the ice-cream from 20 °C to - 10 °C (melting point).

$\Delta Q_1 = mc\Delta T$ putting values $\Delta Q_1 = (2.1 \times 10^3\ J\,kg^{-1}{}^0C^{-1})\,(0.5\,kg)(10\ ^0C)$

Hence, $\Delta Q_1 = 1.05 \times 10^4\ J$

Now we will find heat required for melting ice-cream at its melting point is: $\Delta Q_2 = mL_f$

putting values $\Delta Q_2 = (0.5\,kg)(3.347 \times 10^5\ J\,kg^{-1}) = 16.735 \times 10^4\ J$

Total heat required will be: $\Delta Q = \Delta Q_1 + \Delta Q_2$

putting values $\Delta Q = 1.05 \times 10^4\ J\,kg^{-1} + 16.735 \times 10^4\ J\,kg^{-1}$

Therefore, $\Delta Q = 17.785 \times 10^4\ J\,kg^{-1} = 177.85\ kJ$ — ANSWER

So, a total of 177.85 kJ of heat will be required to melt an ice-cream of 0.5 kg at - 20 °C.

11.5 PRESSURE EXERTED BY GAS PARTICLES

The molecules of a gas are in a state of continuous random motion in a container. They collide with one another and also with the walls of the container, as shown in figure 11.21. Pressure is the measure of force exerted by the gas particles on unit area of the walls of the container perpendicularly.

$$\text{Pressure} = \frac{\text{Force exerted by particle due to collision}}{\text{Area of the walls of container}} \quad \text{or} \quad P = \frac{F}{A}$$

Pressure of a gas in a container change with change in temperature, volume and amount of substance (number of particles).

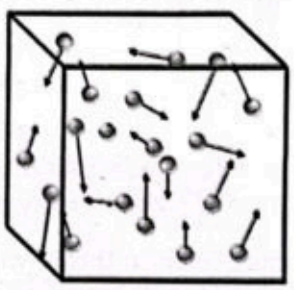


FIGURE 11.21
Random motion gas particles in a container

A. Effect of temperature: If the temperature of the gas increases, the particles move faster. Faster particles collide with the walls with greater force and more frequently. This increases the pressure of the gas in the container. Pressure of the gas will decrease if its temperature decreases. So, the pressure of a gas inside a container is directly proportional to its temperature provided the volume remains constant.

B. Effect of volume: Pressure of a gas is inversely proportional to its volume if its temperature is kept constant (Boyle's law). If the volume of the container is reduced while keeping the number of particles constant, particles have less space to move around. This increases the number of collisions of its particles with the walls, which results in increase in pressure. Conversely, If the volume is increased, particles have more space and collide with the walls less frequently, which decreases the pressure as shown in figure 11.22.

C. Effect of amount of gas (number of particles): By increasing the number of particles of the gas in a fixed volume increases the number of collisions of gas molecules with the walls of the container and hence, it increases the pressure of the gas in the container. By decreasing the number of particles of the gas in the container, its pressure will decrease as shown in figure 11.22.

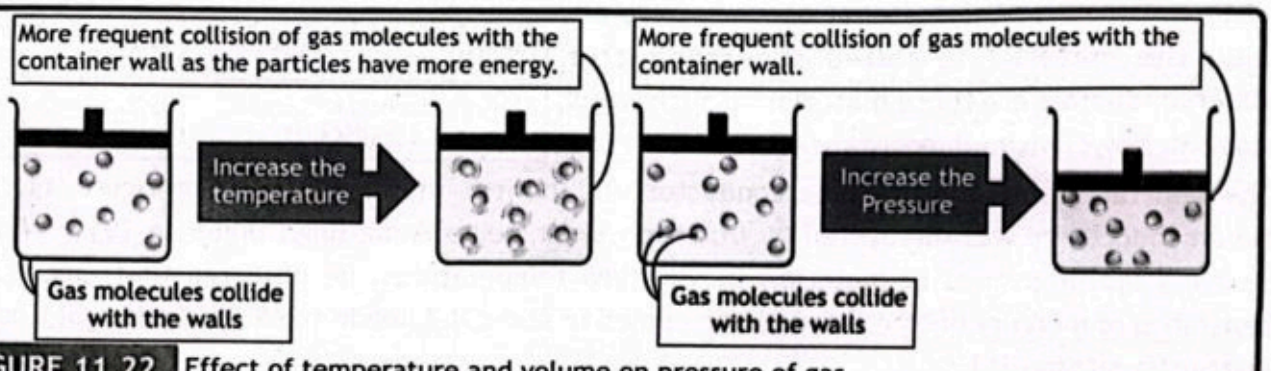


FIGURE 11.22 Effect of temperature and volume on pressure of gas

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Consider an inflated balloon filled with gas. When heated, the gas particles inside the balloon move faster and hit the balloon's inner walls more forcefully. This causes the balloon to expand. If you cool the balloon in air or in cold water, the particles move slow down, hit the walls less forcefully, and the balloon may shrink.



Note: Perform this in your home under the supervision of your parents.

11.6 SUPERCONDUCTIVITY

When we connect a wire or a device like bulb with the cell, current flows through it. Current flow means free electrons in the wire move through gaps between the atoms of the conductor. But they collide with the atoms of the conductor. This cause a hindrance to their flow which is called resistance of the conductor and if we relate it with the material then it is called specific resistance or resistivity of the material of the conductor. Atoms of the conductor are in vibrational motion. With decrease in temperature, their amplitude of vibration decreases. This increases the size of the gap between the atoms. Due to which collisions of flowing electrons with the atoms of the conductor decrease and hence, resistivity of the material also decreases.

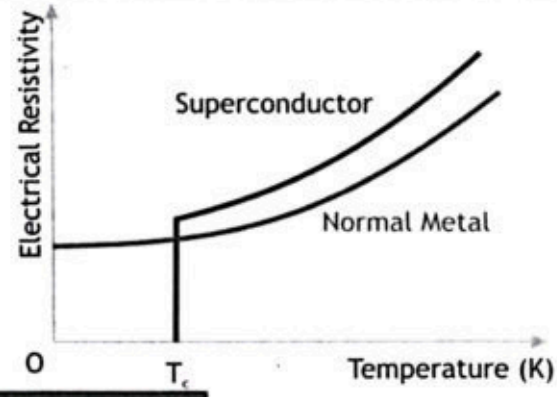


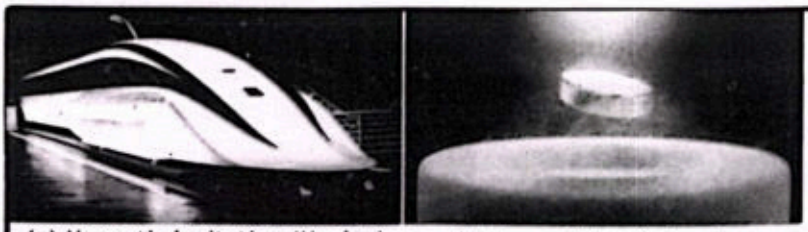
FIGURE 11.23 Superconductors

If we keep on decreasing the temperature then at a certain temperature (critical temperature) comes when resistivity of the material becomes zero and then the material is called superconductor. **Superconductors are those material through which current flows without resistance.**

Table 11.6 CRITICAL TEMPERATURES OF SOME SUBSTANCES

Substance	Critical temperature
Mercury (Sb)	4.2 K
Aluminum (Al)	1.18 K
Tin (Sn)	3.72 K
Lead (Pb)	7.2 K
Yttrium Barium Copper Oxide (YBCO)	92 K
Bismuth Strontium Calcium Copper Oxide (BSCCO)	108 K

The general graph relating superconductor and normal metal is shown in figure 11.23. Superconductivity was discovered by Dutch physicist Heike Kamerlingh Onnes in 1911. While studying the properties of materials at very low temperatures, he observed that electrical resistance of mercury becomes zero when cooled to about 4.2 Kelvin (-268.95°C). He got Nobel Prize in Physics in 1913.



(a) Magnetic levitation (Maglev) trains

(b) Magnetic levitation by superconductors

FIGURE 11.24 Applications of superconductors

DO YOU KNOW?

Critical Temperature: The temperature at which and below which the resistance and resistivity of substance become zero is called the critical temperature or superconducting transition temperature.

Superconductors are used in powerful electromagnets, particle accelerators, magnetic levitation (Maglev) trains as shown in figure 11.24 (a), small but powerful electric motors, fast computer chips, and potentially more efficient power transmission lines. Researchers continue to explore ways to achieve superconductivity at higher temperatures, which would make it more practical for everyday use.

SUMMARY

- **Freezing** is the phenomenon in which liquid changes into solid.
- **Melting** is the phenomenon in which solid changes into liquid.
- **Vaporization** is the phenomenon in which a liquid is converted into gas (vapours) upon boiling.
- **Evaporation** is phenomenon of conversion liquid into vapours at any temperature.
- **Condensation** is a phenomenon in which gases (vapours) change into liquids.
- **Sublimation** is a phenomenon in which solids change directly into gases.
- **Deposition** is a phenomenon in which gas changes directly to solid.
- **Thermal expansion** means "increase in size of matter on heating".
- **Linear thermal expansion** of solids is increase in length of substance on heating.
- **Volume thermal expansion** of solids is increase in volume of substance on heating.
- **Coefficient of linear thermal expansion** is the fractional change in length per kelvin change in temperature.
- **Coefficient of volume thermal expansion** is the fractional change in volume per kelvin change in temperature.
- **Real volume expansion** is thermal expansion in volume of liquid when it is heated directly.
- **Apparent volume expansion** is thermal expansion of volume of liquid in a container without considering the expansion of its container.

- **Bimetallic Strips** consists of two thin strips of different metals joined together which bend on heating.
- **Humidity** is content of water in air.
- **Refrigerant** is a material used to produce cooling in refrigerator that absorb an releases heat by cycling between liquid and gaseous state.
- **Latent Heat** is the amount of heat energy absorbed or lost by a substance during its phase change without change in its temperature.
- **Latent Heat of Fusion** is the amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state without change in its temperature is called its latent heat of fusion.
- **Latent Heat of Vaporization** is the amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state without any change in its temperature is called its latent heat of vaporization.
- **Pressure** is Force on unit area on an object perpendicularly.
- **Pressure of Gas** is the measure of force exerted by the gas particles on unit area of the walls of the container perpendicularly.
- **Superconductor** are those material through which current flows without resistance.
- **Critical temperature** is the temperature at which and below which the resistance and resistivity of substance become zero is called the critical temperature.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. During a hot summer day, a metal bridge might expands slightly. This expansion is caused by
   A. the bridge rusting and weakening.
   B. the metal atoms in the bridge vibrating more intensely.
   C. the weight of cars driving over the bridge.
   D. a decrease in the air pressure around the bridge.

2. Fog forms on a cold window pane in the morning. Which change of state is occurring?
   A. Melting B. Boiling C. Condensation D. Deposition
3. Which process involves the change of state from a gas to a solid without passing through the liquid phase?
   A. Deposition B. Melting C. Freezing D. Sublimation
4. Boiling point of water is:
   A. 212 °C B. 212 °F C. 100 K D. 373 °C
5. $J\,kg^{-1}K^{-1}$ is the unit of:
   A. specific Heat Capacity B. heat Capacity
   C. latent Heat of Fusion D. heat Energy
6. Evaporation takes place from
   A. surface B. bottom C. center D. any location
7. Relation between linear and volume expansion of solids is
   A. $\beta = \alpha/3$ B. $\beta = 1.5\,\alpha$ C. $\alpha = \beta/3$ D. $\alpha = 3\,\beta$
8. Heat added to a substance, at its melting pointing, is used to:
   A. increase K.E. of particle.
   B. decrease K.E. of particles
   C. increase the attraction between particles
   D. decrease the attraction between particles
9. 336 J/g is latent heat of fusion of a material. How much heat is required to melt 10 g of material at its melting point?
   A. 336 J B. 3360 J C. 33600 J D. 3.36×10^5 J
10. Which of the following factors increases the rate of evaporation?
    A. Decrease in temperature B. Increase in humidity
    C. Increase in wind speed D. Decrease in surface area
11. What is value of α for a solid if its β is $9 \times 10^{-7}\,K^{-1}$?
    A. $3 \times 10^{-7}\,K^{-1}$ B. $4.5 \times 10^{-7}\,K^{-1}$ C. $9 \times 10^{-7}\,K^{-1}$ D. $27 \times 10^{-7}\,K^{-1}$
12. The process that involves the latent heat of vaporization is
    A. Melting of ice B. Freezing of water C. Eveporation D. Condensation of steam
13. The sum and difference of the coefficient of real and apparent expansion of a liquid are in the ratio 2:1. The ratio of the coefficient of real expansion and apparent expansion must be
    A. 1:1 B. 2:1 C. 2:3 D. 3:1

14. Latent heat refers to the energy absorbed or released by a substance during a change of state, but with no change in temperature. What does "latent" mean in this context?

A. Constant B. Visible C. Hidden D. Transparent

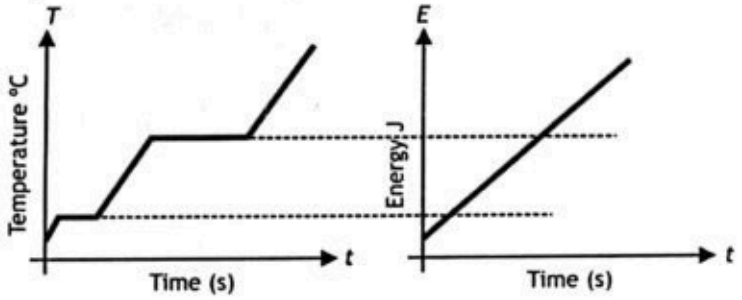
CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Look at these graphs for heating the ice, Energy (E)-time (t) graph shows that energy is being supplied to ice at constant rate to change it into liquid and finally into steam. While the temperature (T)-time (t) graph shows that change of temperature of ice and water during different stages.

a. There are two horizontal parts of this graph, where temperature is not changing but energy is being supplied to substance at constant rate. Explain why does temperature not change at these two stages?

b. Explain why the temperature and energy trends are not same for the same time intervals.



2. A heater supplies energy at a constant rate to a 100g of a substance. The variation with time of the temperature of the substance is shown in the figure. The substance is perfectly insulated from its surroundings. The power of the heater is 250 W.

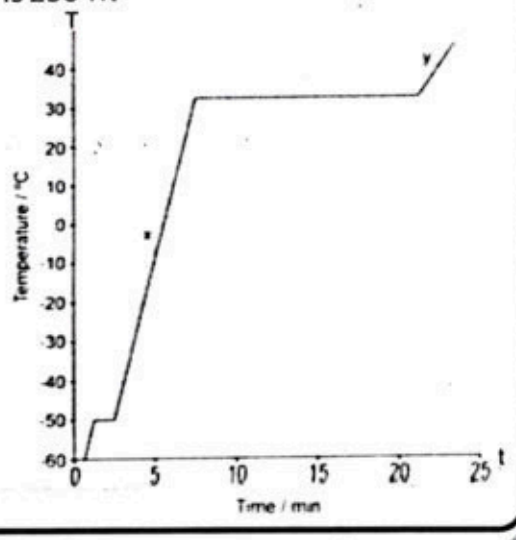
From the figure, answer the following questions:

a. What is melting and boiling point of the substance?

b. How long does it take to melt completely and how long does it take to vaporise from liquid state?

c. How much temperature increases in its liquid phase (x part of the graph)?

d. Calculate latent heat of vaporization of the substance?



SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Why do dew-drops form on leaves and grass in a spring morning?
2. What is the effect of pressure and temperature variation on sublimation and deposition?
3. Why do vapors form on the handle and cylinder of a fire extinguisher when it is discharged?
4. How does sweating helps to cool our body down during exercise?
5. Consider a piece of metal X initially at a temperature of 100 °C. It is placed on a heater (which is providing heat at constant rate) until it reaches a final temperature of 400 °C. The metal has a melting point of 250 °C.

   (i) Draw a temperature-time graph illustrating the changes in temperature of metal X as it is heated.

   (ii) Now, examine a different metal, Y, which has a higher latent heat of fusion compared to metal X. Both metals have identical melting points and heat capacities. The heating procedure for metal Y is conducted under the same energy supply rate as metal X. Describe how the temperature-time graph for metal Y will differ from that of metal X, considering the implications of its greater latent heat of fusion.
6. How does the pressure in a car tyre change during a long drive on a hot day?
7. How does understanding thermal expansion help prevent cracks in sidewalks during hot weather?
8. Imagine you are stuck in the snow with your car. Which would be more effective for melting the snow trapped underneath, a pot of hot water or a high-powered heat lamp?
9. How does the evaporation of water from a plant's leaves help to transport water and nutrients throughout the plant?
10. Why does adding ice to a drink cool it down more effectively than adding cold water?
11. What are the challenges associated with maintaining the extremely low temperatures required for superconductivity to occur?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Define latent heat. Differentiate between latent heat and specific latent heat of fusion. Write their formulae.
2. Differentiate between latent heat of vaporisation and specific latent heat of vaporisation. Give their formulae and units.
3. What is evaporation? Differentiate between boiling and evaporation. On what factors evaporation depends?

4. What are linear and volume thermal expansion of solids? Discuss qualitatively the factors upon which these thermal expansions depend.
5. What are uses of thermal expansion in our daily life? Give examples
6. Explain thermal expansion of liquids in detail.
7. Discuss the application of bimetallic strips in temperature control devices like thermostats. Explain the principle of thermal expansion that allows the bimetallic strip to function, and illustrate how the differing expansion rates of the two metals are utilized in practical.
8. What is superconductivity? Explain the phenomenon in detail. What is their scope in future world?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

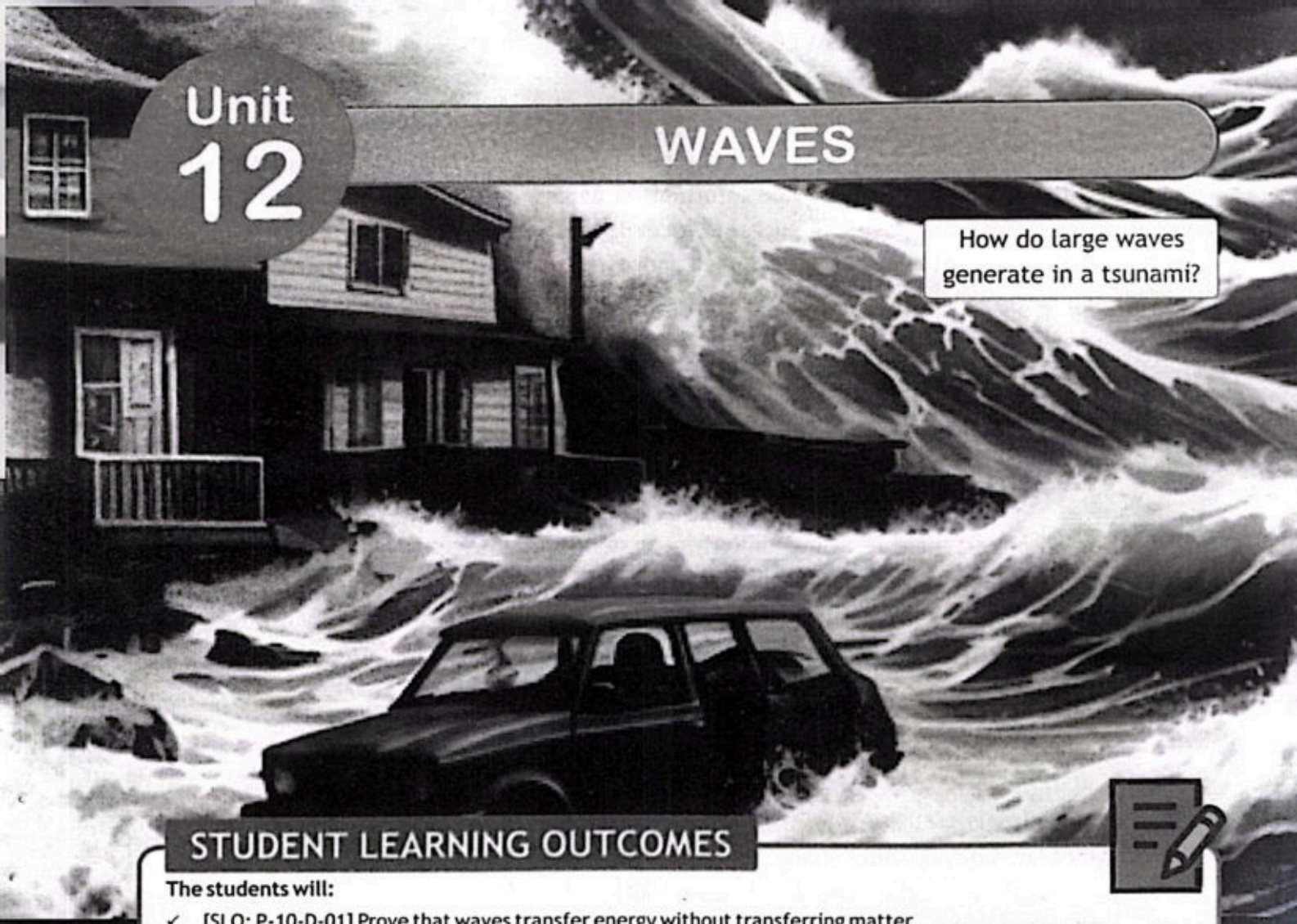
1. Consider a steel bar of length 1.5m at 10 °C. It is heated to raise its temperature to 100 °C. Calculate (a) Increase in length (b) Final length at 100 °C. (Coefficient of linear thermal expansion of steel is $1.2 \times 10^{-5}\ K^{-1}$) **(Ans. 1.62 mm, 1.5 m)**
2. A solid cube of side length 10 cm at 25 °C is heated. What will be increase in its volume at 125 °C if its coefficient of linear thermal expansion is $9 \times 10^{-6}\ K^{-1}$. **(Ans. 2.7 cm^3)**
3. A steel railroad track segment is 10 meters long at a cool morning temperature of 15 °C. The coefficient of linear expansion for steel is 1.2×10^{-5} per °C. Later in the day, the temperature rises to 30 °C. How much will the steel track segment expand in length?

   (Ans. 1.8 mm)
4. A 2-liter (2000 cm^3) glass bottle is filled completely with orange juice at a room temperature of 20 °C. The coefficient of volumetric expansion for orange juice is 5×10^{-5} per °C. If the bottle is left in a hot car where the temperature reaches 40 °C, what volume of orange juice will overflow? Expansion of glass bottle is negligible. **(Ans. 2 cm^3)**
5. How much heat is required to change 15 kg of ice into water at its melting point?

   (Ans. 4.95×10^6 J)
6. How much heat is required to change 7 kg of water into steam at its boiling point?

   (Ans. 1.58×10^7 J)
7. 4 kg of ice has temperature of -20 °C. It is heated to convert into steam. Its final temperature is 120 °C. Calculate the total amount of heat energy involve for this conversion of ice into steam. (Specific heat of ice = 2100 J $kg^{-1}\ K^{-1}$,Specific heat of water = 4200 J J $kg^{-1}\ K^{-1}$,Specific heat of steam = 2000 J J $kg^{-1}\ K^{-1}$,Latent heat of fusion of ice = 3.3×10^5 J $kg^{-1}$and Latent heat of vaporization of water = 2.26×10^6 J kg^{-1}).

   (Ans. 1.236×10^7 J)



Unit 12 WAVES

How do large waves generate in a tsunami?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-D-01] Prove that waves transfer energy without transferring matter
- ✓ [SLO: P-10-D-02] Describe what is meant by wave motion [as illustrated by vibrations in ropes and springs and by experiments using water waves.]
- ✓ [SLO: P-10-D-03] Describe the features of a wave [in terms of wavefront, wavelength, frequency, time period, crest (peak), trough, compression, rarefaction, amplitude and wave speed]
- ✓ [SLO: P-10-D-04] Define the terms frequency, wavelength, and amplitude.
- ✓ [SLO: P-10-D-05] Recall and apply the equation wave speed = frequency × wavelength ($v = f \cdot \lambda$)
- ✓ [SLO: P-10-D-06] 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 S-waves (secondary)]
- ✓ [SLO: P-10-D-07] Illustrate that for a longitudinal wave, the direction of vibration is parallel to the direction of the energy transfer [including give examples such as sound waves and seismic P-waves (primary))]
- ✓ [SLO: P-10-D-08] Describe how waves can undergo reflection, refraction and diffraction
- ✓ [SLO: P-10-D-09] Describe how wavelength affects diffraction at an edge
- ✓ [SLO: P-10-D-10] Analyze the phenomenon of tsunamis generated under the surface of water [in terms of underwater earthquakes/volcanic activity generating waves that increase in frequency and amplitude as they encounter increasingly shallow water]
- ✓ [SLO: P-10-D-11] Describe how wavelength and gap size affects diffraction through a gap

Waves are a fundamental aspect of both the natural world and technological advancements, embodying the transfer of energy and information across various mediums. From the gentle ripples on a pond to the powerful surges of ocean tides, waves are omnipresent, influencing weather patterns, communication systems, and even the fundamental structure of matter. Understanding waves involves exploring their properties, behaviors, and the principles governing their propagation, which are crucial in fields ranging from physics and engineering to medicine and environmental science. This introduction delves into the fascinating world of waves, unraveling their complexities and highlighting their significance in our daily lives and the broader universe.

12.1 WAVE MOTION

Waves play an important role in our daily life. It is because waves are carrier of energy and information over large distances. Waves require some oscillating or vibrating source. Here we demonstrate the production and propagation of different waves with the help of vibratory motion of objects, some of the waves are water waves, sound waves, electromagnetic waves etc.

12.1.1 WATER WAVES

When a stone is thrown into the water, it creates ripples that propagate outward. These ripples, or water waves, clearly transfer energy: you can see the motion of the boat bobbing up and down as the waves pass. However, the boat itself does not significantly move from its position. This illustrates that the energy from the wave causes the boat to oscillate vertically, but the boat (matter) remains mostly in the same place.

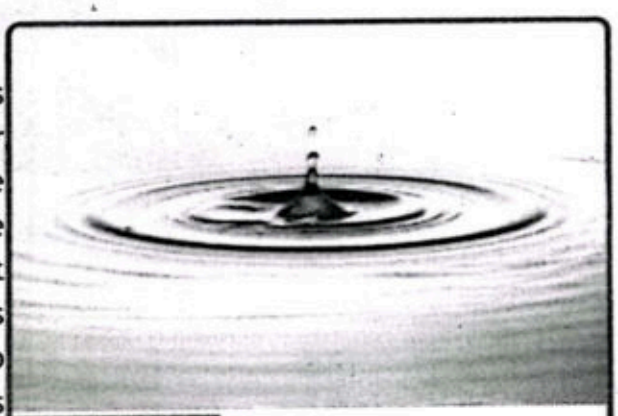
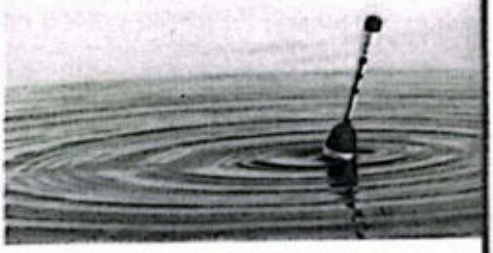


FIGURE 12.1 Water Waves

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When you drop a stone into a pond, it creates waves on the water's surface that spread outwards. If you place a cork a little distance away from where the stone fell, the cork will start to bob up and down as the waves reach it. This happens because the cork is getting energy from the waves.



This activity demonstrates that water waves, like other types of waves, transfer energy from one place to another without actually moving the water itself.

12.1.2 SOUND WAVES

When you speak, your vocal cords vibrate, producing sound waves that travel through the air. If you place your hand in front of a speaker, you can feel the vibrations of the sound waves, which indicates that energy is being transferred. However, the air molecules themselves do not travel from the speaker to your hand; they oscillate back and forth around their equilibrium positions. This oscillatory motion transfers the sound energy through the medium (air), but the individual air molecules stay relatively in place.



FIGURE 12.2 Sound Waves

12.1.3 ELECTROMAGNETIC WAVES

Consider light waves or radio waves, which are types of electromagnetic waves. When light from the sun reaches Earth, it brings energy that warms the planet and powers photosynthesis in plants. However, there is no medium like air or water involved in the transfer of electromagnetic waves through the vacuum of space. Instead, electric and magnetic fields oscillate perpendicular to each other and the direction of wave propagation, carrying energy across vast distances without the need for a material medium.



FIGURE 12.3 Electromagnetic Waves

12.1.4 WAVE IN ROPE

A wave in a rope provides a clear example of transverse wave motion, where the oscillations of the medium (the rope) are perpendicular to the direction of wave propagation.

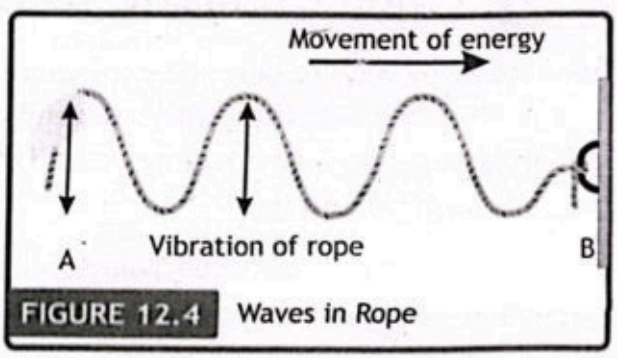


FIGURE 12.4 Waves in Rope

12.2 WAVE PROPAGATION

The key to understanding wave energy transfer without matter transfer lies in the nature of wave propagation. Waves are disturbances that travel through a medium (or space, in the case of electromagnetic waves), causing particles of the medium to oscillate around their equilibrium positions. Here's a step-by-step explanation:

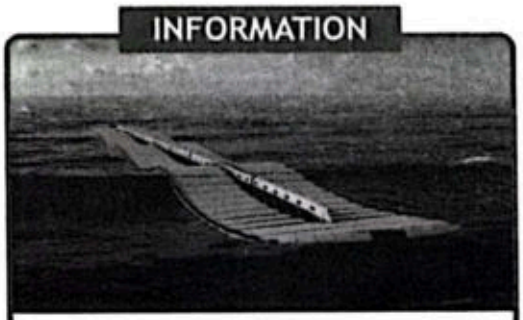
12.2.1 OSCILLATION

In a wave, particles of the medium experience periodic oscillations or vibrations. These oscillations can be longitudinal (particles move parallel to the wave direction, as in sound waves) or transverse (particles move perpendicular to the wave direction, as in water and electromagnetic waves).

12.2.2 ENERGY TRANSFER

The energy of the wave is transferred through these oscillations. For example, in a sound wave, compressions and rarefactions of air molecules transfer kinetic and potential energy from one particle to the next.

INFORMATION



Generating a high frequency wave, requires more energy per second than to generate a low frequency wave. Thus, a high frequency wave carries more energy than a low frequency wave of the same amplitude.

12.2.3 NO NET MOVEMENT

Despite the oscillatory motion, the particles of the medium do not undergo a net displacement. They return to their original positions after the wave passes. Therefore, there is no overall transfer of matter, only energy.

SCIENCE TIDBITS



A human eardrum can oscillate back and forth up to 20,000 times in one second.



12.3 CHARACTERISTIC WAVE PARAMETERS

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

12.3.1 WAVELENGTH 'λ'

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

The unit of wavelength is 'm'. The wavelength is the repeated distance of the wave pattern—a shift of the wave pattern by one wavelength to the right (or the left) reproduces the original wave pattern. The wave length may be the distance between two successive crests or troughs as shown in figure 12.5, or it may be the distance between two successive compressions.

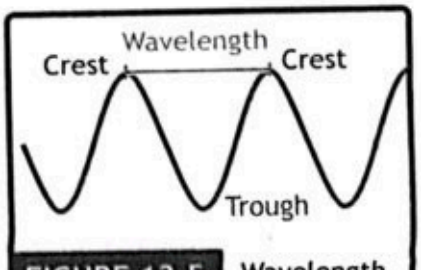


FIGURE 12.5 Wavelength

12.3.2 WAVEFRONT

Huygens stated that light is a wave propagating through space like ripples in water or sound in air. Hence, light spreads out like a wave in all directions from a source. The locus of all points that travelled some distance during a fixed interval is called a wavefront.

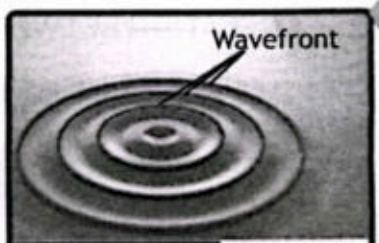


FIGURE 12.6 Wavefront

12.3.3 WAVE CREST AND TROUGH

A crest point on a wave is the maximum value of upward displacement within a cycle. A crest is a point on a surface wave where the displacement of the medium is at a maximum. A trough is the opposite of a crest, so the minimum or lowest point in a cycle.

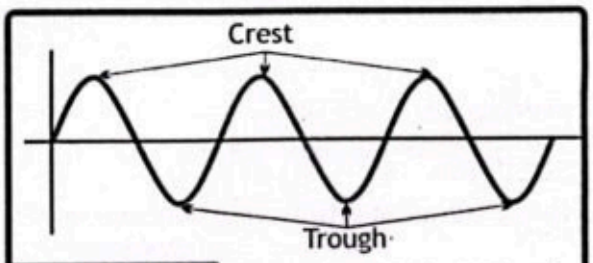


FIGURE 12.7 Wave Crest & Wave Trough

12.3.4 DISPLACEMENT

The separation between mean position and any point either on right or left of the mean position is called displacement (x). Displacement is measured in meters (m).

12.3.5 AMPLITUDE

The maximum displacement form mean on either side is called amplitude (x_o). As amplitude is also a displacement that's why is measured in meters (m).

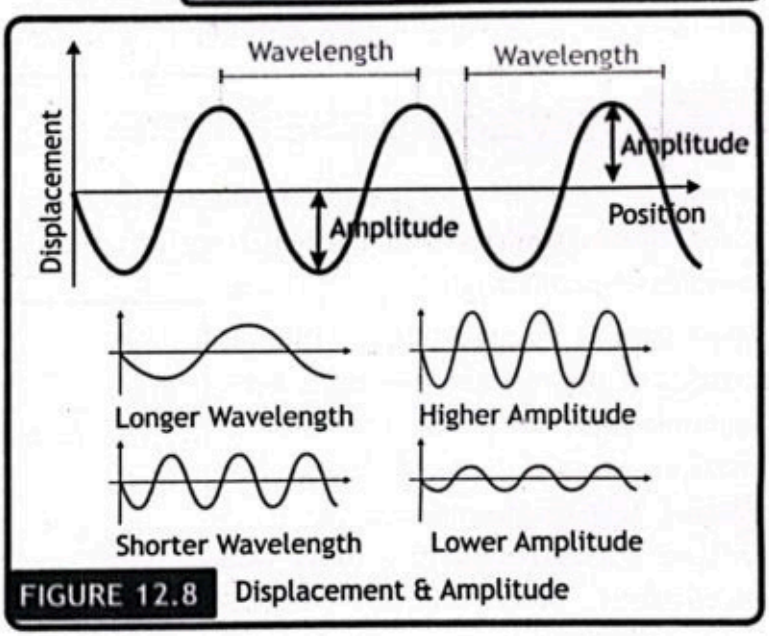


FIGURE 12.8 Displacement & Amplitude

12.3.6 TIME PERIOD

The maximum displacement form mean on either side is called amplitude (x_o). As amplitude is also a displacement that's why is measured in meters (m).

12.3.7 FREQUENCY

The number of cycles completed by an oscillating body in one second is called frequency (f). It is measured in cycles per second (cps) or hertz (Hz).

12.3.8 RELATION BETWEEN TIME PERIOD AND FREQUENCY

Time period and frequency are reciprocal of each other. Greater the time period smaller will be the frequency and vice versa.

$$T = \frac{1}{f} \quad \text{— 12.1}$$

Example 12.1

A student oscillates a pendulum having 5 vibrations per second, Calculate its time period.

GIVEN:
Frequency 'f' = 5 Hz

REQUIRED:
Time Period 'T' = ?

SOLUTION:
Using frequency-time relation, we have: $T = \frac{1}{f}$ putting values $T = \frac{1}{5\,Hz}$

Therefore $T = 0.2\,s$ — ANSWER

So the pendulum will oscillate with a period of 0.2 s.

12.4 WAVES AND THEIR TYPES

Waves are carrier of energy and information over large distances. Wave is a disturbance that moves outward from its point of origin, transferring energy by means of vibrations with little or no transport of medium.

Wave motion is related to oscillation as particles of the medium execute simple harmonic motion about their mean position when a wave passes. For example, take a rope and colour a part of it. Attach one end of the rope to the wall and wiggle the other end continuously. A wave train will be produced. The colored part of rope will execute oscillations about certain mean position, as shown in figure 12.9 (b).

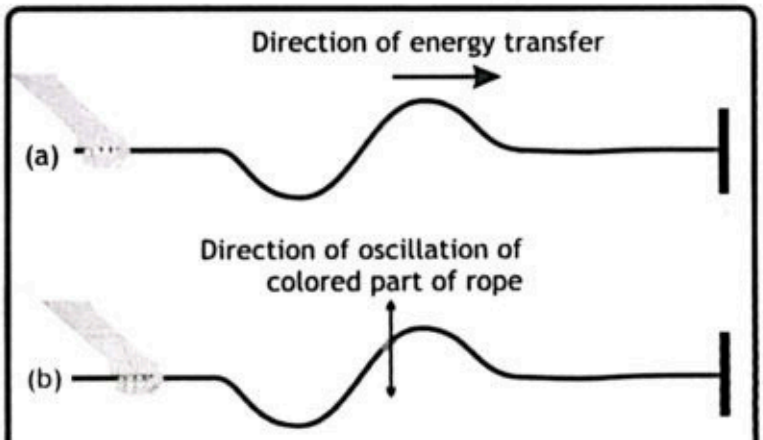


FIGURE 12.9 Direction of energy and oscillation

12.5 TYPES OF WAVES ON THE BASIS OF MEDIUM

Waves are divided into two types on the basis of medium requirement.

A. Mechanical waves: Such types of waves which require material medium to propagate from one

POINT TO PONDER



We receive sun light (electromagnetic wave) but not the sound (mechanical wave) of fusion reactions occurring at the surface of earth. It is because there is vacuum in between earth and sun. Light waves can travel in vacuum but sound waves cannot.



point to another point are called mechanical waves. If medium does not exist, mechanical waves cannot travel from one point to another point. For example, sound wave, rock wave in water, seismic wave etc.

B. Electromagnetic waves: Such type of waves which do not require material medium to propagate from one point to another point are called electromagnetic waves. It means that the existence of material medium is not necessary for propagation of electromagnetic waves. It consists of electric and magnetic fields as shown in figure 12.10. Examples of electromagnetic waves are light waves, x-rays, ultraviolet waves, infrared waves etc.

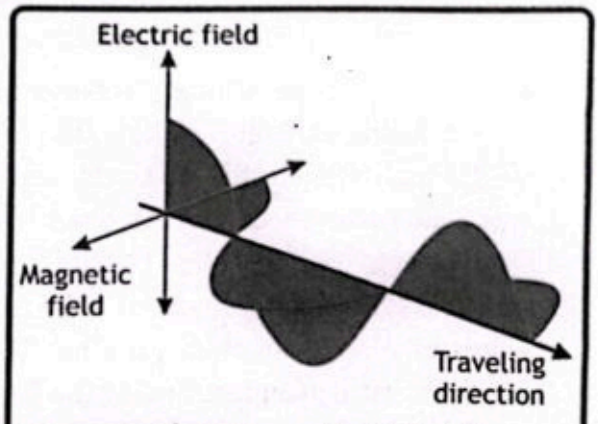


FIGURE 12.10 Travelling of Electromagnetic wave

12.6 TYPES OF WAVES ON THE BASIS OF PROPAGATION

Waves are divided into two types on the basis of their propagation.

12.6.1 TRANSVERSE WAVES

The type of waves in which the disturbance occur perpendicular to the direction of motion of the waves are termed as transverse waves. This means the vibrations are at right angles to the wave's motion as shown in figure 12.11. Transverse waves are common in nature and can be observed in various forms. Waves produced in a string when its one end is fixed to a support and the other end is moved up and down is an example of transverse waves.

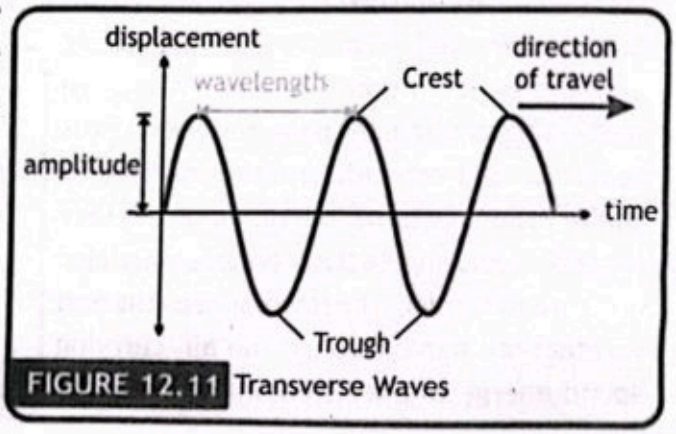


FIGURE 12.11 Transverse Waves

A. Electromagnetic Radiation: Electromagnetic waves, such as light, X-rays, and radio waves, are examples of transverse waves. These waves do not require a medium

to travel. The electric and magnetic fields vibrate at right angles to each other and to the direction of energy transfer. For example, sunlight travels through space as an electromagnetic wave, bringing energy from the Sun to Earth.

B. Waves on the Surface of Water: Waves on the surface of water are another example of transverse waves. The water particles move up and down (vibration), while the wave energy travels horizontally across the surface. For instance, when a stone is thrown into a pond, ripples spread outwards from the point of impact, showing the transverse motion of the water particles.

C. Seismic S-Waves (Secondary Waves): Seismic S-waves, produced during earthquakes, are transverse waves that move through the Earth. In these waves, the ground vibrates side-to-side or up-and-down, while the wave energy travels horizontally. Unlike P-waves, S-waves cannot travel through liquids, as they require the shear strength of a solid medium for their vibrations. These waves are critical in understanding the Earth's interior and locating earthquake epicenters.

DO YOU KNOW?

Do mechanical waves pass through vacuum, that is, empty space?

DO YOU KNOW?



Earthquake produces waves through the crust of the Earth in the form of seismic waves. By studying such waves, the geophysicists learn about the internal structure of the Earth and information about the occurrence of future Earth activity.

12.6.2 LONGITUDINAL WAVES

Type of waves in which the disturbance occur parallel to the line of travel of the wave are termed as longitudinal waves. This means that the vibrations and the energy transfer occur along the same line. A longitudinal wave can be generated with a Slinky, as shown in Figure12.12. When one end is pushed forward along its length (i.e., longitudinally) and then pulled back to its starting point, as in part a, a region where the coils are compressed together is sent traveling to the right.

Parts of the wave having higher density and pressure are called compressions and parts having smaller density and pressure are called rarefactions.

A. Sound Waves: Sound waves are a classic example of longitudinal waves. When we speak, the air particles near our vocal cords compress and expand, creating regions of compression (where particles are close together) and rarefaction (where particles are spread apart). These compressions and rarefactions move through the air, carrying sound energy to the listener. For instance,

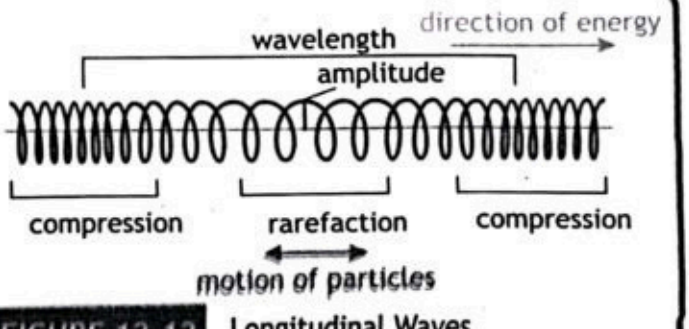
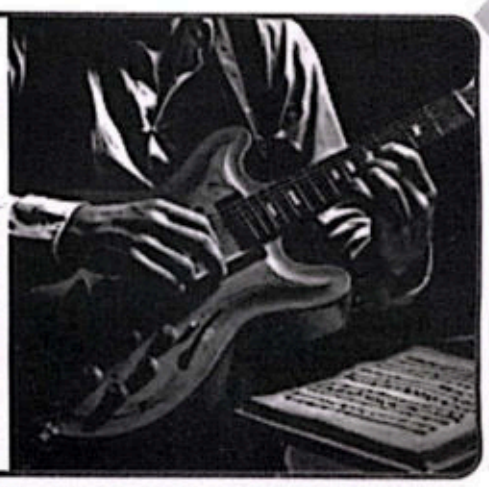


FIGURE 12.12 Longitudinal Waves

SCIENCE TIDBITS



When you pluck a guitar string, it produces transverse waves along the string, meaning the vibrations move perpendicular to the length of the string. These transverse vibrations then cause the air around the string to vibrate, producing sound waves.



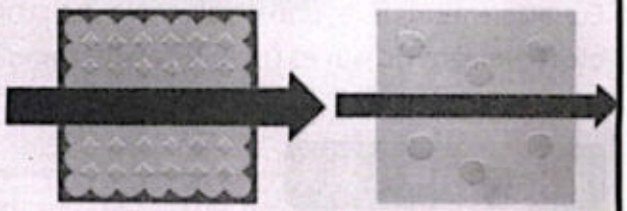
Sound waves are longitudinal waves, which mean the vibrations occur in the same direction as the wave travels, compressing and rarefying the air molecules to create the sound we hear. So, while the motion on the string is transverse, the resulting sound waves in the air are longitudinal.

when we clap, the sound travels as longitudinal waves through the air to reach someone nearby.

B. Seismic P-Waves (Primary Waves): Seismic P-waves, generated during earthquakes, are another example of longitudinal waves. These waves cause particles in the Earth to vibrate back and forth in the same direction as the wave's movement. P-waves are the fastest type of seismic wave and can travel through solids and liquids. These characteristic helps scientists study the Earth's structure and detect earthquakes. For example, the time difference between the arrival of P-waves and slower S-waves at a seismic station helps determine the location of the earthquake's epicenter.

INFORMATION

Longitudinal waves move faster through solids than through gases or liquids. Transverse waves move through solids at a speed of less than half of the speed of longitudinal waves. It is because the restoring force exerted during this up and down motion of particles of the medium is less than the restoring force exerted by a back and forth motion of particles of the medium in case of longitudinal waves.



Fastest in solids Slowest in gases

12.7 WAVE CHARACTERISTICS

Some of the main characteristics of waves are as follows:

A. Wave Cycle: As a wave passes a given point along its path, that point undergoes cyclic motion. The point is displaced first in one direction and then in the other direction. Finally, the point returns to its original equilibrium position, there by completing one cycle. Number of wave cycles are represented by 'N'. As it is a pure number, so it has no unit.

B. Frequency: The number of wave cycles passing through some point per unit time is called frequency of the waves. Mathematically:

$$f = \frac{N}{t} \quad \text{— 12.2}$$

Frequency is measured in Hertz (Hz).

C. Time Period: The time required for one wave cycle to pass through certain point is called Time Period. It is represented by "T" and its unit seconds (s).It is the time any vibrating element of wave takes to move through one complete oscillation. Time period is the reciprocal of frequency. Mathematically:

$$T = \frac{1}{f} \quad \text{— 12.3}$$

D. Wave Speed: The distance travelled by a wave per unit time is called wave speed. Mathematically:

$$\text{Wave speed } v = \frac{\Delta d}{\Delta t} \quad \text{— 1}$$

If a wave travels distance equal to its wavelength 'λ', then the time taken will be equal to its time period 'T'. Putting these values in equation 1:

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

As frequency is reciprocal of time period, given from equation 12.3, putting in equation 2:

$$v = f\lambda \quad \text{— 12.4}$$

Equation 12.4 is a universal wave equation that can be used for all types of waves. For electromagnetic waves travelling with speed 'c', equation 12.4 can be given by:

$$c = f\lambda \quad \text{— 12.5}$$

Example 12.2

An athlete in the gym moves one end of a rope up and down, whose other end is fastened with a wall, with a speed of 2.5 m/s. It produces oscillations whose wavelength is 0.5 m. Calculate the frequency of waves generated in the rope.

GIVEN:
Wavelength 'λ' = 0.5 m
Wave speed 'v' = 0.5 m/s

REQUIRED:
Frequency 'f' = ?

SOLUTION:
By universal wave equation: $v = f\lambda$ or $f = \frac{v}{\lambda}$ putting values $f = \frac{2.5 m/s}{0.5 m}$

Therefore $f = 5 Hz$ — ANSWER

The rope therefore oscillates at 5 times per second.

Example 12.3

Find the wavelengths of the lowest and highest frequency sounds that human can hear which travels with a speed of 343 m /s in air?

GIVEN:
Lowest frequency 'f_1' = 20 Hz
Highest frequency 'f_2' = 20,000 Hz
Speed of sound 'v' = 343 m/s

REQUIRED:
Low Wavelength 'λ_1'= ?
High Wavelength 'λ_2'= ?

SOLUTION:
By universal wave equation: $v = f\lambda$ or $\lambda = \frac{v}{f}$

For lowest frequency sound, the above equation becomes: $\lambda_1 = \frac{v}{f_1}$

putting values: $\lambda_1 = \frac{343\,m/s}{20\,Hz}$ Therefore $\boxed{\lambda_1 = 17.15\,m}$ — ANSWER

Similarly for highest frequency sound: $\lambda_2 = \frac{v}{f_2}$

putting values $\lambda_2 = \frac{343\,m/s}{20{,}000\,Hz}$ Therefore $\boxed{\lambda_2 = 0.017\,m}$ — ANSWER

12.8 PROPERTIES OF WAVES

The basic properties of waves like reflection, refraction and diffraction can be described with the help of a ripple tank by using water waves. Ripple tank is also used to calculate frequency, wavelength and speed of waves on water's surface. It also analyzes the characteristics of waves like transverse and longitudinal behavior.

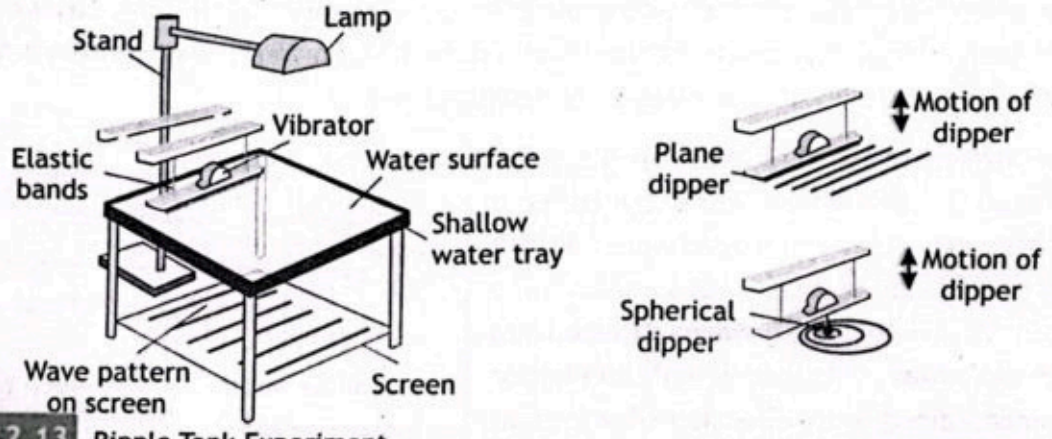


FIGURE 12.13 Ripple Tank Experiment

Basic Construction and working: A ripple tank consists of shallow tray of water with a transparent base, usually illuminated from above, so that light shines through the water. The ripples on the water show up as shadows (bright and dark lines) on the screen underneath the tank. The ripples are created by a small electric motor (vibrator). The motor has an off-center weight attached. When the motor is turned-on, it makes the strip vibrate and thus create ripples on the surface of water. Straight waves can be set up by using a straight dipper while circular waves can be formed by using a spherical dipper.

In order to get consistent plane waves, the motor assembly is lowered until it just touches the surface of water and the motor is then turned on. You should be able to see straight waves being created which travel across the surface of the tank, often called plane waves.

By lighting the wavefronts being created, clear peaks and troughs can be seen on the screen as shown in figure 12.13. The imaginary surface representing corresponding points (crests and troughs) of a wave that vibrate in unison is called a wavefront. It may be plane or spherical depending upon the dipper used

12.8.1 REFLECTION

The change in direction of a wave front at an interface between two different media or rigid barrier so that the wavefront returns in to the medium from which it is originated is called reflection as shown in figure 12.14. When a wavefront strikes a straight rigid barrier or irregular surface, it is reflected back along its original path.

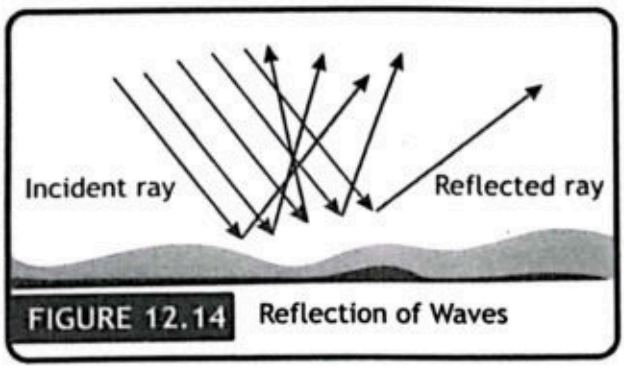


FIGURE 12.14 Reflection of Waves

12.8.2 REFRACTION

When waves travel from one medium into another its speed changes and in some cases divert from its original path, the phenomenon is called refraction. When a water wave enters a medium in which it moves more slowly, its wavelength decreases as well.

The phenomenon of refraction can be demonstrated in the ripple tank by using a boundary between shallow and deep water. A thick plastic sheet is placed in the tray at some angle to the wavefront. When water waves travel from shallow to deep water, its wavelength and hence speed changes along with direction of waves as shown in figure 12.15.

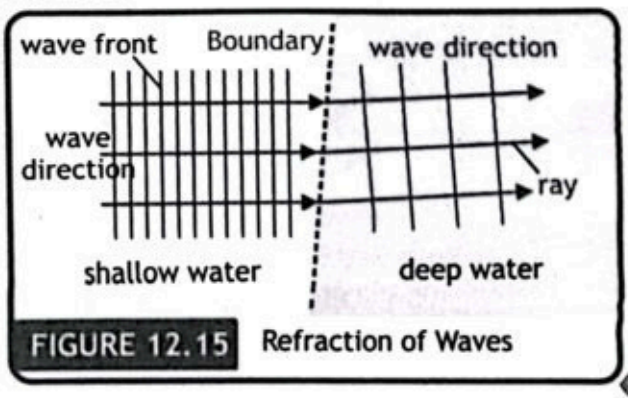
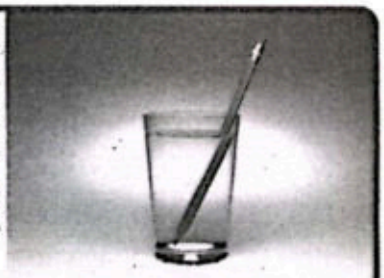


FIGURE 12.15 Refraction of Waves

MINI LAB

Place a pencil in the water, placing it so that it is tipped to one side. Look through the front of the glass and notice that the pencil is bent. The science behind it: Light "bends" when it passes though one substance to another of a different density.



12.8.3 DIFFRACTION

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

We can observe the phenomenon of diffraction in a ripple tank by generating straight waves and place two obstacles in such a way that the separation is comparable to the wavelength of the waves generated in the ripple tank. Waves, after passing through the narrow opening, spread out in every direction and turn into circular waves. This effect is greatest when the size of the opening is less than or equal to the size of the wavelength of generated waves as shown in figure 12.16 (a).

It is, however, to be noted that wavelength (or speed) of the wave is not affected by diffraction. If the separation is large between obstacles compared to the wavelength, it can be seen that central part of the wave is not affected, only part of the wave at the edges diffracts as shown in the figure 12.16 (b).

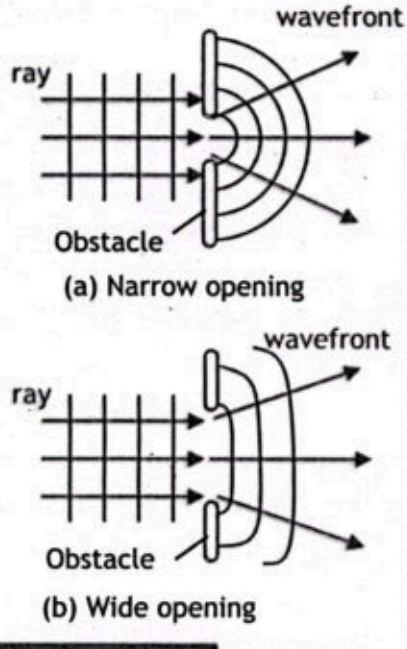


FIGURE 12.16 Diffraction

A. Wavelength and Diffraction: The wavelength is the distance between consecutive crests (or troughs) of a wave.

- **Shorter Wavelengths:** Waves with shorter wavelengths diffract less. If the wavelength is much smaller than the size of the gap, the waves will primarily travel straight through with minimal spreading.
- **Longer Wavelengths:** Waves with longer wavelengths diffract more. This means that if the wavelength is large compared to the size of the gap, the waves will spread out significantly after passing through the gap.

UV light, which has a shorter wavelength, diffracts less than IR light, which has a longer wavelength, as shown in figure 12.17.

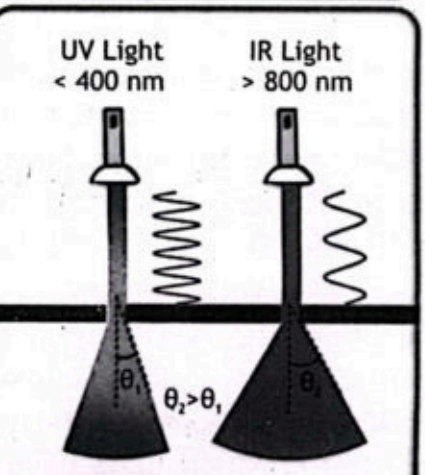


FIGURE 12.17 Wavelength and diffraction

B. Gap Size and Diffraction: The size of the opening through which the waves pass.

- ***Narrow* Gaps:** When the gap size is comparable to or smaller than the wavelength of the wave, significant diffraction occurs. The waves spread out widely on the other side of the gap.
- **Wide Gaps:** When the gap size is much larger than the wavelength, diffraction is minimal. The waves pass through the gap with only slight spreading, and most of the wave energy remains in the original direction of propagation.

For example sound waves have relatively large wavelength that is why they can diffract around obstacles and through openings, allowing you to hear sounds even when you can't see the source. Whereas light wave has much shorter wavelength, visible light has a wavelength range from about 400 nm to 700 nm. When light passes through a slit or an aperture that is much larger than its wavelength, there is minimal diffraction, and the light beam remains well-defined. However, if the slit is on the order of the light's wavelength (as in a diffraction grating), significant diffraction and interference patterns can be observed.

12.9 TSUNAMIS

A tsunami is a series of large ocean waves created by underwater disturbances. These waves travel quickly across the ocean and can reach great heights when they approach the shore, causing massive flooding and damage to coastal areas as shown in figure 12.17 .



FIGURE 12.18 Tsunami destruction

12.9.1 TSUNAMI GENERATION

Tsunamis are most commonly caused by underwater earthquakes, especially those that happen at tectonic plate boundaries where one plate is pushed beneath another. This sudden movement of the ocean floor displaces a large amount of water, resulting in powerful waves that travel across the ocean as shown in figure 12.18. Tsunamis can also be triggered by underwater volcanic eruptions, as the explosion displaces water and creates waves that spread outward. Additionally, landslides occurring under the ocean can displace water and generate tsunamis. The movement of sediment and rock on the seafloor causes water displacement, leading to the formation of tsunamis. Although rare, large meteorites impacting the ocean can also cause massive waves due to the significant displacement of water.

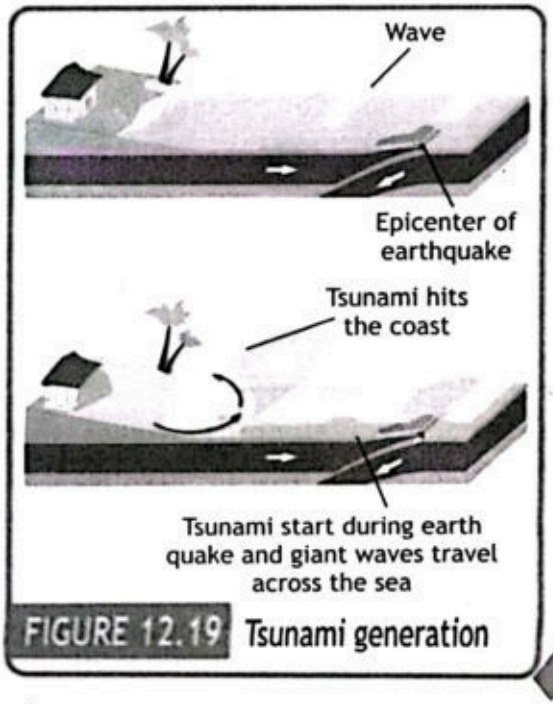


FIGURE 12.19 Tsunami generation

12.9.2 CHARACTERISTICS OF TSUNAMIS

Tsunami waves move quickly across the ocean after the initial disturbance, often traveling at speeds of 500-800 km/h (310-500 mph). In deep waters, the waves are not very high, making them hard to spot. However, as they near the coast, their speed slows down while their height increases significantly as the wave energy gets compressed.

DO YOU KNOW?

Lituya Bay, Alaska, July 9, 1958 A notable exception was the 1958 tsunami triggered by a landslide in a narrow bay on Alaska's coast. Its over 1,700-foot wave was the largest ever recorded for a tsunami.

When tsunamis hit land, they can cause massive destruction with their towering height and powerful energy, flooding coastal regions, demolishing structures, and resulting in substantial loss of life and property.

SUMMARY

- **Wave** is the energy transfer mechanism without the transport of material media.
- **Mechanical Waves** are the waves that require medium for their propagation.
- **Electromagnetic waves** are the waves that do not require any media for their propagation.
- **Transverse waves** are the waves in which particles of the medium vibrate/oscillate perpendicular to the direction of motion of waves.
- **Longitudinal waves** are the waves in which particles of the medium vibrate/oscillate parallel to the direction of motion of waves.
- **Seismic waves** are caused by the sudden movement of materials within the Earth, such as slip along a fault during an earthquake.
- **Reflection** is the throwing back by a body or surface of light, heat, or sound without absorbing it.
- **Refraction** is the change in direction of a wave passing from one medium to another caused by its change in speed.
- **Diffraction** is the bending of waves around the edges of an obstacle.
- **Tsunamis** are a series of enormous ocean waves caused by earthquakes, underwater landslides, volcanic eruptions or asteroids.

EXERCISE



MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. If a body performing simple harmonic motion completes its one vibration in 2 seconds, its frequency of vibration is:

   A. 2 Hz B. 1 Hz C. 0.5 Hz D. 10 Hz

2. 360 waves are passing through a point in a river in one hour, time period of the wave is:

   A. 0.1 s B. 1 s C. 10 s D. 100 s

3. Time period of electrical vibrator of ripple tank is 0.5 s, water waves in ripple tank has speed of 10 m/s and amplitude of 5 cm. Calculate the frequency of the waves.

   A. 50 Hz B. 0.5 Hz C. 200 Hz D. 2 Hz

4. Which of the followings is longitudinal wave?

   A. X- rays B. Light C. String waves D. Sound

5. When water waves enter from deep water to shallow water:

   A. Frequency of water waves increases B. Time period of water waves decreases

   C. Speed of water waves decreases D. Wavelength of water waves increases

6. Listening to radio transmission in deep valleys of mountain areas is due to:

   A. Reflection of waves B. Refraction of waves

   C. Interference of waves D. Diffraction of waves

7. Which of the following are transverse waves:

   A. X- rays B. Light C. String waves D. All of these

8. Tsunamis are most often generated by

   A. Flood B. Bomb blast C. Earth quake D. None of these

9. Waves transfer:

   A. energy B. frequency C. wavelength D. velocity

10. Which of the following characteristics of a wave is independent of the others?

    A. speed B. frequency C. amplitude D. wavelength

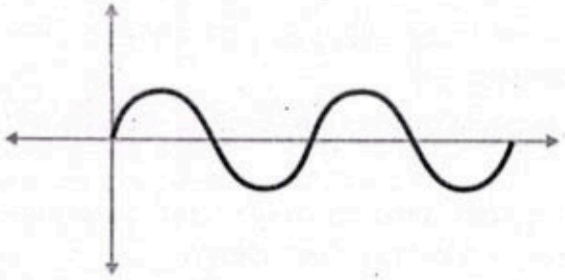
11. The relation between v, f and λ of a wave is:

    A. $v f = \lambda$ B. $f \lambda = v$ C. $v \lambda = f$ D. $v = \lambda / f$

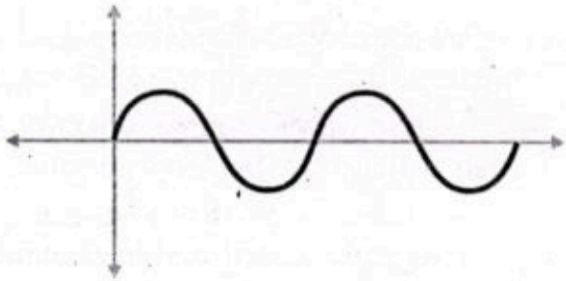
CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. (a) In the graph below represent crest, trough and origin. (b) Also in similar graph drawn again show displacement, amplitude and wavelength.



(a)



(b)

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. What will happen to frequency of waves in a ripple tank if time period of electrical vibrator is decreased? What will happen to speed of waves?
2. What will happen to wavelength, speed, frequency and time period of the water waves in ripple tank if water waves enter from deep water to shallow water regions?
3. Nuclear fusion explosions are taking place at Sun, we get heat on earth but do not hear sound. Why?
4. Why do water waves refract at the boundary of shallow water and deep water? Relate this behavior to refraction of light.
5. Classify different wave types based on whether they require a medium for propagation. Justify why electromagnetic waves do not need a medium.
6. Under what conditions maximum diffraction of waves occurs?
7. Distinguish between reflection and refraction by describing how each process affects wave direction and speed. Design an experiment to demonstrate both phenomena using a ripple tank, and evaluate how changes in medium affect each process.

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. How does a wave transfer energy without transferring matter? How does this principle apply to different media like ropes, water, and air?

2. Describe the key characteristics of a wave (wavelength, frequency, amplitude) and their relationships to each other. How do these characteristics affect the wave's energy and behavior?
3. Explain the relationship between wave speed, frequency, and wavelength using the equation $v = f\lambda$. Analyze a scenario where one of these variables changes and discuss the impact on the others.
4. Compare and contrast transverse and longitudinal waves, providing examples of each. Why is this distinction important in understanding wave behavior?
5. Describe how waves undergo reflection, refraction, and diffraction. Analyze a real-world scenario to illustrate these phenomena.
6. How does the wavelength of a wave affect its diffraction pattern? What factors determine the extent of diffraction, and how can this principle be applied in technology?
7. Explain the formation of tsunamis due to underwater earthquakes. Discuss how these waves change as they move from deep to shallow water and their potential impacts.
8. How does the amplitude of a wave relate to the amount of energy it carries? Use mathematical reasoning and real-world examples to support your answer.
9. Differentiate between primary (P) and secondary (S) seismic waves. How do these waves provide insights into the Earth's internal structure?
10. Discuss practical applications of wave reflection, refraction, and diffraction in technology. Provide examples and analyze their significance.

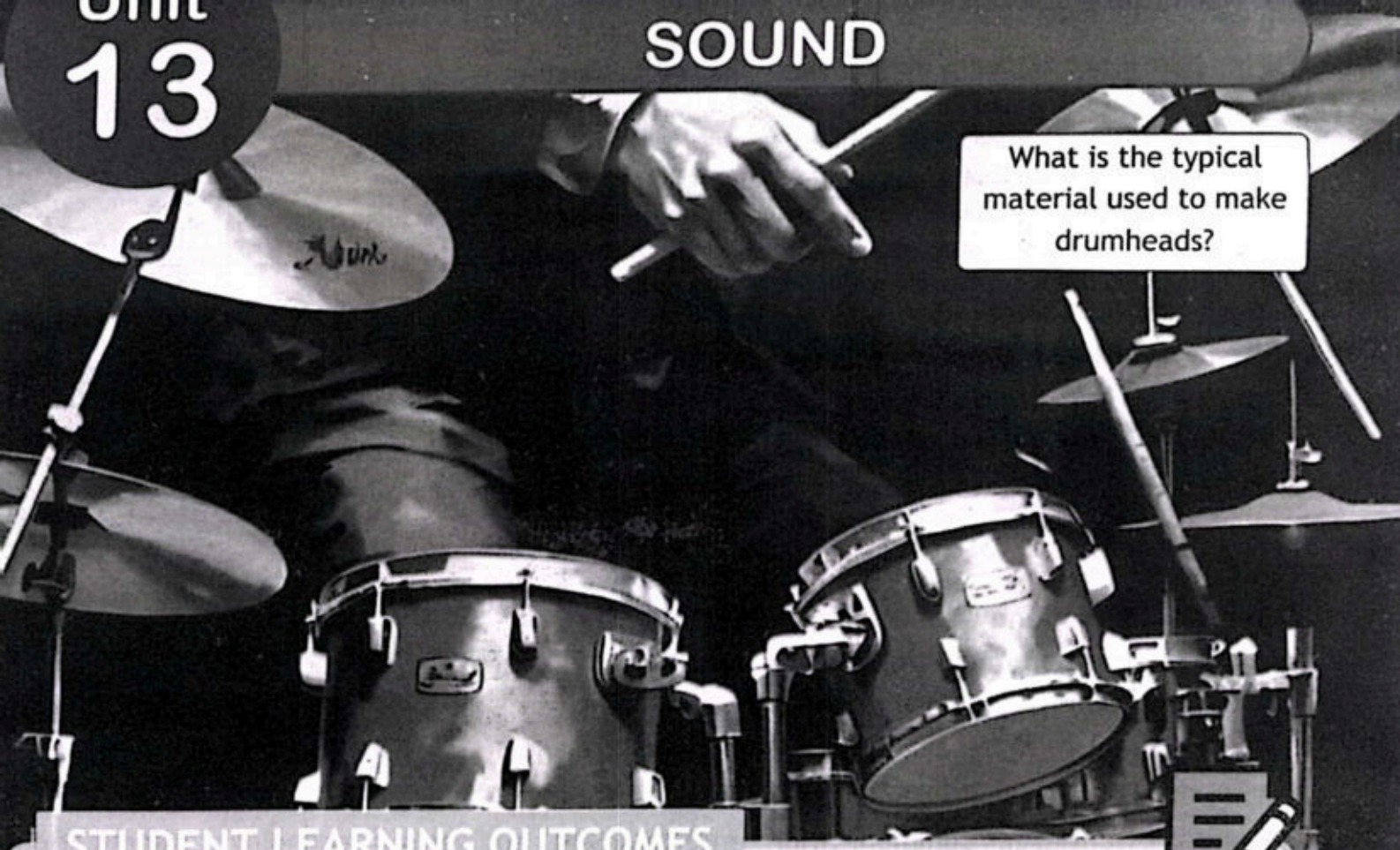
NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. If 10 waves are produced on a long-stretched string of length 20 m. What is wavelength of the waves? What will be frequency of the wave if speed of waves is 12 ms^{-1}. **(Ans. 2 m, 6 Hz)**
2. In a ripple tank of length 1.5 m, waves cover this length in 2 seconds. If distance between two successive crest and trough is 10 cm then find the number of waves, frequency of waves and their time period? **(Ans. 7.5 waves, 3.75 Hz, 0.266 s)**
3. Calculate the frequency of red light of wavelength 700 nm in vacuum? **(Ans. 4.29×10^{14} Hz)**
4. A wooden bar vibrating into the water surface in a ripple tank has a frequency of 12 Hz. The resulting wave has a wavelength of 3 cm. What is the speed of the wave? **(Ans. 0.36 m s^{-1})**
5. What is the wavelength of the radio-waves transmitted by an FM station at 90 Mhz? **(Ans. 3.33 m)**

Unit 13

SOUND



STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-D-12] Describe the production of sound.
- ✓ [SLO: P-10-D-13] Describe the longitudinal nature of sound waves.
- ✓ [SLO: P-10-D-14] State the approximate range of frequencies audible to humans as 20Hz to 20000Hz.
- ✓ [SLO: P-10-D-15] Justify why sound waves cannot travel in a vacuum.
- ✓ [SLO: P-10-D-16] Describe how changes in amplitude and frequency affect the loudness and pitch of sound waves.
- ✓ [SLO: P-10-D-17] Describe how different sound sources produce sound waves with different timbres.
- ✓ [SLO: P-10-D-18] Describe an echo as the reflection of sound waves.
- ✓ [SLO: P-10-D-19] Justify simple experiments to show the reflection of sound waves.
- ✓ [SLO: P-10-D-20] Illustrate a method involving a measurement of distance and time for determining the speed of sound in air.
- ✓ [SLO: P-10-D-21] State that the speed of sound in air is approximately 330 - 350m/s.
- ✓ [SLO: P-10-D-22] Describe that, in general, sound travels faster in solids than in liquids and faster in liquids than in gasses.
- ✓ [SLO: P-10-D-23] Define ultrasound as sound with a frequency higher than 20 kHz.
- ✓ [SLO: P-10-D-24] Illustrate and analyze the uses of Ultrasound [in cleaning, prenatal and other medical scanning, and in sonar.
- ✓ [SLO: P-10-D-25] Illustrate the use of infrasound.
- ✓ [SLO: P-10-D-26] Analzye the effects of noise pollution on the environment.

- ✓ [SLO: P-10-D-27] Justify the importance of acoustic protection.
- ✓ [SLO: P-10-D-28] Describe how knowledge of the properties of sound waves is applied in the design of buildings with respect to acoustics.
- ✓ [SLO: P-10-D-29] Explain the use of soft materials to reduce echo sounding.
- ✓ [SLO: P-10-D-30] Explain, with examples, how sound can reflect, refract and diffract.
- ✓ [SLO: P-10-D-31] Explain how sound is converted by the eardrum and nerves into electrical signals that are then interpreted by the brain.

Sound is a mechanical wave that originates from the vibration of particles in a medium such as air, water, or solids. These vibrations create longitudinal waves, where particles oscillate parallel to the direction of wave propagation, causing regions of compression and rarefaction. The properties of sound waves, including frequency, amplitude, and speed, determine the characteristics of the sound, such as pitch and loudness. Sound waves require a medium to travel, and their behavior can be influenced by reflection, refraction, diffraction, and interference.



FIGURE 13.1 Sound Devices

Sound is essential for communication, entertainment, and various technological applications, making its study important in diverse fields.

13.1 SOURCE OF SOUND

That object which is basically the cause of vibration is called Source of Sound. For Example; Our clapping hands, chirping birds, Musical instruments etc. as shown in figure 13.2.

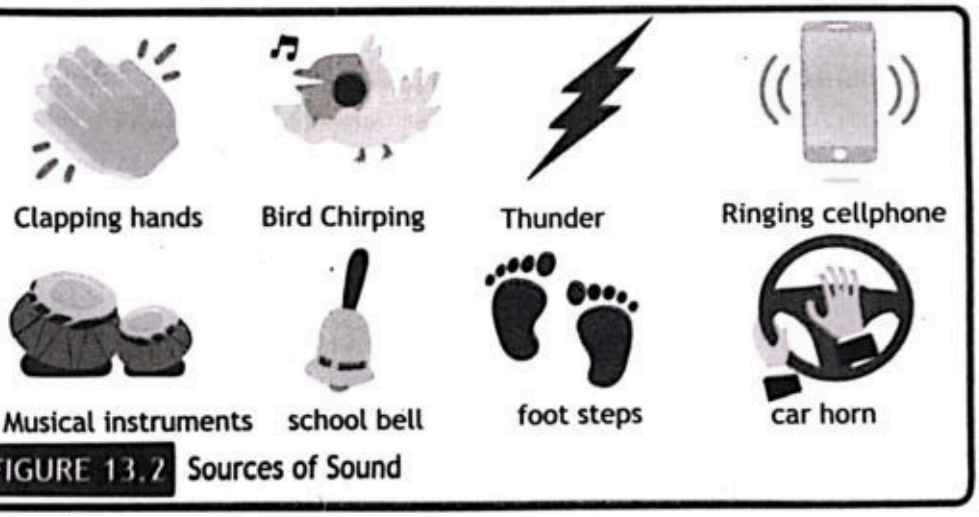


FIGURE 13.2 Sources of Sound

POINT TO PONDER



A stethoscope works by transmitting sound from the chest-piece to the listener's ears through air-filled hollow tubes. The chest-piece typically has a plastic disc known as the diaphragm. The diaphragm picks up vibrations from physiological noises.

These vibrations create acoustic pressure waves, which travel up the tubing to the listener's ears after multiple reflections.



13.1.1 HOW SOUND IS PRODUCED?

Production of sound totally depends upon vibration of object. Vibrating source transforms energy, due to vibration and it compels to the surrounding medium to vibrate through which sound wave travels. The surrounding medium particles obey to and fro motion. Basically sound waves are such waves which produce sensation of listening when strike with ear drum. Production of pressure waves are the main cause of vibration, later on it collides with our auditory system resultantly we are able to listen sound. Sounds surround us from machines and vehicles to birds and conversations. Experiments show that vibrations are essential for sound production, such as: blowing across a bottle, Plucking a stretched rubber band, flapping cardboard or bird wings and striking a bell or drumhead.

Let's perform a very simple and short duration experiment to show the vibration is necessary for production of sound. Few things are required in this experiment like Tuning fork, rubber- pad, Glass and water only. First of all take glass which is filled with full of water. Secondly hit tuning fork on rubber pad and touch one prong of vibrating tuning fork very gently with surface of water as shown in figure; 13.3(a). In third step, vibrating tuning fork will be dipped vertically into glass of water as shown in figure; 13.3 (b).

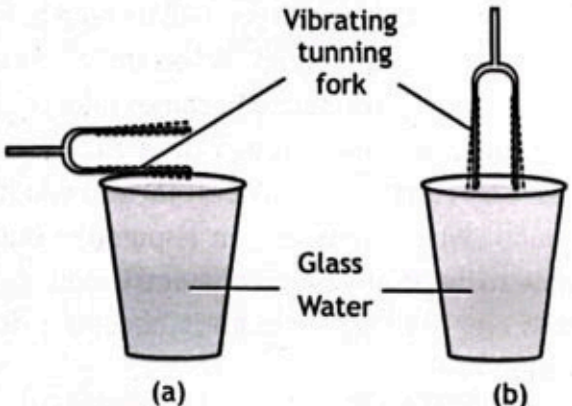


FIGURE 13.3 Production of sound

In both of the above positions of vibrating tuning fork, sound can be observed due to vibration of tuning fork with particles of medium (water molecules). This experiment can be performed with empty glass and sound of vibration of tuning fork can also be heard, but in both cases sound impact will be different because in empty glass air exists so sound impact is smaller as compare to presence of water.

INFORMATION



Bats can hear frequencies up to 120,000 Hz. Other animals cannot hear such high-pitched sounds. Mice can hear frequencies up to 100,000 Hz, dogs up to 35,000 Hz, and cats up to 25,000 Hz. Humans hear sounds only upto about 20,000 Hz, but children can usually hear higher-frequency sounds than adults

13.1.2 MEDIUM FOR PROPAGATION OF SOUND

As we know that sound waves are mechanical longitudinal in nature so for propagation of sound waves from one point to another point medium is required. Without the existence of medium these waves may be produced by vibrating objects but cannot travel from one place to another place. For example; in class room if air does not exit, students will be able to listen all lecture points are delivered by teacher. Let's discuss a very simple experiment for understanding the importance of medium for propagation of sound waves.

Let's take an electric bell and an airtight glass bell jar. The electric bell is suspended inside the airtight bell jar. The bell jar is connected to a vacuum pump, as shown in figure13.4.

If you press the switch you will be able to hear the bell. Now start the vacuum pump. When the air in the jar is pumped out gradually, the sound becomes fainter, although the same current is passing through the bell. After some time when less air is left inside the bell jar you will hear a very feeble sound. When complete air is pumped out, you will not be able to listen any sound of electric bell. By this experiment; it is cleared that medium is necessary for propagation of sound wave.

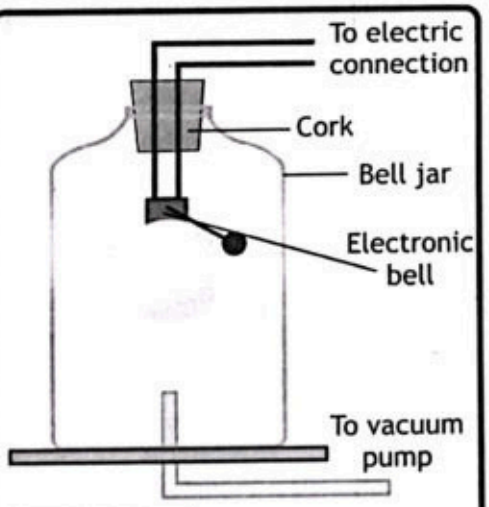


FIGURE 13.4 Propagation of Sound

MINI LAB

Make a String Telephone:

Cut a length of string and thread it through the hole in each cup. Tie a paper clip on the end of each string, on the inside of the cup. Find a friend, walk apart until the string is tight then talk through the inside of your cup while they listen on their cup.



DO YOU KNOW?

The speed of sound in air was first accurately measured in 1738 by members of the French Academy. They used two cannons positioned on hills about 29 kilometers apart. By measuring the time interval between seeing the flash of a cannon and hearing its "boom," they were able to calculate the speed of sound. To minimize errors from wind and observer reaction times, they fired the cannons alternately. From their observations, they deduced that sound travels at approximately 332 meters per second at 0°C.



13.2 NATURE OF SOUND WAVES

Sound waves are mechanical longitudinal on nature. These waves are also called pressure wave. When any object (source of sound) vibrates, this vibration causes the vibration of molecules of medium (air, fluid etc.). Ultimately this initiated vibration is converted into a chain of vibrations after transferring its energy into molecules of medium till sound wave travels through medium.

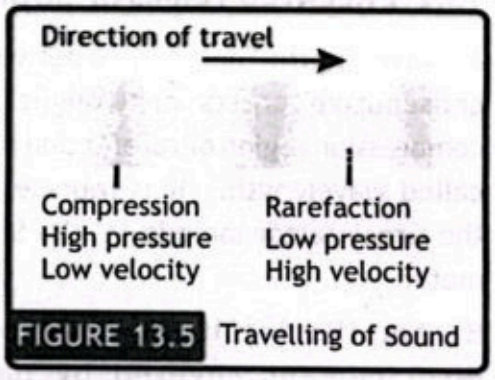


FIGURE 13.5 Travelling of Sound

Actually when any object vibrates, its vibration shows existence of kinetic energy. This kinetic energy is transmitted to the medium's molecules. These medium's molecules transfer acquired kinetic energy to next molecules of medium. Due to kinetic energy these molecules start vibrational movement in forward direction as shown in figure 13.5. By this way vibrational energy produced by sound source is transferred from one point to another point.

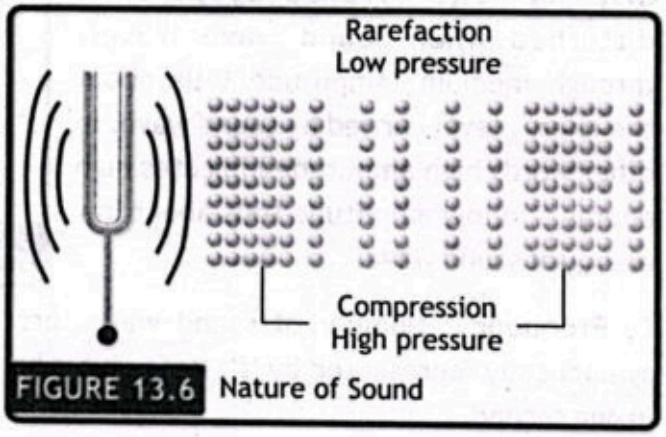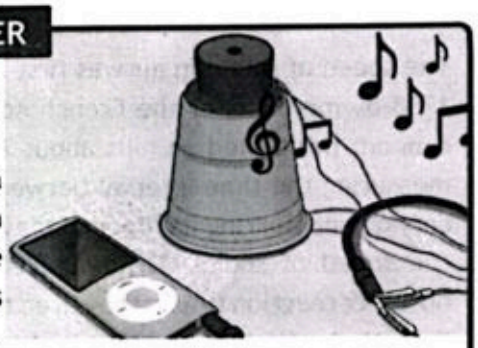


FIGURE 13.6 Nature of Sound

13.2.1 COMPRESSION AND RAREFACTION

Sound waves are the combination of compressions & rarefactions. Compression is that high pressure portion within sound wave, where molecules of medium acquire low velocity, which is produced due to vibrational kinetic energy of sound source. Here molecules of medium have very short distance between them. Rarefaction is that low pressure portion within sound wave, where molecules of medium acquire high velocity within a sound wave which is produced due to vibrational kinetic energy of sound source. Here molecules of medium have comparatively large distance between them as shown in figure 13.6.

PROJECT: MAKING SPEAKER



Materials Needed: Plastic or paper cup, Copper wire (1 meter), Small magnet, Tape, 3.5 mm audio jack with exposed wires, Scissor.

Instructions: Make a Coil and Wrap 1 meter of copper wire around a pen to make a coil. Leave 6 inches of wire free on each end. Attach Coil and Magnet, Tape the coil to the bottom of the cup. Place the magnet inside the coil at the bottom of the cup. Connect the Wires i.e. twist the ends of the copper wire to the wires of the audio jack.

Test the Speaker: Plug the audio jack into a phone or computer and play music.

13.2.2 RELATED TERMS OF SOUND WAVES

A. Wavelength: The distance between two consecutive crests or troughs within compression region or rarefaction region is called wavelength. It is represented by the Greek letter lambda 'λ'. Its SI-unit is meter.

B. Amplitude: It is the maximum displacement covered by particle disturbed when sound wave travels through medium. Amplitude tells about the energy level carried by sound wave. In other words high amplitude indicates high energy and low amplitude tells about low energy of sound wave.

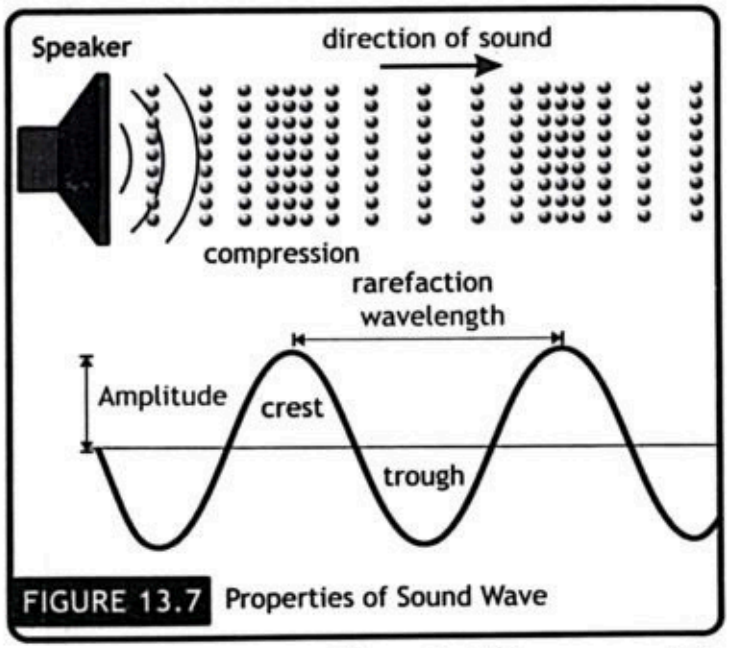


FIGURE 13.7 Properties of Sound Wave

C. Frequency: Number of sound waves produced in one second is called frequency. It is symbolically represented by 'f'. Its SI-unit is hertz. One hertz means one sound wave is produced in one second.

D. Time Period: Time taken by a wave to complete one cycle is called time period. It is symbolically represented by 'T'. It SI-unit is second.

13.2.3 TYPES OF SOUND WAVES

Sound waves have different names which are taken as its types. All types of sound waves are basically referenced dependent. For example; Unpleasant or pleasant effect of sound, Soft or hard sound, Musical sound or sound etc. In general sound waves can be categorized as Rhythmic and non-Rhythmic sound waves as shown in figure 13.8.

Human ear has limitation of detection of sound waves. The audible range is in between 20 hertz to 20000 hertz. If wave has frequency less than 20 hertz, it be not audible to our ear, these waves are called "Infrasonic waves". These are used to detect map-rock, underground petroleum formation, earthquakes etc. Interesting point is that there are so many animals which usually use infrasonic waves for communication across impressive distances for examples; Whales, Elephants, Giraffes etc. Human ear can listen sound having frequencies greater than 20 hertz and less than 20000 hertz (figure 13.9).

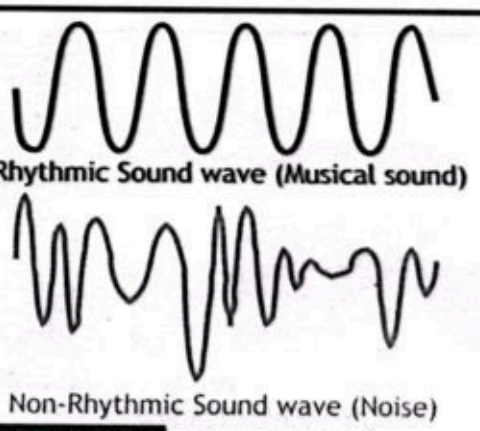


FIGURE 13.8 Types of Sound

Such waves which have frequency greater than 20,000 hertz is called "Ultrasonic waves". These waves are mostly used in medical field for examination of internal organs of patients. Ultrasonic waves are also used to navigation purposes and so on.

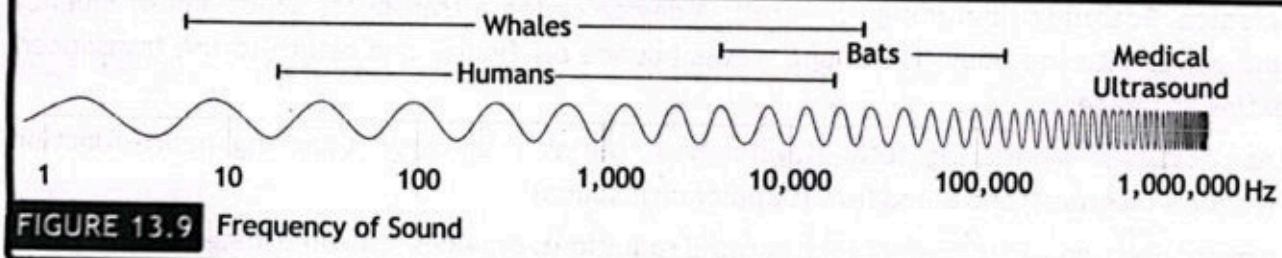


FIGURE 13.9 Frequency of Sound

13.3 ULTRASOUND

Ultrasound refers to sound waves that have frequencies above the upper limit of human hearing, which is around 20 kilohertz (kHz). Humans can typically hear sounds in the range of 20 Hz to 20 kHz. Sounds with frequencies higher than this range are considered ultrasonic.

Ultrasound has a wide range of applications in various fields. In medicine, it is commonly used for diagnostic imaging, such as in prenatal ultrasound scans to monitor the development of a fetus. Ultrasound waves can penetrate bodily tissues and produce images of internal structures without the need for invasive procedures. In industrial settings, ultrasound is used for nondestructive testing of materials, detecting flaws, and cleaning delicate objects. It is also employed in applications like sonar, which uses sound waves to detect objects underwater.

13.3.1 USES OF ULTRASOUND

A. Cleaning: High-frequency sound waves create tiny bubbles in a liquid. These bubbles implode, producing small shock waves that clean surfaces.

- **Applications:** Cleaning jewelry, electronic parts, and surgical tools.



(a) Ultrasonic Cleaning (b) Medical Scanning (c) Sonar

FIGURE 13.10 Applications of ultrasound

- **Advantages:** Non-damaging, reaches small and hard-to-clean areas, often only needs water or mild detergents.

B. Medical Scanning (Including Prenatal): A device called a transducer sends high-frequency sound waves into the body. The sound waves bounce off tissues and return to the transducer, creating an image.

- **Applications:** Monitoring fetal development during pregnancy. Checking heart function (echocardiograms) and blood flow (Doppler ultrasound).
- **Advantages:** Non-invasive, safe (no harmful radiation), provides real-time images.

C. Sonar (Sound Navigation and Ranging): A sonar device sends out sound pulses underwater. The pulses hit objects and return as echoes. The time it takes for the echoes to return is used to calculate distance.

- **Applications:** Mapping the ocean floor, finding underwater objects like shipwrecks, and measuring water depth.

13.3.2 CALCULATING DEPTH OR DISTANCE

Ultrasound can be used for measuring depth or distance , it involves sending sound pulses from a ship to the ocean floor and measuring the time it takes for the echoes to return. The depth is calculated using the formula:

$$\text{Depth or Distance } (d) = \frac{v \times t}{2} \quad \text{— 13.1}$$

for example, If the sound takes 2 seconds to return and the speed of sound in water is 1500 m/s

$$d = \frac{1500 \times 2}{2} \qquad \text{or} \qquad d = 1500\, m/s$$

Example 13.1

A ship sends sound wave in Pacific Ocean and it takes 14.7 s to return to the ship. Find depth of Pacific Ocean.

GIVEN:
Speed of sound in water 'v' = 1500 m/s
Time taken by sound to return 't' = 14.7 s

REQUIRED:
Depth of Pacific Ocean 'd' = ?



SOLUTION:
Speed of sound is given by: $d = \frac{v \times t}{2}$

putting values $d = \frac{1500\,ms^{-1} \times 14.7\,s}{2}$

Therefore $d = 11{,}025\,m = 11.025\,km$ — ANSWER

The depth of Pacific Ocean is 11,025m (Approx).

13.4 INFRASOUND

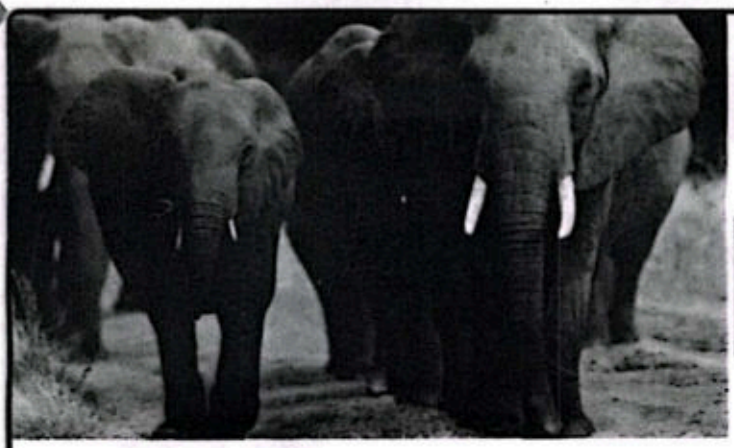
Infrasound referred to as low frequency sound, describes sound waves with a frequency below the lower limit of human audibility (generally less than 20Hz).Infrasonics find the following applications in daily life.

13.4.1: COMMUNICATION BY ANIMALS

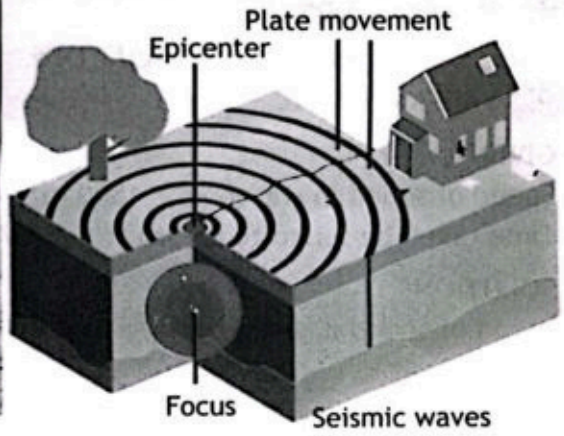
Giraffes were once believed to be silent creatures. However, it was later found that they actually make murmuring sounds at a very low frequency, making it hard for humans to hear. Typically, larger animals produce sounds in lower frequencies, while smaller animals produce higher frequencies. These sounds can travel far through the air and ground, and the ability to hear them depends on the size and structure of the animal's ears.

For example, elephants utilize infrasound to convey messages to each other across vast distances. The infrasound they produce can only be detected using complicated.devices. They communicate warnings about potential threats and coordinate their movements. This form of communication enables them to stay connected over long distances and in areas with limited visibility, such as dense vegetation.

This remarkable ability to transmit messages across vast distances not only highlights the intelligence and social complexity of elephants but also underscores their remarkable adaptability to their natural habitats. By harnessing the power of infrasound, these magnificent creatures have developed a sophisticated means of communication that enables them to navigate and thrive in even the most challenging of environments.



(a) Communication by Elephants



(b) Seismic Activity

FIGURE 13.11 Applications of Infrasonic

13.4.2 SEISMIC ACTIVITY

Infrasound is generated by natural events like earthquakes, volcanic eruptions, and explosions. Specialized instruments called infrasound sensors detect these low-frequency sound waves. Monitoring seismic activity to predict earthquakes and volcanic eruptions. Studying and understanding the behavior of natural disasters. It provides early warnings for natural disasters. It also helps in understanding the Earth's internal processes. For example infrasound sensors placed around a volcano can detect low-frequency rumblings that indicate an imminent eruption, allowing timely evacuation of nearby populations.

SCIENCE TIDBITS



Infrasound can travel incredibly long distances without losing much of its energy. This means that infrasound waves produced by natural events, such as volcanic eruptions or earthquakes, can be detected thousands of kilometers away from their source. For instance, the infrasound waves generated by the eruption of Krakatoa in 1883 were recorded all around the world, circling the globe multiple times.

This long-range propagation makes infrasound a powerful tool for monitoring and studying geological and atmospheric phenomena on a global scale.



13.5 CHARACTERISTICS OF SOUND WAVE

There are basically three main characteristics of sound wave, pitch, *loudness and quality.*

13.5.1 PITCH

That characteristic of sound wave by which we can differentiate between grave and shrill voices. It is not a physical quantity that's why it cannot be measured directly. Basically it is the characteristic regarding perception of frequency, which also depends upon wavelength and speed of sound too. It cannot be detected directly and only can be analyzed on the basis of frequency of sound wave.

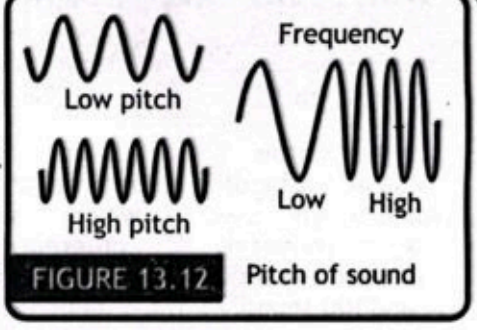


FIGURE 13.12 Pitch of sound

Pitch describes about number of vibrations produced by vocal chord in unit interval of time (one second). That's why pitch has direct relation with frequency of sound wave.

Pitch of sound wave $\propto$ *Frequency of sound wave*

Low pitch of sound waves means less frequency while high pitch tells about high frequency. For example; A bird produces high-pitched sound whereas roaring of a lion is a low-pitched sound, the voice of a woman has a higher pitch than that of a man and so on.

13.5.2 LOUDNESS

It is that characteristic of sound wave by which we can differentiate between loud and faint sound. It is also not a physical quantity that's why it cannot be measured directly. Loudness can be measured on the basis of "Amplitude of sound wave".

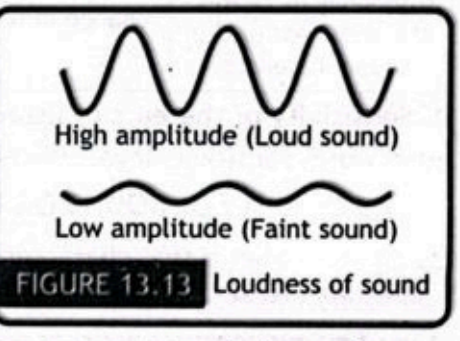


FIGURE 13.13 Loudness of sound

Loudness of sound wave $\propto$ (Amplitude of sound wave)^2

Basically loudness of sound wave is the sensation to test the strongest level of sound wave. Amplitude of the wave is the best parameter to check the strongest level of sound wave. Loudness level can be studied in term of 'decibel'.

There are basically 4-factors which directly affect the loudness of sound.

A. Vibrational amplitude of source of sound: Vibrational amplitude has direct relation with loudness of sound. It means that greater the vibration amplitude of vibrating object (Source of sound) will cause the production of high loudness.

B. Surface area of source of sound: Surface area is directly proportional to relation with loudness of sound. It means that greater the surface area of source of sound will produce of high loudness.

C. Distance from source of sound: Distance of listener form source of sound has inverse relation with loudness of sound wave. It means that short distance listener will feel more impact of loudness as compare to long distance listener.

TABLE 13.1 COMPARATIVE SKETCH OF LOUDNESS & PITCH OF SOUND WAVE	
Pitch	Loudness
Pitch is the characteristic of sound which is used for differentiating between the shrill and flat sound.	Loudness is the property of sound which is used for differentiating between the loud and faint sound
Pitch is independent of the energy received by the ear in unit time interval.	Loudness is dependent upon the energy received by the ear in unit time interval
Pitch is dependent on the change in the frequency. As the frequency increases, the shrillness of the sound increases.	Loudness is independent of the change in frequency

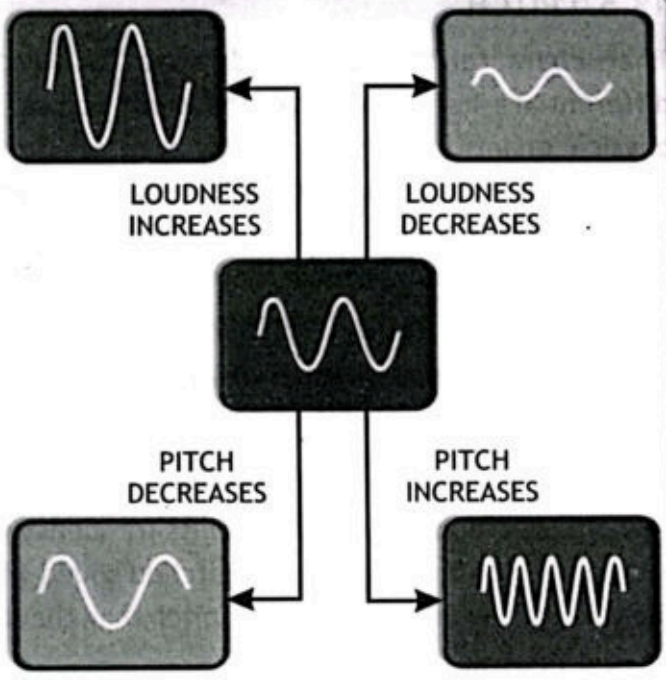


FIGURE 13.14 Pitch of waves

D. Sensitivity of the ears of listener: More sensitive ears can feel more effect of loudness. In other words Sensitivity level of ears has direct relation with loudness of sound wave.

13.5.3 QUALITY OF SOUND OR TIMBRE

Quality or timber is that characteristic of sound which helps our ear to distinguish between such two sound waves, which have same loudness and pitch. Timbre is that term which helps us to study dynamic characteristics as well as harmonic contact of sound waves.

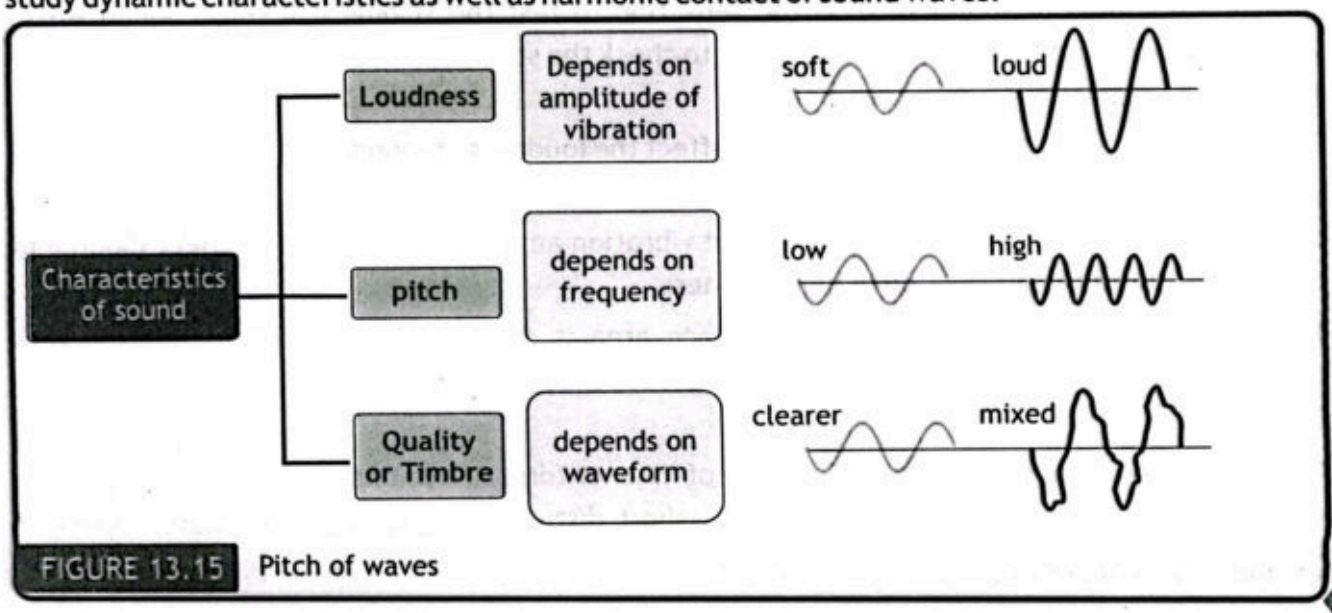


FIGURE 13.15 Pitch of waves

The word harmonic contact describes that during traveling of sound waves from one point to another point, the way adopted by molecules of medium for transmitting vibrational energy. The quality of sound depends upon relative intensities of overtones. The word over tones means an overtone is any harmonic with frequency greater than the fundamental frequency of a sound.

13.6 ANALYZING SOUND WAVES

Sound waves are vibrations that travel through the air (or other mediums) and reach our ears. These vibrations are usually produced by an object, like a guitar string, vocal cords, or a speaker, while Timbre (pronounced "tam-ber") as the quality or color of a sound that makes it unique. It's what allows us to distinguish between different instruments or voices, even if they are playing the same note. For analyzing sound wave oscilloscope is used.

Oscilloscope is a device that allows us to see sound waves. It displays a sound wave as a trace (a line) on a screen, whereas Waveform explains that different sound sources produce different waveforms on an oscilloscope. These shapes can help us understand the timbre of the sound.



FIGURE 13.16 Oscilloscope

Some waves start with a pure tone, like that from a tuning fork. On an oscilloscope, this produces a smooth, regular sine wave called Pure Tones and Sine Waves.

This type of sound has a simple timbre, while compare this to a more complex sound, like a note from a piano or a violin, which produces a more complex waveform on an oscilloscope called Complex Waves. These sounds have richer timbres because they include multiple frequencies and overtones.

For examples string instruments explain how plucking a string on a guitar produces a sound wave with a specific shape. The oscilloscope trace will show the fundamental frequency and various overtones, resulting in a unique waveform, also wind instruments like blowing into a flute creates vibrations in the air column inside the instrument. This produces a different waveform, visible on the oscilloscope, and gives the flute its distinctive timbre.

13.7 SPEED OF SOUND

The speed of sound can be defined as: **The distance covered by sound wave per unit time is called speed of sound.** Mathematically:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad \text{or} \quad v = \frac{d}{t} \qquad 13.2$$

The speed of sound in air is generally between 330 m/s and 350 m/s, depending on the temperature. One key factor that influences the speed of sound is temperature. When the air is warmer, sound travels faster because the air particles have more energy and move more rapidly. In contrast, in colder air, the particles move more slowly, and the speed of sound decreases. For example, on a cold winter day, sound might travel closer to 330 m/s (1188 km/h), while on a hot summer day, it could reach up to 350 m/s (1260 km/h).



FIGURE 13.17
Supersonic Speed

For example, during a thunderstorm, you often see lightning before hearing thunder. This is because light travels almost instantly, while sound takes longer due to its comparatively slower speed. The difference in *their speeds* allows us to estimate the distance of the storm by counting the seconds between seeing lightning and hearing thunder. When an object moves faster than the speed of sound, it is referred to as supersonic speed, as illustrated in figure 13.17.

The speed of sound is fastest in solids, slower in liquids, and slowest in gases. This difference is due to how particles are arranged in each state of matter as shown in figure 13.18. The speed of sound in general depends on particle spacing, elasticity and density.

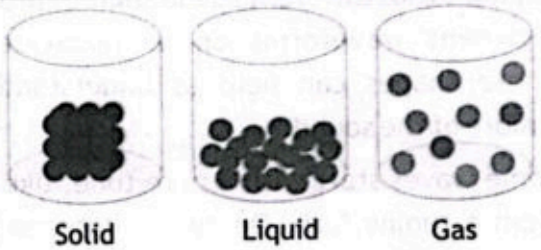


FIGURE 13.18
Speed of Sound in different medium

A. Sound Travels Fastest in Solids: Sound travels the fastest in solids because the particles in solids are tightly packed and held together by strong forces. When a sound wave moves through a solid, the vibrations transfer efficiently from one particle to the next due to their close proximity. For example, if you place your ear on a metal rod and tap one end, you will hear the sound almost instantly. In metals like steel, sound can travel at speeds of over 5000 m/s, much faster than in air or water.

B. Sound Travels Faster in Liquids: In liquids, particles are less tightly packed than solids, but they are still closer together than in gases. This allows sound waves to travel faster in liquids than in gases, though not as fast as in solids. For instance, sound travels in water at approximately 1500 m/s, which is about four times faster than in air. This is why marine animals, such as dolphins and whales, rely on sound for communication over long distances in water.

C. Sound Travels Slowest in Gases: In gases, the particles are widely spaced, making it harder for vibrations to transfer from one particle to another. This is why sound travels slowest in gases, with a speed of around 340 m/s in air at room temperature. The large gaps between particles cause more delay in the transfer of sound energy.

Example 13.2

A boy at night heard sound of thunder with a gap of about 3.0 seconds when he saw lightning. How far away is the lightning, taking speed of sound as 343 m/s?

GIVEN:
Speed of sound 'v' = 343 m/s
Time taken 't' = 3.0 s

REQUIRED:
Distance of lightning 'd' = ?

SOLUTION:
Speed of sound is given by: $v = \frac{d}{t}$ or $d = v \times t$

putting values $d = 343\,ms^{-1} \times 3.0\,s$

or $d = 1029\,m = 1.029\,km$

Therefore $d = 1.029\,km = 1km$ — ANSWER

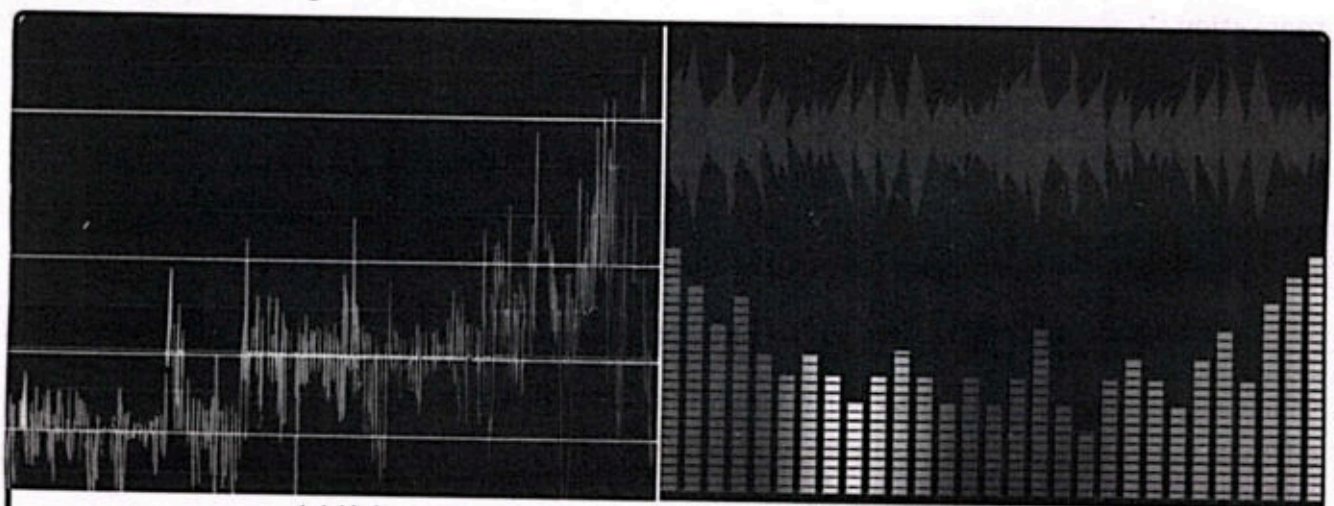
Therefore the clouds are at about 1 km distance.



13.8 NOISE

In general; the term noise means unpleasant sound waves experienced by listener. But in physics noise has following characteristics; these sound waves have;

- Non-Rhythmic behavior
- Irregular time intervals for completion of vibrations
- Variable energy states
- Irregular intensities



(a) Noise (b) Musical Sound

FIGURE 13.19 Difference between noise and musical sound

Basically; sound waves can be studied in two manners as 'periodic sound waves' and 'non-periodic sound waves'. Human ears structures are designed for periodic sound waves. It means that our



Industrial buildings | Construction sites | Transportation | Public places

FIGURE 13.20 Pitch of waves

ears feel pleasant effect for those sound waves which have regular periodic vibrations, energies, frequencies and even intensities levels.

The range of periodic sound waves is about 15 hertz to 4000 hertz. While beyond this range periodic sound waves are converted into non-periodic waves which give very unpleased effect to listener. Beyond this range receiving sound signals are painful.

Noise is also one of the main causes for creating psychological and physical stress in daily routine. Noise also provides negative impact on concentration level to perform any a daily life activity. We all are mostly affected by environmental noise sources for examples.

- **Industrial buildings;** factories and machineries, air-conditioning systems.
- **Construction sites;** site formation (e.g. excavation), piling, road work, demolition, renovation.
- **Transportation;** aircrafts, trains, road vehicles, vessels.
- **Public places;** open markets, streets, parks.

Noise pollution can be reduced by use of earplugs, turning off appliances when not in use, planting more trees, lowering the volume, regular maintenance of vehicles and machines etc. By controlling noise we can control negative health effects that noise pollution has on everyone.

13.9 REFLECTION, REFRACTION AND DIFFRACTION OF SOUND

Sound waves interact with their surroundings in different ways. They can reflect, refract, and diffract depending on the surfaces or materials they encounter. These behaviors help us understand how sound travels and why we hear it in various situations.

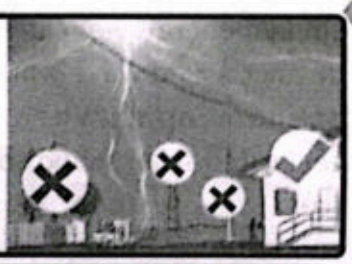
13.9.1 REFLECTION

Sound can reflect when it hits a surface and bounces back, just like light reflecting from a mirror. Reflection of sound waves is used to find the depth of ocean as shown in figure 13.21 (a). For example, when you clap your hands in a large room with tiled walls, the sound seems to "bounce"

DO YOU KNOW?

If you heard the sound of thunder, you are safe now, how?

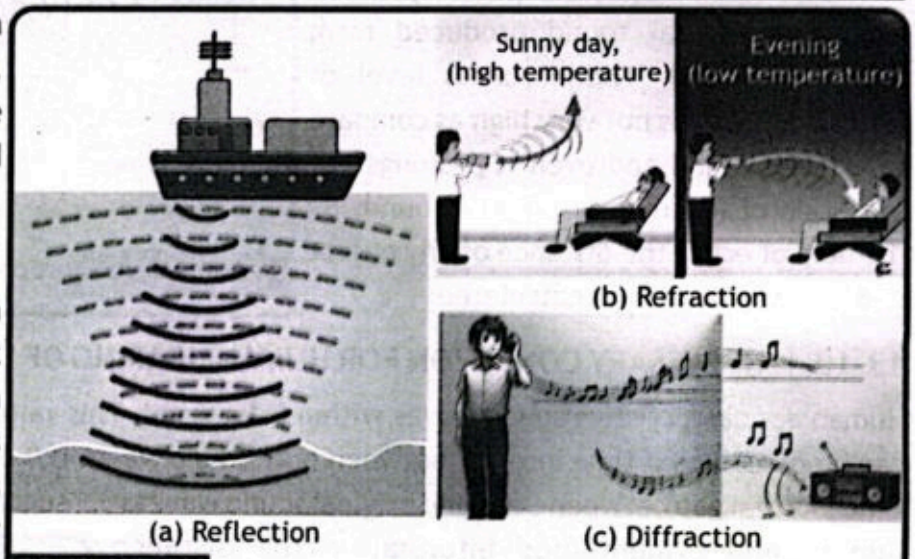
It is because thunder has occurre a bit earlier and you heard the sound later because sound travels at much lower speed than light. But still it is instructed to find some covered space and stays there during thunder.



around the room. Similarly, in a small space like a bathroom, you might notice your voice sounds louder due to sound waves reflecting off the walls.

13.9.2 REFRACTION

Sound waves change direction as they pass through different materials or layers of air with varying temperatures. This causes the sound to bend as its speed changes. For example, distant sounds are clearer at night when cooler ground air and warmer upper air cause sound waves to bend towards the ground as shown in figure 13.21 (b). Sound waves bend when they move through water layers that have different temperatures and densities. This bending impacts how submarines and marine animals, like whales, communicate underwater.



(a) Reflection (b) Refraction (c) Diffraction

FIGURE 13.21 Sound waves in reflection, refraction and diffraction.

13.9.3 DIFFRACTION

Sound waves bend around obstacles or spread out after passing through small openings. his allows sound to spread into areas where there is no direct line of sight. For example, you can hear music playing from another room, even if the door is slightly closed, because the sound waves bend and spread as shown in figure 13.21 (c). Similarly, when someone calls your name from behind a corner, you can still hear them because the sound waves diffract around the wall.

13.10 ECHO

Basically the term echo is such behavior of sound wave by which it comes back to the listener after striking with any obstacle due to Wave-reflection phenomenon. Like other waves, Sound waves also bounce back from any nature of hard surface (obstacle) like a bouncing of rubber ball from the surface of earth or wall.

So in general we can say that ECHO is distinct sound wave which obeys reflection phenomenon. When sound wave is generated from sound source its reflection from any surface (obstacle) produces another wave which is separately heard from the original sound produced form source of sound. The hardness level of reflecting sound is not very high as compare to original sound and even it prolongs the sensation of listening of original sound. By the help of echo, the distance of any object under water can also be calculated.

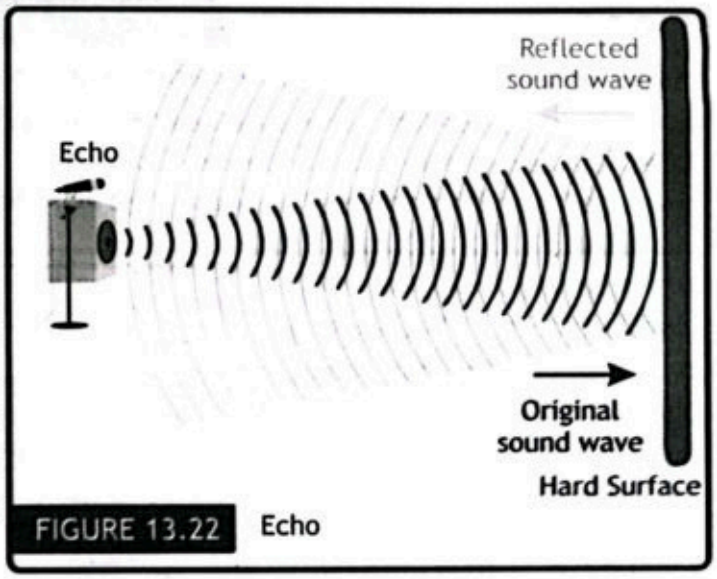


FIGURE 13.22 Echo

13.10.1. NECESSARY CONDITION FOR HUMAN HEARING OF ECHO

Human ear can perceive sound waves within 0.1 second. This value shows that two sound waves can be perceived if time interval between both sound waves is 0.1 second. So it is clear that the time interval gap between Echo and original sound wave is 0.1 second.

Due to above mentioned information the distance between source of sound and reflecting surface can be calculated as: Distance travelled by sound 'D' = 2d

Time taken by echo 't' = 0.1 s

If the speed of sound is 'v', then

$$v = \frac{D}{t} \quad \text{or} \quad D = v \times t$$

putting values: $2d = v \times 0.1$ or $d = v \times \frac{0.1}{2}$

Therefore, $$d = \frac{v}{20} \quad (13.3)$$

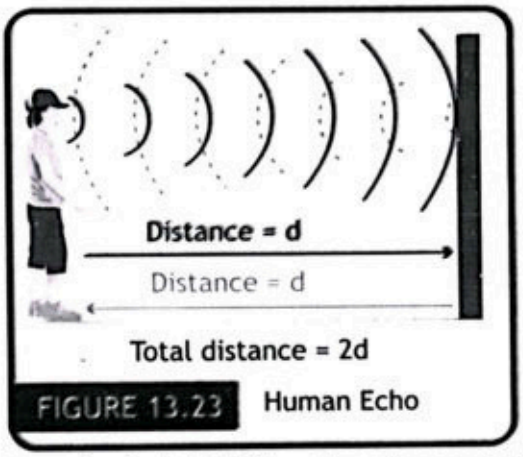


FIGURE 13.23 Human Echo

This result tells that minimum required distance for production of echo is 1/20th value of speed of sound. For example, if speed of sound in air is 340 m/s then for producing echo the least distance should be 17 m.

13.10.2 APPLICATIONS OF ECHO

There are so many applications of echo are common in daily life; by the help of echo

- Speed of sound can be determined
- Usage in obstetric ultrasonography and so on

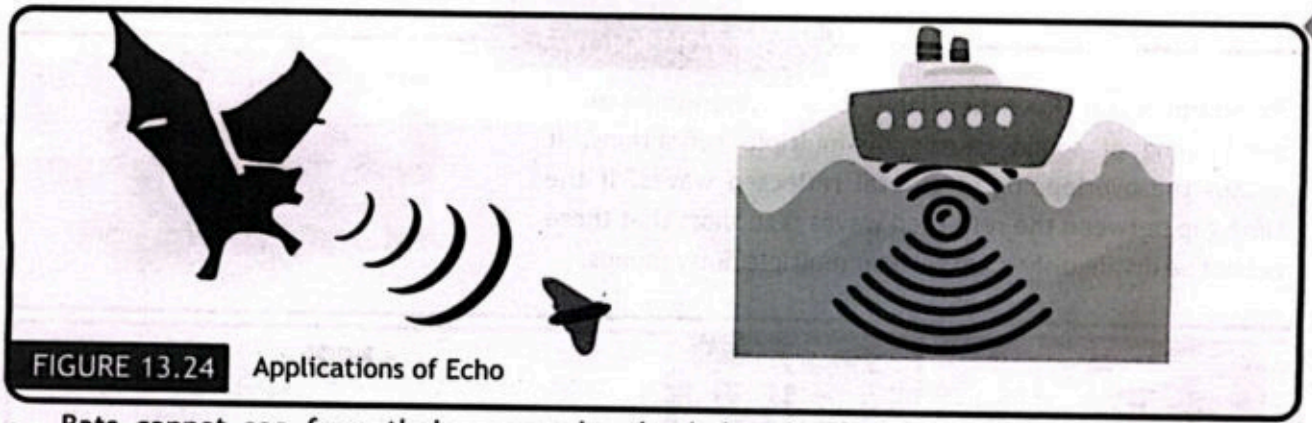


FIGURE 13.24 Applications of Echo

- Bats cannot see from their eyes o by the help of echolocation they can reach their destinations and even can identify things which come on their ways.
- Depth of sea or presence of submarines can be located by echo-techniques.

Example 13.3

A teacher took students to a nearby hill for performing Echo experiment. Abdullah shouted and the teacher and all other students heard his echo after 1.2 s, using a stop watch. If speed of sound is 346 m/s, how far will the cliff be from him?

GIVEN:
Time taken for echo 'Δt' = 1.2 s
Speed of sound in air 'v' = 346 m/s

REQUIRED:
Distance of cliff d = ?

SOLUTION:
Using the equation for echo: $d = \frac{v \times \Delta t}{2}$ putting values $d = \frac{(346\,m/s) \times (1.2\,s)}{2}$

Therefore $d = 207.6\,m$ — ANSWER

So, the cliff is 207.6 m away from him.

13.11 ACOUSTICS

It is that branch of physics which deals with study of sound; its characteristics, production, transmission, effects and so on. There are so many types of acoustic like; Environmental Noise, Musical Acoustics, Ultra-sounds, Infra-sounds, Vibration and Dynamics.

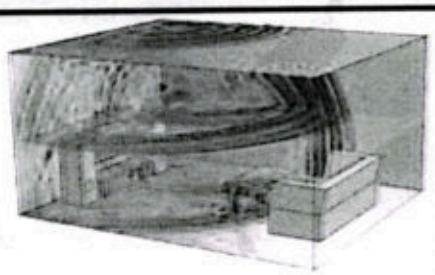
Environmental noise is defined as undesirable or destructive open-air sound created by human activity, such as noise emitted by means of road traffic transport, industrial activity, rail traffic, and air traffic.

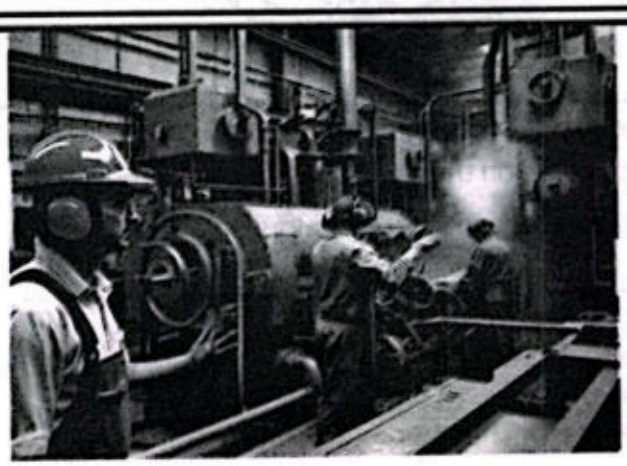
13.11.1 ACOUSTIC PROTECTION

The technique or method used to absorb undesirable sounds by soft and porous surface is called

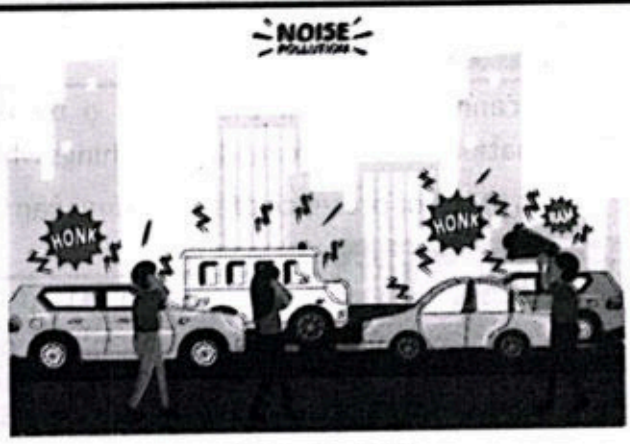
DO YOU KNOW?

Reverberation: Reverberation is the phenomenon of overlapping of sound caused by multiple reflections. It causes the overlapping of several reflected waves. If the time gap between the reflected waves is so short that these cannot be distinguished. So we hear multiple noisy sounds.





(a) Acoustic protection



(b) Traffic Noise

FIGURE 13.25 Acoustic

acoustic protection. Reflection of sound is more prominent if the surface is rigid and smooth, and less if the surface is soft and irregular. Soft porous materials, such as draperies and rugs absorb large amount of sound energy and thus quiet echoes and softening noises. Thus by using such materials in noisy places, we can reduce the level of noise pollution. However, if the surface of "classrooms or public halls are too absorbent, the sound level may be low for the audience.

13.11.2 IMPORTANCE OF ACOUSTIC PROTECTION

Acoustic protection is crucial for several key reasons:

A. Health and Well-being:

- **Hearing Protection:** Prevents hearing loss from prolonged noise exposure.
- **Mental Health:** Reduces stress, anxiety, and sleep disorders by minimizing noise pollution.

B. Productivity and Performance:

- **Workplace Efficiency:** Enhances concentration, reduces errors, and prevents accidents by limiting distractions.
- **Learning Environments:** Improves students' ability to focus and retain information.

C. Environmental and Community Impact:

UNIT OPENER?



What is the typical material used to make drumheads?

Animal skins like calf skin or goat skin are used to make drum heads. Although some modern drumheads are often made of plastic or synthetic materials, but traditional drumheads were made from animal skin.



- **Wildlife Preservation:** Protects animals that rely on sound for communication and navigation.
- **Quality of Life:** Ensures quieter, more pleasant living environments for communities.

D. Legal and Regulatory Compliance:

- **Occupational Safety:** Helps organizations meet noise exposure regulations.
- **Building Standards:** Ensures buildings provide adequate noise control as per codes.

E. Technological and Industrial Development:

- **Innovation:** Drives the creation of new materials and quieter machinery, benefiting various industries.

DO YOU KNOW?

Without acoustic protection, people can suffer hearing loss and increased stress levels. Productivity in workplaces and learning environments may drop due to constant noise distractions. Additionally, excessive noise can disrupt community peace and harm wildlife.



13.11.3 APPLYING ACOUSTICS IN BUILDING DESIGN

Understanding sound wave properties is crucial for designing buildings with good acoustics

A. Sound Absorption: Materials like carpets, acoustic panels, and curtains are used to absorb sound and reduce echoes.

B. Sound Reflection: Design of walls and ceiling are made in such a way that it reflects sound where needed, materials like glass and concrete are used for such purpose.

C. Sound Transmission: We Use thick walls, double-glazed windows, and insulated doors to prevent sound from traveling between spaces. Mostly Dense Materials or Heavy materials like concrete block are used.

D. Sound Diffusion: For acoustic protection we install elements that scatter sound evenly, like

irregular surfaces or special panels.

E. Resonance Control: The size and design of the room are taken in consideration to avoid amplification of certain sounds. Also Bass Traps are used in these studios to control low-frequency sounds.

F. Noise Control: Gaps are properly sealed to ensure that doors and windows are well-sealed to block noise. Also barrier walls, fences, and landscaping are used to reduce outside noise.

G. Vibration Control: For damping we use rubber mounts and floating floors to reduce vibrations. And isolate noisy equipment to prevent vibrations from spreading.

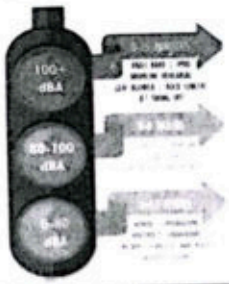
Practical examples are Concert halls in which combine absorbing, reflecting, and diffusing materials for clear sound. In offices we use absorbing materials to reduce noise and increase productivity. In homes incorporate soundproofing are used for privacy and quiet. Using sound wave properties helps design buildings that sound good and are comfortable.

Soft materials are used on walls of classrooms and public buildings in order to reduce echo, which have following benefits.

- **Sound Absorption:** Soft materials like carpets, curtains, and acoustic panels absorb sound waves, reducing reflections and echoes. It ensures students can hear and understand the teacher effectively, leading to better learning outcomes.
- **Reducing Reverberation Time:** Soft materials shorten the time it takes for sound to decay, making speech and other sounds clearer. It creates an environment conducive to concentration and productivity in spaces like libraries and lecture halls. A quieter environment reduces stress and fatigue, enhancing comfort in places like hospitals and auditoriums.

DO YOU KNOW?

The sound pressure level needed for the human ear to recover from NITTS, the effective quiet level, is approximately 55 dB. This is probably the safe noise exposure level to prevent NIHL from a single exposure, with 55-60 dB time-weighted average being the actual safe noise exposure level for a day.



13.12 HUMAN HEARING SYSTEM

In physics, the process of converting sound into electrical signals that are interpreted by the brain involves several steps that can be described through the principles of wave mechanics, mechanical vibrations, and signal transduction.

A. Sound Waves Enter the Ear: Sound waves are vibrations in the air that travel into the ear canal

and hit the eardrum.

B. Eardrum Vibration: The eardrum vibrates in response to these sound waves.

C. Ossicles Amplify Vibrations: These vibrations are passed to three tiny bones in the middle ear called the ossicles (malleus, incus, and stapes), which amplify the vibrations.

D. Vibrations Enter the Cochlea: The stapes (one of the ossicles) sends the vibrations into the cochlea, a fluid-filled spiral structure in the inner ear.

E. Fluid Waves in the Cochlea: The vibrations create waves in the fluid inside the cochlea.

F. Hair Cells Detect Vibrations: These fluid waves move the basilar membrane inside the cochlea, causing hair cells on the membrane to bend.

G. Conversion to Electrical Signals: When the hair cells bend, they generate electrical signals.

H. Electrical Signals Travel to the Brain: These electrical signals are sent through the auditory nerve to the brain.

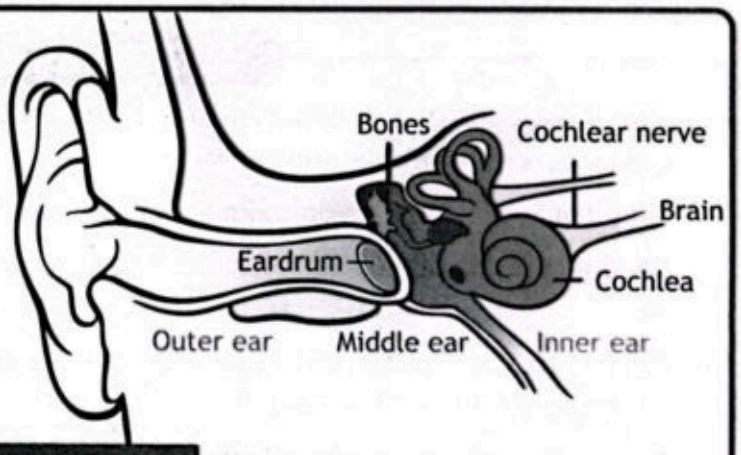


FIGURE 13.26 Human Hearing System

I. Brain Interprets the Signals: The brain processes these signals and interprets them as sound, such as music or speech.

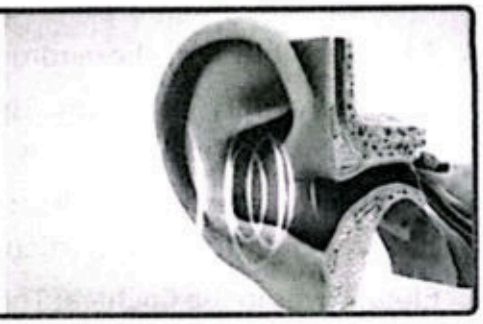
CAUTION

Continuous use of hands-free devices like earphones and headphones, especially at high volumes, can lead to noise-induced hearing loss (NIHL), tinnitus (ringing in the ears), ear infections from bacteria on dirty earphones, and temporary hearing fatigue. To protect your hearing, follow the 60/60 rule (no more than 60% volume for 60 minutes), use noise-canceling headphones, take regular breaks, opt for over-ear headphones, and get regular hearing checks. These measures help minimize the risk of hearing damage while using these devices.



DO YOU KNOW?

The human ear is incredibly sensitive and can detect a wide range of sounds. It can hear sounds as quiet as a whisper (about 20 decibels) to as loud as a rock concert (about 120 decibels). This wide range of sensitivity is due to the precise way the inner ear's hair cells and auditory nerve work together to convert sound waves into electrical signals for the brain to interpret.



SUMMARY

- **Sound** is a disturbance of matter that is transmitted from its source to outwards and which produces sensation of hearing in ear.
- **Speed of Sound** in Air is approximately 330-350m/s.
- **Loudness** is the perception of sound intensity; greater the intensity, louder the sound will be.
- **Pitch** is the perception of frequency of sound; greater the frequency, greater will be the pitch and shriller will be the sound.
- **Quality** is number and relative intensity of multiple sound frequencies.
- **Musical Sound** is a sound that is pleasant and harmonious.
- **Noise** is any loud, discordant or dis-agreeable sound.
- **Acoustic Protection** is the application of soft and porous material to protect individuals against undesirable sounds and noises.
- **Audible Frequency Range** is the range of frequency from 20 Hz to 20,000 Hz that humans can hear.
- **Infrasound waves** are the sound waves having frequency less than 20 Hz, which human cannot hear.
- **Ultrasound waves** are the sound waves having frequency greater than 20 kHz, which human cannot hear.
- **Reverberation** is the reflected sound that cannot be distinguished from original sound (is heard before 0.1 s of the original sound).
- **Echo** is the reflected sound that can be distinguished from original sound (is heard after 0.1 s or more of the original sound).



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. What are the three main parts of the human ear?
   A. Outer ear, Middle ear, Inner ear
   B. Inner ear, Cochlea, Eardrum
   C. Middle ear, Eardrum, Auditory nerve
   D. Outer ear, Auditory nerve, Cochlea
2. Sound produced by piano and violin gives _____ waveform on oscilloscope.
   A. Simple B. Harmonic C. Complex D. Symmetric
3. Which is NOT true for sound?
   A. Sound is produced by vibrating body
   B. Sound travels due to variation of pressure in air
   C. Sound transfer energy along with matter of medium
   D. Sound is compressional and longitudinal wave
4. Sound travels faster in:
   A. rubber B. air C. water D. steel
5. Speed of sound in air is 332 ms^{-1}. What is its speed in vacuum?
   A. Equal to 332 ms^{-1} B. Great than 332 ms^{-1} C. Less than 332 ms^{-1} D. Zero
6. The sound travels from water to an iron rod and then into air and back into water. The speed of sound will successively:
   A. increase, decrease, increase
   B. decrease, increase, decrease
   C. increase, increase, increase
   D. decrease, decrease, decrease
7. What will happen to speed of sound, if frequency is doubled? It will become:
   A. half B. double C. four times D. remain same
8. Infrasonic waves have frequency:
   A. greater than 20Hz B. less than 20Hz C. of 20 Hz D. of 20 kHz
9. For echo, the minimum distance of a person from obstacle is:
   A. 17 m B. 34 m C. 0.1 m D. any distance above 50 m
10. The property of waves which is directly related with loudness of sound is
    A. Frequency B. Wavelength C. Speed D. Amplitude

11. Sound entered in ear is amplified by:

A. Ossicles B. Cochlea C. Eardrum D. Brain

12. Silent whistle is used to train dog. When trainer blows the whistle, human beings do not hear it but dog do listen. Its possible frequency is:

A. > 20 Hz B. < 20 Hz C. < 20000 Hz D. > 20000 Hz

13. The pitch of sound depends upon:

A. frequency B. amplitude C. quality D. displacement

14. Two sound waves having same loudness and pitch can be distinguished by one of the characteristics of sound called:

A. loudness B. pitch C. quality D. intensity

15. The sensation of sound persists in our brain for about

A. 10 s B. 1 s C. 0.1 s D. 0.01 s

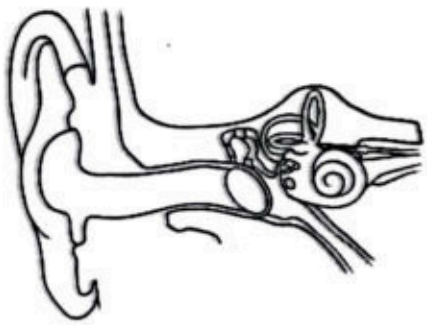
CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Mark the frequency region for Infrasound, Human Audible Frequency and Ultrasound.

0 Hz	10 Hz	20 Hz	1000 Hz	3500 Hz	13,000 Hz	20,000 Hz	40,000 Hz	55,000 Hz	80,000 Hz

2. Label the major parts of Human Hearing System.



SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Analyses the process of sound transmission from outer ear to brain.
2. What are common sources of harmful noise, assess their impact on human health?

3. How do animals use infrasound for communication? Compare this with human communication methods.
4. Evaluate the advantages and limitations of ultrasonic cleaning.
5. Why does sound travel faster in solids than liquids and gases?
6. How two plastic glasses with a string stretched between them could be better way to communicate than merely shouting through the air?
7. How can we distinguish between two sounds having same loudness?
8. During a match in cricket stadium, you see a batsman striking the ball but we hear stroke sound slightly later. Explain this time difference?
9. When a pendulum vibrates, we do not hear its sound. Why?
10. Two students are talking in the corridor of your school, you can hear them in your class room but you cannot see them. How?
11. What steps would you take to stop echo and reverberation effects in a large room?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Explain the production of sound waves with examples.
2. Justify why sound waves cannot travel in a vacuum. Design an experiment that demonstrates this principle.
3. What is nature of sound waves? How is sound propagated? Explain.
4. Discuss how changes in amplitude and frequency affect the loudness and pitch of sound waves.
5. What is quality of sound? How do the shape and material of a sound source influence the waveform of the sound it produces.
6. Explain the speed of sound in different media. How does the speed of sound differ in solids, liquids, and gases? Explain why, and discuss real-world implications.
7. What is reflection of sound? Differentiate between echo and reverberation.
8. Explain the phenomenon of an echo as the reflection of sound waves. Design an experiment to measure the time delay of an echo, and discuss how this can be used to determine distances in various applications, such as sonar.
9. Differentiate between noise and music? Explain that how is noise nuisance?

10. Justify the importance of acoustic protection in environments such as schools and hospitals. How can design elements and materials contribute to creating sound-friendly spaces?
11. Analyze the effects of noise pollution on the environment and human health. What strategies can be implemented to mitigate these effects, and how can communities balance development with acoustic quality?
12. Humans can hear frequencies from approximately 20 Hz to 20,000 Hz. Analyze how sounds outside this range (infrasound and ultrasound) are utilized in nature and technology. What are the implications of these frequencies for human hearing?
15. Explain how sound waves are converted into electrical signals by the eardrum and auditory nerves.

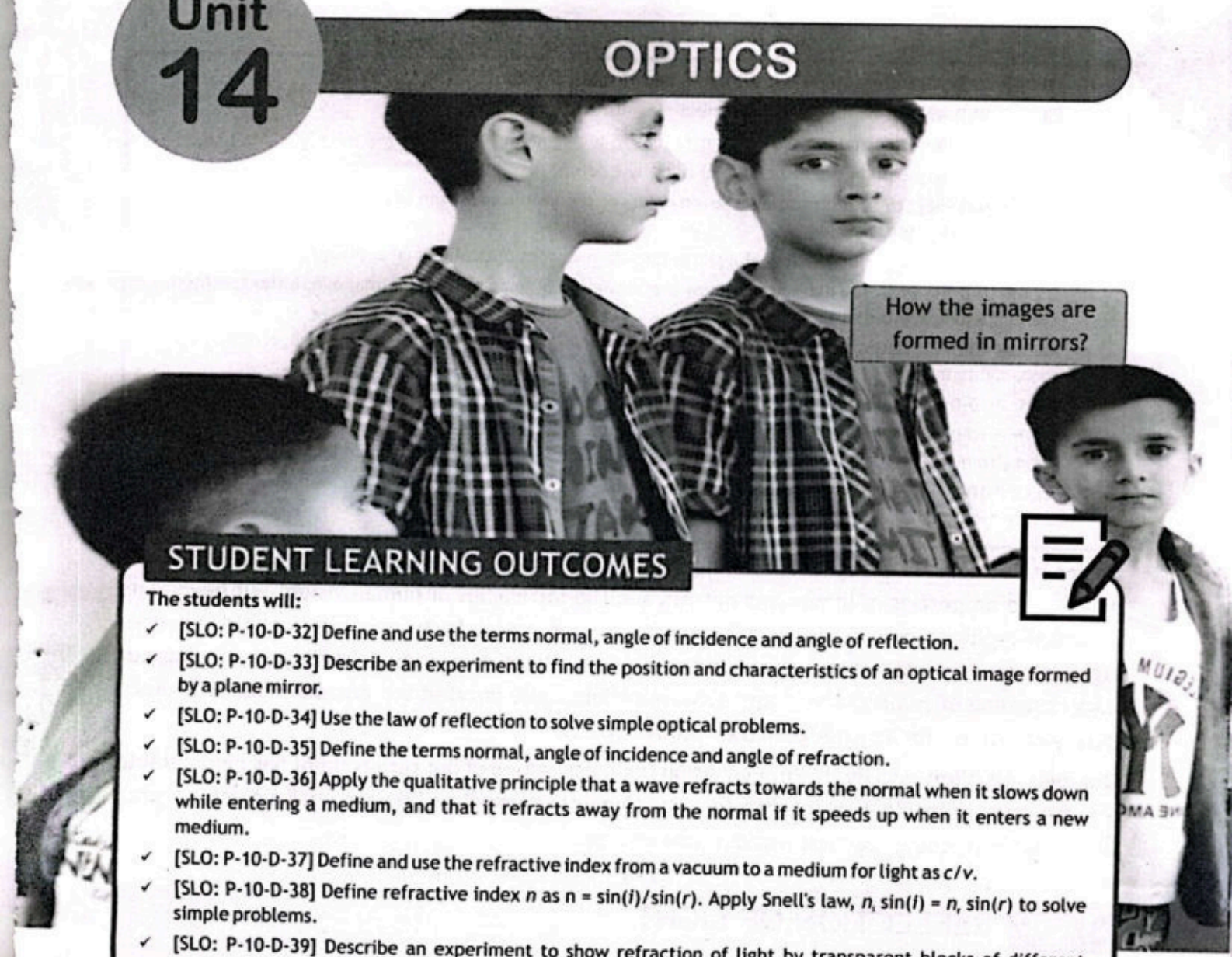
NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. A tourist clapped his hands near a cliff and heard the echo after 5 s. What is the distance of the cliff from the student if the speed of the sound is taken as 344 m/s? **(Ans. 860 m)**
2. Speed of sound in seawater is 1500 m/s. If its wavelength is 45 cm, find the frequency of these sound waves. **(Ans. 3,333.3 Hz)**
3. A sound wave in seawater travels at speed of 1500 m/s, it is sent and detected back after reflection from seabed in 8.5 s. Find the distance from surface to the bottom of the sea. **(Ans. 6,375 m)**
4. A physician counts 69 heartbeats in 1 min. Calculate the frequency and period of the heartbeats. **(Ans. 1.15 Hz, 0.8696 s)**
5. Find the range of wavelengths at speed 343 m/s for audible frequency range (20 Hz to 20 kHz). **(Ans. 17.15 m, 0.01715 m)**
6. During thunder storm, thunder sound is heard after 3 second of lightning flash. Find the distance of clouds from ground. (Speed of sound = 340 m/s). **(Ans. 1020 m)**
7. SONAR (sound navigation and ranging system) sends ultrasound signal towards sea bed. It is received back after 5.3 s. If speed of sound in sea water is 1550 m/s. Find the depth of sea there. **(Ans. 4107.5 m)**

Unit 14

OPTICS



STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-D-32] Define and use the terms normal, angle of incidence and angle of reflection.
- ✓ [SLO: P-10-D-33] Describe an experiment to find the position and characteristics of an optical image formed by a plane mirror.
- ✓ [SLO: P-10-D-34] Use the law of reflection to solve simple optical problems.
- ✓ [SLO: P-10-D-35] Define the terms normal, angle of incidence and angle of refraction.
- ✓ [SLO: P-10-D-36] 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.
- ✓ [SLO: P-10-D-37] Define and use the refractive index from a vacuum to a medium for light as c/v.
- ✓ [SLO: P-10-D-38] Define refractive index n as $n = \sin(i)/\sin(r)$. Apply Snell's law, $n_1 \sin(i) = n_2 \sin(r)$ to solve simple problems.
- ✓ [SLO: P-10-D-39] Describe an experiment to show refraction of light by transparent blocks of different shapes.
- ✓ [SLO: P-10-D-40] Define the terms critical angle and total internal reflection.
- ✓ [SLO: P-10-D-41] Derive the equation $n = 1/\sin(c)$.
- ✓ [SLO: P-10-D-42] Apply the equation $n = 1/\sin(c)$ to solve simple problems.
- ✓ [SLO: P-10-D-43] Describe experiments to show internal reflection and total internal reflection.
- ✓ [SLO: P-10-D-44] Evaluate and illustrate the use of optical fibers.
- ✓ [SLO: P-10-D-45] Analyze the action of thin converging and thin diverging lenses on a parallel beam of light.
- ✓ [SLO: P-10-D-46] Define and use the terms focal length, principal axis and principal focus (focal point).
- ✓ [SLO: P-10-D-47] Draw ray diagrams to illustrate the formation of real and virtual images of an object by a converging lens.

- ✓ [SLO: P-10-D-48] Differentiate between real and virtual images.
- ✓ [SLO: P-10-D-49] Define and calculate linear magnification.
- ✓ [SLO: P-10-D-50] Describe the use of a single lens as a magnifying glass.
- ✓ [SLO: P-10-D-51] Explain the dispersion of light by a prism.
- ✓ [SLO: P-10-D-52] State the traditional seven colors of the visible spectrum in order of frequency and in order of wavelength.
- ✓ [SLO: P-10-D-53] Describe the use of a single lens as in various optical device applications.
- ✓ SLO: P-10-D-54] Draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye and a long-sighted eye.
- ✓ [SLO: P-10-D-55] Describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness.
- ✓ [SLO: P-10-D-56] Illustrate with examples how the biological eye processes color in various organisms.
- ✓ [SLO: P-10-D-57] State that extreme gravity from interstellar objects like blackholes can cause light to bend (from the perspective of the observer) in a way that is analogous to a simple lens.
- ✓ [SLO: P-10-D-58] State that 'acoustic lenses' are made of materials and shapes that work to focus or diverge sound.

Optics is the science of light and its interaction with matter. It explores the behavior of light waves, the properties of lenses and mirrors and the intricacies of human vision. But beyond its practical applications in fields like photography, microscopy and astronomy, optics holds a deeper significance. How do we see the world around us? What role does light play in shaping our understanding of reality? These and alike questions have puzzled the ancient scientists which derived the quest for knowledge in the realm of optics.

Our lives are filled with light, through vision the most valued of our senses. light has innumerable uses beyond vision like it can carry telephone signals through glass fibers or cook a meal in a solar oven. Life itself could not exist without light energy.

14.1 REFLECTION OF LIGHT

Light from this page is formed into an image by the lens of your eye much as the lens of camera that made this photograph. Light can travel in three ways: directly from the source to the observer (like sunlight reaching Earth through space), through different materials like air or glass, or after being reflected by objects like mirrors. In all cases, light travels in a straight line or as a ray. The word ray comes from mathematics and it means a straight line, we would use the travelling of light in ray diagram in this unit.

Reflection of light is a fascinating phenomenon that occurs when light rays bounce off a surface. Whenever you look into mirror you are seeing a reflection even when you look at this page, actually you are seeing the light reflected from this page. Large telescopes use reflection to form

an image of stars and other astronomical objects. To study the reflection of light from a surface we use some terms like perpendicular to the surface which is a line "normal" to the reflecting surface. One ray which strikes the surface is called the "incident ray" which makes an angle called "angle of incidence" with the reflecting surface. Similarly after striking the surface the ray of light reflected this is called "reflected ray" at some angle known as "angle of reflection" as shown in figure 14.1 (a).

'When a ray of light approaches a smooth polished surface and bounces back is called reflection'.

14.1.1 LAWS OF REFLECTION

There are two laws which govern the reflection of light as:

1. The incident ray, the reflected ray, and the normal all lie in the same plane.

2. The angle of incidence 'θ_i' and angle of reflection 'θ_r' are equal. This can be represented mathematically as:

$$\theta_i = \theta_r \quad \text{— 14.1}$$

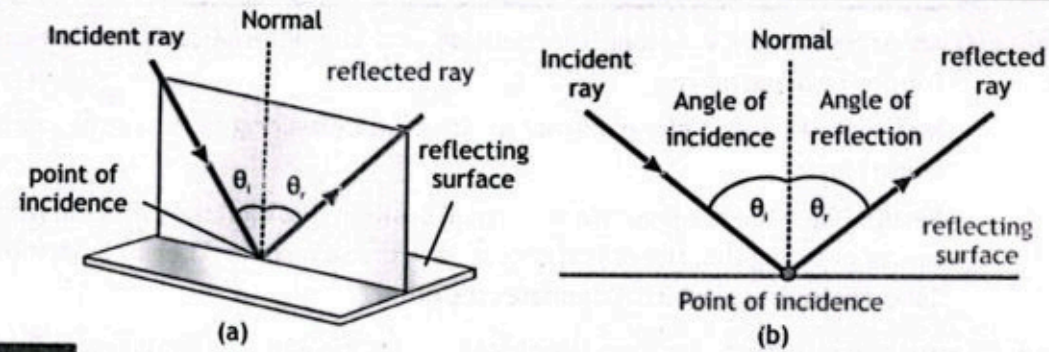


FIGURE 14.1 Laws of reflection

A. Regular or specular reflection: this occurs on smooth surfaces like mirrors, where the reflection is clear and sharp. The angles of reflection are consistent across the surface leading to a distinct image being formed. This phenomenon is shown in figure 14.2 (a).

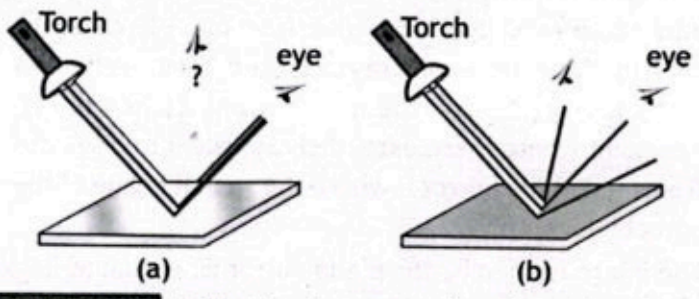


FIGURE 14.2 Reflection from smooth and rough surfaces

POINT TO PONDER



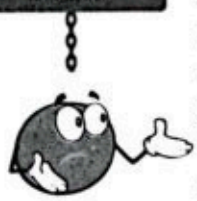
How does multiple reflections occur?

When light bounces between two mirrors facing each other, it creates multiple reflections. For instance, in a barber shop, you can see a series of your images due to the reflections between the front and back mirrors as shown.



B. Diffused reflection: This happens on rough surfaces where the reflected rays scatter in many directions. This type of reflection allows us to see most non-shiny objects like this page of your book that is why you can see this page from all sides not from only at a single point the diffused reflection of light and image from many sides is shown in figure 14.2 (b).

CAN YOU TELL?



A light ray strikes a reflective plane surface at an angle of 47° with the surface. Find the angle of incident, angle of reflection and angle between the incident and reflected rays.

MINI LAB

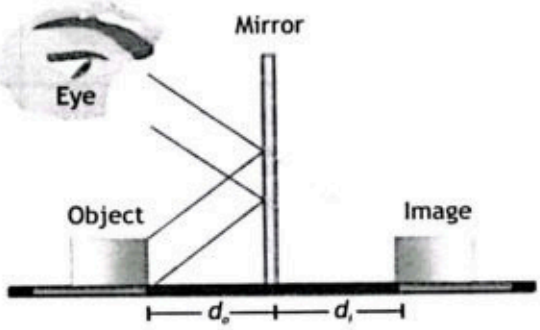


An experiment for finding the position and characteristics of an optical image formed by plane mirror.

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

Setup: Place the plane mirror in vertical position. Position the object in front of the mirror ensuring that the object should have the same or less height as that of mirror. Take a light source which illuminates the object.

Procedure: Observe the reflected rays from the object that strike the mirror surface. Note that two rays emerged from the object strike the mirror and reflect into observer's eye. Use the law of reflection to construct the reflected rays. Extend these reflected rays backward behind the mirror (using dashed lines). The point where these extended rays seem to originate from behind the mirror is where the virtual image of the object is located.



The image formed by the plane mirror is, virtual as it cannot be projected onto a screen. It is erect means image has same orientation as that of the object. The size of the image is the same as the size of the object. The distance of the image is the same as the distance of the object from the mirror i.e. $d_i = d_o$ (where d_i and d_i are the distances of object and image from the mirror respectively.)

UNIT OPENER?



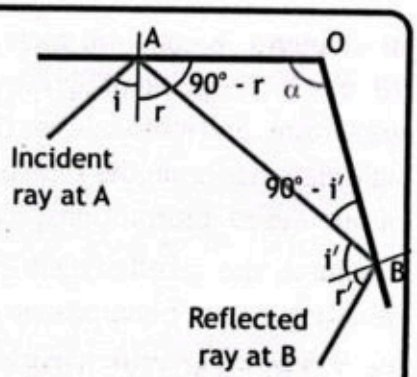
We see ourselves in a mirror it appears that our image is actually behind the mirror. We see the light coming from a direction determined by the law of reflection. The angles are such that our image is exactly the same distance behind the mirror as we stand away from the mirror. If the mirror is on the wall of room the images in it are all behind the mirror which can make the room seem bigger.



To understand it consider an object which is placed in front of a mirror at distance 'd_o'. Light rays coming from the object after reflecting from the mirror enter into the eye of observer. To the observer these light rays appear to be coming from behind the mirror from a distance 'd_i'. Hence the image will be seen by you behind the mirror due to reflection of light.

Example 14.1

Find the angle 'α' made by the system of the two mirrors as shown, provided that the incident ray '*A*' and the reflected ray '*B*' are parallel.



GIVEN:
Incident ray '*A*' is parallel to reflected ray '*B*'

REQUIRED:
Angle 'α' = ?

SOLUTION:
To find the value of angle we use laws of reflection as for the incident ray at 'A' and the reflected ray at 'B' to be parallel. and the angles $(i + r)$ and $(i' + r')$ have to be supplementary: $i + r + i' + r' = 180°$

By laws of reflection: $i = r$ and $i' = r'$

Using these values we get: $i + i + i' + i' = 180°$ and $i + i' = 90°$

In the triangle 'AOB' we have: $\alpha + (90° - r) + (90° - i') = 180°$ or $\alpha = r + i' = i + i'$

Therefore $\alpha = 90°$ — ANSWER

So, for incident ray '*A*' and the reflected ray '*B*' to be parallel 'α' must be 90°.

14.2 REFRACTION OF LIGHT

It is easy to notice odd things when you look on half submerged things into the water. For example if you dip a straight pencil into the glass water such that the full length of pencil does not sink into the water you would observe that the pencil is not straight but it is bended or broken which is known as broken pencil illusion as shown in figure 14.3. This is because the light coming from the

water to us changes direction when it leaves the water and enters into the air. In this case the light has to travel two different paths to get to our eyes. **'The changing of a light ray's direction when it passes through variations in matter is called diffraction'.** Refraction is responsible for a tremendous range of optical phenomenon from the action of lenses to voice transmission through optical fibers.



FIGURE 14.3
Broken pencil illusion due to diffraction of light.

14.2.1 SPEED OF LIGHT IN MATERIAL MEDIA

Why does light changes direction when passing from one material to another? It is because the speed of light does vary in a precise manner with the material it traversed i.e. going from one material to another. So before we study the law of refraction it is useful to discuss the speed of light and how it varies in different media. Although the speed of light in vacuum 'c' is constant such that it is accepted as universal constant with a fixed value *'$c = 3 \times 10^8\ m/s$'*. The speed of light through matter is less than that of in vacuum, because light interacts with atoms and molecules of the medium which hinders the speed of light that is why the speed of light depends upon the type of material. The speed of light is slower in denser mediums because of increased interactions, causing light to bend towards the normal. Conversely, in rarer mediums, the speed of light is faster due to fewer interactions, resulting in light bending away from the normal.

Table 14.1 REFRACTIVE INDICES

Medium	Refractive index (n)
Air	1.000293
Carbon dioxide	1.00045
Oxygen	1.000271
Benzene	1.501
Glycerin	1.473
Water	1.333
Diamond	2.419
Polystyrene	1.49
Glass (crown)	1.52
Glass (flint)	1.66
Ice	1.309
Zircon	1.923

14.2.2 REFRACTIVE INDEX

As we have discussed that the speed of light in any material media is always less than the speed of light in vacuum hence we can take the speed of light in vacuum as reference. The quantity which describes the speed of light in any medium as compared to the speed of light in vacuum as called as refractive index and can be defined as:

'The measure of bending of a light ray when passing from one medium to another is called refractive index such that one medium is vacuum'. It can also be defined as the ratio of the velocity of a light ray in an empty space to the velocity of light in a substance. If 'c' is the velocity of light in vacuum and the 'v' is the velocity of light in some medium then the refracted index 'n' of that medium can be given as:

$$n = \frac{c}{v} \quad \text{— 14.2}$$

As the speed of light in vacuum is the highest hence the above ratio i.e. refractive index of any medium cannot be equal to or less than unity. It has unit value only for vacuum itself. Refractive index being the ratio of similar quantities hence has no unit and a dimensionless quantity which describes how fast the light travels in a medium. In gases the value of refractive index is taken as unit if great precision is not needed as the atoms and molecules of gases are widely separated hence light interacts with them rarely. Refractive indices of some commonly used transparent materials are given in table 14.1.

Example 14.2

What is the speed of light in diamond, a material with a refractive index of 2.49, often found in jewelry?

GIVEN:
Refractive index 'n' = 2.419
Speed of light 'c' = 3×10^8 m/s

REQUIRED:
Speed of light in medium 'v' = ?

SOLUTION:
To find the speed of light in diamond we use formula: $n = \frac{c}{v}$ Rearranging $v = \frac{c}{n}$

putting values $v = \frac{3 \times 10^8 m\ s^{-1}}{2.419}$ Therefore $v = 1.24 \times 10^8 m\ s^{-1}$ — ANSWER

The speed of light reduces to 1.2×10^8 m/s

14.2.3 LAWS OF REFRACTION (SNELL'S LAW)

To study the laws of refraction first we have to know about the terms associated with the refraction phenomenon like normal, incident ray and refracted ray as shown in figure 14.4. The perpendicular line to the boundary of the two media is known as "normal", the light ray coming from the first medium is known as "incident ray" and the angle it makes with the normal is called "angle of incidence" while the ray entering into the other medium is called "refracted ray" and the angle it makes with the normal is called "angle of refraction".

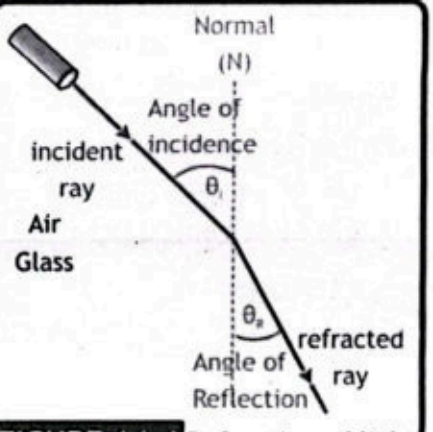


FIGURE 14.4 Refraction of light

The amount that a light ray changes its direction depends both on the incident angle and the amount that the speed changes. For a ray at a given incident angle a large change in speed causes a large change in direction and thus a large change in angle of refraction. Similarly, for the same speed of incident ray of light the large angle of incident causes a large change in refracted angle (up to a limit only). The laws of refraction are also known as Snell's law, after the name of a Dutch scientist (1591-1626) but were first given by a Muslim scientist Ibn-e-Sahl in 984 in his book "On

burning *mirrors and lenses*". These laws can be given in two steps i.e.

1. The first law states that the incident ray of light, the normal and the refracted ray of light all lie in the same plane.

2. The second law is about the relationship between the angles and the indices of refraction of the two media. It can be mathematically given as:

$$n_1 \sin\theta_i = n_2 \sin\theta_r \quad \text{— 14.3}$$

Here 'n_1' and 'n_2' are the refractive indices of the two media and 'θ_i' is the angle of incident and 'θ_r' is the angle of refraction. The same relation can also be written as:

$$\frac{n_1}{n_2} = \frac{\sin\theta_r}{\sin\theta_i}$$

If one of the two media is vacuum, and light enters from vacuum to some medium then '$n_1 = 1$' and relation reduces to:

$$\frac{1}{n_2} = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{or simply} \quad \frac{1}{n} = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{— 14.4}$$

When light enters into vacuum from some medium then '$n_2 = 1$' and relation becomes:

$$n_1 = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{or simply} \quad n = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{— 14.5}$$

Example 14.3

Find the refractive index for the medium if light enters into it from air at an angle 37° and refracted into it at angle 21°.

GIVEN:
Refractive index of air 'n_1' = 1
Angle of incident light 'θ_i' = 37°
Angle of refracted light 'θ_r' = 21°

REQUIRED:
Refractive index of medium 'n_2' = ?

SOLUTION:
The Snell's law can be written as: $\frac{n_2}{n_1} = \frac{\sin\theta_i}{\sin\theta_r}$ putting values $\frac{n_2}{1} = \frac{\sin 37^\circ}{\sin 21^\circ}$

Therefore $n_2 = 1.68$ — ANSWER

This is the refractive index of a type of glass which is used for the core of optical fibers.

14.2.4 EXPERIMENT TO STUDY REFRACTION

To study the refraction due to transparent blocks of different shapes we can device an experiment even in our classroom or lab in the school.

A. Aim of the Experiment: To study the refraction of light using a rectangular block, semi-

SCIENCE TIDBITS

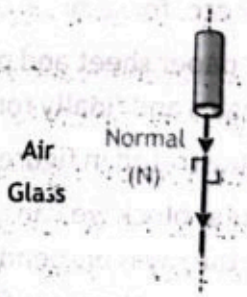
If the light enters from one medium to another medium perpendicular to the surface which divides the media then the angle of incident becomes zero. As in this case the light is incident parallel to the normal then Snell's law will give the angle of refraction also to be zero as:

$$n_1 \sin\theta_i = n_2 \sin\theta_r \quad \text{as} \quad \sin 0 = 0$$

$$\text{as} \quad 0 = n_2 \sin\theta_r \quad \text{and} \quad \theta_r = \sin^{-1} 0$$

$$\text{Finally,} \quad \theta_r = 0$$

This shows that whenever light enters from one medium to another at right angle, whatever their refractive indices may be the angle of refraction will be zero i.e. the light does not bend in such situations.



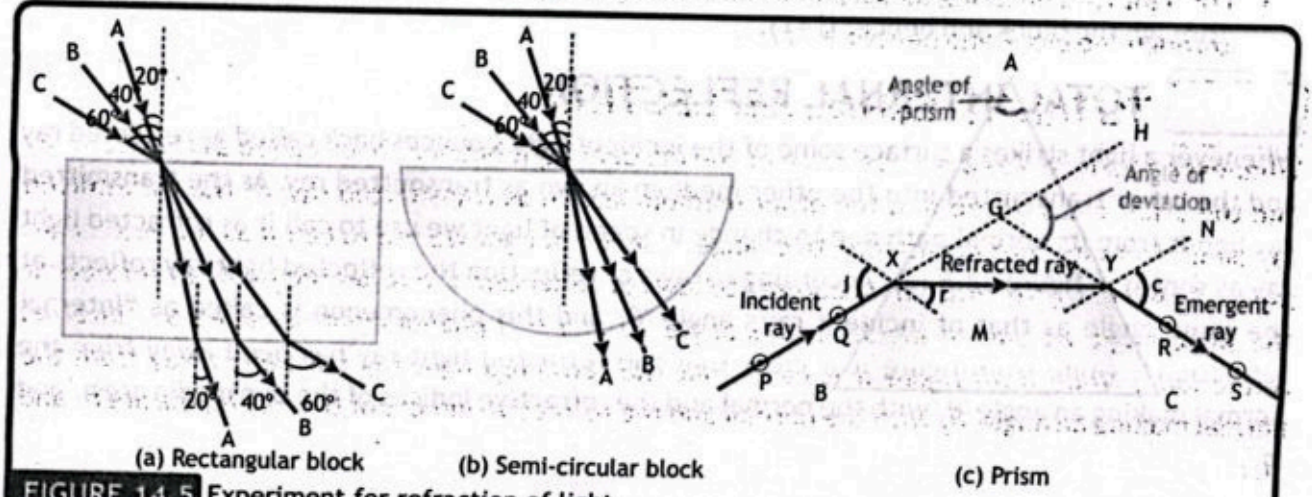
circular block and triangular prism made of glass.

B. Equipment required: Laser light, protractor, sheet of paper , pencil, ruler and perspex blocks (rectangular, semicircular and prism).

C. Method for studying refraction: Place the glass rectangular block on the paper draw lines around it. Now draw the perpendicular lines which are called as normal. Illuminate one plane side of the block making some angle with the normal already drawn on the paper.

Mark the following and carefully make observations:

- A point on the paper near the light source.
- A point where the light ray enters into the block.
- The point where the light ray exits the block.
- Another point along the path of exit light ray at a distance of say 4 to 5 cm.



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

FIGURE 14.5 Experiment for refraction of light

- Remove the light source and the block and join the points marked on the paper sheet with straight lines.
- Replace the block again and repeat the above experiment for some different angles like for 20°, 40° and 60° etc. for semi-circular block too.

Now take another paper sheet and perform the same experiment for the semi-circular block with three different angles and finally for a glass prism.

All the three are illustrated in figures 14.5 (a), (b) and (c).

For the semi-circular block we can see that the light rays are not refracting because at each point the radial path of the ray is perpendicular to the tangent hence the light rays are leaving the block along the normal line and hence suffer no refraction.

D. Results: Consider the light paths for different shaped blocks.

- The final diagram for each shape will include multiple light ray paths for the different angles of incidents (i) at which the light strikes the blocks.
- This will help to demonstrate how the angle of refraction (r) changes with the angle of incident.
- Label these paths for first two blocks as 'A', 'B' and 'C' to make the paths clear.
- Incident and refracted angles are always measured from the normal.
- In all the cases you would observe that:
  - the light entering the block bends towards the normal line hence: $(i > r)$.
  - For light rays exiting the Perspex blocks all the light rays refract away from the normal line hence: $(i < r)$.
  - For light rays entering along the normal the light ray does not refract i.e. it passes straight through the block and hence: $(i = r)$.

14.3 TOTAL INTERNAL REFLECTION

Whenever a light strikes a surface some of the incident light bounces back called as reflected ray and the other transmitted into the other medium known as transmitted ray. As the transmitted ray bends from its normal path due to change in speed of light we use to call it as refracted light ray as shown in figure 14.6 (a). According to laws of reflection the reflected light ray reflects at the same angle as that of incident ray's angle 'θ_1' and this phenomenon is called as "internal reflection", while from figure it is clear that the refracted light ray has bend away from the normal making an angle 'θ_2' with the normal and the refractive indices of the two media are 'n_1' and 'n_2'.

When light travels from a less dense medium to a denser one, it bends toward the normal line. As the angle of incidence increases, the angle of refraction decreases, causing the refracted light to approach the normal line. In contrast, when light moves from a denser medium, such as glass or water, to a less dense medium like air, it bends away from the normal. Increasing the angle of incidence results in a larger angle of refraction, moving it further from the normal line.

If we further increase the angle of incident the refracted light ray by moving away from the normal makes an angle of 90° with the normal as shown in figure 14.6 (b). At this angle the refracted light without entering into the second medium rather it moves along the boundary between the two media. At this stage the incident angle is called the critical angle, which can be defined as: **"The angle of incidence for which the angle of refraction is 90 degrees is called as the critical angle."**

The critical angle is represented by 'θ_c'. When the angle of incidence of the light ray becomes greater than the critical angle the refracted light ray also reflects back into the same medium from the boundary of two media. At this stage there is no more refraction of light and is known as the total internal reflection of light as shown in figure 14.6 (c), total internal reflection can be defined as: **"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."**

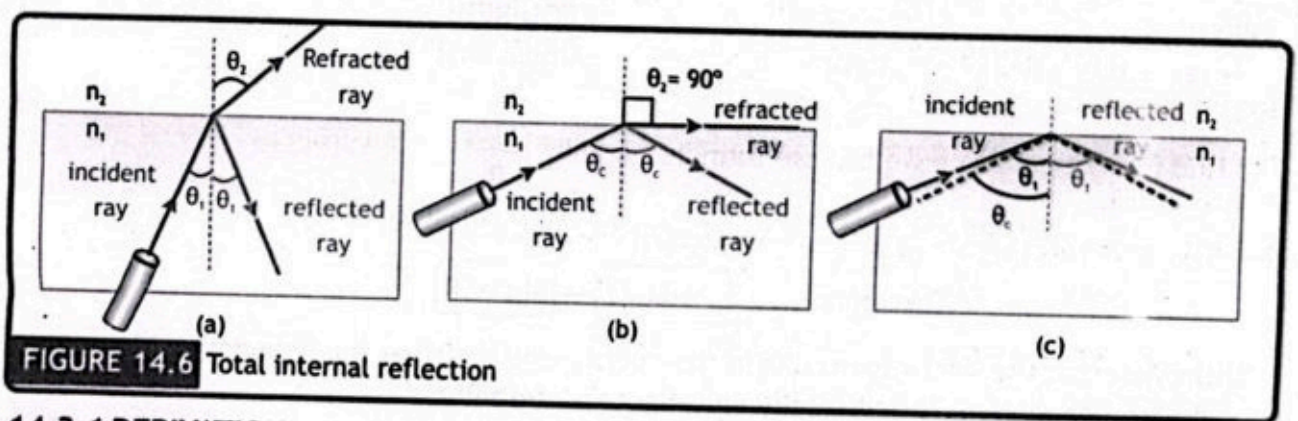


FIGURE 14.6 Total internal reflection

14.3.1 DERIVATION

To derive a relation for the total internal reflection we use Snell's law from equation 14.3:

$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

As for total internal reflection the refracted angle becomes 90° as shown in figure 14.11, hence the above equation gets the form:

$$n_1 \sin\theta_1 = n_2 \qquad \text{as} \quad \sin 90^\circ = 1$$

The sine of critical angle for the given combination of materials is: $\sin\theta_c = \frac{n_2}{n_1}$ — (1)

The critical angle can be found as: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ — (14.6)

As we know that the trigonometric ratio of sine can have values maximum up to 1, for this it is necessary that the refractive index of first medium (from which light ray is incident) should be greater than the refractive index of the second medium (in which light ray is entering) i.e. total internal reflection can only be happened if light ray travels from denser medium into the lighter medium. If second medium is air we can take the refractive index of air unity as '$n_2 = 1$' then '$n_1 = n$' and equation (1) becomes:

$$\sin\theta_c = \frac{1}{n}$$

And in general refractive index of the other material can be given as: $n = \frac{1}{\sin\theta_c}$ — (14.7)

The above relation holds good only if light is entering from any denser medium having refractive index 'n' into the air.

Example 14.4

Find the critical angle of polystyrene (n = 1.49) pipe surrounded by air.

GIVEN:
The refractive index of polystyrene 'n' = 1.49

REQUIRED:
critical angle 'θ_c' = ?

SOLUTION:
To find the critical angle we can use formula: $\sin\theta_c = \frac{1}{n}$

putting values $\sin\theta_c = \frac{1}{1.49}$ or $\theta_c = \sin^{-1}(0.671)$

Therefore $\theta_c = 42.2°$ — ANSWER

This mean that the light ray moving in the polystyrene if strikes the boundary with an angle greater than 42.2° will totally be reflected internally.

14.3.2 EXPERIMENT TO STUDY TOTAL INTERNAL REFLECTION:

To study the total internal reflection due to transparent block of semi-circular shape we can device an experiment even in our classroom or lab in the school.

A. Aim of the Experiment: To study the total internal reflection of light using a semi-circular block of glass.

B. Equipment required: Laser light, protractor, sheet of paper, pencil, ruler and perspex block.

C. Method for studying reflection: Place the semi-circular glass block on the paper draw lines

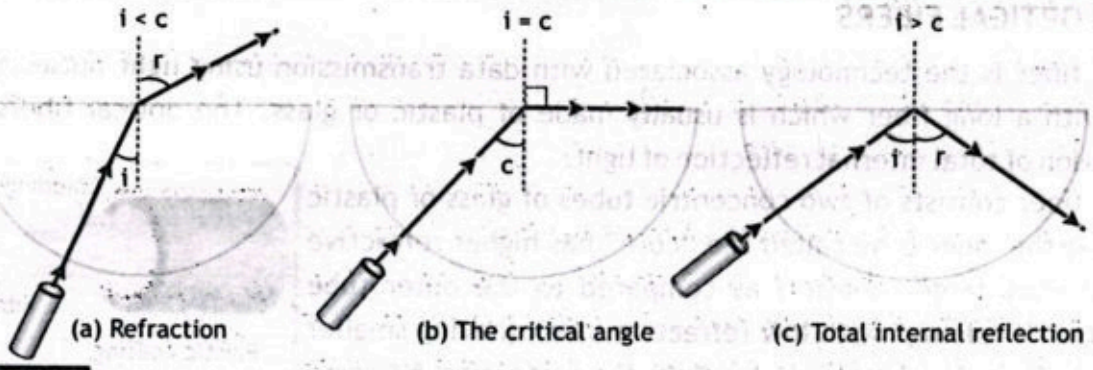


FIGURE 14.7 Experiment for total internal reflection

around it. Now draw the perpendicular line which is called as normal. Illuminate one plane side of the semi-circular block making some angle with the normal already drawn on the paper. Make the following carefully.

- A point on the paper near the light source
- A point where the light ray enters into the block
- The point where the light ray exits the block
- Another point along the path of exit light ray at a distance of say 4 to 5 cm
- Move the light source slowly such that the angle of incidence keeps on increasing.

While moving the light source the angle of incident increases which in turn increases the angle of refraction until the refracted line makes an angle of 90° with the normal this incident angle is called as 'critical angle'. Now mark two points for incoming ray at this stage.

Now increase the incidence angle further the refracted light now enters back into the same semi-circular block in spite of going into the other medium this phenomenon is known as total internal reflection as shown in figure 14.7.

D. Results: Consider the light paths for different angles and draw lines. These lines give the following results about the phenomenon of refraction and reflection as:

- In the case when the incidence angle was less than the critical angle we noticed the phenomenon of refraction and light entered into the lighter medium from the semi-circular glass block: $i < c$.
- For the case when the incidence angle was equal to that of the critical angle we noticed the refracted light made an angle of 90° with the normal and traveled on the boundary between the two media: $i = c$.
- For the case when the incidence angle was greater than the critical angle we noticed the phenomenon of total internal reflection and light bounced back to the same block in spite of going into the lighter medium from the semi-circular glass block: $i > c$.

14.3.3 OPTICAL FIBERS

Optical fiber is the technology associated with data transmission using light pulses travelling along with a long fiber which is usually made of plastic or glass. The optical fibers use the application of total internal reflection of light.

Optical fiber consists of two concentric tubes of glass or plastic such that the inner tube called the "core" has higher refractive index (having larger density) as compared to the outer tube called the "cladding" with low refractive index (having smaller density). The whole setup is covered for protection by some material called "jacket". The light enters into the core at an angle greater than the critical angle of the core material, moves within the core by successive total internal reflections. An optical fiber cable is shown in figure 14.8. Optical fibers have applications in many fields of life but the most commonly used application of optical fibers is their role in modern telecommunications. Optical fibers offer several advantages over traditional copper based network infrastructure some of them can be given as:

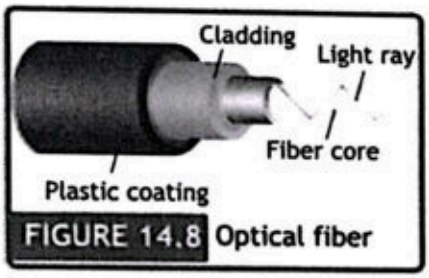


FIGURE 14.8 Optical fiber

A. High bandwidth: Optical fibers provide significantly higher band width compared to copper wires, where band width is the data transfer capacity of a network in bits per second. In modern times we need a lot of data from our internet at very high speed hence larger bandwidth of optical fibers serves the best to our requirement

B. Faster Speed: They can transmit data at faster speeds due to the use of light pulses instead of electrical signals. They transfer the data from one place to another at the speed of light

C. Resistance to electrical interference: As we use light in optical fibers hence the electrical interference has no effect on the data as it was a major problem in copper-network transmissions

D. Long Distance: It can transmit data over much longer distances without significant signal loss like under-sea cables and inter-continental connections.

E. Low Power: They consume less power than copper cables and their durability and longevity reduces maintenance costs.

Optical fibers are used in various sectors, including healthcare, defense, manufacturing, broadcasting, lighting, and communications. In telecommunications, they are essential for data transmission, offering greater speed and accuracy than copper wires. Optical fiber cables are lighter, more flexible, and can carry more data. Data is converted into a light signal using transducers like LEDs or laser diodes and introduced into the fiber's core at an angle greater than the critical angle as shown in figure 14.9.

This light signal travels through the optical fibers for long distances until it reaches the destination. At the receiving end the light signal is converted into electrical signal with the help of transducers like photo-diode, PIN diode or avalanche diode. These diodes convert light signal into electrical signal near the user end and electrical signal is finally converted into text, voice or video data as required.

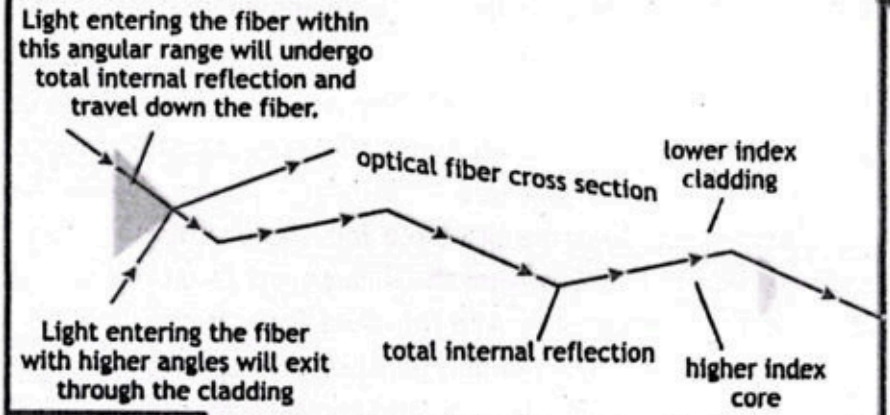


FIGURE 14.9 Light signal transmission through optical fibers

14.4 THIN LENSES

Optics is a fascinating branch of physics that explores the behavior and properties of light. One of the most intriguing aspects of optics is the study of lenses which can be defined as: **'The transparent objects that refract light in specific ways to form images are called the lenses.'**

Understanding the action of lenses is fundamental to various applications in science, technology and everyday life from eye-glasses, cameras, microscopes and telescopes etc. lenses are optical devices made from transparent materials typically glass or plastic with at least one curved surface. They work on the principle of refraction which is the bending of light as it passes from one medium to another.

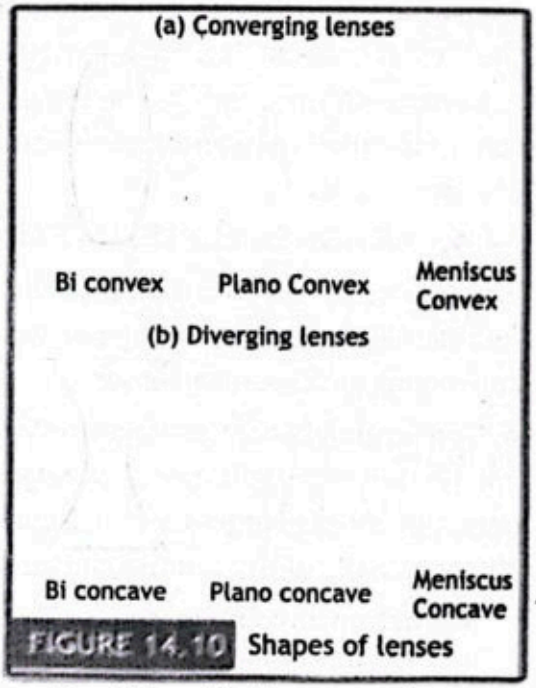


FIGURE 14.10 Shapes of lenses

Lenses are broadly classified into two main types i.e. converging (also called a convex lens) and diverging (also called a concave lens) lenses with variety of different shapes as shown in figure 14.10. There are some common terms associated with the lenses which are required to study the image formation from the lenses which can be given as:

A. Focal Length: The focal length *'f'* of a lens is the distance from the lens to its focal point (focal point may be real or virtual). For a converging lens the focal length is positive. It represents the distance from the lens to the point where parallel rays converge after passing through the lens while for a diverging lens the focal length is negative. It represents the distance from the lens to the point where parallel rays appear to diverge from (the virtual focal point).

B. Principal Axis: The principle axis is an imaginary straight line passing through the center of the lens. Light rays that pass through the center of the lens along the principle axis are not deviated.

C. Principle Focus (Focal Point): The principle focus is also called the focal point which is the point on the principle axis where parallel rays of light converge for a converging lens and appear to diverge from a diverging lens.

For a converging lens the principle focus is on the opposite side of the lens from the incoming parallel rays and for diverging lens the principle focus is on the same side as the incoming parallel rays but it appears to be behind the lens, all the above terms of a lens are shown in figure 14.11.

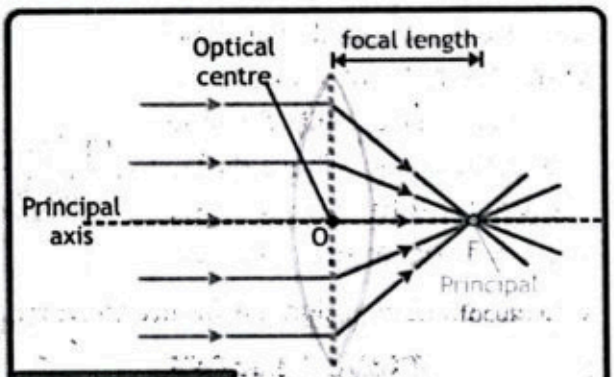


FIGURE 14.11 Lenses terms

D. Optical Centre: The centre of a lens is the point from which the principle axis passes through is called the "optical center" it is represented by *'O'*.

E. Centre of Curvature: As the lenses are the parts of spherical materials then the centre of the sphere is called the center of curvature of the lens. This is usually twice apart from the lens as that of focal point.

14.4.1 ACTION OF LENSES ON PARALLEL RAYS:

When we strike parallel light rays to a lens these light rays after refraction from the lens show a fascinating pattern. Upon the behavior of a lens to the parallel light rays lenses are classified as converging and diverging lenses.

A. Converging Lens: Convergence lens is thicker at its center and thinner at the edges. When a parallel beam of light passes through a thin converging lens (convex lens) the lens refracts the light rays and converges them to a point known as focal point on the other side of the lens. The key characteristics of this process can be given as:

- **Refraction and Convergence:** The parallel rays are bent towards the principal axis of the lens due to refraction. The curvature and the refractive index of the lens material cause this bending. After passing through the lens all the parallel rays converge at a single point on the principle axis that is the focal point of the lens.
- **Formation of Image:** The formation of image from the lens depends upon the location of the lens. The image from the converging is normally real and inverted but in some cases it may be virtual image. The behavior of converging lens towards the parallel light rays is shown in figure 14.12 (a).

B. Diverging Lens: Divergence lens is thinner at its center and thicker at the edges. When a parallel beam of light passes through a thin diverging lens (concave lens) the lens refracts the

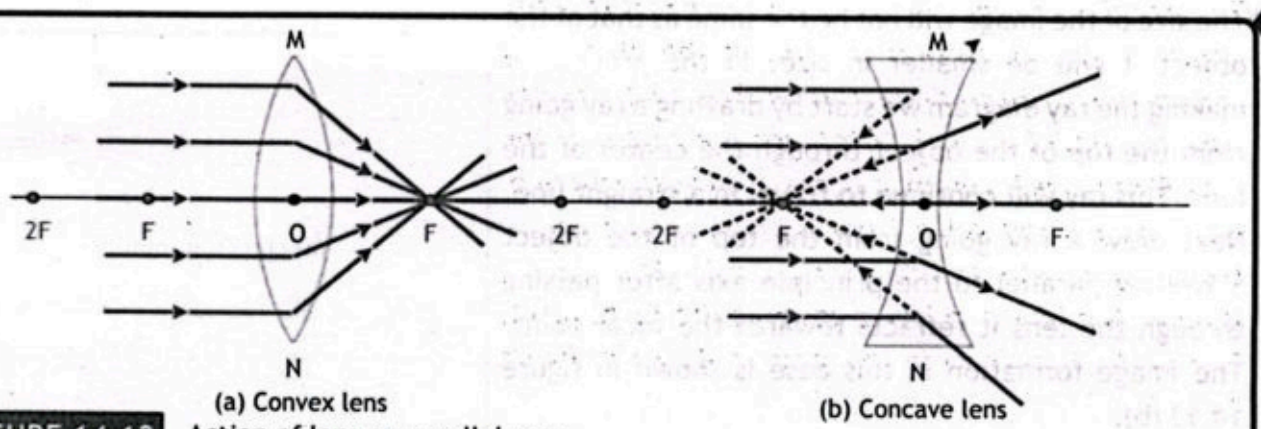


FIGURE 14.12 Action of lens on parallel rays

light rays and diverges them as if they are coming from a point known as the focal point on the same side of the lens from which the light is coming the characteristics of this process are:

- **Refraction and Divergence:** The parallel rays are bent away from the principle axis of the lens due to refraction. This divergence gives the impression that the rays are emanating from a focal point behind the lens.
- **Virtual Focal Point:** The focal point for a concave lens is virtual because the light rays do not actually converge there instead they appear to be diverging from this point when extended backward.
- **Formation of Image:** If an object is placed at infinity the image formed by the diverging lens will be at its virtual focal point and the image will be virtual, upright and diminished. The divergence of parallel light rays from a divergence lens is shown in figure 14.12 (b).

14.4.2 RAY DIAGRAMS BY THE LENSES

Lenses can be used to form images of the objects placed in front of them the location and nature of the image can be found by drawing a ray diagram. In this process we take a minimum of two light rays emerging from the object and pass them through the lens from two different points join to give us an image. The distance of the object from the lens determined the nature of the image formed.

A. Object Placed at Infinity: When an object is placed at infinity the real image is formed at the focus. The size of the image is highly diminished and it seems as an image of point size. In the process of making the ray diagram we take all the rays coming from the body as parallel because the body is at infinity hence the rays after travelling such a long distance can be considered as parallel rays and converge all the rays at focal point. The ray diagram for an object at infinity is shown in figure 14.13 (a).

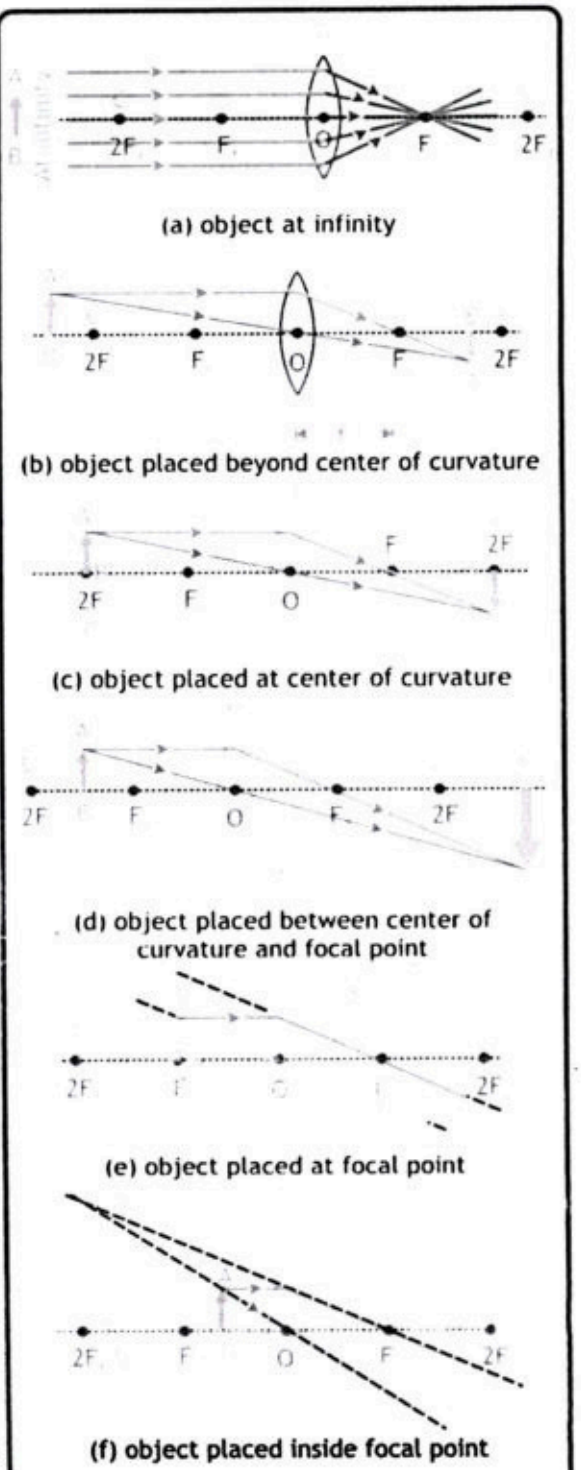
B. Object Placed Beyond 2F: When an object is placed beyond the center of curvature 'C' (beyond 2F) the real and inverted image is formed between the center of curvature and the focus.

The size of the image will not be the same as that of the object it will be smaller in size. In the process of making the ray diagram we start by drawing a ray going from the top of the object through the center of the lens. This ray will continue to travel in a straight line. Next draw a ray going from the top of the object travelling parallel to the principle axis after passing through the lens it refracts towards the focal point. The image formation in this case is shown in figure 14.13 (b).

C. Object Placed at 2F: When an object is located at the center of curvature (2F), a real image is produced at the same point. The image will be the same size as the object, and it will be inverted and real. To illustrate this, start by drawing a ray from the top of the object that passes through the center of the lens, continuing in a straight line. Then, draw another ray from the top of the object that travels parallel to the principal axis; after it passes through the lens, it will refract towards the focal point. This image formation is depicted in figure 14.3 (c).

D. Object Placed between F and 2F: When an object is positioned between the center of curvature (2F) and the focal point (F), a real image is produced beyond the center of curvature. This image will be larger, inverted, and real. A ray from the top of the object that passes through the center of the lens will continue in a straight line. Additionally, a ray from the top of the object that travels parallel to the principal axis will refract towards the focal point after passing through the lens. The intersection of these two rays will determine the location of the image. This process is illustrated in figure 14.13 (d).

E. Object Placed at F: When an object is placed at the focal point (F) the real image is formed at infinity. The size of the image will be much larger than the object in size. The image formed will be larger, inverted and real.



(a) object at infinity

(b) object placed beyond center of curvature

(c) object placed at center of curvature

(d) object placed between center of curvature and focal point

(e) object placed at focal point

(f) object placed inside focal point

FIGURE 14.13 Image formation in convex lens

In the process a ray going from the top of the object through the center of the lens will continue to travel in a straight line. Next draw a ray going from the top of the object travelling parallel to the principle axis after passing through the lens it refracts towards the focal point. The lines appear to move in parallel fashion but the image will be formed but at infinity. The image formation in this case is shown in figure 14.13 (e).

F. Object Placed inside F: When an object is positioned at the focal point (F), a virtual image is created beyond the center of curvature and on the same side of the lens as the object. This image will appear larger larger, upright, and virtual. A ray originating from the top of the object and passing through the center of the lens will continue in a straight line. Next, draw a ray from the top of the object that travels parallel to the principal axis; after passing through the lens, it will bend towards the focal point. As these two rays diverge, they will not meet, so we extend dotted lines backward until they intersect. The intersection point of these dotted lines indicates the location of the image. This process is illustrated in figure 14.13 (f).

14.4.3 LINEAR MAGNIFICATION

Linear magnification is a fundamental concept in optics particularly when dealing with lenses and mirrors. It can be defined as: **'The ratio of height (or length) of image to the height (or length) of an object is called the linear magnification.'**

It describes how much an image appears larger or smaller compared to the actual object. It is also known as lateral magnification or transverse magnification. Mathematically it can be given as:

$$M = \frac{I}{O} \quad \text{—(1)}$$

Here 'M' is the linear magnification, 'I' is the height of the image and 'O' is the height of the object. Measure the length of the object you are examining which can be done using a ruler or any other measuring tool then determine the length of the image produces by the lens this is the size of the image as it appears in the lens or on a screen. Some of the characteristics of linear magnification are given in the table 14.2.

Table 14.2 LINEAR MAGNIFICATION

Condition	Explanation
$\|M\| > 1$	The image size is less than that of object size
$\|M\| < 1$	The image size is greater than that of object size
$\|M\| > 0$	The image has the same vertical orientation as the object called an upright image
$\|M\| < 0$	The image has the opposite vertical orientation as the object called an inverted image

In some cases the size of images or objects are so small that they cannot be measured easily for such condition we can find linear magnification with the help of distances of image and object from the lens. It is very interesting fact that the ratio of distance of image from the lens to the

distance of object from the lens is same as that of the ratio of sizes of image to the object. We can also define linear magnification as: **'The ratio of the distance of image from the lens to the distance of object from the lens is called the linear magnification.'** Mathematically,

$$M = \frac{q}{p} \quad \text{— 2}$$

Here 'M' is the linear magnification, 'q' is the distance of the image from the lens and 'p' is the distance of the object from the lens. Measure the distance of the object you are examining which can be done using a ruler or any other measuring tool then determine the distance of the image produces by the lens.

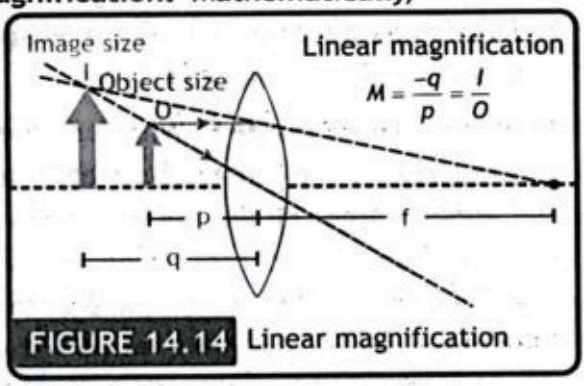


FIGURE 14.14 Linear magnification

From equation 1 and 2 we can write as: $M = \frac{I}{O} = \frac{q}{p}$ — 14.8

For real image we use the distance of image '$+q$' as positive and for virtual image we use the distance of image '$-q$' as negative. The light ray diagram for calculating the linear magnification is shown in figure 14.14.

Example 14.5

Find the distance and height of the image if the object of height 2cm is placed at 6cm from a converging lens with magnification as 3. Also find the nature of image if the focal point of the lens is 5cm from the lens.

GIVEN:
Heigh of object 'O' = 2 cm
Distance of object 'p' = 6 cm
Magnification 'M' = 3

REQUIRED:
Height of image 'I' = ?
Distance of image 'q' = ?
Nature of image

SOLUTION:

The relation for magnification is: $M = \frac{I}{O}$ or $I = M\,O$ Using values $I = (3)\ (2\ cm)$

Therefore $I = 6\ cm$ — ANSWER

To find the distance of image we can again use magnification relation as: $\frac{I}{O} = \frac{q}{p}$

or $q = p \times \frac{I}{O}$ Using values $q = (6\ cm) \times \frac{(6\ cm)}{(2\ cm)}$

Therefore $q = 18\ cm$ — ANSWER

As the object is placed outside of the focal point hence the image formed in this case will be real, inverted, enlarged and opposite side of the lens as that of object.

14.4.4 DIFFERENCE BETWEEN REAL AND VIRTUAL IMAGES

Lenses can make two types of images one is called a real image and the other is called as virtual image. The differences between real and virtual images are given in table 14.3.

Table 14.3 DIFFERENCE BETWEEN REAL AND VIRTUAL IMAGES

Real Image(s)	Virtual image(s)
can be caught on the screen	cannot be caught on the screen
is always inverted	is always erect
formed when the rays of light after reflection or refraction actually meet at some point	formed when the rays of light after reflection or refraction appear meet at some point
formed by the actual intersection of light rays	formed by the imaginary intersection of light rays
can be formed in a screen	can only be seen in mirrors
formed by only convex lens	concave lens, convex lens and plane mirrors also
formed on the other side of lens then the side of the object	formed on the same side of lens as the side of the object
Example is the image on our TV screen	Example is our reflection in mirror

14.5 APPLICATIONS OF LENSES

Lenses are fundamental optical elements that play an important role in a wide range of scientific, engineering, medical and everyday life applications from the simple magnifying glass to complex systems. They are used in consumer optics like eyeglasses, camera and binoculars, microscope optics like scientific and medical research and diagnostics, telescope optics like using telescopes to explore the cosmos, photographic optics like capturing images. Some of the commonly used applications of lenses are given here:

14.5.1 MAGNIFYING GLASS

A single lens is used as magnifying glass which is a simple optical device designed to magnify objects. The lens used in the magnifying glass is convex lens. As we know that when an object is placed near the lens such that the object's distance from the lens is less than the distance of focal point of the lens, it produces an enlarged, erect and virtual image of the object. The eye perceives this image as being larger than the actual object. A magnifying glass is shown in figure 14.15 (a). To use a magnifying glass, we have to take care of the following steps:

- **Position:** The position of object is crucial in the use of magnifying glass. Hold the magnifying glass close to the object you want to magnify.
- **Distance:** Move the lens closer to or further from the object until the image comes into clear focus.

- **Viewing:** Look through the lens to see the magnified image the optical viewing distance is usually a few centimeters away from the object.

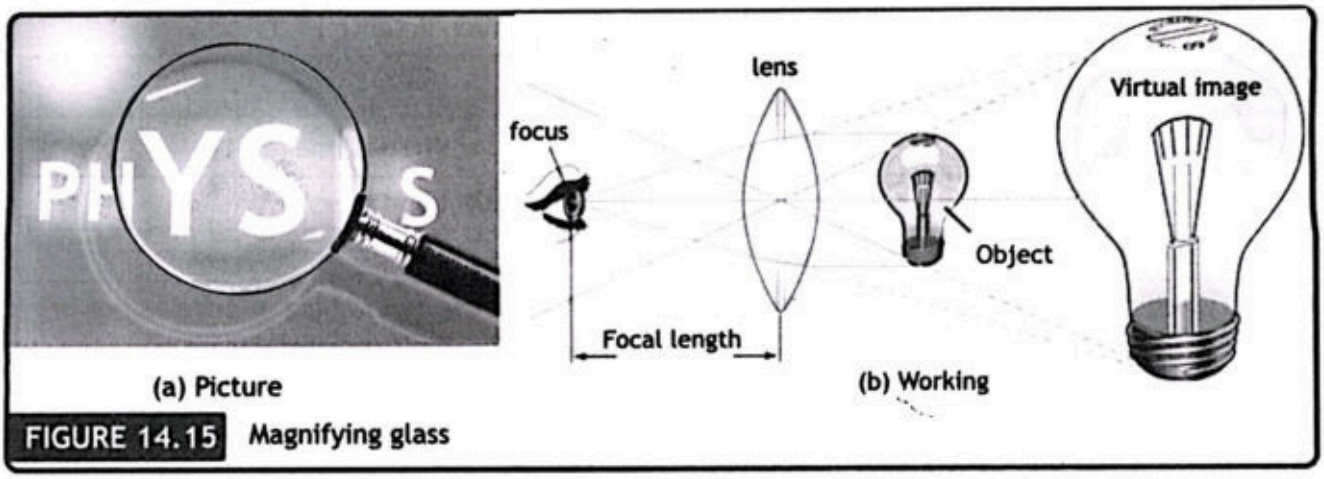


FIGURE 14.15 Magnifying glass

14.5.2 DISPERSION OF LIGHT BY PRISM

A prism is an optical element which is usually made of glass with triangular and rectangular sides. It has the ability of bending the light passing through it due to refraction. As we know that the visible light has a range of wavelengths and refraction of light depends upon the wavelength hence different wavelengths diffract at different extent which disperse the light.

Dispersion of light can be defined as: **'The splitting of white light into seven constituent colors when passed through the prism is called the dispersion of light'.**

The white light that travels through the prism is separated due to the processes of refraction and dispersion. As white light enters the prism, it slows down and bends toward the normal line. Each color of light has a unique wavelength, and as the light moves through the prism, each wavelength is refracted by varying degrees. This results in the shorter wavelengths, such as violet and blue, bending more than the longer wavelengths like red and orange. Consequently, the light that exits the prism is split into seven distinct colors, ranging from red to violet. This collection of colors is known as the visible light spectrum as illustrated in figure 14.16 (a).

Beyond the visible spectrum, there are wavelengths of light that the human eye cannot perceive, such as infrared and ultraviolet. These wavelengths can also be dispersed by the prism, but since they are invisible, alternative detection methods are necessary. One such method involves thermometers equipped with sensors that can detect a broad range of wavelengths. These thermometers can sense infrared radiation emitted by objects, which correlates with their temperature. When the dispersed light from the prism reaches these thermometers, they can detect both infrared and visible light. By measuring the intensity of the infrared radiation, the thermometer can determine the temperature of the emitting body. These thermometers can also

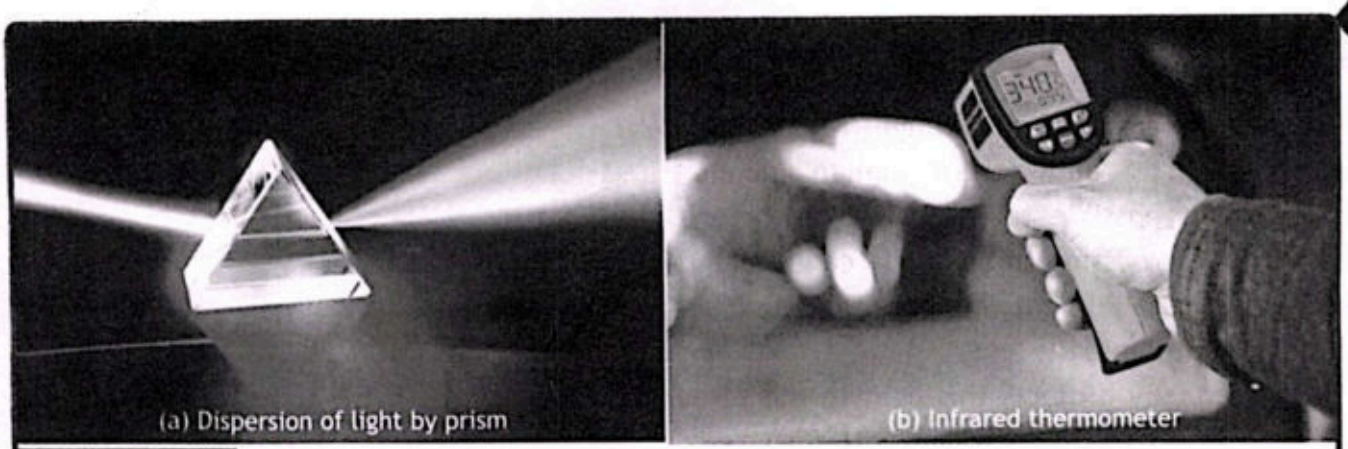


FIGURE 14.16 Light dispersion

measure human body temperature without direct contact. An example of such an infrared thermometer is shown in figure 14.16 (b).

14.5.3 SOME OPTICAL DEVICES WITH SINGLE LENS

Lenses have wide range application in everyday life. Even a single lens can be used to make many valuable devices like a magnifying glass, camera, projector and a photographic enlarger etc. We can show how these devices form images with the help of ray diagrams.

A. Camera: Most people today have a mobile phone with a built-in camera, so we are all familiar with cameras. Figure 14.17 illustrates the process of how a photographic camera creates an image. In simple explanation a camera has a lens and an image film placed in line to the lens. Every time the button is pressed, light from an object positioned '*p*' units away from the camera lens enters the lens. The light then goes through a shutter that opens briefly to allow the light from the object to reach the photographic film or CCD. Here, the information in the form of light about the object is received, creating a real and inverted image of the object at a distance '*q*' from the lens.

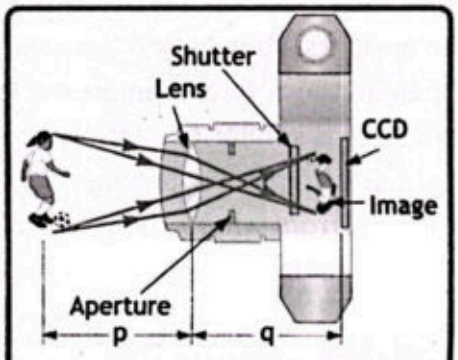


FIGURE 14.17
Image formation in camera

B. Projector: We commonly use slide projectors in our classrooms, seminar rooms and halls which show an enlarged image on the main screen or wall. The slide projector is also a single lens device. The working of the projector is shown by the ray diagram as shown in figure 14.18. In the projector there is a bulb which produces light behind it we use a concave mirror which reflects back the light coming from the bulb to increase the intensity of light so that a sharp and detailed image can be formed by the projector.

The next part of the projector is the condensing lens the aim of the condenser lens in a projector is to align the light rays into a straight path this allows the maximum amount of the light possible to reach the projector screen. After passing through the condensing lenses the parallel light rays pass through the slide and enter into the lens.

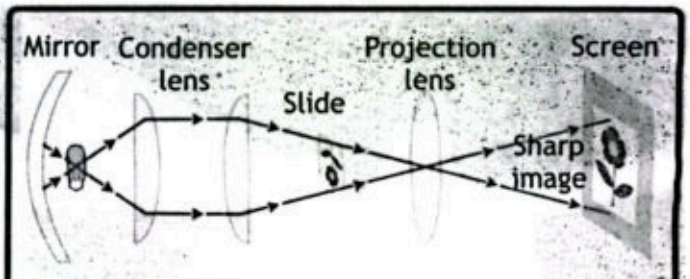


FIGURE 14.18 Image formation by projector

The lens finally projects this light to the screen by magnifying it many times so that a small object's image may be seen in a very large size.

C. Photographic Enlarger: The enlarger in photography is a device that gives an image of object larger than the original size. It consists of a projection assembly which includes an illumination system like a bulb, a lens for projecting the image onto the photographic paper and a mechanism for focusing the image on the paper.

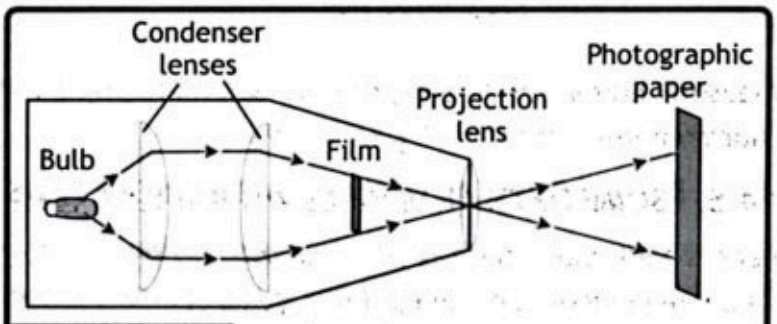


FIGURE 14.19 Photographic enlarger

An optical system called the condenser is used in it which is a system of lenses that focus the beam of light towards the enlarging lens through the film. The optical system of the photographic enlarger is similar to that of the system used in projector and is shown in figure 14.19. Here the light of bulb passing through the condenser lenses which focus the light on film and hence falls on the lens from where the lens makes an enlarge image on photographic paper. The final image is made clear by using intense light to give more details and enlarged as compared to the object.

14.6 VISIBLE SPECTRUM

Among the large ranges of electromagnetic radiations, only a small portion is visible to the human eye. This portion is referred to as the visible spectrum, which is categorized into seven distinct color ranges How we see colors? Why the sky is seen blue? Why the traffic signal to stop the vehicles is seen as red? The answer to all these questions depends on how we see objects. A Muslim scientist Al-Hazen (Ibn al Haithem) gave the concept of vision. When light strikes an object, it experiences two main phenomena: some of the light is absorbed by the object (or passes through it), while the remaining light reflects off the object and enters our eyes, allowing us to see. If an object absorbs all wavelengths of light and reflects none, we perceive it as black. If it absorbs all wavelengths except for red, we see it as red. Similarly, if it absorbs all wavelengths except blue, it appears blue to us. When only one color's wavelength hits an object and reflects back, we

perceive the object's color as that of the incident light, as illustrated in figure 14.20. The visible spectrum consists of seven primary colors: red, orange, yellow, green, blue, indigo, and violet, each with its own range of wavelengths and frequencies. In order of frequency and wavelength the seven colors can be given as:

A. Red: Light of red color has the largest range of wavelengths i.e. ranging from 620-750 nm which are among the largest wavelengths in visible spectrum. Conversely this range has the lowest frequencies ranging from 400-480 Thz.

B. Orange: Light of orange color has larger wavelengths than the red color and smaller than rest of the colors. The wavelength range for orange color is 590-620 nm with frequencies from 480-510 Thz.

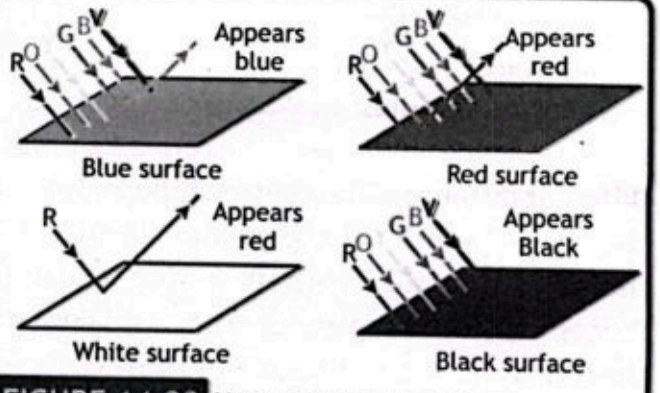


FIGURE 14.20 How colors appear to us

C. Yellow: Light of yellow color has larger wavelengths than the red and orange colors and smaller than rest of the colors. The wavelength range for yellow color is 565-590 nm with frequencies from 510-530 Thz.

D. Green: Light of green color has intermediate wavelength range within visible spectrum. The wavelength range for green color is 500-565 nm with frequencies from 530-600 Thz.

E. Blue: Light of blue color has larger wavelengths than the indigo and violet colors and smaller than rest of the colors. The wavelength range for blue color is 485-500 nm with frequencies from 600-620 THz.

F. Indigo: Light of indigo color has larger wavelengths than the violet color and smaller than rest of the colors. The wavelength range for indigo color is 450-485 nm with frequencies from 620-670 THz.

G. Violet: Light of violet color has the smallest wavelengths in the entire range of the visible spectrum and highest frequencies among all the colors in visible light. The wavelength range for violet color is 400-450 nm with frequencies from 670-790 THz.

14.7 HUMAN EYE AND COLOR PERCEPTION

The human eye is one of the natural optical instrument which is the most interesting and important of all the optical instruments. It performs a vast number of functions. A Muslim scientist Ibn al Haithem was the first scientist who explained the image formation by our eyes, he was known as the father of optics. He recognized that light reflected from objects entered the

eye through the lens and was passed to the optic nerves. The basic structure of human eye is shown in figure 14.21. The cornea and lens form a system that acts like a single thin lens. For clear vision a real image must be projected on the retina which lies a fixed distance from the lens. The flexible lens of the eye allows it to adjust the radius of curvature of the lens to produce an image on the retina for objects at different distances. The centre of the image falls on the "fovea" which has the greatest density of light receptors and the sharpest in the visual field. Processing of visual optic nerve impulses begins from the retina and end into the brain. These optic nerves convey the signals by the eye to the brain. The cornea acts like a thin lens with approximate focal length of 2.3 cm and the lens of eye has an approximate focal length about 6.4 cm. the image formed by the eye is much like the image made by the convex lens i.e. a real and inverted image. Although images formed in the eye are inverted the brain inverts them once more to make them seem erect. The nearest point an object can be placed so that eye can form a clear image of that object is called the "near point" of the eye and it is 25 cm from the eye.

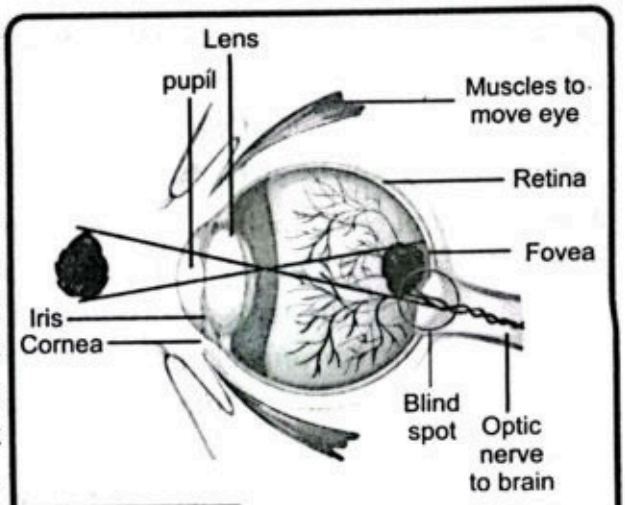
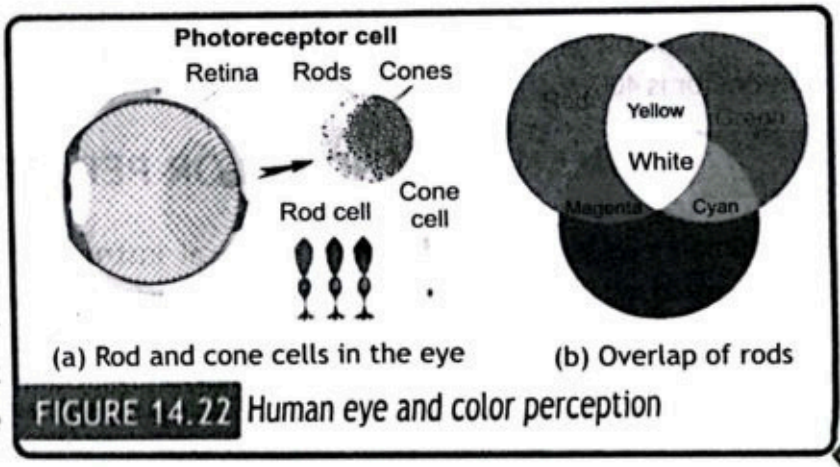


FIGURE 14.21 Structure of human eye

14.7.1 COLOR PERCEPTION

In the figure 14.35 we see that the back of the eye is lined with a thin layer called retina this is where the photoreceptors are located. The retina also contains the nerves that tell the brain what the photoreceptors are seeing. Photoreceptors are the special cells in the eye's retina that are responsible for converting light into signals that are sent to the brain. Photoreceptors give us our color vision and night vision. There are two types of photoreceptor cells i.e. rods and cones as shown in figure 14.22 (a).

Rods work at very low levels of light hence we use them for night vision because a very less amount of light can activate a rod. Rods cannot help in color vision that is why at night we see everything in almost grey scale. A human eye has over 100 million rod cells. On the other hand, cones require a lot more light and they are used to see color. The



(a) Rod and cone cells in the eye (b) Overlap of rods

FIGURE 14.22 Human eye and color perception

human eye has 6 million cones many of these are packed into the fovea which helps with the sharpness or details of images. We have three types of cones red, blue and green and each cone is most sensitive to a specific color of light still they can detect other colors also. This is possible due to the overlap of cones and how the brain integrates the signals sent from the cones as shown in the figure 14.22 (b). As every cone upon reception of light stimulate specific color the brain determines the color perception for example if red cone and green cone equally stimulated the brain gives the yellow color. The brain processes the electrical signal from the cones in the retina and combines them to produce the color perception. The three color vision system enables human to perceive a rich spectrum of colors by mixing the combination of red, blue and green. In fact, rods are responsible for night vision and motions around us while the cones are responsible for the colorful view of this world for us. Due to having cones of three different colors human have trichromatic vision. Some animals have dichromatic vision as they have only two types of cone cells for example dogs and cats have dichromatic vision and they can primarily see shades of blue and yellow color. Dichromatic vision is advantageous for those animals which use to operate in dim light like the hunters. Many birds have tetra-chromatic vision i.e. they have four different types of cone cells in their eyes. In addition to red, blue and green they have one extra cone which can detect ultraviolet light this enables the birds to see colors and patterns which are invisible to humans.

14.7.2 FORMATION OF IMAGE ON NORMAL EYE

The image for a normal eye is made on retina i.e. all the rays coming from the object focused on retina which makes the clear image of the object on eye. The ray diagram for the formation of image by eye on retina is shown in figure 14.23. The light rays from the object after converging from the lens of eye focused on retina. Consider the path of two light rays coming from the top of the object named '1' and '2' again coincide on retina similarly the rays coming from the bottom of the object also coincide at retina to make a clear image on retina.

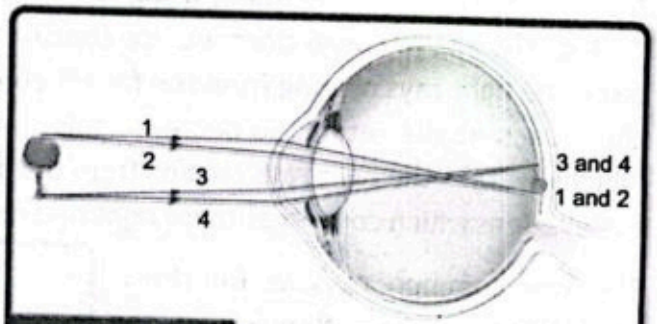


FIGURE 14.23 Image formation by eye

14.7.3 SHORT-SIGHTEDNESS

The short-sightedness or myopia is the condition in which a person can see near objects clearly but distant objects appear blurry. This condition usually occurs in early ages or in adults which is due to the reason that the eye over converges the nearly parallel rays coming from the distant object due to which they cross in front of the retina and hence the image is formed before

SCIENCE TIDBITS



Mantis Shrimp: live in warm, shallow waters in the oceans, they possess an extraordinary vision system that sets it apart from most other animals. They have 12 to 16 color channels which make them to distinguish a much broader spectrum of colors.



They can see ultraviolet light which help them underwater lifestyle and for catching their prey. They can also detect polarized light (the light which has the oscillations in only one direction). As under-water the light becomes polarized after travelling some distance and mentis shrimp perceive this polarized light which is helpful for them for hunting and communication the eyes of a mantis shrimp are shown in figure.

reaching to retina as shown in figure 14.24 (a). As it is seen from the figure that the rays reaching retina are not focused but they are dispersed and hence the image formed on the retina will by blurry.

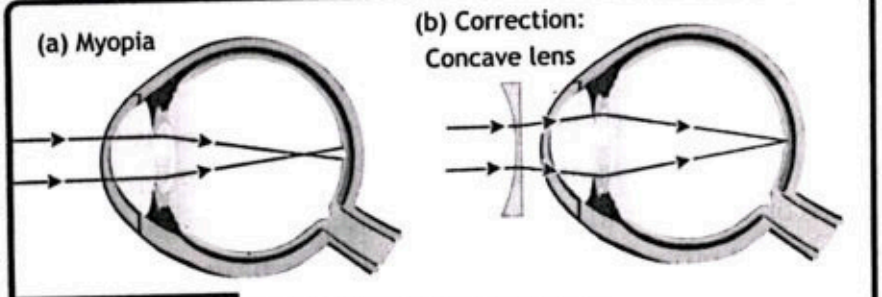


FIGURE 14.24 Short-sightedness or myopia

Correction: The short-sightedness can be corrected by using lenses as in eye-glasses or in the form of contact lenses. In both of the above corrections we use concave lens. As the eye in myopia condition, converges more the light rays coming from the far off objects which results in the cross of light rays before they reach at the retina. To decrease this convergence of the eye lens we use a concave lens which diverges the light rays coming from the object then more spread light rays are received by the eye-lens which converges these light rays exactly on the retina as shown in figure 14.24 (b).

The two common reasons for short-sightedness are the thinning of the eye-lens or the size of the eye to be too long. If the eye-lens becomes thin it converges more and focus the image before retina similarly if the length of eye increases the eye-lens focus at normal distance but due to long eye retina is moved backward and image does not form on retina as shown in figure 14.25.

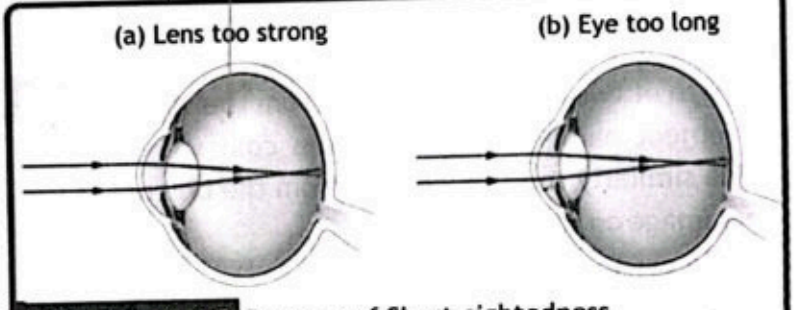


FIGURE 14.25 Reasons of Short-sightedness

14.7.3 LONG-SIGHTEDNESS

In the normal eye when the object is placed at near point of the eye the light rays coming from the

object after converging from the eye-lens meet at retina and make a clear, real and inverted image which can be seen as distinct image of an object as shown in figure 14.26 (a) The long-sightedness or hyperopia is the condition in which a person can see distant objects clearly but near objects appear blurry to him. Hyperopia is also called as hypermetropia.

This condition usually occurs in elderly ages, which is due to the reason that the eye converges less the nearly parallel rays coming from the nearer objects due to which they cross after passing the retina and hence the image is formed behind reaching to retina as shown in figure 14.26 (b) as the object is not placed at near point (N) in spite of it the object is placed nearer than the near point of the eye at (N′). As it is seen from the figure that the rays reaching retina are not focused but they are dispersed and hence the image formed on the retina will by blurry.

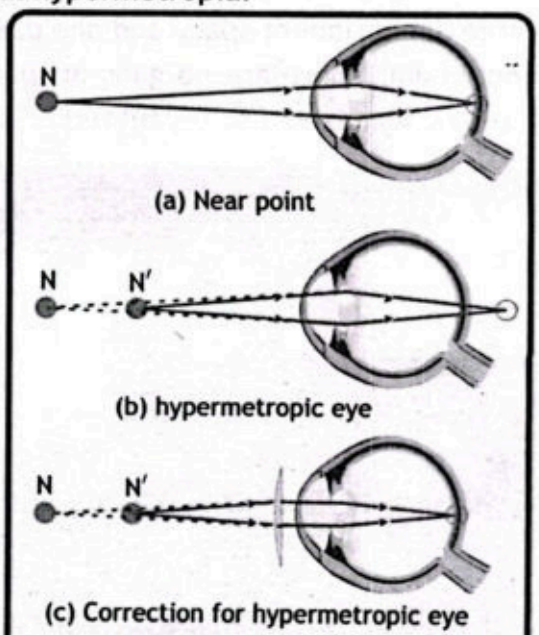


FIGURE 14.26 Long-sightedness

Correction: The long-sightedness can be corrected by using lenses as in eye-glasses or in the form of contact lenses. In both of the above corrections we use convex lens. As the eye in hypermetropia condition, converges less the light rays coming from the nearer objects which results in the cross of light rays after they passed by the retina. To increase this convergence of the eye lens we use a convex lens which additionally converges the light rays coming from the object then less spread light rays are received by the eye-lens which converges these light rays exactly on the retina as shown in figure 14.26 (c).

The two common reasons for long-sightedness are the thickening of the eye-lens or the size of the eye to be too short. If the eye-lens becomes thick it converges less and focus the image after retina similarly if the length of eye decreases the eye-lens focus at normal distance but due to short eye retina is moved forward and image does not form on retina as shown in figure 14.27.

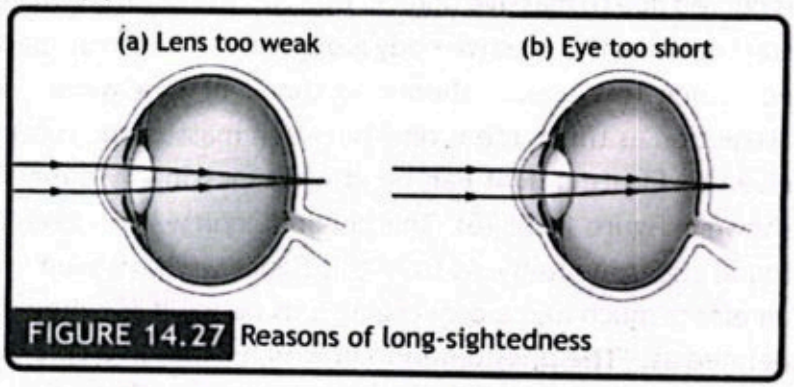


FIGURE 14.27 Reasons of long-sightedness

14.8 GRAVITATIONAL LENSING

As we know the classical view of gravity i.e. every point mass in this universe attracts any other point mass towards it with a force known as the force of gravitation. This force depends upon the

magnitude of masses and distance between the point masses. Einstein gave the modern view of gravitation which is somehow different to the classical view of gravitation. He gave the idea of curvature of space-time around the massive bodies in his famous general theory of relativity. In this theory space time also called space-time continuum is a mathematical model that fuses the three dimensions of space and one dimension of time into a single four dimensional space-time continuum. There are no gaps in space or time as Einstein showed that time and space are inseparably mixed. Each event requires three space dimensions and one time dimension.

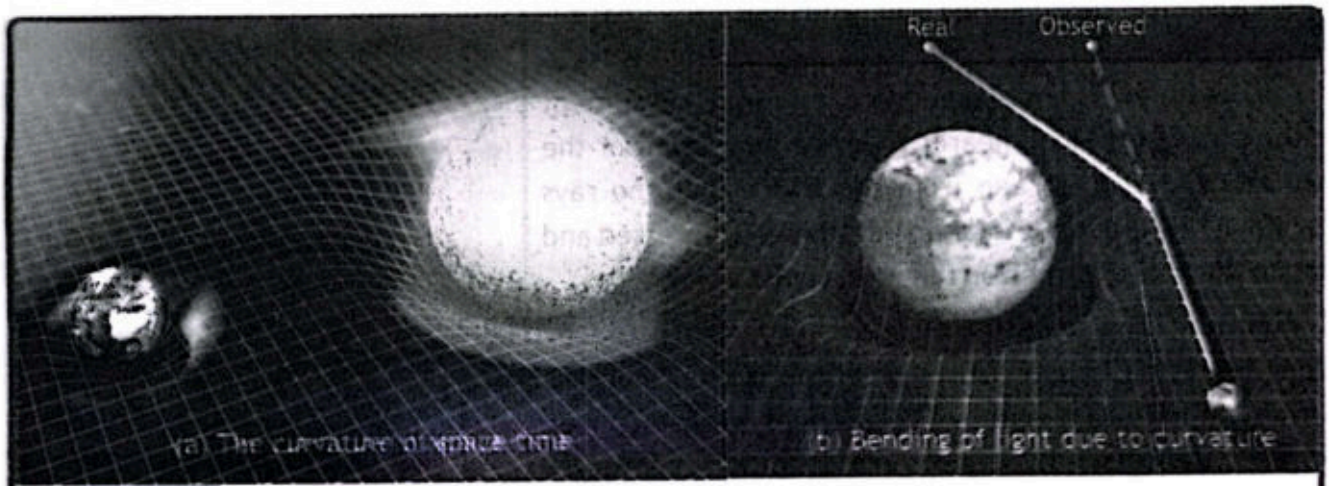


FIGURE 14.28 Generation of gravitational lensing

To understand it you can take an example of space time as a fabric of elastic material when you placed a heavy object upon it you observe that the massive body makes a curve in the fabric having center of curve at the location of body. Similarly, he took space and time as a fabric and it is curved due to massive bodies. Due to this curvature the lighter bodies when come close to them start orbiting the massive body along the curvature of space and time as shown in figure 14.28 (a). According to classical theory as the light is a wave and wave cannot feel the gravitational attraction as this force is only between masses but according to the modern view of gravitation given by Einstein light can bend while passing by a massive body due to curvature of space as shown in figure 14.28 (b). This phenomenon was not given attention at that times but later it was found experimentally. As from this figure we have seen that light bent towards a mass producing an effect much like a converging lens hence it is called as "gravitational lensing" which can be defined as: **'The phenomenon in which a massive celestial body causes a sufficient curvature of space-time for the path of light around it to be visibly bent as if by a lens is called gravitational lensing.'**

The body causing the light to curve is called a gravitational lens. For this phenomenon to be observed the body should be massive enough like a galaxy, a black hole or a cluster of galaxies etc. On galactic scale the light from a distant galaxy could be lensed into several images while passing

POINT TO PONDER



Gravitational lensing serves as a powerful tool for finding the distribution of dark matter (it is invisible glue that keeps stars, dust and gasses together in galaxies and make up majority of galaxy's mass) and dark energy in the universe as dark matter exerts gravitational influence without emitting light. Future advancements in observational techniques such as next generation telescopes and surveys promise to revolutionize our understanding of the universe unveiling new discoveries and insights into the nature.

close by another galaxy on its way to reach the Earth. Einstein predicted this effect but he considered it unlikely that we would ever observe it. But in 1979 gravitational lensing was observed and it becomes an observable phenomenon when the double Quasar (Quasars are the highly luminous cores of distant galaxies) was discovered became the first example of lensed object, as it was behind another galaxy i.e. that galaxy lies exactly between the Earth and the double Quasar. This quasar was named as "double" due to a special effect of the phenomenon of gravitational lensing i.e. gravitational lensing can lead to the formation of multiple images of the same distant source. This can be explained by the figure 14.29 (a).

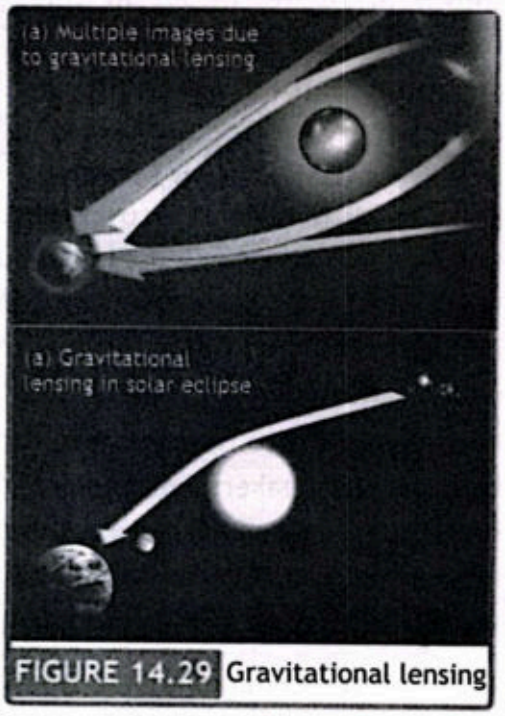


FIGURE 14.29 Gravitational lensing

As from the above figure it is seen that the light coming from the source is bending from both sides of the intervening galaxy and making two images of the source. Similarly in some cases when the source lies exactly behind a galactic object due to bending of light all around the intervening object makes a ring of light around it and is called "Einstein rings". The first time the bending of light due to a heavy object was found in 1919 during the observation of total solar eclipse and found that the light was bent by the amount predicted by the general relativity as shown in figure 14.29 (b).

14.9 ACOUSTIC LENSING

Sound is a form of energy which can be transmitted from one place to another. It is the form of pressure wave created by the vibration of bodies. The science of sound is known as acoustics and can be defined as: **'The branch of physics that deals with examining and studying the sound is called acoustics.'**

It deals with the production, transmission and effects of sound. The main application of acoustics is to make the music or speech sound as good as possible. When a sound wave is used as an

information carrier or energy orientation method its energy gradually reduces during propagation. Therefore, we must use different techniques to focus sound waves to efficiently utilize sound energy.

Acoustic lenses can focus the energy of sound waves in a relatively small space which is a region with high energy density as shown in figure 14.30. In this figure an electrical signal is converted into sound which is released from a speaker (which acts like an object plane) then we use acoustic lens which focuses these sound waves on a single point at the end which acts like the image plane. Acoustic lenses manipulate sound waves in a manner similar to how optical lenses handle light and can be defined as: **'A lens that brings sound waves to a focus by having walls of collodion film and being filled with a heavy gas, which retards and refract sound waves, is called acoustic lens.'**

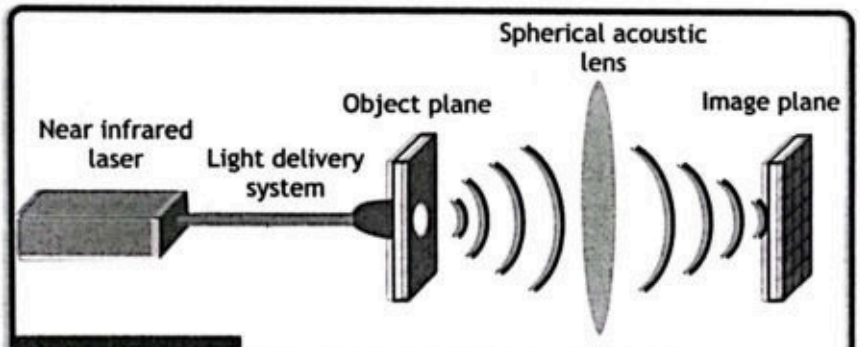


FIGURE 14.30 Focusing sound with acoustic lenses

The aim of the acoustic lens is to focus sound in much the same way that an optical lens focuses light. In loudspeakers a mechanical device used to improve the dispersion of high frequencies so that dispersion is much more uniform across the audible spectrum. A high frequency loudspeaker mechanical acoustic lens spreads a single point sound source into a parallel wave front.

14.9.1 TYPES OF ACOUSTIC LENSES:

There are two commonly used types of acoustic lenses i.e. the slant-plate lenses and perforated-plate lenses.

A. Slant-Plate Lens: The design of the most commonly seen acoustic lens is the slant-plate lens which utilizes a series of plates with carefully calculated hyperbolic shapes which results in a horizontal response patterns. A slant-plate lens is shown in figure 14.31 (a). They make to select portion of expanding pressure wave to travel farther than other portions of the wave this tend to shape the pressure wave by controlling the dispersion.

B. Perforated-Plate lens: Perforated-plate lenses consist of a collection of perforated barriers at the horn

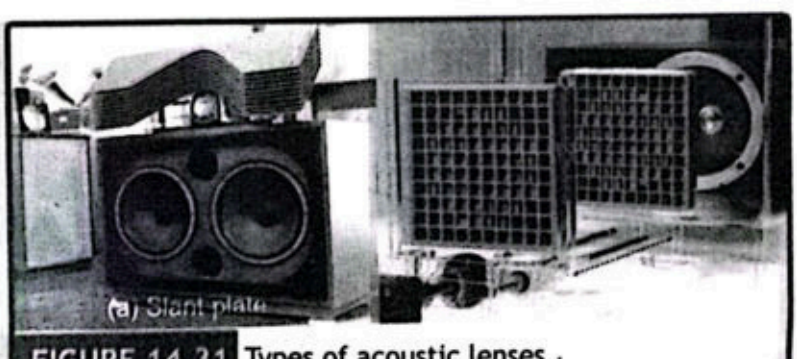


FIGURE 14.31 Types of acoustic lenses

mouth. These perforated screens are actually ring shaped with varying sizes of center cutouts. These perforated plate lenses can diverge as well as converge the sound just like diverging and converging lenses do with the light signals. Perforated plate lens is shown in figure 14.31 (b).

14.9.2 MATERIAL AND SHAPES OF ACOUSTIC LENSES:

Acoustic lenses can be made from various materials like plastic, epoxy, rubber and liquids due to reasons given below:

A. Plastic: Plastic materials are commonly used for making acoustic lenses because it can easily be fabricated and have good acoustic properties.

B. Epoxy: Epoxy is also commonly used material for making acoustic lenses it offer good sound permeability and can be molded into specific shapes.

C. Rubber: Rubber is used in acoustic lenses for their flexibility and the ability to deform the lenses.

D. Liquid: Some acoustic lenses use liquid filled chambers to converge or diverge sound waves.

Similarly acoustic lenses come in different shapes each shape serves specific purpose. They can be shaped in spherical, ellipsoidal, parabolic and gradual geometric curves as explained here:

E. Spherical Acoustic Lenses: These acoustic lenses have curved surface like a sphere, they focus or diverge the sound waves according to their curvature.

F. Ellipsoidal Acoustic Lenses: These are similar to spheres but a little elongated in one direction (somehow like an egg) they can focus sound waves in a specific direction.

G. Parabolic Acoustic Lenses: These acoustic lenses have a parabolic shape and are excellent at focusing sound waves to a single point.

H. Gradual Geometric Acoustic Lenses: Lenses with gradual geometric curves achieve gradient refractive index distribution allowing precise acoustic focusing.

Acoustic lenses are important for applications like under water imaging, sonar systems and medical ultrasound etc. They are also used in non-destructive testing of materials which are opaque to light but sound waves can penetrate the material and find the voids and cracks without destructing the material. Now researchers are exploring 3-D printed meta-materials with balcony like structures to create impact resistant acoustic lenses.

SUMMARY

- **Optics** is the science of light and its interaction with matter.
- **Reflection of light** is when a ray of light approaches a smooth polished surface and bounces back is called reflection.
- **First law of reflection** states that the incident ray, the reflected ray and the normal all lie in same plane.

- **Second law of reflection** states that the angle of incident ray is equal to the angle of the reflected ray.
- **Refraction of light** is the phenomenon in which the light ray's direction changes when it enters from one medium to another.
- **Speed of light in vacuum** is constant but in other transparent media the speed of light decreases, its speed depends upon the density of the medium.
- **Refractive index** is the measure of bending of a light ray when passing from one medium to another.
- **Perspex Block** is a tough transparent plastic block which is used instead of glass blocks.
- **Total internal reflection** is the phenomenon in which a light ray travelling in denser medium bounces back to the same medium after striking the boundary of a rarer medium.
- **Critical Angle** is the angle of incident light ray for which in spite of transmission into other medium the light ray moves along the boundary between the two media.
- **Optical Fibers** are the doubly refractive indices concentric tubes of glass or plastic which are used for transmission of light using the phenomenon of total internal reflection.
- **Lenses** are transparent objects that refract light in a specific way to form images.
- **Convex Lens** is a type of lens which is thick from the center and thin from the outer edges it converges the parallel light rays to a single point.
- **Concave Lens** is a type of lens which is thin from the center and thick from the outer edges it diverges the parallel light rays.
- **Focal length** is the distance from the lens to its focal point for a converging lens the focal length is positive while for a diverging lens the focal length is negative.
- **Magnifying glass** is a single lens device which is used to see bigger images of the objects.
- **Dispersion from a prism** is the phenomenon in which white light splits into its seven constituent colors due to different extent of refraction.
- **Near Point** is the minimum distance at which if the object is placed we have clear image on our retina.
- **Gravitational Lensing** is the phenomenon in which light bends while passing by a heavy galactic object due to its strong gravity.
- **Acoustic Lensing** is the technique in which some materials are used to focus or diverge sound waves.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. A glass slab is dipped in a transparent liquid having same refractive index as that of glass slab. We cannot see the boundary of the two media (glass and liquid) due to ___ refraction.
   A. Maximum B. Minimum C. Zero D. Unit
2. An incident ray makes an angle of 45° with a plane mirror. The angle of reflection is:
   A. 30° B. 45° C. 60° D. 90°
3. Two plane mirrors are arranged parallel facing each other. The image(s) formed may be:
   A. One B. Two C. Four D. Infinite
4. The apparent flattening of the Sun at the dawn and dusk is due to phenomenon of:
   A. Refraction B. Reflection C. Dispersion D. Polarization
5. On summer days you see the reflections on roads which is called mirage. It is due to:
   A. Refraction B. Reflection C. Dispersion D. Total internal reflection
6. The colors in the rainbow are formed by:
   A. Refraction B. Reflection C. Dispersion D. Total internal reflection
7. The lenses in your eyes produce image on retina:
   A. Inverted and virtual B. Inverted and real
   C. Erect and virtual D. Erect and real
8. What is the speed of light in diamond if its refractive index is 2.5?
   A. 1.2×10^8 m/s B. 2.5×10^8 m/s C. 2.1×10^8 m/s D. 5.2×10^8 m/s
9. In a convex mirror when the object is placed at 'c' the image formed will be:
   A. Smaller B. Larger C. Same size D. Zero size
10. The working principle of optical fibers is:
    A. Refraction B. Diffraction C. Reflection D. Total internal reflection
11. If an object is placed at 10 cm from the convex lens having focal length 5 cm. the linear magnification of convex lens is?
    A. 0.5 B. 1 C. 2 D. 5
12. Non-luminous matter which can be studied with the help of gravitational lensing is called:
    A. Visible Matter B. Red matter C. Dark matter D. White matter

13. Image formed by plane mirror is always:
    A. Real and inverted B. Virtual and erect C. Real and erect D. Virtual and inverted
14. Einstein rings are seen due to a phenomenon:
    A. Converging lensing B. Diverging lensing C. Gravitational lensing D. Acoustic lensing
15. The _____ phenomenon is used in non-destructive testing of materials for voids and cracks in opaque materials?
    A. Converging lensing B. Diverging lensing C. Gravitational lensing D. Acoustic lensing
16. All waves exhibit the phenomenon of reflection but light waves are the only waves which exhibit the phenomenon of:
    A. Refraction B. Diffraction C. Reflection D. Total internal reflection
17. The working principle of optical fibers is:
    A. Refraction B. Diffraction C. Reflection D. Total internal reflection
18. The white light passing through the prism, due to refraction shows a behavior of _____light:
    A. Interference B. Dispersion C. Reflection D. Diffraction
19. The visible light spectrum lies in the range of_____ nm of wavelength:
    A. 400-850 B. 500-700 C. 400-750 D. 700-900
20. The rods and cones a human eye has are:
    A. 6 million and 100 million B. 100 million and 6 million
    C. 6 million and 6 million D. 100 million and 100 million

CONSTRUCTED RESPONSE QUESTIONS

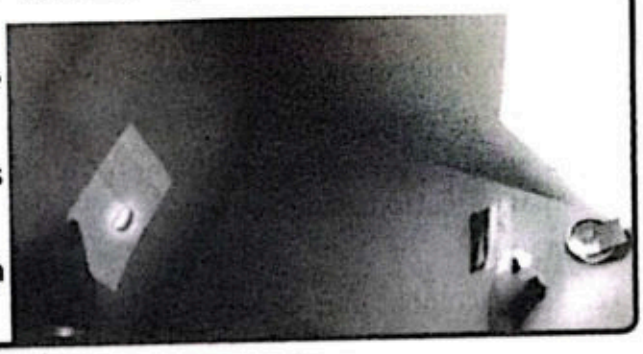
QII. Follow the directions to respond to the following questions.

1. Take some water in the bowl and put a small mirror in it such that some part of mirror is dipped in the water. Fall sunlight on the mirror in such a way that the reflection of mirror appears on the wall or white board of the class.

(a) Why the seven color pattern is shown on the wall?

(b) What is the role of water in this phenomenon?

(c) Discuss the basic principle used here which converts the white sunlight into seven colors?



SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Why is the index of refraction always greater than or equal to unity?
2. Which physical process is responsible for the decrease in the speed of light in material mediums?
3. How powder takes the shine off of a person's nose?
4. Why an object in water always appears to be elevated to its real depth?
5. Refractive index of air is lower for air at high temperatures, explain.
6. Rainbow forms due to dispersion of light by the rain drops suspended in air. How double rainbow form? Can a triple rainbow be formed?
7. Can you photograph a virtual image? Explain.
8. What is meant by the negative magnification?
9. Can a flat transparent glass be considered as a lens of infinite focal length? If yes, where does it form an image?
10. If we dip a lens in water what would happened to its focal length? Elaborate.
11. When you open your eyes in water why the things look blurry?
12. Evaluate the statement that "a real image is always inverted"?
13. Argue about the nature of gravitational lensing as optical or not?
14. Inspect the reason for the curved ceilings of school halls?
15. Propose a reason for producing more sound by an empty container as compared to a filled one.

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

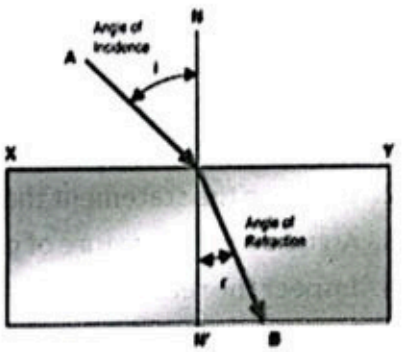
1. What is reflection of light? Also explain the laws of reflection.
2. Discuss the types of reflection.
3. How images are formed in plane mirrors? Explain.
4. Describe the position and characteristics of images formed by plane mirrors.
5. Elaborate the refraction of light and the laws of refractions.
6. Analyze the speed of light in material medium.
7. What is refractive index? Elaborate your answer.
8. Differentiate total internal reflection from reflection. Also derive a relation for critical angle.
9. Enlist the uses of fiber optics in telecommunication system.
10. Illustrate thin lenses. Also explain behavior of converging and diverging lens to parallel beam of light.
11. Evaluate how images are formed by converging lens using ray diagram.

12. Differentiate between real and virtual images.
13. Assess linear magnification as a property of thin lenses.
14. Discuss the dispersion of light through a prism.
15. Design some single lens optical devices.
16. Analyze the visible spectrum of electromagnetic radiations.
17. Illustrate human eye and color perception.
18. Outline short-sightedness and long-sightedness also explain how they can be fixed?
19. Define and explain gravitational lensing.
20. Explain acoustic lensing and its applications.

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Calculate the angle of refraction at the boundary of two media if the angle of incidence is 37°.



(Ans. 53°)

2. Calculate the speed of light in a medium if its refractive index is 1.7.

(Ans. 1.76×10^8 m s^{-1})

3. A light ray moving through a medium of refractive index 1.6 enters at an angle of incidence 21° into the other medium of refractive index 1.7. Calculate the angle of refraction.

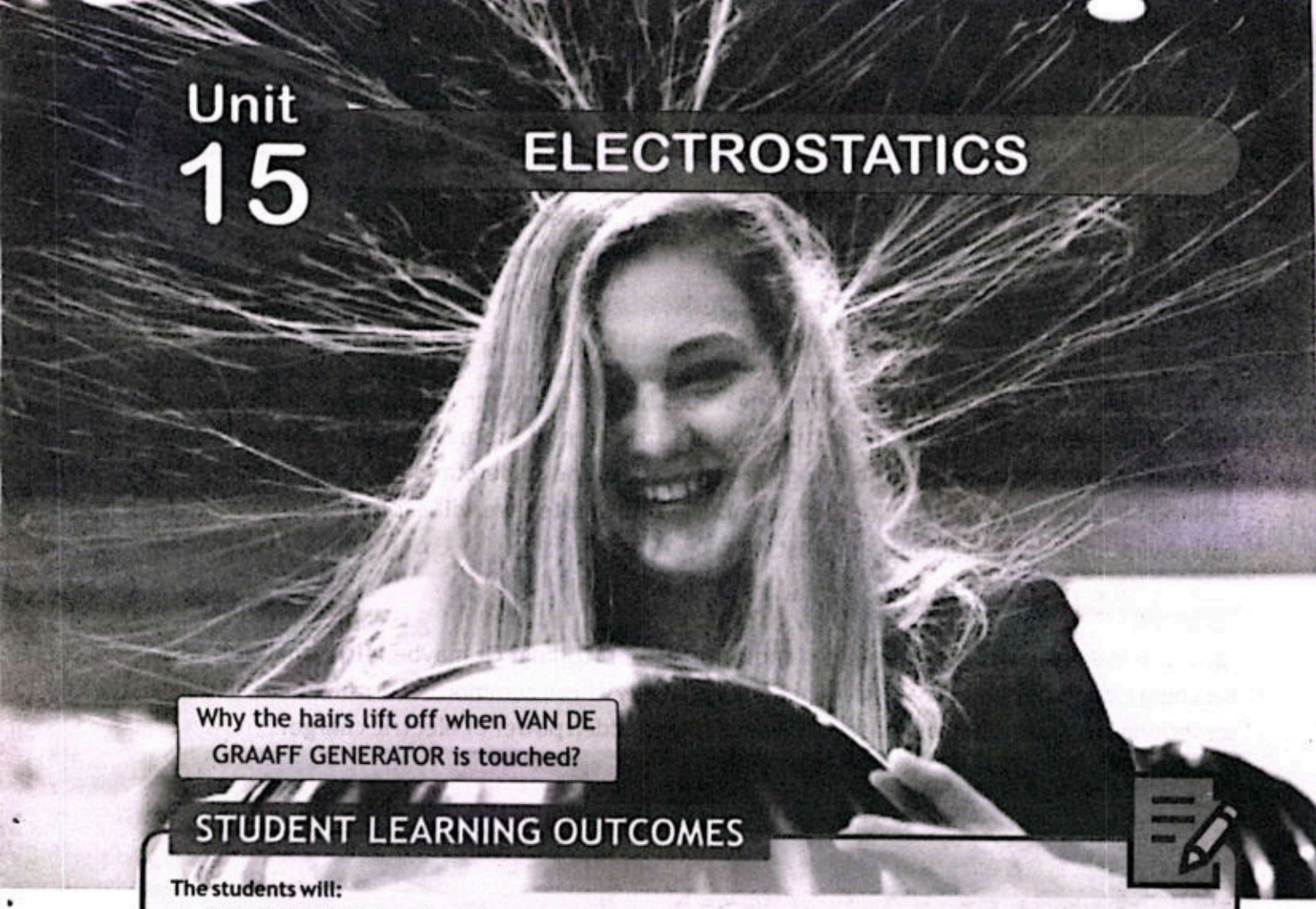
(Ans. 19.71°)

4. Assess the value of the critical angle if light travels from a medium of refractive index 1.63 into a medium of refractive index 1.35.

(Ans. 55.9°)

5. Measure the distance and height of image of an object with height and distance of 3 cm and 5 cm respectively from a lens having magnification as 3.

(Ans. 15 cm, 9 cm)



Unit 15 ELECTROSTATICS

Why the hairs lift off when VAN DE GRAAFF GENERATOR is touched?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-01] State that there are positive and negative charges.
- ✓ [SLO: P-10-E-02] State that unlike charges attract and like charges repel.
- ✓ [SLO: P-10-E-03] Describe experiments to show electrostatic charging by friction.
- ✓ [SLO: P-10-E-04] Explain that charging of solids by friction involves only a transfer of negative charge (electrons).
- ✓ [SLO: P-09-E-05] Explain how and why an insulator can be discharged by (a) putting it above a flame, and (b) exposing it to damp conditions.
- ✓ [SLO: P-10-E-06] Explain how a conductor can be charged by electric induction and then "earthing".
- ✓ [SLO: P-10-E-07] Describe examples where charging could be a problem e.g. lightning.
- ✓ [SLO: P-10-E-08] Suggest how charging and discharging is used in the application of various devices.
- ✓ [SLO: P-10-E-09] Describe an electric field as a region in which an electric charge experiences a force.
- ✓ [SLO: P-10-E-10] 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.
- ✓ [SLO: P-10-E-11] Analye and illustrate simple electric field patterns.
- ✓ [SLO: P-10-E-12] State examples of electrical conductors and insulators.
- ✓ [SLO: P-10-E-13] Describe an experiment to distinguish between electrical conductors and insulators.
- ✓ [SLO: P-10-E-14] state and use a simple electron model to explain the difference between electrical conductors and insulators.

- ✓ [SLO: P-10-E-15] Explain how a lightning rod can protect humans.
- ✓ [SLO: P-10-E-16] Explain electrical breakdown.
- ✓ [SLO: P-10-E-17] State that Corona discharge and Lichtenberg figures are visible examples of electrical breakdown.
- ✓ [SLO: P-09-E-18] Explain how lightning is generated.
- ✓ [SLO: P-10-E-19] State that there are many kinds of atmospheric lightning.

Electricity and magnetism are the governing forces behind everything we observe in the physical world. These electromagnetic forces control the structure of atoms and all materials. We are surrounded by light and other electromagnetic waves. The understanding of these forces is a remarkable achievement in the field of science. In this chapter, we will explore charges that are not moving and hence the name electrostatics.

15.1 STATIC CHARGE

Have you ever experienced your hair standing up after brushing? Or maybe felt a small jolt when touching a doorknob after leaving your car? Surprisingly, these common occurrences are all due to something known as electrostatic force, which is the hidden power of electric charge.

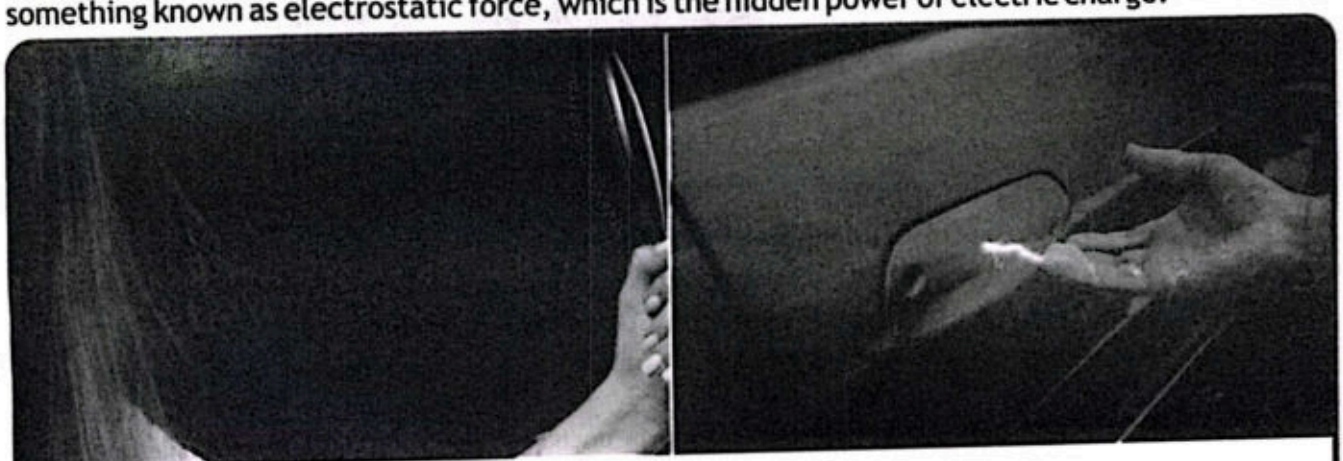


FIGURE 15.1 Electrostatic phenomena

Charge is measured in coulombs (C), named for the French physicist Charles A. de Coulomb (1736-1806), who discovered a relationship between electric force and charge.

Everything surrounding you, from your hair to your clothes and even the doorknob, is composed of minuscule building blocks called atoms. Inside these atoms are even tinier particles - some with a positive charge (+) inside nucleus known as protons, and others with a negative charge (-)

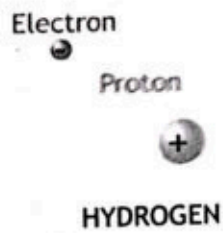


FIGURE 15.2 Structure of atom

clouding around nucleus called electrons, whereas, neutrons with no charge are also found inside the nucleus. Refer to figure 15.2 and Table 15.1 for more details.

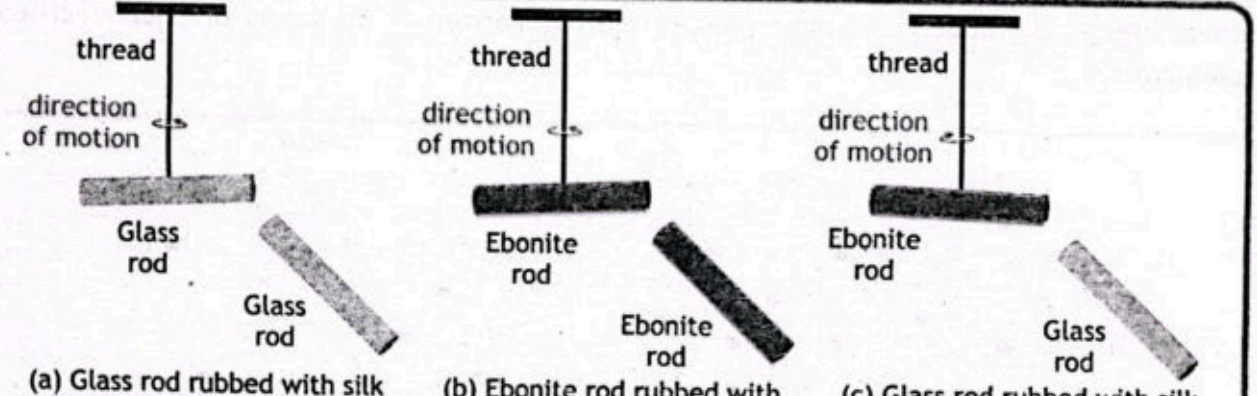
How do we know that charges are of two types? When you rub a glass rod vigorously with a silk cloth and hang it up, then bring another glass rod rubbed with silk close to it, the glass rods will push away from each other. The same goes for ebonite (hard rubber) rods rubbed with fur - when you hang one up and bring another close, they will also repel.

TABLE 15.1: BASIC PARTICLES AND THEIR CHARGES

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

Now, if you hang a glass rod rubbed with silk and bring an ebonite rod rubbed with fur near it, they will be attracted to each other. The same thing happens when you hang an ebonite rod rubbed with fur and bring a glass rod rubbed with silk close - they will attract.

This experiment proves that there are two types of charges: like charges repel, while opposite charges attract as shown n figure 15.3. According to Newton's third law of motion, the repulsive and attractive forces are balanced and act on different objects.



(a) Glass rod rubbed with silk cloth brought near another suspended glass rod rubbed with silk cloth. Repulsion is observed.

(b) Ebonite rod rubbed with animal fur brought near another suspended Ebonite rod rubbed with animal fur. Repulsion is observed.

(c) Glass rod rubbed with silk cloth brought near a suspended Ebonite rod rubbed with animal fur. Attraction is observed.

FIGURE 15.3 Experimental demonstration of like charges repel and opposite charges attract

15.1.1 CHARGE IS CONSERVED

Charge cannot be created or destroyed, so how does an object get charged? When objects are charged, electric charge is not actually created; instead, charges are simply transferred between the objects, which is known as electrification. The excess charge is most commonly produced by a transfer of electrons, not protons. Protons are bound in the nucleus and, under most common situations, stay fixed.

When a glass rod is rubbed with a silk cloth, both the glass rod and silk cloth become charged. The electrons from the glass rod move to the silk cloth, making the glass rod positively charged. At the same time, the silk cloth gains electrons and becomes negatively charged. This silk cloth will repel a hanged rubber rod rubbed with fur just like as it was repelled by another rubber rod rubbed with fur. Similarly, when a rubber rod is rubbed with animal fur, both materials become charged. Electrons move from the animal fur to the rubber rod, giving the rubber rod a negative ch: ge and the animal fur a positive charge.

When you charge an object, you either add or remove electrons. If you remove electrons, the object will have a positive charge; if you add electrons, it will have a negative charge. The number of protons in the object remains constant in both cases. The change in charge is a result of gaining or losing electrons. The net charge in solids is due to an excess or deficiency of electrons.

15.2 CONDUCTORS AND INSULATORS

Conductors are distinguished from insulators by their capacity to conduct or transmit electric charge. Materials like metals are known for being efficient conductors of electric charge, while others like glass, rubber, and most plastics are categorized as insulators or poor electrical conductors.

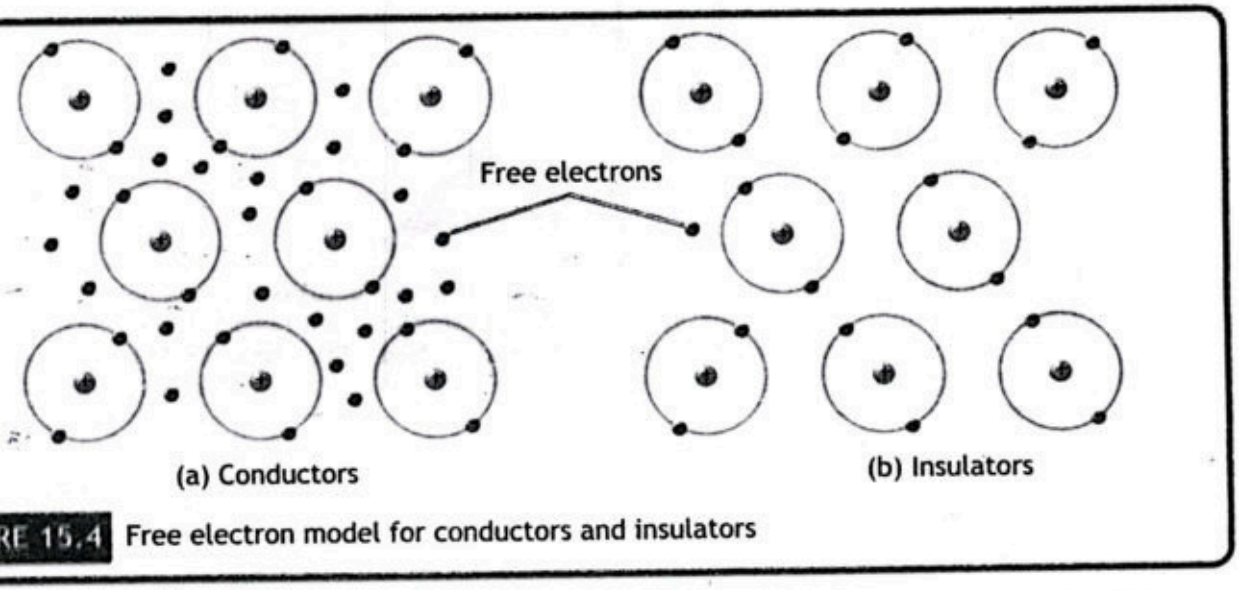


FIGURE 15.4 Free electron model for conductors and insulators

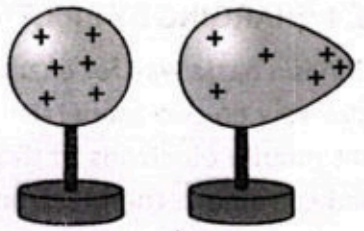
In conductors, the valence electrons, which are the electrons in the outermost atomic orbits, are loosely bound to their atoms. This loose binding allows the electrons to be easily detached from the atom, enabling them to move freely within the conductor or even leave the conductor entirely as shown in figure 15.4 (a).

Unlike in other materials, the presence of these mobile electrons, known as free electrons, is significant in conductors. As a result, conductors can efficiently transfer electric charge.

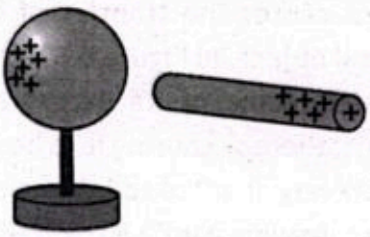
On the other hand, in insulators, even the least tightly bound electrons are firmly attached to their atoms. As a result, these electrons cannot move freely, preventing charge from flowing through the material. This strong attachment means that electric charge cannot be easily redistributed or removed from an insulator, making it ineffective for conducting electric charge compared to conductors as shown in figure 15.4 (b).

When a charge is placed on a spherical conductor, it spreads out evenly across its surface. However, on other shapes, charges have a tendency to repel each other and move towards the more pointed areas as shown in figure 15.5 (a).

However, insulators on the other hand, do not allow charges to move easily, therefore the charge will remain in the spot where it is introduced as shown in figure 15.5 (b).



(a) On a spherical conductor, the charge spreads out evenly. On other shapes of conductors, the charges tend to repel one another toward the more pointed surfaces.



(b) On an insulator, the charge remains in the spot where it was introduced.

FIGURE 15.5 Charge distribution

This means that when you create a charge on one part of an insulator, such as rubbing wool on a plastic rod, the charge will stay in that area while the rest remains neutral due to the restricted movement of charges in insulators.

15.3 CHARGING AND DISCHARGING

Sliding across a car seat results in the transfer of electrons between materials, leading to an accumulation of negative charges on your body. This static charge remains stationary and is known as an electrostatic charge. Friction between surfaces generates this charge, which persists until the electrons can disperse due to their repulsion. Typically, when you reach for a metal doorknob, the electrons find an escape route, resulting in a spark. Metal doorknobs, being good electrical conductors, allow electrons to freely move within the material. Conversely, if you touch plastic or wood, you won't experience a shock. There are three main ways to charge objects: through friction, contact, and induction.

15.3.1 CHARGING BY FRICTION

Friction is a basic way for charge transfer between objects. The direction and amount of charge transfer rely on two properties of atoms: ionization energy and electron affinity. Atomic nuclei attract mobile electrons in their outer orbitals. The stronger the attraction, the more energy needed to remove the electrons. Removing electrons ionizes the atom. The energy needed to remove the outermost electron is called ionization energy.

15.3.2 CHARGING BY CONTACT (CONDUCTION)

When a charged object comes into contact with a neutral object, the excess or deficit of electrons in the charged object causes the transfer of charge to the previously neutral object. In Figure 8.6, a negatively charged object transfers some of its excess electrons to the neutral object, thereby causing it to become negatively charged. A positively charged rod draws electrons out of a neutral object, leaving it with an overall positive charge.

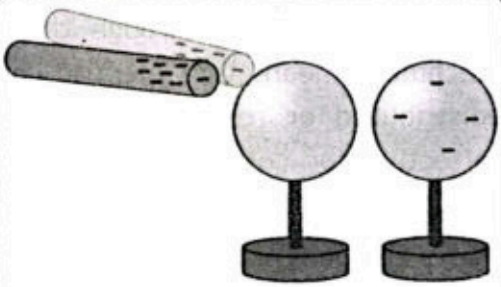


FIGURE 15.6 Charging by Contact.

15.3.3 CHARGING BY INDUCTION

Imagine a negatively charged rubber strip near an insulated metal sphere labeled 'X' as shown in Figure 15.7 (a). The negative charge in the strip repels the electrons in sphere 'X', pushing them towards the far side of the connected sphere labeled 'Y'. This creates a temporary separation of charge within 'Y', with an excess of negative charge on the far side. Importantly, there's no transfer of electrons between the objects.

If we separate spheres X and Y while the charged strip remains nearby as shown in Figure 15.7 (b), the separated charges are "frozen" in place. Sphere X, which lost electrons, becomes positively charged. Sphere Y, with the repelled electrons concentrated on its side, becomes negatively charged. This demonstrates how electrostatic induction can be used to separate charges and

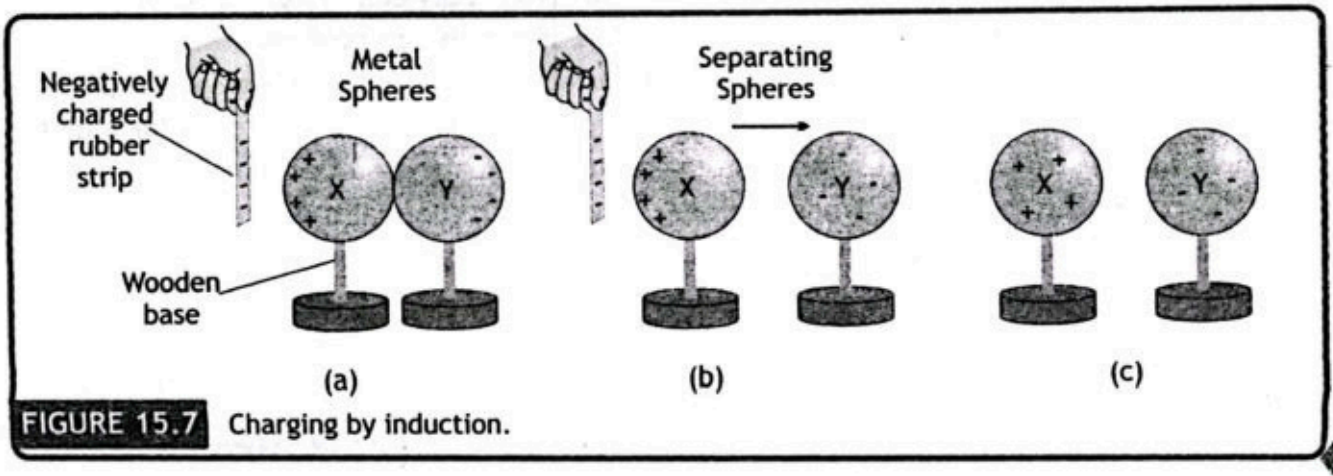


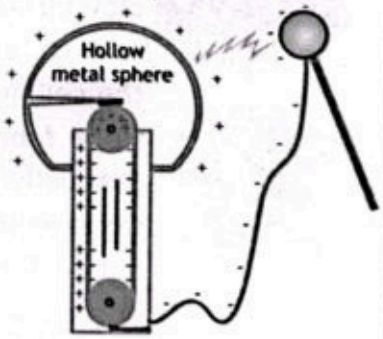
FIGURE 15.7 Charging by induction.

UNIT OPENER?



Why the hairs lift off when Van de Graaff generator is touched?

A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high electric potentials. It produces very high voltage direct current (DC) electricity at low current levels.



Van de Graaf Generator

It was invented by American physicist Robert J. Van de Graaff in 1929. A pulley drives an insulating belt by a sharply pointed metal comb which has been given a positive charge by a power supply. Electrons are removed from the belt, leaving it positively charged. A similar comb at the top allows the net positive charge* to spread to the dome.

The strands of their hair all have the same net charge and therefore repel each other strongly, making them to lift off.

create charged objects as shown in Figure 15.7 (c).

From the above two activities, we can conclude that bodies can be charged by a process called electrostatic induction. ***A change in distribution of electrical charge in an object, caused by the influence of nearby charges is called electrostatic induction.***

One way to charge by induction is through grounding. This involves connecting a neutral object to the ground temporarily to let extra charges escape. For instance, if a negatively charged object is brought close to a neutral conductor like a metal sphere, the positive charges in the neutral sphere will be drawn towards the negatively charged object and negative charge will be pushed to side of the object. This causes the electrons in the sphere to move away from the side facing the charged object. Earthing or grounding is giving charge a path to escape into the ground, therefore, by briefly grounding the sphere with a finger, extra electrons can flow into the ground, resulting in the sphere having a net positive charge as shown in figure 15.8.

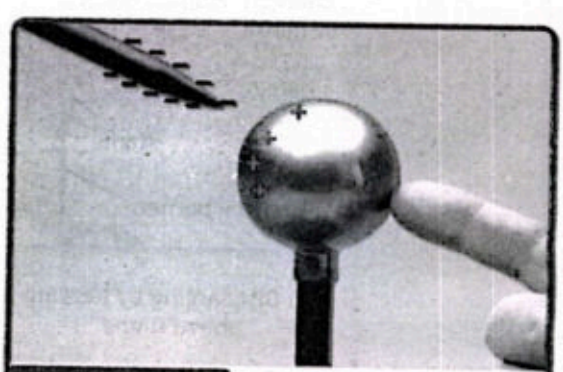
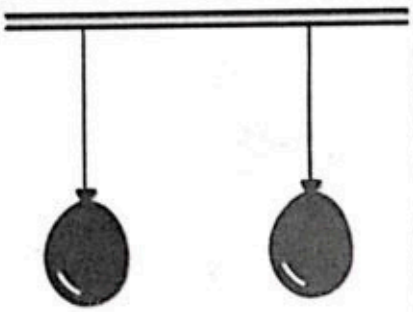


FIGURE 15.8 Using finger as ground

MINI LAB

Blow up two latex balloons, attach a light string to each, and hang them about 1 ft apart from the ceiling or a rod. Rub both balloons with a furry fabric or your hair to charge them. Gradually bring the balloons closer together. Observe for signs of an electric force. If you notice the force, clarify whether it is attractive or repulsive. Also, identify the two key factors influencing the strength of the electric force.

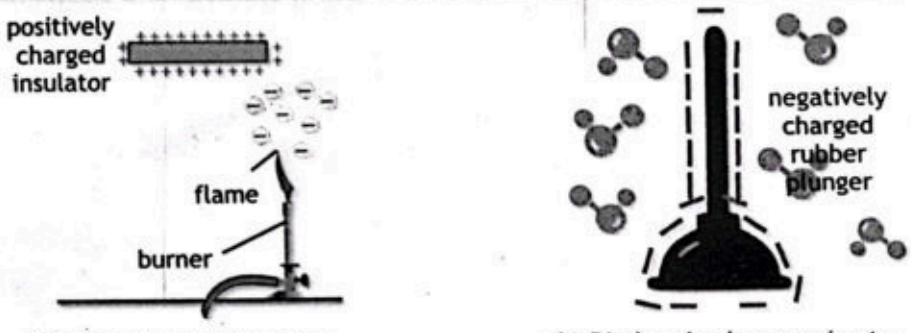


15.3.4 METHODS TO DISCHARGE INSULATORS

Electrical discharging is the process of neutralizing or dissipating electric charges on a material or surface. In conductors, this occurs when excess charge is redistributed or flows away through a conductive path, returning the material to a neutral state. Conductors can be discharged by grounding or applying an opposite charge. Conversely, insulators, which resist electric charge flow, can also be discharged under certain conditions.

Discharging insulators typically requires altering the material's environment to enable charge movement or neutralization. Two effective techniques for discharging insulators include heating them over a flame and exposing them to humid conditions.

- **A. Heating above flame:** When an insulator is heated with a flame, the heat excites the electrons and can make the surrounding air conductive, aiding in charge neutralization. Additionally, the heat can temporarily enhance the surface conductivity of the insulator, allowing static charges to move and discharge as shown in figure 15.9 (a).



(a) Discharging by heating above flame

(b) Discharging by exposing to humid conditions

FIGURE 15.9 Techniques for Discharging Insulators

- **B. Exposing to Humid Conditions:** Placing an insulator in damp conditions promotes discharge by allowing water molecules to adhere to its surface. These polar molecules interact with charged areas, creating a thin conductive layer that facilitates charge movement. Moreover, the ions present in humid air assist in neutralizing static charges on the insulator's surface, making this an effective discharging method as shown in figure 15.9 (b).

15.3.5 A SURFACE CHARGE CAN BE INDUCED ON INSULATORS BY POLARIZATION

Imagine running a plastic comb or brush through your hair. As you rub, some electrons from your hair transfer onto the comb, giving it a negative charge. Now, envision small pieces of paper nearby. These pieces of paper typically have a balanced charge, but when brought close to the negatively charged comb, these pieces of paper fly towards the comb. How is this possible? Why attraction of uncharged objects not repulsion?

The paper pieces start off with an equal number of positive and negative charges. However, when you run a comb through your hair, electrons transfer from your hair to the comb, making the comb negatively charged. This negatively charged comb creates an electric field around it as it approaches the paper. The negative charge on the comb repels the negative charges in the paper, but it also attracts the positive charges. Since positive charges are more mobile within an atom, they move closer to the comb while the negative charges are pushed away. In the end, the attractive force between the negatively charged comb and the positively charged side of the paper becomes stronger than the repulsive force between the comb and the negative charges.

This net attraction pulls the paper pieces towards the comb. The induced movement of positive charges towards the comb creates a stronger overall attraction, like a coordinated team in a tug-of-war winning the battle and bringing the paper closer. The same effect can be seen with a plastic (or amber) rod rubbed with fur, as shown in figure 15.10 (a) and (b). Similarly, a balloon rubbed against hair can attract a falling stream of water as shown in figure 15.10 (c) and (d).

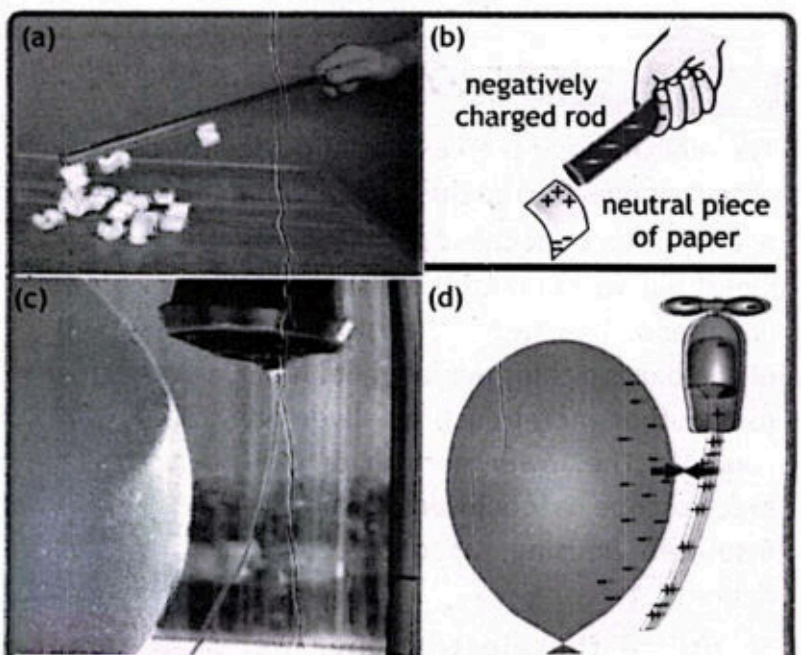
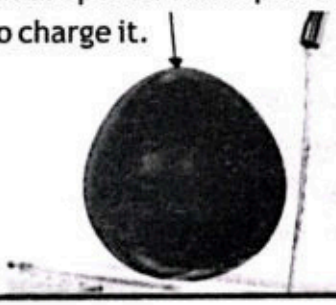


FIGURE 15.10 Surface charge induced by polarization

MINI LAB

Materials required: Baloon and water faucet

Activity: Turn on a water faucet and adjust the flow to create a small but steady stream. The stream should be slow enough to remain continuous, without breaking into individual droplets. Rub a plastic rod, latex balloon, or plastic comb with wool or fur to charge it.



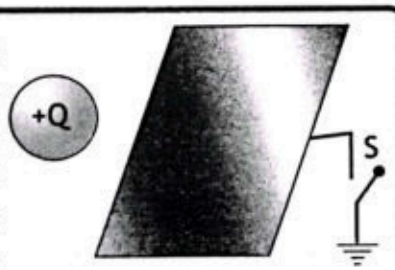
Hold the charged end of the balloon close to the stream of water, but make sure the balloon does not touch the water.

Observation: What happens to the stream of water?

Question: What might be causing this to happen?

CAN YOU TELL?

A metal plate is connected by a conductor to a ground through a switch. The switch is initially closed. A charge +Q is brought close to the plate without touching it, and then the switch is opened. After the switch is opened, the charge +Q is removed. What is the charge on the plate then?



15.4 ELECTROSCOPE

The electroscope is an essential device for detecting and analyzing the charge present on an object. It operates on the principle that like charges repel and vice versa.

A basic electroscope consists of a metal bar with a metallic disk at its upper end. Attached to the lower end of the bar is a thin, flexible gold leaf (or another metal such as silver or copper). The lower portion of the electroscope is enclosed within an insulated housing, as depicted in figure 15.11.

To utilize the electroscope, we simply touch the metal disk with the object we wish to examine in order to

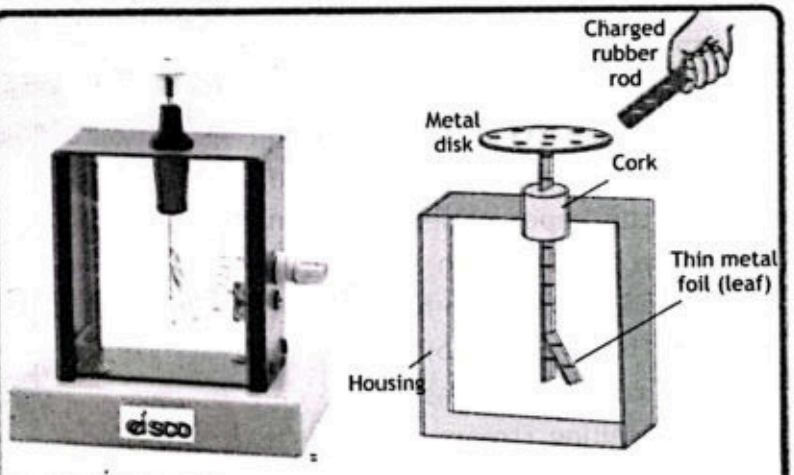


FIGURE 15.11 Gold-leaf electroscope.

detect its charge. For instance, if we touch the disk with a negatively charged plastic rod, some of the rod's excess electrons will transfer to the disk. These electrons will then disperse throughout the metal bar and the gold foil due to the phenomenon of electrostatic induction. The similar charge on the metal rod will cause the flexible metal leaf to repel and move away from the rod, rising higher. Likewise, if a positively charged rod is brought near the metallic disk, it will attract electrons from the electroscope, resulting in a net positive charge on the disk. Once again, the foil will rise.

When a charged rod is brought near an electroscope, it shows that the rod is charged, but it doesn't indicate the charge's sign. However, if the electroscope is first given a known type of charge, the sign can be determined. For instance, if electrons are transferred to the electroscope from a negatively charged object, the electrons in the rod will repel each other and some will transfer to the electroscope.

As a result, the leaf of the electroscope will diverge from the metal, indicating that it has been charged as shown in figure 15.12 (a). If a negatively charged rod is brought close to the already negatively charged electroscope, the leaf will diverge even further as more electrons are repelled as shown in figure 15.12 (b). On the other hand, a positively charged rod will attract electrons up to the bulb and away from the leaf area, causing the leaf to collapse as shown in figure 15.12 (c).

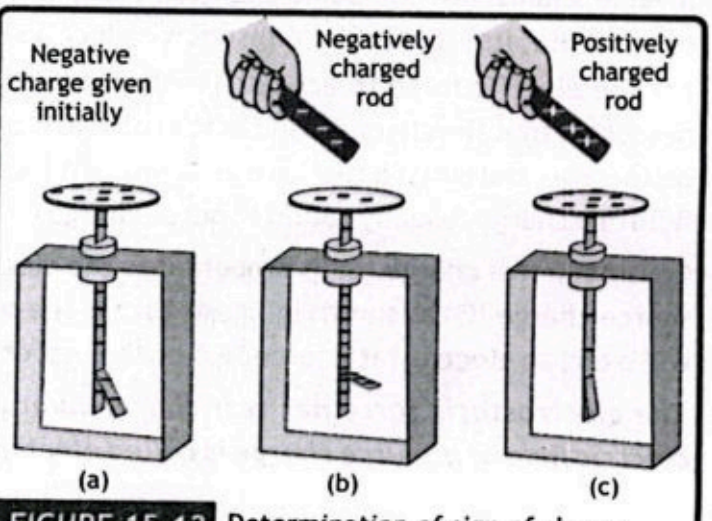


FIGURE 15.12 Determination of sign of charge

It is possible to create a positively charged electroscope using a negatively charged rubber rod through charging by induction. By grounding the electroscope with a finger, electrons can escape from the bulb to the ground as shown in Figure 15.13. When a negatively charged rod is brought close to the bulb, electrons are repelled through the finger and body to the Earth. Removing the finger while keeping the charged rod nearby results in a net positive charge on the electroscope.

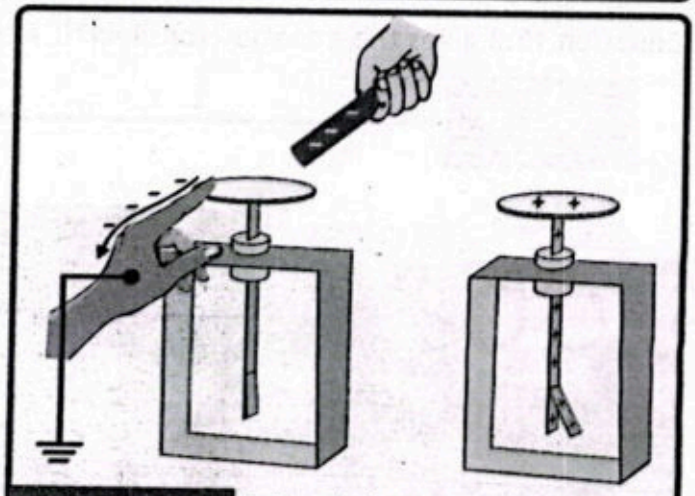


FIGURE 15.13 Induced charge on electroscope

15.5 ELECTRIC FIELD

CAN YOU TELL?



Why on dry days, static electricity is much more noticeable compared to humid or rainy days?

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. The region around a charge where it can attract or repel another charge is described by the concept of the electric field.

An electric field is defined as the region around a charge where it exerts a force on other charges. The electric field strength decreases with distance from the charge, following an inverse square law for point charges. Thus, while the electric field is theoretically present everywhere, its influence diminishes with increasing distance.

For the electric force to act upon a charge particle, it is not necessary that the charges will come in physical contact. It will be there as and when a test charge is brought into the electric field of a charge (usually called a source charge).

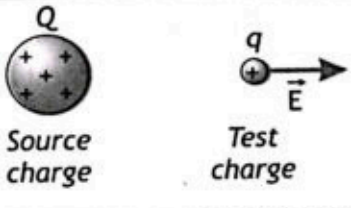


FIGURE 15.14 Electric field Intensity

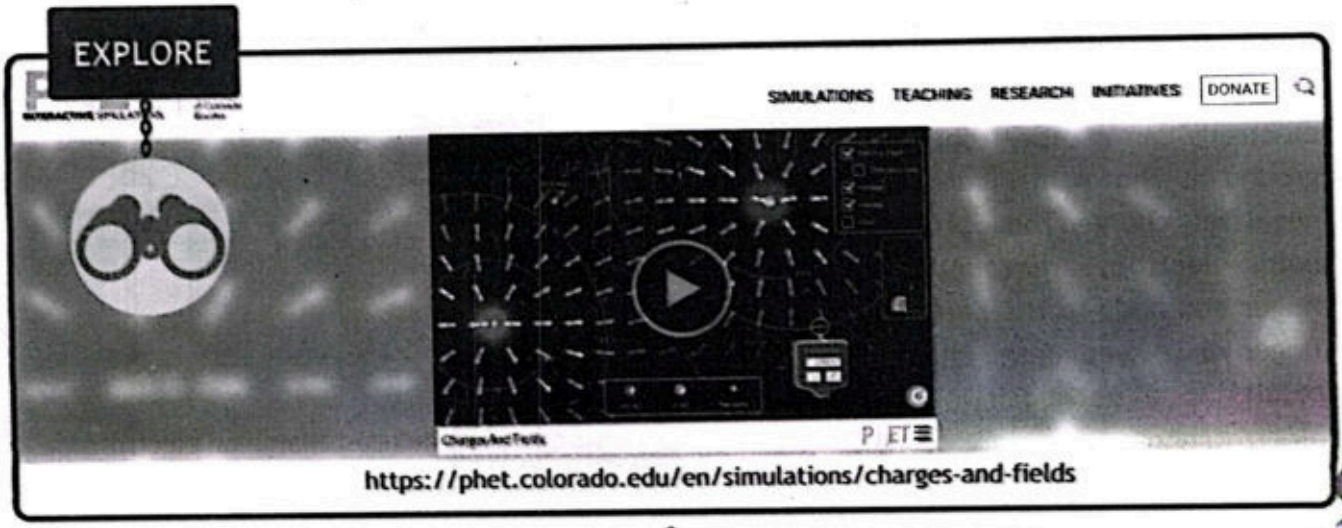
Consider a test charge 'q_o' is brought into the electric field of a source charge 'Q' as shown in figure 15.14. The source charge will exert an electrostatic force "F_E" on the test charge.

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,

$$E = \frac{F_E}{q_0} \quad \text{— 15.2}$$

Equation 15.2 gives the equation for electric field intensity. Its S.I unit is N/C.

EXPLORE



https://phet.colorado.edu/en/simulations/charges-and-fields

Electric field intensity (electric field strength) is a vector quantity having both magnitude and direction. The direction of electric field intensity at a point will be the direction of force on a positive test charge at that point.

Example 15.1

A positive charge of magnitude + 2.2 × 10^6 C experiences a force of 0.40 N from a source charge 'Q' at certain distance 'r'. What is the field strength at this position??

GIVEN
Force 'F' = 0.40 N
Test charge 'q_o' = + 2.2 × 10^6 C

REQUIRED
Electric field strength 'E' = ?

Solution:
The electric field intensity is: $E = \frac{F}{q_o}$ putting values $E = \frac{0.40\ N}{2.2 \times 10^6\ C}$

Therefore, $E = 1.8 \times 10^{-5}\ N/C$ — ANSWER

The field strength at this point will be 1.8 × 10^{-5} N/C.

15.5.1 ELECTRIC FIELD LINES

To visualize electric field around a source charge, the direction of force on positive test charge is represented by a line which give direction of electric field intensity at that point or region. That is why these lines are called as electric field lines.

These lines were first introduced by Michael Faraday. These lines are imaginary and have no physical existence.

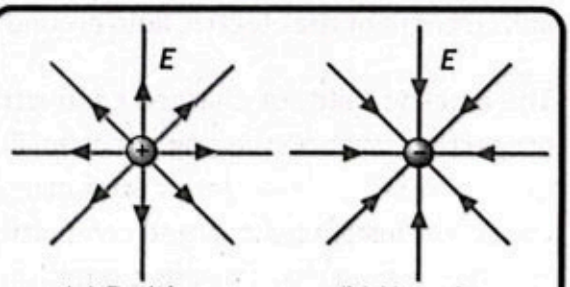
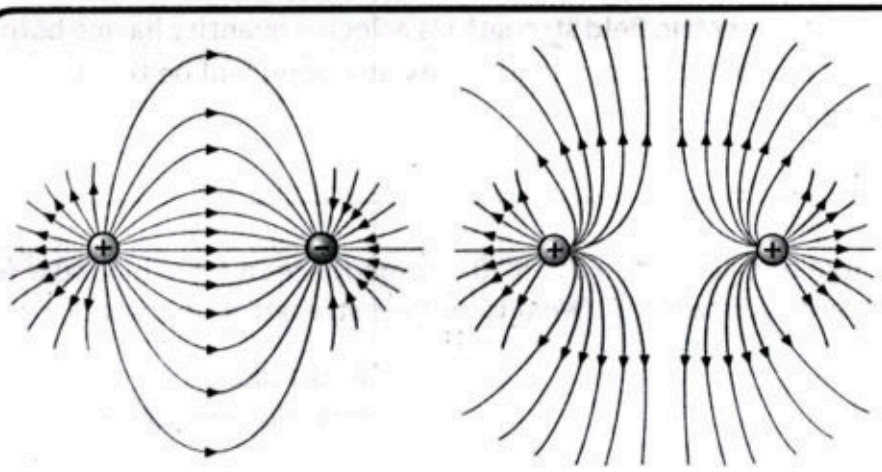


FIGURE 15.15 Electric field around a single charge

For positive charge, the electric field lines or shortly field lines are directed away from positive charge because a positive charge will repel positive test charge as shown in figure 15.15 (a). For negative charge, the field lines are directed towards the charge as it will attract a positive test charge when brought to its field as shown in figure 15.15 (b).

In Figure 15.16 (a), the symmetric electric field lines for a pair of point charges with equal magnitude but opposite signs are shown, forming an electric dipole. The lines originate from the positive charge and terminate at the negative charge. The concentrated lines between the



(a) Oposite charges (b) Similar charges

FIGURE 15.16

2-dimensional drawing of electric field lines of two charges placed near each other.

charges indicate a powerful electric field in that region, particularly between the charges.

Figure 15.16 (b) shows two particles with the same type of charge (both positive), they repel each other. This repulsion can be visualized using electric field lines, which show the direction and strength of the electric field around the charges.

The electric fields of charged conductors have interesting properties. When studying electric fields, analyzing the field around a charged conducting sphere provides important insights. A charged conducting sphere generates an electric field that spreads out uniformly if it is positively charged as shown in figure 15.17, or inward if it is negatively charged.

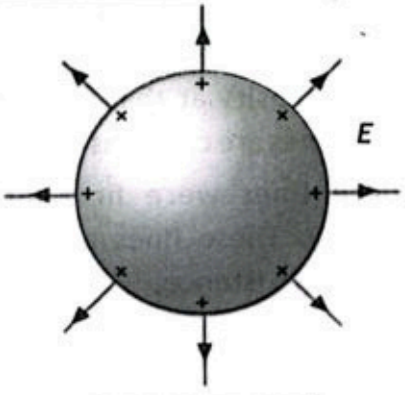


FIGURE 15.17

Electric field of a positively charged spherical conductor

Outside the sphere, the electric field behaves similarly to that of a point charge, decreasing with distance according to the inverse square law. However, inside the sphere, the electric field is zero because the charges distribute themselves evenly on the surface, creating a balanced field within. In contrast, a point charge generates an electric field that spreads out from a single point and decreases with the inverse square of the distance, without any interior region.

When studying electric fields, an important example is two parallel plates that are oppositely charged. One plate has a positive charge, and the other has a negative charge. The electric field between these plates is shown in Figure 15.18.

The positive plate has a uniform positive charge, while the negative plate has a uniform negative charge, both created by connecting the plates to a battery. The electric field in this region is uniform, which means that both the strength and direction of the electric field remain constant throughout the space between the plates. The electric field lines move in straight paths from the positive plate to the negative plate, showing the direction in which a positive charge would move.

This uniformity is a significant characteristic of the electric field created by parallel plates, as it simplifies calculations and predictions regarding the behavior of charged particles within the field.

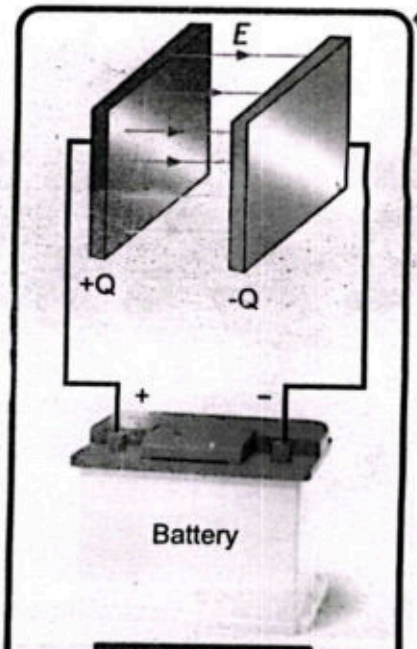
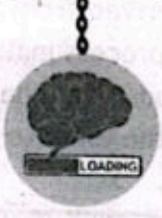
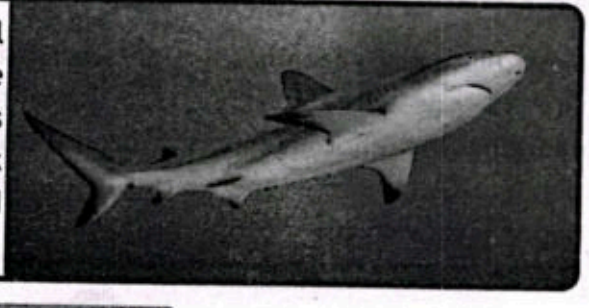


FIGURE 15.18
Electric field of oppositely charged conducting plates

SCIENCE TIDBITS



Sharks are sensitive to the small electric field surrounding possible prey, such as fish. Experiments have shown that a shark will attack an artificial electric field and ignore a piece of food.



15.6 APPLICATIONS OF ELECTROSTATICS

Electrostatic have a number of applications in our daily life.

15.6.1. ELECTROSTATIC PRECIPITATOR AND DUST EXTRACTION

Electrostatic precipitator and dust extractor works on the principle of electrostatics. To reduce air pollution, coal burning power stations uses electrostatic precipitation phenomena to extract dust from the smoke in chimneys before releasing it to the environment as shown in figure 15.19. Air mixed with dust enters the device across a positively charged mesh. The airborne particles become positively charged when they make contact with the mesh. Then they pass through a second, negatively charged mesh. The electrostatic force of attraction

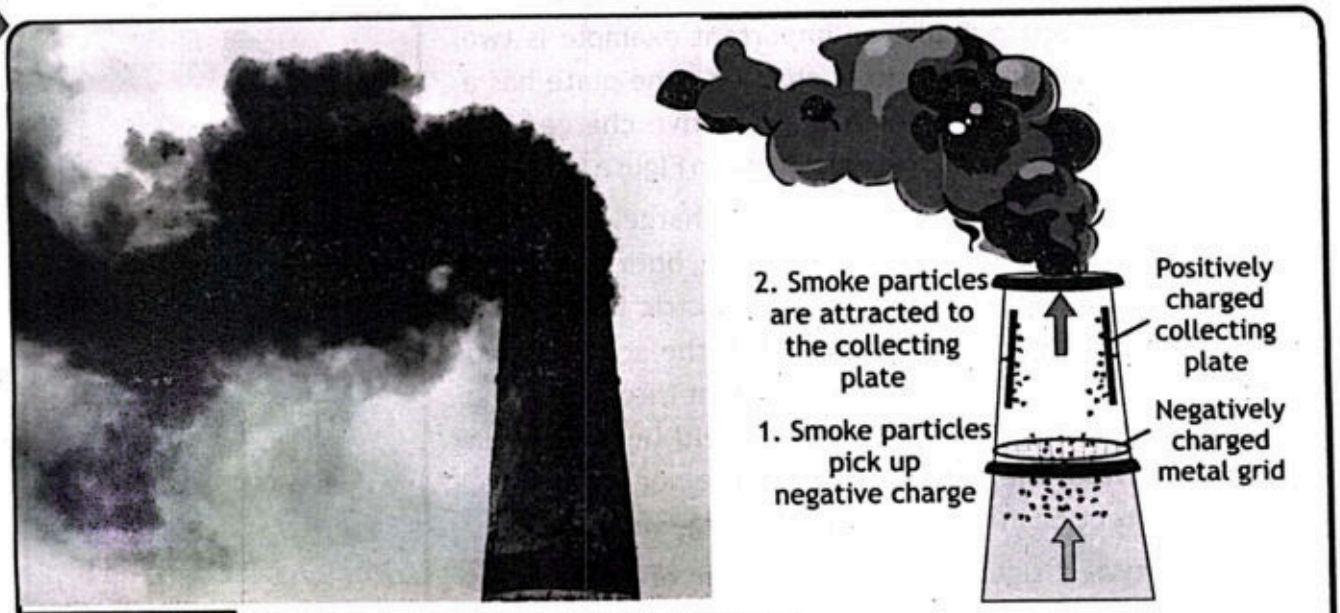


FIGURE 15.19 Electrostatic precipitator and dust extractor

between the positively charged particles in the air and the negatively charged mesh causes the particles to precipitate out on the surface of the mesh.

15.6.2. PHOTOCOPIER MACHINE

Most photocopy machines use an electrostatic process called xerography, derived from the Greek words "xeros" for dry and "graphos" for writing. The major steps in this process include charging the photoconducting drum, transferring an image, creating a positive charge duplicate, attracting toner to the charged parts of the drum, and transferring the toner to the paper as shown in figure 15.20.

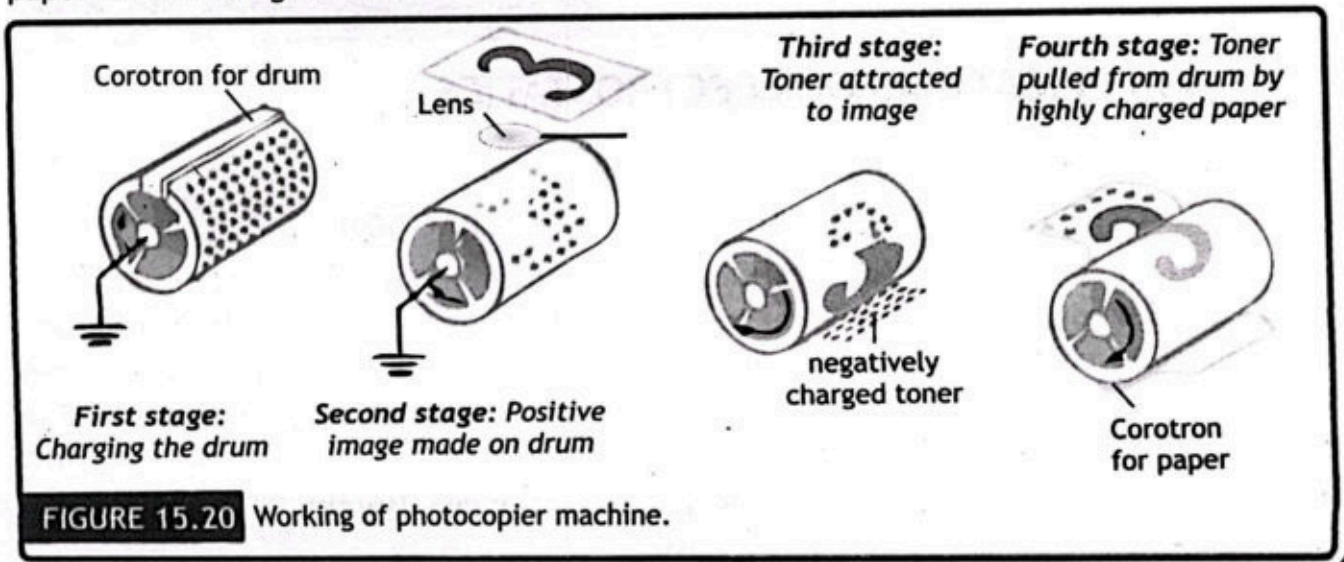
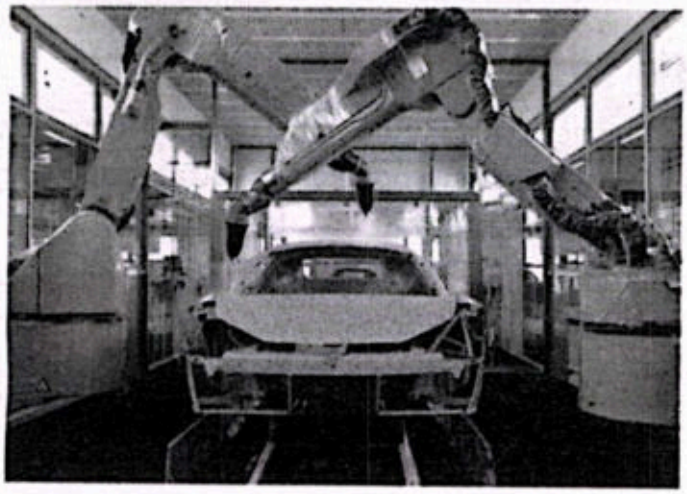
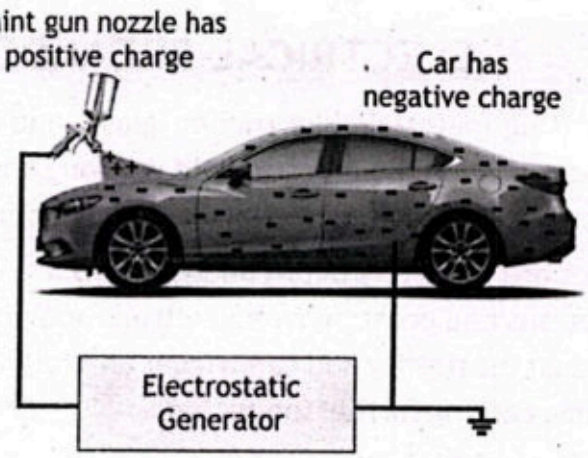


FIGURE 15.20 Working of photocopier machine.

SCIENCE TIDBITS

Automobile manufacturers use electropainting to paint new cars. The body of a car is charged and then the paint is given the opposite charge by charging the nozzle of the sprayer. Charging is either by applying a negative electric charge to the paint while it is in the container or applying the charge in the barrel of the spray painter gun.

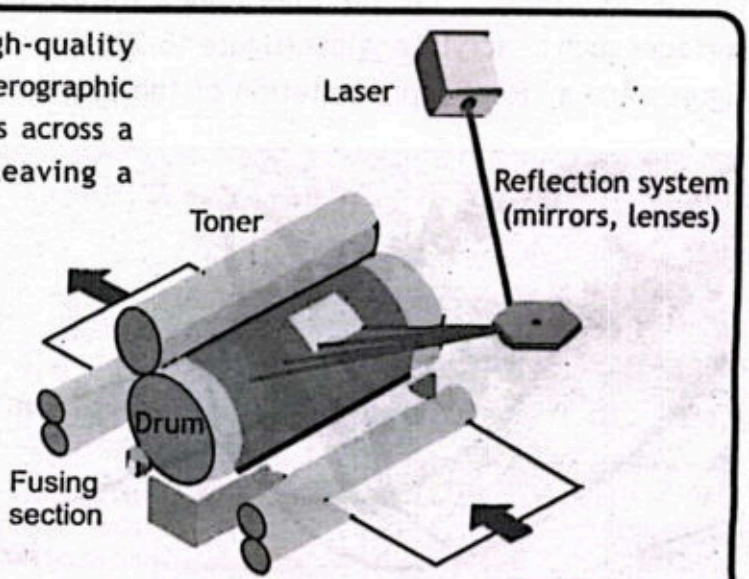




The paint is then pushed through the gun, rubbing against the side, and gaining a static electric charge as it moves. Opposite charges attract each other which helps to distribute the paint particles evenly and get uniform coverage.

SCIENCE TIDBITS

Laser printers create high-quality images on paper using the xerographic process. A laser beam scans across a photoconducting drum, leaving a positively charged image.



The drum is then charged and the image is transferred to paper, similar to xerography. Laser printers can produce high-quality images due to the precise control of laser light. They receive output from a computer and can achieve high-quality results.

The process begins with a selenium-coated aluminum drum, which is sprayed with a positive charge from a device called a corotron. Selenium acts as a photoconductor, meaning it behaves as an insulator in the dark and becomes a conductor when exposed to light. This unique property allows the drum to hold a static charge in dark areas while discharging in areas exposed to light, thereby creating a latent image on the drum's surface. Toner particles, which are oppositely charged, are then attracted to the charged areas of the drum. Finally, the toner is transferred to a piece of paper and fused using heat and pressure, producing a clear copy of the original document.

15.7 ELECTRICAL BREAKDOWN

Insulating materials like rubber, glass, and some plastics typically do not conduct electricity. However, when the electric field is strong enough, they can reach a breakdown voltage, allowing electrons to be pulled from atoms and enabling current flow.

Gases are generally poor conductors, but a strong electric field can ionize gas atoms, removing electrons and creating free electrons and positively charged ions. This process allows the gas to conduct electricity and can trigger an avalanche effect, where freed electrons collide with other atoms, causing further ionization.

15.7.1 VISIBLE EXAMPLES

Corona discharge and Lichtenberg figures show how electrical breakdown happens. Corona discharge appears as a faint glow around sharp points or edges of conductors at high voltages. This occurs because air molecules around the conductor become ionized, causing a localized breakdown. You can see this effect around power lines (figure 15.21) or during thunderstorms.

Lichtenberg figures, on the other hand, are intricate branching patterns formed on insulating surfaces such as acrylic or glass (figure 15.22) when subjected to a high-voltage discharges. These figures are a visual representation of the path taken by the electric current as it propagates

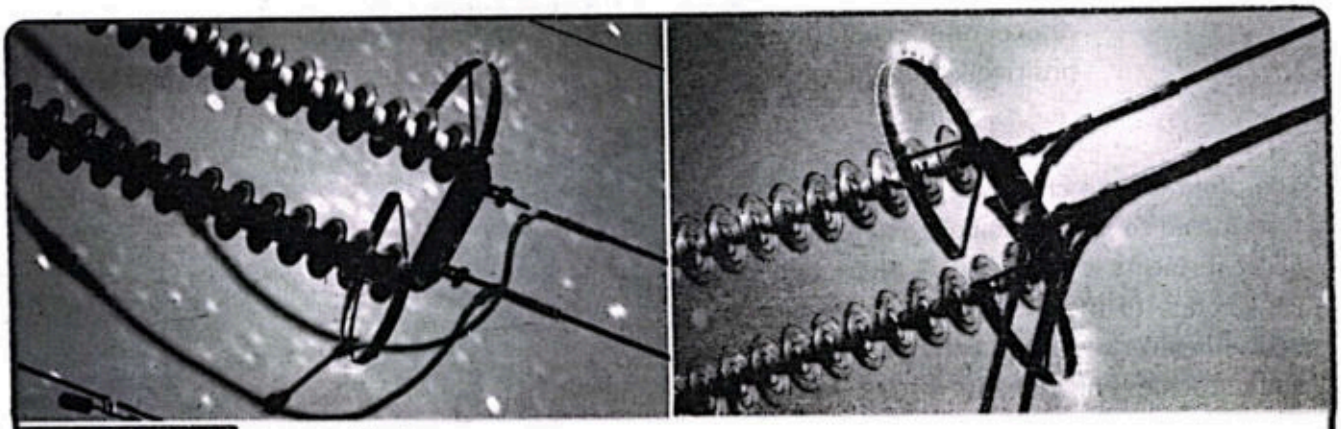


FIGURE 15.21 Corona discharge

through the material, leaving behind permanent, tree-like patterns.

Both phenomena clearly demonstrate electrical breakdown in various situations.

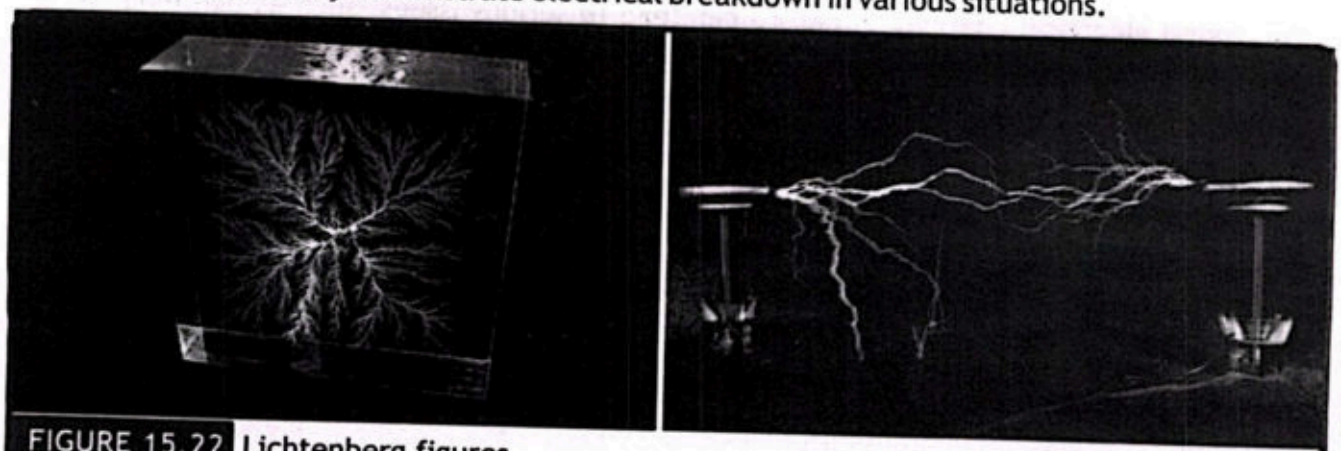


FIGURE 15.22 Lichtenberg figures

15.7.2 LIGHTNING GENERATION

Lightning is a powerful release of electrical energy that occurs in clouds when air, water droplets, or volcanic ash collide, causing electrical charges to separate. Positive charges rise to the top of the cloud, while negative charges sink. This creates a conductive plasma as the cloud becomes more charged. Excess electrons at the cloud's base travel to the ground in a zigzag pattern called a step leader.

The negative charge at the cloud's bottom induces a positive charge on the Earth's surface, creating a polarized effect. Nearby air molecules ionize and rise, forming a positive charge known as a streamer. When the streamer connects with the step leader, a complete path is established, resulting in a lightning strike, with the negative charge moving to the ground at speeds up to 100,000 km/s.

15.7.3 VARIETIES OF ATMOSPHERIC LIGHTNING

Lightning isn't limited to the common cloud-to-ground strike. Most lightning occurs entirely within a cloud (intracloud discharges), where it cannot be seen. However, visible discharges do take place between clouds (cloud-to-cloud discharges) and between a cloud and the Earth (cloud-to-ground discharges).There are many fascinating, less-understood types of lightning that occur high in the atmosphere, such as:

- Sprites - Short-lived, red flashes above thunderstorms.
- Jets - Narrow, upward bursts of blue light.
- Elves - Expanding rings of faint, white light.
- And others with even more whimsical names - Trolls, Pixies, Ghosts, Ball Lightning - These are all being actively researched by scientists.

15.7.4 UNCONTROLLED ELECTRICAL CHARGING

Uncontrolled electrical charging in nature can lead to serious issues, such as lightning. When clouds accumulate positive and negative electricity, the air can no longer insulate, resulting in a lightning strike that can damage property, harm people, and ignite fires.

To stay safe during thunderstorms, seek shelter in a sturdy building. If outside, crouch with your feet together and avoid tall objects and water.

Lightning is destructive because it generates strong currents in poor conductors, creating extreme heat that can endanger buildings. A lightning rod, invented by Benjamin Franklin in the 1750s, helps protect structures. It consists of a pointed metal rod on a building, connected to a buried rod as shown in figure 15.23. This system attracts lightning and provides a safe path for the current to the ground, preventing damage and stopping harmful electrical surges.

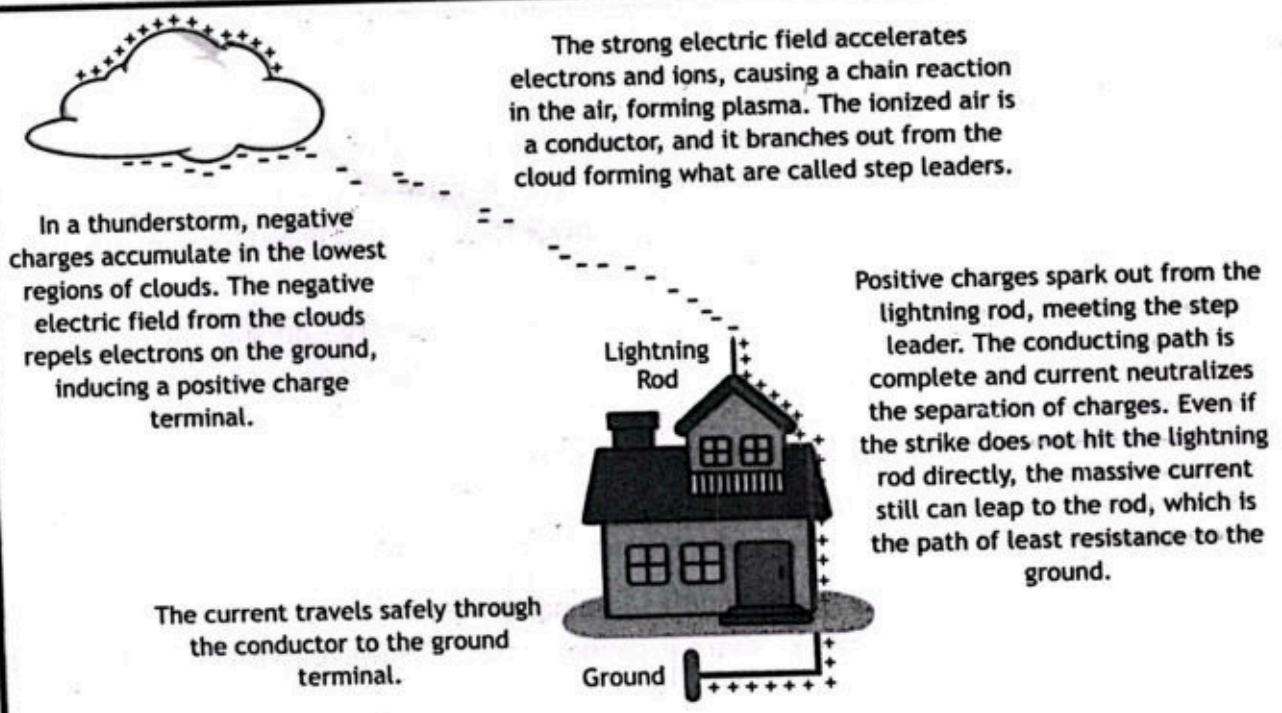


FIGURE 15.23 Lightning and lightning rod

SUMMARY

- **Electrification** is the process by which an object acquires an electric charge. This can happen through various methods like friction, contact, or induction.
- **Conservation of charge** is a fundamental law stating that the total electric charge in an isolated system remains constant. In simpler terms, charge can't be created or destroyed, only transferred between objects.
- **Quantization of charge** is the principle that electric charge exists in discrete units called electrons and protons. These fundamental particles have specific charges (negative for electrons, positive for protons), and charge cannot be further subdivided.
- **Conductors** are materials that allow electric charge to flow freely through them. They have loosely bound electrons that can easily move under the influence of an electric field. Examples include metals like copper and aluminum.
- **Insulators** are materials that resist the flow of electric charge. They have tightly bound electrons that are difficult to move. Examples include rubber, plastic, and wood.
- **Charging by friction** involves rubbing two dissimilar materials together transfers electrons from one material to the other.
- **Charging by contact** is the process when a charged object comes into contact with a neutral object, some electrons transfer between them, causing the neutral object to acquire the same charge type (positive or negative) as the charged object, but to a lesser degree.
- **Charging by induction** is a method where a charged object influences the distribution of charge in a nearby neutral object without physically touching it. This creates a temporary separation of charges in the neutral object.
- **Discharging** is the process by which an object loses its electric charge. It can happen through conduction (touching a grounded object), convection (charged particles carried by air), or a spark (sudden movement of charge).
- **Induced polarization** occurs when a charged object is brought near an insulator, the electric field from the charged object redistributes the charges within the insulator, creating a slight separation of positive and negative charges.
- **Electroscope** is a simple instrument used to detect the presence and sign (positive or negative) of electric charge. It typically consists of two thin metal leaves that diverge when charged.
- **Electric field** is a region of space where a charged object experiences a force. The strength and direction of the electric field depend on the amount and type of charge present.

- **Electric field lines** are imaginary lines that depict the direction and strength of an electric field. They point away from positive charges and towards negative charges, with the density of lines indicating the field's strength.
- **Electrostatic precipitator** is a device that uses an electric field to remove dust particles and other pollutants from air. Charged particles are attracted to collection plates, removing them from the air stream.
- **Corona discharge** is a faint glow or ionization of air caused by a strong electric field around a conductor. It can be seen around high-voltage power lines.
- **Lichtenberg figures** are branching, fern-like patterns left on an insulator's surface when a high-voltage discharge passes through it.
- **Lightning Generation** is the rapid discharge of electricity that occurs within a cloud or between a cloud and the ground. This is caused by the buildup of electric charge within the cloud due to various atmospheric processes.
- **Lightning control rod** are a well-established and effective method for protecting structures from lightning strikes.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. A rubber rod is rubbed with fur. The fur is then quickly brought near the bulb of an uncharged electroscope. The sign of the charge on the leaves of the electroscope is

   A. positive B. negative C. neutral D. zero

2. A negatively charged object is brought close to the surface of a conductor, whose opposite side is then grounded. What kind of charge is left on the conductor's surface?

   A. positive B. negative C. neutral D. zero

3. A small metal ball hangs from the ceiling by an insulating thread. The ball is attracted to a positively charged rod held near the ball. The ball must be:

   A. positive. B. negative. C. positive or neutral. D. negative or neutral.

4. A positive ion is formed when:

   A. a neutral atom loses electron B. a neutral atom gains electron

   C. negatively charged atom loses electron D. can be true for all these cases

5. A charged rod is brought near a suspended object, which is repelled by the rod. We can conclude that the suspended object is:

   A. uncharged
   B. Charged with different sign
   C. Charged with same sign
   D. can be true for all these cases

6. You have two lightweight metal spheres, each hanging from an insulating nylon thread. One of the spheres has a net negative charge, while the other sphere has no net charge. You now allow the two spheres to touch. Once they have touched, will the two spheres:

   A. attract each other
   B. repel each other
   C. exert no force on each other
   D. neutralize each other

7. A negative point charge moves along a straight-line path directly toward a stationary positive point charge. Which aspect(s) of the electric force on the negative point charge will remain constant as it moves?

   A. Magnitude
   B. direction
   C. both magnitude and direction
   D. neither magnitude nor direction

8. To be safe during a lightning storm, it is best to be

   A. in the middle of a grassy meadow.
   B. inside a metal car.
   C. next to a tall tree in a forest.
   D. on a metal observation tower.

9. What causes the leaves of an electroscope to move apart when charged?

   A. Attraction of unlike charges
   B. Repulsion of like charges
   C. Neutral nature of leaves
   D. Air Pressure

10. Corona discharge is most likely to occur at which of the following locations on a conductor?

    A. Flat surfaces B. Sharp points C. Smooth spheres D. Insulated areas

11. What do Lichtenberg figures typically look like?

    A. Straight lines
    B. Circular rings
    C. Branching tree-like patterns
    D. Rectangular shapes

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. (a) In your notebook, draw two parallel lines representing metal plates, one positive and one negative.

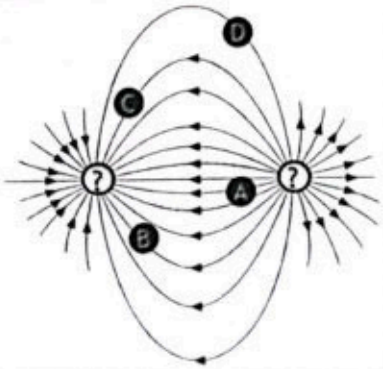
(b) Eight negative point charges of equal magnitude are distributed evenly around a circle. Sketch the electric field in the region around and within this charge distribution. Explain how this charge distribution can be used to model the electric field inside a coaxial cable.

2. Figure shows a source that consists of two charged particles.

(a) What is the sign of the charge on each particle?

(b) In which region (A, B, C or D) is the electric field the weakest?

(c) In which region (A, B, C or D) is the electric field the strongest?



SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. What is the relationship between charge and mass when a metal becomes charged, and assess whether the mass change is significant?
2. How do grounding systems prevent static buildup in fuel trucks, what are the dangers without grounding?
3. Why do electrons transfer charge instead of protons or neutrons, and how does this affect circuit and device design?
4. Why does a charged balloon stick to a neutral wall due to polarization? Compare the interaction with a conductor vs. an insulator.
5. How do positive and negative charges behave differently in an electric field?
6. What are the effects of changing electric field direction or strength in applications like capacitors?
7. Compare electric and gravitational fields in terms of strength, range, and forces, and evaluate situations where both fields affect objects.
8. Can insulators be charged by induction, under what conditions does this happen, and what are alternative methods for charging insulators?
9. What is corona discharge around conductors, especially sharp points?
10. How does electric field concentration cause ionization, and what are its practical uses or problems?
11. What causes Lichtenberg figures to form after lightning strikes, why don't they always appear?
12. How do lightning rods protect buildings, what is the role of pointed rods in attracting discharge?
13. How can lightning rod design and placement be optimized for better protection?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Explain electrification and how charge conservation and quantization govern particle behavior, with real-world examples like electronics.
2. Describe how objects gain charge through triboelectric effects and how they behave when in contact with conductors.
3. Compare conductors and insulators at the atomic level, focusing on electron configurations and their practical uses.
4. Evaluate charging methods (friction, conduction, induction) and their efficiency in different materials, with real-world applications.
5. Design a procedure to charge two metal spheres via electrostatic induction and discuss realworld uses of induction.
6. Analyze electric fields and how field lines help visualize field intensity, with applications like capacitors and shielding.
7. Explain how an electroscope works to detect charge and suggest improvements for detecting weaker charges.
8. Analyze electrostatic precipitators and photocopiers, and propose ways to improve their energy efficiency and performance.
9. Investigate electric breakdown, how it occurs, and suggest safety measures for high-voltage environments.
10. Explain lightning production and how lightning rods work, proposing additional safety measures for lightning-prone areas.

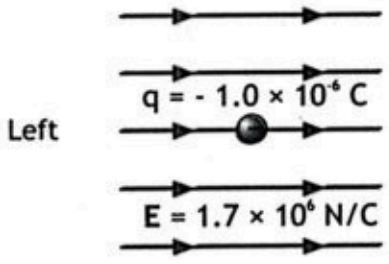
NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

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

(Ans. 2.00×10^4 N/C)

2. How much force is exerted on a charge of -1.0×10^{-6} C in a field of strength 1.7×10^{6} N/C (right)? Now when the field strength is doubled, how much force is exerted on a charge of $+1.0 \times 10^{-6}$ C?

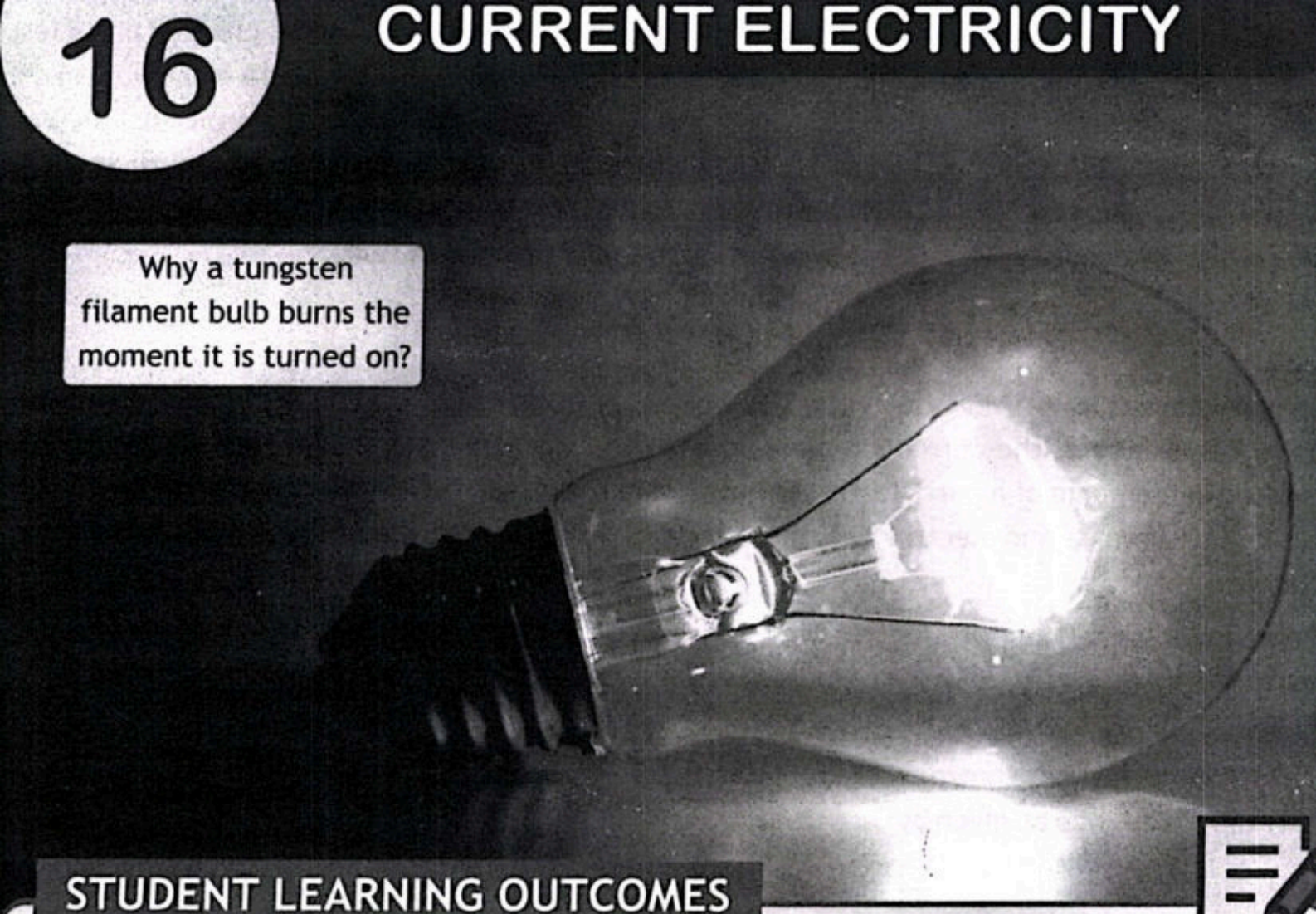


(Ans. 1.7 N [left], 3.4 N [right])

3. Find magnitude of the positive test charge that experiences a force of 0.5 N when placed in an electric field of 2.0 N/C. (Ans. 0.25 C)
4. A small Charge of 3.0 μC is placed in a uniform electric field of 1.5 N/C. Calculate force on the charge. (Ans. 4.5 μN)
5. Calculate the electric field strength when an electron enters it and experiences a force of 0.01 N. The charge of an electron is 1.6×10^{-19} C. (Ans. 6.25×10^{16} N/C)
6. What is magnitude of force on an electron released from rest in a uniform electric field of magnitude 20 N/C? (Ans. 3.2×10^{-18} N)

16 CURRENT ELECTRICITY

Why a tungsten filament bulb burns the moment it is turned on?



STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-20] Define and calculate electric current.
- ✓ [SLO: P-10-E-21] Explain electrical conduction.
- ✓ [SLO: P-10-E-22] state that current is measured in amps (amperes) and that the amp is given by coulomb per second (C/s).
- ✓ [SLO: P-10-E-23] Differentiate between direct current (d.c.) and alternating current (a.c.).
- ✓ [SLO: P-10-E-24] Differentiate between conventional and actual current.
- ✓ [SLO: P-10-E-25] Justify and illustrate the use of ammeters.
- ✓ [SLO: P-10-E-26] Define e.m.f.
- ✓ [SLO: P-10-E-27] Define p.d. (potential difference).
- ✓ [SLO: P-10-E-28] State that e.m.f. and p.d. are measured in volts and that the volt is given by joule per coulomb (J/C).
- ✓ [SLO: P-10-E-29] Justify and illustrate the use of voltmeters.
- ✓ [SLO: P-10-E-32] Describe an experiment to determine resistance.
- ✓ [SLO: P-10-E-33] Define and calculate resistivity.
- ✓ [SLO: P-10-E-34] Define and apply Ohm's law.
- ✓ [SLO: P-10-E-35] Describe the effect of temperature increase on the resistance of a resistor.
- ✓ [SLO: P-10-E-36] Interpret current-voltage graphs.

In this unit, we delve into the intriguing world of electric current—a stream of charged particles, visualized as tiny marbles with an electric charge, coursing through a conductive pathway like a wire. This stream, known as electric current, is the cornerstone of electrical operations, fuelling our households and energizing gadgets. As we traverse through this chapter, we will dissect the nature of electric current, ascertain how to compute it using formulas, and grasp its crucial role within electrical networks, electricity hazards, and safety considerations.

16.1 ELECTRIC CURRENT

Electric current is produced due to the flow of either positive or negative charges or sometimes both. For example, the current in metals is due to flow of negatively charged electrons. The current in the beam of a particle accelerator is due to positively charged protons, while in some cases such as gases and electrolytes, the current is due to the flow of both positive and negative charges.

The time rate of flow of electric charges through a cross-sectional area is called electric current.

Consider charge 'ΔQ' flowing through any cross-sectional area in time 'Δt', as shown in figure 16.1, the electric current 'I' will then be given by:

$$I = \frac{\Delta Q}{\Delta t} \quad \boxed{16.1}$$

The SI unit of current is the ampere, which is denoted by (A). One ampere current in terms of flow of charge is stated as "when one coulomb of charge flows through any cross-sectional area in one second". Mathematically:

$$1A = \frac{1C}{1s}$$

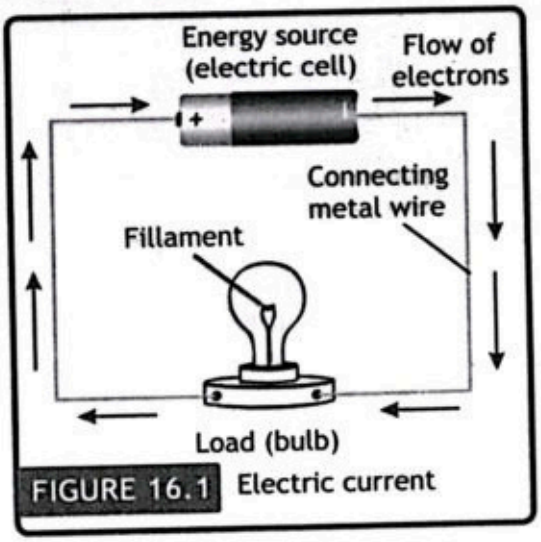


FIGURE 16.1 Electric current

Ampere is a large unit of electric current, that's why the following sub-multiples of ampere are most commonly used:

1 milliampere = 1 mA = 10^{-3} A

1 microampere = 1 μA = 10^{-6} A

16.1.1 CONVENTIONAL FLOW OF CURRENT

Before the discovery of electron it was thought that electric current is due to the flow of positive charges in conductors. This assumed direction of current flow is now called conventional current.

Current flowing from positive terminal to negative terminal of a battery due to the flow of positive charges is called conventional current.

Current flowing from positive terminal to negative terminal of a battery due to the flow of positive charges is called conventional current.

For practical purposes positive charges moving in one direction is equivalent to negative charges moving in opposite direction. Conventional current produces the same effect as the current flowing from negative terminal to the positive terminal due to the flow of negative charges. That's why both are used in electrical circuit problems as shown in 16.2.

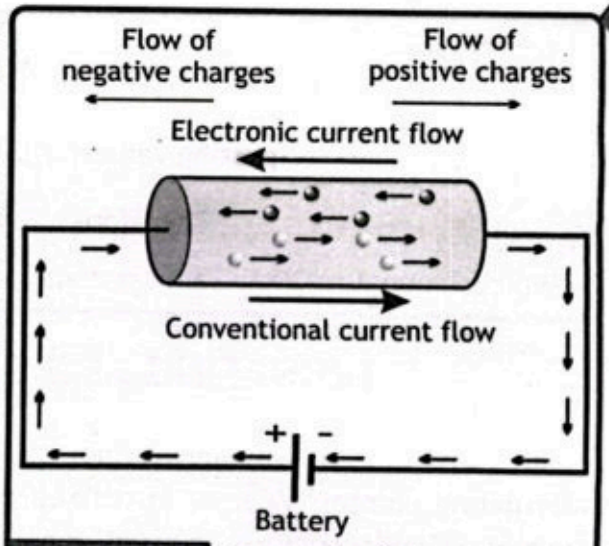


FIGURE 16.2 Conventional flow of current

16.1.2 ELECTRICAL CONDUCTION IN METALS

In metals, the valence electrons are not tightly bound by the nucleus and can move around freely like the movement of gas molecules in a container. When there is no battery or power supply connected to a metal piece like a copper wire, as shown in figure 16.3 (a), the net motion of free electrons is zero and hence no electrical current. When a battery is connected to the end of this copper wire piece, free electrons start motion in one direction as shown in figure 16.3 (b). The positive plate of the battery will attract free electrons while the negative plate will push.

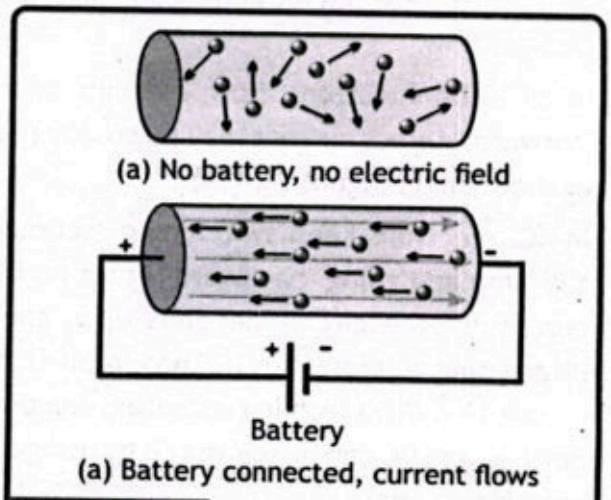


FIGURE 16.3 Electric current in metals

The electrons start drifting in the metal, like leaves carried by a gentle breeze. These electrons will collide with each other and with nuclei of other atoms, which slows them down.

The net movement of these free electrons in one direction creates what we call an electric current. So, the electrical conduction in metals happens because of the movement of free electrons when an electric field is applied across it, creating an electric current.

Example 16.1

A battery of an electric car is charged at a charging station using a current of 10.0 A for two hours. How much charge passes to the battery?

GIVEN:
Current 'I' = 10.0 A, Time 'Δt' = 2 hr = 2 × 3600 s = 7200 s

REQUIRED:
Charge 'ΔQ' = ?

SOLUTION:

By definition of electric current: $I = \frac{\Delta Q}{\Delta t}$ or $\Delta Q = I \times \Delta t$

putting values: $\Delta Q = 10.0\,A \times 7{,}200\,s$

Therefore $\Delta Q = 72{,}000\,C$ — **ANSWER**

Which is equal to 20 Ah, a most commonly used specification for batteries.

16.2 ALTERNATING AND DIRECT CURRENT

Electricity flows in two ways; either changing direction called alternating current (AC), or in a fixed direction called direct current (DC). Electricity or "current" is nothing but the movement of charges (electrons here) through a conductor, like a wire. The difference between AC and DC lies in the direction in which the charges flow.

In DC, the electrons flow steadily in a single direction, or "forward." Direct current may be steady (i.e., uniform) or varying as shown in the figure 16.4 (a).

In AC, electrons keep switching directions, going "forward" half the time and going "backward" other half time. The direction of current in the circuit depends upon the changing polarity of alternating voltage source. The circuit sign for AC is also given in Figure 16.4 (b). Electric generators can produce either DC or AC. Both AC and DC can be measured by using a multimeter as there is an option for both.

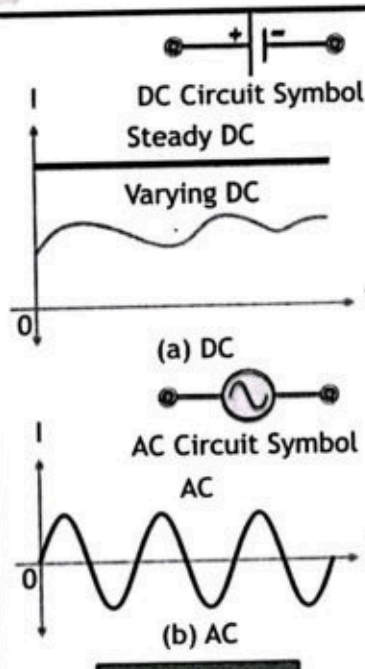


FIGURE 16.4
Direct and alternating current

POINT TO PONDER



Is AC more dangerous than DC?

Alternating current at high voltage (above 500 V) is more dangerous than direct current at the same voltage. When a person touches a high-voltage DC source, it usually causes a single muscle contraction that can be strong enough to push the person away from the source. By contrast, touching a high-voltage AC source can cause a continuing muscle contraction that prevents the victim from letting go of the source.



16.3 POTENTIAL DIFFERENCE

Connecting one end of a conductor to positive terminal of the battery and another with negative terminal, a potential difference will be produced between the two ends of the conductor.

The difference of electric potential between two points is called potential difference.

Conventionally, positive terminal of a battery is at higher potential while negative terminal is at lower potential. So, the end of a circuit component connected to positive terminal will be at higher potential as compared to the other end connected to the negative terminal of the battery.

Consider an electric circuit in which a light bulb is connected to a battery as shown in figure 16.5. Connecting one end of a conductor to positive terminal of the battery and another with negative terminal, a potential difference will be produced between the two ends of the conductor.

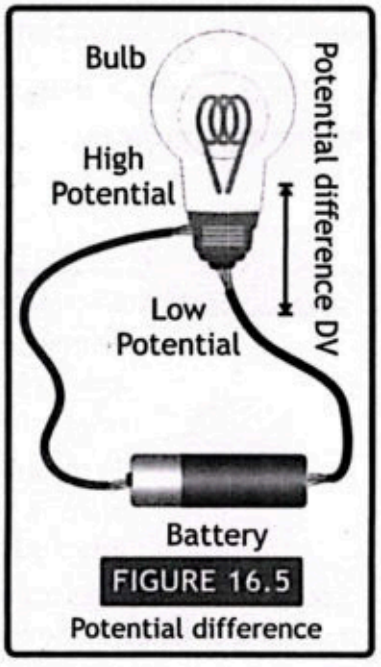


FIGURE 16.5
Potential difference

The flow of current continues as long as there is a potential difference. The device which provides the potential difference for the steady flow of current in the copper wire or any other conductor is the battery (or any other source, which we will study in emf topic).

The charge leaving the positive terminal of the battery has potential energy, a part of which is lost in the device. Thus, there is difference of potential energy per coulomb of charge between the ends of the battery that is also transferred to the device and is termed as potential difference. Mathematically:

$$\Delta V = \frac{\Delta U}{\Delta q} = \frac{\Delta W}{\Delta q} \quad \text{16.2}$$

SI unit of potential difference is volt. One volt of potential difference is defined as "when a potential energy of 1 joule is needed to move a charge of 1 coulomb from one point to another inside the field.

16.4 EMF

To maintain a steady current in the circuit, there must be a source that continuously converts non-electrical energy into electrical energy.

The energy supplied by a battery per unit positive charge when it flows through the closed circuit is called electromotive force (emf).

emf source is a device which converts nonelectrical energy into electrical energy, and is required in a circuit to maintain a constant potential difference across the its components i.e., devices.

Consider a battery is connected through conducting wires with a device (light bulb) as shown in figure 16.6. The positive charge leaves the positive terminal of the battery, passes through the conductor and reaches the negative terminal of the battery. As positive charge enters the battery at its lower potential point (negative terminal), the battery has to perform work on the positive charge to drive it to a point of higher potential i.e., positive terminal.

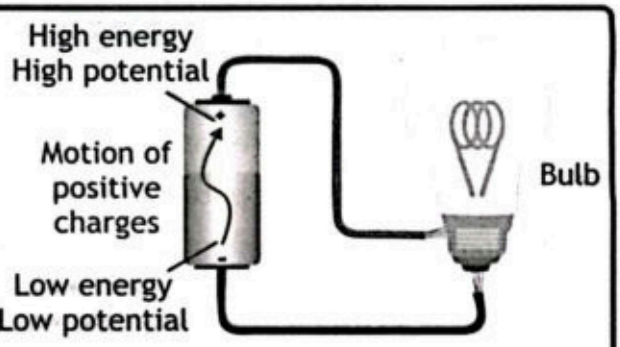


FIGURE 16.6 Electromotive Force (emf)

If 'W' is the work done by battery on positive charges 'q' then electromotive force (emf or ε) of the battery is given by:

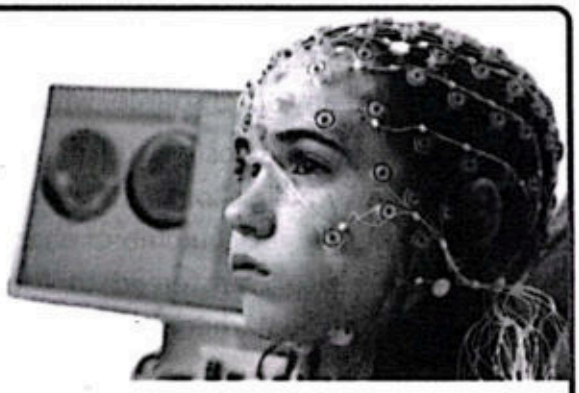
$$\varepsilon = \frac{W}{q} \quad \text{— 16.3}$$

SCIENCE TIDBITS



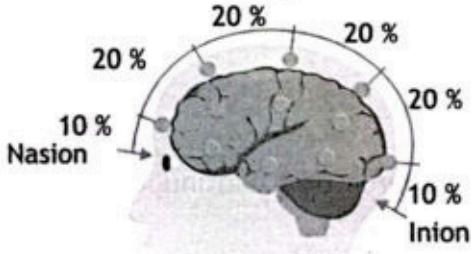
Electroencephalography (EEG) is a neurological test that uses electronic monitoring device to measure and record the electrical activity of brain.

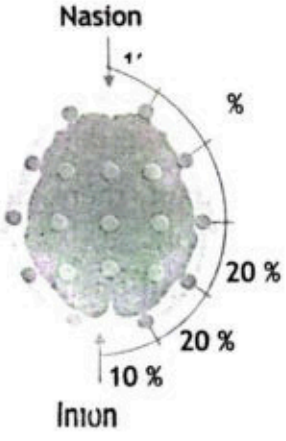
To record the electrical activity of the brain, 8 to 16 pairs of electrodes are attached to the scalp.

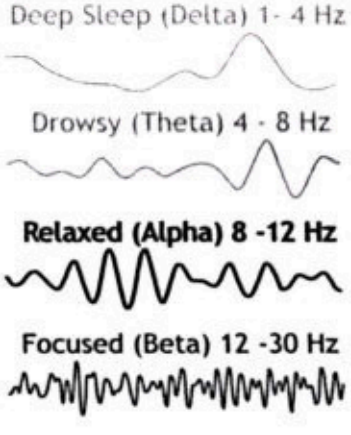


Each pair of electrodes transmits a signal to one of several recording channels of the electroencephalograph.

This signal consists of the difference in the voltage between each pair of electrodes. The rhythmic fluctuation of this potential difference is shown through graph by the recording channel.







S.I unit of electromotive force is same as that of electric potential as J/C = V. Examples of emf sources are batteries (converts chemical energy into electrical energy), solar panels (solar to electrical), thermocouples (thermal to electrical) and generators (mechanical to electrical).

16.5 OHM'S LAW

Ohm's law states the relationship between electric current flowing through a conductor and potential difference applied across it.

The current between two points, in a conductor, is directly proportional to the applied voltage across these points as long as temperature and the physical state of the conductor is kept constant.

If 'V' is the potential difference across the two ends of a conductor, then current 'I' will flow through it. Mathematically:

$$I \propto V \qquad \text{(Temperature T = Constant)}$$

Replacing sign of proportionality with equality and putting a constant:

$$I = \frac{V}{R} \quad \text{or} \quad V = IR \qquad 16.4$$

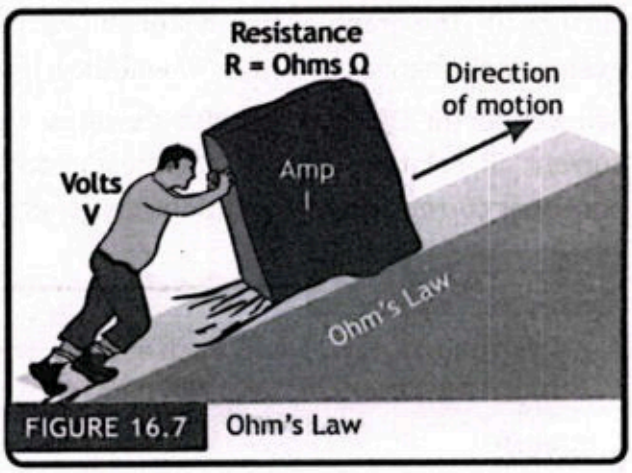


FIGURE 16.7 Ohm's Law

Whereas 'R' is proportionality constant and is called resistance.

Ohm's law is not applicable to all devices. It can only be applied to certain devices, mostly metals, which are called ohmic devices. Examples of ohmic devices are copper and silver wires and resistors.

Devices which do not obey Ohm's law are called non-ohmic devices. Examples of non-ohmic devices are filament bulb, thermistor and semiconductor diode.

16.5.1 LIMITATIONS OF OHM'S LAW

Ohm's law is applicable only for materials for which V versus I graph is a straight line. However only metallic conductors show this behavior and that too only over limited range of voltages. Many important devices do not obey Ohm's law and are called non-ohmic devices.

16.5.2 OHMIC AND NON-OHMIC DEVICES

Figure 16.8 (a) shows that 'R' is constant the slope 'I' Vs 'V' graph is a straight line. However all the materials have no straight line graph as we can see from the graph given in figure 16.8 (b, c, d). The graph of filament bulb, thermistor and semiconductor diode are all curved therefore they are termed as non-ohmic materials. The graph of filament bulb shows that current saturates as the

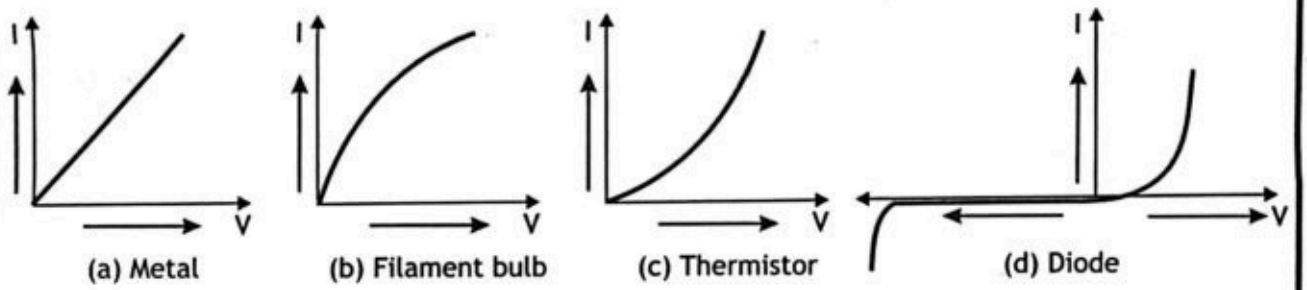


FIGURE 16.8 Ohmic and non-ohmic devices

current is increased and at large value even a large change in voltage 'V' will show small change in current 'I'. The graph of thermistor shows that resistance decreases sharply thus at large value even a small change in voltage 'V' will show large change in current 'I'.

Semiconductor Diode graph also deviates very strictly from the straight line voltage 'V' and current 'I' relationship. In fact most modern electronic devices, such as transistors, have nonlinear current-voltage relationships; therefore they are non-ohmic.

Example 16.2

A torch bulb uses two cells each of 1.5 V, connected in series, to glow. What current will flow through the circuit of torch when its resistance is 20.0 Ω.

GIVEN:
Potential difference 'V' = 2 × 1.5 V = 3.0 V
Resistance 'R' = 20.0 Ω

REQUIRED:
Current 'I' = ?

SOLUTION:
By Ohm's law: $V = IR$ or $I = \frac{V}{R}$ putting values: $I = \frac{3.0V}{20\Omega}$

Therefore $I = 0.15A = 150mA$ — ANSWER

Thus, a current of 0.15 A pass through the circuit of torch.

16.6 RESISTANCE

Resistance is defined as **'the opposition to the flow of charges'**. From equation 16.6, resistance can be given by:

$$R = \frac{V}{I} \quad \text{— 16.5}$$

Its unit is volt per ampere called ohm (Ω). The resistance of a wire will be one ohm if a voltage of one volt causes a current of one ampere to flow through the wire.

Usually following multiples are used for a wide range of resistance values.

$$1 \text{ kilo - ohm} = 1 \text{ k}\Omega = 10^3\ \Omega$$

$$1 \text{ mega - ohm} = 1 \text{ M}\Omega = 10^6\ \Omega.$$

Value of resistance is independent of the voltage and current as increase in voltage will increase current and the ratio V/I, will remain constant. Resistance depends upon nature of the material, geometrical properties (length and cross-sectional area) and temperature of the material. There are many types of resistors shown in figure 16.9.

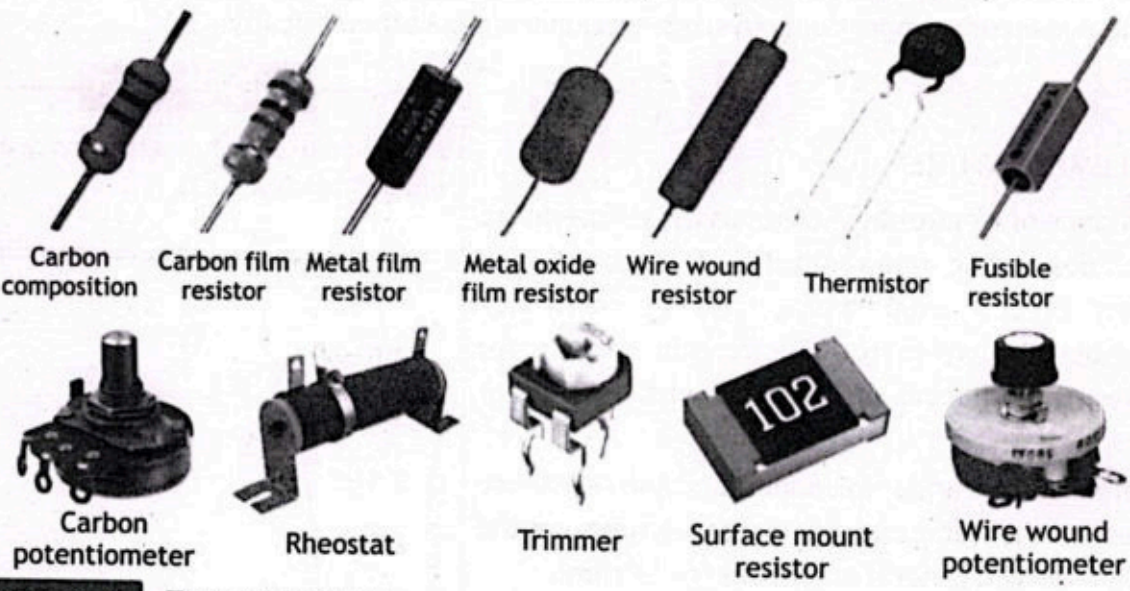


FIGURE 16.9 Types of resistors

Example 16.3

What will be the resistance of a device when connected to a battery of 12 V and it allows a current of 200 mA?

GIVEN:
Potential difference 'V' = 12.0 V
Current 'I' = 200 mA = 200×10^{-3} A

REQUIRED:
Resistance 'R' = ?

SOLUTION:
By definition of resistance: $R = \frac{V}{I}$ putting values: $R = \frac{12.0V}{200 \times 10^{-3} A}$

Therefore $R = 60\,\Omega$ — ANSWER

So, the device connected in the circuit has 60 ohms resistance.

Since the resistance is provided by collisions of the free electrons with the lattice atoms, thus, any factors that affect the number of collisions will also affect a material's resistance.

16.6.1 LENGTH OF WIRE

Greater the length of a conductor (wire), greater will be its resistance i.e., resistance is directly proportional to length. Mathematically:

$$R \propto L \quad \text{—(1)}$$

16.6.2 CROSS-SECTIONAL AREA OF WIRE

Greater the cross-sectional area of a conductor (wire), smaller will be its resistance i.e., resistance is inversely proportional to cross-sectional area. Mathematically:

$$R \propto \frac{1}{A} \quad \text{—(2)}$$

SCIENCE FACT

A dry human body has a resistance of the order of 10 kΩ or 10^4 Ω.

16.6.3 TEMPERATURE

The resistance of a material changes as the temperature changes, depending upon nature of material. For conductor, as the temperature rises its resistance increases because when free electrons in a conductor get heated, the chances of collisions with each other increases.

In case of insulators and semiconductors, the resistance decreases as the temperature increases because the thermal energy will generate more charge carriers.

Therefore, we conclude that as the temperature changes the resistance of material also changes. Mathematically:

$$\Delta R \propto \Delta T \quad \text{—(3)}$$

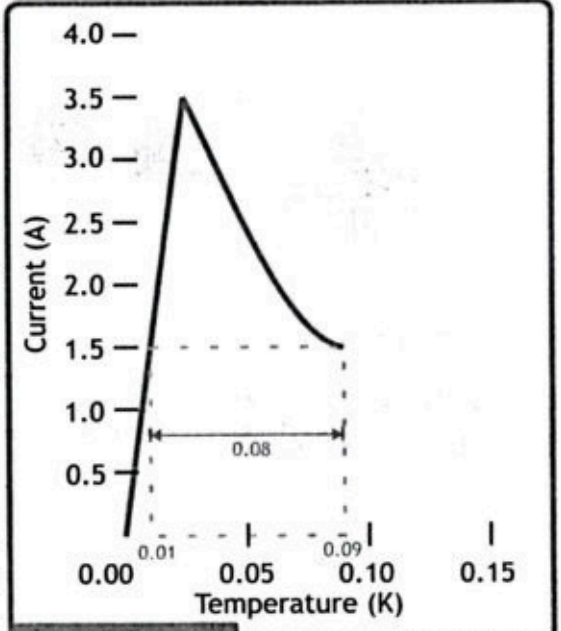


FIGURE 16.10 Resistance of tungsten

The filament of a bulb is made of tungsten, which is a conductor. Initially, the temperature of tungsten is low and so its resistance, so a maximum current passes through it. This will heat up the tungsten and its temperature increases. As the temperature increases, its resistance increases and the current drops as shown in the figure 16.10.

16.6.4 MATERIAL NATURE OF WIRE

The resistance of a body also depends upon the nature of material. Its value changes from material to material. Usually, insulators have greater resistivity while conductors have smaller. Different conductors have different resistivities depending upon their internal structure.

SCIENCE FACT

Conductance is reciprocal of resistance $\left(G = \frac{1}{R}\right)$ and is defined as how easy charge can flow through a material. Its unit is per ohm or mho or Siemens.

Conductivity is reciprocal of resistivity $\left(\sigma = \frac{1}{\rho}\right)$ and is defined as the conductance of unit length and unit area. Its unit is per ohm per meter or mho-m^{-1} or Siemens per meter.

16.7 RESISTIVITY

Specific resistance or resistivity ρ of a material is the resistance offered by a wire of length 1 m having cross-sectional area 1 m^2'.

Keeping the temperature constant, the resistance of conductor is directly proportional to length 'L' and inversely proportional to its cross-sectional area 'A',

mathematically: $R \propto \frac{L}{A}$ or $R = \rho \frac{L}{A}$ — 16.6

Whereas 'ρ' is proportionality constant and is called resistivity of the material. Mathematically:

$$\rho = R\frac{A}{L} \quad \text{— 16.7}$$

The unit of resistivity is ohm-m (Ωm).

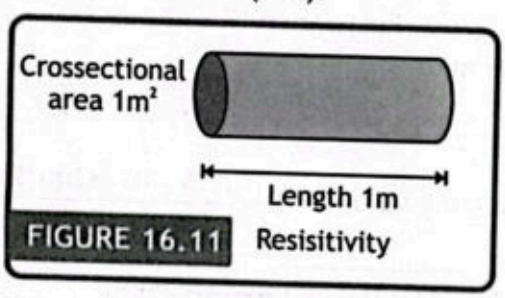


FIGURE 16.11 Resisitivity

Every material has a characteristic resistivity that depends on its nature and on temperature. Good electric conductors have very low resistivities, and good insulators have very high resistivities. If L = 1 m and A = 1 m^2 as shown in figure 16.11, then R = ρ. The resistivity of some materials is given in the table 16.1.

TABLE 16.1 RESISTIVITIES OF SOME MATERIALS AT (20° C)

Material	Resistivity, ρ (Ω.m)
Typical Metals	
Silver	1.59×10^{-8}
Copper	1.72×10^{-8}
Gold	2.24×10^{-8}
Aluminum	2.56×10^{-8}
Tin	11.0×10^{-8}
Tungsten	5.52×10^{-8}
Iron	9.71×10^{-8}
Lead	20.6×10^{-8}
Typical Semiconductors (pure)	
Carbon	3.5×10^{-5}
Germanium	$1 - 500 \times 10^{-3}$
Silicon	0.1 - 60
Typical Insulators	
Glass	$1 - 1000 \times 10^{9}$
Fused quartz	7.5×10^{17}
Rubber	$1 - 100 \times 10^{13}$

UNIT OPENER



The tungsten filament bulb burns out when switched on is because of large amount of current flows through the filament. As tungsten is a conductor, so when it is cold its resistance is low and hence a large amount of current passes through it. When a large current passes through the filament, it gets heated and its temperature increases to a much greater value.



Over time, the filament oxidizes and becomes more and more brittle. So, it cannot withstand such a high temperature and burns out. Since the oxidation occurs gradually and builds up, the light bulb should give out randomly, at any time.

Modern lights use LEDs and so don't fail the same way. They often do things like flicker because the electronic circuit powering them has a fault.

The resistivity of metals and alloys is very small therefore they are very good conductors of electricity. On the other hand resistivity of insulators is very high, that is why they difficultly conduct current. Whereas the resistivity of semiconductor lies between those of conductors and insulators. By doping semiconductors (introducing controlled amounts of impurities), their resistivities can be changed dramatically, which is one reason that semiconductors are used to make computer chips and other electronic devices.

Example 16.4

A 1 m silver wire (resistivity = 1.6×10^{-8} Ωm) has a cross-section area of 0.4 cm². Calculate its resistance.

GIVEN:
Length of silver wire 'L' = 1 m
Cross-section area 'A' = 0.4 cm² = 0.4×10^{-4} m²
Resistivity of silver 'ρ' = 1.6×10^{-8} Ωm

REQUIRED:
Resistance 'R' = ?

SOLUTION:
The relation for resistance is: $R = \frac{\rho L}{A}$ putting values: $R = \frac{(1.6 \times 10^{-8}\,\Omega m)(1m)}{0.4 \times 10^{-4} m^2}$

Therefore $R = 4 \times 10^{-4}\,\Omega = 0.4\,m\Omega$ — **ANSWER**

So, the given silver wire will have a resistance of 0.4 mΩ.

16.7.1 TEMPERATURE DEPENDENCE OF RESISTIVITY

The resistance of every conductor varies with temperature. At higher temperatures, the internal energy of the material increases, causing the positive ions to vibrate with greater amplitudes. This increased vibration leads to more frequent collisions between electrons and ions.

Consequently, the motion of electrons is hindered, reducing the current for a given electric field. This phenomenon explains why the resistivity of metals typically increases with rising temperature.

Consider a conductor having resistivity 'ρ_o' at 0° C and 'ρ_T' at T°C. It is found that for normal temperatures the change in resistivity '$\Delta\rho = \rho_T - \rho_o$' is directly proportional to:

I. initial resistivity ρ_o $\quad \rho_T - \rho_o \propto \rho_o$ —— 1 and

II. rise in temperature T $\quad \rho_T - \rho_o \propto \Delta T$ —— 2

combining proportionalities in 1 and 2, we get:

$$\rho_T - \rho_o \propto \rho_o \Delta T$$

Changing the sign of proportionality into equality, we get:

$$\rho_T - \rho_o = \alpha\, \rho_o \Delta T$$

Where 'α' is the constant of proportionality and is called **temperature coefficient of resistivity.** It value depends only upon the nature of material. Mathematically:

$$\alpha = \frac{\rho_T - \rho_o}{\rho_o \Delta T} \quad \text{—— 16.8}$$

The units of temperature coefficient of resistance or resistivity are $°C^{-1}$ or K^{-1}. For common metals, 'α' typically has a value of 0.003 to 0.005 $°C^{-1}$. That is, an increase in temperature of 1 C° increases the resistance by 0.3% to 0.5%.

TABLE 16.2 TEMPERATURE COEFFICIENTS OF SOME MATERIALS (AT 20° C)

Material	α ($°C^{-1}$)
Typical Metals	
Silver	3.8×10^{-3}
Copper	3.9×10^{-3}
Gold	3.4×10^{-3}
Aluminum	3.9×10^{-3}
Manganin	0.002×10^{-3}
Tungsten	4.5×10^{-3}
Iron	6.5×10^{-3}
Lead	3.9×10^{-3}
Typical Semiconductors (pure)	
Carbon	-0.5×10^{-3}
Germanium	-50×10^{-3}
Silicon	-75×10^{-3}

The resistivity of a metallic conductor nearly always increases with increasing temperature, this relationship is quantified by the temperature coefficient of resistivity, which is positive for metals, as indicated in Table 16.2.

Interestingly, the temperature coefficient of resistivity is negative for semiconducting materials. This means that, unlike metals, the resistivity of semiconductors decreases with increasing temperature. However, the specific mechanisms and processes by which this decrease in resistivity is achieved in semiconductors are complex and beyond the scope of this book.

Understanding these principles is crucial for the practical application and manipulation of metals in electrical and electronic systems.

Example 16.5

At some temperature, the resistivity of a metallic conductor is 5.6×10^{-8} Ω m. If the temperature is increased by 30 K, find the new resistivity. Take temperature coefficient of resistivity as $0.0045\ K^{-1}$.

GIVEN:
Initial resistivity 'ρ_o' = 5.6×10^{-8} Ω.m
Temperature difference 'ΔT' = 30 K
Temperature co-efficient of resistivity 'α' = $0.0045\ K^{-1}$

REQUIRED:
Final resistivity 'ρ_T' = ?

SOLUTION:
The temperature coefficient of resistivity is: $\alpha = \dfrac{\rho_T - \rho_o}{\rho_o \Delta T}$ or $\rho_T = \rho_0(1+\alpha\Delta T)$

putting values, $\rho_T = (5.6\times10^{-8}\ \Omega.m)\{1+(0.0045)(30\,K)\}$

Therefore $\rho_T = 6.3\times10^{-8}\ \Omega.m$ — ANSWER

So, the resistivity of the metallic conductor will become 6.3×10^{-8} Ω.m when the temperature is raised by 30 K.

16.8 ELECTRICAL MEASURING INSTRUMENTS

Devices used for measuring different electrical aspects such as current, voltage, resistance, power etc. are called Electrical measuring instruments.

16.8.1 AMMETER

Ammeter is a device used to measure current. To measure the current, an ammeter must be connected in a circuit in series as it finds current flowing through a component of the circuit. Figure 16.12 shows an analogue and digital ammeter along with circuit diagram. Since the ammeter must be able to make measurements by disturbing the current in the circuit as little as possible, ammeters are designed to have as low a resistance as possible (because they are



FIGURE 16.12 Analogue and digital ammeter along with circuit connection.

connected in series), usually of the order of 1 Ω, so they do not have an appreciable effect on the currents they measure.

Range of ammeter: Generally ammeters of different ranges are used based on the amount of current in the circuit. When you are measuring current in your home appliances, usually an ammeter with ampere values ranging from 1 A to 100 A is used. For small currents we use milli-ammeter (mA) or micro-ammeter (μA) as shown in figure 16.13.

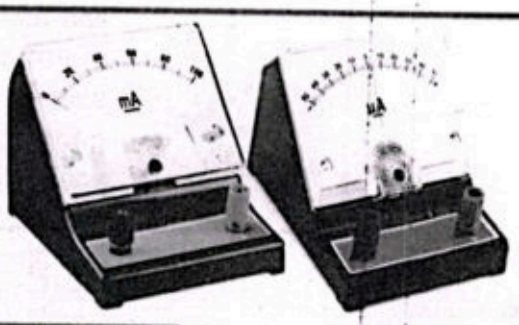
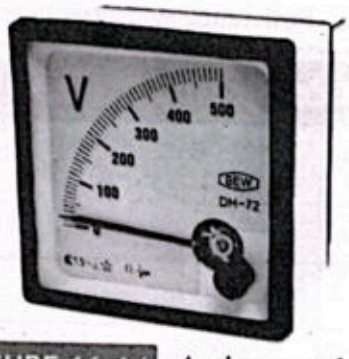
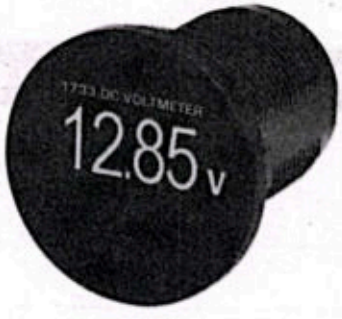


FIGURE 16.13 Range of ammeter

16.8.2 VOLTMETER

Voltmeter is a device used to measure potential difference. To measure the potential difference, voltmeter must be connected in parallel with the component across which the potential difference is to be measured. Figure 16.14 shows a voltmeter placed in the circuit to measure the potential drop across resistor R. Since the voltmeter must be able to make measurements while





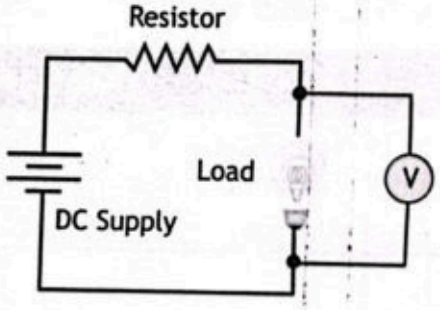


FIGURE 16.14 Analogue and digital voltmeter along with circuit connection.

disturbing the circuit as little as possible voltmeters are designed to have as high resistance as possible, usually of the order of 10 MΩ (10^7Ω), so they have a negligible effect on the potential differences they are measuring.

Range of voltmeter: Like ammeters, voltmeters also have different ranges based on its use. For home voltage measurement voltmeter with volt values ranging from 1 V to 500 V is used. Milli-voltmeter (mV) is used for small voltage measurements as shown in figure 16.15.

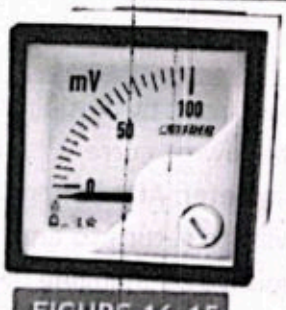


FIGURE 16.15 Millivoltmeter

POINT TO PONDER



It is said that voltmeter and ammeter are the modified forms of another device called galvanometer. Can you explain how?



16.9 EXPERIMENT FOR DETERMINATION OF RESISTANCE

The experimental setup for finding an unknown resistance is shown in figure 16.16. The unknown resistance is connected in series with the ammeter while the voltmeter is connected in parallel with the unknown resistance. A variable resistance called rheostat is also connected in series with the unknown resistance and ammeter. Ensure the indicators on both the voltmeter and the ammeter align with the zero mark on their scales.

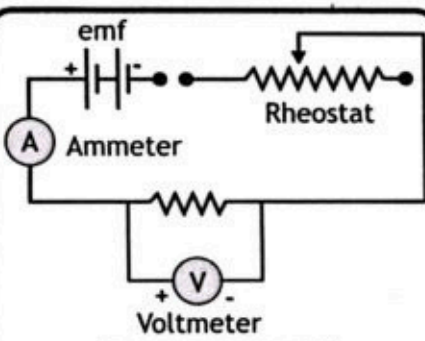


FIGURE 16.16
Resistance Measurement

Record the full scale and smallest division value (least count) for both the voltmeter and the ammeter provided. Engage the circuit by closing the switch (key K) and adjust the rheostat towards the position that yields the lowest current flow. Observe and make a note of the readings from both the voltmeter and ammeter. After disconnecting the circuit by opening the switch (removing the key K), allow the wire to return to ambient temperature. Then, initiate the circuit again and gradually raise the voltage by changing the position of the rheostat.

TABLE 16.3 RESISTANCE CALCULATION

Sr. No.	Ammeter reading (A)	Voltmeter reading (V)	Resistance $R = \frac{V}{I}$
1.			
2.			
3.			
4.			

Record the readings of the ammeter and voltmeter. Put values of current and voltage in the relation V/I for calculation of resistance given in table 16.3. Continue with this procedure, adjusting the rheostat incrementally to achieve four distinct voltage levels.

SUMMARY

- **Electric Current** is the rate of flow of charges
- **Ampere** is the unit of electric current and is defined as one coulomb charge per second.
- **Conventional Current** is the direction of flow of positive charges per unit time.
- **DC** is the type of electric current that is unidirectional and does not change its direction.
- **AC** is the type of electric current which changes its direction continuously.
- **Potential Difference** is the amount of work done in moving a unit positive charge from one point to another inside an electric field.
- **emf Source** is any device that converts non-electrical energy into electrical energy.
- **Ohm's Law states** that the amount of electric current in a circuit depends upon the potential difference while keeping temperature constant.
- **Resistance** is the opposition to the flow of charges or opposition to electric current.
- **Resistivity** is the resistance of unit length and unit area.
- **Temperature Coefficient of Resistance** is a measure of how a material's resistance changes with temperature.
- **Ammeter** is a device used to measure electric current through any device.
- **Voltmeter** is a device used to measure potential difference across any device.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. Ampere-hour (Ah) is the unit of:

   A. electric current B. charge C. energy D. resistance

2. Which of the following is a non-ohmic device?

   A. Copper wire B. Carbon resistor C. Diode D. all of these

4. Electric current is measured using:

   A. ammeter B. voltmeter C. ohmmeter D. meter rod

5. Voltmeter measures

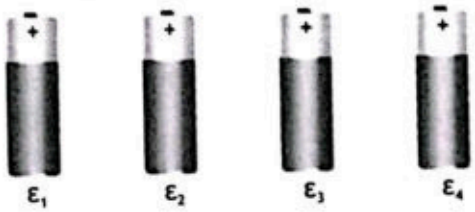
   A. Potential difference B. electric current C. resistance D. resistivity

6. If 3 A of current flows for 2 minutes, the amount of charge crosses the cross-section of a conductor will be:
   A. 3 C B. 6 C C. 60 C D. 360 C
7. A current of 1 mA is passing through a wire. Number of electrons passing through a point in the wire in 10 seconds is:
   A. 6.25×10^{19} B. 6.25×10^{18} C. 6.25×10^{17} D. 6.25×10^{16}
8. Resistance of a material always decreases when:
   A. its temperature increases B. its temperature decreases
   C. Number of free electrons increases D. Number of free electrons decreases
9. The resistance of a metallic conductor varies inversely as:
   A. area of cross section B. length C. temperature D. all of these
10. Directions of actual current and conventional current are:
    A. same B. opposite to each other
    C. perpendicular to each other D. none of these
11. As temperature of a semiconductor increases, its resistance:
    A. increases B. decreases C. remains constant D. becomes zero
12. The SI unit of temperature coefficient of resistance (α) is:
    A. K B. K^{-1} C. ΩK D. Ω / K
13. By increasing temperature, the resistivity of semiconductors:
    A. increases B. decreases
    C. remains constant D. first increases then decreases

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Draw connections so that the emf sources given in figure become in series and parallel.



2. Compare and contrast the roles of ammeters and voltmeters in electrical circuits. Include a discussion on how each instrument measures different electrical properties.

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Why is copper preferred over silver for household wiring, considering cost, conductivity, and durability?
2. Why free electrons in metals don't create a current without a potential difference?
3. How conventional and actual current directions affect circuit behaviour, and why conventional current is important in diagrams and calculations.
4. Compare emf and potential difference, and why this distinction matters in circuit analysis.
5. How is a current-carrying wire electrically neutral?
6. Would the lights still work if a car battery's positive and negative terminals were interchanged?
7. Evaluate the limits of Ohm's law for different materials, especially under extreme conditions.
8. How does a wire's shape affect its resistance, whether bending changes it?
9. The temperature coefficient of copper is 0.004 $^{\circ}C^{-1}$. How does this affect copper's performance in electrical systems under varying temperatures?
10. How would you define fluid resistance for a water-carrying pipe?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Explain electric current and its unit (ampere) by exploring charge flow. Discuss the difference between conventional and actual current and when this distinction matters.
2. Analyse electrical conduction in metals and how external factors like temperature and magnetic fields affect electron movement and conduction efficiency.
3. Compare DC and AC in terms of their behaviour in circuit elements. Discuss the pros and cons of each in applications like power transmission and electronics.
4. Examine electromotive force (emf) and its role in maintaining current.
5. Distinguish between emf and potential difference, using real-world examples like batteries.
6. Critically analyse Ohm's law and its limitations for non-ohmic devices. Discuss the importance of I-V graphs and propose experiments to explore non-linear materials.
7. Investigate the relationship between resistance and resistivity and design an experiment to measure resistance. Discuss factors affecting accuracy, such as temperature.

8. Analyse how factors like temperature, material, length, and area affect resistance. Discuss practical applications, such as wiring or heating elements, and ways to optimize resistance.
9. How does temperature influence the resistance of materials, and what implications does this have for electrical components in different environments?
10. Examine the placement of ammeters and voltmeters in circuits and how misconnection affects measurement. Propose strategies to avoid errors.

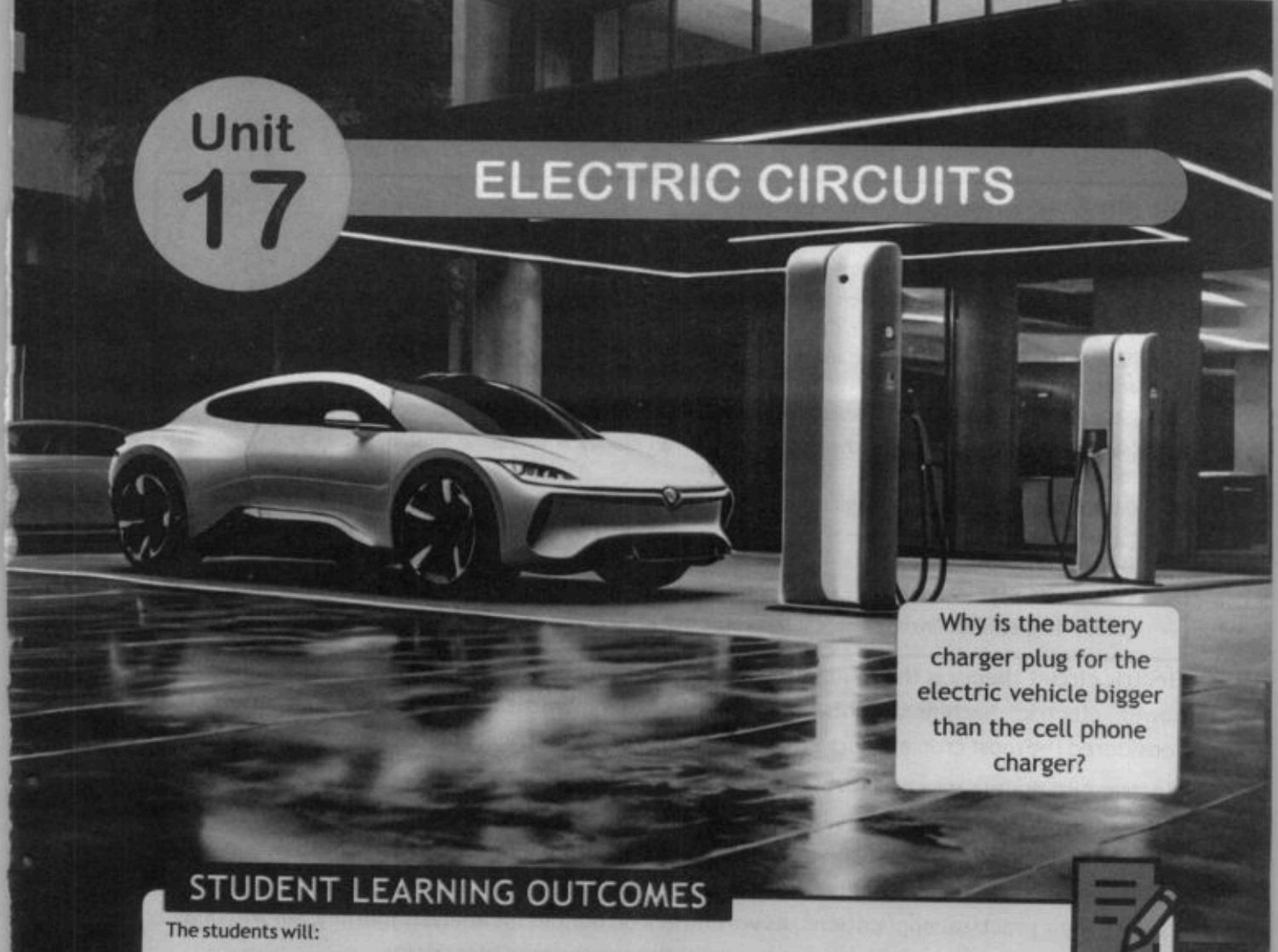
NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. How much time will it take to charge a 200 Ah battery when it is connected to a current of 25 A? (Answer: 8 hr)
2. A 12.0 V emf source is connected to a purely resistive electrical appliance (a light bulb). An electric current of 2.0 A flows through it. Consider the conducting wires to be resistance-free, calculate the resistance offered by the electrical appliance. (Answer: 6 Ω)
3. The potential difference across the two ends of the component decreases to one fourth of its initial value while its resistance remains constant. What change will occur in the current through it? (Answer: 1/4)
4. What voltage is necessary to pass a current of 50 amperes through a resistance of 100 Ω? (Answer: 5,000 V)
5. The current passing through a resistor in a circuit is 0.5 A when the voltage across it is 6.0 V. What current will pass through the same resistor when the voltage across it is 9.0 V? (Answer: 0.75 A)
6. The length and area of wire are given as 2 m and 0.4 mm^2 respectively. The resistance of that wire is 0.085 Ω, calculate the resistivity? (**Ans.** 1.7×10^{-8} Ωm)
7. Resistivity of a given copper wire of length 2 m is 1.7×10^{-8} Ω m. (a) If the wire is stretched to double of its length, what will be the new resistivity? (b) If its temperature is increased by 20 K, find the new resistivity. (Take $\alpha = 3.9 \times 10^{-3} K^{-1}$) (**Ans.** (a) 1.7×10^{-8} Ω m (b) 1.83×10^{-8} Ω m)
8. At some temperature T_o, the resistivity of a metallic conductor is 1.7×10^{-8} Ω.m. If the temperature is increased by 50 K, find the new resistivity by taking temperature coefficient of resistivity as 0.004. (**Ans.** 2.04×10^{-8} Ω m)

Unit 17

ELECTRIC CIRCUITS



Why is the battery charger plug for the electric vehicle bigger than the cell phone charger?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-30] Calculate the total e.m.f. where several sources are arranged in series.
- ✓ [SLO: P-10-E-31] State that the e.m.f of identical sources connected in parallel is equal to the e.m.f. of one of the sources.
- ✓ [SLO: P-10-E-37] Draw circuit diagrams.
- ✓ [SLO: P-10-E-38] Use common rules regarding current and voltage distribution in circuits to solve problems.
- ✓ [SLO: P-10-E-39] Calculate the combined resistance of two or more resistors in series.
- ✓ [SLO: P-10-E-40] Calculate the combined resistance of two resistors in parallel.
- ✓ [SLO: P-10-E-41] Calculate current, voltage and resistance in parts of a circuit or in the whole circuit.
- ✓ [SLO: P-10-E-42] Describe the action of negative temperature coefficient (NTC) thermistors and light-dependent resistors.
- ✓ [SLO: P-10-E-43] Analyze the function of variable potential dividers in circuits.
- ✓ [SLO: P-10-E-44] Justify and illustrate the use of color codes for resistors.
- ✓ [SLO: P-10-E-48] State common uses of electricity.
- ✓ [SLO: P-10-E-49] Justify the advantages of connecting lamps in parallel in a lighting circuit.
- ✓ [SLO: P-10-E-50] Use the equation, power = current × voltage $P = IV$ to solve simple problems.
- ✓ [SLO: P-10-E-51] Use the equation energy = current × voltage × time $E = IVt$ to solve simple problems.

- ✓ [SLO: P-10-E-52] Define the kilowatt-hour (kWh).
- ✓ [SLO: P-10-E-53] Explain the need to choose components with suitable power ratings.
- ✓ [SLO: P-10-E-54] Calculate the cost of using electrical appliances where energy unit is kWh.
- ✓ [SLO: P-10-E-55] State common electric hazards that may be caused from malpractice and lack of maintenance.
- ✓ [SLO: P-10-E-56] Explain the use and operation of trip switches and fuses and choose appropriate fuse ratings and trip switch settings.
- ✓ [SLO: P-10-E-57] Explain what happens when a live wire touches a metal case that is earthed.
- ✓ [SLO: P-10-E-58] Explain why the outer casing of an electrical appliance must be either non-conducting (double-insulated) or earthed.
- ✓ [SLO: P-10-E-59] state that a mains circuit consists of a live wire (line wire), a neutral wire and an earth wire.
- ✓ [SLO: P-10-E-60] Explain why fuses and circuit breakers are connected into the live wire for the circuit to be switched off safely.
- ✓ [SLO: P-10-E-61] Explain why domestic supplies are connected in parallel.
- ✓ [SLO: P-10-E-62] Explain the damage that electric shock could do to a human being.

Electric circuit theory is the foundation for various branches of electrical engineering, including power, electric machines, control, electronics, communications, and instrumentation. It is considered the most crucial course for students studying electrical engineering.

Electric circuits play a crucial role in various devices such as radios, TVs, cell phones, power distribution systems, computers, and even the nervous systems of animals. There are different types of electric circuits that serve specific purposes, from illuminating a room to powering the high-speed trains. In this chapter, we delve into the fascinating world of electric circuits and explore their practical applications. As we embark on our circuit analysis journey, we will heavily rely on the power of circuit diagrams to unravel the mysteries of electricity.

17.1 CIRCUIT ELEMENTS AND DIAGRAMS

An electric circuit is an interconnection of electrical elements. Electric circuits are formed by connecting electrical components (elements) in a specific way.

A basic circuit, like the one shown in figure 17.1, typically includes conductors (often wires), a power source (like a battery), a Load (for instance a lamp), and a switch to turn the circuit on and off. This type of circuit can be used independently for various purposes like a torch light or a search light etc. The key thing to remember is that a circuit creates a closed loop, starting and ending at the same point.

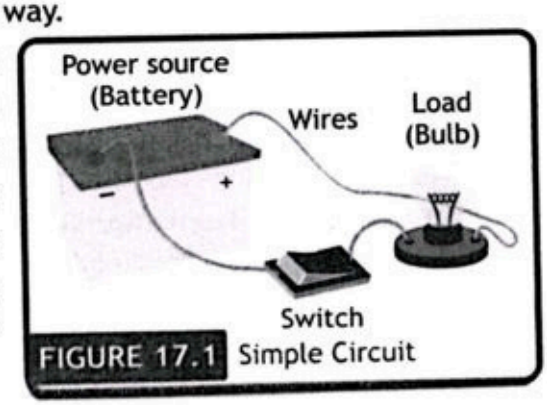


FIGURE 17.1 Simple Circuit

While bare copper wire can be used as a conductor for demonstration purposes, insulated wires are generally used for safety reasons.

Electric circuits consist of two types of elements: active elements and passive elements. Active elements can supply or generate energy (e.g., batteries, generators), while passive elements cannot generate energy; instead, they absorb, store, or dissipate energy (e.g., resistors, capacitors, inductors).

A circuit diagram is a simplified map showing how various components are interconnected and helps in understanding the flow of current. In a physical circuit, as shown in figure 17.2(a), components are connected with electrical wires, which are represented as straight lines in a circuit diagram, as shown in figure 17.2(b). Using symbols in a circuit diagram helps to recognize electric components and the flow of electricity. Such diagrams provide a fundamental understanding of electrical systems and the relationships between voltage, current, and resistance.

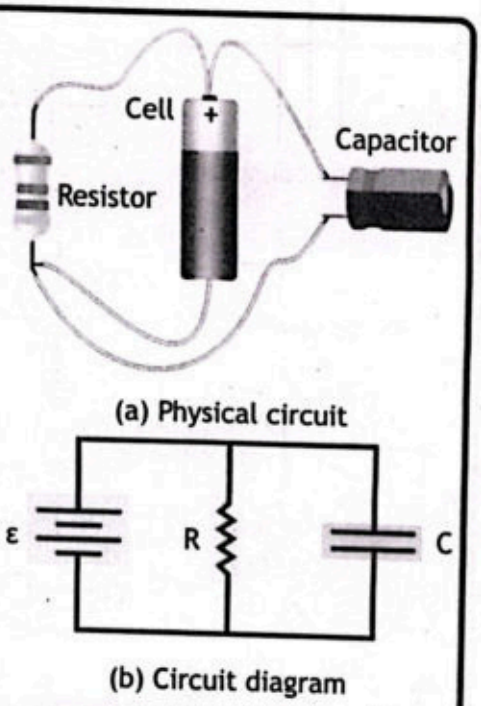


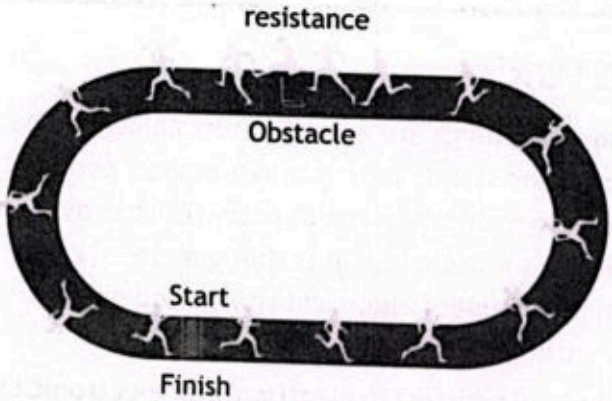
FIGURE 17.2 Circuits Through Diagrams

Figure 17.3 shows the symbols used to represent different electric and electronic components that are used in a circuit diagram.

SCIENCE TIDBITS



Electricity loves to travel in closed loops called circuits! Imagine it like a race track for electrons—these tiny particles zoom around the circuit but must start and end at the same point. If there's a break in the track (an open circuit), the electrons come to a halt, and nothing happens. But if the path is complete, they speed along, powering lights, gadgets, and so much more!



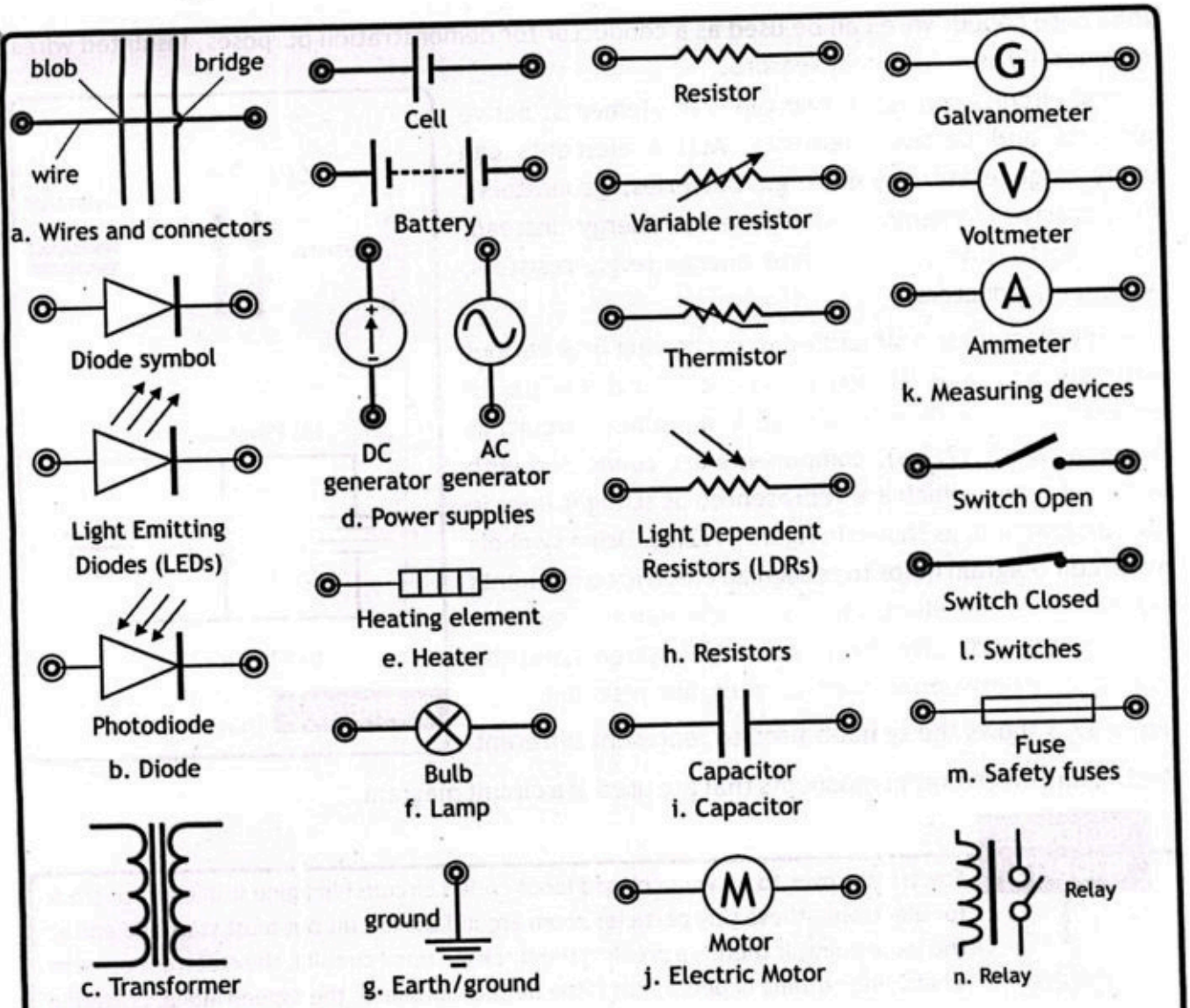


FIGURE 17.3 Circuit symbols for various devices

17.2 RESISTORS

Tiny components in electronics are essential for managing the flow of electricity. Among these components, the resistor stands out as a key player, controlling the current in a circuit. The component of an electric circuit whose function is to provide a specified value of resistance is called a resistor. Unlike some components that generate power, resistors are considered passive. They consume a small amount of electrical energy and dissipate it as heat, thereby regulating the overall power flow within the circuit.

The most commonly used resistors in electrical and electronic circuits are carbon resistors. Since

a carbon resistor is quite small, it is more convenient to use colour code indicating the resistance value than to imprint the numerical value on the case. Carbon resistors consists of a ceramic core, on which a thin layer of crystalline carbon is deposited as shown in figure 17.4.

Table 17.1 RESISTOR COLOUR CODES

Color	Number	Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Gree	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Silver		10^{-1}	± 05 %
Gold		10^{-2}	± 10 %
Colourless			± 20 %

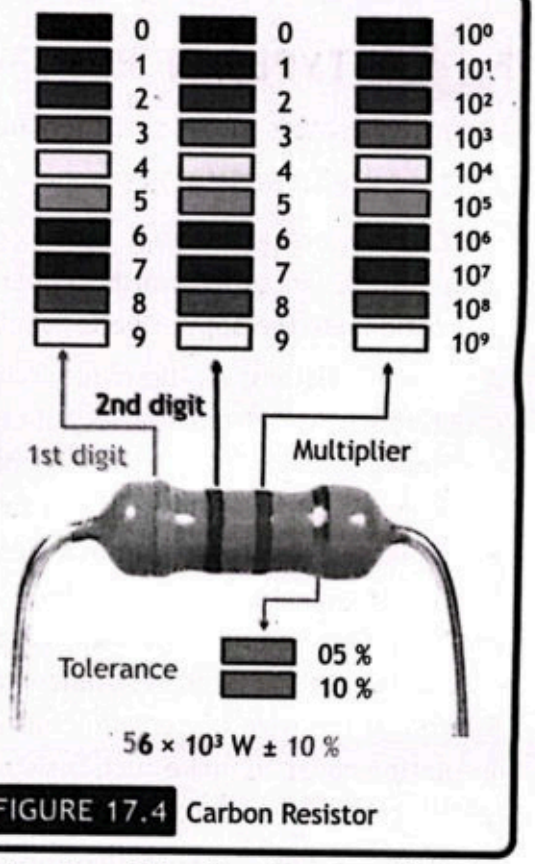


FIGURE 17.4 Carbon Resistor

These resistors are cost-effective, reliable, and small in size. Color bands are utilized to represent the resistance value based on the guidelines provided in Table 17.1. Usually three color bands are employed to signify the resistance values: the first two bands represent the significant figures of resistances, the third band indicates the decimal multiplier following them. The fourth band, either silver or gold, indicates the tolerance of the resistor. It must be noted that if there is

SCIENCE TIDBITS



While reading the colour code, hold the resistor with colour bands to your left. Resistors never start with a metallic band on the left. In order to remember the colour code, the following mantra may be helpful.



BB ROY GBVGW

no fourth band, the tolerance is 20 %.

For the resistor shown in Figure 17.5, the first digit is 5 (for green), the second digit is 6 (for blue), decimal multiplier is 3 (for orange) written as 10^3 and tolerance = 5% (gold). The value of resistance is 56×10^3 or 56 kΩ with the tolerance value 5 % collectively written as $56 \times 10^3 \pm 5$ %.

17.3 TYPES OF RESISTORS

Normally resistors can be classified into two types namely linear resistor and non-linear resistor.

17.3.1 LINEAR RESISTORS

Linear resistors are resistors whose values change as a function of applied voltage and temperature. In other words, linear resistors are resistors whose current value is precisely proportional to the applied voltage (obey Ohm's Law). There are two types of linear resistors.

A. Fixed Resistors: As the name indicates fixed resistors have a single resistance value. Fixed resistors are made from a variety of resistor materials. The most common material used to make a resistor is carbon. A fixed resistor may be readily attached to the circuit and can handle high voltages. However, they are, less stable, which means their temperature coefficient is quite high.

B. Variable Resistors: Variable resistors have the general characteristic of allowing the resistance value to be adjusted. Usually a mechanical movement is used to modify the resistance. High stability and high accuracy resistors are always wire wound. As the resistance of wire of certain length has fixed resistance and increasing the length of the wire, increases resistance. Therefore the wire of certain length of known resistance is wound around and enclosed in an insulating cover to make such resistors. These resistors can also be made variable by putting a sliding contact, which can vary the length of the wire and thus resistance as shown in figure 17.5.

Generally nickel and chromium are used as wire material because of their low temperature coefficient of resistance. They are called rheostats when they are used as a variable resistance to regulate the current in a circuit. They are termed as potentiometers when they are used as a variable voltage divider. A potential divider is a circuit that divides a voltage into two or more smaller voltages. Using potential divider, we can obtain a variable potential difference from a fixed voltage applied. **'A circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}) is called potential divider'.** It is a simple and fundamental circuit in electronics used to generate a voltage that is a fraction of its input voltage.



FIGURE 17.5 *Variable resistors (Rheostat and potentiometer)*

When a fixed voltage 'V' is applied across the ends of a wire wound variable resistor, and 'R' is the total resistance of wire AB, as shown in figure 17.6, then by Ohm's Law, the current 'I' is:

$$I = \frac{V}{R} \quad \text{—(1)}$$

Since slider contact 'C' can slide over resistance 'R'. If 'R_2' is the resistance of the portion of wire between the contact 'B' and 'C', then the potential difference 'V_2' is given as:

$$V_2 = IR_2 \quad \text{—(2)}$$

similarly, $V_1 = IR_1$ —(3)

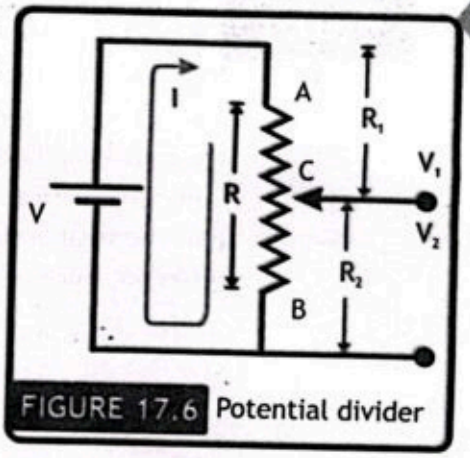


FIGURE 17.6 Potential divider

Dividing equation 3 by equation 2, we get:

$$\frac{V_1}{V_2} = \frac{R_1}{R_2} \quad \text{—17.1}$$

putting equation 1 in equation 2, we get:

$$V_2 = \frac{R_2}{R} V \quad \text{—17.2}$$

Thus, the potential difference 'V_2' is some fraction of the total potential applied depending upon the position of the sliding contact. By moving sliding contact the potential difference can be varied from zero to 'V'.

Since 'V_2' is the output voltage 'V_{out}' and V is the input voltage 'V_{in}' and resistance $R = R_1 + R_2$, therefore equation '17.2' can also be written as:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

As a special case if $R_1 = R_2 = r$, then:

$$V_{out} = \frac{r}{r + r} V_{in} \quad \text{or} \quad V_{out} = \frac{r}{2r} V_{in}$$

$$\text{Therefore,} \quad V_{out} = \frac{1}{2} V_{in}$$

This means that the input voltage is split into two equal halves at the output.

Potential dividers are commonly used in electronics to adjust the level of a voltage signal or to measure voltage accurately. It is used in the volume control knob of music systems. Sensory circuits using light-dependent resistors and thermistors also use potential dividers.

17.3.2 NON-LINEAR RESISTORS

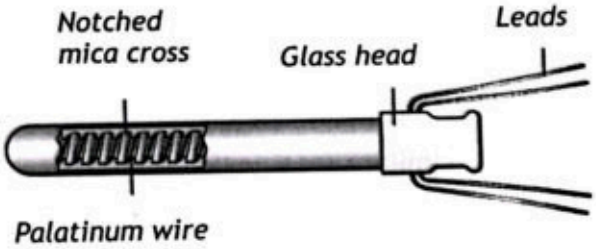
In non-linear resistors the resistance value fluctuates in response to temperature, light, or voltage. Theses resistors are further divided as thermistors, varistors and photo resistors.

A. Thermistor: *A thermistor is a type of resistor whose resistance varies significantly with temperature.*

SCIENCE TIDBITS

Resistance thermometers, also called Resistance Temperature Detectors (RTDs), are sensors used to measure temperature by correlating the resistance of the RTD ele ..nt with temperature. Most RTD elements consist of a length of fine coiled wire, wrapped around a ceramic or glass core. The RTD element is made from a pure material such as Platinum, Nickel, Copper that has a predictable change in resistance as the temperature changes; it is this predictable change that is used to determine temperature.





Platinum is the best metal for RTDs because it follows a very linear resistance-temperature relationship and it follows the R vs T relationship in a highly repeatable manner over a wide temperature range. The unique properties of platinum make it the material of choice for temperature standards with the range from - 185 °C to 630 °C.

Thermistor (figure 17.7) is short for thermal-resistor, device which have heat sensitive resistance, thus the temperature coefficient of thermistor is very high. The material used in a thermistor is generally a semiconductor ceramic or polymer.

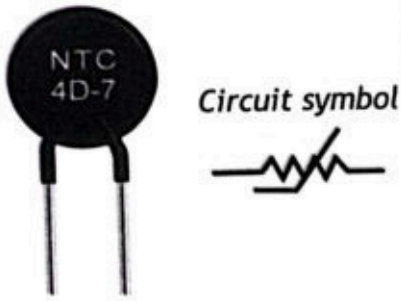


FIGURE 17.7
Thermistor and its circuit symbol

Thermistors are of two types;

- **Positive Temperature Coefficient (PTC)** thermistors increases its resistance with the increase of temperature and
- **Negative Temperature Coefficient (NTC)** thermistors decreases its resistance with the increase of temperature.

Thermistors of different sizes and shapes are formed according to the need of the industry. Their sensitivity to change in temperature enables them to perform many functions as given below.

a. Inrush current limiter: An inrush current limiter or input surge current, is the peak current drawn by an electrical device when powered on. For example, incandescent bulbs have high inrush currents until their filaments heat up. NTC thermistors can limit inrush current in power supply circuits by initially exhibiting high resistance, which restricts large currents during startup.

b. Over heating Alarm: NTC thermistors can trigger alarms when the temperature of motor, transformer, or generator windings rises. They maintain high resistance at lower temperatures, allowing minimal current flow. As temperature increases, resistance drops,

allowing more current to flow to an alarm system. This principle is also applicable in fire alarms and thermostats.

c. Temperature Measurement: Thermistors provide precise temperature measurements due to their high temperature coefficient. Their resistance changes with temperature, enabling effective detection and response to temperature variations.

B. Varisters (VDR): Varisters (figure 17.8) are voltage dependent Resistors (VDR) which are used to eliminate the high voltage transients. They are type of variable resistors used to protect circuits from destructive voltage spikes.

When voltage increases (due to lighting or line faults) across a connected sensitive device or system, then it reduces the level of voltage to a secure level i.e. it changes the level of voltages. Varistors are typically made from metal oxide materials, with zinc oxide (ZnO) being the most common. They consist of a ceramic body composed of zinc oxide grains, which are interspersed with other metal oxides such as bismuth, cobalt, and manganese. The grain boundaries act as the non-linear junctions that give the varistor its voltage-dependent characteristics.

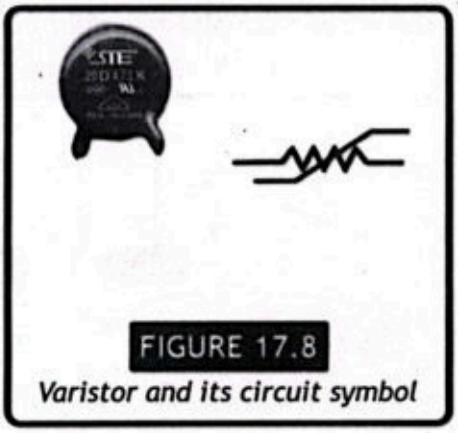


FIGURE 17.8
Varistor and its circuit symbol

C. Light Dependent Resistor (LDR): Light Dependent Resistor (LDR), also known as Photo Resistor or photocell, is a light-sensitive device that changes resistance based on the intensity of light as shown in figure 17.9. In low light conditions, LDRs have high resistance, which decreases as light intensity increases.

They are commonly used in light-sensing applications, with materials like cadmium sulfide and lead sulfide used to make them. The surface of the LDR is designed to be exposed to light, with a serpentine pattern to increase light exposure. LDRs sense light levels and adjust resistance accordingly, making them useful in various applications like automatic lighting control, photography, and security systems.

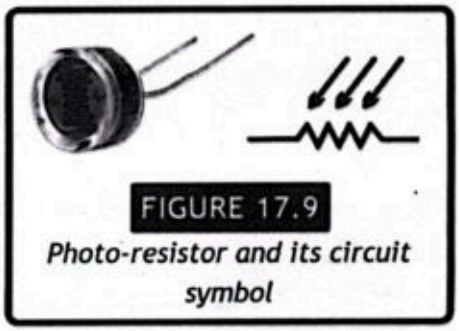


FIGURE 17.9
Photo-resistor and its circuit symbol

Light Dependent Resistors (LDRs) are versatile and cost-effective components used to detect and respond to changes in light levels. Their simplicity and wide range of applications make them valuable in many fields.

17.4 COMBINATION OF RESISTORS

For any combination of resistors that obey Ohm's law, we can always find a single resistor that could replace the combination and result in the same total current and potential difference. The resistance of this single resistor is called the equivalent resistance of the combination. For series

and parallel combinations, we can derive general equations for the equivalent resistance.

17.4.1 RESISTORS IN SERIES

In a series circuit, there is only one path for the charges to follow, so the same current flows in each device. In such a circuit, the voltage is divided among the devices: the voltage on the first device plus the voltage on the second device, and so on, equals the voltage of the power supply. For example, if three lightbulbs with the same resistance are connected in series to a 12-volt battery, the voltage on each bulb is 4 volts. If the bulbs had different resistances, each one's "share" of the voltage would be proportional to its resistance. If the resistors are in series, as shown in figure 17.10, the current I must be the same in all of them.

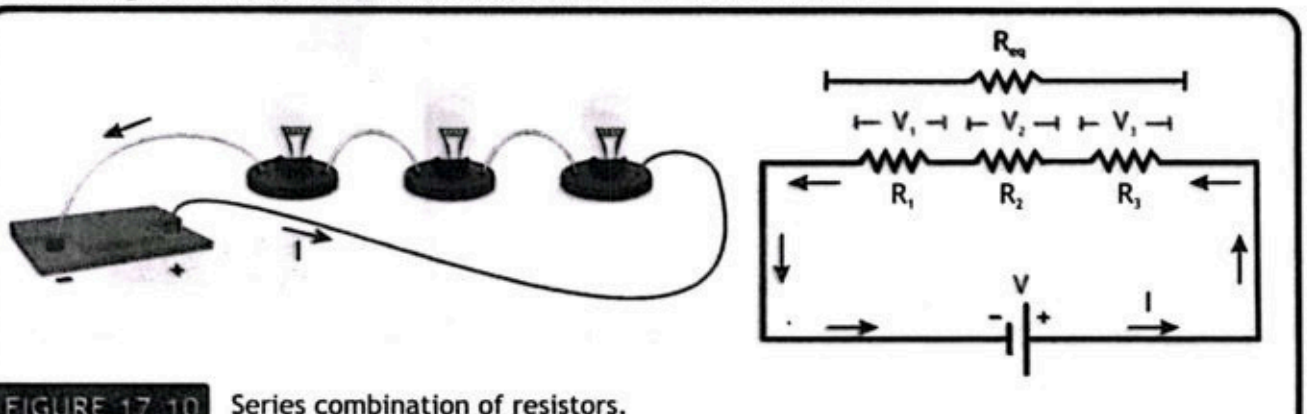


FIGURE 17.10 Series combination of resistors.

If '*V*' is the combined potential difference, by applying Ohm's law *(V = IR)* to each resistor, we have:

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

The potential difference V is the sum of individual potential difference across each resistor, Hence:

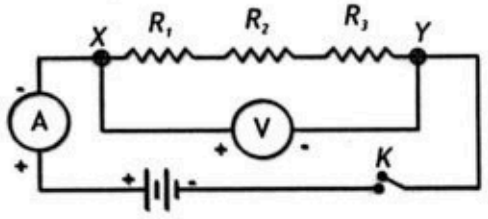
$$V = I(R_1 + R_2 + R_3) \qquad \text{or} \qquad \frac{V}{I} = R_1 + R_2 + R_3$$

Since the equivalent resistance 'R_{eq}', is given as: $R_{eq} = \frac{V}{I}$

MINI LAB



Join three resistors of different values in series. Connect them with a battery, an ammeter and a plug key, as shown in Fig. 11.6. You may use the resistors of values like 1 Ω, 2 Ω, 3 Ω etc., and a battery of 6 V for performing this activity. Plug the key. Note the ammeter reading.



Change the position of ammeter to anywhere in between the resistors. Note the ammeter reading each time. Do you find any change in the value of current through the ammeter?

Comparing equation 1 and equation 2, we get: $R_{eq} = R_1 + R_2 + R_3$ — 17.3

Hence, the equivalent resistance of any number of resistors (n) in series combination equals the sum of their individual resistances.

$$R_{eq} = R_1 + R_2 + R_3 + R_4 + \cdots\cdots + R_n \quad \text{— 17.4}$$

The equivalent resistance is always greater than any individual resistance.

Example 17.1

Three resistors $R_1 = 10\,\Omega$, $R_2 = 20\,\Omega$ and $R_3 = 30\,\Omega$ are connected in series across a 20 V battery. Find equivalent resistance and voltage drop across each resistor.

GIVEN:
Potential difference 'V' = 20 V
Resistance 'R_1' = 10 Ω
Resistance 'R_2' = 20 Ω
Resistance 'R_3' = 30 Ω

REQUIRED:
Equivalent resistance 'R_{eq}' = ?
Voltage drop 'V_1' = ?
Voltage drop 'V_2' = ?
Voltage drop 'V_3' = ?

SOLUTION:
For series combination the equivalent resistance is given by: $R_{eq} = R_1 + R_2 + R_3$

putting values $R_{eq} = 10\,\Omega + 20\,\Omega + 30\,\Omega$ Therefore $R_{eq} = 60\ \Omega$ — ANSWER

For series combination of resistors, current remains same through all resistors, given by:

$$I_1 = I_2 = I_3 = \frac{V}{R_{eq}} \qquad \text{putting values, } I = \frac{20.0V}{60\,\Omega}$$

Therefore $I = 0.333A$

In series combination of resistors, the voltage drop splits among resistors.

Voltage drop across 'R_1' is given by: $V_1 = IR_1$ putting values, $V_1 = 0.333\,A \times 10\,\Omega$

Therefore $V_1 = 3.33V$ — ANSWER

Voltage drop across 'R_2' is given by: $V_2 = IR_2$ putting values, $V_2 = 0.333\,A \times 20\,\Omega$

Therefore $V_2 = 6.67V$ — ANSWER

Voltage drop across 'R_3' is given by: $V_3 = IR_3$ putting values, $V_3 = 0.333\,A \times 30\,\Omega$

Therefore $V_3 = 9.99V$ — ANSWER

it is worth noting that $V_1 + V_2 + V_3 = 3.33 + 6.67 + 9.99 = 20$ V = V, that is voltage of the battery attached.

17.4.2 RESISTORS IN PARALLEL

In a parallel circuit, the current through the power supply is "shared" among the devices while each has the same voltage. The current flowing in the first device plus the current in the second device, and so on, equals the current output by the power supply. There is more than one path for the charges to follow, in this case, three. If one of the devices burns out or is removed, the others still function. The light-bulbs in multiple-bulb light fixtures are in parallel so that if one bulb

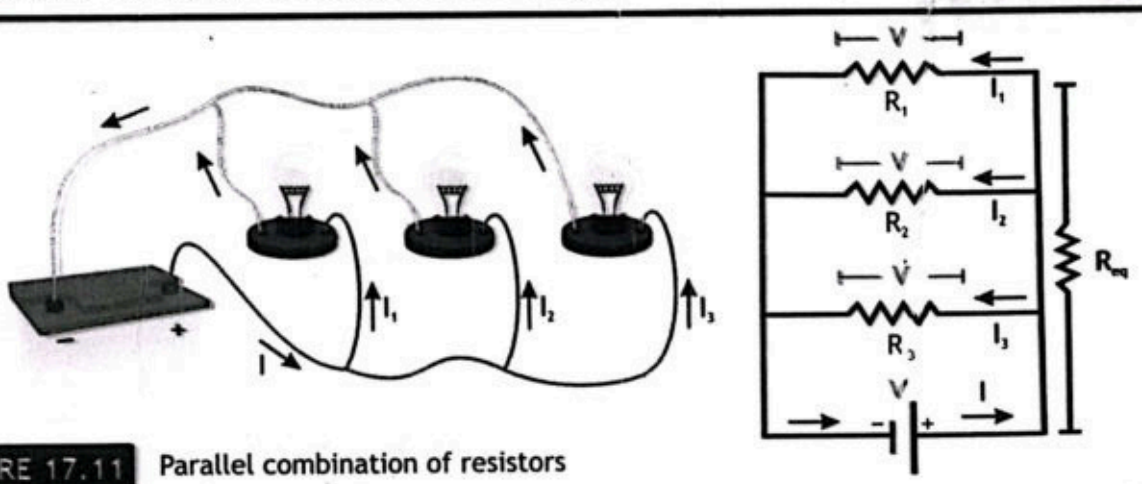


FIGURE 17.11 Parallel combination of resistors

burns out, the others remain lit. For resistors in parallel, as shown in figure 17.11, the potential difference between the terminals of each resistor must be the same and equal to V.

Let's call the currents in the three resistors 'I_1', 'I_2' and 'I_3', then By Ohm's law, we have:

$$I_1 = \frac{V}{R_1}, \qquad I_2 = \frac{V}{R_2} \qquad \text{and} \qquad I_3 = \frac{V}{R_3}$$

Charge is neither accumulating at, nor draining out, thus, the total current 'I' must equal the sum of the three currents in the resistors:

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \qquad \text{or} \qquad \frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

But by definition, the equivalent resistance, is: $\frac{I}{V} = \frac{1}{R_{eq}}$

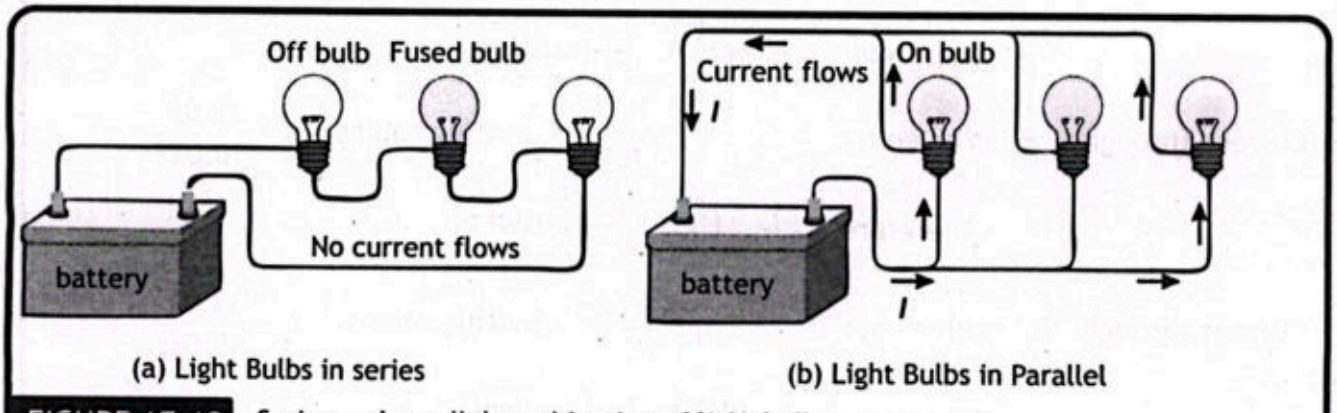
Therefore $$\frac{I}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (17.5)$$

For any number of resistors (n) in parallel, the reciprocal of the equivalent resistance equals the sum of the reciprocals of their individual resistances:

$$\frac{I}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \cdots\cdots + \frac{1}{R_n} \qquad (17.6)$$

The equivalent resistance is always less than any individual resistance. Household appliances are always connected in parallel so that even if one is switched off, the other devices could function properly.

The primary distinction between series and parallel connections lies in how they respond to component failure. In a series circuit, all components are connected along a single current pathway. If one element, such as a lamp fuse, fails, the entire circuit is interrupted, and all devices stop working (Figure 17.12 (a)). On the other hand, parallel circuits offer multiple independent paths for current to flow. Each device, like a lamp in your home, is directly connected to the power source. If one lamp fuse blows, the current simply redirects through the remaining branches, allowing the other lamps to continue shining (Figure 17.12 (b)). This redundancy makes parallel circuits ideal for powering multiple devices in homes and buildings. Even if one device malfunctions, the others remain operational.



(a) Light Bulbs in series (b) Light Bulbs in Parallel

FIGURE 17.12 Series and parallel combination of light bulbs.

Additionally, parallel circuits provide individual control. You can turn off a single lamp without affecting the others, unlike in a series circuit where turning off one device disrupts the entire circuit. This independent control adds to the practicality and flexibility of parallel connections.

Example 17.2

Three resistors $R_1 = 5.0\,\Omega$, $R_2 = 10.0\,\Omega$ and $R_3 = 15.0\,\Omega$ are connected in parallel across a 12.0 V battery. Find equivalent resistance and current passes through each resistor.

GIVEN:

Potential difference 'V' = 12 V
Resistance 'R_1' = 5.0 Ω
Resistance 'R_2' = 10.0 Ω
Resistance 'R_3' = 15.0 Ω

REQUIRED:

Equivalent resistance 'R_{eq}' = ?
Current 'I_1' = ?
Current 'I_2' = ?
Current 'I_3' = ?

SOLUTION:

For parallel combination, the equivalent resistance is given by:

$$\frac{I}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

putting values, $\frac{1}{R_{eq}} = \frac{1}{5.0\Omega} + \frac{1}{10.0\Omega} + \frac{1}{15.0\Omega} = \frac{11}{30.0\Omega}$

Therefore $R_{eq} = 2.73\Omega$ — ANSWER

For parallel combination of resistors, voltage drop remains same across all resistors, given by:

$$V_1 = V_2 = V_3 = 12.0V$$

Total current in the circuit is given by: $V_1 = IR_{eq}$ or $I = \frac{V}{R_{eq}} = \frac{12.0V}{2.73\Omega} = 4.4A$

In parallel combination of resistors, the current splits among resistors.

Current through 'R_1' is given by: $I_1 = \frac{V}{R_1}$ putting values, $I_1 = \frac{12.0V}{5.0\Omega}$

Therefore $I_1 = 2.4A$ — ANSWER

Current through s 'R_2' is given by: $I_2 = \frac{V}{R_2}$ putting values, $I_2 = \frac{12.0V}{10.0\Omega}$

Therefore $I_2 = 1.2A$ — ANSWER

Current through 'R_3' is given by: $I_3 = \frac{V}{R_3}$ putting values, $I_3 = \frac{12.0V}{15.0\Omega}$

Therefore $I_3 = 0.8A$ — ANSWER

It is worth noting that $I_1 + I_2 + I_3 = 2.4\ A + 1.2\ A + 0.8\ A = 4.4\ A$, which is the total current flowing through the circuit.

17.5 COMBINATION OF EMF SOURCES

Combination of emf sources is referred to when two or more emf sources are connected in such a way that a combined effect of these sources is obtained. Normally, there are two possible combinations, series and parallel.

17.5.1 SERIES COMBINATION OF EMF SOURCES

When positive terminal of an emf source, like battery, is connected to negative terminal of another source and so on. Finally the negative terminal of the first emf source is connected to the positive terminal of the last source through other circuit elements like bulbs, fans etc. as shown in figure 17.13. Here four batteries are connected in series where the emf of all batteries are added and provide the resultant emf (6 V) to the external circuit.

Generally, for 'n' number of batteries connected, we can mathematically write:

$$\varepsilon_{net} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \cdots + \varepsilon_n \quad \text{17.7}$$

Series combination of emf sources is used when a higher voltage is required as compared to the voltage of available sources and no change in ampere-hour (Ah) values. If, for example, the above batteries are 1.5 V 2.5 Ah each. The equivalent rating when connected in series will be 6.0 V 2.5 Ah.

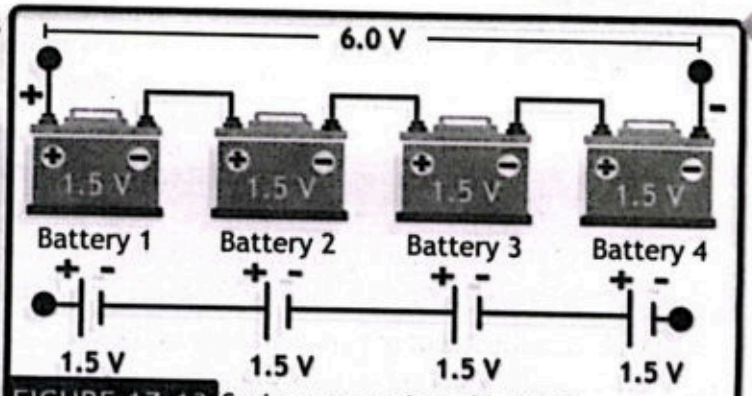


FIGURE 17.13 Series connection of batteries.

17.5.2 PARALLEL COMBINATION OF EMF SOURCES

In parallel combination of emf sources, the positive and negative terminals of all the sources are connected to each other respectively. Finally, the load is connected by taking one connection from positive terminal and one from negative terminal as shown in figure 17.14.

When identical sources (like 12 V in given figure) are connected in parallel, the equivalent emf is equal to the emf of one of the sources i.e. 12 V here. Generally, for 'n' number of batteries connected, we can mathematically write:

$$\varepsilon_{net} = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \cdots = \varepsilon_n \quad \text{17.8}$$

Parallel combination of emf sources is used when a higher ampere-hour is required as compared to the available sources and no change in voltage values. If, for example, the above batteries are 12 V 2 Ah each, the equivalent rating when connected in parallel will be 12 V 6 Ah.

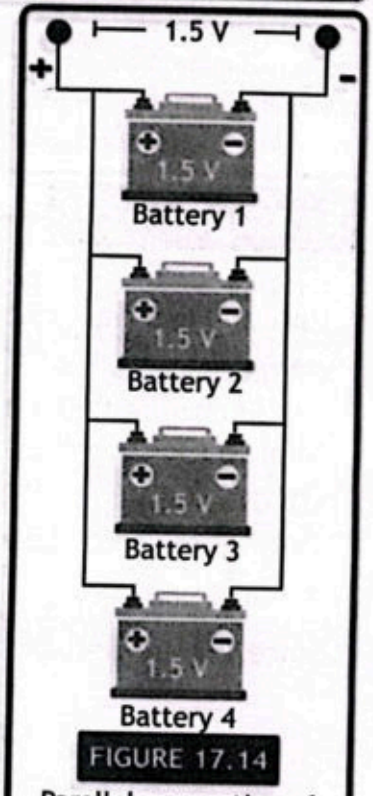


FIGURE 17.14 Parallel connection of batteries.

SCIENCE TIDBITS



When batteries are connected in series, their voltages add up, but if one battery is weaker, it can cause issues. The weaker battery may drain faster, which can limit the power of the entire system and reduce performance. It might also get overworked, leading to overheating or damage. Balancing batteries in series is important for safe and steady power output. To keep them balanced, we can use special circuits that monitor each battery's charge or occasionally charge each battery individually. Proper balancing ensures the system works efficiently and safely.

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Materials: Four lemons, copper wire (four copper strips), Four galvanized nails, Two alligator clips and a standard LED.

Procedure: In the first step, cut your copper wire into four 6-inch lengths. Strip about 1 inch of insulation from both ends of each wire. Roll and squeeze a lemon so that you break up the small juice packets inside it, but not enough to break the skin.

Use a nail to make one hole in one end, push a copper wire into that hole, and push the nail into the other end, as shown in figure 1. Repeat the process for the other lemons; each will become a separate battery. Connect the copper wire side of one lemon to the nail side of another lemon. Connect the long leg from the LED to the copper wire, and connect the short leg to the nail, as shown in figure 2.

Figure 1

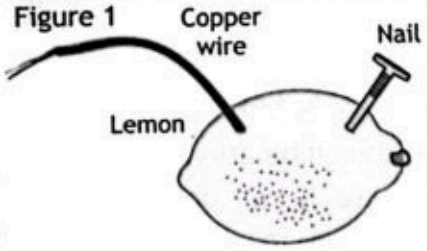
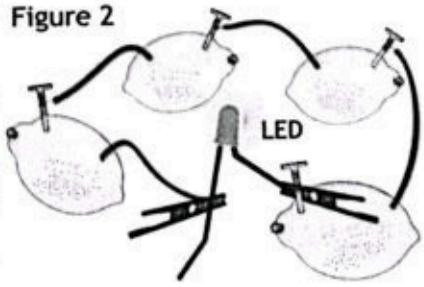


Figure 2



Example 17.3

A series combination consisting of 'n' number of identical cells. If each cell is of 0.4 V and the total emf in series combination is 12 V, find 'n'.

GIVEN:
emf of each cell 'ε' = 0.4 V
Total emf in series 'ε_{net}' = 12 V

REQUIRED:
Number of cells 'n' = ?

SOLUTION:
As in series combination the emfs of individual cells are added, so:

$$\varepsilon_{net} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots + \varepsilon_n$$

Since, all the cells are identical, so $\varepsilon_{net} = n(\varepsilon)$ or $n = \frac{\varepsilon_{net}}{\varepsilon}$

putting values: $n = \frac{12V}{0.4V}$

Therefore $n = 30$ — ANSWER

So, there are a total of 30 identical cells of emf 0.4 V that are arranged in series and give a total emf of 12 V.

17.6 ELECTRICITY AND ITS USES

Electricity is a versatile form of energy that serves numerous purposes in our daily lives. From providing illumination to powering electronic devices, its applications are vast and diverse

A. Heating: Electricity plays a crucial role in keeping us warm and cozy during colder months.

Electric heaters come in various forms, from portable space heaters to central heating systems in homes and buildings. These heaters work by converting electrical energy into heat, which is then distributed throughout the space to maintain a comfortable temperature. Similarly, electric stoves provide a convenient and efficient way to cook our meals by generating heat through electrical resistance in the stove's heating elements. Whether it's warming up a room or cooking a delicious meal, electricity ensures that we stay comfortable and well-fed, even in chilly weather.

B. Lighting: Electric lighting systems brighten up our surroundings, allowing us to see and navigate both indoors and outdoors, regardless of the time of day. In our homes, electric light bulbs illuminate our living spaces, providing ambiance and functionality for various activities such as reading, cooking, and socializing. Streetlights powered by electricity illuminate roads and pathways, enhancing safety and visibility for pedestrians and motorists during the night. Whether it's creating a warm and inviting atmosphere indoors or ensuring safety and security outdoors, electric lighting systems play a crucial role in our daily lives.



FIGURE 17.15 Uses of electricity

D. Powering Motors: Electric motors are the driving force behind a wide range of machinery, appliances, and transportation vehicles. From household appliances like washing machines and vacuum cleaners to industrial equipment such as conveyor belts and manufacturing machinery, electric motors provide the mechanical power needed to perform various tasks efficiently. In the automotive industry, electric motors power electric vehicles (EVs), offering a cleaner and more sustainable alternative to traditional internal combustion engines. Whether it's powering our everyday appliances or propelling us forward on our daily commutes, electric motors play a vital role in modern society.

C. Battery Charging: In today's digital age, portable electronic devices have become indispensable tools for communication, entertainment, and productivity. These devices, such as smartphones, laptops, and tablets, rely on rechargeable batteries to power their operations. Electricity powers the charging process, allowing us to replenish the energy stored in these batteries and keep our devices running smoothly. Whether we're at home, at work, or on the go, access to electricity for battery charging ensures that our devices remain functional and accessible whenever we need them.

E. Powering Electronic Systems: From the moment we wake up to the time we go to bed, we interact with numerous electronic devices powered by electricity. Computers enable us to work, communicate, and access information with ease. Televisions entertain us with a vast array of programs and content. Refrigerators keep our food fresh, while air conditioners maintain

comfortable indoor temperatures. These electronic systems, along with countless others like smartphones, gaming consoles, and home automation devices, rely on electricity to function. By powering these electronic devices, electricity enhances our productivity, entertainment, and overall quality of life in the digital age.

17.7 ELECTRICAL ENERGY

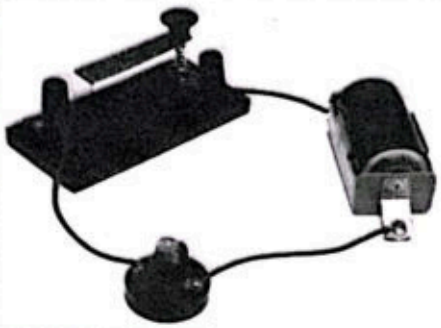


FIGURE 17.16 Electrical Energy

When a voltage source e.g., a battery is connected to a device like bulb (or any other device), the source delivers some electrical energy to it. There will be a potential difference across both the ends of the device (a bulb is shown in the figure 17.16). This potential difference can be given from equation 14.2 as:

$$V = \frac{W}{q} = \frac{E}{q} \quad \text{or} \quad E = qV \quad \text{—(1)}$$

From the definition of electric current: $q = It$ —(2)

Putting equation 2 in equation 1: $E = It\,V$ —(17.9)

Equation 17.8 gives the equation for electrical energy consumed in a device. From Ohm's law '$V = IR$' therefore the electrical energy 'E' from equation 17.9 can also be written as:

$$E = I^2Rt \quad \text{—(17.10)}$$

From Ohm's law '$I = V/R$' therefore the electrical energy 'E' from equation 17.9 can also be written as:

$$E = \frac{V^2}{R}t \quad \text{—(17.11)}$$

CAN YOU TELL?



How we can use equation 7.8 for determining the unit of electrical energy as joule?

UNIT OPENER?



Why is the battery charger plug for the electric vehicle bigger than the cell phone charger?

The battery charger plug for an electric vehicle is larger than a cell phone charger due to power delivery and safety reasons. Electric cars require significantly more power to charge their larger batteries compared to phones. Electric vehicle chargers can deliver thousands of watts, ranging from 2.4 kW to 350 kW, while phone chargers typically deliver only 5W to 30W.

The larger size of the EV charger plug is necessary to handle the higher power safely, with thicker wires and larger connectors to accommodate the increased current flow. Additionally, EV chargers require extra safety features like overload protection and grounding to prevent overheating and electrical hazards, which take up more space in the plug design.

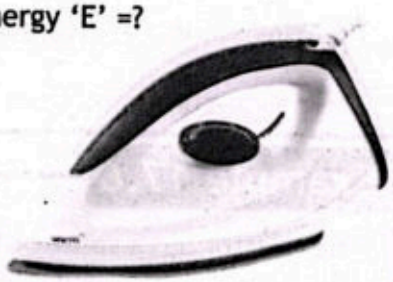
All the equations (17.9, 17.10 and 17.11) give relations for calculating electrical energy.

Example 17.4

An electric iron working at a potential difference of 200 V draws 7 A of current. How much the electrical energy will it consume in 1 hour?

GIVEN:
Potential difference 'V' = 200 V
Current 'I' = 7 A
Time 't' = 1 hr = 60 × 60 s = 3600 s

REQUIRED:
Electrical energy 'E' =?



SOLUTION:
The electrical energy is given by: $E = I t V$

putting values, $E = (7\ A) \times (3600\ s) \times (200\ V) = 5{,}040{,}000\ J$

Therefore $E = 5.04 \times 10^6\ J$ — ANSWER

Thus, the electric iron will consume 5.04 MJ of electrical energy in an hour.

17.8 ELECTRIC POWER

The rate at which electric work is done by the voltage source (i.e battery) in maintaining electric current in the electric circuit is called electric power of the circuit or The electrical energy consumed by a device per unit time s called electrical power. Mathematically:

$$P = \frac{E}{t} \quad \text{— (1)}$$

As we know that electrical energy '$E = I t V$', putting in equation 1: $P = \frac{I t V}{t}$

Therefore $P = IV$ — (17.12)

From Ohm's law '$V = I R$', putting in equation 17.12: $P = I^2 R$ — (17.13)

Also from Ohm's law '$I = V / R$', putting in equation 17.12: $P = \frac{V^2}{R}$ — (17.14)

All the three equations (17.11, 17.12 and 17.13) are equally valid for calculation of electric power. The SI units for electrical power is watt (W). A power of '*1 W*' is said to be consumed in an electrical circuit if potential difference of '*1 V*', causes a current of '*1 A*' to flow through a circuit.

Example 17.5

What is the power consumption of an electric toaster if its resistance is 19 Ω, and its operates on a household circuit with 200 V?

GIVEN:
Resistance 'R' = 19 Ω
Voltage 'V' = 200 V

REQUIRED:
Electric Power 'P' = ?

SOLUTION:
By Ohm's law, the current 'I', is: $I = \frac{V}{R}$ putting values $I = \frac{200\,V}{19\,\Omega}$ or $I = 10.5\,A$

The power 'P', can now be obtained by multiplying current and voltage, as: $P = IV$

putting values, $P = (10.5\,A) \times (200\,V)$ Therefore $P = 2100\,W$ — ANSWER

The power consumption of an electric toaster is 2100 W if its resistance is 19 Ω

Example 17.6

The resistor has a value of 100 Ω and a power rating of ½ W. If the resistor is connected to a 10-V power supply, will it be damaged?

GIVEN:
Resistance 'R' = 100 Ω
Rated Power 'P_R' = 0.5 W
Connected voltage 'V' = 10 V

REQUIRED:
Power dissipated 'P' = ?



SOLUTION:
We would calculate the amount of heat dissipated in resister by using formula for power dissipated in resistor.

$P = \frac{V^2}{R}$ putting values, $P = \frac{(10\,V)^2}{100\,\Omega}$

Therefore $P = 1W$ — ANSWER

Because the resistor has a power rating of ½ W, and the amount of heat that will be dissipated is 1 W, the resistor will be damaged.

Example 17.7

An Air Conditioner (of power 2200 W) is used for an average of 24 hours daily. How much electrical energy will it consume and what will be the cost of electricity for a month (30 days) if cost of electricity is Rs.25.0 / kWh?

GIVEN:
Electric power 'P' = 2200 W = 2.2 kW
Monthly Time 't' = 30 × 24 hours = 720 h
Tariff rate = PKR 25.0 /kWh

REQUIRED:
Energy consumed in kWh 'E' = ?
Cost of electricity 'C' = ?

SOLUTION:
The electric power is given by: $P = \frac{E}{t}$ or $E = P \times t$

POINT TO PONDER



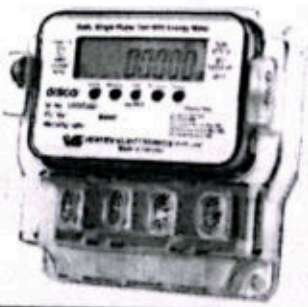
Does the unit of electrical energy kilo-watt-hour (kWh) measure, electric energy or electric power?

The unit kilowatt hour has a unit of power, which suggest that it might be unit of power. However, the unit kilowatt-hour (kWh), measures electric energy, not electric power.

Electric power is the rate at which electrical energy is transferred or consumed. It is measured in watts (W) or kilowatts (kW), where 1 kilowatt equals 1,000 watts.

Power is an instantaneous measurement, indicating how much energy is being used or generated at a specific moment in time. Electric Energy on the other hand is the total amount of electrical work done or energy consumed over a period of time. It is measured in kilowatt-hours (kWh) because electrical energy is consumed in homes and industry in large amounts for which joule is a small unit. Mathematically,

$$1 \text{ kW-hr} = 1000 \text{ W} \times 1\text{hr}$$
$$= 1000 \text{ J/s} \times 3600\text{s}$$
$$= 3.6 \times 10^6 \text{ J}$$



One kilowatt-hour represents the amount of energy consumed when a power of one kilowatt is used for one hour. For example, if a device rated at 500 watts (0.5 kW) operates for 2 hours, it will consume 1 kWh of energy (0.5 kW × 2 hours = 1 kWh).

putting values, $E = 2.2\,kW \times 720\,h$ Therefore $E = 1584\,kWh$ — ANSWER

The total consumed energy is 1584 kWh (or 1584 commercial units), the cost of which can be calculated as:

$$Cost = E \times Tariff\ \ Rate = (1584\,kWh) \times (PKR.25.0)$$

or $Cost = 39{,}600\,rupees$

The cost of electricity for an AC for the whole month is PKR. 39,600.

17.9 HOUSEHOLD CIRCUITS AND ELECTRIC SAFETY

Even though household circuits utilize alternating current, which hasn't been discussed yet, their functioning (along with numerous practical applications) can be comprehended by applying the same circuit principles just studied. In household wiring, the electrical elements should be connected in parallel. For example, when a bulb in a lamp in your kitchen burns out, other appliances on the same circuit, like the coffee maker, should still work. Additionally, household appliances and lights are typically designed to work at around 220 V. If they were connected in series, each appliance would only receive a fraction of 220 V.

17.9.1 HOUSEHOLD WIRING SYSTEM

A mains circuit is composed of three wires: a live wire (line wire), a neutral wire, and an earth wire as shown in figure 17.17. Each wire has a distinct function in guaranteeing the secure distribution and utilization of electricity. It is crucial to comprehend their roles in order to uphold electrical safety in residential and industrial environments.

The live wire, also known as the line wire, is responsible for carrying the electrical current from the power source to the electrical devices or appliances. The live wire carries the potential difference or voltage that powers the electrical devices. The neutral wire, on the other hand, is responsible for completing the electrical circuit. It provides a return path for the electrical current back to the power source. It carries the same current as the live wire but with an opposite polarity. The earth wire, also known as the grounding wire, is a safety measure in case of electrical faults or malfunctions. The earth wire provides a low-resistance path for the electrical current to flow into the ground, preventing electric shocks and reducing the risk of fire. It acts as a safety backup, redirecting the current away from people or objects in case of a fault.

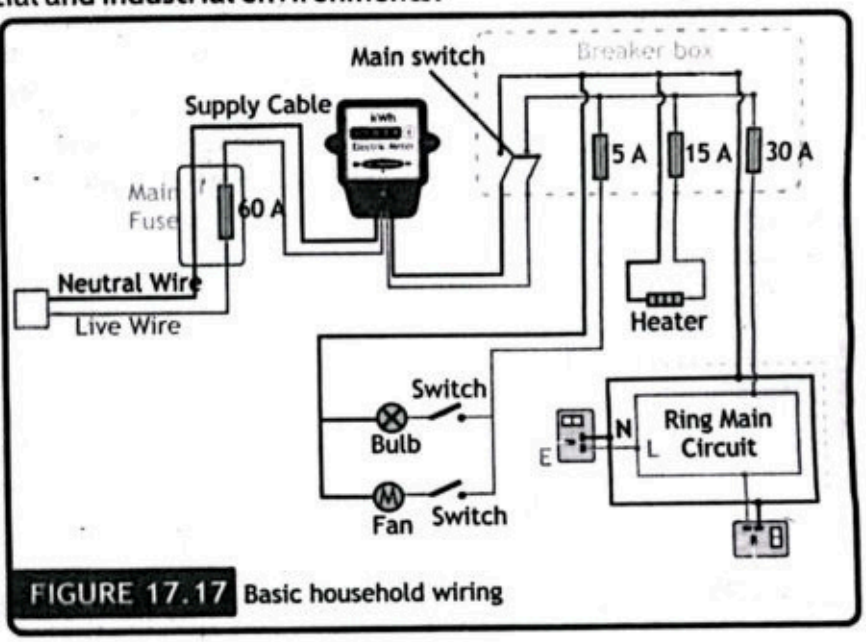
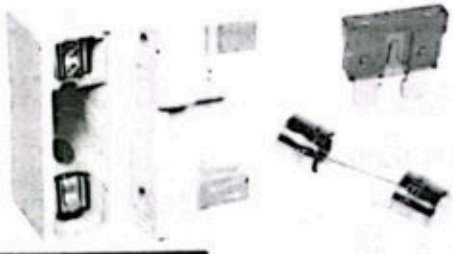


FIGURE 17.17 Basic household wiring

17.9.2 FUSES

To avoid overloading, current is restricted using fuses or circuit breakers. Fuses, (figure 17.18) found in older homes, Inside the fuse is a metal strip that melts when the current is larger than the rated value (the threads for example have specific to their current ratings). The melting of the strip opens the circuit, and the current drops to zero.


FIGURE 17.18 Some fuse types

17.9.3 CIRCUIT BREAKERS

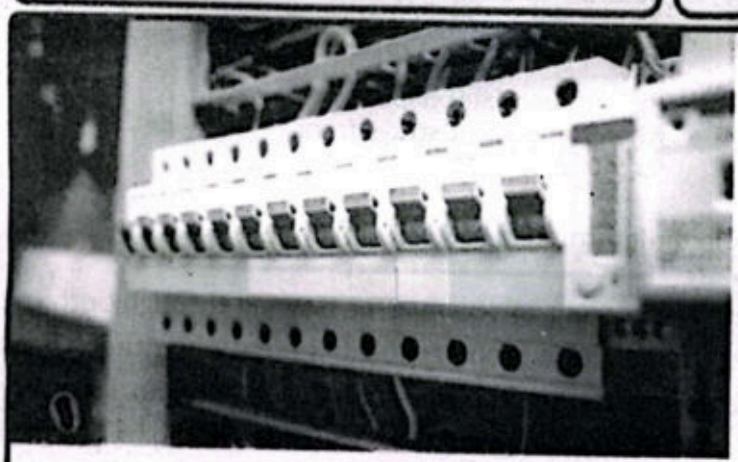
Newer homes exclusively use circuit breakers. One such type of circuit breaker utilizes a bimetallic strip as shown in figure. When the current flowing through the strip increases, it heats up and bends (figure 17.19). Once the current reaches its rated value, the strip bends enough to

SCIENCE TIDBITS

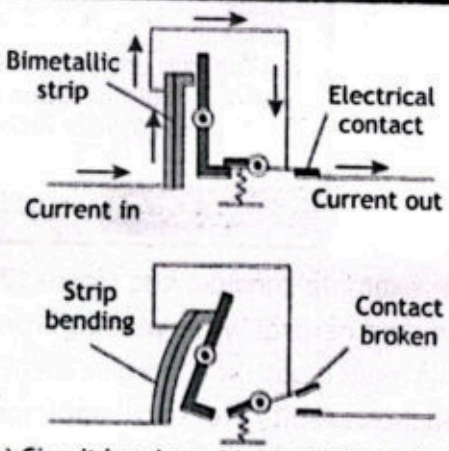
The electrical power produced (dissipated) by a resistor is $I^2 R$. It depends on the square of the current. Hence, if current is doubled, the power will increase by four times. Similar explanation holds true for voltage also.

SCIENCE TIDBITS

A common misconception is that electrons are used up in an electric circuit, but this is not true. In reality, we pay the electric company for the energy needed to power our devices and move electrons through the circuit.



(a) A typical bank of household circuit breakers



(b) Circuit breaker with bimetallic strip

FIGURE 17.19 Circuit breaker

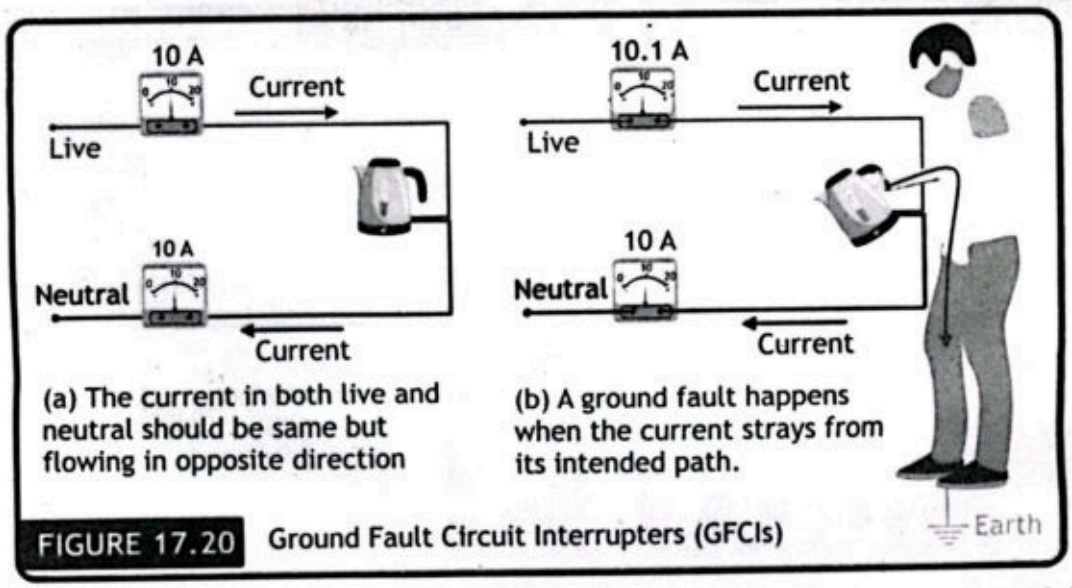
open the circuit (trip elements using magnetic principles also exist). Afterward, the strip cools down, allowing the breaker to be reset.

However, if a fuse blows or a circuit breaker trips, it indicates that the circuit is drawing excessive current. It is important to identify and fix the problem before replacing the fuse or resetting the circuit breaker. It is crucial not to temporarily replace a blown fuse with one that has a higher current rating. This is because it can lead to further damage or even fire hazards.

Adding a third grounding wire to the circuit helps prevent electric shocks by providing a low-resistance path through the metal casing of appliances. If a hot wire touches the casing, the circuit is completed through this wire, blowing the fuse or tripping the circuit breaker. In case of contact, the current would flow through the ground wire, minimizing harm to you.

17.9.4 RESIDUAL CURRENT DEVICES

Residual-Current Devices (RCDs), also known as Ground Fault Circuit Interrupters (GFCIs), are modern safety devices designed to protect against electric shock and reduce the risk of electrical fires. They do this by detecting differences in the electrical current between the live (hot) and neutral wires of a circuit. Ideally, the current in both wires should be equal but opposite in direction.



(a) The current in both live and neutral should be same but flowing in opposite direction

(b) A ground fault happens when the current strays from its intended path.

FIGURE 17.20 Ground Fault Circuit Interrupters (GFCIs)

For example consider the figure 17.20 there is a current of 10 amperes flowing through both the live and neutral wires passing through electric kettle. A ground fault happens when there is an unintended path for the electrical current to flow to the ground. Imagine someone accidentally touches a faulty electrical appliance (electric kettle), a new path for the current can be created through his body. Let's assume that there is a current of 0.1 ampere flowing through the person. This means that the live wire now carries a current of 10.1 amperes, while the neutral wire still has a current of 10 amperes.

To protect people from such situations, GFCIs are designed to detect this difference in current and interrupt the circuit when it detects a current difference of around 5 milliamperes (0.005 ampere). This helps to prevent electric shocks and potential harm to individuals.

17.9.5 ELECTRICAL HAZARDS

Electric hazards are often the result of negligence or lack of maintenance. Damaged insulation, overheating cables, damp conditions, and overloading of electrical outlets are among the common hazards encountered. Identifying these hazards and addressing them promptly through regular inspection and maintenance is crucial to prevent accidents and ensure safety.

Electric shock can have severe consequences on the human body, including burns, cardio-respiratory failure, and seizures. Understanding these effects underscores the importance of adhering to safety protocols and implementing preventive measures. First aid procedures should be known and readily available to mitigate the impact of electric shock incidents.

The amount of current passing through our body at a specific voltage is a complex question with no simple answer. The current flow is dependent on the resistance of the path it takes. Since different individuals have varying levels of resistance, it is difficult to give a definitive answer. Moreover, factors such as sweating on a hot day, which enhances conductivity due to saltwater, as well as one's diet and the length of the current path, also influence the body's resistance. Therefore, it is crucial to consider all these factors when assessing body resistance. Table 17.2 illustrates the effects of different amounts of current on the body. This data is general – as some people may have less tolerance to electricity than others.

TABLE 17.2: THE EFFECTS OF ELECTRIC CURRENT ON THE BODY

Sr No.	Current in milliamperes (mA)	Effect on body
1.	2 to 3	A slight tingling sensation
2.	9 to 10	Moderately painful
3.	10 to 20	Highly painful
4.	20 to 30	A person to seize the line and be unable to let go of the circuit.
5.	30 to 40	Causing muscular paralysis
6.	40 to 60	Causing breathing difficulty
7.	60 to 100	Breathing becomes extremely difficult
8.	100 to 200	Generally cause death because the heart usually goes into fibrillation, a condition in which the heart begins to "quiver" and the pumping action stops.

SUMMARY

- **Electric Circuit** is a closed pathway through which electricity flows, typically consisting of a power source, wires, and components like resistors.
- **Resistor** is an electrical component that limits the flow of electric current in a circuit, measured in ohms (Ω).
- **Series Combination of Resistors** include connecting resistors end-to-end in a single path so that the same current flows through each.
- **Parallel Combination of Resistors** include connecting resistors side by side across the same voltage source, allowing multiple current paths.
- **Potential Divider** is a circuit arrangement used to divide a voltage into smaller fractions using resistors connected in series.
- **Electric Power** is the rate at which electrical energy is transferred or consumed in a circuit, measured in watts (W).
- **Electrical Energy** is the ability of electricity to do work or produce heat, measured in joules (J) or kilowatt-hours (kWh).

- **Kilowatt Hour (kWh)** is the unit of electrical energy commonly used to measure consumption or production over time, equal to one kilowatt of power used for one hour.
- **Electricity and Its Uses** include flow of electric charge through conductive materials, utilized for heating, lighting, powering devices, and various applications.
- **Electrical Safety** involves the practices and measures to prevent accidents and injuries related to electricity, including proper installation, maintenance, and following safety guidelines.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. Two resistances of 4 ohm are connected in parallel and this combination is connected to another 6 ohm resistance in series. The equivalent resistance will be:

   A. 4 Ω B. 6 Ω C. 8 Ω D. 10 Ω

2. In series connection of resistors, the current across each resistor:

   A. increases B. decreases

   C. remain the same D. first increases then decreases

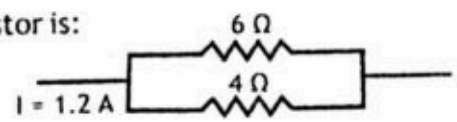
3. A resistor's first three colours are brown, black and red, its value is:

   A. 10 Ω B. 10 kΩ C. 200 Ω D. 1000 Ω

4. The relation for electric power in a circuit is P =

   A. IV B. I^2R C. V^2/R D. all of these

5. In the given figure, the current passing through 6Ω resistor is:

   A. 0.40 A B. 0.48 A

   C. 0.72 A D. 80 A

6. When four cells, each with an emf of 0.5 V, are connected in parallel, the net emf is:

   A. 4.5 V B. 2.0 V C. 0.75 V D. 0.5 V

7. The purpose of grounding electrical systems is to:

   A. provide a path for current to flow B. protect against electric shocks

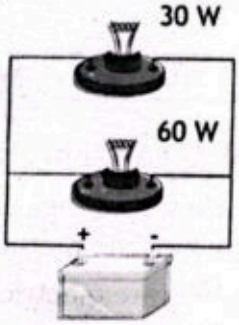
   C. reduce electrical resistance D. increase energy efficiency

8. The purpose of a circuit breaker is to:
   A. increase electrical resistance
   B. prevent electrical shock
   C. regulate voltage
   D. interrupt the flow of electricity in case of a fault
9. Which electrical element control the flow of the electric current in a circuit?
   A. conductor B. insulator C. Resistor D. capacitor
10. A and B are two bulbs connected in parallel. A is glowing brighter than B, then the relation between R_A and R_B is:
    A. $R_A > R_B$ B. $R_A < R_B$ C. $R_A = R_B$ D. $R_A = 0$
11. The S.I unit for electrical power is:
    A. watt B. Joule C. volt D. kWh
12. A wire of resistance R is divided in 10 equal parts. These parts are connected in parallel, the equivalent resistance of such connection will be:
    A. 10 R B. R C. 0.1 R D. 0.01 R

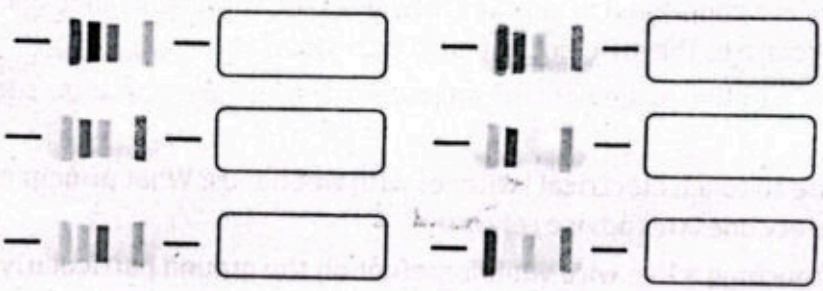
CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. A battery of voltage V is connected to 30 W bulb and 60 W bulb as shown in the figure. (a) Identify brightest bulb (b) which bulb has greater resistance? (c) Suppose the two bulbs are connected in series, which bulb will glow brighter?

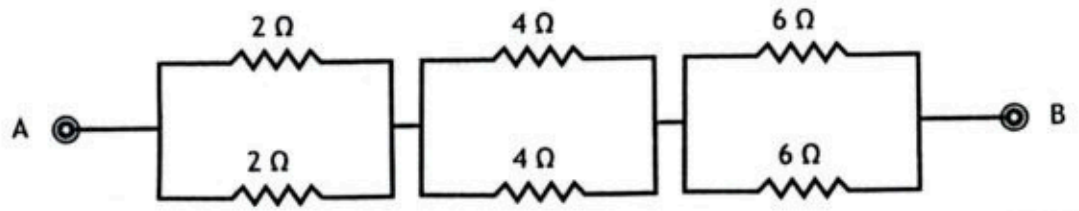


2. What is the value of resistance of the following resistors?

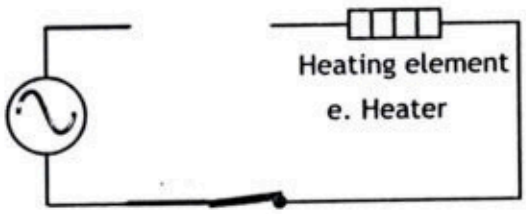


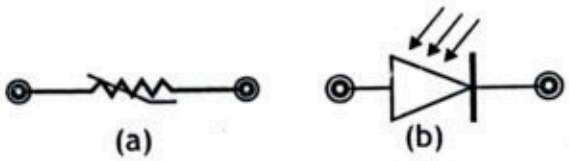
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3. Calculate the equivalent resistance between points A and B in the given circuit.



4. Consider a circuit in which a heater is in series with the supply voltage. Which device out of the following should be placed to present a higher resistance initially, preventing large currents from flowing at turn-on?







SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. How does the color code on a carbon resistor provide information about its properties, and why is this method chosen over other labeling techniques?
2. Why are electrical devices in homes connected in parallel rather than in series? How would household functionality be impacted if they were connected in series?
3. When resistors are connected in parallel, why does the total resistance decrease? How does this principle relate to the efficiency of electrical systems?
4. How incorrect parallel placement of ammeters can damage circuits, suggesting ways to prevent this.
5. Why is it unsafe to touch electrical switches with wet hands? What principles of conductivity and human safety does this advice rely on?
6. What makes touching a live wire while barefoot on the ground particularly dangerous? How do the factors involved influence the severity of electrical shock?
7. How does a circuit breaker protect a household's electrical system? What might happen in the absence of a circuit breaker during a power surge or overload?

8. In what ways does grounding an appliance's case enhance user safety? How docs grounding mitigate potential electrical hazards?
9. How does an appliance's wattage influence its energy consumption and operational cost? How can understanding this relationship help in making energy-efficient choices?
10. In what ways do electrical energy and electrical power differ in function and application? How do these differences impact our understanding and measurement of electricity?
11. How does the kilowatt-hour serve as a unit of energy consumption, and what steps can you take to convert energy usage from joules to kilowatt-hours?
12. Describe a situation in your daily life where electrical energy is essential. How does this energy transform to allow the device to perform its function?
13. What are three common sources of electrical energy, and how do their advantages and disadvantages influence our choice of energy sources?
14. Examine the effects and risks of connecting different emf sources in parallel, and suggest safe ways to combine power sources

LONG RESPONSE QUESTIONS

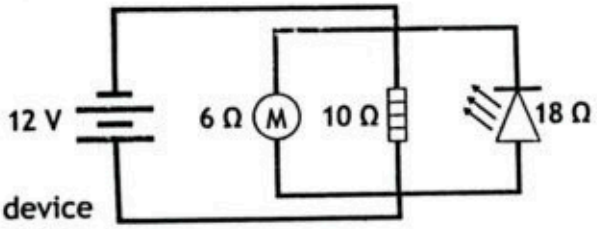
QIV. Give a detailed response to the following questions.

1. What is the significance of different types of resistors in electronic circuits, and how do their characteristics influence circuit design?
2. Explain the principles behind the series combination of resistances and illustrate how the total resistance changes when more resistors are added?
3. How does the concept of equivalent resistance in parallel circuits differ from that in series circuits, and what practical applications can you identify for each?
4. Discuss the effects of connecting emf sources in series or parallel and their practical uses.
5. In what ways can electric power be measured, and why is it important to understand the different formulas for calculating power in electrical systems?
6. What are the common hazards associated with household electricity, and how can individuals effectively mitigate these risks through safety measures?
7. In what various ways is electricity utilized in everyday life, and how has its application evolved over time?
8. Describe the working principle of a potential divider and discuss its practical uses in electronic circuits?
10. What are thermistors, and how do their types (NTC and PTC) differ in terms of functionality and applications in temperature sensing and control?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. A fan, a heater and an LED bulb are connected to a battery as shown in the figure.
   (a) Find equivalent resistance
   (b) Calculate the current passing through each device

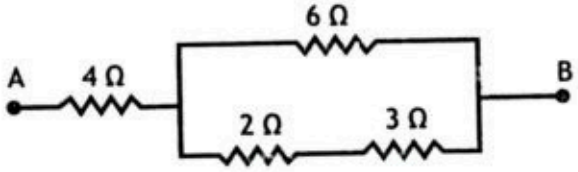


(Ans. (a) 3.1 Ω, (b) 2 A, 1.2 A, 0.67 A)

2. Three resistors $R_1 = 8\ \Omega$, $R_2 = 12\ \Omega$ and $R_3 = 18\ \Omega$ are connected in parallel. Calculate the total resistance of the combination. (Ans. 3.789 Ω)
3. A device with a resistance of 10 Ω is connected to a 120 V power source. Calculate the power consumed by the device. (Ans. 1440 W)
4. A light bulb with a power rating of 60 W is switched on for 5 hours. Calculate the electrical energy consumed by the light bulb. (Ans. 300 Wh)
5. One hundred identical cells are connected in series, each of emf 0.2 V. What will the resultant emf when these identical cells are connected in series? When parallel?

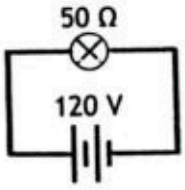
(Answer: 20 V, 0.2 V)

6. In the circuit shown, what is the value of the total resistance of the circuit between points A and B?



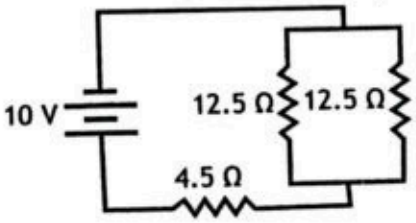
(Ans. 6.73 Ω)

7. Calculate the
   (a) power consumed,
   (b) current flowing through and
   (c) electrical energy consumed by the bulb in the given figure.

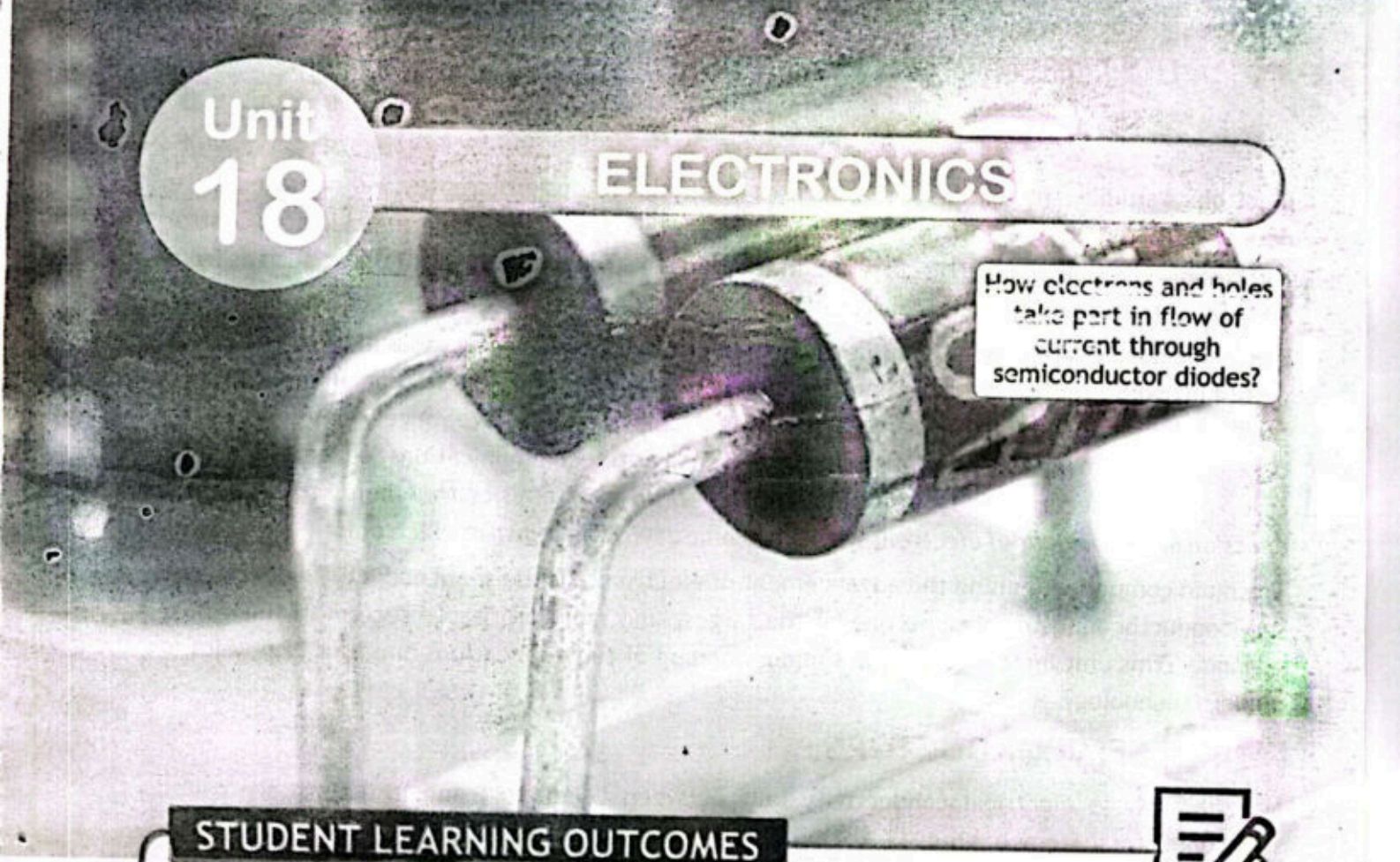


(Ans. 288W, 2.4 A, 1440 Wh)

8. Calculate the total resistance of the circuit shown in the figure:



(Ans. 10.75 Ω)



Unit 18 ELECTRONICS

How electrons and holes take part in flow of current through semiconductor diodes?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-45] Describe the working of a diode.
- ✓ [SLO: P-10-E-46] Describe the action of a light-emitting diode in passing current in one direction only and emitting light.
- ✓ [SLO: P-10-E-47] Describe and explain the action of relays in switching circuits.
- ✓ [SLO: P-10-E-63] Explain that electronic devices are built from digital logic circuits.
- ✓ [SLO: P-10-E-64] Explain that Boolean logic is the basis for converting analogue data to digital data.
- ✓ [SLO: P-10-E-65] State in words and in truth table form, the action of logic gates.
- ✓ [SLO: P-10-E-66] Identify the use of logic gates for security purposes.
- ✓ [SLO: P-10-E-67] Use circuit symbols for the logic gates.
- ✓ [SLO: P-10-E-68] Identify in given problems how Boolean switches can be put into combinations that then allow them to achieve logical operations.
- ✓ [SLO: P-10-E-69] Describe the action of a bipolar npn transistor as a switch.
- ✓ [SLO: P-10-E-70] Explain that transistors are commonly used in digital devices because they are both economical and act as rapid-response switches.
- ✓ [SLO: P-10-E-71] State that circuits that maintain their 'state' after receiving an input can be said to exhibit 'memory'.
- ✓ [SLO: P-10-E-72] State that quantum computers are still in early stages of development, and have to overcome manufacturing challenges such core components only functioning at very cold temperatures that are at almost absolute zero.
- ✓ [SLO: P-10-E-73] Compare analogue and digital electronics.

Electronics studies and applies the principles of physics to design, create, and operate active devices such as diodes, transistors and integrated circuits (ICs). These electronic devices control and amplify the flow of electric current and to convert it from one form to another, such as from AC to DC or from analog signals to digital signals.

Electronic devices are playing a major role in modern civilization. The various electronic devices we use in everyday life include computers, mobile phones, automated teller machine (ATM), pen drive, television and digital camera etc. Electronic devices have hugely influenced the development of many aspects of modern society, such as telecommunications, education, health care, industry, security and entertainment. *The branch of physics that helps to study the emission and behaviour of electrons with electronic devices is known as electronics.*

The main component behind the advancement of electronics is the semiconductor industry. The semiconductor industry became one of the largest and most profitable sectors in the global economy. This unit increases student's understanding of the applications and uses of physics in modern technology.

18.1 SEMICONDUCTORS

Materials whose electrical conductivity falls between conductors and insulators are called semiconductors. Atoms of group IV-A of periodic table are semiconductors.

Silicon is a semiconductor material. Atoms in pure silicon contain four electrons in outer orbit. In the crystal lattice structure of Si, the valence electrons of every Si atom are locked up in covalent bonds with the valence electrons of four neighboring Si atoms, as shown in figure 18.1. In pure form, Si wafer does not contain any free charge carriers. Such types of pure semiconductors are called intrinsic semiconductors.

In order to make useful semiconductor devices, materials such as phosphorus (P) and aluminium (Al) are added to Si. Those semiconductors that are doped with some specific impurities are called extrinsic semiconductors. These impurities modify the electrical properties of the semiconductor and make it more suitable for electronic conductivity. The extrinsic semiconductors are of two types; p-type and n-type.

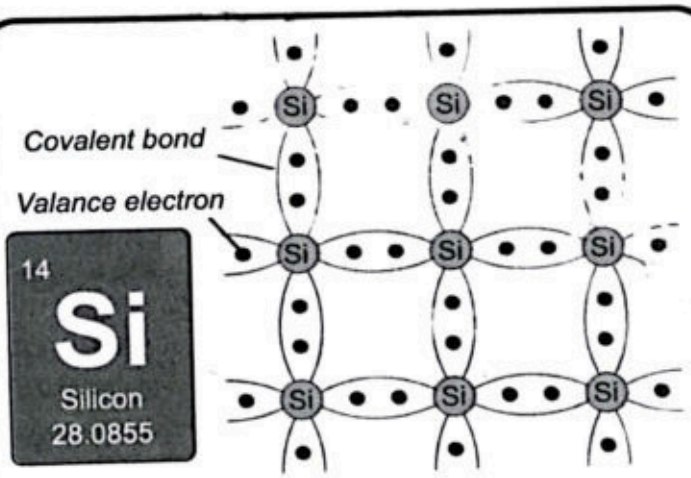


FIGURE 18.1

2-D crystal lattice of silicon. Bonds are formed by sharing of electrons (i.e. bonds are covalently bonded).

18.2 N-TYPE & P-TYPE SEMICONDUCTORS

When a pentavalent impurity (group V-A elements) such as phosphorus is added to Si, the resulting mixture is called N-type. Four valence electrons of every phosphorus atom are locked up in covalent bond with valence electrons of four neighboring Si atoms. However, the 5th valence electron of phosphorus atom does not find a binding electron and thus remains free to float in the material, as shown in figure 18.2.

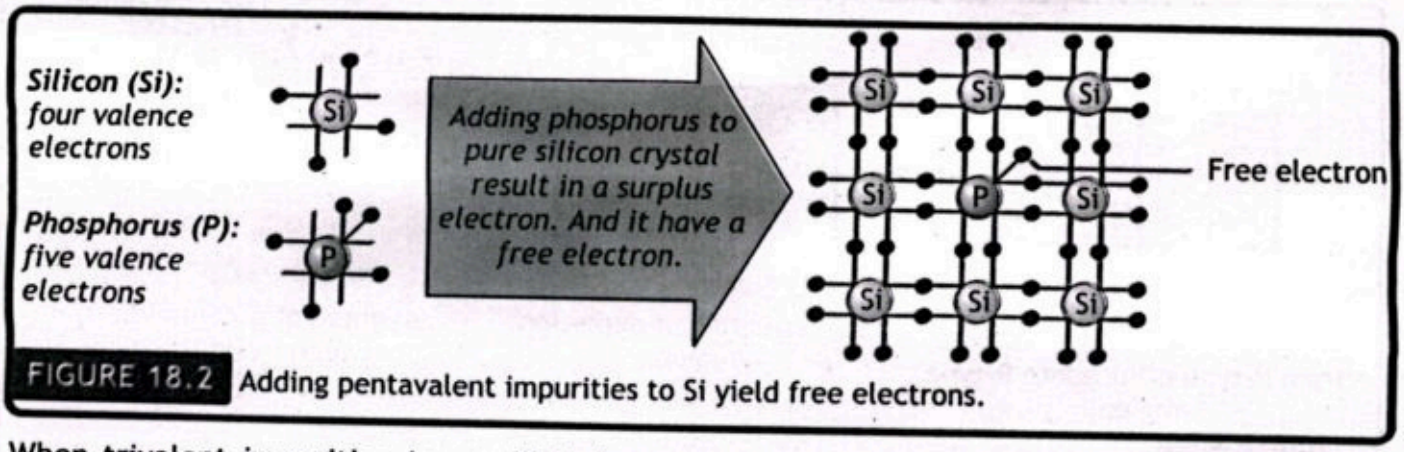


FIGURE 18.2 Adding pentavalent impurities to Si yield free electrons.

When trivalent impurities (group III-A elements) such as boron is added to Si, the resulting mixture is called P-type. Three valence electrons of every boron atom are locked up in covalent bond with valence electrons of three neighboring Si atoms. However, the fourth electron of the Si atom remains unpaired. A vacant spot "hole" is created within the covalent bond between one boron atom and a neighboring Si atom, as shown in figure 18.3. These holes are considered to be positive charge carriers

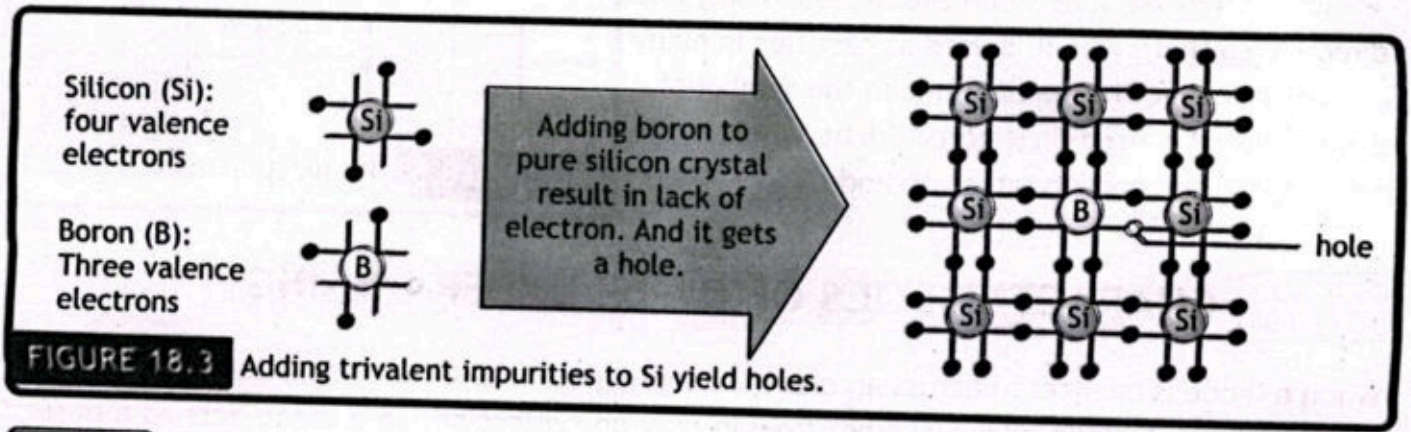
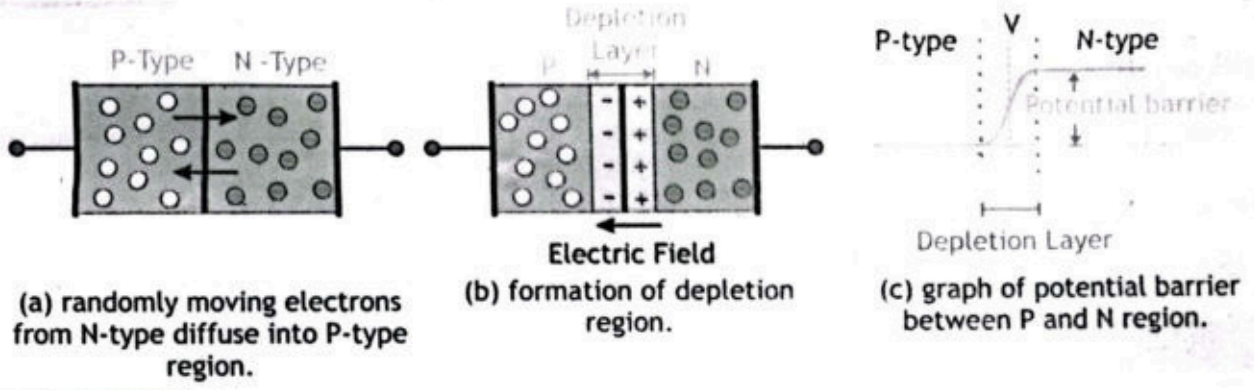


FIGURE 18.3 Adding trivalent impurities to Si yield holes.

18.3 PN JUNCTION (OR DIODE)

When a crystal of semiconductor is grown in such a way that it's one half is doped with trivalent impurity (p-type) and other half is doped with pentavalent impurity (n-type), then a junction is formed between the two regions. Such a grown crystal is called PN junction. At the junction

between the two regions, randomly moving electrons from N-type diffuse into P-type region and hence fill the vacancies in P-type, as shown in figure 18.4 (a). As a result of this diffusion, negative and positive ions are formed near the junction as shown in figure 18.4 (b). These ions create an electric field directed from N-type to P-type region. It is called depletion region. Thus, a potential barrier is formed at the junction. The value of potential barrier for Ge crystal is 0.3 V and for Si crystal is 0.7 V.



(a) randomly moving electrons from N-type diffuse into P-type region.

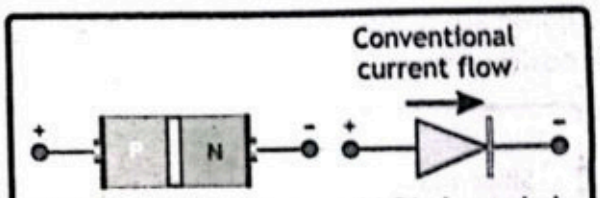
(b) formation of depletion region.

(c) graph of potential barrier between P and N region.

FIGURE 18.4 PN junction and formation of depletion region

The depletion region is free of mobile charges. The width of depletion layer depends upon carrier concentration. Depletion region stops further diffusion of electrons and holes and maintains the separation of charge carriers.

PN junction diode allows current to pass in only one direction so that's why it is used as rectifier in many electric circuits. The vertical line in the symbol of a diode shows the n-region (figure 18.5 b), whereas the arrow head represents p region of diode.



(a) Diode structure (b) Diode symbol

FIGURE 18.5 PN junction diode

18.4 CHARACTERISTICS OF DIODE UNDER BIASING

When a diode is connected across an electric supply (potential difference), then it is said to be under biasing. A diode allows current flow in only one direction, so a diode acts as a perfect insulator for currents flowing in one direction and as a perfect conductor for currents flowing through it in the other direction. The biasing in which the diode allows current to flow is called the forward bias and that in which current is resisted is called reverse bias.

18.4.1 FORWARD BIASED

When the positive terminal of a DC source is connected to p-type and negative terminal is connected to n-type semiconductor of a pn junction as shown in 18.6 (a), the junction is said to be in forward biased.

In this circuit, the holes on the P-side being positively charged particles are repelled from the positive bias terminal and driven towards the junction. Similarly, the electrons on the N-side are repelled from the negative bias terminal and driven towards the junction. The result is that the depletion region is reduced in width and the barrier potential is also reduced. Once the potential barrier is reduced by the forward voltage, a conducting path is established for flow of current. The electrons and holes combine causing the current to pass through the junction. This current is called forward current and it is of the order of a few miliamperes (mA). The variation of forward current through the pn junction with the biasing voltage can be studied with the help of the circuit shown in the figure 18.6 (b).

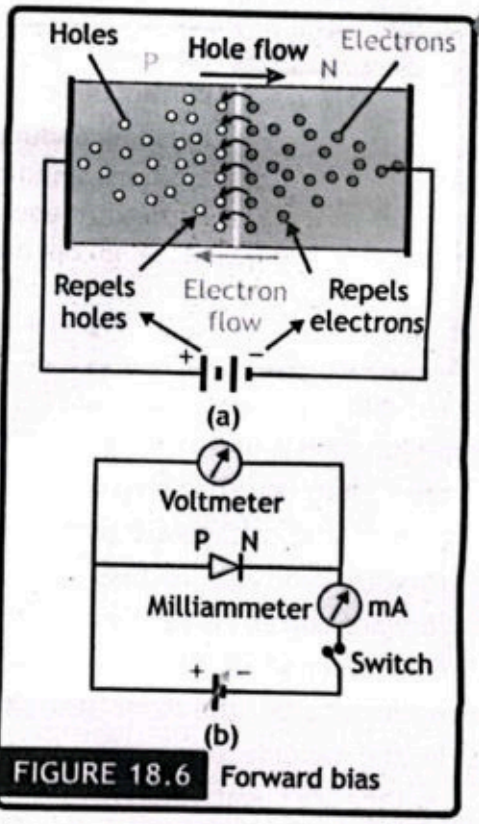


FIGURE 18.6 Forward bias

18.4.2 REVERSED BIASED

When potential at anode (p-type) is smaller than the potential at cathode (n-type), the diode is said to be reverse biased as shown in figure 18.7 (a). In a reverse-biased diode current is blocked.

In a reverse-biased connection, holes in the n-side are forced to the left while electrons in the p-side are forced to the right. This result in an empty zone around the pn-junction that is free of charge carries creating a wider depletion region. This depletion region acts as an insulator as no current flows through the junction due to majority charge carriers. Only a small current of the order of few microamperes (μA) flows due to minority charge carriers. This small current is known as reverse or leakage current.

The variation of reverse current through the pn-junction with the biasing voltage can be studied with the help of the circuit shown in the figure 18.7 (b).

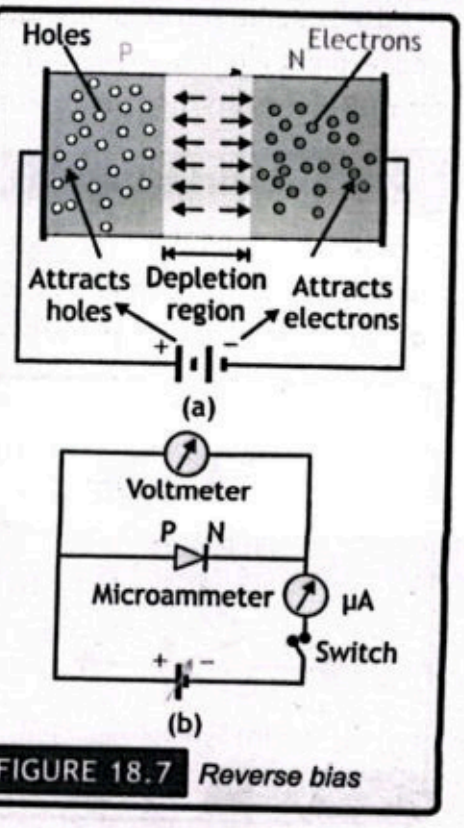


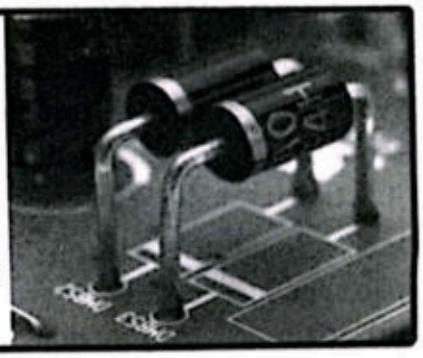
FIGURE 18.7 *Reverse bias*

UNIT OPENER?



How electrons and holes take part in flow of current through semiconductor diodes?

In semiconductors current is caused by both electrons and holes. If an external electric field is applied to the semiconductor, the electrons and holes move in opposite directions. Hence they both contribute to the flow of current through semiconductor material.



The current (I) verses voltage (V) graph for a pn junction is shown in figure 18.8. It can be seen that, in the forward biase region, current and voltage are positive. When the *forward* voltage is less than 'V_d', the forward current is nearly zero so the diode does not conduct. When the forward current is equal to 'V_d' the diode starts to conduct. In the reverse biase region, current and voltage are negative. As reverse bias voltage is raised, depletion region width increases and a point comes when junction breaks down. This results in large flow of current.

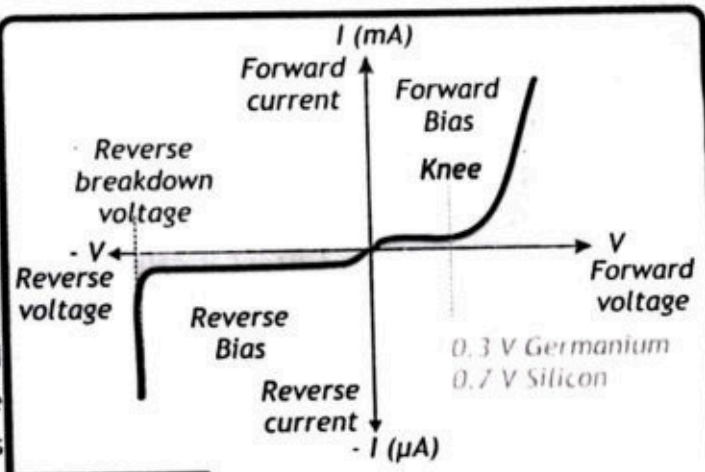
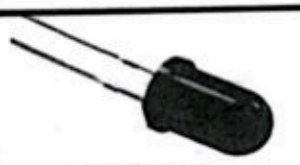


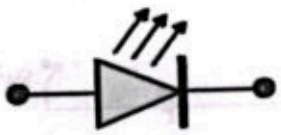
FIGURE 18.8 *I-V curve for a semiconductor diode.*

18.5 LIGHT-EMITTING DIODE (LED)

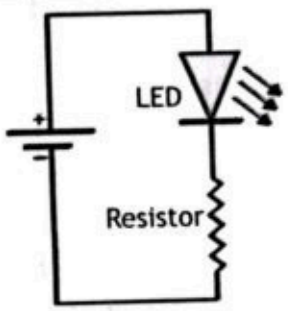
Light-Emitting Diode emits energy in the form light and hence they glow when the electric current passes through it. These diodes are made from gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP). The picture and symbol of LED is shown in figure 18.9 (a) and 18.9 (b).



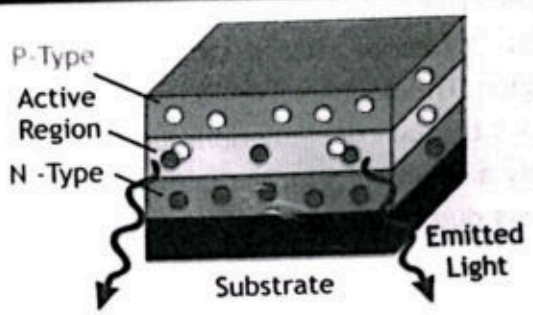
(a) Picture



(b) Symbol



(c) Forward bias



(d) Action of Light-Emitting Diode

FIGURE 18.9 Light-Emitting Diode (LED)

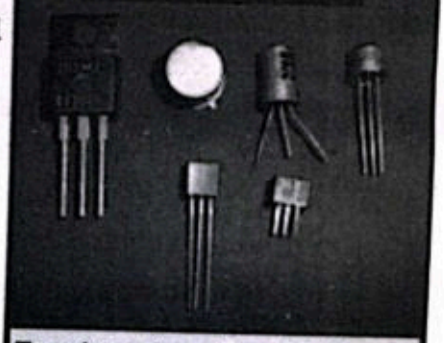
When the LED is forward biased as shown in figure 18.9 (c), the potential barrier is lowered. The conduction band free electrons from n-region cross the barrier and enter the p-region. As these electrons enter the p-region, they fall into the holes lying in the valence band. Hence, they fall from a higher level to a lower energy level. In the process, they radiate energy as shown in figure 18.9 (d).

A LED is enclosed with a transparent cover to view the emitted light. LEDs can emit light of different colours such as red, green and blue etc. LEDs are widely used in decorative lamps, optical communication and display devices.

18.6 TRANSISTOR

A transistor is a device composed of semi-conductor material that can both conduct and insulate (e.g. germanium and silicon). Transistors switch and modulate electronic current. The transistor was the first device designed to act as both a transmitter, converting sound waves into electronic waves, and resistor, controlling electronic current. The name transistor comes from the 'trans' of transmitter and 'sistor' of resistor. These words describe the operation of a transistor which is the transfer of an input signal from a low resistance circuit to a high resistance circuit.

DO YOU KNOW?



Transistor is a bi-polar device, bipolar refers to the fact that both holes and electrons participate in the conduction process. If only one carrier is employed (electron or hole), it is considered a unipolar device.

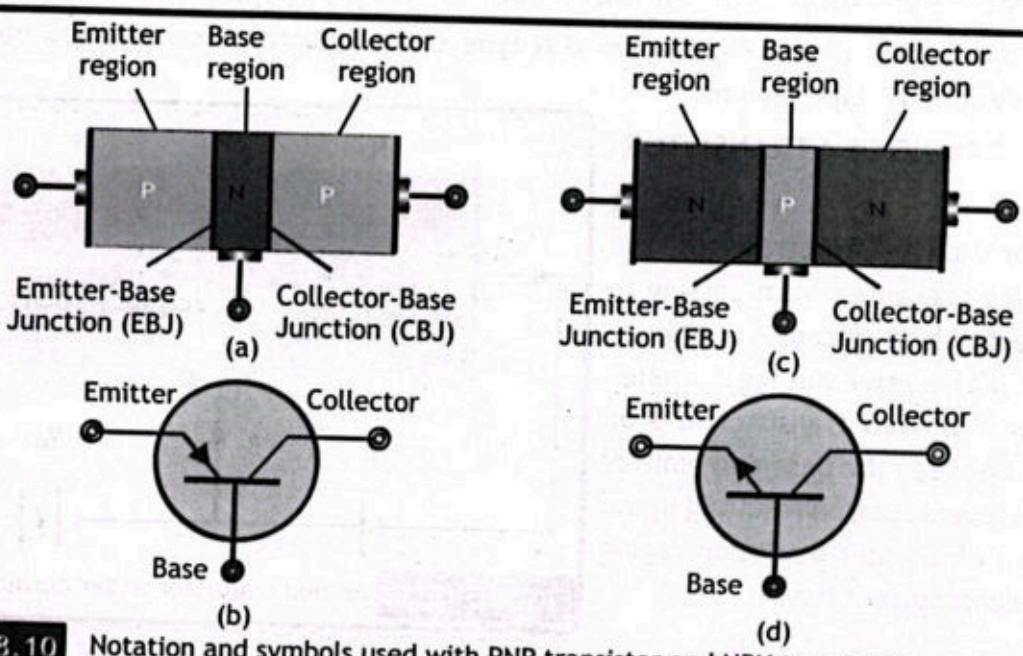


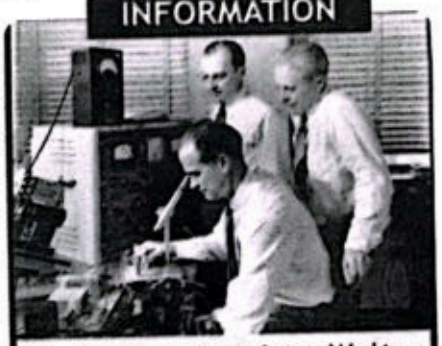
FIGURE 18.10 Notation and symbols used with PNP transistor and NPN transistor.

In general, all transistors have three regions: base (B), collector (C), and emitter (E).

- **Emitter:** It is moderately sized and heavily doped region.
- **Base:** It is at the center of the transistor. It is thin and lightly doped.
- **Collector:** It is larger than the emitter and is moderately doped.

A transistor is a three-terminal semiconductor device that consists of two p-n junctions namely BE and CE. A transistor is constructed in such a way that a lightly doped region called base is sandwiched between two regions called the emitter and collector. The function of a transistor is to amplify current. This makes them useful as switches or amplifiers. They have an extensive use in electronic devices like televisions, radio transmitters and mobile phones.

INFORMATION



In 1948, scientists Walter Brattain, John Bardeen, and William Shockley developed a device known as a transistor at Bell Laboratories. This invention was awarded the 1956 Nobel Prize in Physics. Transistor is the basis of the integrated circuits that run our computers and many modern technologies.

18.6.1 TYPES OF TRANSISTOR

Transistors are made in two types: PNP and NPN.

A. NPN Transistor: An NPN transistor is made by joining one P-type semiconductor in between two N-type semiconductors. Here a lightly doped P-type semiconductor is sandwiched between two heavily doped N-type regions.

B. PNP Transistor: A PNP transistor is made by sandwiching a N-type semiconductor in between two P-type semiconductors. Here a lightly doped N-type semiconductor is sandwiched between two heavily doped P-type regions.

18.6.2 WORKING OF A TRANSISTOR

When no voltage is applied at transistor's base, electrons in the emitter are prevented from passing to the collector side because of the pn junction. If a negative voltage is applied to the base of NPN transistor, the pn junction between the base and emitter becomes reverse biased resulting in the formation of a wider depletion region that prevents current flow.

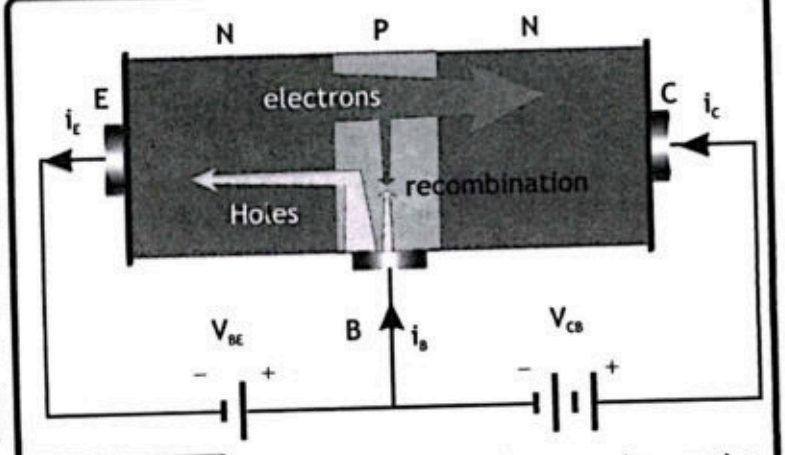


FIGURE 18.11 An npn transistor under normal operation.

Usually, two batteries are required for normal operation of a transistor; let we name these batteries as V_{BE} and V_{CB} (as shown in figure 18.11). For an NPN transistor, the negative terminal of the battery V_{BE} is connected to the N-type emitter and the positive terminal of the same battery is connected to the P-type base.

Therefore, the emitter-base junction of the transistor is forward biased. In the collector circuit, the N-type collector is connected to the positive terminal of the battery VCB and the P-type base is connected to the negative terminal of the same battery. Hence the collector-base junction of the transistor is reverse biased.

Electrons enter the emitter from the negative terminal of battery V_{BE} and flow toward the junction. The forward bias has reduced the potential barrier of the emitter-base junction. The electrons then combine with the hole carriers in the base to complete the emitter base circuit. However, the base is a very thin region, about 0.001 inches. Most of the electrons flow on through to the collector as the collector terminal is connected to positive terminal of the battery V_{CB} and this reverse biased potential is very large so most of the majority charge carriers are attracted and will cross the large base to collector depletion region due to large reverse biased potential.

Direction of conventional current in the external circuit is shown in figure 18.11. It can be seen that sum of collector current (I_C) and base current (I_B) is equal to the emitter current (I_E), i.e.

$$I_E = I_B + I_C \quad \text{— 18.1}$$

Approximately 95 % to 98 % of the current through the transistor is from an emitter to collector and about 2 % to 5 % of the current moves from emitter to base. The ratio between collector current and base current gives the current gain (β). i.e.

$$\text{Current gain} \quad \beta = \frac{I_C}{I_B} \quad \text{— 18.2}$$

Equation (18.2) gives the static or dc value of β. The dynamic or ac value is calculated for changes in the current values. The ratio between collector current and emitter current gives the current gain (α). i.e.

$$\text{Current gain} \quad \alpha = \frac{I_C}{I_E} \quad \text{— 18.3}$$

18.6.3 ROLE OF TRANSISTOR IN ADVANCEMENT OF COMPUTER TECHNOLOGY

The transistor is an important invention that changed the history for computers. Before transistors, digital circuits were composed of vacuum tubes. The vacuum tube used to amplify voice but the tubes consumed power, created heat and burned out rapidly, also requiring high maintenance. Transistors are commonly used in digital devices because they are both economical and act as rapid-response switches.

Transistors transformed the world of electronics and had a huge impact on computer design. Transistors made of semiconductors replaced tubes in the construction of computers. By replacing bulky and unreliable vacuum tubes with transistors, computers could now perform the same functions, using less power and space. With advances in engineering, the number of transistors that can be fit per unit area onto a circuit board has continued to increase dramatically; this has rapidly enhanced computing power. The first generation of computers used vacuum tubes; the second generation of computers used transistors; the third generation of computers used integrated circuits; and the fourth generation of computers used microprocessors.

Example 18.1

When collector current in a junction transistor is 99.9 mA and base current is 0.1 mA, how much is the emitter current?

GIVEN:
Collector current 'I_C' = 99.9 mA
Base current 'I_B' = 0.1 mA

REQUIRED:
Emitter current 'I_E' = ?

SOLUTION:
The relationship between emitter, base and collector current is: $I_E = I_B + I_C$

putting values $I_E = 99.9\ mA + 0.1\ mA$

Therefore $I_E = 100\ mA$ or $0.1\ A$ — ANSWER

Emitter current will be 0.1 A.

Example 18.2

Find the value of base current required to turn on the transistor for a collector current of 150 mA, for a transistor having current gain β = 190.

GIVEN:
Collector current 'I_C' = 150 mA
Current gain 'β' = 190

REQUIRED:
Base current 'I_B' = ?

SOLUTION:
The relationship for current gain is: $\beta = \frac{I_C}{I_B}$ or $I_B = \frac{I_C}{\beta}$ putting values $I_B = \frac{150\,mA}{190}$

Therefore $I_B = 0.789\ mA$ — ANSWER

Base current to run transistor will be around 0.8 mA.

18.7 RELAYS AND SWITCHING CIRCUITS

A Relay is an electrically operated switch that open and close the circuits by receiving electrical signals from outside sources. It consists of a set of input terminals for a signal and a set of operating contact terminals. For example consider figure 18.12, when you push the button on a TV remote to watch TV, it sends an electrical signal to the relay inside the TV, turning the main power ON.

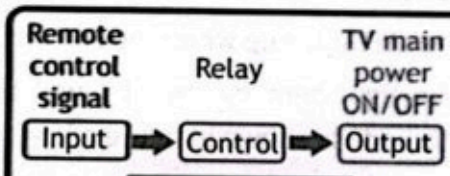


FIGURE 18.12

Block diagram of relay used in a TV.

Relays are very important in electronics. These are used to control a high power or high voltage circuit (or devices) with a low power circuit. A relays embedded in electrical products receive an electrical signal and send the signal to other equipment by turning the switch ON and OFF. For example:

- A timer circuit with a relay could switch power at a preset time.
- Relays are used to protect electrical circuits from overload or faults.
- Relays are used to turn on/off high-power devices like lamps or garage door motors with just a small DC voltage signal.

18.7.1 TYPES OF RELAY

There are various types of relays used in many applications to control different amounts of currents and number of circuits.

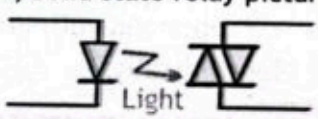
Relay technology can be divided into two main categories: Movable contacts (mechanical relay) and no movable contacts.

A. Movable Contacts (Mechanical Relay): This type of relay has contacts that are mechanically motivated to open/close by a magnetic force to switch signals, currents and voltages ON or OFF.

B. No Movable Contacts: Solid state relay (SSR), as shown in figure 18.13 (a), is an example of No-movable contact. It does not have any moving part, thus increasing long-term reliability. A solid state relay uses semiconductor and electrical switching device, activated by the control signal, to switch the controlled load. An optocoupler (a light-emitting diode coupled with a photo transistor or photo-TRIAC) can be used to isolate control and controlled circuits, as shown in figure 18.13 (b). Solid state relay (SSR) is commonly used for two reasons; a faster-switching process and durability.



(a) Solid state relay picture



(b) **Optocoupler:** a light-emitting diode coupled with a photo-TRIAC.

FIGURE 18.13

Solid state relay (SSR)

18.7.2 OPERATING PRINCIPLES OF SOLID STATE RELAYS

Solid State relays operate according to the following principles.

1. The LED lights up when the current is connected at the input side as shown in figure 18.14 (a).

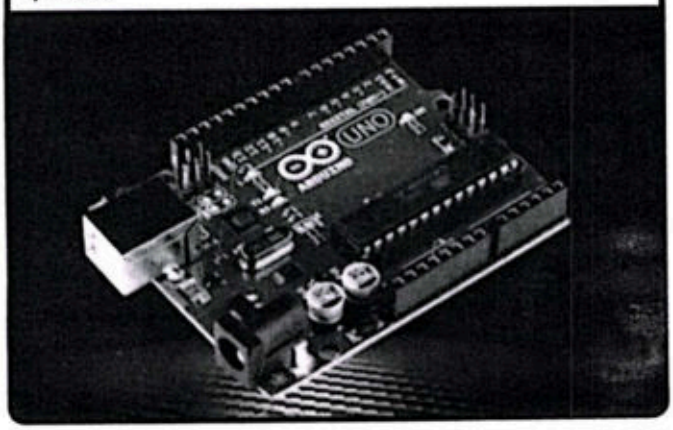
2. The light sent by the LED will be converted into voltage gain when it is received by the photodiode as shown in figure 18.14 (b).

3. This voltage will be a gate voltage to derive the transistor via control circuit as shown in figure 18.14 (c).

SCIENCE TIDBITS

You can use a microcontroller (such as Arduino) to create the logic for when to turn your lamp ON and OFF. It uses an electrical relay to do the switching of the lamp.

This makes it easy to make lights that activate only at night, control your garage door motor or other home appliances with a signal generated by your phone.



By the operation of these electronic circuits, signals (currents and voltages) are switched ON or OFF electronically.

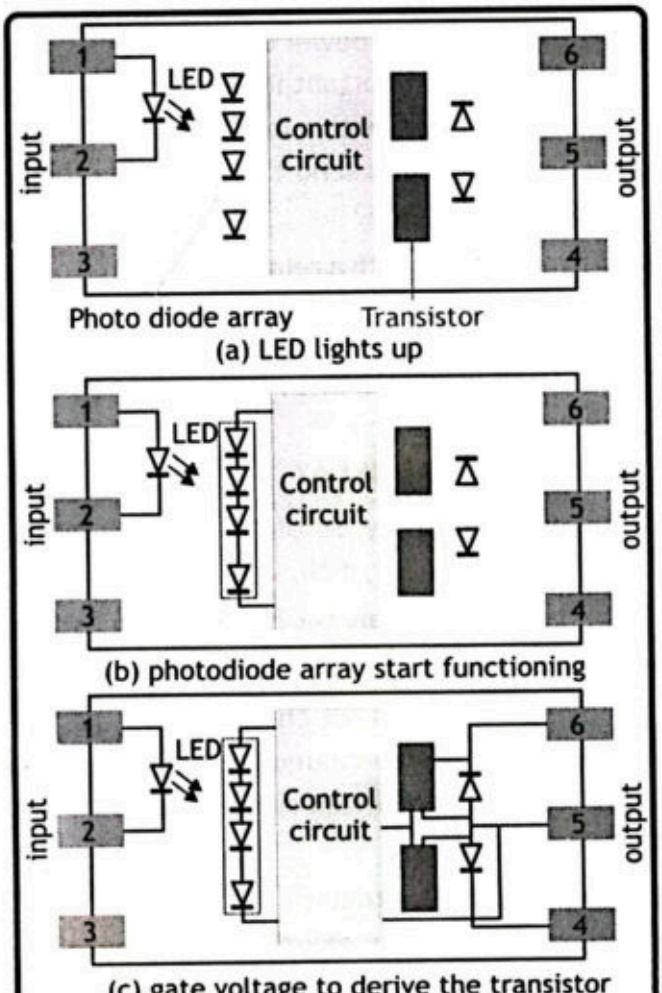


FIGURE 18.14 Operation of solid state relays

18.8 TRANSISTOR AS A SWITCH

The transistor can be used as a switch if biased in the saturation and cut-off regions. The collector C and emitter E of transistor behave as the terminal of switch. The base 'B' and emitter 'E' act as the control terminal to decide the state of the switch either on or off. The main reason behind

using the transistor as a switch is that the current at the base (I_B) controls the current present at the collector (I_C): as from the relation $I_C = \beta I_B$. If the current at the base exceeds the minimum cut-off value, then the behavior of the transistor is like a closed switch otherwise it will behave like an open switch.

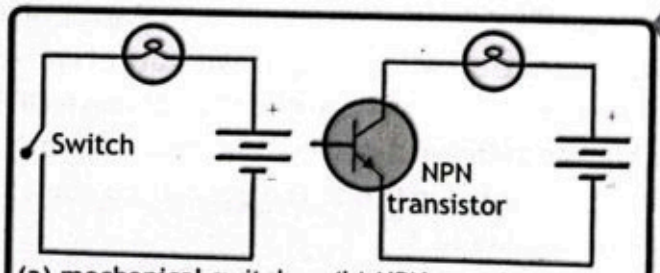


FIGURE 18.15 Transistor as a switch.

Suppose we have a lamp that we want to turn on and off with a switch, as shown in the figure 18.15 (a). Let's introduce a transistor in place of the switch as shown in figure 18.15 (b).

If the base of transistor is not connected to a suitable voltage, the base current will become zero. Consequently, the transistor cannot turn on. So, we must connect a switch between the base and collector wires of the transistor.

If the switch is open as shown in figure 18.16 (a), there will be no current through the base. According to the relation $I_C = \beta I_B$, no current will flow from the collector to the emitter. In this situation, the resistance between C and E become infinite and CE behaves as an open switch. In this state, the transistor is said to be in cutoff.

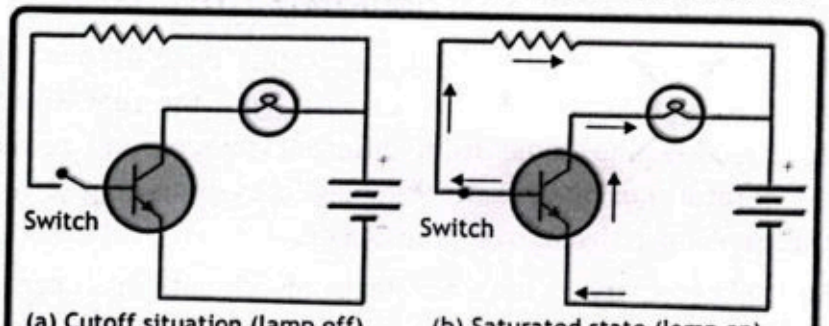


FIGURE 18.16 NPN transistor switching.

If the switch is closed as shown in figure 18.16 (b), current will be able to flow from the base to the emitter of the transistor through the switch. This base current will enable a much larger current flow from the collector to the emitter due to small resistance between C and E, thus lighting up the lamp. In this state circuit current is maximum and the transistor is said to be saturated.

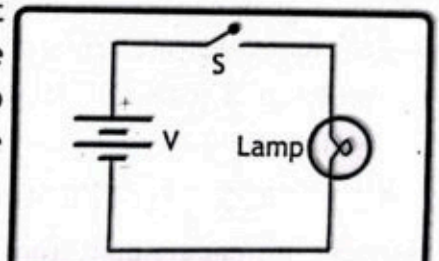


FIGURE 18.17 Switch.

18.9 DIGITAL ELECTRONICS

Digital electronic circuits deal with the situation having only two 'states': ON or OFF, TRUE or FALSE, HIGH or LOW, and YES or NO etc. For example, consider a circuit as shown in figure 18.17.

There are only two possible positions to flip a light switch i.e., ON or OFF (It's of no concern to you that there could be 110 volts, 120 volts or 220 volts i.e., fluctuating analog "signal", running

TABLE 18.1 SWITCHING

Switch (Input)	Lamp (Output)
Open	OFF
Closed	ON

through the electrical wiring connected to the light switch).

We call state of switch as input and state of current or lamp as output. When the switch is open no current passes through the circuit and lamp is OFF. In other words, when input is 0 output is also 0. When the switch is closed current passes through the circuit and lamp is ON. In other words, when input is 1 output is also 1. The possible combinations of input and output states of this circuit are shown in Table 18.1.

Like this ON/OFF switching, the same logic used to build the digital electronic circuits inside your laptop computer, GPS device and smart-phone. The two states can be best operated mathematically if the states are numerically represented by binary digits 1 and 0, also known as Boolean variables. English alphabets (A, B, C, etc.) are used to represent the Boolean variables. Boolean algebra is a formal way of describing logical operations. It is based on three basic logical operators such as: AND, OR and NOT.

18.9.1 CONVERTING ANALOGUE DATA TO DIGITAL DATA

The Analogue-to-Digital Converter (ADC) enables microprocessor-controlled circuits, like Arduinos and Raspberry Pi, to connect with the real world. In reality, analogue signals vary continuously and come from different sources and sensors that can detect sound, light, temperature, or movement. Many digital systems engage with their surroundings by measuring these analogue signals from transducers.

So it is necessary to have an electronic circuit which can convert the continuously changing analogue signals to discrete digital signals, such circuits are known as Analogue-to-Digital Converters. Whereas Digital-to-Analogue Converter (DAC) allow to convert discrete digital signal to analogue signals.

18.9.2 UNIT OF DATA IN COMPUTING

Analogue signals can be continuous and provide an infinite number of different voltage values. On the other hand, digital circuits work with binary signal which have only two discrete states, a logic "1" (HIGH) or a logic "0" (LOW). Each digit in binary (0 or 1) is called a bit, which is an abbreviation of binary digit.

18.9.3 LOGIC GATES: THE BUILDING BLOCKS OF ALL DIGITAL ELECTRONIC CIRCUITS

Electronic devices are built from digital logic circuits. Logic gates are the main building blocks of all digital logic circuits. These circuits can act as switches and convert incoming voltage into binary electrical pulses of high (or 1) and low (or 0). **Digital electronic circuits use to implement binary/logical operations are known as logic gates.**

Logic gates can have one or more inputs but only one output. Electronic devices are usually made from large assemblies of logic gates, often packed in integrated circuits. Common logic gates are AND, OR, NAND, NOR and NOT. Set of inputs and outputs of a logic system in binary form is called truth table.

18.10 FUNDAMENTAL LOGIC GATES

The three logic gates AND, OR and NOT are known as fundamental logic gates.

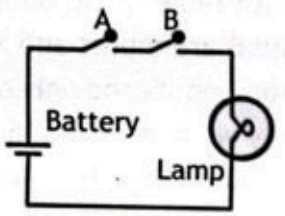
18.10.1 AND GATE

Consider the figure 18.18 (a) in which a lamp is connected in series with a battery using two switches (A and B) as two inputs.

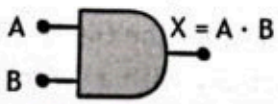
There are following four possible states of these two switches:

- When both the switches A and B are open then the lamp is OFF.
- When the switch A is open but B is closed then the lamp is OFF.
- When the switch A is closed but B open then the lamp is OFF.
- When both the switch A and B are closed then the lamp is ON.

It is clear that "the lamp will glow only if both the switches are closed". A logic gate which implements such action is known as AND gate. Symbol of AND gate is shown in figure 18.18 (b).



(a) Switch depiction



(b) Circuit symbol

FIGURE 18.18
AND gate

Boolean expression for AND operation is:

$$X = A \cdot B$$

(read as "X equals A AND B").

Where the symbol dot (•) represents the AND operation. The truth table of AND operation is shown in Table 18.2 AND gate has two or more inputs and only one output. Output of AND gate will be '1' only when all of its inputs are '1', and for all other situations output of AND gate will be '0'.

TABLE 18.2 AND GATE

Switch (Input)		Lamp (Output)
A	B	X = A • B
0	0	0
1	0	0
0	1	0
1	1	1

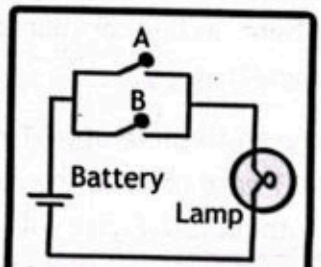
18.10.2 OR GATE

Consider the figure 18.19 (a) in which a lamp is connected in parallel with a battery using two switches (A and B) as two inputs.

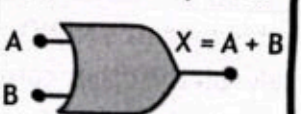
There are following four possible states of these two switches:

- When both the switches A and B are open then the lamp is OFF.
- When the switch A is open and B is closed then the lamp is ON.
- When the switch A is closed and B is open then the lamp is ON.
- When both the switches A and B are closed then the lamp is ON.

It is clear that "the lamp will glow if at least one of the switches is closed". A logic gate which implements such action is known as OR gate. Symbol of OR gate is shown in figure 18.19 (b).



(a) Switch depiction



(b) Circuit Symbol

FIGURE 18.19
OR gate

Boolean expression for OR operation is: $X = A + B$

(read as "X equals A OR B").

Where the symbol plus (+) represents the OR operation. The truth table of OR operation is shown in Table 18.3, where A and B are inputs and X is output (lamp). OR gate has two or more inputs and only one output. Output of OR gate will be '0' only when all of its inputs are '0', and for all other situations output of OR gate will be '1'.

TABLE 18.3 OR GATE

Switch (Input)		Lamp (Output)
A	B	X = A + B
0	0	0
1	0	1
0	1	1
1	1	1

18.10.3 NOT GATE

Consider the figure 18.20 (a) in which a lamp is connected in parallel to a battery with a switch A as inputs. There are two possible states of these two switches which are given below:

- When the switch A is open, current will pass through the lamp and it will glow.
- When the switch A is closed, no current will pass through the lamp due to large resistance of its filament and it will not glow.

It is clear that "the lamp will glow if the switch is open". A logic gate which implements such action is known as NOT gate. Symbol of NOT gate is shown in figure 18.20 (b).

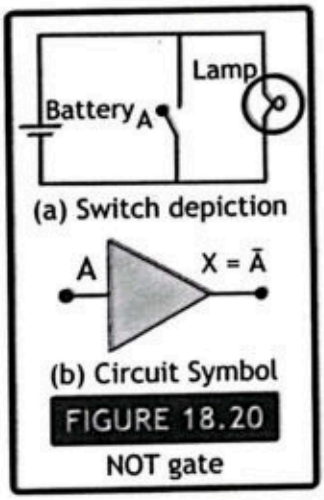


FIGURE 18.20
NOT gate

Boolean expression for NOT operation is:

$$X = \bar{A}$$

(read as "X equals A NOT")

Where a line or bar over the symbol represents the NOT operation.

TABLE 18.4 NOT GATE

Switch (Input)	Lamp (Output)
A	X = Ā
0	1
1	0

The truth table of NOT operation is shown in Table 18.4, where A is input and X is output (lamp). NOT gate has one inputs and one output. NOT operation inverts the state of Boolean variable. Output of NOT gate will be '0' when its inputs are '1', and vice versa.

18.11 UNIVERSAL LOGIC GATES

The logic gates NAND and NOR gates are known as "universal gates" because they can be used to make all the other gates.

18.11.1 NAND GATE

NAND gate is obtained by coupling a NOT gate with the output terminal of the AND gate, as shown in figure 18.21 (a). The NOT gate inverts the output of the AND gate. Thus, NAND gate is the

reciprocal of AND gate. Symbol of NAND gate is shown in figure 18.21 (b) (small circle shows the NOT operation).

Boolean expression for NAND operation is:

$$X = \overline{A \bullet B}$$

(read as "X equals A AND B NOT").

The truth table of NAND operation is shown in Table 18.5.

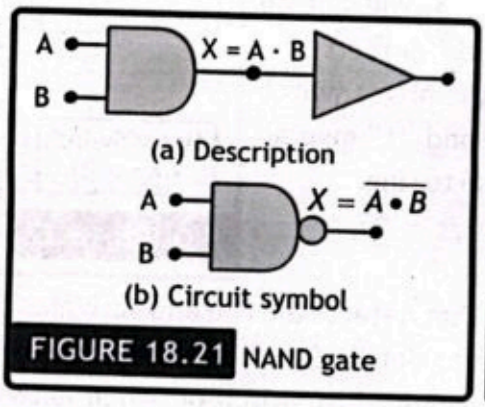


FIGURE 18.21 NAND gate

TABLE 18.5 NAND GATE

Switch (Input)		Lamp (Output)
A	B	$X = \overline{A \bullet B}$
0	0	1
1	0	1
0	1	1
1	1	0

18.11.2 NOR GATE

The NOR gate is obtained by coupling the output of the OR gate with the NOT gate, as shown in figure 18.22 (a). The NOT gate inverts the output of the OR gate. Symbol of NOR gate is shown in figure 18.22 (b).

Boolean expression for NOR operation is:

$$X = \overline{A + B}$$

(read as "X equals A OR B NOT").

The truth table of NOR operation is shown in Table 18.6.

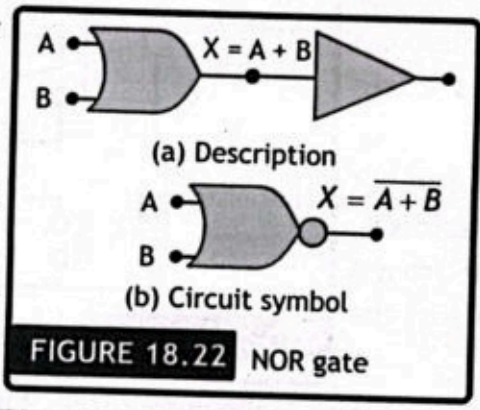


FIGURE 18.22 NOR gate

TABLE 18.6 NOR GATE

Switch (Input)		Lamp (Output)
A	B	$X = \overline{A + B}$
0	0	1
1	0	0
0	1	0
1	1	0

18.12 USES OF LOGIC GATES

Every day in our lives, we encounter many things that work with the help of logic gates. Logic gates are used in electronic circuits to do useful tasks. These are also used for security purposes e.g; burglar alarm and fire extinguisher etc.

18.12.1 BURGLAR ALARM

A burglar alarm system detect movement or the opening of doors and windows using sensors and contacts, and aloud alarm is emitted to warn others.

A simple burglar alarm circuit can be made by using an AND gate. We have two inputs which are the person sensor and the alarm switch, as shown in figure 18.23.

- If both the person sensor and the alarm switch are ON, then the burglar alarm is activated.
- If only one input is ON, the burglar alarm will not be activated.

For example, if the person sensor is ON but the alarm switch is not, the burglar alarm will not be activated. When the person sensor detects the person, it gives the signal 1. Then the alarm switch will also give a signal 1. Thus, "1" and "1" give an output "1" which will make the alarm to ring.

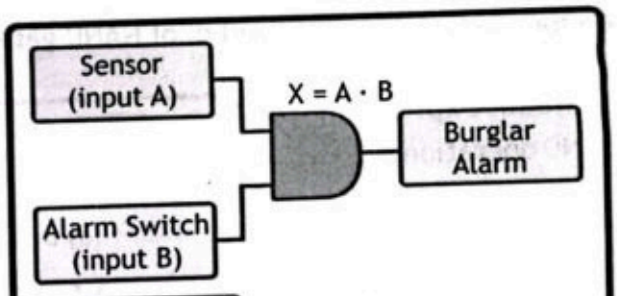


FIGURE 18.23 Burglar alarm

18.12.2 FIRE EXTINGUISHER

Fire alarm circuit is a simple circuit that detects the fire and activates the Siren Sound. Fire Alarm Circuits are very important devices to detect fire in the right time and prevent any damage to people or property. The circuit is required to switch on when activated then sound a buzzer continuously. A fire alarm circuit using a NAND gate is shown in figure 18.24.

The buzzer is initially off so the output from A is 0. This requires the output from gate B must be 1. There being no fire, the thermistor is cold and it's resistance is high, so there is a voltage across it and so the two inputs to gate A are both 1.

When the thermistor is warmed by a fire, it's resistance falls, as does the voltage across it, and input 1 falls to 0. The output from A becomes 1 so there is a voltage across the buzzer, which sounds.

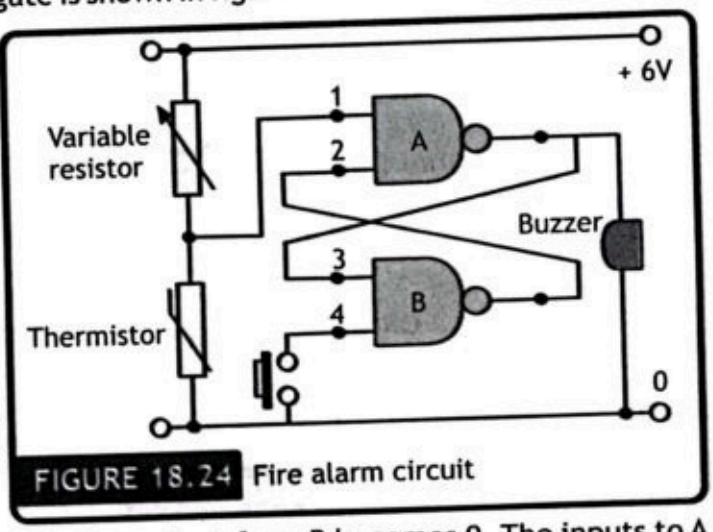


FIGURE 18.24 Fire alarm circuit

Input 3 to B becomes 1, and since input 4 is also 1, the output from B becomes 0. The inputs to A are 1 and 0, so the output stays at 1. To reset the alarm, the reset switch R must be pressed. This will make input 4 into a 0, so the output from B will be 1 and A will have inputs of 1 and 1, so output 0 as originally.

18.13 ANALOGUE AND DIGITAL ELECTRONICS, A COMPARISON

Based on types of signals used, the electronics can be broadly classified into two branches: Analog Electronics and Digital Electronics. Analog electronics is the branch of electronics that deals with the electronic systems and devices with the continuous time signals. Analog electronics can be used to amplify signals, filter noise, and perform a wide variety of other functions. In analog electronics, two types of components are used to design the systems which are: the active elements such as diode, transistors, etc. and the passive elements such as resistors, capacitors, inductors, etc. Analog electronics is widely used in radio and audio devices such as FM radios, TVs, telephones, etc.

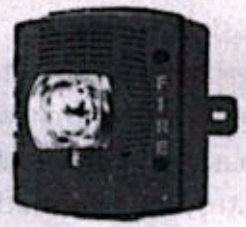
Digital electronics is the branch of electronics that deals with the electronic systems and devices with digital signals or discrete time signals. The digital electronics uses binary logic function to perform operations, the basic mean of binary logic function is that it has only two states 'active high' and 'active low'. One of the most common application of digital electronics is in computers. Other applications include, data processing and storage, automation and digital watches.

Digital electronics systems are usually made from a combination of logic gates, often packaged in an integrated circuit (IC). Digital electronics uses active components only. Digital system has many advantages over analogue, some are given below:

- Digital system has small size.
- Digital systems are generally easier to design.
- Accuracy and precision are greater.
- Digital systems need less power to operate.
- Operation can be programmed.
- Digital circuits are not affected by noise (noise is fluctuations in voltage).

INFORMATION

Fire Alarm Circuits and Smoke Sensors are a part of the security systems which help in detecting or preventing damage. Installing Fire Alarm Systems and Smoke Sensors in commercial buildings like offices, hospitals, schools, shopping malls and other public places is compulsory.



An analog quantity (or signal) is one having continuous values over limit. For Example, temperature, time, pressure, sound and distance etc., are analogue quantities. The digital quantity (or signal) is one having a set of discrete values over limit.

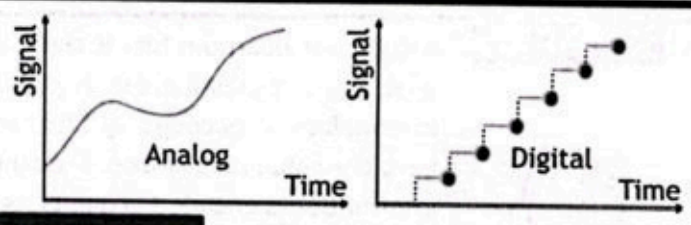
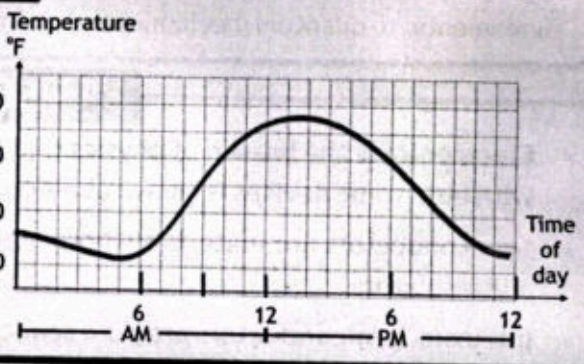


FIGURE 18.25 Operation of solid state relays

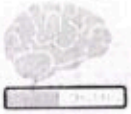
INFORMATION

The temperature of air varies in a continuous fashion during 24 hours of a day. If we plot a graph between temperature and time, we get graph as shown below. This graph shows that temperature varies continuously with time. The air temperature does not go from, say, 75 °F to 80 °F instantaneously, it takes the infinite values in between. Therefore, we say that temperature is an analogue quantity.

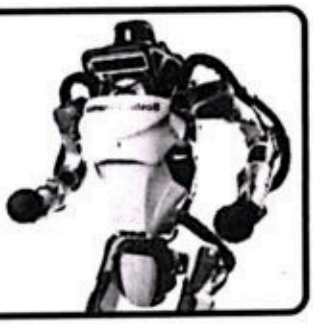


These quantities change in discrete steps. Graphs of both analogue and digital signals are shown here in figure 18.25.

SCIENCE TIDBITS



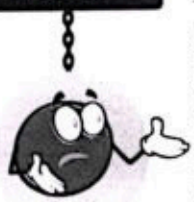
In today's technological world, both analog and digital electronics are equally used to implement most efficient and fast processing systems such as robotics, quantum computing, telecommunication, etc.



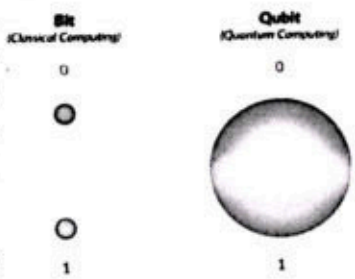
18.14 QUANTUM COMPUTERS

Quantum computing uses phenomena in quantum physics to create new ways of computing. Unlike traditional computers that use bits to represent information as either a 0 or a 1, quantum computers use qubits (or quantum bit), which can exist in multiple states simultaneously. This allows quantum computers to perform complex calculations at an exponentially faster rate than classical computers. Quantum computers are still in early stages of development, and have to overcome manufacturing challenges such core components only functioning at very cold temperatures that are at almost absolute zero. Most qubits must be cooled to within a few thousandths of a degree of absolute zero to eliminate thermal noise and vibrations, which tend to destroy the information contained in the qubits.

CAN YOU TELL?



A qubit (or quantum bit) is the quantum mechanical analogue of a classical bit. In classical computing the information is encoded in bits, where each bit can have the value zero or one. In quantum computing the information is encoded in qubits. In a classical system, a bit would have to be in one state or the other.



However, quantum mechanics allows the qubit to be in a coherent superposition of multiple states simultaneously. This property is fundamental to quantum mechanics and quantum computing.

SUMMARY

- **Electronics** is the branch of physics that helps to study the emission and behaviour of electrons with electronic devices is known as electronics.
- Semiconductors are materials whose electrical conductivity falls between those of conductors and insulators.
- **Intrinsic Semiconductors** are pure semiconductors (such as Si or Ge).
- **Extrinsic Semiconductors** are those semiconductors that are doped with some specific impurities.

- **Pentavalent impurities** such as phosphorus, arsenic, antimony, and bismuth have five valance electrons and belong to group V-A of periodic table.
- **Trivalent impurities** e.g., boron, aluminum, indium, and gallium have three valance electrons and belongs to group III-A of periodic table.
- **Majority Charge Carriers** in n-type semiconductor are electrons and in p-type semiconductor are holes.
- **Forward Bias** is the condition when the positive terminal of a DC source is connected to p-type and negative terminal is connected to n-type semiconductor of a pn junction.
- **Light-Emitting Diode** emits energy in the form light when the electric current passes through it.
- **Transistor** acts as both a transmitter and resistor. It is made in two types: PNP and NPN.
- **Relay** is an electrically operated switch that open and close the circuits by receiving electrical signals from outside sources.
- **Analogue-to-Digital Converter** is electronic circuit which can convert the continuously changing analogue signals to discrete digital signals.

Digital-to-Analogue Converter (DAC) allow to convert discrete digital signal to analogue signals.

- **Bit** is each digit in binary (0 or 1), which is an abbreviation of binary digit.
- **Logic gates** implement binary operations to digital electronic circuits.
- **Fundamental logic** gates are three logic gates AND, OR and NOT logic gates.
- **Universal logic gates** are the logic gates NAND and NOR because they can be used to make all the other gates.
- **Quantum Computing** uses phenomena in quantum physics to create new ways of computing.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. The approximate potential barrier for germanium and silicon transistors are _____ respectively?

   A. 0.3 V and 0.7 V B. 0.7 V and 0.3 V C. 0.7 V and 0.5 V D. 0.5 V and 0.7 V

2. The current ratio of a beta is:

   A. I_C / I_E B. I_B / I_C C. I_E / I_B D. I_C / I_B

3. Which of the following relation is correct for a transistor?

   A. $I_C = I_B + I_E$ B. $I_B = I_C + I_E$ C. $I_E = I_C + I_B$ D. $I_E = I_C - I_B$

4. The heavily doped region of the transistor is:
   A. Emitter B. Collector C. Base D. All of these
5. A transistor has _____ PN junctions.
   A. 1 B. 2 C. 3 D. 4
6. If $I_E = 1$ mA and $I_C = 0.25$ mA then the I_B value will be:
   A. 0.75 mA B. 0.95 mA C. 0.65 mA D. 0.85 mA
7. If the gain β of a NPN transistor is 200 and its collector current is 4 mA. The value of base current will be:
   A. 20 μA B. 25 μA C. 30 μA D. 35 μA
8. The majority charge carriers in the emitter of an NPN transistor are:
   A. pentavalent atoms B. electrons C. trivalent atoms D. holes
9. The output of a NAND gate is 0 when:
   A. A is '1' and B is '0' B. A is '0' and B is '1' C. both A and B are '0' D. both A and B are '1'
10. If X = A + B, then X is 0 when::
    A. both A and B are '0' B. A or B is '0' C. A is '0' and B is '1' D. A is '1' and B is '0'
11. The output of a NOR gate is '1' when:
    A. both of its inputs are '0' B. both of its inputs are '1'
    C. any of its inputs is '0' D. any of its inputs is '1'
12. The logical operation performed by this gate is:

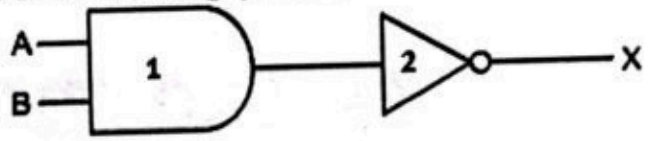


    A. AND B. NOR
    C. NAND D. OR

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Consider the given logic circuit:



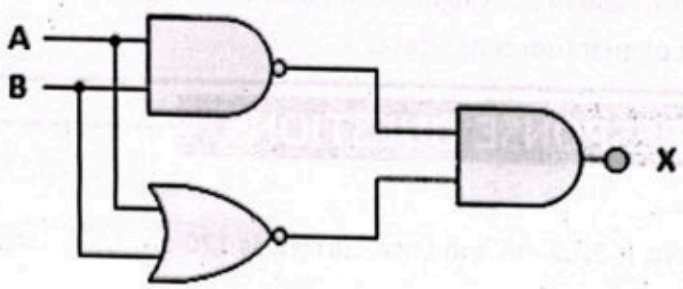
a) Identify the logic gates in the circuit:

Name of the gate 1 is _____

Name of the gate 2 is _____

b) Draw a single logic gate that can replace the given logic circuit

2. Write the expression for the following combination of logic gates. Here A and B are inputs and X is output. Also complete its truth table.



TRUTH TABLE		
Inputs		Output
A	B	X =
0	0	
1	0	
0	1	
1	1	

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. How do N-type materials and forward biasing affect semiconductor devices?
2. Why are pentavalent impurities called donors and trivalent impurities acceptors?
3. How do relays improve electrical systems? Give examples.
4. How do the three terminals of a transistor work together to amplify signals?
5. Why is one transistor region highly doped and another the smallest in size?
6. What does the arrow in a transistor symbol represent, and why is it important?
7. Explain the normal biasing of an NPN transistor. What happens if it is reversed?
8. How does biasing (forward or reverse) change the depletion region in a diode?
9. Why does an n-type or p-type material have zero net charge?
10. Why are NAND and NOR gates called universal gates?
11. For a NOR gate, how do you determine the output for different inputs?
12. What makes digital systems better than analog systems?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. What is an extrinsic semiconductor? How do impurities affect its conductivity?
2. Describe how a PN junction forms and explain the effects of forward and reverse biasing on it.
3. Using a diagram, explain how a solid-state relay works and its advantages over mechanical relays.
4. Describe how an NPN transistor operates, focusing on the movement of charge carriers.

5. How can a transistor function as a switch? Provide examples of its use in circuits.
6. Explain the working of an OR gate with a circuit diagram. How does it process input signals?
7. How are logic gates used in burglar alarms and fire extinguishers? Explain with examples.
8. Discuss the challenges in development of quantum computers.

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. In a junction transistor, emitter current is 5.82 mA and base current is 120 μA. Calculate the collector current.

(Ans. 5.7 mA)

2. For a 600 μA base current and 30 mA collector current, how much is the current gain β?

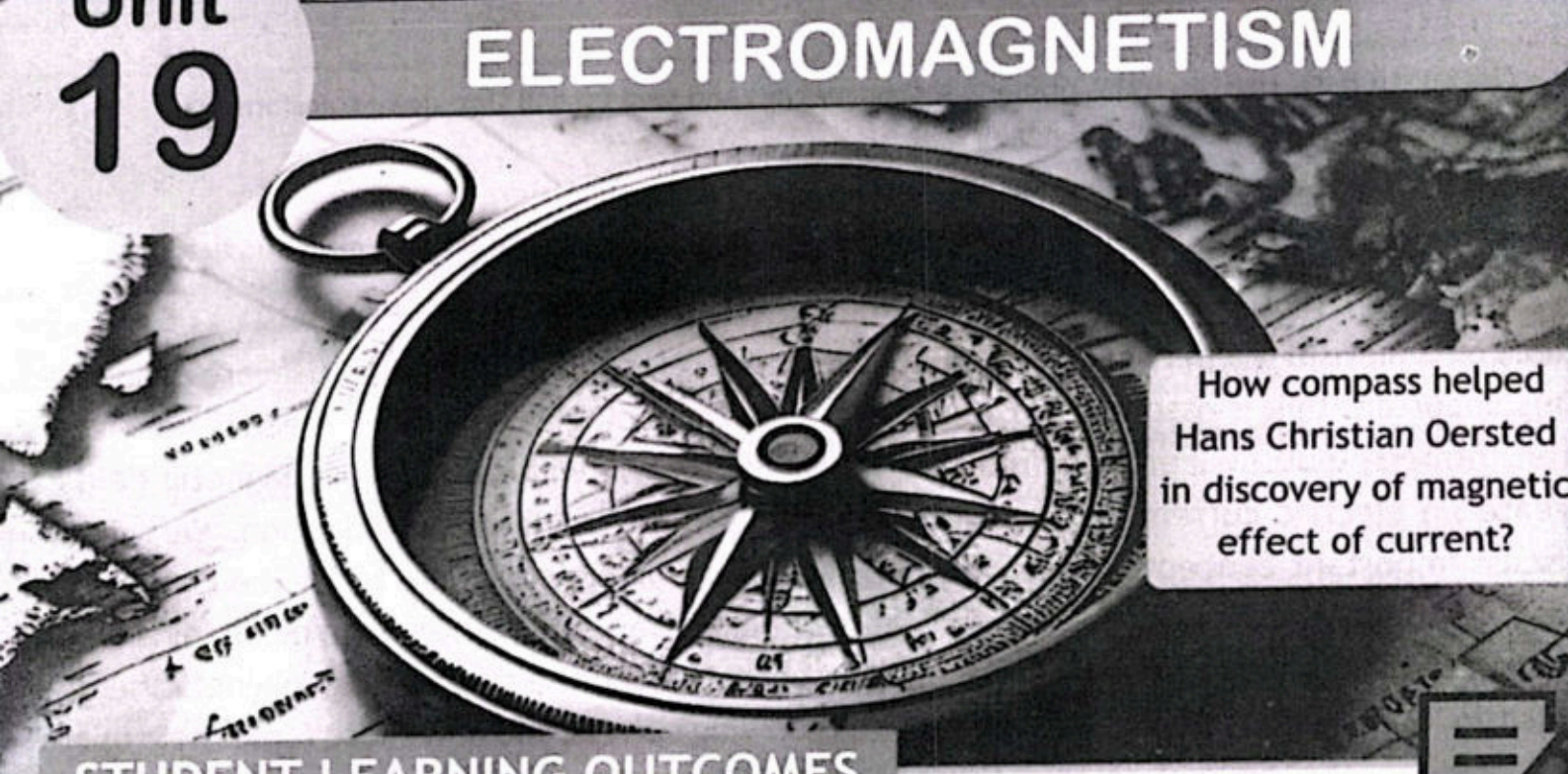
(Ans. 50)

3. Calculate the value of β gain if an emitter current is changed by 4 mA and the collector current is changes by 3.5 mA.

(Ans. 7)

Unit 19

ELECTROMAGNETISM



How compass helped Hans Christian Oersted in discovery of magnetic effect of current?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-74] Describe an experiment to demonstrate electromagnetic induction.
- ✓ [SLO: P-10-E-75] Use the fact that the magnitude of an induced e.m.f. is affected by (a) the rate of change of the magnetic field or the rate of cutting of magnetic field lines, and (b) the number of turns in a coil, to solve simple electromagnetic problems.
- ✓ [SLO: P-10-E-76] 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).
- ✓ [SLO: P-10-E-77] Describe how a.c. generators work.
- ✓ [SLO: P-10-E-78] Sketch and interpret graphs of e.m.f. against time for simple a.c. generators.
- ✓ [SLO: P-10-E-79] Describe the pattern and direction of the magnetic field due to currents in straight wires and in solenoids.
- ✓ [SLO: P-10-E-80] State the effect on the magnetic field of changing the magnitude and direction of the current.
- ✓ [SLO: P-10-E-81] Describe how the magnetic effect of a current is used in relays and loudspeakers.
- ✓ [SLO: P-10-E-82] Describe an experiment to show that a force acts on a current-carrying conductor in a magnetic field.
- ✓ [SLO: P-10-E-83] state and use the relative directions of force, magnetic field and current.
- ✓ [SLO: P-10-E-84] Describe the magnetic field patterns between currents in parallel conductors and relate these to the forces on the conductors.
- ✓ [SLO: P-10-E-85] 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.
- ✓ [SLO: P-10-E-86] Describe the operation of an electric motor, including the action of a split-ring commutator and brushes.
- ✓ [SLO: P-10-E-87] State that it is theorized that the Earth's magnetic field is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion.
- ✓ [SLO: P-10-E-88] Explain the principle of operation of a simple iron-cored transformer.

- ✓ [SLO: P-10-E-89] Use the terms primary, secondary coils and step-up and step-down transformer.
- ✓ [SLO: P-10-E-90] Use the equation $V_p/V_s = N_s/N_p$.
- ✓ [SLO: P-10-E-91] Justify the advantages of high-voltage transmission.
- ✓ [SLO: P-10-E-92] Describe the deflection of an electron beam by electric fields and magnetic fields.
- ✓ [SLO: P-10-E-93] Interpret waveforms on oscilloscopes.

Electromagnetism is a part of physics that studies how electricity and magnetism are connected. This important link is essential for many everyday technologies, including electric generators, transformers, loudspeakers, and relays. In this chapter, we will learn how a magnetic field can create an electric current through a process called electromagnetic induction. We will also discuss important concepts like Lenz's Law, which shows how currents resist the changes that produce them. Additionally, we will look at how a.c. generators work to turn mechanical energy into electrical energy and how changes in current influence the surrounding magnetic field. We will also investigate the forces acting on wires carrying current and how these forces help operate key devices. By the end of this chapter, you will see how electromagnetism powers many technologies in our modern world.

19.1 MAGNETIC FIELD DUE TO CURRENT CARRYING WIRE

Ampere discovered that when a current pass through a conductor, it produces magnetic field around it. To understand this fact, let's perform a simple activity.

ACTIVITY 19.1

Take a cardboard and a straight wire of conducting material.

- Make a hole at the centre of cardboard.
- Pass the wire vertically through a cardboard, as shown in the figure 19.1 (a).
- Connect the two ends of the wire with the terminals of the battery so that current (I) flows through the wire in the anti-clockwise direction.
- If we place a compass needle at different points in the region of magnetic field, it will align along the direction of magnetic field that would be in the form of concentric circles.
- If we reverse the direction of the current by reversing the terminals of the battery, the compass needle also reverses its direction, as shown in the figure 19.1 (b).
- The magnetic field produced is stronger near the current-carrying conductor and weaker farther away from it.

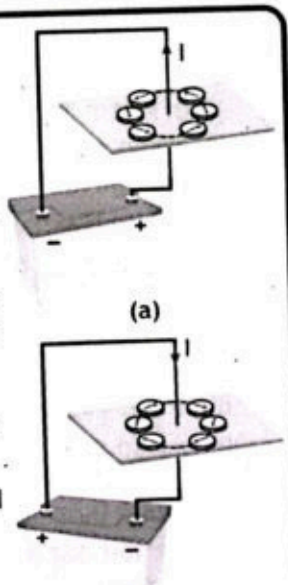


FIGURE 19.1

Conclusion: Following conclusion can be drawn from the above experiment.

- Current through a conducting wire creates a magnetic field around the wire.
- Magnetic field lines are circular and their direction depends on the direction of current.

19.1.1 DIRECTION OF THE MAGNETIC FIELD OF CURRENT CARRYING WIRE

The direction of the magnetic field (B) around a current carrying straight wire can be determined by the right-hand rule, as shown in figure 19.2 (a). According to right-hand rule: If the wire is grasped in fist of right hand with the thumb pointed in the direction of the current, the fingers of the hand will curl in the direction of magnetic field.

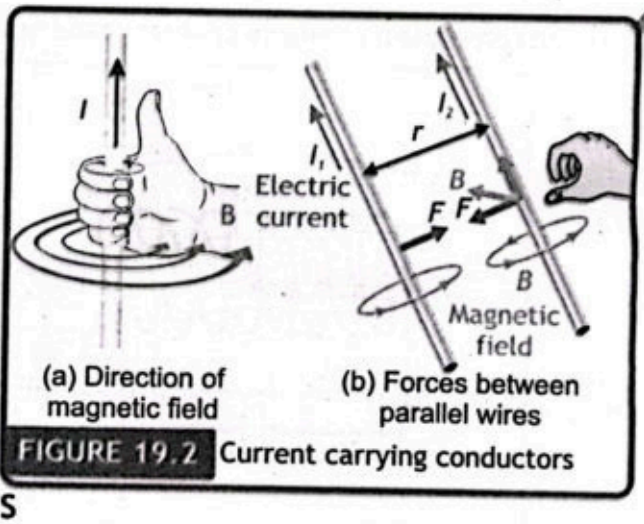


FIGURE 19.2 Current carrying conductors

19.1.2 PROPERTIES OF MAGNETIC FIELD LINES

Like electric field lines, magnetic field lines are also imaginary lines and don't exist physically. The properties of magnetic field lines are given below:

- Magnetic field lines emerge from north poles and ends on south poles.
- Magnetic field lines form closed paths.
- Tangent to the magnetic field lines gives the direction of magnetic field at any point.
- Magnetic field lines never intersect or cross each other.
- Density of magnetic field lines at any point indicates magnetic field strength at that point.

The properties of magnetic field lines help us to understand and visualize magnetic fields. These lines also help us to understand the working of magnets in electric motors and generators etc.

19.1.3 FORCES ON PARALLEL CURRENT CARRYING CONDUCTORS: When current in the two wires are in same direction, as shown in the figure 19.2 (b), then magnetic fields created along each of the two wires will be such that their opposite poles are in between the two wires. These opposite poles attract each other. Thus, two long parallel wires carrying a current in same direction attract each other. What will happen if the current is in opposite direction?

19.2 MAGNETIC FIELD DUE TO CURRENT CARRYING SOLENOID

A solenoid is a long, tightly wound (spring like) coil of wire, as shown in figure 19.3.

When current passes through a solenoid, magnetic field established around the solenoid. The field from each loop in a solenoid adds to the fields of the other loops and creates greater total field strength. The magnetic field of a solenoid is strong and uniform along its axis, whereas negligibly weak outside, as shown in figure 19.4 (a).

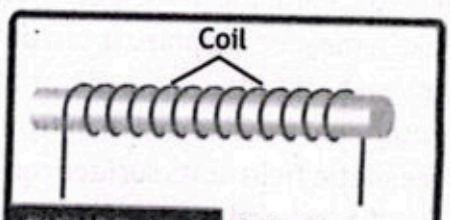
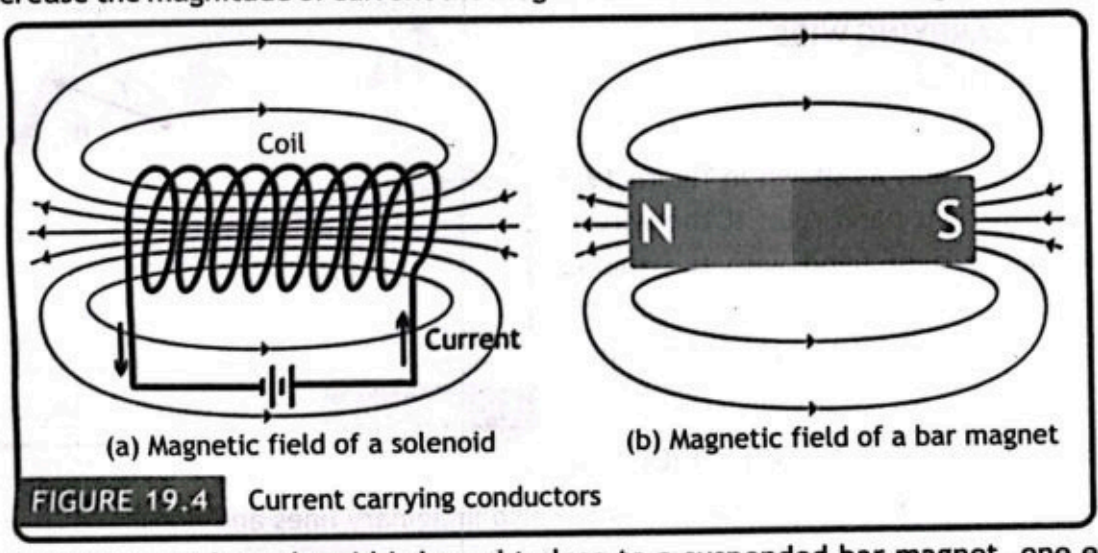


FIGURE 19.3 Solenoid

If we increase the magnitude of current the magnetic field will become stronger.



(a) Magnetic field of a solenoid (b) Magnetic field of a bar magnet

FIGURE 19.4 Current carrying conductors

When a current-carrying solenoid is brought close to a suspended bar magnet, one end of the solenoid repels the north pole of the bar magnet. Thus, the current carrying solenoid has a north and a south pole and behaves like a permanent bar magnet.

The direction of the magnetic field produced by a solenoid can be found with the help of right-hand rule, as shown in 19.5. According to this rule if we grip the coil with our right hand by curling our fingers in the direction of the conventional current, our thumb will indicate the north pole of the coil, which is along the axis of solenoid.

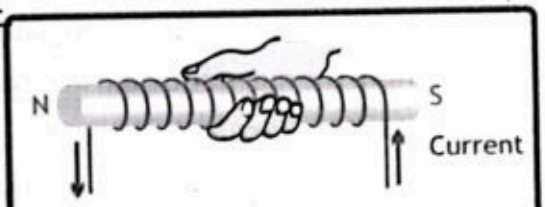


FIGURE 19.5 Right-hand rule for solenoid

19.3 EARTH'S MAGNETIC FIELD

The Earth can be thought of as containing an enormous bar magnet in its core, as shown in the figure 19.6. The magnetic south pole of Earth's magnet is at the geographic North Pole, and conversely magnetic North pole of Earth's magnet is at the geographic South Pole (as opposite magnetic poles attract and the north end of a magnet, like a compass needle, points toward Earth's South magnetic pole). The Earth's magnetic field appears like a magnetic dipole. It can be represented by the field of a bar magnet, tilted at an angle of about 11° with respect to Earth's rotational axis, as shown in figure 19.7. The magnitude of Earth's magnetic field at its surface ranges from 25 to 65 μT (0.25 to 0.65 G). It is several hundred times weaker than the field around the bar magnet.

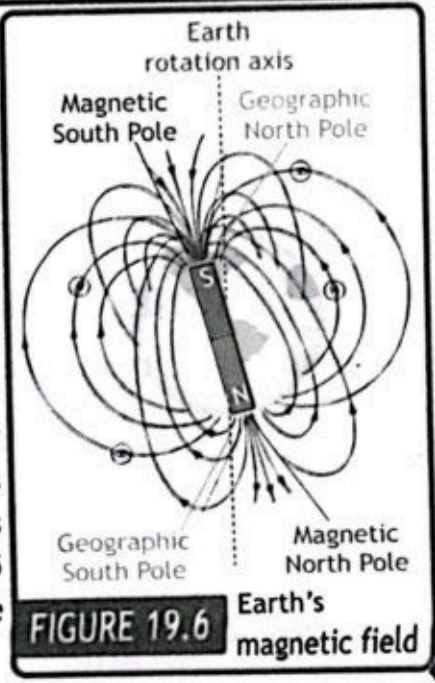


FIGURE 19.6 Earth's magnetic field

The magnetic field lines are parallel to the surface of the Earth at the equator, and normal to the Earth's surface at the magnetic poles.

The Earth's magnetic field (also known as the geomagnetic field) is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion. Core is primarily made up of the molten magnetic material such as iron and nickel. Molten iron is a good conductor. The movement of this molten iron, driven by convection currents and influenced by Earth's rotation, creates electrical currents within the outer core. These currents produce a magnetic field, which maintains a stable and protective magnetic shield around the Earth. Earth's magnetic field starts in the core of the Earth, coming out into space forming a magnetosphere.

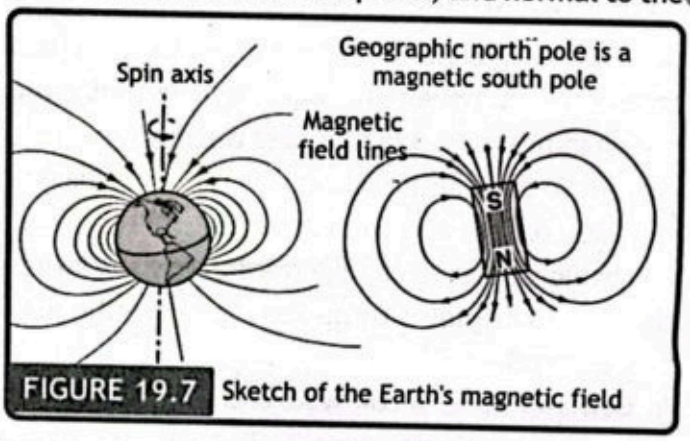


FIGURE 19.7 Sketch of the Earth's magnetic field

19.4 APPLICATION OF MAGNETIC EFFECT OF A CURRENT

There are many devices that work on magnetic effect of current. Two such devices are discussed here.

19.4.1 LOUDSPEAKERS

In a loudspeaker, the magnetic effect is a fundamental principle that enables the conversion of electrical energy into mechanical energy, which then produces sound. The loudspeaker consists of a permanent magnet and a coil of wire (known as the voice coil) which is attached to the speaker cone, as shown in figure 19.8.

When an electrical signal (corresponding to the sound to be produced) is passed through the voice coil, it creates a magnetic field around the coil. This magnetic field interacts with the magnetic field of the permanent magnet. Depending on the direction of the current, the voice coil is either attracted to or repelled from the permanent magnet. This movement of the voice coil causes the attached speaker cone to vibrate. These vibrations move the air particles around the speaker, creating pressure waves that our ears perceive as sound.

The amplitude of the electrical signal determines the volume of the sound. A larger current will cause a stronger magnetic field, resulting in larger vibrations and a louder sound.

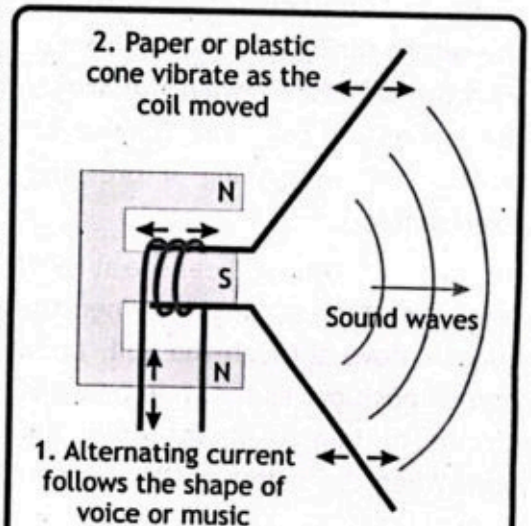


FIGURE 19.8 Loudspeaker.

19.4.2 RELAY

A relay is an electrical control device that facilitates interaction between the input and output circuits, as shown in figure 19.9 (a). It uses the magnetic effect of a current to control the output circuit. A mechanical relay consists of an electromagnet, a switch, and some mechanical parts to change the state of the switch when the electromagnet is turned on. Here are the main parts inside the relay:

A. Coil and core: A coil wound around a magnetic core makes up an electromagnet. It generates a magnetic field around it when an electrical current passes through the coil.

B. Armature: The armature is a movable component within the relay. When the coil is energized, the magnetic field it produces attracts the armature, causing it to move.

C. Return Spring: The return spring is connected to the armature, providing a restoring force when the coil is de-energized. It ensures that the armature returns to its original position when the electrical current through the coil ceases.

D. Moving Contact: Attached to the armature through the return spring, the moving contact physically moves with the armature. When the armature is attracted by the energized coil, the moying contact changes its position, either making or breaking contact with the fixed contacts.

How a Relay Works: Let's see at how a lamp is turned on using a switch and a relay. When the switch is OFF, no current flows through the coil, armature remain in its normal position, as shown in figure 19.9 (b). In this way circuit of lamp remains open and lamp does not glow.When the switch is ON, current flows through the coil, armature got attracted toward the coil, as shown in figure 19.9 (c). In this way circuit of lamp get closed and lamp glows.

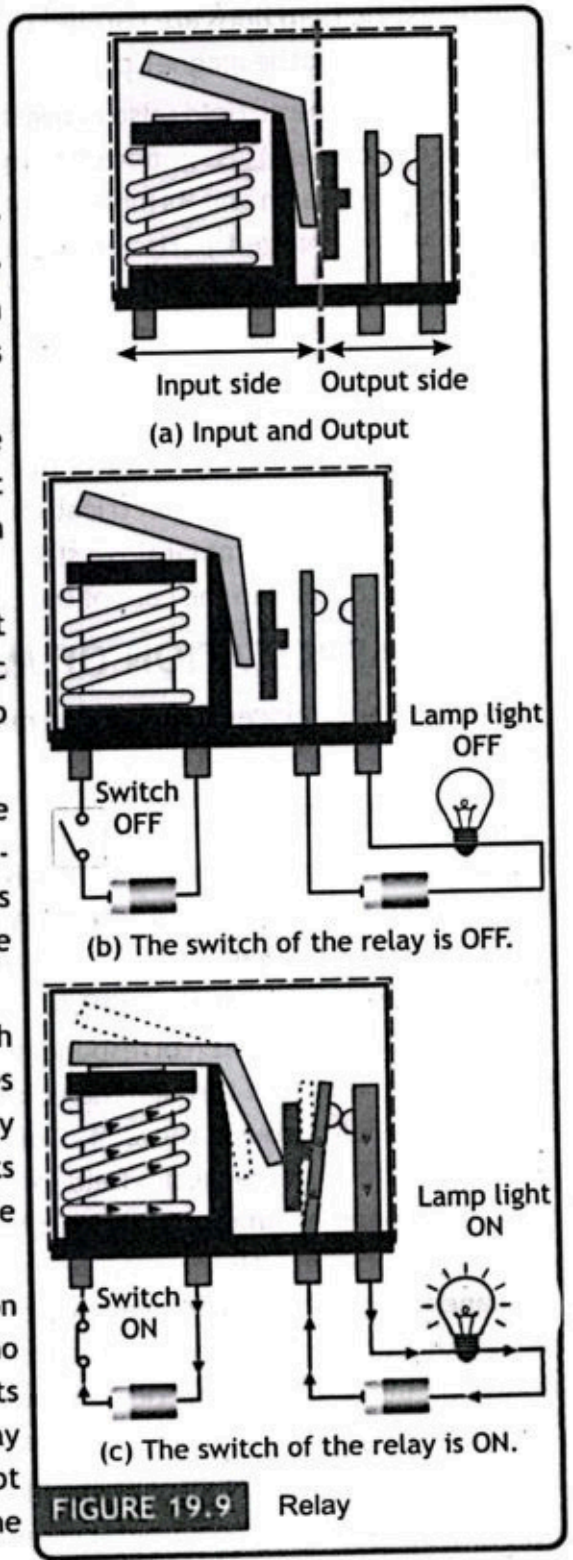


FIGURE 19.9 Relay

The circuit breaker uses mechanical relay to disconnects the electric supply automatically if current exceeds the normal value. It acts as a safety device in the same way as a fuse.

19.5 FORCE ON A CURRENT CARRYING CONDUCTOR PLACED IN MAGNETIC FIELD

When a current carrying conductor is placed in a magnetic field it experiences a force. Let us take a simple activity to observe this effect.

ACTIVITY 19.2

Take a battery, two magnets of different sizes and intensities, small aluminium rod AB, connecting wires and an iron stand.

Arrange the setup as shown in the figure 19.10. Now, bring the magnet with lower magnetic intensity closer to the aluminium rod. The rod deflects. Now observe the velocity of the rod. The displacement of the rod in the above activity suggests that a force is exerted on the current carrying conductor when it is placed in a magnetic field.

Now stable the rod and bring both the magnets closer together to ensure that the magnetic field is stronger than before. The rod moves towards the magnet but faster than before. This is possible only if the force acting on the rod is stronger than before. Thus, the force acting on a current carrying conductor placed in a uniform magnetic field increases with increase in field strength. When the current is switched off, the wire moves back to its original position. The direction of the force on the aluminium rod can be reversed by reversing:

- The direction of the current
- The direction of the magnetic field

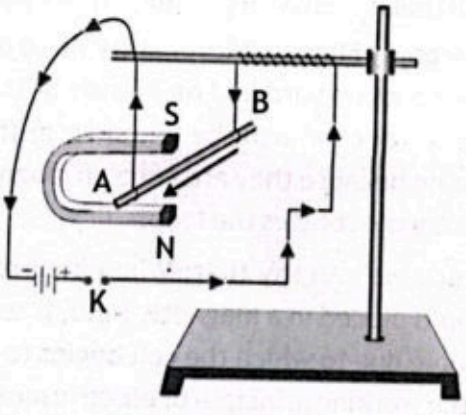


FIGURE 19.10

The conductor in a magnetic field experiences a force due to the reason that:

As a current-carrying wire produces its own magnetic field. When such wire is brought near an external magnetic field, the magnetic field of the wire interacts with the external magnetic field as a result a conductor experiences a force. The force is increased if

- The current in the wire is increased.
- Strength of magnetic field is increased.
- The length of the wire inside the magnetic field is increased.

The direction of the force on a current-carrying wire in a magnetic field is always perpendicular to that of the magnetic field and the current. It can be found by using Fleming's left hand rule, as shown in figure 19.11. Fleming's left hand rule can be defined as: Stretch the thumb, forefinger and the middle finger of the left hand mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb would indicate the direction of the force acting on the conductor.

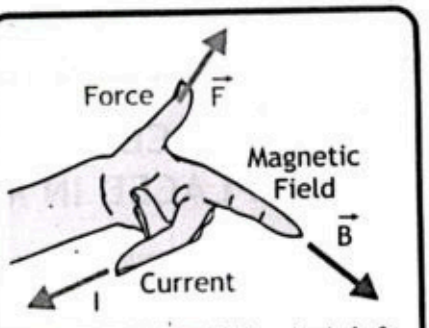


FIGURE 19.11 Fleming's left hand rule.

19.6 CURRENT CARRYING COIL IN A MAGNETIC FIELD

Consider a current carrying rectangular coil PQRS is lying perpendicular to the magnetic field of a permanent magnet, as shown in figure 19.12. Now if the ends of the coil are connected with the terminals of a battery, a current would start flowing through the coil.

Now apply Fleming's left hand rule to each side of the coil. We can see that on PQ side of the loop force acts upward and on RS side of the loop force acts downward (it is because the direction of the current through the two sides of the loop is opposite to each other). These two forces form a couple because they are equal in magnitude but opposite in direction. The resulting torque due to the couple rotates the loop.

Hence we can say that; When a current-carrying loop is placed in a magnetic field, it experiences a couple due to which the coil begins to rotate. This is the working principle of electric motors.

The turning effect (or torque) is increased by increasing:

(a) the number of turns on the coil.

(b) the magnitude of the current passing through the loop.

(c) the strength of the magnetic field.

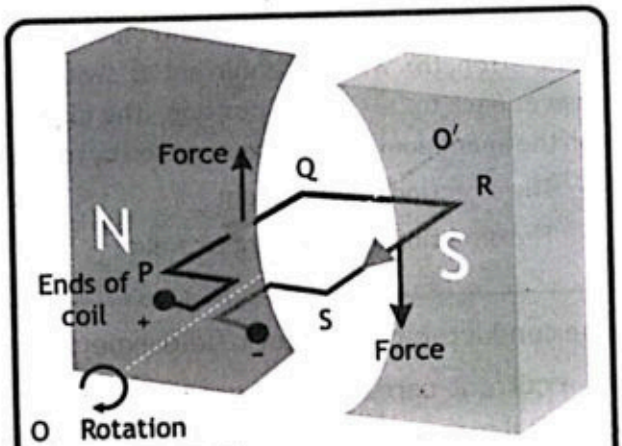


FIGURE 19.12 Current carrying coil

19.7 ELECTRIC MOTOR

When a current carrying coil placed in a magnetic field experiences a torque. This is the working principle of electric motors.

UNIT OPENER?



How compass helped Hans Christian Oersted in discovery of magnetic effect of current?

A Danish scientist Hans Christian Oersted while working with electricity he happened to have a compass (a device shown in cover picture of this chapter) near to a wire that he had connected to a battery. He noticed that the compass needle moved from its rest position of North.

Oersted had discovered that the current flowing in the wire had created a magnetic field strong enough to deflect the compass needle. He had accidentally discovered electromagnetism; that electricity and magnetism were inseparably interrelated.

An electric motor is device that converts electric energy into mechanical energy (rotational K.E). An electric motor is shown in the figure 19.13. It consists of:

- A rectangular coil, which is placed between the poles of permanent magnet.
- Brushes, that are usually pieces of graphite which allow current to flow into the coil.
- Split Ring Commutator (a ring that is split into two halves), as the coil rotates, so does the commutator.
- Permanent magnets or electromagnet to produce magnetic field.

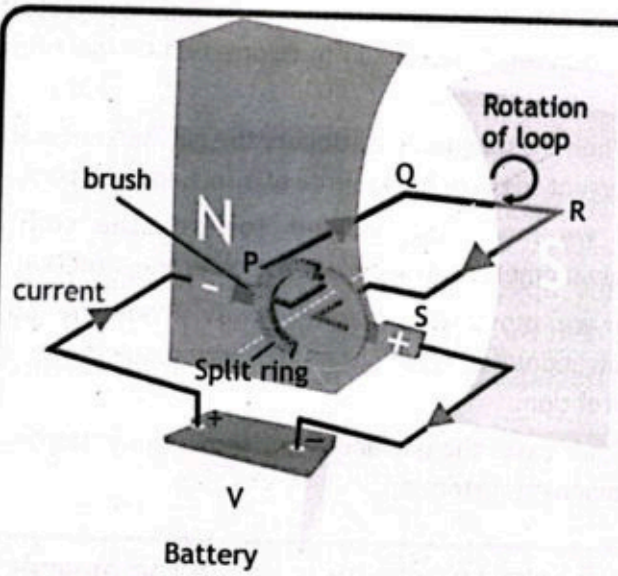


FIGURE 19.13 Electric motor

A simple coil placed in a magnetic field cannot rotate more than 90°. The forces push the PQ side of the coil up and the RS side of the loop down until the loop reaches the vertical position (plane of the loop is perpendicular to the magnetic field). So the loop will not continue to turn because the forces are still up and down and hence balanced (the net force on the coil is zero). To reverse direction of current, the connection to coil is made through an arrangement of brushes and split ring commutator. The split ring is arranged so that each half of the commutator changes brushes just as the coil reaches the vertical position. Changing brushes reverse the current in the loop. As a result, the direction of the force on each side of the coil is reversed and it continues to rotate.

INFORMATION



In an electric motor, the coil is actually made up of many loops mounted on a shaft or axle. Such coil is called armature.

This process repeats at each half-turn, causing coil to rotate in the magnetic field continuously.

19.8 ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the production of an electromotive force across a conductor when it is exposed to a varying magnetic field. Due to this electromotive force a current flow across the conductor. This can either happens when a conductor is placed in a moving magnetic field or when a conductor is constantly moving in a stationary magnetic field. To understand the phenomenon of electromagnetic induction let us perform the following activities.

ACTIVITY 19.3

Take a coil C of conducting wire and connect it to a galvanometer G, as shown in figure 19.14. Now bring a bar magnet near the coil.

- When the magnet is stationary the galvanometer shows no current so there is no source of e.m.f. in the circuit.
- If we move the magnet towards the coil C, the galvanometer will show deflection in one direction.
- If we move the magnet away from the coil, the galvanometer again shows deflection but in the opposite direction.

In either case, the galvanometer shows deflection as long as the magnet is in motion.

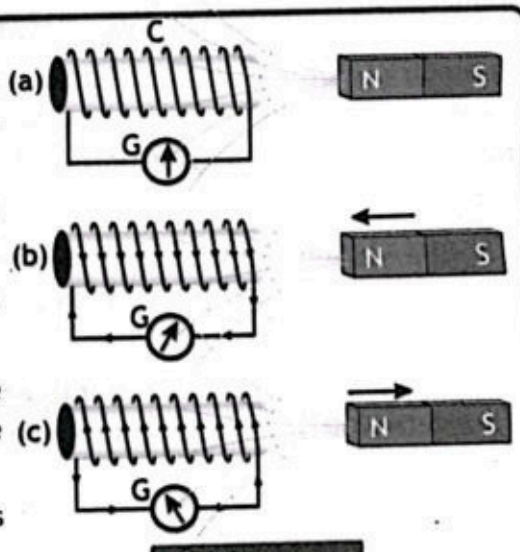


FIGURE 19.14

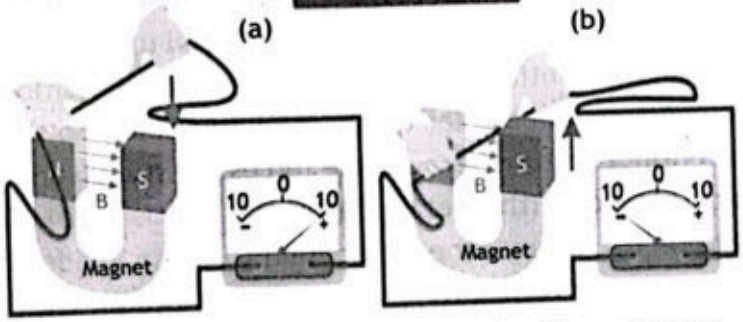
Now we take an activity in which the magnet is at rest but the conductor is moving.

ACTIVITY 19.4

Take a piece of wire and connect its two ends with a galvanometer, as shown in figure 19.15.

- Now hold the wire stationary or move it parallel to the magnetic field of a strong U-shaped magnet. Galvanometer shows no deflection and hence there is no current.

FIGURE 19.15



- Now move the wire downward through the field, current is induced in one direction (figure 19.15a).
- Now move the wire upward through the field, current is induced in opposite direction (figure 19.15b).

A. Conclusion: From the above two activities we conclude that *'an electromotive force (e.m.f) is induced in the coil when there is a relative motion between the coil and the magnet'.*

INFORMATION

The electromagnetic induction is a way of producing electrical energy in a circuit by using magnetic fields and not just by batteries. Everyday machines like generators and transformers work on the principle of electromagnetic induction.

B. Factors Affecting Induced e.m.f: The magnitude of induced e.m.f. is affected by the following factors:

(a) the rate of change of the magnetic field or the rate of cutting of magnetic field lines.

(b) the number of turns in a coil.

19.9 LENZ'S LAW

In 1834 a physicist Heinrich Lenz gave the idea that **"the direction of induced current in a circuit is always such that it opposes the cause which produces it"**. This statement is called Lenz's Law.

To demonstrate the Lenz's law, consider the N-pole of the magnet towards the coil, as shown in figure 19.16 (a). As the N-pole of the magnet moves towards the coil, an e.m.f. will be induced in the coil by electromagnetic induction. The direction of the induced current in the coil by the induced e.m.f. will be such that it will repel the north pole of the magnet. This is only possible if the left end of the solenoid becomes a north pole.

Hence, according to right hand grip rule, the direction of the induced current in the coil will be anticlockwise.

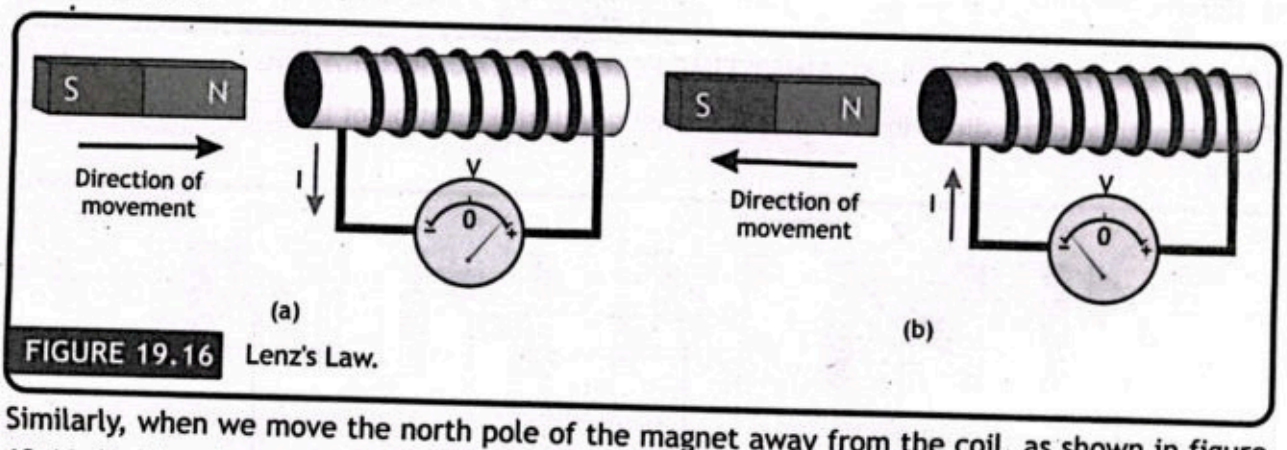


FIGURE 19.16 Lenz's Law.

Similarly, when we move the north pole of the magnet away from the coil, as shown in figure 19.16 (b). The direction of the induced current will be clockwise. In this case, left end of coil becomes South Pole. Hence in both the cases, the direction of induced current generates a magnetic field that oppose the motion of the bar magnet.

19.10 ELECTRIC GENERATOR

Electricity is one of the most important necessities of everyday life. So, to generate electricity is our main concern. There are many ways to produce electricity but the most common way is to generate electricity through generators.

As we have studied that an electromotive force (e.m.f) is induced in the coil when there is a relative motion between the coil and the magnet'. This is the working principle of electric generator.

A.C generator converts mechanical energy into electrical energy.

An alternating current generator is shown in figure 19.17. It consists of a coil/ armature, two slip rings that are made up of copper, two carbon brushes and a permanent magnet. When the coil is made to rotate in a magnetic field by some mechanical means, an induced e.m.f. is induced in the coil. When such coil is connected to some external circuit the current flows through the external circuit by slip rings. As the armature rotates, the strength and the direction of the current changes. Current can also be generated by rotating magnet setup and keeping the coil stationary.

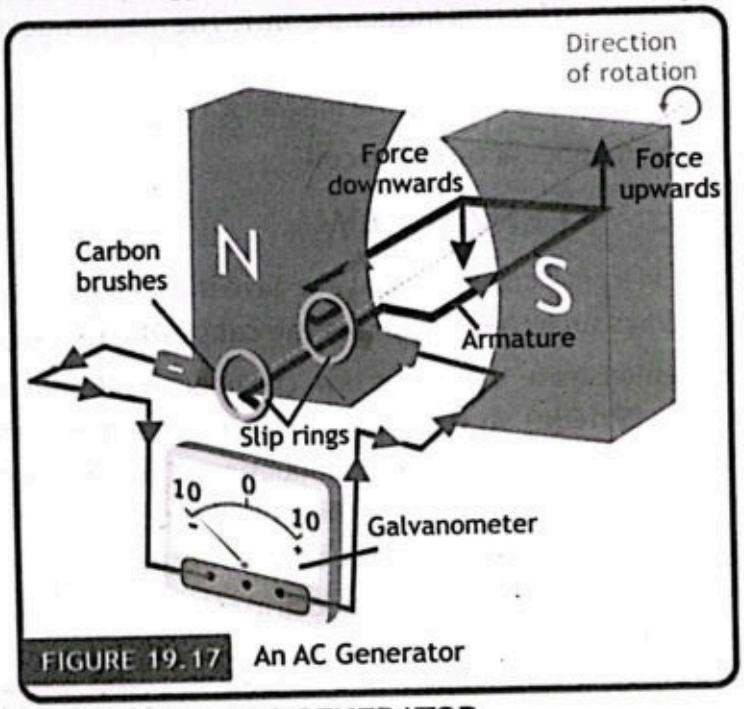


FIGURE 19.17 An AC Generator

19.10.1 GRAPHS OF E.M.F. AGAINST TIME FOR SIMPLE AC GENERATOR

The strength and the direction of current changes with the rotation of loop, as shown in figure 19.18.

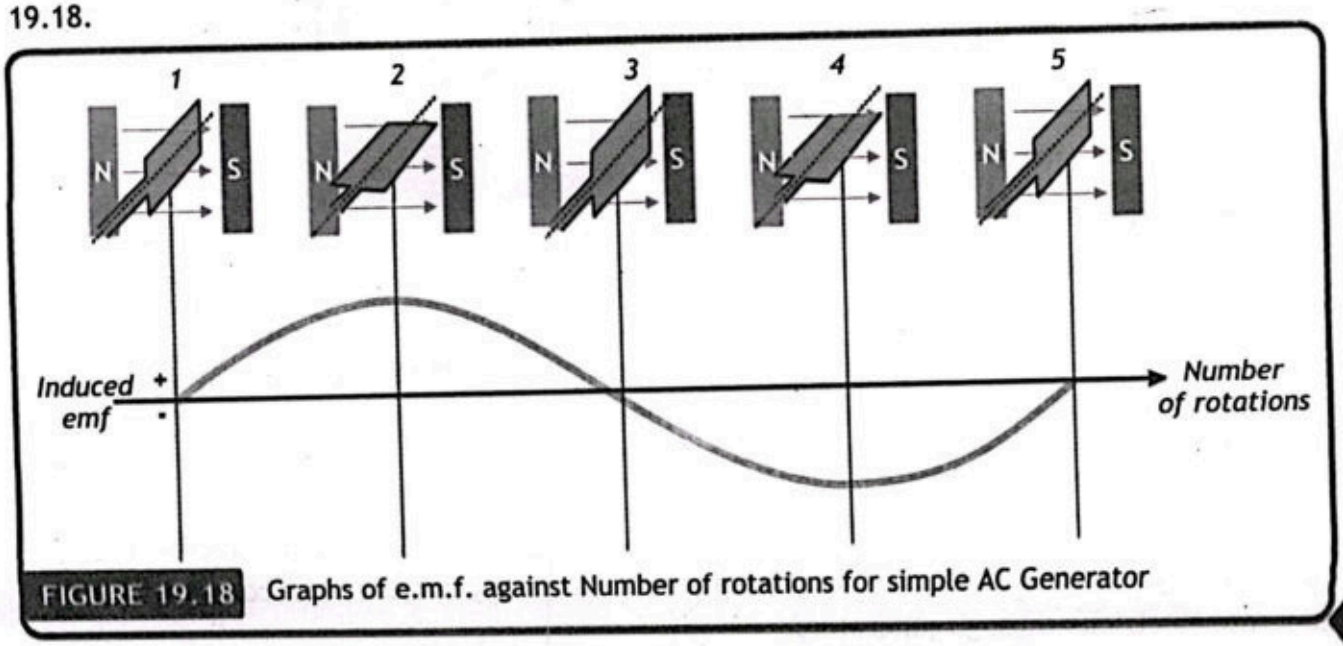


FIGURE 19.18 Graphs of e.m.f. against Number of rotations for simple AC Generator

The diagram shows how the e.m.f of the generator varies as its coil is rotated clockwise. Thus, the e.m.f change smoothly from zero to some maximum values and back to zero during each half-turn of the loop. Basically, you can see that the output is alternating; it is a maximum when the coil is horizontal and zero when the coil is vertical.

INFORMATION

The generation of electricity through generator is an important application of electromagnetic induction. The domestic electricity supply has a frequency of 50 hertz, which means that the generator makes fifty revolutions each second.



19.11 TRANSFORMER

Many devices in our homes, such as game systems, printers, mobile chargers and stereos use transformers. Transformer is an electrical device which is used to increase or decrease the value of an alternating voltage.

A transformer consists of three main parts: primary coil, secondary coil and a laminated iron core. Both the primary and secondary coils are wounded on two different sides of a laminated iron core. The primary coil is connected to the input electrical supply, which has to be AC to work properly. An AC current through the coil creates a changing magnetic field which is concentrated through the iron core.

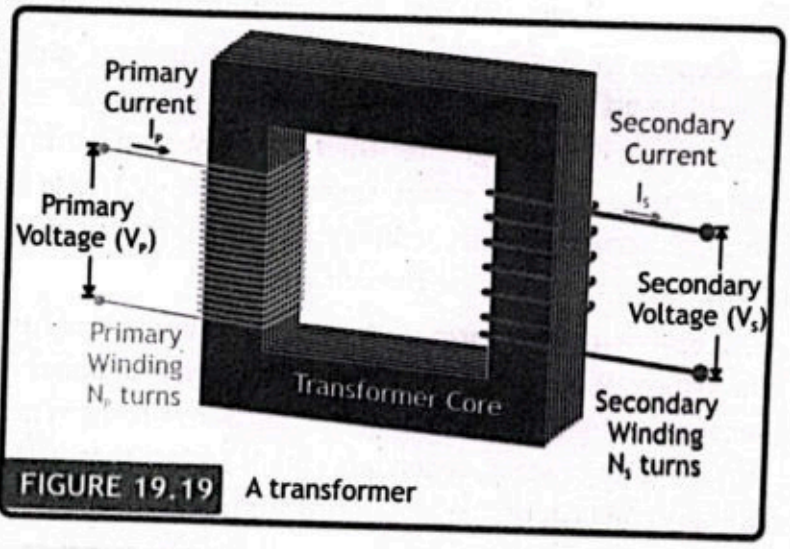


FIGURE 19.19 A transformer

When the primary coil is connected to a source of AC voltage V_p, the changing current creates a changing magnetic field, which is carried through the core to the secondary coil. In the secondary coil, the changing field induces an alternating e.m.f called the secondary voltage V_s. The secondary voltage is proportional to the primary voltage V_p. The secondary voltage also depends of the ratio of number of turns N_s on the secondary coil to the number of turns N_p on the primary coil, as shown the following expression:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \quad \text{19.1}$$

This is the basic equation for transformer.

Example 19.1

A step-down transformer converts 240 V into 12 V. If there are 2000 turns on the primary coil, then find the number of turns on the secondary coil.

GIVEN:
Primary voltage 'V_P' = 240 V
Secondary voltage 'V_S' = 12 V
Turns in primary 'N_P' = 2000

REQUIRED:
Turns in secondary 'N_S' = ?

SOLUTION:
The basic transformer equation is: $\frac{V_S}{V_P} = \frac{N_S}{N_P}$ or $N_S = \frac{V_S}{V_P} \times N_P$

putting values $N_S = \frac{12V}{240V} \times 2000$ Therefore $N_S = 100$ — ANSWER

The secondary coil should only have 100 turns compared to 2000 turn in the primary.

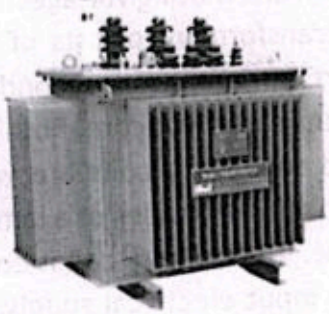
19.11.1 TYPES OF TRANSFORMER

There are two types of transformer: step-up and step-down.

A. Step-up Transformer: A step-up transformer is shown in the figure 19.20 (a). In step-up transformer number of turns in secondary coil (N_S) is greater than the number of turns in primary coil (N_P), so voltage across secondary coil (V_S) is greater than voltage across primary coil (V_P). Hence function of step-up transformer is to increase the voltage.

B. Step-down Transformer: A step-down transformer is shown in the figure 19.20 (b). In step-down transformer number of turns in secondary coil (N_S) is less than the number of turns in primary coil (N_P), so voltage across secondary coil (V_S) is less than voltage across primary coil (V_P). Hence function of step-down transformer is to decrease the incoming voltage.

INFORMATION



A step-down transformer is installed in our streets which decrease the voltage to 220 volts.

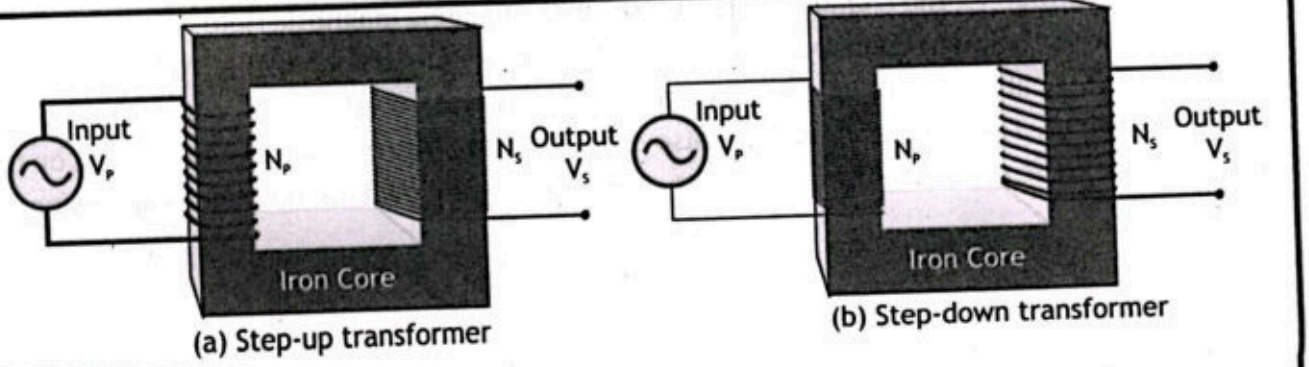


FIGURE 19.20 Types of transformer.

19.11.2 IDEAL TRANSFORMER

In an ideal transformer, the electric power delivered to the secondary circuit is equal to the power supplied to the primary circuit.

An ideal transformer dissipates no power itself, and for such a transformer, we can write:

Power in primary = Power in secondary

or $I_S V_S = I_P V_P$ — 19.2

19.11.3 HIGH ELECTRIC POWER TRANSMISSION

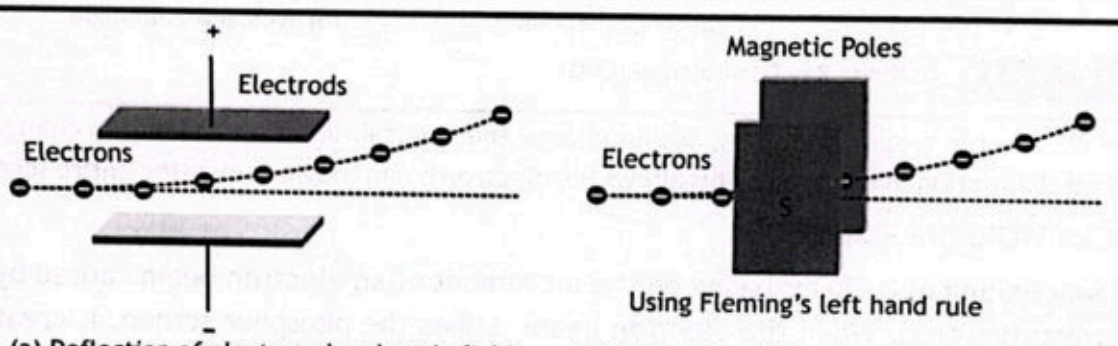
Electric power is usually generated at places which are far away from the places where it is consumed. The power is transmitted over long distances at high voltage to minimize the loss of energy in the form of heat during transmission. As heat dissipation in the transmission cable of resistance R is I^2R t. Hence, by reducing the current through the cable, power loss in the form of heat dissipation can also be reduced. High-voltage transmission allows for more efficient transmission over longer distances. High-voltage transmission reduce infrastructure costs by reducing the need for intermediate substations, requires fewer lines and towers, so increasing economic benefits.

Thus, high-voltage transmission in modern power systems, enabling efficient, reliable, and economic transmission of electricity over long distances.

19.12 DEFLECTION OF AN ELECTRON BEAM

When a charge particle such as electron passes through an electric or magnetic field, it shows deflection.

A. Deflection of electrons by electric field: When an electron beam passes through an electric field then the electrons are deflected towards the positive plate, as shown in the figure 19.21 (a). The reason for this is that electrons are attracted by the positive charges and are repelled by the negative charges due to electric force. The degree of deflection of electrons from



(a) Deflection of electrons by electric field (b) Deflection of electrons by magnetic field

FIGURE 19.21 Deflection of electron in electric and magnetic fields.

their original direction is proportional to the strength of the applied electric field E.

B. Deflection of electrons by magnetic field: When an electron beam passes through a magnetic field then the electrons are deflected, as shown in the figure 19.21 (b). The degree of deflection of electrons from their original direction depends on the velocity of electron, strength of the applied magnetic field and the angle at which the electron enters into the magnetic field.

19.13 CATHODE RAY OSCILLOSCOPE (CRO)

The cathode ray oscilloscope (CRO) is an electrical instrument that converts electric signals into visual signals for displaying and analyzing waveforms and other electronic phenomena.

The block diagram of the CRO can be seen in figure 19.22 (a), where the electron beam from the electron gun is focused onto a fluorescent screen by the focusing electrode. This results in a visible spot at the center of the screen where the electron beam hits. The visible spot is created because the screen is coated with a thin layer of phosphor, which emits light when struck by electrons. The horizontal and vertical plates, located between the focusing electrode and the screen, detect the beam based on the input signal.

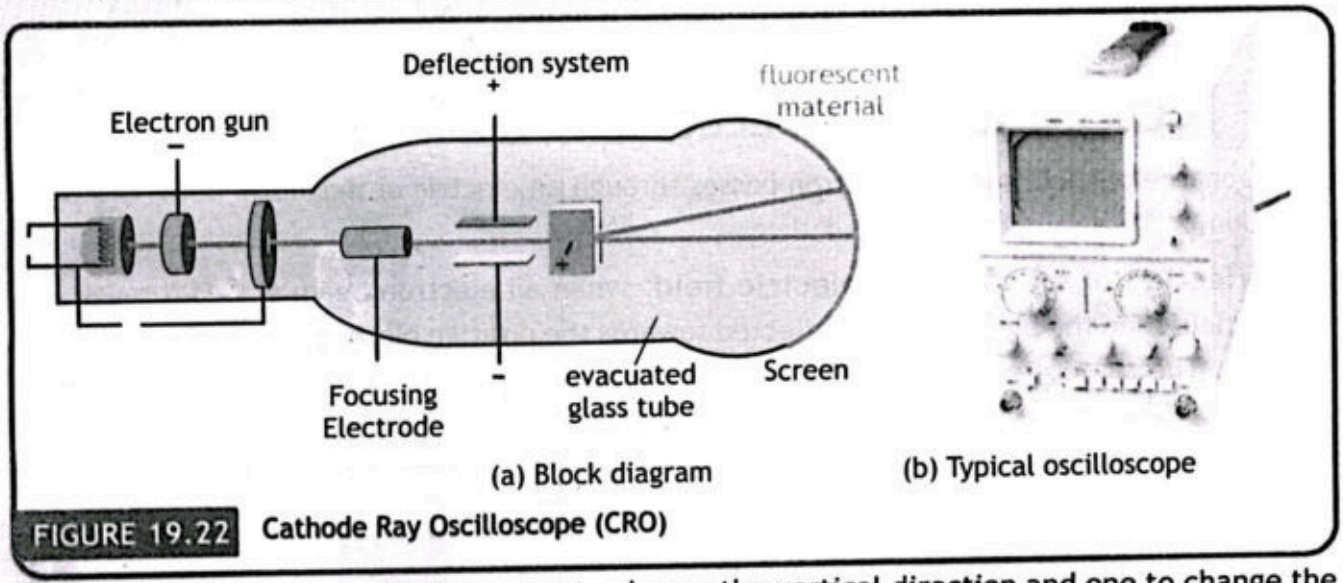


FIGURE 19.22 Cathode Ray Oscilloscope (CRO)

The deflector has two mechanisms, one to change the vertical direction and one to change the horizontal direction of the beam. This allows the electron beam to sweep over the entire screen.

19.13.1 WORKING PRINCIPLE

The functioning of a CRO is based on the movement of an electron beam caused by the electrostatic force. When the electron beam strikes the phosphor screen, it creates a bright spot. A Cathode Ray Oscilloscope directs electrostatic energy onto the electron beam from two vertical directions.

The spot on the phosphor screen moves as a result of these two perpendicular electrostatic forces, creating the required waveform of the input signal.

19.13.2 WAVEFORMS ON OSCILLOSCOPE

A typical waveform of a signal received from an AC source is display on an oscilloscope, as shown in the figure 19.23. It is showing the time on the horizontal axis and potential difference on the vertical axis.

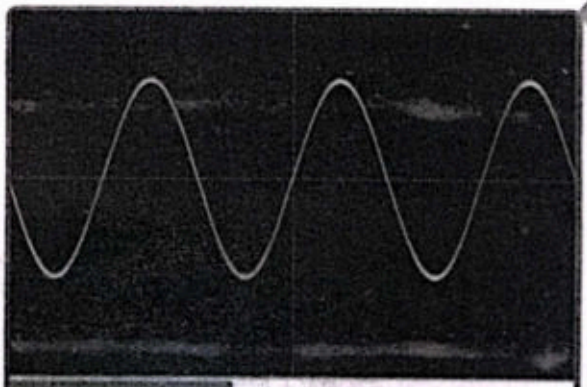


FIGURE 19.23 Waveform on screen

SUMMARY

- **Right-hand rule for current carrying wire** is that the wire is grasped in fist of right hand with the thumb pointed in the direction of the current, the fingers of the hand will curl in the direction of magnetic field. This is the right-hand rule for current carrying wire.
- **Two long parallel wires carrying a current** in same direction attract each other.
- **Right-hand rule for solenoid** is that If we grip the coil with our right hand by curling our fingers in the direction of the conventional current, our thumb will indicate the north pole of the coil, which is along the axis of solenoid.
- **The Earth's magnetic field** is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion.
- **Relay** is an electrical control device that facilitates interaction between the input and output circuits.
- **Current carrying conductor is placed in a magnetic field** experiences a force.
- **Fleming's left hand rule** is that stretch the thumb, forefinger and the middle finger of the left hand mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb would indicate the direction of the force acting on the conductor.
- **Working principle of electric motors** is when a current-carrying loop is placed in a magnetic field, it experiences a couple due to which the coil begins to rotate.
- **Electric motor** is device that converts electric energy into mechanical energy.
- **Electromagnetic induction** is the production of an electromotive force across a conductor when it is exposed to a varying magnetic field.
- **Lenz's Law** states that the direction of induced current in a circuit is always such that it opposes the cause which produces it.
- **A.C generator** converts mechanical energy into electrical energy.
- **Transformer** is an electrical device which is used to increase or decrease the value of an alternating voltage.
- **Step-up transformer is** used to increase the incoming voltage.
- **Step-down transformer** is used to decrease the incoming voltage.
- **The waveform on oscilloscope** can be controlled by applying electric field of suitable magnitude.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

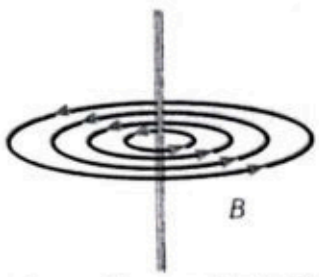
1. The presence of a magnetic field can be detected by a
   A. small mass
   B. stationary positive charge
   C. stationary negative charge
   D. magnetic compass
2. A DC motor converts:
   A. mechanical energy into electrical energy
   B. mechanical energy into chemical energy
   C. electrical energy into mechanical energy
   D. electrical energy into chemical energy
3. Which of the following device works on the principle of electromagnetic induction?
   A. Magnetic compass B. Motor C. Transformer D. Oscilloscope
4. Voltage in the secondary coil of transformer does not depend upon
   A. frequency of source B. primary voltage C. power losses D. turns ratio
5. Which of the following quantities remain constant in an ideal step-up transformer?
   A. current B. voltage C. power D. heat
6. Step-up transformer has a transformation ratio of 3:2. What is the voltage in secondary, if voltage in primary is 30 V?
   A. 15 V B. 45 V C. 90 V D. 300 V
7. Toward which magnetic pole of Earth is the north pole of a compass needle attracted?
   A. The north pole of a compass needle is attracted to the north magnetic pole of Earth, which is located near the geographic North Pole of Earth.
   B. The north pole of a compass needle is attracted to the south magnetic pole of Earth, which is located near the geographic North Pole of Earth.
   C. The north pole of a compass needle is attracted to the north magnetic pole of Earth, which is located near the geographic South Pole of Earth.
   D. The north pole of a compass needle is attracted to the south magnetic pole of Earth, which is located near the geographic South Pole of Earth.

8. The step-up transformer:
   A. increases the input current
   B. increases the output voltage
   C. has more turns in the primary
   D. has less turns in the secondary coil
9. A step up transformer is used before electricity is transmitted by overhead cables. Select the statement that explains why this is done.
   A. It increases the voltage to increase the speed at which the electricity travels.
   B. It increases the voltage to reduce energy loss in the cables.
   C. It increases the current to increase the speed at which the electricity travels.
   D. It increases the current to reduce energy loss in the cables.
10. Which of the following does not change in an ordinary transformer?
    A. power B. Frequency C. Current D. Voltage

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

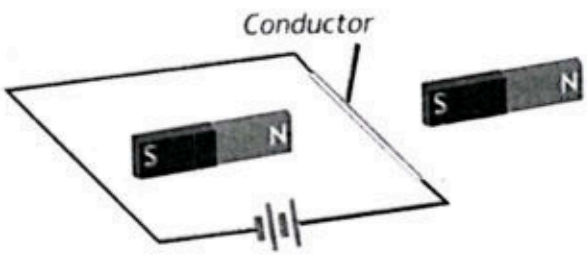
1. In which direction the current must be flowing through the conductor to create the magnetic field shown in the diagram? Up or Down?



2. In the following diagram, will there be a North pole or a South pole at the left side of the solenoid? Also draw its magnetic field having arrows to show its direction.



3. A current carrying conductor is place in the magnetic field, as shown.



a) In which direction will the conductor move? Up, down, left or right?

Ans: _____

b) If the magnetic field was reversed then in which direction will the conductor move?

Ans: _____

c) If both the magnetic field and the current are reversed, then in which direction will the conductor move?

Ans: _____

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. How does a generator differ from a motor, and what is their relationship to each other?
2. Why is a transformer ineffective with DC voltage?
3. Explain the relationship between the direction of a current-carrying conductor and the magnetic field it produces.
4. Describe the interaction between a current-carrying conductor and a magnetic field, and how to determine the direction of the force exerted.
5. Why is high voltage used for long-distance transmission of electrical power?
6. Design an experiment to generate an electric current using a coil of wire and a bar magnet.
7. What factors influence the strength of an induced electromotive force (EMF)?
8. Compare and contrast the two primary types of transformers.
9. Identify three devices that operate on the principle of electromagnetic induction.

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Design an experiment to qualitatively demonstrate the existence of a magnetic field around a current-carrying conductor.
2. Describe an experimental setup to induce an EMF in a circuit using a changing magnetic field. How can you measure the induced EMF?
3. Explain Lenz's law in your own words, and provide a real-world example to illustrate its application.
4. Define an alternating current (AC) generator. Draw a labeled diagram and explain its components and operation. How does it convert mechanical energy into electrical energy?
5. What is an AC motor? Draw a labeled diagram and explain its components and operation. How does it convert electrical energy into mechanical energy?
6. Define a transformer. Explain its principle of operation, components, and applications. How does it change the AC voltage?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. A step-up transformer has a turn ratio of 1:100. An alternating supply of 20 V is connected across the primary coil. What is the secondary voltage?

(Ans. 2000 volts)

2. A step-down transformer has a turns ratio of 100:1. An ac voltage of amplitude 170 V is applied to the primary. What is the voltage across the secondary?

(Ans. 1.7 volts)

3. Calculate the input voltage if it draws 0.5 A. Also calculate turn ratio of primary to secondary coil if a transformer is rated for an output of 100 W and 8.3 A. Also identify the type of transformer.

(Ans. 200 volt, 1:16.6, step down)

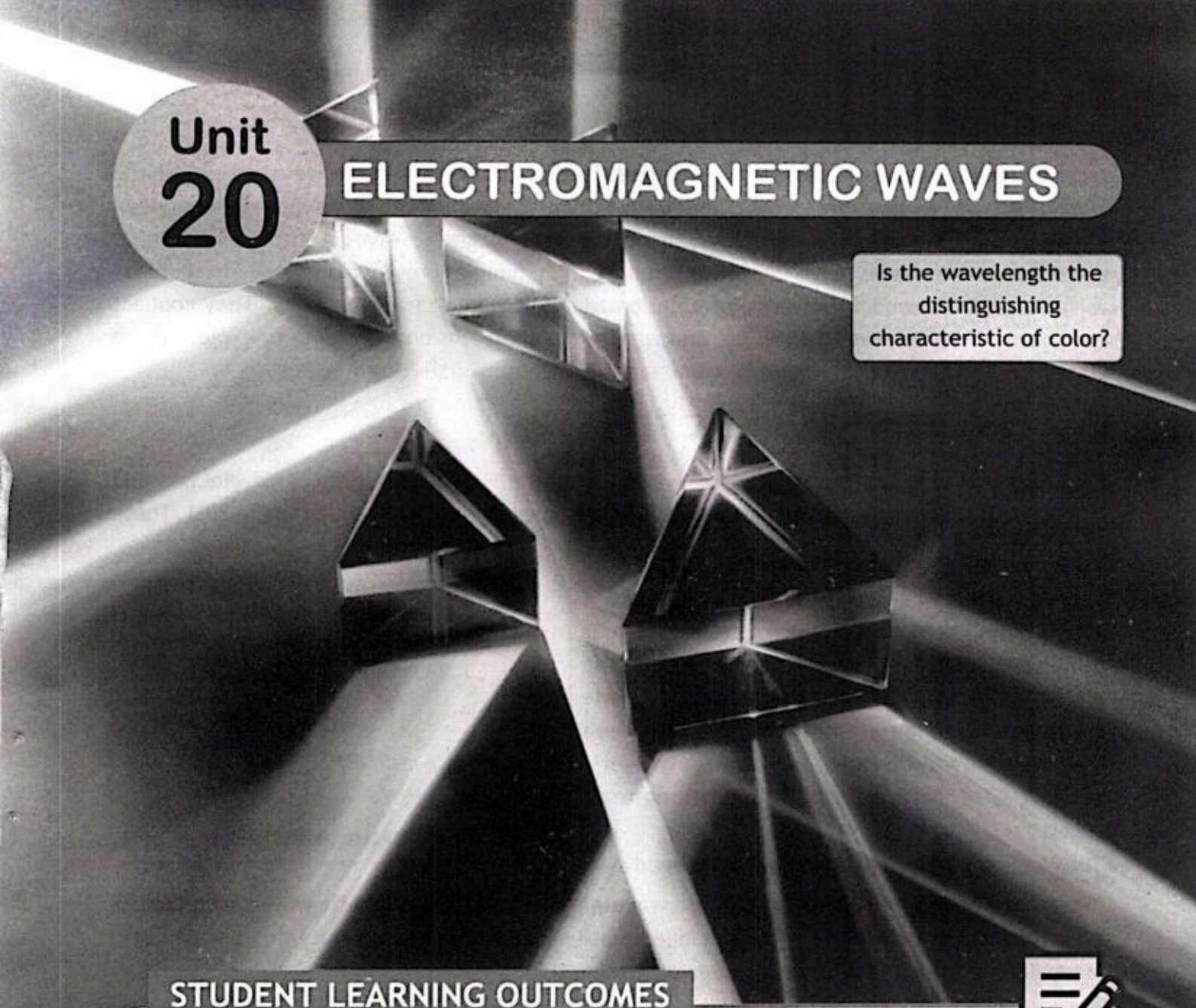
4. Calculate the output power and output current of the following step-down transformer. The value of input current is 0.050 A (Assuming that the transformer is 100% efficient).



(Ans. 11.5 W, 1.9 A)

5. A transformer in an adapter steps up a 115 V to the 230 V needed for a hair dryer. A current of 5 A flows through the hairdryer. Assuming that the transformer is 100% efficient, calculate the current drawn from the mains supply.

(Ans. 10 A)



Unit 20 ELECTROMAGNETIC WAVES

Is the wavelength the distinguishing characteristic of color?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-E-94] state the main regions of the electromagnetic spectrum in order of frequency and in order of wavelength
- ✓ [SLO: P-10-E-95] state that the speed of all electromagnetic waves in: (a) a vacuum is 3.0×10^8 m/s
- ✓ (b) air is approximately the same as in a vacuum.
- ✓ [SLO: P-10-E-96] Describe the applications of electromagnetic waves in society.
- ✓ [SLO: P-10-E-97] Describe the damage caused by electromagnetic radiation.
- ✓ [SLO: P-10-E-98] Explain qualitatively, how scattering of light by molecules in the air give the sky its blue color during the day and its shades of red during sunset.
- ✓ [SLO: P-10-E-99] State that theoretically light can also considered to be made of massless particles that carry energy and momentum called 'photons'.

UNIT 20 ELECTROMAGNETIC WAVES

Electromagnetic waves are essential to our lives. The exploration of these waves started with the work of Michael Faraday and James Clark Maxwell. Their experiments showed the link between electricity and magnetism, forming a key theory of electromagnetic waves in Physics. Since then, electromagnetic waves have played a vital role in human progress and advancement in technology, from sending wireless information to studying the far off galaxies. They connect everything, bridging what we can see and what we cannot. It is now our duty to explore these waves, for helping us to gain a better understanding of the universe and ourselves.

20.1 ELECTROMAGNETIC SPECTRUM

Electromagnetic waves are transverse waves generated by the oscillations of electric and magnetic fields that are mutually perpendicular to each other, as illustrated in Figure 20.1, These waves do not require a medium for propagation, enabling them to travel through the vacuum of space. The direction of wave propagation is perpendicular to the vibrations of both the electric and magnetic fields. Electromagnetic waves are categorized into different types based on their frequency, wavelength, or energy levels, collectively forming the electromagnetic spectrum.

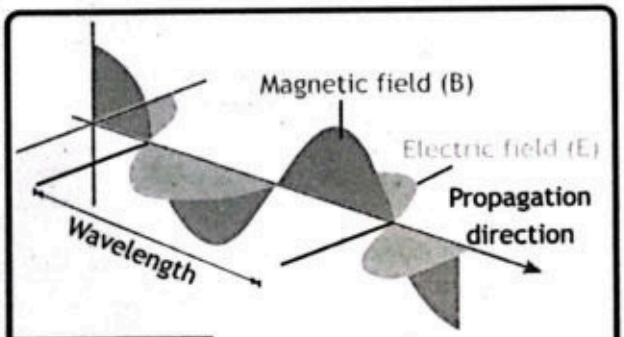


FIGURE 20.1 Electromagnetic wave

The electromagnetic spectrum can be defined as:

'The range of different frequencies and wavelengths of electromagnetic waves is called the electromagnetic spectrum'. This include radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays as given in table 20.1.

TABLE 20.1 SPECTRUM OF ELECTROMAGNETIC WAVES

Type of radiation	Wavelength range	Frequency range (Hz)
Radio	> 1 mm	$< 3 \times 10^{11}$
Microwave	1 mm - 25 μm	3×10^{11} - 3×10^{13}
Infrared	25 μm - 2.5 μm	10^{13} - 4×10^{14}
Visible	750 nm - 400 nm	4×10^{14} - 7.5×10^{14}
Ultraviolet	400 nm - 1 nm	10^{15} - 10^{17}
X-Rays	1 nm - 1 pm	10^{17} - 10^{20}
Gamma Rays	$< 10^{-12}$	$10^{20} \times 10^{24}$

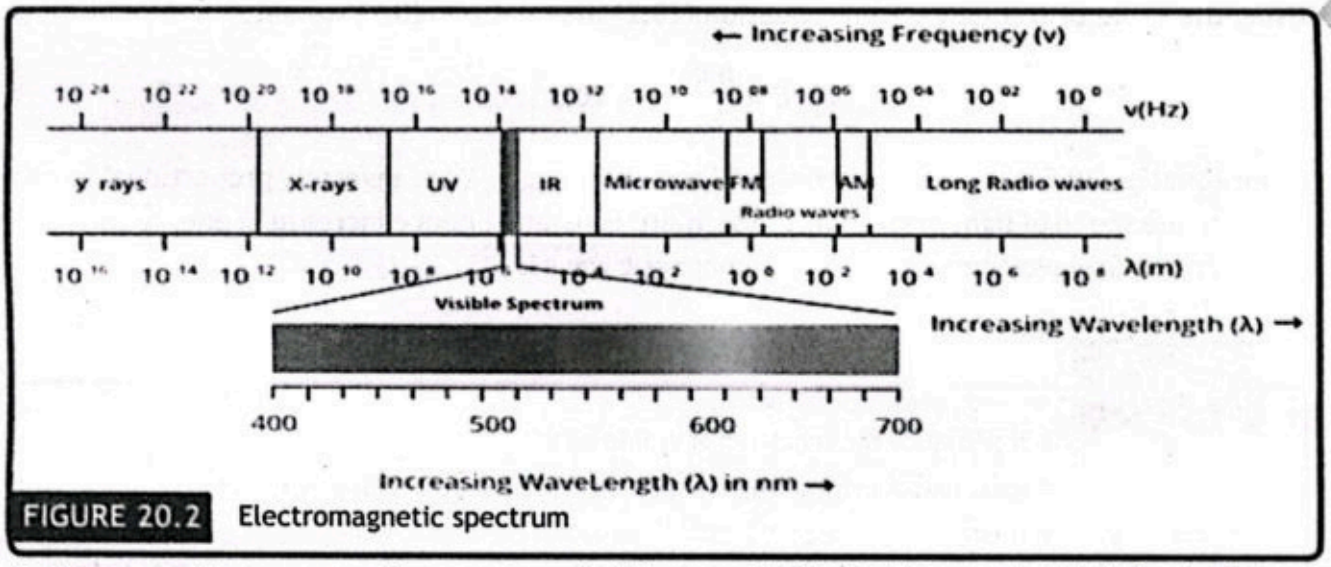


FIGURE 20.2 Electromagnetic spectrum

In a vacuum, electromagnetic waves travel at the speed of light. The speed of light in the vacuum is a universal constant and is denoted by 'c' whose value can be given as '$c = 3 \times 10^8$ m/s'. The speed of light does not remain the same in mediums as it slows down due to interaction of light with the its particles, however in air it is approximately same as that of vacuum.

The electromagnetic spectrum consists of a span of all electromagnetic radiations (waves) which further contains many sub ranges which are commonly known as portion of the electromagnetic radiation as shown in figure 20.2. The visible light which is a portion of electromagnetic spectrum is divided into sub ranges i.e. the colors of light like red, orange, yellow, green, blue and violet etc. We can study the spectrum of light with the help of a prism or diffraction grating.

The relation between energy 'E' frequency 'f' and the wavelength 'λ' can be found by Max Plank's equation:

$$E = h f \quad \text{— 20.1}$$

Here 'h' is the Plank's constant whose value is '6.63×10^{-34} Js'.

From the equation 20.1 it is clear that frequency 'f' and energy 'E' are directly proportional to each other hence increase in frequency will result in an increase in energy of the electromagnetic waves. As we know that speed, wavelength and frequency are related as:

$$c = f\lambda \qquad \text{or} \qquad f = \frac{c}{\lambda} \quad \text{— 20.2}$$

Here 'c' is the speed of light whose value is '3×10^8 m/s.

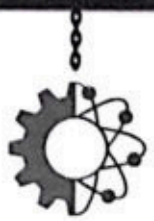
Equation 20.2 shows that frequency 'f' and wavelength 'λ' are inversely proportional to each other as the speed of light is constant in vacuum, hence increase in frequency will result in a decrease in wavelength of the electromagnetic waves.

Using the value of frequency from equation (20.2) in equation (20.1) we get:

$$E = \frac{h\,c}{\lambda} \quad \text{— 20.3}$$

From equation 20.3 it is clear that energy 'E' and wavelength 'λ' are inversely proportional to each other as the speed of light in vacuum 'c' and 'h' are constants, hence increase in energy will result in a decrease in wavelength of the electromagnetic waves.

MINI LAB

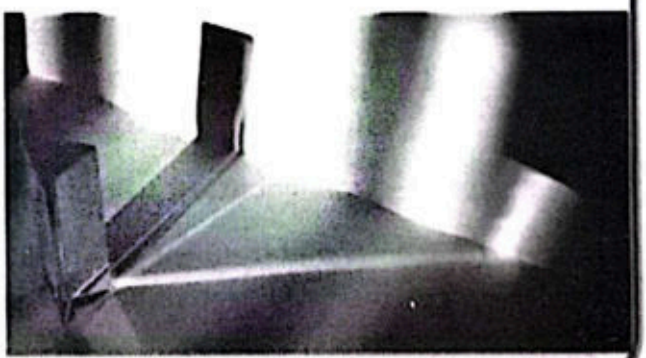


Aim: To study the spectrum of visible light.

Apparatus: A prism, white paper, light coming through a window or a white light source.

Performance: To perform the activity for studying the spectrums of visible light, you have to do the following tasks:

- Take a prism which has two triangular faces and three rectangular faces as shown below in the figure.
- Cover the window of your room such that the covering has a small portion from which light can enter into the room.
- The sunlight from that small portion coming into the room is white light (which is not a pure color but a mixture of many colors).
- If you do not have the facility of light coming from the window you can use some artificial source of white light like a torch.
- The spectrum of white light can be seen by placing a prism in the path of the light such that one of its rectangular faces is facing towards the incident light.
- You will observe that after passing through the prism the white light splits into its component colors, as the prism has the property of bending the light from its straight line path due to difference of speed of light in air and in glass and also due to difference of wavelengths of the components of the white light.
- The spectrum of the sunlight is shown here:



Conclusion: from the above project we learnt that the white light coming from the Sun is actually a mixture of different wavelengths of different colors. Due to different wavelengths each component after passing through the prism deviates at different extent which splits all the constituent colors of white light.

Example 20.1

Find the energy range for the infrared, visible and ultra-violet for their corresponding maximum and minimum wavelengths.

GIVEN: From table 20.1:

For Infrared radiation:

Maximum Wavelength 'λ_L' = 250 μm,
Minimum Wavelength 'λ_S' = 2.5 μm

For visible radiation:

Maximum Wavelength 'λ_L' = 750 nm,
Minimum Wavelength 'λ_S' = 400 nm

For ultraviolet radiation:

Maximum Wavelength 'λ_L' = 400 nm,
Minimum Wavelength 'λ_S' = 1 nm

REQUIRED:

For Infrared radiation:

Maximum Energy 'E_{max}' = ?,
Minimum Energy 'E_{min}' = ?

For visible radiation:

Maximum Energy 'E_{max}' = ?,
Minimum Energy 'E_{min}' = ?

For ultraviolet radiation:

Maximum Energy 'E_{max}' = ?,
Minimum Energy 'E_{min}' = ?

SOLUTION:

To find the value of energy we use the equation: $E = \frac{h\,c}{\lambda}$

For Infrared radiation:

The maximum energy corresponds to smallest wavelength hence:

$$E_{Max} = \frac{h\,c}{\lambda_S} = \frac{(6.63\times10^{-34}\,Js)\ (3\times10^{8}\,ms^{-1})}{(2.5\times10^{-6}\,m)}$$

$E_{Max} = 7.96\times10^{-20}\,J$ — ANSWER

The minimum energy corresponds to largest wavelength hence:

$$E_{min} = \frac{h\,c}{\lambda_L} = \frac{(6.63\times10^{-34}\,Js)\ (3\times10^{8}\,ms^{-1})}{(250\times10^{-6}\,m)}$$

$E_{mim} = 7.96\times10^{-22}\,J$ — ANSWER

For visible radiation:

The maximum energy corresponds to smallest wavelength hence:

$$E_{Max} = \frac{h\,c}{\lambda_S} = \frac{(6.63\times10^{-34}\,Js)\ (3\times10^{8}\,ms^{-1})}{(400\times10^{-9}\,m)}$$

$E_{Max} = 4.97\times10^{-19}\,J$ — ANSWER

The minimum energy corresponds to largest wavelength hence:

$$E_{min} = \frac{h\,c}{\lambda_L} = \frac{(6.63\times10^{-34}\,Js)\ (3\times10^{8}\,ms^{-1})}{(750\times10^{-9}\,m)}$$

$E_{mim} = 2.65\times10^{-19}\,J$ — ANSWER

For ultraviolet radiation:

The maximum energy corresponds to smallest wavelength hence:

$$E_{Max} = \frac{h\,c}{\lambda_S} = \frac{(6.63\times10^{-34}\,Js)\ (3\times10^{8}\,ms^{-1})}{(1\times10^{-9}\,m)}$$

$E_{Max} = 1.99\times10^{-16}\,J$ — ANSWER

The minimum energy corresponds to largest wavelength hence:

$$E_{min} = \frac{h\,c}{\lambda_L} = \frac{(6.63\times10^{-34}\,Js)\ (3\times10^{8}\,ms^{-1})}{(400\times10^{-9}\,m)}$$

$E_{mim} = 4.97\times10^{-19}\,J$ — ANSWER

These are the energy ranges in joules for the infrared, visible and ultra-violet for their corresponding maximum and minimum wavelengths.

UNIT OPENER



Every primary color has its unique wavelength. You can say that the wavelength is the finger print of every primary color. A color can be recognized by its wavelength and no two (different) colors have the same wavelength.

But in case of secondary colors like white which is you can say a mixture of different colors do not have particular wavelength. In spite of it such colors have many wavelengths in them which can be separated with the help of prism or raindrop into its constituent colors to form a rainbow as shown in the figure.



20.2 APPLICATIONS OF ELECTROMAGNETIC WAVES

The electromagnetic spectrum has a wide range of electromagnetic waves from very long radio waves to the very short gamma rays. These incredible waves play an essential role in various scientific, medical and technological applications in our everyday lives.

20.2.1 APPLICATIONS OF RADIO WAVES

Radio waves have the longest wavelengths in the electromagnetic spectrum. Without radio waves it would not be possible to send and receive information as easy as it is. Radio Waves are used in the working of television, mobile phones, wireless network, GPS receivers, wireless clocks and even small items like small door openers.

A. Radio and Television Broadcasting: Radio and television broadcasting are essential components of modern communication, utilizing radio waves to transmit audio and video signals from broadcasting stations directly into our homes. The radio waves carry coded information (like

POINT TO PONDER



At atomic and subatomic levels and even for the energy of electromagnetic radiation we do not use the joule as the unit for energy. We need some small unit for measuring energy at those levels. Electron-volt is a smaller unit of energy which can be used for energy of electromagnetic radiations.

We can convert energy from joules 'J' into electron-volts 'eV' by simple dividing the energy by the magnitude of charge on single electron as:

$$1\ J = \left(\frac{1}{1.6\times10^{-19}}\right) eV = 6.25\times10^{18}\ eV$$

audio and video signals) from broadcasting antennas to our devices, which then decode and show the content.

This process starts with the generation of content at radio and TV stations, ranging from news and music to entertainment and educational content. Once the content is ready, it is encoded into a format suitable for transmission. This encoding process involves converting the audio and video signals into a series of coded information.

The encoded signals are then transmitted from broadcasting antennas, which are strategically located to cover wide geographical areas. These antennas emit radio waves, as the radio waves propagate, they can be received by various devices, such as radios, televisions, and smartphones. Each of these devices is equipped with a tuner that can detect specific frequencies corresponding to the broadcasting station as illustrated in figure 20.2.

When such a device picks up these radio waves, it involves decoding the received signals. This process is carried out by the device's internal circuitry, which interprets the coded information and converts it back into audio and video formats.

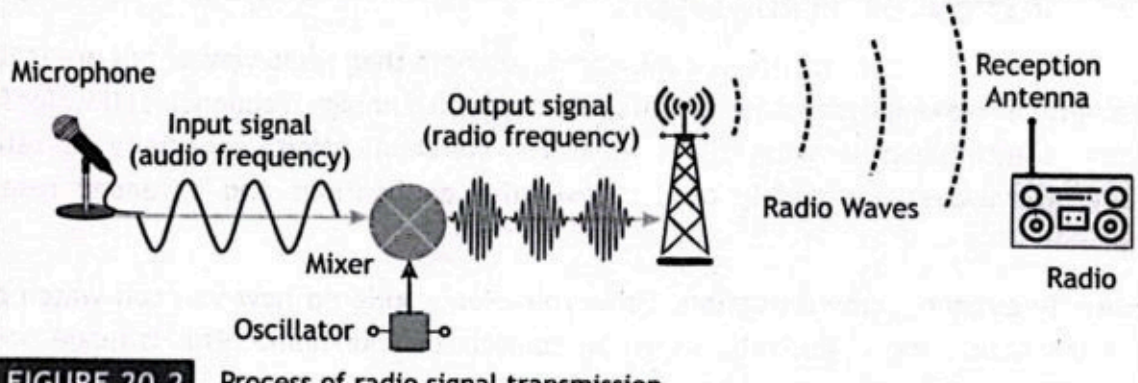


FIGURE 20.2 Process of radio signal transmission

B. Astronomy: Astronomical objects with changing magnetic fields can emit radio waves. The study of these radio waves from space is known as radio astronomy. By analyzing the radio waves from these sources, scientists can gain valuable insights into the composition, structure, and motions of celestial bodies in the universe.



FIGURE 20.3 Radio telescope

You may be familiar with the sighting of the moon for Ramadan or eid using optical telescopes. However, sometimes the moon cannot be observed due to

POINT TO PONDER



Have you ever wondered how scientists uncover the secrets of substances without even touching them? Spectroscopy makes this possible! It demonstrates how electromagnetic waves interact with matter, allowing us to understand the hidden structures and behaviors of atoms and molecules.

Why do only specific waves get absorbed while others pass through? Consider how energy differences between electronic states lead to this unique interaction—an amazing process that helps us uncover the secrets of the universe!

obstacles like clouds or bright sunlight. In such cases, radio telescopes offer a significant advantage, as their observations are unaffected by sunlight, clouds, or rain. One limitation of radio telescopes, however, is that radio waves are much longer than visible light waves. To achieve image resolutions comparable to those of optical telescopes, radio telescopes (like the one shown in Figure 20.3) need to be significantly larger in size.

20.2.2 APPLICATIONS OF MICROWAVES

Microwaves have a higher frequency and shorter wavelength than radio waves, but are still low-energy radiations, making them generally safe for humans. Their high frequencies allow for faster information transmission, making them ideal for communication, especially in satellite technology. Microwaves are widely used in everyday applications and advanced research, including:

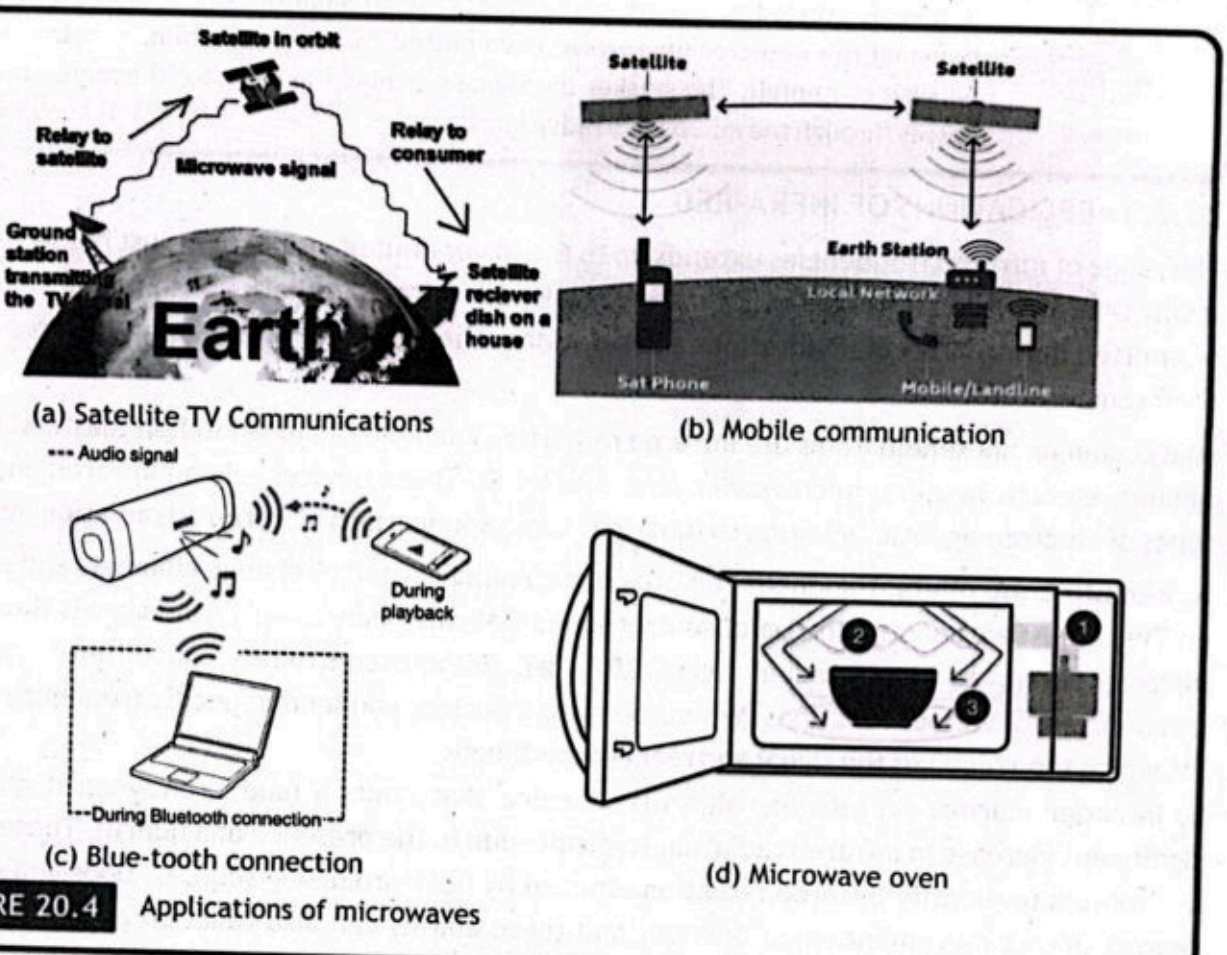
A. Satellite Television Communication: Have you ever wondered how you can watch a live cricket match happening in Australia from the comfort of your home? This is made possible through satellite television communication.

Microwaves, with their high frequency and shorter wavelength, can easily travel through the Earth's atmosphere. In satellite communication, television signals are transmitted via microwaves to a satellite in space. The satellite amplifies these signals and retransmits them back to Earth, enabling coverage in areas where terrestrial transmission cannot reach. Dishes and other receiving antennas then pick up these signals, as illustrated in Figure 20.4 (a).

It is important to note that satellite television communication often requires more than one satellite to ensure uninterrupted coverage across different regions.

B. Mobile Phones: Mobile phones communicate to a mobile phone tower using radio waves then mobile phone towers communicate with satellites using microwaves. Microwaves are used as they can pass through the atmosphere. The signal can be sent to a satellite and used to communicate around the world. The mobile signals are sent to the satellite by microwaves and

these signals are interchanged between satellites and on Earth stations as shown in figure 20.4 (b).



(a) Satellite TV Communications

(b) Mobile communication

(c) Blue-tooth connection

(d) Microwave oven

FIGURE 20.4 Applications of microwaves

C. Blue tooth: Bluetooth uses radio waves and microwaves to transmit information between two devices directly. It uses weaker waves which use less power to generate them and makes the Bluetooth a particularly useful technology for battery powered devices. Those weaker waves also mean that Bluetooth typically works only over short distances less than 30 feet or 9 meters. A typical Bluetooth connection is shown in figure 20.4 (c). Bluetooth connection between two devices will stay active as long as they remain within range without the need for a router or any other intervening device.

D. Microwave Oven: Microwave ovens are used to cook and heat the food evenly and efficiently. They are called microwave oven as they use microwave in their working. Microwaves cause the molecules in food to vibrate which create heat to cook the food. The different parts of microwave work together to cook food properly. A typical consumer microwave oven uses 2.45 GHz frequency and the wavelength of 12.2 cm and can be shown in figure 20.4 (d).

SCIENCE TIDBITS



Microwaves traversed through the atmosphere will be absorbed by the water. This process is utilized by the weather department to monitor rain. If weak signals are reaching the detector microwave have passed through more rain. It helps in the analysis of rainfall. The weaker the signal reaching the detector the more rain has passes through the microwave radiation.

20.2.3 APPLICATIONS OF INFRA-RED

The range of infrared frequencies extends up to the lower limit of visible light just below red that is why they are called infra-red which means below red. Infrared radiation is commonly absorbed or emitted during molecular vibrations and rotations. Therefore, all objects emit infrared due to their temperature.

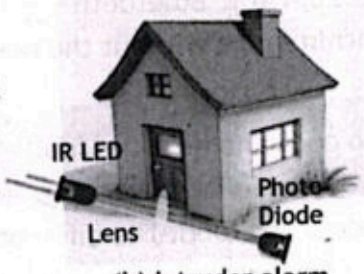
Many common household items use infrared radiation. Examples include kitchen toasters, mobile phones, electric heaters, microwave ovens, and Wi-Fi. These devices rely on infrared and other types of electromagnetic radiation to function. Some applications of infra-red radiation include:

A. Remote Controllers: Handheld 'remotes' are commonly used to change channels and settings on TVs, adjust air conditioners, and control sound systems. They usually send signals through an infrared beam, as illustrated in figure 20.5 (a). Remote controllers use different infrared frequencies for various functions. When you press a button, you send a specific frequency to your TV, which then receives the signal and reacts accordingly.

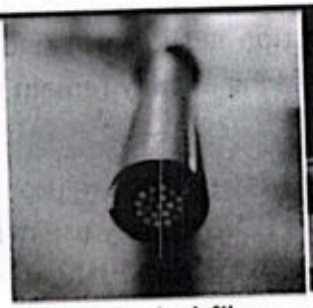
B. Intruder alarms: An intruder alarm is a device that emits a loud siren when it detects a significant increase in infrared radiation, typically due to the presence of a human. These alarms use sensors to identify infrared radiation emitted by heat-producing sources. Door and window sensors detect movement when opened, and these alarms can also function as fire alarms by detecting the large amounts of infrared radiation emitted by fire. Additionally, some alarms work using an LED and photodiode circuit, where the continuous infrared beam is disrupted by movement, breaking the circuit and triggering the alarm, the setup for such an alarm is shown in figure 20.5 (b).



(a) Remote controller



(b) Intruder alarm



(c) IR Optical fiber



(d) Thermal imaging

FIGURE 20.5 Applications of infra-red radiations

POINT TO PONDER



Reconnaissance satellites can detect buildings, vehicles and even individual humans by their infrared emission. Such satellites were used for military purposes in Afghan war. More mundanely we use infrared lamps which are also called as quartz heaters to warm us because we human absorb infrared better than our surroundings.



C. Optical Fibers: Optical fibers are thin strands of glass or plastic with double refractive indices. Light or infrared radiation entering the core reflects from the core-cladding boundary due to total internal reflection, allowing it to travel through the core at the speed of light. Ordinary light, laser light, and infrared radiation are used in optical fibers. Infrared radiation is particularly advantageous because its wavelength has low absorption in glass optical fibers, enabling long-distance data transmission with minimal power loss as shown in figure 20.5 (c).

D. Thermal Imaging: Thermal imaging involves converting infrared radiation (heat) emitted by objects into visible images using a thermal camera. This technology is highly effective in penetrating smoke, dust, aerosols, and clouds, making it useful in various conditions both during the day and at night as shown in figure 20.5 (d).

E. Night Vision: Infrared radiation makes the night vision possible as the night vision scopes can detect the infrared emitted by various warm objects including humans and converts it to visible light as shown in figure 20.6. The Sun radiates with a 6000 K surface temperature in which about half of the solar radiations reaching on the Earth is in the infrared region with most of the rest in the visible part of the spectrum and a relatively small amount in the ultraviolet region.

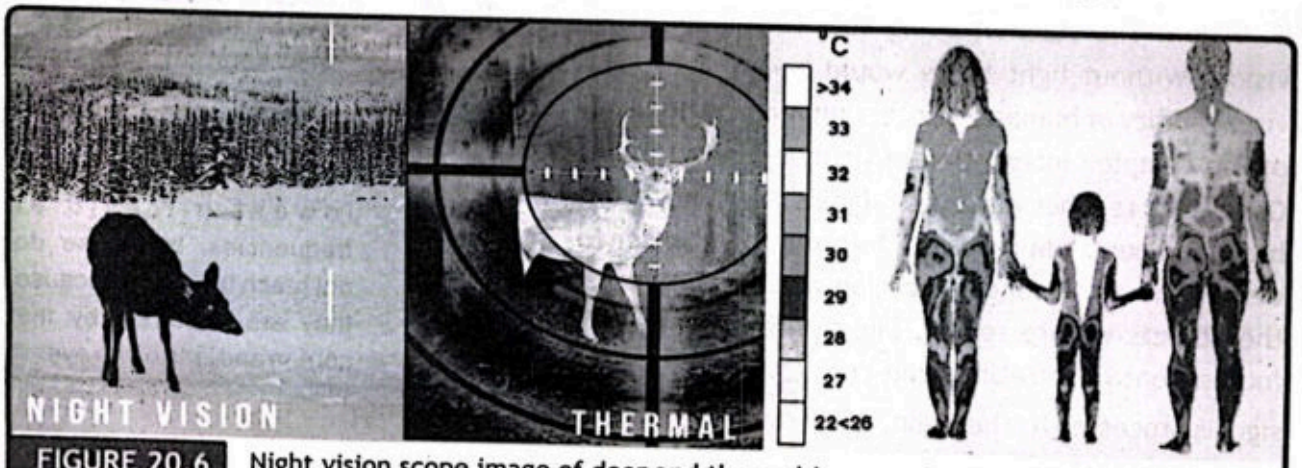


FIGURE 20.6 Night vision scope image of deer and thermal images of stag and humans.

20.2.4 APPLICATIONS OF VISIBLE LIGHT

Visible light is the narrow segment of the electromagnetic spectrum to which the normal human eye responds. The part of spectrum which is known as visible light with the colors associated with pure wavelengths is shown in figure 20.7.

Red light has the lowest frequency and longest wavelength while violet has the highest frequency and smallest wavelength in visible spectrum. Visible light is the most prominent aspect of electromagnetic radiation in our lives and we enjoy the beauty of nature through visible light. Among many uses we are discussing only two uses of visible light spectrum as:

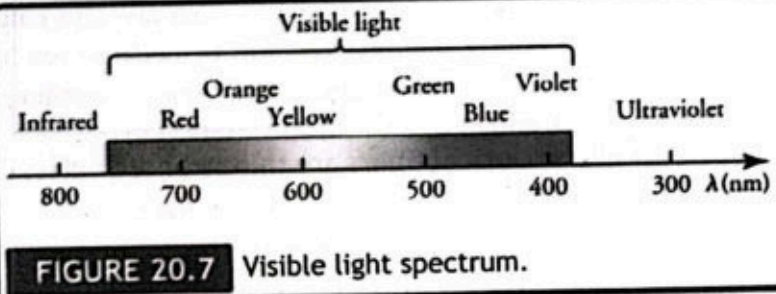


FIGURE 20.7 Visible light spectrum.

A. Photography: In photography, visible light plays a pivotal role in capturing images. Cameras are designed to mimic the human eye's ability to detect and focus on visible light. Photographic sensors and film capture the light reflected or emitted by the subject, which is then processed to create an image. Different wavelengths of visible light are responsible for the colors we see in photographs. Advances in photographic technology have enabled high-resolution, color-accurate images that are used in everything from art and media to scientific research and documentation. A visible light camera is shown in figure 20.17.

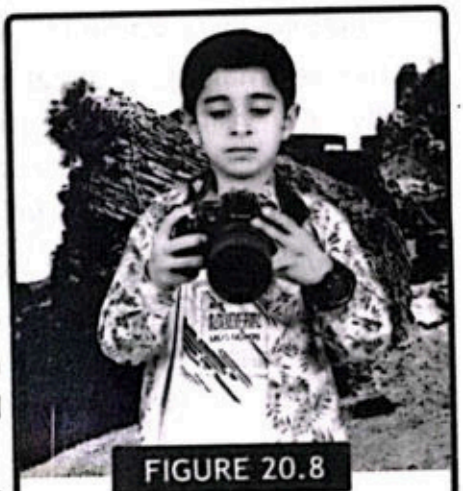


FIGURE 20.8 Visible light camera

B. Vision: The state of being able to see something is called vision. Without light there would be no sight. The visual ability of human and other animals is the result of the complex interaction of light, eyes and brain. Once light reaches our eyes, signals are sent to our brain and our brain reads the information in order to detect the appearance, location and movement of the objects we are seeing. Light enters the eye, is focused onto the retina, and converted into neural signals processed by the brain, allowing us to perceive our surroundings.

POINT TO PONDER



The retina of our eyes actually responds to the lowest ultraviolet frequencies, but these do not reach the retina because they are absorbed by the cornea and lens of the eye.

20.2.5 APPLICATIONS OF ULTRAVIOLET WAVES

Ultraviolet means 'above violet'. The frequency of ultraviolet radiations extends upward from

violet the highest frequency in visible spectrum. Solar ultraviolet are further subdivided into three regions ultraviolet-A from 320 to 400 nm, ultraviolet-B from 290 to 320 nm and ultraviolet-C from 220 to 290 nm ranked from long to short wavelengths. Most ultraviolet-B and all ultraviolet-C are absorbed by the ozone (O_3) molecules in the upper atmosphere resulting 99% of the solar ultraviolet radiations reaching the Earth's surface are ultraviolet-A. Some practical applications of UV light are:

A. Security Marking: An ultraviolet watermark is included on many sensitive documents like credit cards, driver's licenses and passports to help prevent frauds. The watermark can only be seen when viewed under ultraviolet emitting light source. The ink used in this process do the fluorescence (a process in which any material absorbs radiations of high energy and frequency like ultraviolet and re-emit low energy radiations like visible light). The ink absorbs ultraviolet radiations and then emits visible light which can be seen by human eye as shown in figure 20.9 (a).

B. Detecting Counterfeit Bank Notes: Currencies of various countries including Pakistan's bank notes have an image as well as many multicolor fibers that are visible only under ultraviolet light to thwart counterfeiters. The whole process in this system is the same as in security marking by fluorescence we can see the fibers and images on the bank notes to check their reliability as shown in figure 20.9 (b).

C. Sterilizing Water: Sterilizing water means to purify the water from harmful microorganisms like bacteria and viruses etc. An ultraviolet purifier treats micro-biologically unsafe water with germ killing ultraviolet light. An ultraviolet sterilizer is shown in figure 20.9 (c). Ultraviolet sterilization is considered to be one of the most effective water treatment methods for disinfection. It quickly sterilizes the water and not any need of additional chemicals, it is cost effective and there is no danger of overdosing.



(a) UV security marking (b) Detecting Counterfeit in bank notes (c) UV sterilizer

FIGURE 20.9 Application of UV light.

20.2.6 APPLICATIONS OF X-RAYS

The low range of x-rays overlaps with the ultraviolet and high energy x-rays overlaps gamma rays (in low energy region). X-rays have many medical, technological and social applications some of them are:

A. Medical Imaging: The widest use of x-rays is for imaging objects that are opaque to visible light such as human body. The ability of x-rays to penetrate matter depends on density, so an x-ray image can reveal very detailed density information. The fracture of bones can be found by using x-rays as shown in figure 20.10 (a). The use of x-rays technology in medical science is called radiology. X-rays are widely available and used extensively in medical diagnostics. An x-rays can affect a photographic film. When a person stands in front of a photographic film x-ray is bombarded on his/her body to form an image.

B.Security Scanners: X-rays scanners are used to detect threats such as weapons or explosives that a person could be carrying under their clothing, the scanners used for this purpose a use very low energy x-rays that are reflected back to the scanner which shows any metal object. Along with this x-rays scanning technology is also used in many industrial and commercial applications most notably in security and health care an x-ray scanner is shown in figure 20.10 (b).



(a) Medical x-rays (b) Security x-rays scanner (c) Radiations to kill cancerous cells

FIGURE 20.10 Applications of X-rays

C. Killing Cancerous Cells: Radiation therapy is a cancer treatment that uses high doses of radiation to kill cancer and shrink tumors as shown in figure 20.10 (c). At low doses radiation is used in x-rays to see inside your body.at high doses radiation therapy kills cancer cells or slows their growth by damaging their DNA. Cancer cells whose DNA is damaged beyond repair stop dividing or die.

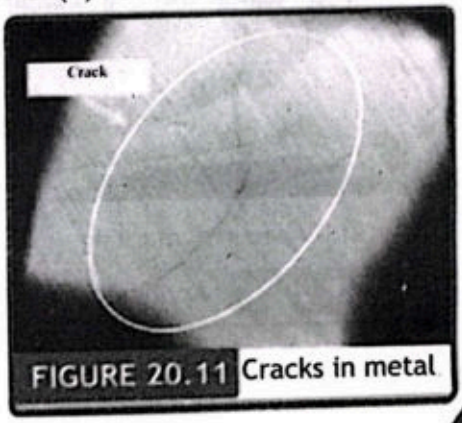


FIGURE 20.11 Cracks in metal

D. Detecting Cracks in Metals: Radiographic testing (RT) is a non-destructive testing (NDT) method which uses either x-rays or gamma rays to examine the internal structure of manufactured components identifying any flaws or defects. In the radiographic testing the test part is place between the

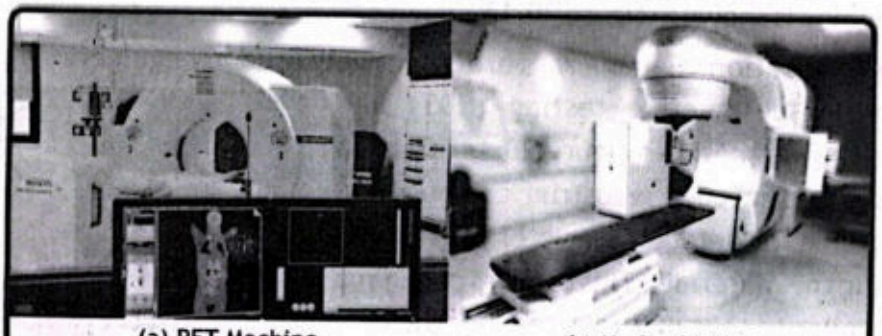
radiation source and the film (or detector). Because x-rays are hardly scattered at the crack, a region where the crack exists is dark and that region where the crack does not exist is light on the image of the scattered x-rays. The crack can be detected from the dark and light regions on the image. As cracks make the portion of metal thinner as compared to other regions and hence more x-rays will pass through the cracks to form an image illustrating the exact size and location of the crack as shown in figure 20.11.

20.2.7 APPLICATIONS OF γ-RAYS

Gamma rays are the most energetic form of electromagnetic radiation, possessing the shortest wavelength. As a type of nuclear radiation, they are emitted from the nucleus of a heavy atom. Due to their high energy, gamma rays are highly penetrating, capable of passing through many materials that block other types of radiation. Few applications of gamma rays are:

B. Medical Treatment: Gamma rays are really useful in medicine for both diagnosing and treating diseases. In the realm of nuclear medicine, healthcare professionals utilize radioactive materials that emit gamma rays. These materials are often introduced into the body through injections or ingested in small amounts. Once inside, the radioactive substances accumulate in specific organs or tissues, depending on their chemical properties.

Specialized imaging equipment, such as gamma cameras or positron emission tomography (PET) scanners, is then employed to detect the gamma rays emitted from these radioactive materials. This imaging technique allows doctors to visualize the internal structures of the body in real-time, providing critical insights into the functioning of various organs.



(a) PET Machine (b) Medical LINAC

FIGURE 20.12 Medical applications of gamma rays

In addition to diagnostic applications, gamma rays are also pivotal in the treatment of cancer through a process known as radiation therapy. In this context, high-energy gamma rays are precisely targeted at cancerous cells to destroy them or inhibit their growth. This treatment can be administered externally, using machines that generate gamma rays, or internally, through a method called brachytherapy, where radioactive sources are placed directly within or near the tumor. The ability of gamma rays to penetrate tissues makes them particularly effective in targeting tumors while minimizing damage to surrounding healthy cells.

C. Sterilizing Food and Medical Equipment: Gamma rays are effectively used for sterilizing both medical equipment and food. Gamma radiation sterilization involves exposing medical products to gamma rays. The radiation source typically used is the Cobalt-60 isotope which emits gamma radiations in the process to destroy any microorganism present. Similarly for food sterilization we again use Cobalt-60 which is used to kill bacteria, mold, parasite and insects in the food. The most important aspect of this process is that the food itself does not become radioactive. A gamma ray sterilization machine is shown in figure 20.13.

POINT TO PONDER



Gamma Knife is a non-invasive brain surgery that uses targeted gamma radiation to treat tumors, lesions, and abnormal tissues. This method effectively eliminates or reduces these tissues while protecting surrounding healthy tissue, making it a safer treatment option.

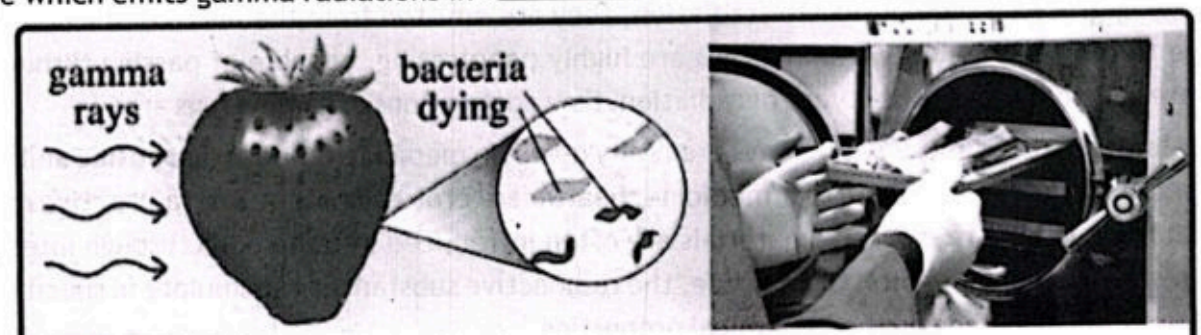


FIGURE 20.13 Gamma ray sterilization of equipment and food

D. Engineering Application: Gamma rays are effectively used in engineering for many purposes particularly in non-destructive testing (NDT) and radiographic testing as shown in figure 20.14. Gamma rays are employed to inspect industrial components, welds and structures for defects, cracks or other flaws without damaging the materials. This process of gamma rays testing is similar to that of x-rays testing, the only difference is that gamma rays have more penetrating power than the x-rays and hence it gives better test for hard materials. In radiography gamma rays penetrate the materials to reveal hidden flaws.



FIGURE 20.14 Gamma ray radiographic testing

20.3 RISKS ASSOCIATED WITH ELECTROMAGNETIC WAVES

The electromagnetic waves along with their many applications have some hazards associated with them. Every type of electromagnetic waves has its particular hazards. Normally majority of the electromagnetic waves in smaller amounts are safe to human and the atmosphere but their

higher intensities can produce damages for the living organism on Earth and its atmosphere. Some of the hazards of electromagnetic spectrum are listed in table 20.2.

TABLE 20.2 ELECTROMAGNETIC WAVES: A HAZARD ANALYSIS

EM wave	Potential Hazards
Radio waves	• High-energy radio waves can cause tissue heating, leading to burns or heat-related injuries. • Continuous exposure can interfere with biological systems and medical devices like pacemakers and hearing aids.
Microwaves	• Microwaves can cause tissue damage, especially in sensitive organs like the eyes, potentially leading to cataracts. • Exposure to high-powered microwaves may result in burns or heat stress and can interfere with implanted medical devices.
Infrared	• Prolonged exposure to infrared waves can cause thermal damage, resulting in burns or overheating. • High-intensity infrared radiation over time can cause eye damage, skin aging, and diseases.
Visible light	• Direct viewing of intense visible light over extended periods can cause eye strain and retinal damage. • Long exposure to bright artificial lighting can disrupt biological rhythms and, in extreme cases, cause burns or permanent eye injuries.
Ultraviolet	• Long-term exposure to UV waves damages skin cells, causing sunburn and increasing the risk of skin cancers. • UV radiation can harm the eyes, leading to cataracts and other vision impairments, and weaken the immune system.
X-rays	• X-rays cause ionization that can lead to tissue damage, cell mutations, and a high risk of cancer. • Frequent or high-dose exposure can cause burns, cataracts, and acute radiation sickness affecting overall health.
γ-rays	• Gamma rays cause cell mutations, leading to cancer or death due to their penetrative and ionizing nature. • Prolonged exposure leads to acute radiation sickness and poses environmental and health threats through nuclear accidents or improper disposal.

Ionizing radiation refers to electromagnetic waves that have enough energy to remove tightly bound electrons from atoms, creating ions. This can lead to various chemical and biological changes in living tissues. Among the electromagnetic (EM) spectrum, ultraviolet (UV) rays, X-rays, and gamma rays are ionizing radiation, differing primarily in their energy levels and wavelengths.

UV rays occupy the part of the EM spectrum with wavelengths shorter than visible light but longer than X-rays. Prolonged exposure to UV radiation can cause skin cancer, cataracts, and other health issues. X-rays have shorter wavelengths and higher energy compared to UV rays. The ionizing power of X-rays can cause cellular damage, increasing the risk of cancer with excessive exposure.

Gamma rays are at the high-energy end of the EM spectrum, with the shortest wavelengths and highest frequencies. Gamma rays have significant ionizing power, capable of penetrating almost any material. This makes them both a powerful tool in medical treatments, such as radiotherapy for cancer, and a considerable hazard in terms of radiation exposure. The intense ionizing effect of gamma rays can cause severe cellular and DNA damage, necessitating strict safety protocols in environments where gamma rays are present.

Lower-energy radiation such as visible light, infrared, microwaves, and radio waves lack sufficient energy to ionize atoms and are generally considered non-ionizing. Thus, they are less harmful in terms of causing immediate biological damage. It is essential to protect oneself from excessive exposure to ionizing radiation, especially X-rays and gamma rays. Shielding, limiting exposure time, and maintaining a safe distance from radiation sources are crucial preventive measures.

20.4 SCATTERING OF LIGHT

Light scattering occurs when light waves bounce off particles in a medium in different directions. The amount of scattering depends on the particle size and the light's wavelength; shorter wavelengths scatter more, while longer wavelengths scatter less and travel straighter. For effective interaction, the light's wavelength must be similar in size to the particles. Sunlight contains almost all wavelengths in the visible spectrum, including shorter wavelengths like blue and violet, as well as longer wavelengths like orange and red.

20.4.1 BLUE COLOR OF SKY

The light coming from the Sun has many wavelengths among them the blue color is present in the major percentage of the lower wavelengths. With the wavelength of the light the scattering efficiency of the small molecules in the atmosphere decreases. The Sun radiates its light which when enters into the atmosphere of the Earth scattered due to the air molecules, dust particles

and water vapors. The major components in the atmosphere are the gases like Oxygen and Nitrogen which cause the major scattering of light. As the sizes of molecules of these gases are small and are comparable to the size of region of smaller wavelengths mainly blue with indigo and violet hence these wavelengths suffers the most interactions with the molecules of the gases and reflect around due to scattering. While the region of larger wavelengths of visible light do not suffer such scattering as their wavelengths are larger than the molecules of the gases and they pass straight through the atmosphere. In upper atmosphere we see scattering of smaller wavelengths which give the appearance of blue color in upper atmosphere which is known as blue sky. This phenomenon is shown in figure 20.15. From figure it can be seen that larger wavelengths (red, orange, yellow etc.) pass through the atmosphere without scattering appreciably while the smaller wavelength (blue, indigo, violet etc.) of light

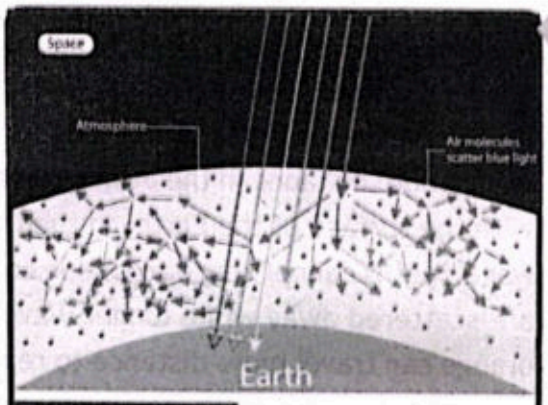
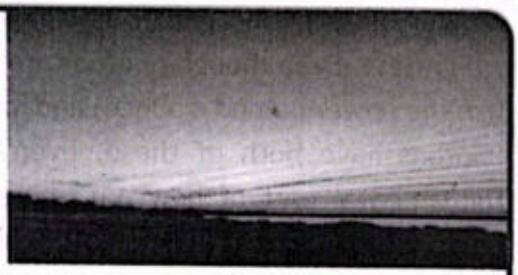


FIGURE 20.15 Blue color of sky

CASE STUDY

A Clear Summer Day and a Beautiful Sunset:

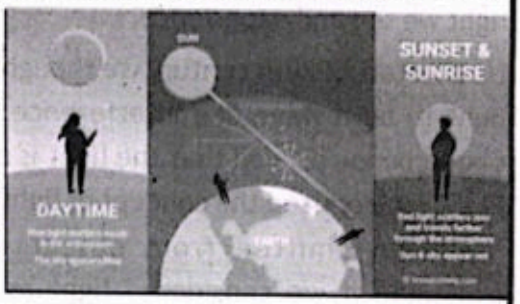


Imagine a summer day at the beach. The sky is bright blue and looks clear and vibrant. But as the sun sets, the sky turns shades of orange, pink, and red, creating a beautiful, colorful scene.

Can you think why does this happen?

Explanation

This color change is due to the way sunlight interacts with the atmosphere of the Earth. Sunlight contains all colors, which means it is a mix of different wavelengths of light.



1. **During the Day:** When sunlight reaches Earth's atmosphere, it interacts with the tiny gas molecules in the air. These molecules scatter the sunlight in all directions. Blue light, with its shorter wavelength, scatters more than other colors like red and green. This scattered blue light reaches our eyes from all directions, making the sky appear blue.

2. **At Sunset:** As the sun moves lower on the horizon, sunlight has to pass through more of the atmosphere to reach us. By the time it gets to our eyes, most of the blue and violet light has scattered out in different directions. This leaves behind more of the red and orange wavelengths, which are longer and scatter less, creating the warm colors of sunset.

This effect, known as Rayleigh scattering, explains why we see different colors in the sky at various times of the day. It's a perfect example of how the behavior of light changes what we see in the natural world.

scattered in all directions filling the sky with a blue hue.

20.4.2 RED SKY AT DUSK

In the evening and in the morning as the Sun light has to travel more distance in the atmosphere due to its low angle with the surface of the Earth. In such situation the smaller wavelengths cannot reach to us due to more scattering and are scattered away while longer wavelengths like red and orange can travel more distance to reach us. This results in the warmth. Reddish hues we see during sunset as the Sun's light passes through more air molecules before reaching our eyes. The phenomenon of red sky in evening is shown in figure 20.16, which shows at smaller angles blue light scattered out and red light reaches to us. The same phenomenon is the early morning's sunrise time the sky appears reddish.

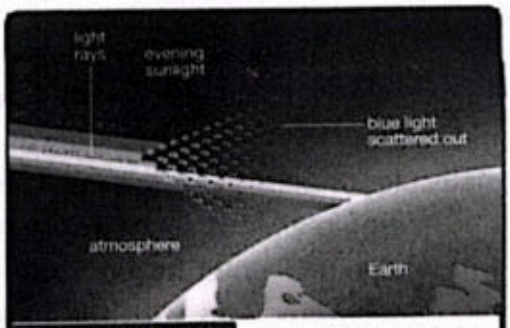


FIGURE 20.16 Red sky in evening

20.5 NATURE OF LIGHT

Imagine light as a stream of tiny, super-fast bullets. These "bullets" are called photons. Unlike regular bullets, photons do not have any mass. That means they are incredibly light, almost weightless. Even though photons are massless, they still carry energy and momentum. Energy is like the power behind a punch, and momentum is like the force that keeps a moving object going. Photons have both of these, even without any mass. This might seem strange, but it's a fundamental part of how our universe works. Scientists have done experiments that prove photons behave like particles with energy and momentum. So, light might seem like a continuous wave, but it's actually made up of these tiny, massless particles called photons (as shown in figure 20.17). They're like the building blocks of light, carrying energy and momentum that make up the light we see and experience.

Up till start of 20th century we thought light as a wave only because we got many evidences about light to be a wave like interference, reflection, refraction, diffraction and polarization, such phenomenon proved that the light is a wave. However, at the beginning of the 20th century, Max Planck introduced the concept of light having a particle nature. He suggested that the behavior of radiation emitted from objects could only be explained if we considered light as tiny packets of energy, which he called "quanta of light."

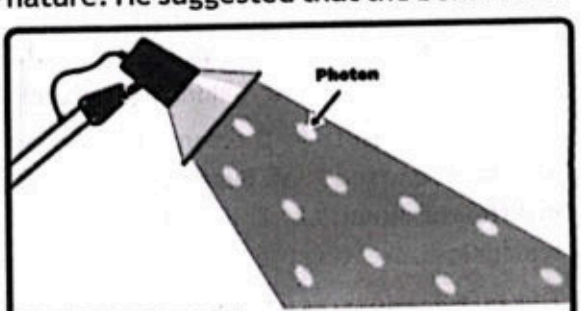


FIGURE 20.17 Particle nature of light

He explained the light to be composed of tiny massless particles called "photons" which carry some energy and momentum but no charge. The energy of photon can be given by equation 20.1 as:

$$E = h f$$

Similarly the momentum of a photon can be given by the equation 20.1 as:

$$p = \frac{h}{\lambda} = \frac{h f}{c} \quad \text{— 20.4}$$

A photon is a fundamental particle and quantum of the electromagnetic field, carrying energy and momentum without mass, always traveling at light speed in a vacuum. As the basic building blocks of light, photons are classified as elementary particles. This raises the question of whether light is a wave or a particle, a puzzle addressed by Louis De Broglie's theory of light's dual nature, which states that light exhibits both properties.

Example 20.2

You are using a radiation monitor which gives you a signal of some radiations received. The wavelength of those radiations was 200 nm. Find the frequency, momentum and energy of the radiation signals.

GIVEN:
Wavelength 'λ' = 200 nm

REQUIRED:
Frequency 'f' = ?, Momentum 'p' = ? and Energy 'E' = ?

SOLUTION:
To find the value of frequency first we use the equation: $f = \frac{c}{\lambda}$

putting values $f = \frac{3\times10^{8} ms^{-1}}{200\times10^{-9} m}$ or $f = 1.5\times10^{15} Hz$ — ANSWER

To find the momentum of radiations we use: $p = \frac{h f}{c}$



putting values $p = \frac{(6.63\times10^{-34} Js)\ (1.5\times10^{15} s^{-1})}{3\times10^{8} ms^{-1}}$

Therefore $p = 3.315\times10^{-27} kg\ m\ s^{-1}$ — ANSWER

Now the energy of radiations can be found by the relation as: $E = \frac{h c}{\lambda}$

using values $E = \frac{(6.63\times10^{-34} Js)\ (3\times10^{8} ms^{-1})}{200\times10^{-9} m}$ or $E = 9.945\times10^{-19} J$ — ANSWER

As frequency of the received radiation lays in the region of ultra violet radiations hence the radiation detected by the radiation monitor are ultra violet radiations.

20.5.1 RADIATION PRESSURE

Imagine tossing a tennis ball; it has weight and you can feel it. Now, think of a tiny, fast bullet made of energy—This bullet doesn't have any weight, but it can still push things around. Photons, which are the particles that make up light, are like these energy bullets. They don't have mass,

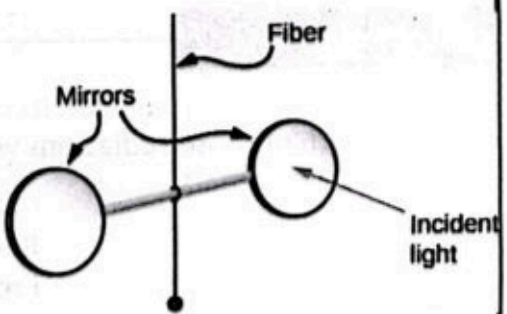
PROJECT

Title: to study the radiation pressure.

Apparatus: Two concave mirrors of very light weight, an inextensible and light weight fiber, a very light pipe and a source of intense light.

Performance: To perform the activity for studying radiation pressure, you have to do the following tasks:

- Take two concave shaped mirrors and connect them by a light rod or pipe.
- Hang the mirror and pipe system by an inextensible light string as shown in figure here.
- Bring the whole apparatus in stationary state.
- Make sure that there is no wind in the room.
- Now take torch which can give you an intense light and strike the light on one mirror you will notice that the whole assembly will rotate a little due to the pressure exerted by the light.
- Change the intensity of light and note the extent of rotation and guess the relation between intensity of light and the radiation pressure.



Conclusion: from the above project we learnt that the when we strike a light of particular intensity we moved the mirrors assembly which can only be possible if the incident light has some pressure i.e. light exerted some force on unit area of the mirror. By changing the intensity of light we noticed that the mirrors assembly moved larger distance which shows that the radiation pressure is directly proportional to the intensity of light.

but they carry energy and momentum. That's why sunlight can warm your skin and why solar sails can move spacecraft.

Despite having no mass, photons significantly interact with matter. Due to transfer of momentum

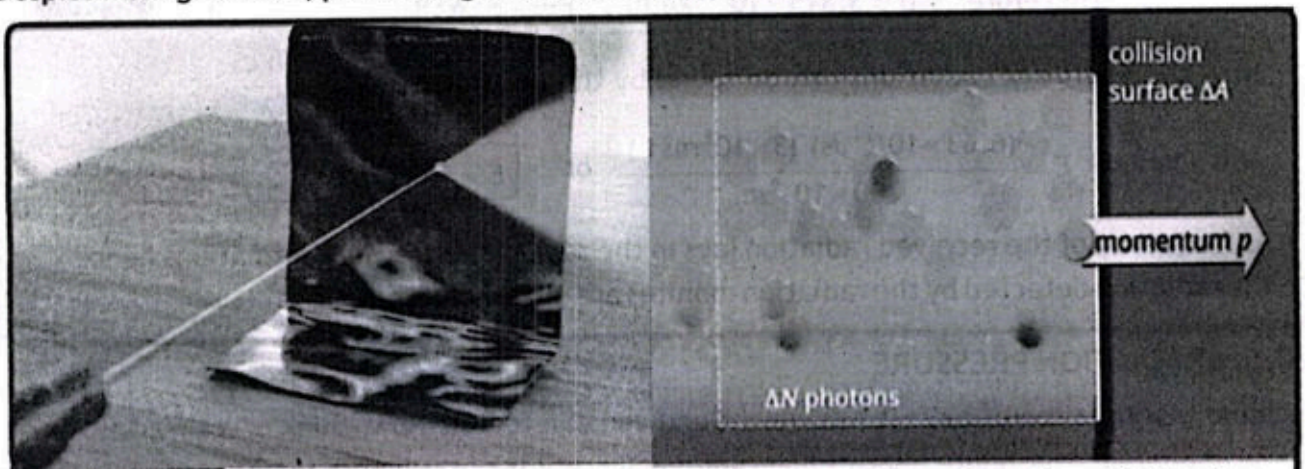


FIGURE 20.18 Radiation's pressure due to collision of photons on the surface where light strikes

light can exert pressure on objects and this phenomenon is known as "radiation pressure" as shown in figure 20.18. This pressure depends on the surface type and light intensity. For instance, sunlight warms your hands by transferring tiny momentum, which is imperceptible due to the high speed of light.

While often too small to notice with regular light, radiation pressure is crucial in astronomical contexts, such as balancing gravitational forces in stars or pushing dust in comet tails. It also has practical applications, like laser cooling and trapping, which manipulate atoms and small objects.

20.5.2 SOLAR SAILS:

With many other applications of radiation pressure one is the "solar sails". The solar sail is a spacecraft propulsion method that utilizes the momentum of photons. These particles of light have no mass yet when they strike something they can impart momentum and provide a tiny push. Solar sails use large but light weight reflective materials to capture and reflect solar radiations providing a continuous thrust. Imagine it like a sailing boat in space where sunlight acts as the wind pushing against the sail propelling the spacecraft forward. The incident photons hit the sail and transfer their momentum to the sail and reflect at some angle which gives a thrust to the sail as shown in figure 20.19.

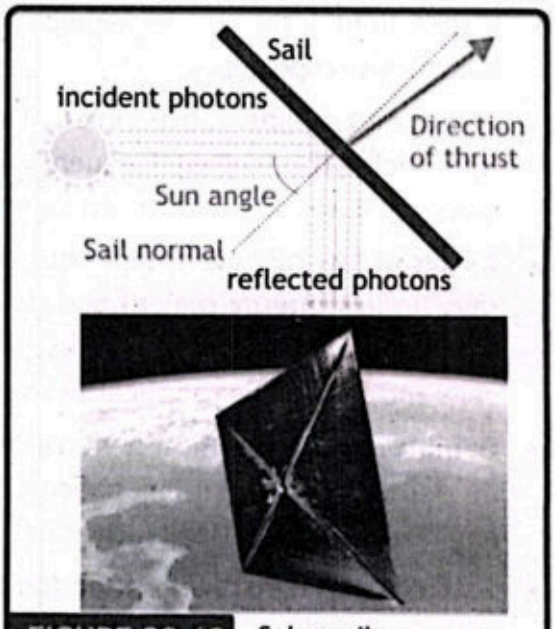


FIGURE 20.19 Solar sail

SUMMARY

- **Electromagnetic waves** are the waves which do not require a material medium for their production and propagation.
- **Electromagnetic Spectrum** is the range of different wavelengths of electromagnetic waves is called the spectrum of the electromagnetic waves.
- **The speed of light** in the vacuum is a universal constant and is denoted by 'c' whose value can be given as 3×10^8 m/s.
- **Spectroscopy** is the branch of Physics which is used to study the ways different electromagnetic waves interact with matter.
- **Radio waves** are the range of longest wavelengths in the family of electromagnetic waves is the radio waves and can travel at the speed of light and can be used in radio transmission, television transmission and in astronomy.

- **Microwaves** have a higher frequency and lower wavelength than radio waves, but they are still generally thought of as low energy radiations and are used by some radars, Bluetooth, headphones, speakers and even Wi-Fi.
- **Infrared radiations** are in general produced by thermal motion, the vibration and rotation of atoms and molecules and have applications in household electrical appliances, remote controllers, intruder alarms, thermal imaging and optical fibers.
- **Visible light** is the narrow segment of the electromagnetic spectrum to which the normal human eye responds.
- **Ultraviolet** means 'above violet'. The frequency of ultraviolet radiations extends upward from violet the highest frequency in visible spectrum and have applications in security marking, detecting counterfeit bank notes and sterilizing water.
- **X-rays** of low range overlaps with the ultraviolet and high energy x-rays overlaps gamma rays (in low energy region) and its applications are in medical, technological and social applications some of them are use in medical imaging, security scanners, killing cancerous cells and engineering applications such as detecting cracks in metal etc.
- **Gamma rays** are the most penetrating nuclear radiations and are used in medical treatment in detecting and killing cancerous cells, sterilizing food and medical equipment, engineering applications such as detecting cracks in metal etc.
- **Scattering of light** is the reflection of light waves in different directions from the particles of the medium.
- **Blue sky** is the phenomenon in upper atmosphere, where scattering of smaller wavelengths of light gives the appearance of blue color in upper atmosphere.
- **Nature of light** have two aspects a wave like and a particle like.
- **Photon** is a tiny massless particle from which the light is composed of.
- **Radiation pressure** is the phenomenon in which due to transfer of momentum light can exert pressure on objects.
- **Solar sail** is a spacecraft propulsion method that utilizes a curious quirk of photons.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. Identify the electromagnetic wave with the greatest ability to penetrate matter.
   A. Radio waves B. Ultraviolet C. X-rays D. Gamma rays
2. Which type of radiation primarily carries heat energy?
   A. Radio waves B. Ultraviolet C. Infrared D. Visible light
3. The wavelength of 10 cm is corresponding to spectrum of:
   A. Microwaves B. Ultraviolet C. Infrared D. X-rays
4. The atomic structure of solids or cracks in solid structure can be investigated by:
   A. Microwaves B. Ultraviolet C. Gamma rays D. X-rays
5. Which waves are used for treating muscle aches in physiotherapy?
   A. Microwaves B. Ultraviolet C. Infrared D. X-rays
6. X-rays have a higher energy than visible light, because of its:
   A. Shorter wavelength B. Longer wavelength C. Lower frequency D. Higher speed
7. Electromagnetic waves are produced due to the motion of which of the following?
   A. Neutral particles B. Charged particles
   C. Accelerating neutral particles D. Accelerating charged particles
8. If the frequency of an electromagnetic wave is 2×10^{18} Hz, to which spectrum it belongs to?
   A. Microwaves B. Ultraviolet C. Infrared D. X-rays
9. Light with longest wavelength in visible spectrum is:
   A. Green B. Violet C. Orange D. Red
10. Electromagnetic waves exhibit particle-like behavior in quantum mechanics. These particles are called:
    A. Atom B. X-ray C. Electron D. Photon
11. The energy of an electromagnetic wave depends directly on its:
    A. Wavelength B. Amplitue C. Frequency D. Speed
12. When an electromagnetic wave enters from one medium into the other which quantity does not change?
    A. Wavelength B. Speed C. Frequency D. Energy

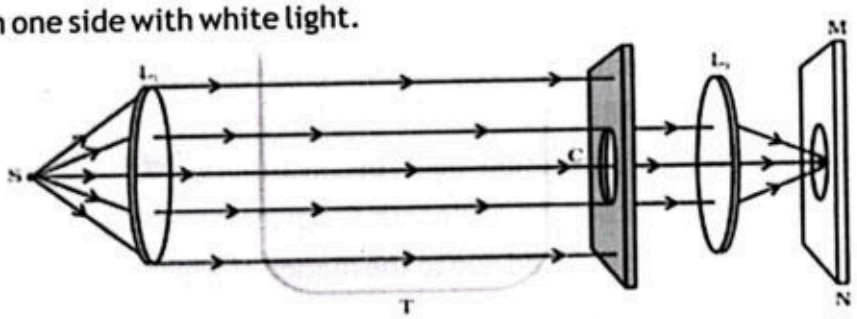
13. On halving the area of a totally reflecting surface, the radiation pressure will:
    A. Remain the same B. Double C. Halve D. Quadruple
14. Solar sails are preferred for deep-space missions because they require:
    A. Electric energy B. Fuel C. Chemical energy D. No fuel
15. Which of these electromagnetic waves has the least momentum?
    A. Gamma rays B. Ultraviolet C. Infrared D. Radio waves

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

Take some colloidal solution of sulphar from your Chemistry lab and fill the solution in some transparent beaker.

Assemble the beaker between a light source 's' and slit 'C' as shown in figure and illuminate the beaker from one side with white light.



Q.1: What color of the solution appears if seen from above? Why?

Q.2: What color spot appears on the screen 'N-M' after the light passes through the whole beaker?

Q.3: What phenomenon is observed in this activity?

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. A leak microwave oven in a home can sometimes cause interference with home's Wi-Fi system. Why?
2. Give an example of energy carried by an electromagnetic wave.
3. Your friend says that more patterns and colors can be seen on the wings of birds if viewed in ultraviolet light. Would you agree with your friend? Explain.

4. Can human body detect electromagnetic radiations that are outside the visible region of the spectrum?
5. What property of light corresponds to loudness in sound?
6. Certain orientations of a television antenna give better reception than others for a particular station. Explain.
7. Why microwaves are used for satellite TV and radio waves are used for terrestrial TV?
8. Can we use x-rays and gamma rays for broadcasting radio and TV signals?
9. When you stand outdoors in the sunlight, why can you feel the energy that sunlight carries but not the momentum it carries?
10. A newscaster in the studio speaks to a reporter from some remote place the voice of reporter is sometimes delayed. What causes this delay?
11. Is the visible region a major portion of the electromagnetic spectrum? Explain.
12. As the light passes through the atmosphere it scatters. Does the same happen with infrared light and radio waves? Explain.
13. Why the radiation pressure of an electromagnetic wave is greater when it is perfectly reflected as compared to when it is absorbed by the surface?
14. How are the photons produced?
15. Explain the reason that why clouds appear white in color?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Break down the electromagnetic spectrum in terms of wavelength and frequency. Why is the speed of electromagnetic waves in air nearly the same as in vacuum?
2. Evaluate the importance of radio waves in communication systems and astronomy compared to other electromagnetic waves. Why are they uniquely suited for this purpose?
3. Compare the use of microwaves in household applications versus industrial or scientific uses. How do their characteristics make them versatile?
4. What are infrared radiations and how they can be produced? Write their characteristics?
5. What is visible light? Why is visible light crucial for life on Earth?
6. Ultraviolet radiation has both beneficial and harmful effects. Discuss its characteristics, applications, and risks. How can we balance its advantages (e.g., sterilization) with its dangers (e.g., skin cancer)?
7. How x-rays are different from the rest of electromagnetic radiations? Discuss in details.

8. Gamma rays are the most energetic. How do their properties make them suitable for applications in nuclear science and astrophysics?
9. What potential hazards are associated with various parts of the electromagnetic spectrum? Compare the risks posed by ionizing and non-ionizing radiation, and evaluate why ionizing radiation is more dangerous in terms of its impact on living tissues and biological systems.
10. Explain the scattering of light from the atmosphere and why the color of sky is appears different at different times in a day?
11. Compare radiation pressure propulsion with chemical propulsion in space exploration. Which is more viable for long-term missions, and why?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Calculate the wavelength of an electromagnetic wave with a frequency of 5.0×10^{14} Hz.

   (Ans. 600 nm)

2. A gamma ray photon has a frequency of 2.0×10^{20} Hz. Calculate its energy.

   (Ans. 1.33×10^{-13} J)

3. A laser emits light with a frequency of 4.0×10^{14} Hz. What is the momentum of each photon?

   (Ans. 8.84×10^{-28} kg m/s)

4. What will be the momentum and energy of the photon from the radio waves with wavelength 100 mm?

   (Ans. 6.63×10^{-33} kg m/s, 1.24×10^{-5} eV)

5. The surface of Earth is hit by many radiations of different frequency and wavelength at all the times mainly during the day times. The maximum energy of radiations received in your room during a sunny day is 4.7 eV. Find the frequency and wavelength of this radiation also tell the type of radiation.

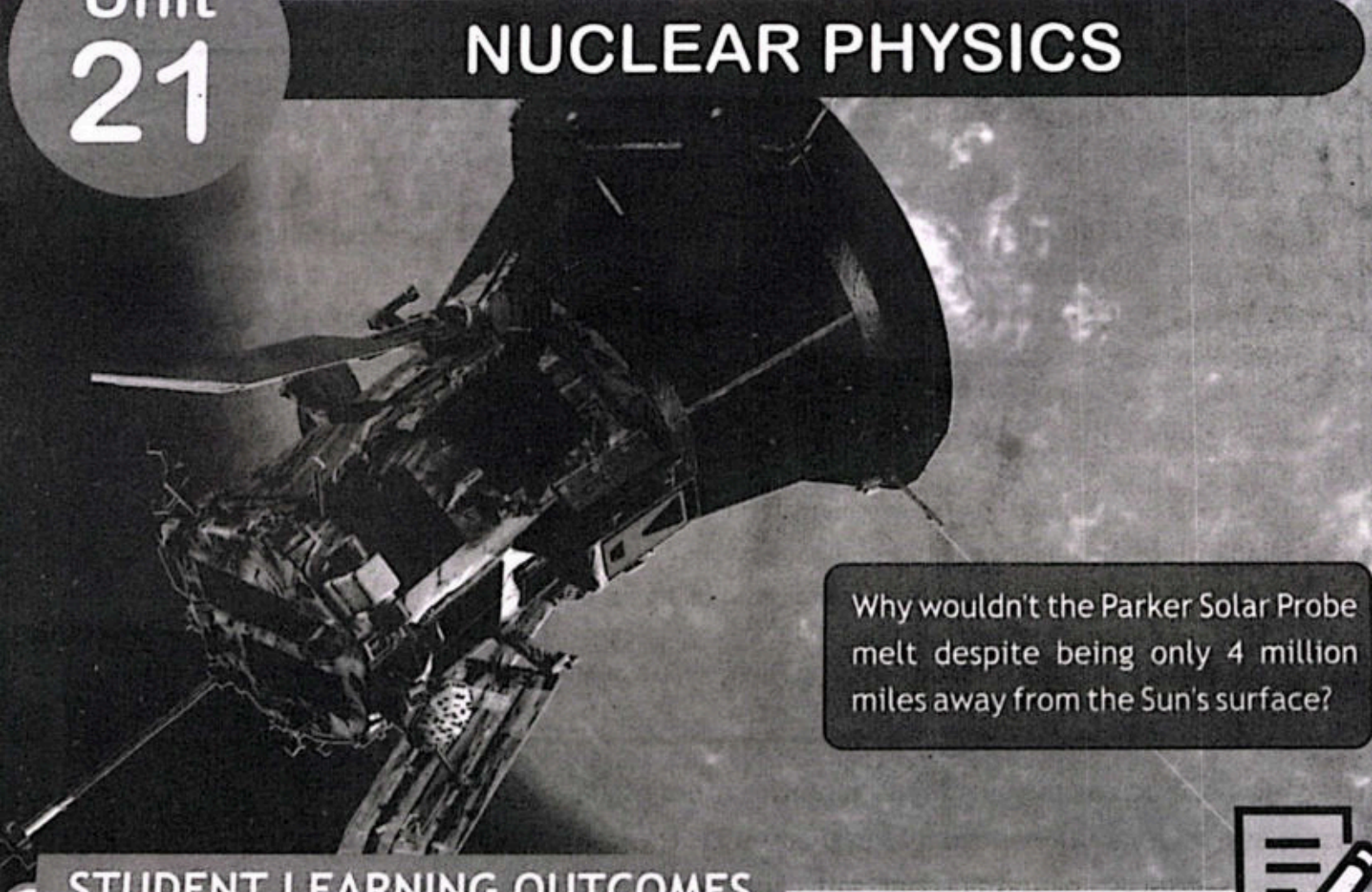
   (Ans. 1.13×10^{15} Hz, 265 nm, UV)

6. Find the momentum and energy of the photon from the visible light of the smallest wavelength.

   (Ans. 3.27 eV, 1.74×10^{-27} kg ms^{-1})

Unit 21

NUCLEAR PHYSICS



Why wouldn't the Parker Solar Probe melt despite being only 4 million miles away from the Sun's surface?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-F-01] Describe the structure of the atom.
- ✓ [SLO: P-10-F-02] Justify the findings of the alpha-particle scattering experiments.
- ✓ [SLO: P-10-F-03] 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.
- ✓ [SLO: P-10-F-04] Recall the term nuclide and use the nuclide notation ${}^{A}_{Z}X$.
- ✓ [SLO: P-10-F-05] Explain what is meant by an isotope and state that an element may have more than one isotope.
- ✓ [SLO: P-10-F-06] Explain what is meant by background radiation.
- ✓ [SLO: P-10-F-07] state the sources that make a significant contribution to background radiation.
- ✓ [SLO: P-10-F-08] Describe the emission of radiation from a nucleus as spontaneous and random.
- ✓ [SLO: P-10-F-09] Describe α-particles, β-particles and γ-radiation.
- ✓ [SLO: P-10-F-10] Justify qualitatively the order of strength for α-particles, β-particles and γ-radiation in terms of their (a) relative ionizing effects (b) relative penetrating powers
- ✓ [SLO: P-10-F-11] Describe the deflection of α-particles, β-particles and γ-radiation in electric fields and magnetic fields.
- ✓ [SLO: P-10-F-12] Explain that radioactive decay is a change in an unstable nucleus that can result, most commonly.
- ✓ [SLO: P-10-F-13] Use decay equations, using nuclide notation, to show the emission of α-particles, β-particles and γ-radiation.
- ✓ [SLO: P-10-F-14] Describe nuclear reactions (fission & fusion) with examples.

- ✓ [SLO: P-10-F-14] Recognise that matter can be converted to energy and vice versa (in this way the law of conservation of energy still holds).
- ✓ [SLO: P-10-F-15] Apply the equation $E = mc^2$ to calculate the energy released in the process of nuclear reactions.
- ✓ [SLO: P-10-F-16] Describe the activity of a radioactive material in terms of counts per unit time.
- ✓ [SLO: P-10-F-17] Define and infer the half-life of materials.
- ✓ [SLO: P-10-F-18] Explain and apply the concept of Carbon dating to solve problems.
- ✓ [SLO: P-10-F-19] Explain how the type of radiation emitted and the half-life of the isotope determine which isotope is used for applications.
- ✓ [SLO: P-10-F-20] State the effects of ionizing nuclear radiations on living things, including cell death, mutations and cancer.
- ✓ [SLO: P-10-F-21] Explain how radioactive materials are moved, used and stored in a safe way.
- ✓ [SLO: P-10-F-22] Explain the nature of the Sun.
- ✓ [SLO: P-10-F-23] Describe that it is hypothesized that most of the matter in the universe is made up of dark matter.
- ✓ [SLO: P-10-G-01] Explain, with examples in Physics, falsifiability as the idea that a theory is scientific only if it makes assertions that can be disproven.

The study of nuclear physics focuses on the atomic nucleus, composed of protons and neutrons known as nucleons. A key principle in this field is the conservation of mass-energy, which explains how mass-energy remains constant during conversions. Nuclear reactions involve the transformation of mass-energy into various forms of energy like kinetic energy, gamma rays, or thermal energy. Radioactivity, another important concept, involves the decay of unstable atomic nuclei and the emission of radiation such as alpha, beta, or gamma particles. The rate of decay is measured by half-life. Nuclear physics has applications in nuclear power generation, medicine, weapons, and astrophysics. It helps understand matter in extreme conditions and uncover the fundamental forces of the universe through the study of atomic nuclei and interactions.

21.1 DISCOVERY ATOMIC NUCLEUS

British physicist J.J. Thomson made a groundbreaking discovery on April 30, 1897, revealing that atoms are made up of smaller components. Following this, Thomson and other scientists worked to understand the complexities of atomic structure. In 1898, Thomson suggested that atoms are positively charged chunks of matter with negatively charged electrons scattered throughout, similar to raisins in a fruitcake. This idea, known as the "plum pudding model," gained attention because of Thomson's role in discovering electrons.

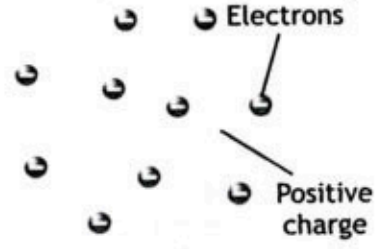


FIGURE 21.1

The Thomson plum pudding model of the atom. Electrons are imbedded in a uniform sphere of positive charge

By the end of the nineteenth century, scientists discovered that electrons make up only a tiny part of an atom's total mass. This led to the conclusion that the rest of the atom must consist of positive charge (since atoms are neutral) and most of the mass. The question remained: how is mass and positive charge spread out in the atom?

Thomson's plum pudding model was disproven in 1911 by Ernest Rutherford's alpha-particle scattering experiment. Rutherford studied uranium's radioactive decay and found that it emits two types of radiation. One type, called alpha (α) rays, is less penetrating than the other type, which he named beta (β) rays. Later in this chapter, we will delve into a detailed study of these rays.

Rutherford and his research assistant, Hans Geiger, created a special device (figure 21.2) to investigate how alpha particles interacted with thin gold foils. They directed alpha rays towards a piece of gold foil and used a screen coated with zinc sulfide to detect the scattered alpha rays. Whenever an alpha particle hit the zinc sulfide, it emitted light that could be seen through a detector. Rutherford moved the detector to different positions around the foil to see if the alpha rays would be deflected.

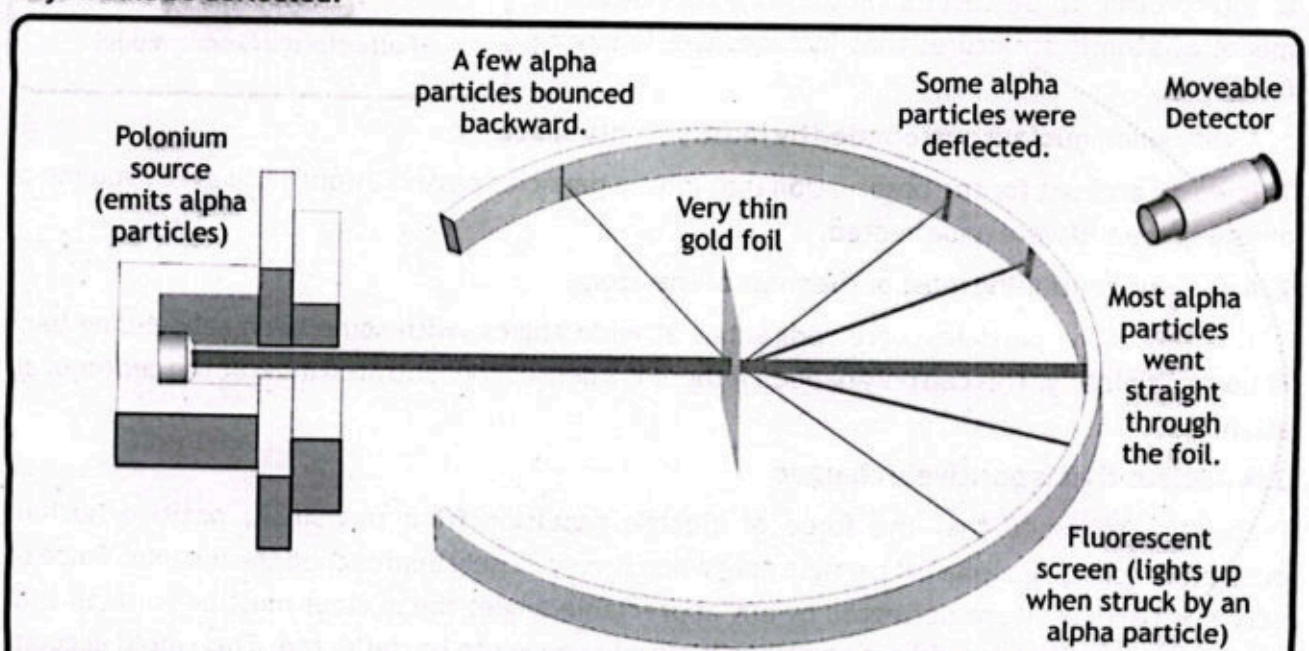


FIGURE 21.6 Rutherford's experiment aimed a beam of alpha rays at a sheet of gold foil.

According to Thomson's model of the atom, the alpha particles should have passed straight through the foil without much deflection. Initially, most of the alpha particles did pass through as expected. However, after a few days, Geiger excitedly informed Rutherford that they had observed some alpha particles scattering at angles greater than 90°.

Rutherford was amazed by this discovery and compared it to the unlikely event of a 15-inch shell bouncing back after hitting a piece of tissue paper. The observations consistently showed that about 1 in every 20,000 alpha particles was deflected more than 90°.

Rutherford determined that the alpha particles could only be repelled by an immensely powerful electrostatic field. For such a field to exist, all the positive charge had to be confined within a minuscule space at the atom's core. Hence, Rutherford put forth his atomic model known as nuclear model of atom, where the majority of an atom's positive charge and mass is concentrated in a tiny region at the center which he termed as 'nucleus', while the negatively charged electrons orbit around it, similar to planets revolving around the Sun, as shown in the Figure 21.3.

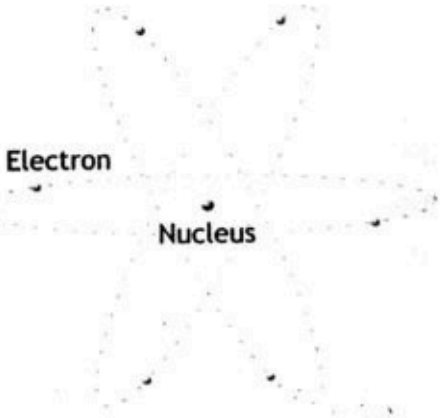


FIGURE 21.3
Rutherford's Atomic Model

In interpreting these results, Rutherford formulated a model of atomic structure, that includes the following features:

1. A very small nucleus surrounded by mostly empty space

This would account for the observation that most a particles passed through this great volume of empty space and were undeflected.

2. A nucleus containing most of the mass of the atom

Only a few alpha particles were redirected at wide angles, with some even rebounding back almost completely. This can only happen if there is a dense, concentrated mass at the center of an atom.

3. A nucleus that is positively charged

Rutherford reasoned that the force of electric repulsion from this small, positive nucleus deflected a positive alpha (α) particle only when it very closely approached the nucleus. Since so very few particles were deflected by any appreciable angle, the nucleus must be so small that most alpha (α) particles did not approach it closely enough to be deflected. This would account for the observation that most alpha (α) particles passed through this great volume of empty space and were un-deflected.

4. A number of very light, negatively charged electrons move in orbits around the nucleus.

As the alpha particles traveled straight through the empty space within the atom, every so often one of them would come across an electron, attract it due to electrostatic force, and continue on its path, hardly affected by the small mass of the electron it picked up.

The gold atom, now missing an electron, would become a positive ion. Rutherford proposed that these electrons orbited the positive nucleus, kept in place by electric attraction, similar to how planets orbit the Sun due to gravity. The currently accepted model is quite different from the Rutherford model of atom.

This simplistic picture is now replaced by more accurate and advanced quantum mechanical description of the atom. In this model the nucleus is made up of protons and neutrons, which are tightly packed together in very small volume. Protons have a positive charge, while neutrons have no charge. The number of protons in the nucleus determines the element of the atom. The size of an atom compared to the nucleus is quite significant. An atom is mostly empty space, with the nucleus located at the center.

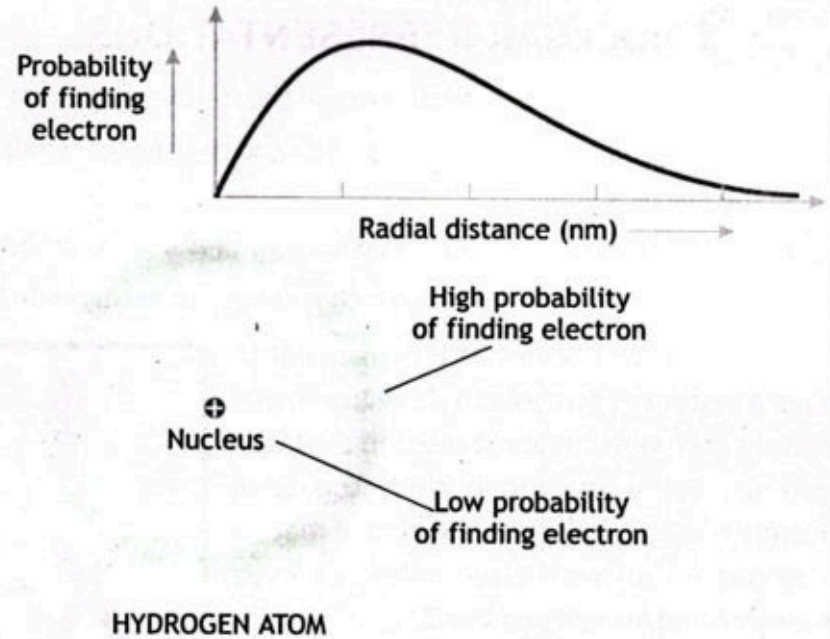


FIGURE 21.4 The electron cloud, or probability distribution, for the ground state of the hydrogen atom. The cloud is most dense—corresponding to the highest probability.

The size of the nucleus is typically about 10,000 times smaller than the size of the atom as a whole. The size difference is like a ping pong ball in the centre of a 2 km circle (akin to a football with flies around it in a boundary of several football fields). The electrons, on the other hand, are much smaller and lighter than the protons and neutrons. They are constantly in motion, buzzing around the nucleus at incredibly high speeds. However, their exact location and movement cannot be determined with certainty. Instead, we can only describe their probable location based on the probabilities dictated by quantum mechanics.

The electrons are organized into different energy levels or shells around the nucleus. These shells are not physical tracks or orbits like the planets in a solar system, but rather they represent the energy levels that the electrons can occupy. The closer a shell is to the nucleus, the lower the energy level of the electrons in that shell. Electrons can move between different energy levels by absorbing or releasing energy. When an electron absorbs energy, it jumps to a higher energy level. Conversely, when it releases energy, it drops to a lower energy level. This energy can come from various sources, such as heat, light, or electrical currents.

If we were able to see an atom, we would not see a distinct boundary between the nucleus and the electron cloud. Instead, we would see a fuzzy cloud of electrons surrounding the nucleus. This electron cloud represents the probable locations of the electrons at any given time (figure 21.4). The nucleus, on the other hand, would appear as a small, dense core within the cloud.

21.2 NUCLEAR REPRESENTATIONS

In describing the atomic nucleus, we use the following quantities

- The atomic number 'Z' (sometimes called the charge number), which is the number of protons in the nucleus.
- The mass number 'A' which is the number of nucleons in the nucleus.
- The neutron number 'N' which is the number of neutrons in the nucleus (N = A - Z).

In representing a nucleus, it is convenient to have a system of symbols to show how many protons and neutrons are present in the given nucleus. For a specific nucleus the term nuclide is used to describe the kind of matter involving nuclei with given values of mass number A and atomic number Z.

The symbol used is ${}^{A}_{Z}X$, where X represents the chemical symbol for the element, Z represents the number of protons and A represents the number of nucleons (i.e number of protons and neutrons) as shown in figure 21.5.

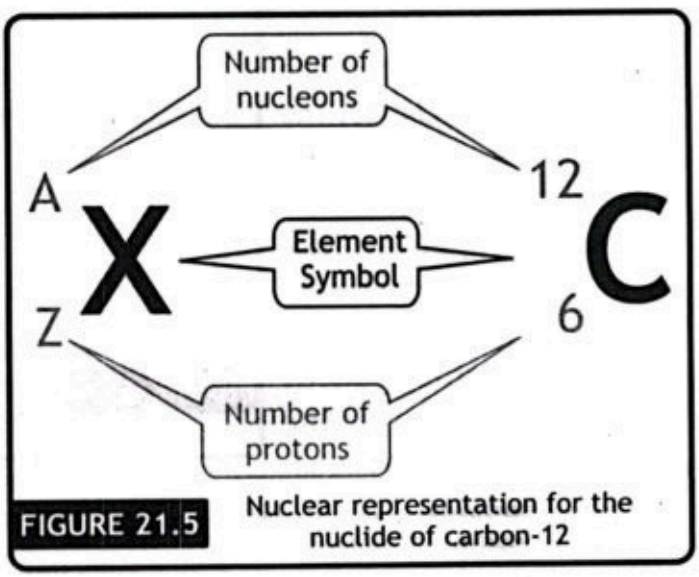


FIGURE 21.5 Nuclear representation for the nuclide of carbon-12

The number of neutrons can be calculated by subtracting number of protons 'Z', from number of nucleons 'A', such that the number of neutrons 'N' is 'A - Z'

21.3 ISOTOPES AND RADIOISOTOPES

Isotopes of an element have the same atomic number (i.e., the same number of protons) but a different mass number (i.e., different number of neutrons). The different numbers of neutrons in isotopes of an element result in different masses for each isotope. An element can exist in various isotopic forms because the number of neutrons in the nucleus of an atom of that element can vary while the number of protons remains the same.

For example consider three isotopes of hydrogen as shown in figure 21.6. The simple hydrogen atom ${}^{1}H$ (protium) has only one proton in its nucleus. ${}^{2}H$ (deuterium) has one proton and one

neutron in its nucleus, whereas ^{3}H (tritium) has one proton and two neutrons in its nucleus. Figure 21.6 shows helium atom which is not an isotope of hydrogen as it has different number of protons (and therefore electrons).

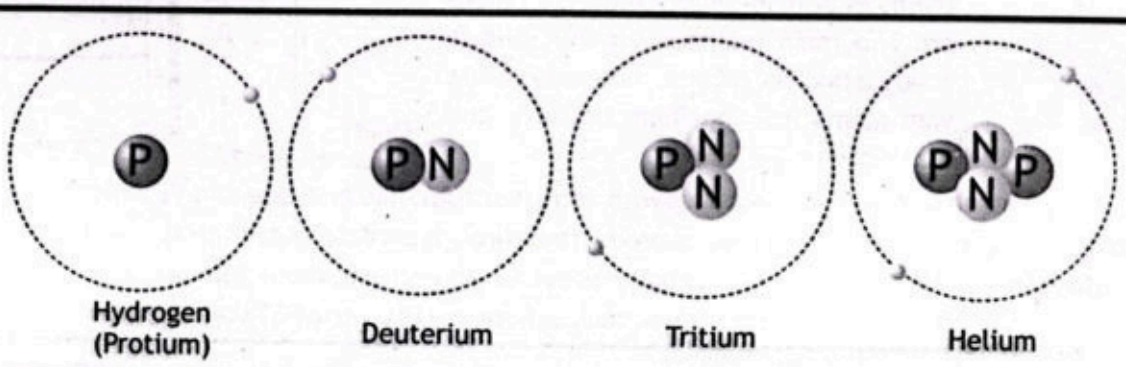


FIGURE 21.6 Three isotopes of hydrogen atom an helium atom.

Isotopes of the same element have same number of electrons therefore they have identical chemical properties. Isotopes cannot be separated by chemical methods, but only by methods that are based on their mass differences, such as mass spectrometry.

Isotopes can exist naturally and can be artificially produced. Some of these are unstable and thus are emit radiations to attain stability, these isotopes are called as radioisotopes.

Relative abundance is the percentage of atoms with a specific atomic mass found in a naturally occurring sample of an element. Relative abundance of ^{20}Ne is 90.48% and that of ^{21}Ne is 0.27%, and ^{22}Ne is 9.25% as shown in figure 21.7. Natural uranium contains two isotopes; ^{238}U (99%) and ^{235}U (little less than 1 %). ^{235}U is used as a fuel in nuclear reactors and in atomic bombs. Therefore, techniques have been developed to separate ^{235}U from natural uranium.

The first 80 elements on the periodic table have stable isotopes. Over 3,000 isotopes either exist



Neon 20
10 Protons
10 Neutrons
10 Electrons

Neon 21
10 Protons
11 Neutrons
10 Electrons

Neon 22
10 Protons
12 Neutrons
10 Electrons

(a) Three natural isotopes of neon

Neon 24
10 Protons
14 Neutrons
10 Electrons

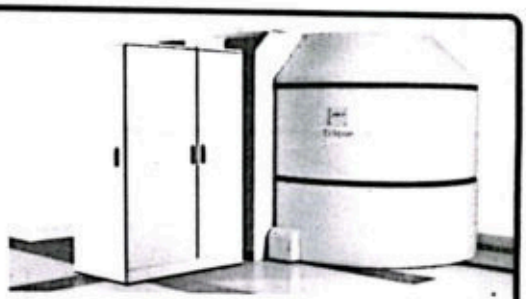
(b) The most stable artificial isotope of Neon

FIGURE 21.7 Isotopes of neon atom.

SCIENCE TIDBITS



Artificially produced radioisotopes are created in labs by bombarding stable atoms with high-energy particles. There are two main methods for this, one is inside a nuclear reactor, neutrons collide with atoms, making them unstable and radioactive.



This process is used to create radioisotopes with extra neutrons, like molybdenum-99 which is important for medical imaging. The other method is production through particle accelerators in which machines like cyclotrons accelerate particles (usually protons) and smash them into atoms. This creates radioisotopes with fewer neutrons than usual, such as fluorine-18 used in PET scans.

in nature or have been made artificially in particle accelerators, out of which only 257 are stable. The remaining isotopes are unstable and are termed as radioisotopes. Radioisotopes are artificially and safely produced in research reactors and accelerators. One of the many uses of radioisotopes is to manage cancer and chronic diseases using radioisotope therapy, which treats cancerous cells in a safe and effective manner.

POINT TO PONDER



Is it possible to have atoms with same nucleon number but different proton number?

Atomic species that have the same mass number (A), but a different atomic number (Z) are called isobars. Isobars should not be confused with isotopes, which share the same atomic number, and therefore belong to the same chemical element. Examples of isobars include ^{14}C; ^{14}N; ^{14}O.

Apart from this two or more species of atoms or nuclei that have the same number of neutrons are called **isotones**. Chlorine-37 and potassium-39 are isotones, because the nucleus of this species of chlorine consists of 17 protons and 20 neutrons, whereas the nucleus of this species of potassium contains 19 protons and 20 neutrons.

21.4 RADIOACTIVITY

Henry Becquerel stumbled upon a groundbreaking discovery in 1896 when he accidentally found radioactivity. His observation of uranium salt crystals emitting invisible radiations that could affect a photographic plate led him to propose that radioactivity stemmed from the breakdown of unstable nuclei. Additionally, he noted that these radiations possessed the power to ionize gas.

Other researchers conducted further experiments that demonstrated the emission of similar radiations by different substances. Marie Curie and her spouse Pierre made the remarkable

discovery of two new elements, polonium and radium, which emitted these radiations. Marie Curie coined the term "**radioactivity**" to describe this phenomenon of radiation emission by certain elements.

'The natural emission of radiations from unstable nuclei is called radioactivity'. The elements which emit such radiations are called radioactive elements. Radioactivity was found to be controlled or influenced by physical factors, such as heating and cooling, and it remained unchanged even after strong chemical reactions. Therefore, it was recognized as a fundamental property of atoms; as radioactive atoms decompose, their nuclei emit such radiations.

Rutherford and his colleagues, when passed the beam of radioactive emission in electric and magnetic field (Figure 21.8), it was found to split into three types, initially referred to as alpha particles, beta particles, and gamma rays. The amount and direction of deflection depend on their charge and mass. Neutral radiation, like γ-rays, does not get deflected at all.

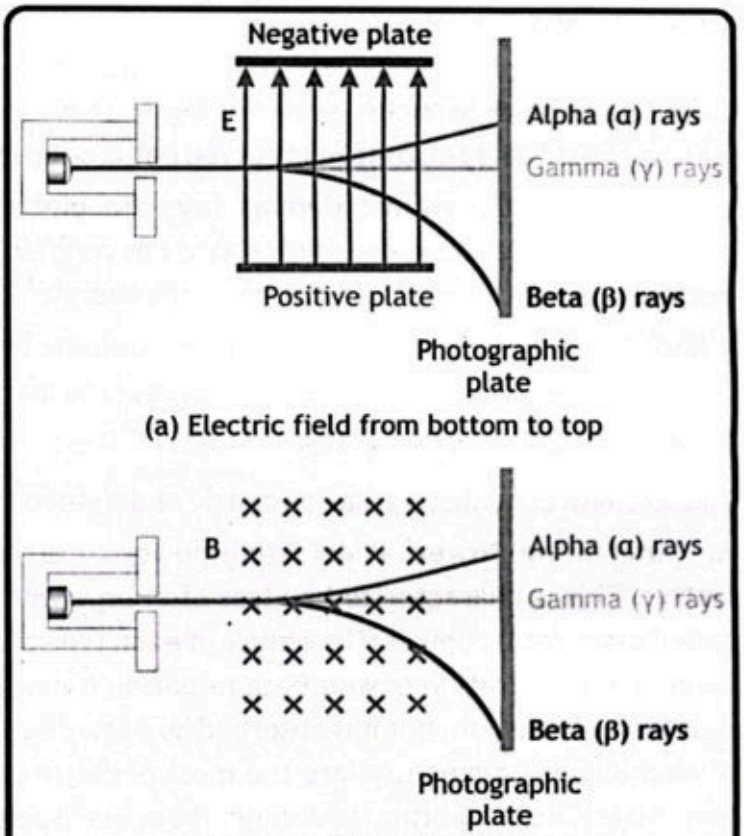


FIGURE 21.8 Three types of nuclear radiations in electric and magnetic fields.

21.4.1 NATURE OF NUCLEAR EMISSIONS

All thee three nuclear radiations were observed to have a distinct nature.

A. Alpha (α) Emissions: Alpha particles are equivalent to helium nuclei (i.e., two protons and two neutrons bounded together) emitted from the nucleus. When the ratio of neutrons to protons in the nucleus is too low, certain atoms restore the balance by emitting alpha particles. Alpha emissions occur in very large atoms (that is, they have high atomic numbers).

In an electric field, they are attracted toward the negative plate. Their deflection is small because they are heavy. In a magnetic field, they move in a curved path determined by Fleming's Left-Hand Rule. Since α-particles are positive, the force acts in the same direction as shown by the thumb.

B. Beta (β) Emissions: Beta particles are mostly fast-moving electrons emitted from the

nucleus, which carry a negative charge. Beta particle emission occurs when the ratio of neutrons to protons in the nucleus is too high. In this case, an excess neutron transforms into a proton and an electron.

In an electric field, negatively charged β-particles (electrons) are attracted to the positive plate, Because β-particles are very light, they are deflected more than α-particles. In a magnetic field, they also move in curved paths determined by Fleming's Left-Hand Rule.

C. Gamma (γ) Emissions: Gamma rays are electromagnetic radiations emitted from the nucleus, they are therefore neutral and has no charge. Gamma ray emission occurs when the nucleus of a radioactive atom has too much energy.

γ-Radiation is not affected by electric or magnetic fields. As a result, it passes straight through without any deflection. This makes γ-rays easy to distinguish from charged particles.

21.4.2 ORDER OF STRENGTH

The strength of nuclear radiation can be understood in two key ways:

A. Penetrating Power: Penetrating power refers to how far radiation can travel through matter. This is characterized by loss of energy when radiation interacts with a substance is called penetration power. The ability of each type of radiation to pass through matter depends upon thee penetration power. Beta radiation is more penetrating than alpha radiation. It can pass through the skin, but it is absorbed by a few centimetres of body tissue or a few millimetres of aluminium. Gamma rays are the most penetrating form of radiation and can pass through most materials, requiring thick concrete or lead to shield them effectively.

B. Ionizing Effects: The process in which an electron is given enough energy to break away from an atom is called ionization. In this process two charged particles or ions are formed. All types of nuclear radiation can ionize atoms and molecules, meaning they knock electrons off, which can damage living cells. Relative ionization ability compares the ionization caused by α,

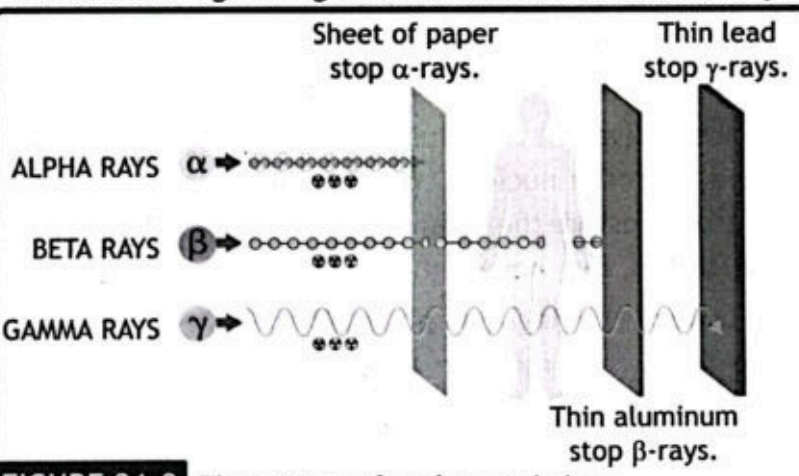


FIGURE 21.9 Three types of nuclear emissions

CAN YOU TELL?



Why beta particles tends to deflect more compared to alpha particles in the applied electric and magnetic fields?

Are beta particles similar to electrons that are in shells around the nucleus, or is there some difference?

TABLE 21.1: RADIOACTIVE EMISSIONS

Emission	Nature of radiations	Charge	Relative Penetrating Power	Relative Ionization ability
alpha (α)	Helium nuclei (two protons and two neutrons)	+2	Stopped by sheet of paper	Highest
beta (β)	Electrons	-1	Several millimetres of aluminum	Medium
gamma (γ)	Short wavelength electromagnetic radiations	0	Several centimetres of lead	Lowest

β, and γ radiations. Alpha particles cause the most ionization per unit path due to their large mass and charge. Beta and gamma rays cause less ionization but can still be harmful, especially because they can travel farther and penetrate deeper into living tissues.

The nature of nuclear emissions and their order of strength are depicted in figure 21.9, and summarized in table 21.1.

21.5 NUCLEAR DECAY

Nuclear disintegration follows several conservation principles, including mass-energy, momentum, and charge. To these laws we add another one for radioactive decay, called the conservation of nucleons. It states that the total number of nucleons (mass number A) must remain constant during nuclear reactions or decay.

21.5.1 ALPHA DECAY

In alpha decay, the original 'parent' nuclide changes into a 'daughter' nuclide by emitting an alpha particle, which is a helium nucleus. When the reaction is balanced, it shows that the daughter nuclide has a nucleon number reduced by four and a proton number decreased by two. This can be expressed mathematically as:

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha \quad \text{— 21.1}$$

Example

$$^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He(\alpha)$$

In this example, radon-222 convert to polonium-218 by releasing an alpha (α) particle. Polonium - 218 is unstable and converts into lead-214, again by releasing another alpha particle as shown in the figure 21.10.

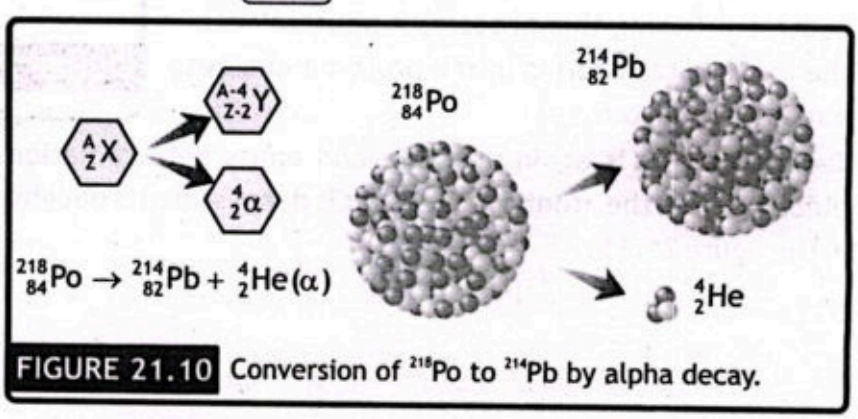


FIGURE 21.10 Conversion of ^{218}Po to ^{214}Pb by alpha decay.

Example 21.1

Find the atomic mass and atomic number of the nuclei that comes after alpha decay of Uranium (U-238)?

Solution:

Alpha decay nuclear reaction is given by: ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha$

For Uranium - 238, the nuclear reaction will become: ${}^{238}_{92}U \rightarrow {}^{238-4}_{92-2}Y + {}^{4}_{2}He(\alpha)$

or, ${}^{238}_{92}U \rightarrow {}^{234}_{90}Y + {}^{4}_{2}He(\alpha)$

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 to be Thorium (Th) with Z = 90.
The finalized nuclear reaction can now be written as:

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

21.5.2 BETA DECAY

In beta decay, the original 'parent' nuclide changes into a 'daughter' nuclide by emitting a beta particle (electron). This electron is expelled from the nucleus, converting a neutron into a proton, which remains in the nucleus. When the reaction is balanced, the nucleon number of the daughter nuclide remains unchanged, while the charge (proton) number increases by one. This can be expressed mathematically as:

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta \quad (21.2)$$

Example ${}^{99}_{42}Mo \rightarrow {}^{99}_{43}Tc + {}^{0}_{-1}\beta$

Molybdenum-99 decays through beta decay due to its unstable nature caused by an excess of neutrons. During this process, a neutron within the nucleus transforms into a proton and a beta particle is emitted.

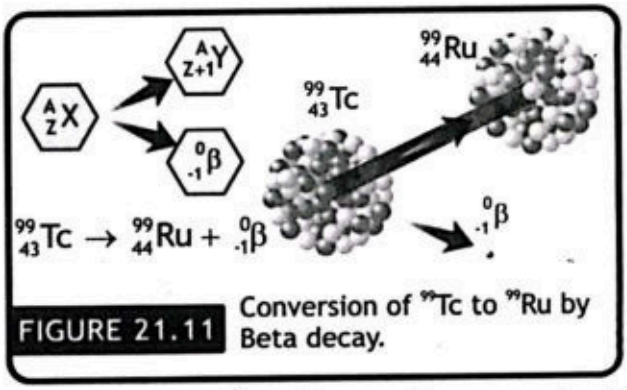


FIGURE 21.11 Conversion of ^{99}Tc to ^{99}Ru by Beta decay.

Technetium-99 is again unstable and emits beta radiation, or the release of an energized electron from the atomic nucleus, as it decays into its daughter isotope, ruthenium-99 as shown in the figure 21.11 .

Example 21.2

Cobalt-60 undergoes beta decay. Write the reaction equation, and determine the identity of daughter nucleus.

Solution:

Beta decay is given by the reaction: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta$

For cobalt-60, the above nuclear reaction will become: ${}^{60}_{27}Co \rightarrow {}^{60}_{27+1}Y + {}^{0}_{-1}\beta$

or, ${}^{60}_{27}Co \rightarrow {}^{60}_{28}Y + {}^{0}_{-1}\beta$

Every element has a unique atomic number. The periodic table shows the new element to be Nickel (Ni) with Z = 28.

The finalized equation can now be written as:

${}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + {}^{0}_{-1}\beta$ — ANSWER

21.5.3 GAMMA DECAY

Gamma radiation is a form of high energy (high frequency/short wavelength) electromagnetic radiation. However, in most cases the α or β emission from the nucleus leave it in excited state such nuclei achieve further stability by radiating energy in the form of gamma rays. This can be expressed mathematically as:

$${}^{A}_{Z}X^{*} = {}^{A}_{Z}X + \gamma \quad \text{— 21.3}$$

Example ${}^{60}_{27}Co^{*} = {}^{60}_{27}Co + \gamma$

21.5.4 STABILITY THROUGH NUCLEAR TRANSMUTATION

When a particle is emitted from a parent nucleus during radioactive decay, the ratio of neutrons to protons changes, and the resulting daughter nucleus tends to become more stable. This process of transforming one element into another is called nuclear transmutation. Typically, a series of successive decays takes place until a stable, non-radioactive configuration is reached.

Nuclear decay is a spontaneous and random process, governed by the inherent characteristics of atomic nuclei. The imbalance between protons and neutrons, along with the energy differences within the nucleus, drives this process without any external intervention—much like how a ball rolls down a hill due to gravity. However, just as we cannot predict exactly when the ball will start moving, it is impossible to determine the precise moment when a specific unstable nucleus will decay. This uncertainty is governed by the principles of quantum mechanics, which incorporate elements of probability.

SCIENCE TIDBITS



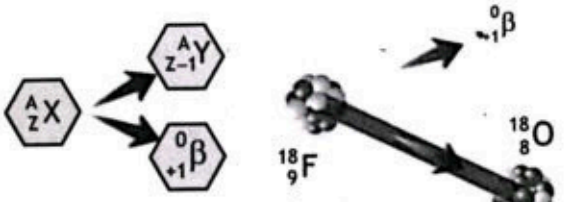
Beta radiation is also composed positrons that are emitted from the nucleus during beta decays. Positron (or antielectron) is the particle with same mass as an electron, however it has positive electric charge of same magnitude (just like proton, and is considered as an antiparticle of electron).

When a positron is emitted, the process is called beta plus decay to distiguish it from electron emmission. It is caused by the transformation of a proton into a neutron (which stays in the nucleus).

As a result, the proton number decreases by one, and the nucleon number does not change given by beta plus decay as:

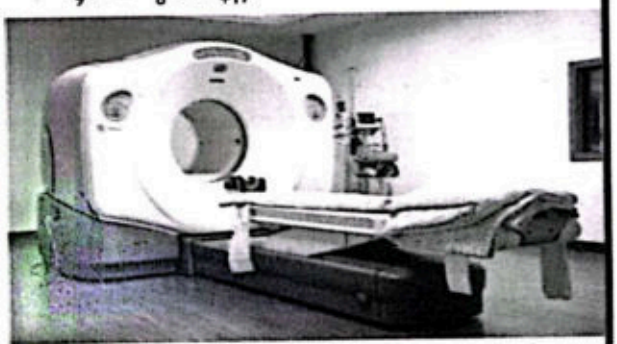
$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta$$

Example $^{46}_{24}Cr = {}^{46}_{23}V + {}^{0}_{+1}\beta$



$^{18}_{9}F = {}^{18}_{8}O + {}^{0}_{+1}\beta$

The emission of a beta plus particle by Chromium-46 results in the formation of Vanadium-46. The emission of a beta plus particle transmute Fluorine - 18 into Oxygen - 18 is used for diagnostic purposes in conjunction with positron emission tomography (PET) imaging as shown. During a PET scan, a radioactive tracer that emits positrons is injected into the body. When these positrons collide with electrons in tissues, they release gamma rays.



By detecting these gamma rays, doctors can create a 3D image that shows which areas of the body are metabolically active, which can help diagnose various conditions like cancer and heart disease.

21.6 HALF LIFE

Radioactivity is an unpredictable and spontaneous process where we cannot foresee which nucleus will decay next. This is why we rely on the concept of half-life to measure the time taken for overall disintegrations.

The time duration in which half of the unstable radioactive nuclei disintegrates into daughter nuclei (by the emission of α, β or γ radiations) is called half life of the sample of radioactive element.

The value of the half life depends on the nature of the radioactive nucleus and not on any other variable like temperature, pressure, humidity etc. For example, iodine-131 has a half-life of 8 days, because it takes this duration for one half of a given quantity of this isotope to disintegrate. In 8 days, half of the sample will be left. In next 8 days only ¼ of the original present sample will be left and son on. In general, let there be N_0 - number of sample nuclei (may be in unit of mass) present at initial and N-number of nuclei present at any time.

21.6.1 USING AN EQUATION TO MODEL RADIOACTIVE DECAY

Quantities whose rate of decay depends upon the amount of substance present are said to undergo exponential decay.

The amount of radioactive isotope in the given sample decrease with time as shown in figure 21.12. The number of nuclei present at time t = 0 s is N = N_o, and the number present at t = $T_{½}$ is N = $N_o/2$. The number present at t = 2 $T_{½}$ is N = $N_o/4$, and so on.

In this instance, the amount '*N*' of radioactive substance left after some time '*t*' has elapsed is given by:

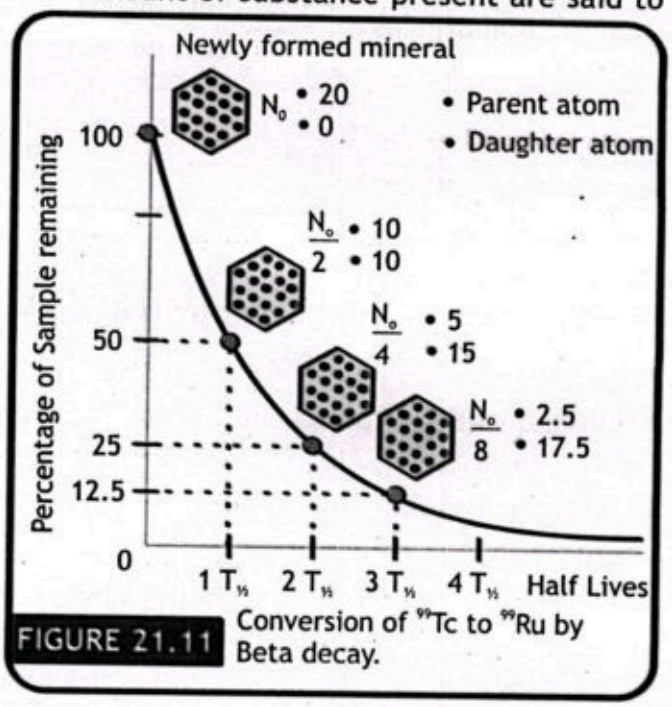


FIGURE 21.11 Conversion of ^{99}Tc to ^{99}Ru by Beta decay.

After 1 half-life: $N_1 = \frac{1}{2}N_o$

After 2 half-lives: $N_2 = \frac{1}{2} \times \frac{1}{2}N_o = \left(\frac{1}{2}\right)^2 N_o$

After 3 half-lives: $N_3 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}N_o = \left(\frac{1}{2}\right)^3 N_o$

After 4 half-lives: $N_4 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}N_o = \left(\frac{1}{2}\right)^3 N_o$

And so on ---------- $N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \ldots\ldots N_o$ or $N = \left(\frac{1}{2}\right)^n N_o = \frac{N_o}{2^n}$ — 21.4

TABLE 21.2: HALF LIVES OF SELECTED RADIOISOTOPES

Element	Half-life	Element	Half Life
Uranium-238	4.5 billion years	Iodine-131	8.02 days
Uranium-235	704 million years	Carbon-14	5,730 years
Plutonium-239	24,110 years	Tritium (Hydrogen-3)	12.3 years
Cesium-137	30 years	Radon-222	3.82 days
Strontium-90	28.8 years	Polonium-210	138 days

Number of half lives (n) can be found by the following relation:

$$\text{Number of half lives} = \frac{\text{Total time passed}}{\text{Half life}} \qquad \text{Therefore, } n = \frac{\Delta t}{T_{½}} \quad \text{— 21.5}$$

Substituting the value for 'n' in equation 21.4, the final equation becomes: $N = \frac{N_o}{2^{\Delta t / T_{½}}}$ — 21.6

Example 21.3

You 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?

GIVEN:
Initial quantity of pure Lead-212 'N_o' = 50 mg
Half-life of Lead - 212 '$T_{½}$' = 10.6h
Total elapsed time 'Δt' = 53h

REQUIRED:
Quantity left 'N' = ?

SOLUTION:
The number of half-lives 'n' is given by: $n = \frac{\Delta t}{T_{½}}$ putting values $n = \frac{53\,h}{10.6\,h}$

Therefore $n = 5$

Original sample remaining after "n" number of half-lives: $N = \left(\frac{1}{2}\right)^n N_0$

putting values $N = \left(\frac{1}{2}\right)^5 \times 50\,mg$

Therefore $N = 1.56\,mg$ — ANSWER

So, 1.56 mg of Lead - 212 will be present after 53 hours or 5 half-lives.

Radioactivity in the natural environment was considered impossible to artificially create until 1934 when Frederic Joliot and Irène Curie successfully produced new radioactive materials using nuclear physics methods. Otto Hahn and Fritz Strassmann later achieved fission of uranium nuclei in 1938/39. The significance of fission was acknowledged by Lise Meitner and Otto Frisch, leading to the pursuit of creating super heavy elements beyond uranium. This quest has resulted in the synthesis of 26 elements that do not exist naturally.

21.6.2 ACTIVITY

The level of radioactivity in a substance can be thought of as the number of nuclear decays per unit time. A substance with high radioactivity experiences rapid decay, resulting in a shorter half-life. If a sample initially contains N unstable nuclei, the rate of decay can be expressed as $\Delta N/\Delta t$.

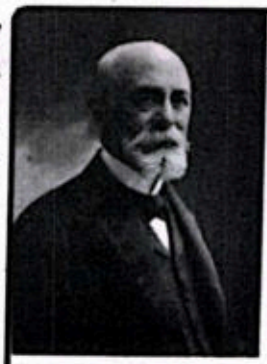
This measure is commonly referred to as activity, denoted as A, and is measured in decays per second.

The SI unit for Activity (decay rate) in disintegrations (counts) per second is the becquerel, symbolized as Bq in honour of Henri Becquerel. This is a very small unit. For example, 1.0 g of radium has an activity of 3.7×10^{10} Bq.

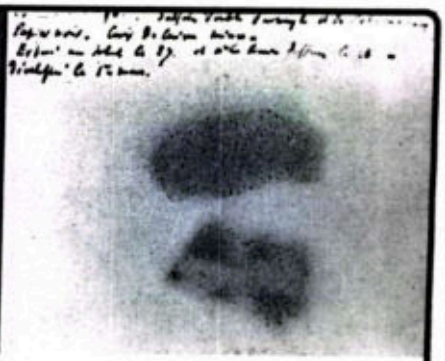
For example, 1.0 g of radium has an activity of 3.7×10^{10} Bq. Therefore, the kilobecquerel (kBq) and the megabecquerel (MBq) are commonly used, so we would say that the activity of 1.0 g of radium is 3.7×10^{4} Mbq.

Another common unit of activity is the curie (approximately equal to the activity of one gram of radium), abbreviated Ci, which is defined to be 3.70×10^{10} decays per second.

1 Ci = 3.70 × 10^{10} Bq = 3.70 × 10^{10} decays/s



Henri Becquerel (1852-1908)



Becquerel's photographic plate. The bottom of the image shows shadow cast due to absorbed radiation.

FIGURE 21.12 SI unit of radiation

15.6.3 RADIOACTIVE DATING

Archaeologists and geologists use radioactive dating to estimate the age of ancient objects. One common procedure uses carbon-14 which has a half-life of 5730 years. The element carbon as we find it in nature consists of 98.89% ^{12}C atoms and only about 1.11% ^{13}C atoms. Carbon in living organisms also contains a trace but measurable amount of ^{14}C, about 1.3×10^{-12}.



Carbon 12	Carbon 13	Carbon 14
6 Protons	6 Protons	6 Protons
6 Neutrons	7 Neutrons	8 Neutrons
6 Electrons	6 Electrons	6 Electrons

FIGURE 21.13 Isotopes of carbon atom.

Neutrons from deep space collide with nitrogen atoms in the atmosphere, causing a proton to be knocked off the nucleus of ^{14}N. The neutron is then absorbed, resulting in the formation of a ^{14}C atom. This carbon atom can react with oxygen in the atmosphere, forming a CO_2 molecule. Through the process of photosynthesis, plants can take in some of this radioactive carbon as they produce their own food. Similarly, animals that consume these plants can also acquire radioactive carbon. As long as the organism is alive, it will continue to absorb and accumulate carbon-14. However, once the organism dies, it will no longer take in carbon-14, and the proportion of carbon-14 will gradually decrease as shown in figure 21.14.

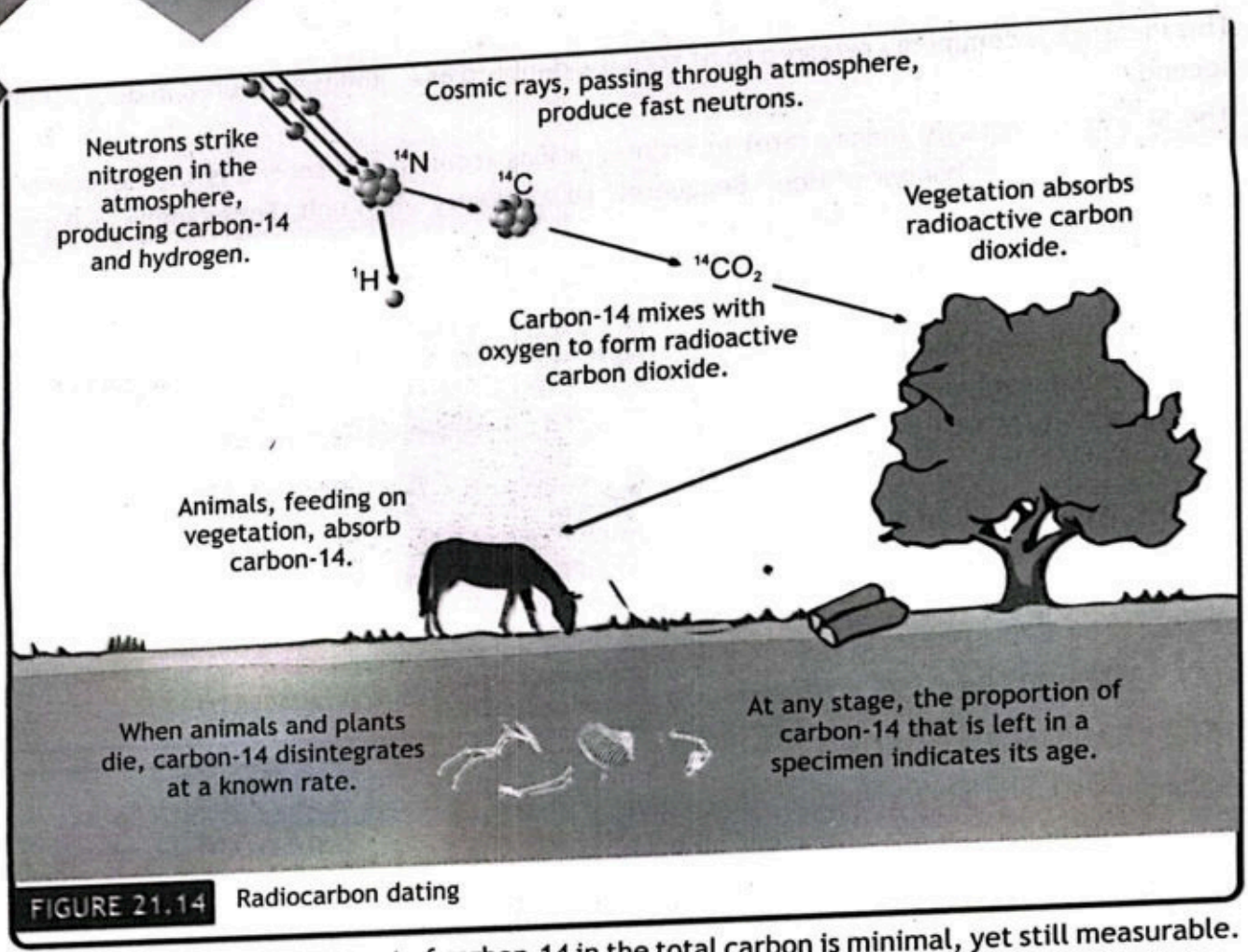


FIGURE 21.14 Radiocarbon dating

As discussed earlier the amount of carbon-14 in the total carbon is minimal, yet still measurable. By measuring the activity, one can estimate the age of a specimen. Carbon-14 dating is effective for biological tissues up to 50 or 60 thousand years old, but it is most accurate for younger samples due to higher ^{14}C nuclei abundance. Geologic formations' age can be determined using materials with longer half-lives. For instance, Uranium-238, with a half-life of 4.53×10^{9} years, can date even the oldest Earth deposits.

Example 21.4

In an animal fossil ^{12}C to ^{14}C ratio is found to be one eighth of the ratio in the bone of living animal. The half life of ^{14}C is 5730 years, how old is the fossil?

GIVEN:

^{12}C to ^{14}C ratio 'N/N_o' = 1/8

Half-life of Carbon - 14 '$T_{½}$' = 5730 years

REQUIRED:

time 'Δt' = ?

SOLUTION:

The half-life equation is: $N = \frac{N_o}{2^{\Delta t / T_{1/2}}}$ or $\frac{N}{N_o} = \frac{1}{2^{\Delta t / T_{1/2}}}$

putting values $\frac{1}{8} = \frac{1}{2^{\Delta t / 5730\,yrs}}$ or $\frac{1}{2^3} = \frac{1}{2^{\Delta t / 5730\,years}}$

Equating powers on both sides $3 = \frac{\Delta t}{5730\,years}$ or $\Delta t = 3 \times 5730\,years$

Therefore $\Delta t = 17{,}190\,years$ — ANSWER

Therefore the fossil is 17,190 years old.

21.7 IONIZING NUCLEAR RADIATIONS

Radiation, or radiant energy, is energy in the form of waves or particles moving through space. Visible light, heat, radio waves, alpha particles and beta particles are examples of radiation. When we feel warmth from the sunlight, we are actually absorbing the radiant energy emitted by the sun.

Radiation can be categorized as ionizing or nonionizing based on its interaction with matter. Normally, an atom has an equal number of protons and electrons. However, through a process called ionization, atoms can lose or gain electrons. Certain types of radiation can ionize atoms by knocking off electrons, leaving the atom in an ionized state. Hydrogen, with the smallest atomic number, requires the least energy (13.6 eV) to eject its K-shell electron. Radiation with energy above 13.6 eV is referred to as ionizing radiation. Ionizing radiation has the ability to alter the chemical state of matter and cause biological damage, making it potentially harmful to human health. If electrons are raised to higher energy levels without being ejected from atoms, it is called excitation, and the atom is considered "excited."

Radiation of energy less than 13.6 eV is termed nonionizing radiation because it cannot eject this most easily removed electron. Nonionizing radiation bounces off or passes through matter without displacing electrons. Examples include visible light and radio waves. Currently, it is unclear whether nonionizing radiation is harmful to human health.

21.7.1 EFFECTS OF IONIZING NUCLEAR RADIATIONS ON LIVING THINGS

Ever since ionizing radiation was first discovered, its ability to cause harmful effects has been recognized. These effects occur when the human body absorbs the energy from the radiation. This energy absorption can lead to ionization (charged particles) and excitation within the body, as well as chemical changes through the creation of free radicals. Ultimately, this creates the potential for biological changes or damage to take place.

Radiation interacts with matter by transferring energy to the molecules of the material it is absorbed by. Since water is the most abundant molecule in a cell, the primary result of this process is an ionized water molecule ($H_2O^{\cdot+}$). These ionized water molecules then react with other water molecules to form hydroxyl radicals ($^{\cdot}OH$) (Figure 21.15). The ejected electrons may have enough energy to cause further ionizations until their energy is dissipated, resulting in the formation of an aqueous electron (e^-_{aq}) or combining with other species to produce reducing species like hydrogen atoms ($H^{\cdot}$) or superoxide ($O_2^{\cdot-}$).

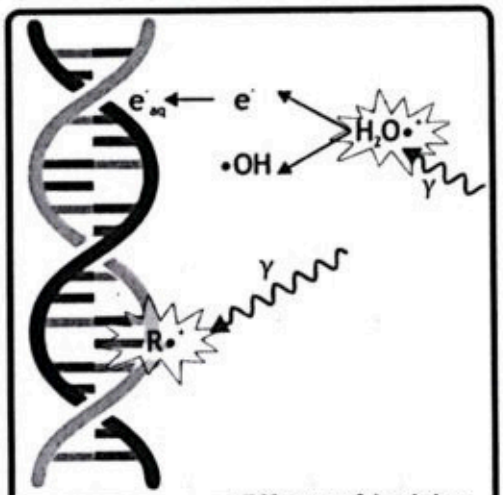


FIGURE 21.15 Effects of ionizing radiation on DNA

Ionizing radiation can harm all types of molecules in a cell, but DNA is a main target. Highly reactive $^{\cdot}OH$ radicals, along with less reactive species, can harm DNA.

Radiation can cause various types of damage to DNA, such as breaks in strands, damage to bases or sugars, and cross-links between molecules (like DNA-DNA or DNA-protein cross-links). Overall, the most harmful effect of radiation is believed to be the DNA double-strand break (DSB).

21.7.2 HARMFUL EFFECTS OF NUCLEAR RADIATIONS

Cell death by radiation occurs when ionizing radiation damages the vital components of a cell, especially its DNA. This damage can be so severe that the cell cannot repair itself and ultimately dies. There are two main types of radiation-induced cell death: mitotic cell death and apoptosis. Mitotic cell death happens when cells try to divide with damaged DNA, leading to their breakdown. Apoptosis, or programmed cell death, is a controlled process where cells self-destruct when they detect significant damage. Both types help protect the body by removing damaged cells that could otherwise cause harm.

Sometimes, the damage caused by ionizing radiation isn't fatal to the cell. However, the damage can alter the cell's DNA, leading to mutations. Mutations are changes in the DNA sequence of a cell's genetic material. These mutations can be passed on to daughter cells during cell division. Mutations can have a variety of effects, some harmless, but some can disrupt the normal functioning of the cell. Worryingly, some mutations can give a cell the ability to grow uncontrollably, which is a hallmark of cancer.

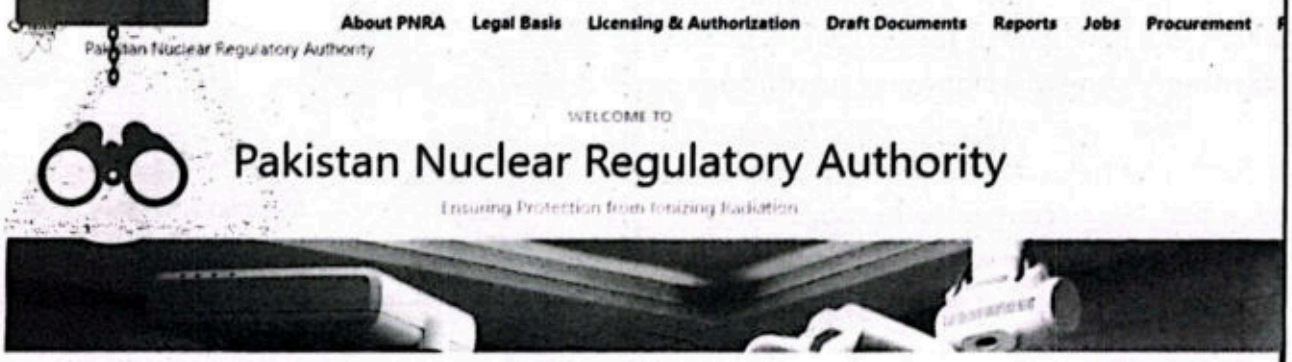
As mentioned above, mutations caused by ionizing radiation can increase the risk of cancer. Cancer is a disease where cells lose control of their growth and division, forming tumors that can invade healthy tissues. The risk of developing cancer from radiation exposure depends on factors like the amount of radiation received, the age of the person exposed, and other individual factors.

Nuclear radiation can harm humans by altering the structure of molecules in living cells through ionization. This can lead to cell death and potentially harm the entire organism. Additionally, if radioactive material is ingested or inhaled, it causes internal damage through contamination as the emitted radiation affects cells from within the body.

Radiation exposure can have serious health consequences, including radiation sickness, cancer, and genetic mutations. These effects can be immediate or develop over time, even from low-level exposure. Radiation sickness refers to the acute effects of radiation exposure. Symptoms can include nausea, vomiting, fever, diarrhea, hair loss, and can even lead to death depending on the dose's severity. Long-term effects of radiation exposure may include chronic health issues such as hair loss, eye cataracts, various types of cancer, and genetic defects that can be passed down to future generations.

Not everyone is equally susceptible to radiation exposure. Children, pregnant women, and people with weakened immune systems are more vulnerable. Radioactive materials can contaminate the environment, posing risks to wildlife and future generations. Therefore all over the world a comprehensive set of rules and guidelines are designed to ensure the safe and secure use of nuclear technology. These 'nuclear regulations' are typically enforced by independent regulatory bodies. These bodies may be national agencies, like the Office for Nuclear Regulation (ONR) in the UK or the Pakistan Nuclear Regulatory Authority (PNRA), or international organizations like the International Atomic Energy Agency (IAEA).

EXPLORE



PNRA in Pakistan has been given the important task of overseeing and managing all matters related to nuclear safety and radiation protection. It has the authority to create rules and regulations, provide guidance on safety measures, and implement policies and programs to safeguard life, health, and property from the risks associated with ionizing radiation. Additionally, PNRA is responsible for regulating the safety aspects of nuclear installations and radiation facilities, granting authorizations and licenses for the use of nuclear material and radioactive sources, and conducting inspections to ensure compliance with safety regulations. For further information, please visit the official website: **https://www.pnra.org/.**

21.7.3 SAFE HANDLING OF RADIOACTIVE MATERIALS

When working around ionizing radiation, remember the mantra: **time, distance, and shielding.** Minimize your exposure time near the source - the less time spent exposed, the lower the dose. Maximize the distance between yourself and the source - radiation intensity weakens rapidly, so even a few extra steps make a big difference. Whenever possible, use barriers like lead or concrete to block radiation.

In a radiation lab, additional precautions are crucial. Always wear personal protective equipment like lab coats, shoes, and safety glasses. Maintain a clean and organized workspace by avoiding unnecessary materials, and meticulously track all radioactive sources in the lab for proper handling and disposal.

Radiation symbols are important to have in places where there are radiation sources, containers, or products with radioactive parts. These symbols can be found on safety documents, warning signs in radiation zones, or permits for handling radioactive materials. They are crucial for alerting people to potential radiation dangers and ensuring clear communication in radiation safety measures. Figure 21.16 shows two common radiation symbols.

A. International (trefoil) symbol of radiation: This sign must be posted where radioactive materials are handled or where radiation-producing equipment is used. Sign is used as a warning to protect people from being exposed to radioactivity.

B. Supplementary Symbol: International Atomic Energy Agency (IAEA) in 2007 has launched a new symbol for 'Ionizing-Radiation Warning'. new symbol is intended to supplement the existing, well recognized, radiation trefoil symbol. The new symbol has been designed to convey the message "Danger – Stay Away" to anyone who sees it, regardless of their age, education, or cultural background.

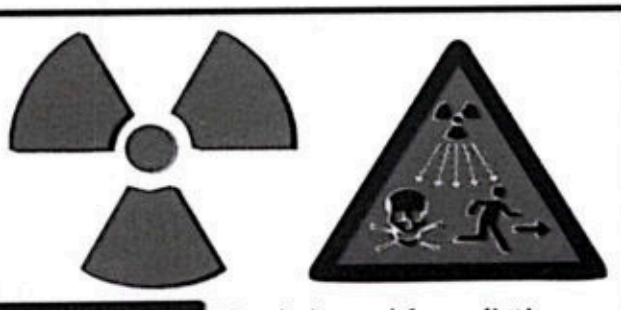


FIGURE 21.16 Symbols used for radiation

SCIENCE TIDBITS

The survey meter is a key tool in keeping nuclear facilities safe. It helps detect radiation levels, protecting workers from harm. Whether in power plants or research facilities, survey meters alert staff to dangers, keeping them safe from unnecessary risks. These devices are crucial for maintaining safety in the nuclear industry.



21.7.4 DOSE DESCRIPTORS

We measure radiation to understand its effects on living things, like humans. This helps us set safety limits to protect people from radiation exposure. There are several biological measures that are commonly used to evaluate the effects of radiation exposure:

A. Absorbed dose: Absorbed dose is a measure of the amount of energy absorbed by a tissue or organ exposed to radiation. It is usually measured in units of gray (Gy) or milligray (mGy).

B. Equivalent dose: Equivalent dose takes into account the type of radiation and the sensitivity of the tissue or organ exposed. It is measured in units of sievert (Sv) or millisievert (mSv).

C. Effective dose: Effective dose is a measure of the overall radiation dose to the entire body, taking into account the dose to different tissues and organs and their respective sensitivities to radiation. It is also measured in units of sievert (Sv) or millisievert (mSv).

TABLE 21.3: RADIATION DOSE LIMITS

Radiation dose limit	Description
1 millisievert (mSv) per year	Annual dose limit for members of the general public
20 mSv per year	Annual dose limit for radiation workers
1 mSv per year	Maximum dose limit for frequent exposure to the public, such as patients undergoing medical procedures
50 mSv in a single year	Maximum dose limit for radiation workers in emergency situations
100 mSv in a single year	Maximum dose limit for radiation workers in life-saving emergency situations

21.8 APPLICATIONS OF RADIATION

Radiation has a wide range of applications across various fields.

21.8.1 SMOKE ALARM

The radioactive material used in smoke detectors is typically americium-241, a man-made element that emits alpha particles. These particles collide with air molecules in the detector, creating ions that allow for the flow of electric current. When smoke particles enter the detector, they disrupt this ion flow, triggering the alarm and alerting occupants to the presence of a potential fire as shown in figure 21.17. This technology has been instrumental in saving countless lives by providing early warning of fires in homes and buildings.

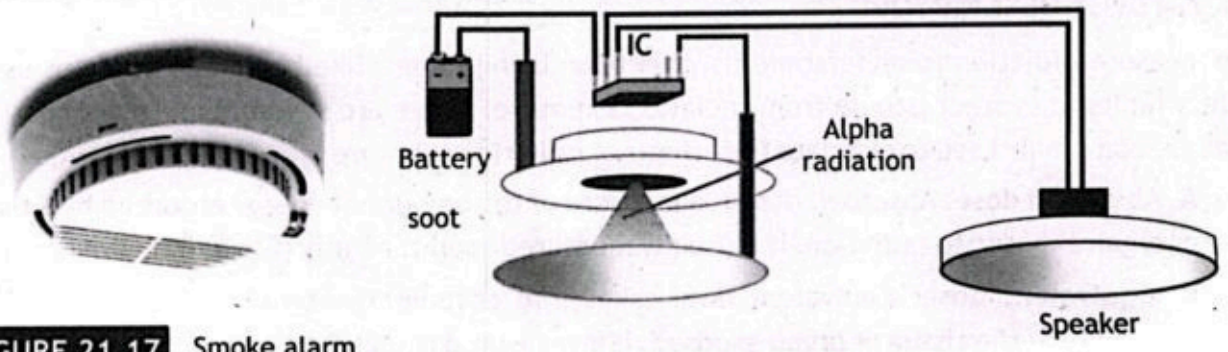


FIGURE 21.17 Smoke alarm

21.8.2 FOOD IRRADIATION

Food irradiation is a method that utilizes radiation to remove bacteria, mold, and insects, which helps to prolong the lifespan of food. It is often used to sterilize spices, meats, and other types of food. Even when food is packaged, gamma rays can still pass through the packaging and successfully eliminate harmful microorganisms, as demonstrated in Figure 21.18. Although this technique greatly extends the shelf life of food, it may sometimes affect the taste of the food.

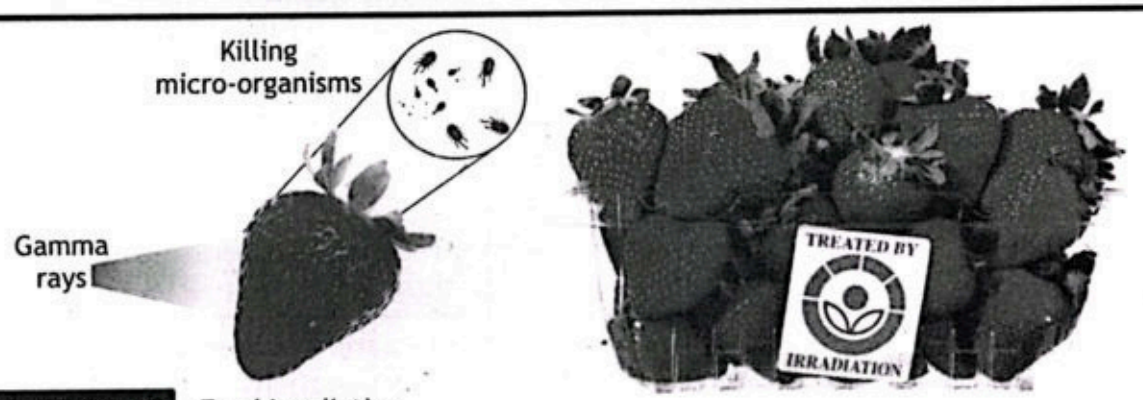


FIGURE 21.18 Food Irradiation

21.8.3 EQUIPMENT STERILIZATION

Radiation has the ability to eliminate bacteria and other tiny organisms, making it a valuable tool for sterilizing medical equipment, food, and various other items (figure 21.19). The use of radiation in healthcare settings is particularly beneficial as it ensures that equipment remains sterile, thus reducing the risk of infections. This is especially important for plastic equipment like syringes, which could be harmed if exposed to high temperatures.

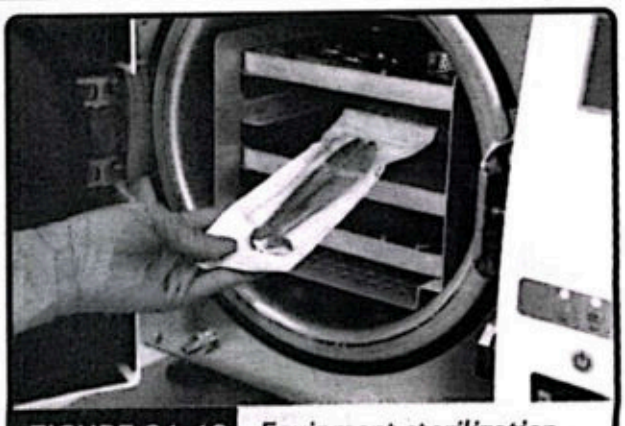


FIGURE 21.19 Equipment sterilization

21.8.4 CONTROLLING THICKNESSES

The choice of isotopes for measuring and controlling material thickness depends on the radiation they emit and their half-life. The main considerations in this selection are the radiation's ability to penetrate and the isotope's stability over time. Beta emitters with moderate penetration are used for thin materials, while gamma emitters with high penetration are used for thicker materials. The half-life ensures the source remains active for the required duration of the application.

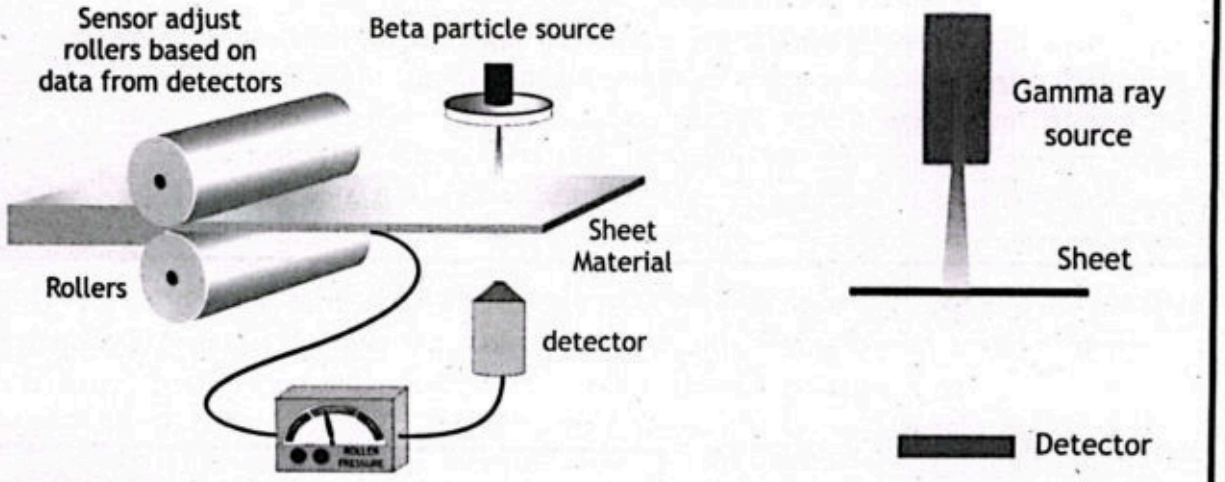


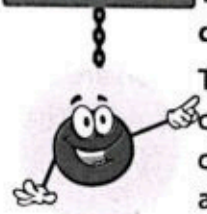
FIGURE 21.20 Food Irradiation

21.8.5 DIAGNOSIS AND TREATMENT OF CANCER

Radiopharmaceuticals play a crucial role in diagnosing and treating various diseases. These drugs, which contain radioactive material, can be administered through injection, inhalation, or oral consumption. They are used for both medical imaging of internal organs and bodily processes, as well as for therapeutic purposes. Ionizing radiation serves two distinct purposes in the field of medicine: diagnosis and therapy.

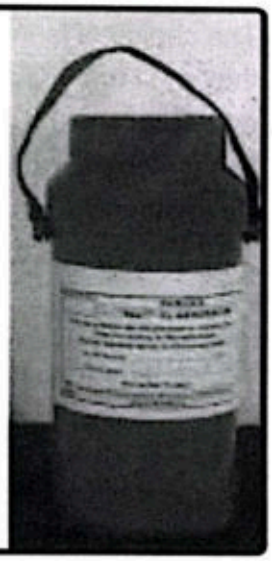
A. Medical diagnostics: Each organ in our bodies functions differently from a chemical perspective. Scientists and medical professionals have identified specific chemicals that are absorbed by certain organs. For instance, the thyroid absorbs iodine, while the brain consumes glucose, among others. Utilizing this knowledge, radiopharmacists can attach different radioisotopes to biologically active substances. These radioisotopes enable the accurate detection of disease progression and staging in vital organs through imaging techniques such as gamma camera or PET scans in nuclear diagnostics. When selecting a radioisotope for diagnosis, it is crucial that it emits gamma rays with enough energy to exit the body and has a short enough half-life to decay soon after imaging is completed.

POINT TO PONDER



What makes technetium-99m the top choice for nuclear diagnostics?

Technetium-99m, an isotope of technetium, is the most commonly used radioisotope in medicine due to its ideal characteristics for diagnostic scans. It has a six-hour half-life, allowing for thorough examination of metabolic processes while keeping radiation exposure to the patient at a minimum.



Additionally, the low energy gamma rays it emits can easily exit the body and be accurately detected. The versatility of technetium's chemistry allows it to be incorporated into various biologically-active substances, ensuring it concentrates in the specific tissue or organ of interest. Lastly, the logistics of technetium generators, supplied to hospitals from nuclear reactors, make it a convenient choice for medical facilities.

B. Radiation therapy: Radiation treatment involves using high-energy radiation to target specific tissues, such as cancerous tumors. One common source of radiation is Cobalt-60, which emits beta particles and high-energy gamma rays that are effective in treating various types of cancer.

Similarly, high-energy gamma rays produced by linear accelerators can be used to achieve the same purpose. Radiation therapy using gamma rays involves targeting cancerous tissues with high-energy radiation to destroy or damage cancer cells, hindering their ability to grow and divide. The two common sources of gamma rays in radiation therapy are Cobalt-60 and linear accelerators (Linacs).

Cobalt-60 is an isotope that emits gamma rays and beta particles. It is contained in a machine known as a cobalt unit as shown in figure 21.21. The gamma rays are aimed at cancerous tissue, penetrating deep within the body due to their high penetration power.

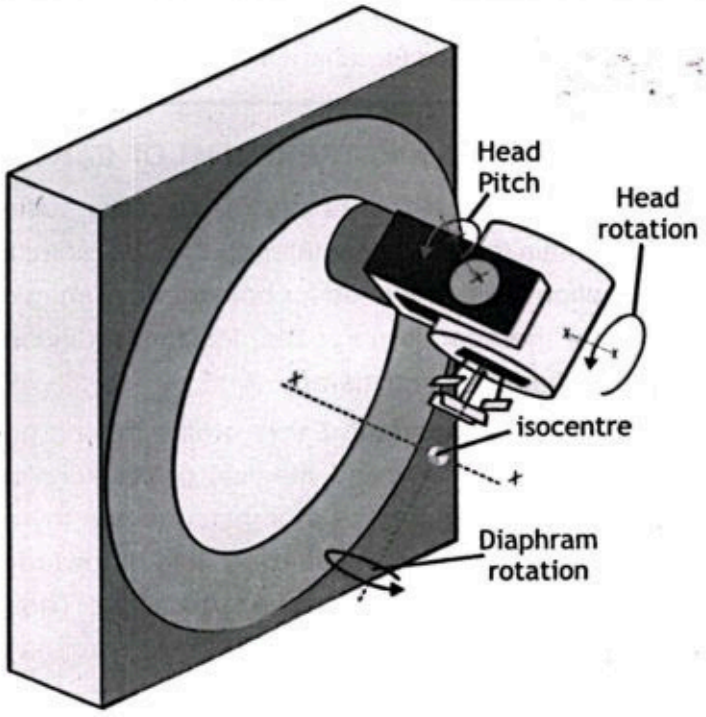


FIGURE 21.21 The cobalt unit

These rays ionize molecules in cells, creating free radicals that damage the DNA of cancer cells. This damage inhibits the cells' ability to replicate, eventually causing them to die off. The cobalt unit rotates around the patient to deliver radiation from various angles, focusing on the tumor while minimizing damage to healthy tissue.

Another approach in radiation therapy involves using radioisotopes, which are absorbed by specific organs. This allows radiation to be concentrated on the affected tissue. For example, iodine-131 is a radioisotope that is specifically absorbed by the thyroid gland, making it an effective treatment for thyroid cancer. By focusing the radiation on the cancerous tissue, these treatments minimize damage to surrounding healthy tissues and improve the effectiveness of cancer treatment.

21.9 BACKGROUND RADIATION

Background radiation refers to the ubiquitous ionizing radiation that everyone is exposed to, originating from natural and artificial sources.

21.9.1 NATURAL BACKGROUND RADIATION

Since the beginning of time, all living things on Earth have been bathed in a sea of radiation from natural sources. This radiation, called background radiation, comes from three main sources:

A. Cosmic rays: These high-energy particles bombard Earth from outer space. The amount of cosmic radiation we receive varies depending on where we live. Higher altitudes and areas with weaker magnetic fields experience slightly higher doses.

B. Terrestrial radiation: Radioactive materials like uranium and thorium exist naturally in soil, rocks, and even water. These materials decay over time, releasing radiation. The amount of terrestrial radiation also varies depending on the local geology.

- **Radon:** Radon, a radioactive gas, is produced from the decay of uranium and thorium in the Earth's crust. It can enter homes through cracks in the foundation, especially in basements. Radon is a major source of terrestrial radiation and a primary cause of lung cancer in non-smokers due to inhaling its decay products.
- **Rocks and Buildings:** Various rocks and minerals have radioactive elements like uranium, thorium, and potassium-40. The radiation from these substances adds to the terrestrial radiation dose people get, especially in regions with high concentrations of these elements.
- **Food and Drink:** Food and beverages naturally contain trace amounts of radioactive elements, namely potassium-40 and carbon-14. These elements are found in all living organisms, including plants and animals, and consequently, they are present in our food. Consuming these radioactive elements leads to internal exposure to radiation, which is a component of terrestrial radiation.

C. Internal radiation: Surprisingly, we even carry small amounts of radioactive materials inside our bodies! Elements like potassium-40 and carbon-14 occur naturally and emit low levels of radiation.

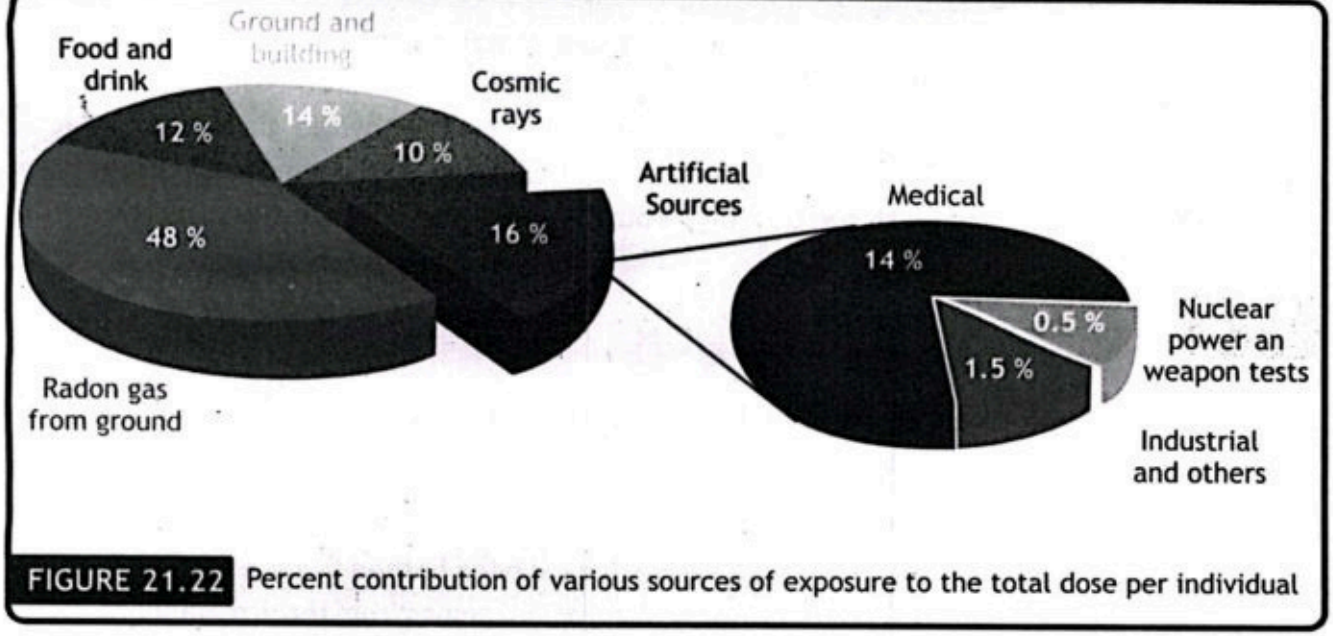


FIGURE 21.22 Percent contribution of various sources of exposure to the total dose per individual

21.9.1 ARTIFICIAL BACKGROUND RADIATION

Artificial sources of background radiation stem from medical procedures, industrial activities, and historical nuclear events.

A. Medical Radiation: Originates from medical procedures and treatments, encompassing diagnostic imaging (such as X-rays and CT scans) and therapeutic treatments (like radiation therapy). It plays a significant role in the overall radiation exposure experienced by individuals who undergo these procedures.

B. Industrial Radiation: Arises from industrial activities and products, including radiation emitted by nuclear power plants, radioactive materials utilized in industrial applications, and consumer products like smoke detectors and specific types of luminous watches. While its contribution to the overall background radiation is generally low, it can be noteworthy in proximity to specific industrial sites.

C. Fallout Radiation: Derives from nuclear weapons testing and nuclear accidents, involving the release of residual radioactive particles into the environment during nuclear explosions or accidents like Chernobyl and Fukushima. The extent of fallout radiation can vary greatly depending on location and historical events. In general, it constitutes a minor portion of the current background radiation.

21.10 NUCLEAR FISSION

Nuclear fission was discovered on December 17, 1938 by Otto Hahn and his assistant Fritz Strassman, and explained theoretically in January 1939 by Lise Meitner and her nephew Otto Robert Frisch. They found that a uranium nucleus, after absorbing a low energy neutron (thermal neutron/slow neutron), splits into two fragments of intermediate size.

The process of splitting up a heavy and unstable nucleus into comparatively smaller nuclei by absorbing a neutron with the emission of more neutrons and a large amount of energy is called nuclear fission.

It can be represented by the following nuclear reaction:

$$ {}_0^1n + {}_Z^A\Delta \rightarrow {}_Z^{A+1}\Delta^* \rightarrow X + Y + \text{neutrons} \qquad \boxed{21.7} $$

For practical considerations Δ may be Uranium-235 (U-235), Plutonium-239 (Pu-239) and Uranium-233 (U-233), Δ^* is an intermediate excited state that lasts for very short time before splitting into fission fragments X and Y. There are different possible fission fragments in different fission reactions. On the average, about 2.5 neutrons are released per fission along with a large amount of energy.

A typical fission reaction of this type is given below and shown in figure 21.23:

$$ {}_0^1n + {}_{92}^{235}U \rightarrow {}_{92}^{236}U^* \rightarrow {}_{56}^{141}Ba + {}_{36}^{92}Kr + 3\,{}_0^1n + Q $$

In this reaction, the total mass of the fission fragments is less than the original mass of the parent nucleus. This reduced mass (mass defect) is released as thermal energy, by Einstein famous mass energy relation:

$$ E = mc^2 $$

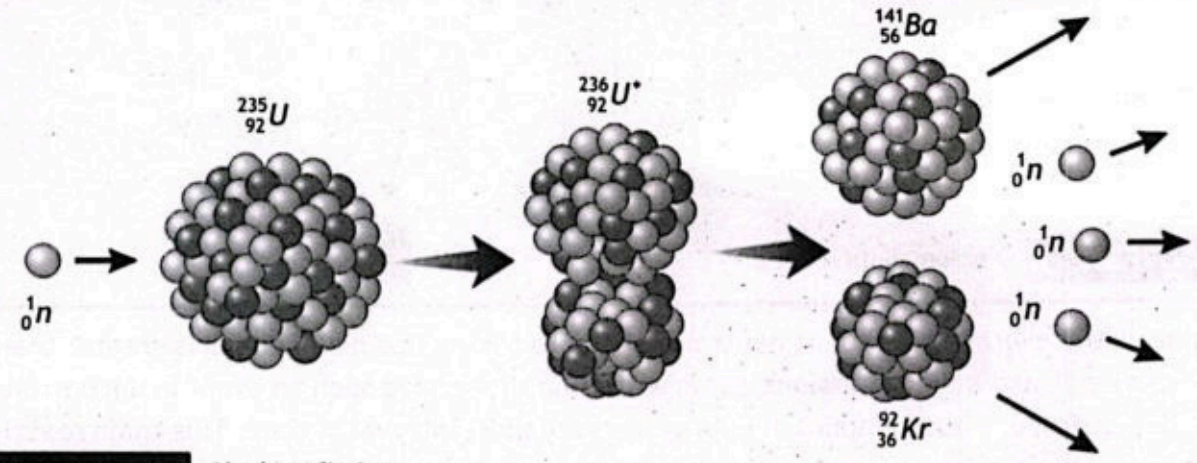


FIGURE 21.23 Nuclear fission

National Book Foundation

Measurements showed that about 200 MeV of energy is released in a single fission event. This is a large amount of energy as compared to the amount of energy released in chemical processes. For example, 1 kg of uranium delivers as much energy as about 3000 tons of coal.

The neutrons emitted in a fission reaction may cause additional fission reactions in other nuclei present in the sample. If each of the neutrons emitted in fission of uranium - 235 is absorbed by another nucleus of uranium-235 and thus induces another fission process, it will result in the emission of still more neutrons, followed by more fissions, and so forth. The process is called fission chain reaction, where different fission fragments may be produced as shown in figure 21.24.

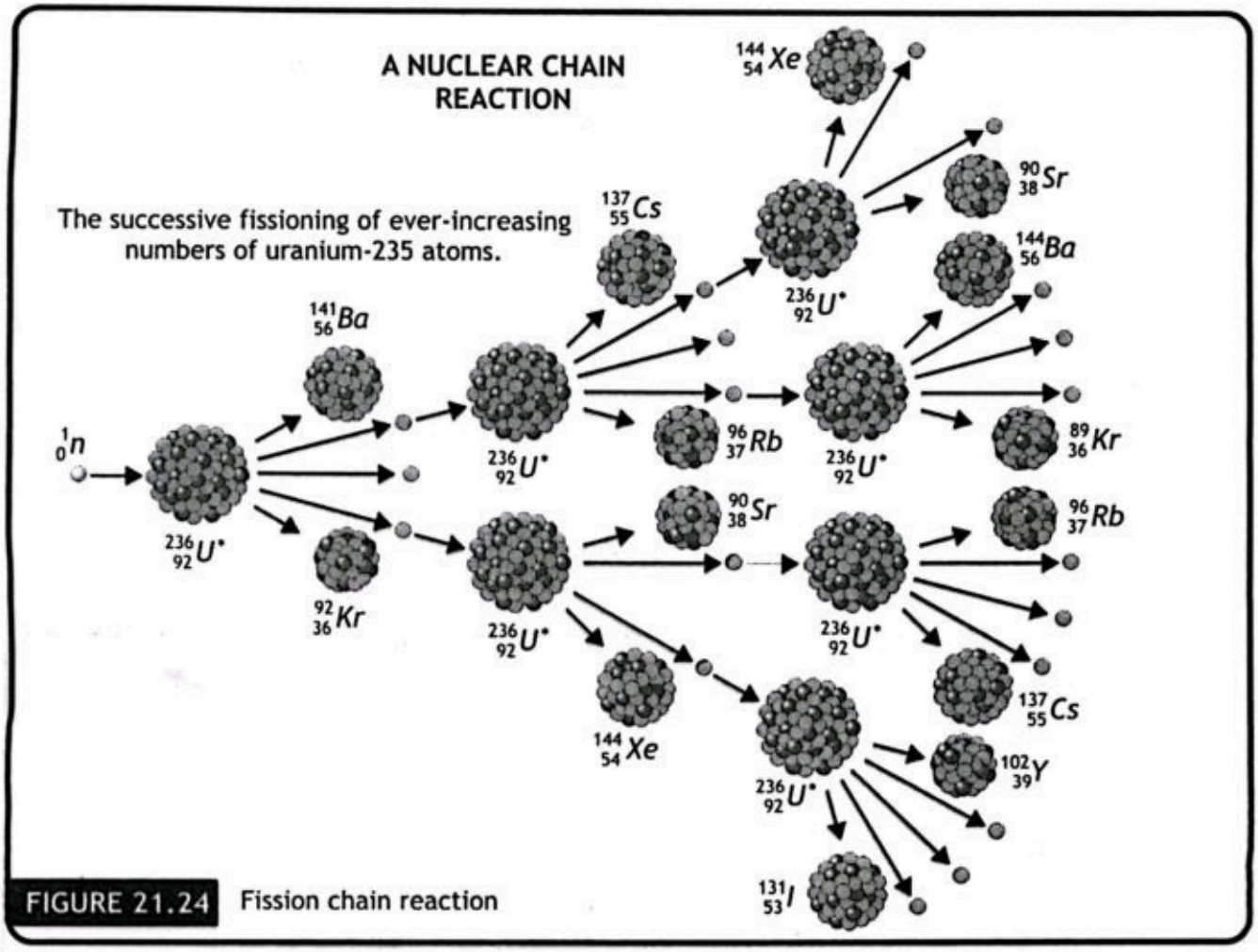


FIGURE 21.24 Fission chain reaction

As long as the average number of neutrons available to produce new fissions is greater than 1 per reaction, the number of fissions grows with time. If we have such an event in uncontrolled way, it may produce huge amount of energy in a very short interval of time. This chain reaction principle is used in atomic bomb, where a huge amount of energy is released in an uncontrolled fission chain reaction.

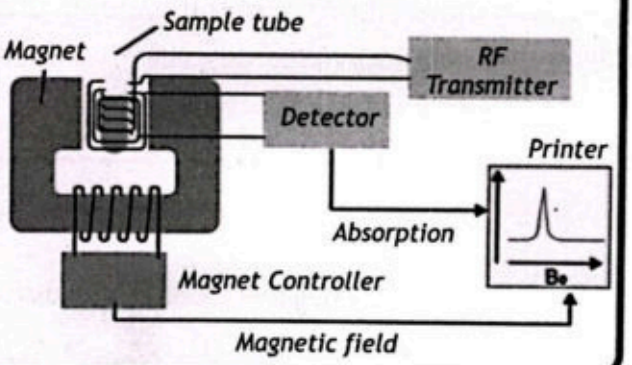
POINT TO PONDER

What is nuclear magnetic resonance spectroscopy?



NMRS is a method used to study magnetic fields around atomic nuclei. Initially, nuclear spins are aligned with a magnetic field, then disrupted by a radio frequency pulse to analyze the emitted electromagnetic waves.

Biophysicists utilize NMR to identify proteins and complex molecules, as well as in MRIs.



In contrast to fission chain reaction (uncontrolled fission), the nuclear reactors release the energy from nuclear fission in a controlled manner which is used for useful purposes as in case of nuclear reactor.

Example 21.5

During a reaction, 5×10^{18} J of energy is released. Calculate mass of the matter converted into energy

GIVEN:
Energy $E = 5 \times 10^{18}$ J
Speed of light $c = 3 \times 10^{8}$ m/s

REQUIRED:
mass 'm' = ?

SOLUTION:
By Einstein mass energy relation: $E = mc^2$ or $m = \frac{E}{c^2}$

putting values $m = \frac{5 \times 10^{18} J}{(3 \times 10^{8} m/s)^2}$

Therefore $m = 55.56\,kg$ — **ANSWER**

So, a mass of 55.56 kg is converted into energy during the reaction.

21.11 NUCLEAR FUSION

When two light nuclei combine to form comparatively heavy nucleus, the process is called nuclear fusion.

When two nuclei form a large nucleus, the mass of larger nucleus is less than the mass of nuclei that formed it. This loss in mass (mass defect) appears in the form of energy.

A self-sustaining fusion reaction is also possible but the energy required to start a fusion reaction is possible only in the environments of stars including sun.

One such cycle is proton proton cycle, in this process the direct collision of protons results in the formation of a heavier nucleus whose collision in turn produces helium nucleus as shown in figure 21.25.

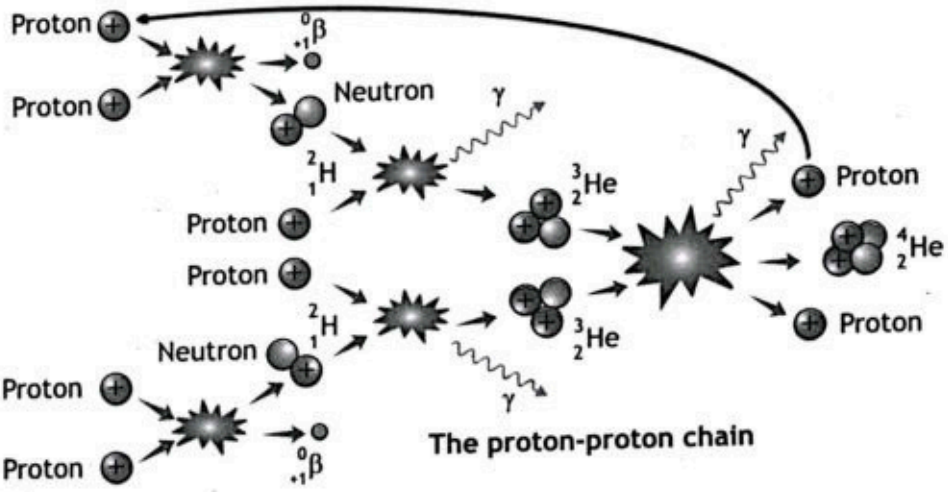


FIGURE 21.25 Fusion reaction

Step-1: In the first step, a proton reacts with another proton to form deuterium nucleus with emission of a beta particle and some energy.

$$^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{+1}\beta$$

Step-2: In the second step, a proton reacts with the deuterium nucleus and forms a He-3 nucleus with the emission of some energy.

$$^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma$$

Step-3: In the third step, two He-3 nuclei fuse together to form an alpha particle (He-4) with the emission of two protons and some energy.

$$^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H + \gamma \quad \boxed{21.8}$$

The "energy" factor on the right-hand side of the equation simply means that the particles on the right possess more kinetic and radiant energy than the particles on the left. In the reaction, mass has been converted into energy in conformity with Einstein's equation, $E = mc^2$ with the total energy released per fusion of about 26.3 MeV. Energy coming from the Sun and stars is supposed to be the result of fusion of hydrogen nuclei into helium nucleus with release of energy.

The Sun is a medium-sized star, just like other stars it is a self-luminous sphere of hot gas held together by gravity and energized by nuclear reactions in its core.

The bright, visible "surface" of the Sun is called the photosphere. The temperature of the photosphere is about 6000 K. Analysis of the Sun's spectrum shows that its photosphere is composed, by mass, of about 75% hydrogen, 25% helium, and less than 1% heavier elements, the most abundant being oxygen, carbon, neon, and iron.

A distinct feature of the Sun's surface is the periodic occurrence of sunspots. Sunspots are huge regions of cooler material on the surface of the Sun where the magnetic field is very intense. Other distinct features of the Sun's surface are solar flares and prominences. Flares are sudden, bright, explosive events originating on the Sun's surface. They are releases of energy associated with the Sun's magnetic field. Prominences are enormous filaments of excited gas arching over the surface and usually extending hundreds of thousands of kilometers outward. For us, one of the most important features of the Sun is that it radiates energy. It radiates most of its energy in the infrared, visible, and ultraviolet regions of the electromagnetic spectrum.

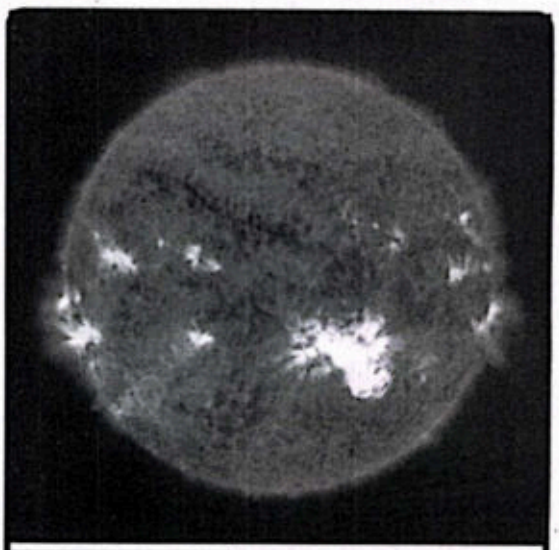


FIGURE 21.26 Our sun

However, not until 1938 did scientists understand that the Sun radiates energy because of nuclear fusion. The Sun's core is the site of several nuclear chain reactions that power its energy output. proton-proton chain is the dominant fusion reaction in the Sun, which converts hydrogen into helium. The fusion process in the sun is initiated by high temperatures and pressures in the sun's core, which cause the hydrogen nuclei to collide with enough energy to overcome their electrostatic repulsion and combine into a single helium nucleus. This fusion reaction is highly efficient, with only a small fraction of the hydrogen being converted into helium at any given time. The Sun contains about 10^{30} kg of hydrogen and has been fusing it into helium for about 5 billion years. Every second in the Sun's interior, about 6.0×10^{11} kg of hydrogen is converted into 5.96×10^{11} kg of helium and 4.0×10^{26} J of energy. Even at this rate, the Sun is expected to radiate energy from hydrogen fusion for another 5 billion years.

The amount of energy that reaches the Earth from the Sun is about 1400 joules per second per square meter (J/s m^2). This amount of energy is called the solar constant. Nearly all life on planet Earth is dependent on energy from the Sun because this energy controls our total environment: atmosphere, food supplies, water sources, and so on.

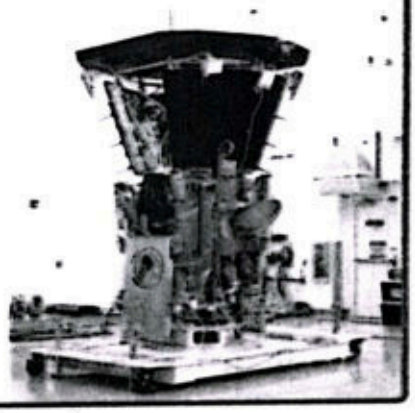
UNIT OPENER?



Why wouldn't the Parker Solar Probe melt despite being only 4 million miles away from the Sun's surface?

The Parker Solar Probe is a NASA spacecraft designed to study the outer atmosphere of the Sun, known as the corona, by traveling closer to the Sun than any previous mission. The Parker Solar Probe was launched on August 12, 2018, and mission is planned to last until 2025, during which the probe will complete 24 orbits around the Sun.

The Parker Solar Probe doesn't melt because it is protected by a heat shield made of a carbon-composite material that reflects and dissipates heat. Despite being only 4 million miles from the Sun, the temperature in space is not as extreme due to the lack of air to transfer heat efficiently. The heat shield keeps the probe's instruments cool, allowing it to withstand the Sun's intense radiation.



21.12 DARK MATTER

The universe is predominantly composed of dark matter and dark energy. Dark matter, an elusive and invisible substance, is five times more abundant than regular matter, making up about 27% of the universe. Although its exact composition remains unknown, we understand that it interacts through gravity but not with electromagnetic forces.

Unlike regular matter, dark matter does not emit, absorb, or reflect light, making it extremely challenging to detect. This enigmatic substance is termed "dark matter" because it is not visible. It occupies space and possesses mass, similar to regular matter, but its presence is inferred rather than directly observed.

One piece of evidence for the existence of dark matter comes from studying the rotation of galaxies. When we measure the orbital speed of matter at various distances from the galactic center, we observe that the speed does not decrease with distance as expected. Instead, the rotation speeds remain relatively constant. As illustrated in Figure 21.27, which shows distance in kiloparsecs (kpc)—equivalent to 3,261.56 light years—and rotation speed in kilometers per second, there is a clear graphical difference between the observed and expected outcomes.

Galaxies rotate at such high speeds that the gravitational force from their visible matter alone should be insufficient to keep them intact; they should have torn apart long ago. This discrepancy suggests the presence of a significant amount of unseen matter at the edges and beyond the visible parts of galaxies.

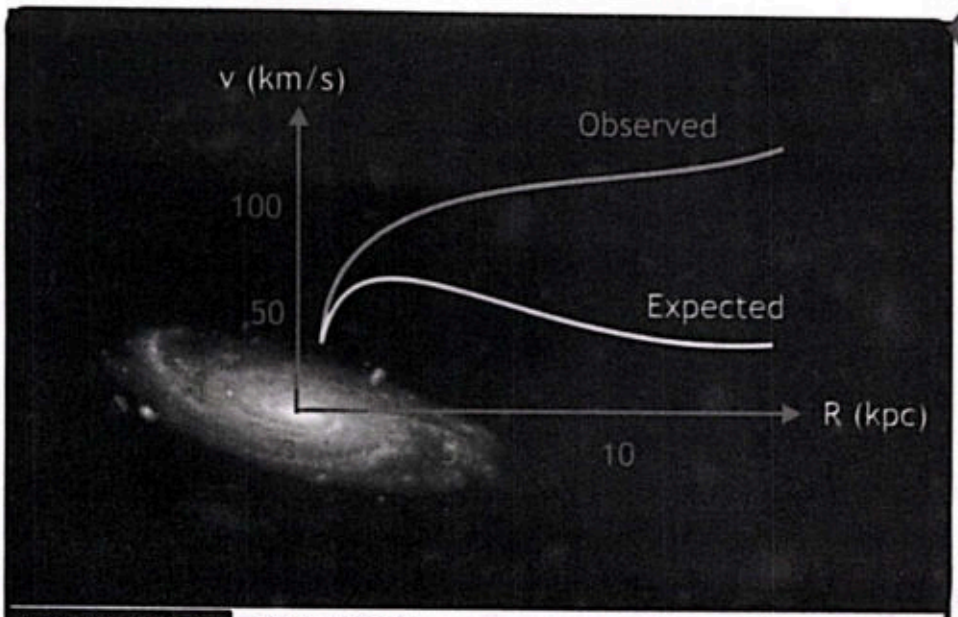


FIGURE 21.27 Dark matter

This phenomenon is also observed in galaxy clusters, suggesting it extends beyond galaxies as well. Scientists theorize that an undetected form of matter (dark matter) provides these galaxies with additional mass, creating the necessary gravitational pull to maintain their structure.

Current scientific understanding suggests that dark matter forms a vast, web-like structure permeating the universe, acting as a gravitational framework that attracts most of the cosmos' normal matter.

21.13 FALSIBILITY

What determines if an idea is legitimately scientific or not? Falsifiability is a key concept in the philosophy of science. It means that a scientific theory is considered valid only if it makes predictions or assertions that can be tested and potentially proven wrong.

Falsifiability means that for a theory to be scientific, there must be a possible observation or experiment that could show the theory to be false or incorrect. If no such test can be conceived, the theory is not scientific because it cannot be empirically tested. This principle helps distinguish scientific theories from pseudoscience, promotes rigorous testing, encourages objective evaluation, and enhances predictive power. This idea is crucial in every field of physics, including nuclear physics and the exploration of dark matter.

For example, observations of the sun's energy output and spectral analysis can test this theory. If the sun's energy output did not match the predictions made by nuclear fusion models, the theory would be questioned. Also by measuring the rotation curves of galaxies, scientists can test the existance of dark matter. If observations showed that galaxies could be explained solely by visible matter without any need for dark matter, the theory would be falsified.

Falsifiability is crucial in science because it allows scientific theories to be tested and potentially disproven. This process is essential for scientific progress. Scientists propose theories, conduct experiments to test these theories, and then refine or reject them based on the results. If a theory cannot be tested or disproven, it is not considered scientific because it lacks empirical validation.

Falsifiability ensures that theories are testable and open to refutation. However, it is not the only criterion for scientific theories. Scientists also consider other factors such as explanatory power, how well a theory fits with existing knowledge, its predictive accuracy, and its simplicity, often referred to as Occam's Razor. Combining these criteria helps ensure that scientific theories are robust and reliable.

SUMMARY

- **Nucleus** is the region consisting of protons and neutrons at the center of an atom.
- **Nucleons** are the particles found inside nucleus (i.e., protons and neutrons).
- **Nuclide** is a type of atom whose nucleus has specific numbers of protons and neutrons.
- **Radioactive Decay** is the process by which an atomic nucleus of an unstable atom loses mass and energy by emitting ionizing particles.
- **Alpha decay** is a type of radioactive decay in which an atomic nucleus emits an alpha particle (which is equal to helium nucleus).
- **Beta Decay** is a type of radioactive decay in which an atomic nucleus emits a beta particle (electron).
- **Gamma Decay** is a type of radioactive decay in which an atomic nucleus emits a gamma particle.
- **Radioactive substance** is a substance or object that emits nuclear radiation.
- **Half-life** is the time needed for half of the original nuclei of a sample of a radioactive substance to undergo radioactive decay.
- **Radioactive dating** is an application of radioactive decay in which the age of a material is determined by the amount of radioactivity of a particular type that occurs.
- **Carbon - 14 dating** is a radioactive dating technique based on the radioactivity of carbon-14.
- **Nuclear radiation** are the rays that originate in the nuclei of atoms
- **Nuclear Fission** is a nuclear reaction in which a heavy nucleus splits into small nuclei with the emission of large amount of energy.
- **Nuclear Fusion** is a nuclear reaction in which two nuclei are combined or fused together to form a larger nucleus and emit large amount of energy.
- **Shielding** is a technique to limit radiation exposure.
- **Background radiation** is a measure of the level of ionizing radiation present in the environment at a particular location which is not due to deliberate introduction of radiation sources.
- **Dark matter** is believed to comprise more than 80% of the universe's matter. Its existence is inferred because celestial objects and cosmic structures cannot be explained without it.
- **Falsibility** is the belief that for any hypothesis to have credence, it must be inherently disprovable before it can become accepted as a scientific hypothesis or theory.



EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

1. Charge on α-particle is how many times of the charge on proton?
   A. two times B. three times C. four times D. one time
2. Uranium with atomic number 92 has an isotope ^{239}U, the number of neutrons in it are:
   A. 92 B. 239 C. 147 D. 331
3. Which of the following is deflected at large angles by electric or magnetic field?
   A. α-particles B. β-particles C. γ-rays D. neutrons
4. Beta (β) particles are fast moving:
   A. electrons B. photons C. hydrogen nuclei D. helium nuclei
5. Cancer treatment involves targeting tumors with radiation. Which type of radiation is most commonly used for its ability to penetrate deep tissues?
   A. α-particles B. β-particles C. γ-rays D. protons
6. Which of the following decay modes is due to a transition between states of the same nucleus?
   A. alpha decay B. beta decay C. gamma decay D. all of these
7. During β-decay, the nucleon number:
   A. decreases by 4 B. does not change C. decreases by 1 D. increases by 1
8. A radioactive element with a half-life of two years, the sample remained after 6 years is
   A. 75 % B. 50 % C. 25 % D. 12.5 %
9. The half life of stable isotope is theoretically:
   A. zero B. 1 s C. 11 day D. infinite
10. The unit for absorbed radiation dose is:
    A. Bequerrel (Bq) B. Curie (Ci) C. Gray (Gy) D. Sievert (Sv)
11. Which of the following is the largest contributor to natural background radiation exposure for most people?
    A. Cosmic radiation B. Radon gas C. Food D. nuclear fallout
12. Radiocarbon dating is a technique used to estimate the age of organic materials. What is the approximate maximum age limit for reliable dating using this method?
    A. 10,000 years B. 50,000 years C. 1 million years D. 5 billion years

13. Food irradiation eliminates bacteria to extend shelf life. Which isotope would be ideal for this purpose?
    A. Strontium-90 (beta emitter, 28.8 years half-life)
    B. Cobalt-60 (gamma emitter, 5.27 years half-life)
    C. Iodine-131 (beta emitter, 8.02 days half-life)
    D. Plutonium-239 (alpha emitter, 24,100 years half-life)
14. A worker is preparing to use a radioactive source for an experiment. Which of the following is the PRIMARY reason to maintain a safe distance from the source during use?
    A. To conserve the radioactive material for future experiments.
    B. To minimize the risk of contamination from the source.
    C. To reduce the intensity of radiation reaching the worker.
    D. To prevent accidental activation of the source.
15. The energy of the sun is released due to:
    A. nuclear fission B. nuclear fusion C. reduction D. oxidation
16. The existence of dark matter is primarily inferred from its:
    A. Light emitted from distant galaxies B. Gravitational influence on visible matter
    C. Chemical reactions with normal matter D. Abundance in meteorites

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Complete the following nuclear decay equations:

(a) Lead-210 converts in to Bismuth (Bi):

$$^{210}_{82}Pb = {}^{210}_{83}Bi + \square$$

(b) Radon-222 emits an alpha particle and transforms into polonium (Po):

$$^{222}_{86}Rn \rightarrow \square + {}^{4}_{2}He$$

(c) Radium - 224 transforms into Radon (Rn):

$$^{220}_{86}Rn \rightarrow {}^{216}_{84}Po + \square$$

(d) Neptunium - 239 releases beta particle converts in to Plutonium (Pu):

$$^{239}_{93}Np \rightarrow \square + {}^{0}_{-1}\beta$$

(e) Iodine - 131 emits a gamma particle:

$$^{131}_{53}I \rightarrow \square + \gamma$$

2. Which isotope X is needed to complete:

(a) the fission reaction $^{1}_{0}n + ^{235}_{92}U \rightarrow X + ^{134}_{54}Xe + 2\,^{1}_{0}n$

⊙. $^{102}_{38}Sr$ ⊙. $^{101}_{37}Rb$ ⊙. $^{102}_{36}Kr$ ⊙. $^{100}_{38}Sr$

X = ☐

(b) the fusion reaction $^{2}_{1}H + X \rightarrow ^{4}_{2}He + ^{1}_{0}n$

⊙. $^{1}_{1}H$ ⊙. $^{2}_{1}H$ ⊙. $^{3}_{1}H$ ⊙. $^{3}_{2}He$

X = ☐

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Imagine you're explaining the difference between a nucleon and a nuclide to a younger sibling. How would you describe each term in a way they could understand?
2. Think about the everyday materials we encounter. How does the presence or absence of radioactivity fundamentally change the properties of a material?
3. Our bodies are made up of countless atoms. Is there a perfect balance between the number of neutrons and protons in every atom within our bodies? Explain your reasoning.
4. Why can a beta particle travel farther through air than an alpha particle, even if they have the same energy level?
5. Alpha particles are known to cause more ionization in solids than beta particles. What explains this difference in their ability to interact with matter?
6. Radium-226 undergoes alpha decay. Explain the process of alpha decay using a balanced nuclear equation and describe the resulting daughter nuclide.
7. Why is carbon dating technique primarily limited to dating materials that were once living organisms?
8. What makes Cobalt-60 a suitable choice in radiotherapy for treating cancer compared to other isotopes?
9. Some food is irradiated with gamma rays to kill bacteria. While gamma rays are powerful, why is there no concern about people consuming food containing residual gamma radiation?
10. Standing too close to a bonfire can burn your skin. How is this similar to the potential dangers of radiation exposure? Explain the fundamental mechanisms behind both phenomena.

11. We are constantly exposed to low levels of ionizing radiation from various sources. What practical steps could you take to reduce your exposure to this radiation?
12. How does the presence of dark matter significantly contribute to our understanding of the universe's structure and evolution?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. How did the discovery of the atomic nucleus transform our understanding of atomic structure and what implications did it have for modern physics?
2. In what ways do stable and unstable isotopes of an element differ in terms of their nuclear properties and applications in science and industry?
3. How do the characteristics of alpha, beta, and gamma radiation influence their use in medical treatments, industrial applications, and scientific research?
4. What are the potential consequences of alpha decay on the stability of an atomic nucleus, and how does this process compare to other types of radioactive decay?
5. When a nucleus ejects an electron during beta decay, what fundamental changes occur in the atomic structure, and how does this process affect the element's identity?
6. How does the concept of half-life facilitate our understanding of radioactive decay, and what practical implications does it have for fields such as archaeology and geology?
7. In what ways do ionizing nuclear radiations impact biological systems, and what are some of the long-term health effects observed in humans exposed to such radiation?
8. What are the most effective safety protocols for handling radioactive materials, and what strategies can be implemented to ensure safe disposal of radioactive waste?
9. How do the applications of radiation in everyday technologies, like smoke alarms and food irradiation, reflect the balance between safety and utility in modern society?
10. What are the primary sources of background radiation in our environment, and how do they contribute to the overall exposure experienced by living organisms?
11. Can you explain the significance of neutron-induced fission in sustaining a nuclear chain reaction, and what factors can influence the rate of this reaction?
12. What are the essential conditions required for nuclear fusion to occur, and how do these conditions relate to the processes occurring in stars like the sun?
13. How does the sun's emission of various wavelengths within the electromagnetic spectrum contribute to life on Earth, and what implications does this have for our understanding of solar energy?
14. What evidence supports the existence of dark matter in the universe, and how does this hypothesis challenge or reinforce our current understanding of cosmology?

15. Why is falsifiability considered a cornerstone of the scientific method, and how does it influence the development and acceptance of scientific theories?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Polonium $^{209}_{84}Po$ is a radioactive nuclei. Determine number of protons, number of neutrons and number of nucleons in it. **(Ans. 84, 125, 209)**
2. Americium $^{241}_{95}Am$ undergoes alpha decay and produces an alpha particle. Write down the chemical equation for it and name the nucleus formed. **(Ans. $^{237}_{93}Np$)**
3. A radioactive substance has a half-life of 16 months. In how much time, one-eighth of the substance will be left? **(Ans. 48 months)**
4. In a nuclear reaction, 2 μg of mass is converted into energy. Find the energy. **(Ans. 180 MJ)**
5. In 420 days, one-eighth of polonium (Po) remains un-decayed. Calculate the half-life of polonium? **(Ans. 140 days)**
6. The half-life of radium is about 1600 years. In how much time, 250 g will remain un-decayed when 1 kg of radium was there initially? **(Ans.3200 y)**
7. Three-fourth of the initial mass of a certain radioactive isotope decays after one hour. Find half-life of isotope in minutes? **(Ans. 30 min)**
8. The half-life of $^{210}_{83}Bi$ is 5 days. If we start with 64,000 nuclei of this isotope then how many number of atoms will left after one month? **(Ans. 1,000 nuclei)**
9. An archeologist digs up a human skull at a dig site. It was found that concentration of carbon-14 with a half-life of 5730 years is 25% of its initial concentration. What is the age of the skull? **(Ans. 11,460 y)**
10. The C-14 content with a half-life of 5730 years of an ancient piece of wood was found to have three tenths of that in living trees (indicating 70% of the C-14 had decayed). How old is that piece of wood? **(Ans.9953 y)**

GLOSSARY

A.C Generator is a device that converts mechanical energy into electrical energy.

AC is the type of electric current which changes its direction continuously.

Acoustic Lensing is the technique in which some materials are used to focus or diverge sound waves.

Acoustic Protection is the application of soft and porous material to protect individuals against undesirable sounds and noises.

Alpha Decay is a type of radioactive decay in which an atomic nucleus emits an alpha particle (which is equal to helium nucleus).

Ammeter is a device used to measure electric current through any device.

Ampere is the unit of electric current and is defined as one coulomb charge per second.

Analogue-to-Digital Converter is an electronic circuit which converts the continuously changing analogue signals to discrete digital signals.

Apparent volume expansion is thermal expansion of volume of liquid in a container without considering the expansion of its container

Audible Frequency Range is the range of frequency from 20 Hz to 20,000 Hz that humans can hear.

Background Radiation is a measure of the level of ionizing radiation present in the environment at a particular location which is not due to deliberate introduction of radiation sources.

Beta Decay is a type of radioactive decay in which an atomic nucleus emits a beta particle (electron).

Bimetallic Strips consists of two thin strips of different metals joined together which bend on heating.

Bit is a digit in binary (0 or 1), which is an abbreviation of binary digit.

Carbon - 14 Dating is a radioactive dating technique based on the radioactivity of carbon-14.

Charging by contact is the process when a charged object comes into contact with a neutral object, some electrons transfer between them, causing the neutral object to acquire the same charge type (positive or negative) as the charged object, but to a lesser degree.

Charging by friction involves rubbing two dissimilar materials together which transfers electrons from one material to the other.

Charging by induction is a method where a charged object influences the distribution of charge in a nearby neutral object without physically touching it which creates a temporary separation of charges in the neutral object.

Coefficient of linear thermal expansion is the fractional change in length per kelvin change in temperature.

Coefficient of volume thermal expansion is the fractional change in volume per kelvin change in temperature.

Concave Lens is a type of lens which is thin from the center and thick from the outer edges it diverges the parallel light rays.

Condensation is a phenomenon in which gases (vapours) change into liquids.

Conduction is the mode of transfer of heat due to direct contact of medium particles, which do not change their positions. It occurs in solids because of difference in temperatures.

Conductors are materials that allow electric charge to flow freely through them because they have loosely bound electrons that can easily move under the influence of an electric field e.g. metals like copper and aluminum.

Conservation of charge is a fundamental law stating that the total electric charge in an isolated system remains constant or charge can't be created or destroyed, only transferred between objects.

Convection is the mode of transfer of heat due to the motion of particles. It occurs in liquids and

gases because of the density difference between different regions.

Conventional current is the direction of flow of positive charges per unit time.

Convex lens is a type of lens which is thick from the center and thin from the outer edges it converges the parallel light rays to a single point.

Corona discharge is a faint glow or ionization of air caused by a strong electric field around a conductor which can be seen around high-voltage power lines.

Critical angle is the angle of incident light ray for which in spite of transmission into other medium the light ray moves along the boundary between the two media.

Critical temperature is the temperature at which and below which the resistance and resistivity of substance become zero is called the critical temperature.

Cyclones are large revolving tropical storms caused by winds blowing around a central area of low atmospheric pressure.

Dark matter is believed to comprise more than 80% of the universe's matter, existence of dark matter is inferred because celestial objects and cosmic structures cannot be explained without it.

DC is the type of electric current that is unidirectional and does not change its direction.

Deposition is a phenomenon in which gas changes directly to solid.

Diffraction is the bending of waves around the edges of an obstacle.

Digital-to-Analogue Converter is an electronic circuit which converts discrete digital signal to analogue signals.

Discharging is the process by which an object loses its electric charge which can happen through conduction (touching a grounded object), convection (charged particles carried by air), or a spark (sudden movement of charge).

Dispersion from a prism is the phenomenon in which white light splits into its seven constituent colors due to different extent of refraction.

Drought is a prolonged dry period (deficiency of precipitation) in the natural climate cycle that can occur anywhere in the world.

Earth's magnetic field is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion.

Echo is the reflected sound that can be distinguished from original sound (is heard after 0.1 s or more of the original sound).

Electric Circuit is a closed pathway through which electricity flows, typically consisting of a power source, wires, and components like resistors.

Electric Current is the rate of flow of charges.

Electric field is a region of space where a charged object experiences a force whose strength and direction depends on the amount and type of charge present.

Electric field lines are imaginary lines that depict the direction and strength of an electric field, which point away from positive charges and towards negative charges, with the density of lines indicating the field's strength.

Electric Motor is device that converts electric energy into mechanical energy.

Electric Power is the rate at which electrical energy is transferred or consumed in a circuit, measured in watts (W).

Electrical Energy is the ability of electricity to do work or produce heat, measured in joules (J) or kilowatt-hours (kWh).

Electrical Safety involves the practices and measures to prevent accidents and injuries related to electricity, including proper installation, maintenance, and following safety guidelines.

Electrification is the process by which an object acquires an electric charge which can happen through various methods like friction, contact, or induction.

Electromagnetic induction is the production of an electromotive force across a conductor when it is exposed to a varying magnetic field.

Electromagnetic spectrum is the range of

different wavelengths of electromagnetic waves is called the spectrum of the electromagnetic waves.

Electromagnetic waves are the waves that do not require any media for their production and propagation.

Electronics is the branch of physics that helps to study the emission and behaviour of electrons with electronic devices is known as electronics.

Electroscope is a simple instrument used to detect the presence and sign (positive or negative) of electric charge, which typically consists of two thin metal leaves that diverge when charged.

Electrostatic precipitator is a device that uses an electric field to remove dust particles and other pollutants from air.

Emf source is any device that converts non-electrical energy into electrical energy.

Evaporation is phenomenon of conversion liquid into vapours at any temperature.

Extrinsic semiconductors are those semiconductors that are doped with some specific impurities, which are of two types; p-type and n-type.

Falsibility is the belief that for any hypothesis to have credence, it must be inherently disprovable before it can become accepted as a scientific hypothesis or theory.

First law of reflection states that the incident ray, the reflected ray and the normal all lie in same plane.

Flooding is an overflow of water onto normally dry land.

Focal length is the distance from the lens to its focal point for a converging lens the focal length is positive while for a diverging lens the focal length is negative.

Forward biased is when the positive terminal of a DC source is connected to p-type and negative terminal is connected to n-type semiconductor of a pn junction, the junction is said to be in forward biased and the diode allows current to flow.

Freezing is the phenomenon in which liquid changes into solid.

Fundamental logic gates are three logic gates AND, OR and NOT.

Gamma decay is a type of radioactive decay in which an atomic nucleus emits a gamma particle.

Gamma rays are the most penetrating nuclear radiations and are used in medical treatment in detecting and killing cancerous cells, sterilizing food and medical equipment, engineering applications such as detecting cracks in metal etc.

Geothermal activity is a group of natural heat transfer processes, caused by the presence of excess heat in the subsurface of the affected area, occurring on Earth's surface.

Global warming is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning.

Good thermal conductors are those materials, through which, heat can easily pass.

Good thermal emitters are those materials, from which, heat can easily emit.

Gravitational Lensing is the phenomenon in which light bends while passing by a heavy galactic object due to its strong gravity.

Greenhouse Effect is the process through which heat is trapped near Earth's surface by substances known as greenhouse gases.

Half-life is the time needed for half of the original nuclei of a sample of a radioactive substance to undergo radioactive decay.

Heat Capacity is the amount of heat required to raise the temperature of any amount of substance by 1 °C or 1 K.

Heat Wave is a period of abnormally hot weather generally lasting more than two days and can occur with or without high humidity.

Humidity is content of water in air.

Hurricane is a tropical system with winds that have reached a constant speed of 74 miles per hour or more.

Induced polarization occurs when a charged object is brought near an insulator, the electric field from the charged object redistributes the charges within the insulator, creating a slight separation of positive and negative charges.

Infrared Radiations are in general produced by thermal motion, the vibration and rotation of atoms and molecules and have applications in household electrical appliances, remote controllers, intruder alarms, thermal imaging and optical fibers.

Infrared Thermometer is a thermometer that measures temperature from infrared radiations emitted by a body due to its temperature.

Infrasound waves are the sound waves having frequency less than 20 Hz, which human cannot hear.

Insulators are materials that resist the flow of electric charge because they have tightly bound electrons that are difficult to move e.g. rubber, plastic, and wood.

Intensity is the power per unit area (or energy per unit area per unit time) carried by a wave.

Intrinsic Semiconductors are pure semiconductors (such as Si or Ge) are called intrinsic semiconductors.

Kilowatt Hour (kWh) is the unit of electrical energy commonly used to measure consumption or production over time, equal to one kilowatt of power used for one hour.

Latent Heat is the amount of heat energy absorbed or lost by a substance during its phase change without change in its temperature.

Latent Heat of Fusion is the amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state without change in its temperature is called its latent heat of fusion

Latent Heat of Vaporization is the amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state without any change in its temperature is called its latent heat of vaporization.

Lenses are transparent objects that refract light in a specific way to form images.

Lenz's Law states that the direction of induced current in a circuit is always such that it opposes the cause which produces it.

Lichtenberg figures are branching, fern-like patterns left on an insulator's surface when a high-voltage discharge passes through it.

Light-Emitting Diode is a types of diode that emits energy in the form light when the electric current passes through it.

Lightning control rod are a well-established and effective method for protecting structures from lightning strikes.

Lightning Generation is the rapid discharge of electricity that occurs within a cloud or between a cloud and the ground, which is caused by the build-up of electric charge within the cloud due to various atmospheric processes.

Linear thermal expansion of solids is increase in length of substance on heating.

Logic Gates are the digital electronic circuits used to implement binary operations.

Longitudinal waves are the waves in which particles of the medium vibrate/oscillate parallel to the direction of motion of waves.

Long-sightedness or hyperopia is the condition in which a person can see distant objects clearly but near objects appear blurry to him.

Loudness is the perception of sound intensity; greater the intensity, louder the sound will be.

Magnetic Field is produced around a wire when a current is passing through it.

Magnifying glass is a single lens device which is used to see bigger images of the objects.

Majority Charge Carriers are electrons in n-type semiconductors and holes in p-type semiconductors.

Mechanical Waves are the waves that require medium for their propagation.

Melting is the phenomenon in which solid changes into liquid.

Microwaves have a higher frequency and lower wavelength than radio waves, but they are still generally thought of as low energy radiations and are used by some radars, Bluetooth, headphones, speakers and even Wi-Fi.

Minority Charge Carriers are electrons in p-type semiconductors and holes in n-type semiconductors.

Modulation is the process in which low frequency signal (modulator) is added with the high frequency carrier wave, the sum of these two is called the modulated wave for radio transmission.

Musical Sound is a sound that is pleasant and harmonious.

Nature of Light have two aspects a wave like and a particle like.

Near Point is the minimum distance at which if the object is placed we have clear image on our retina.

Noise is any loud, discordant or dis-agreeable sound.

N-Type Semiconductors are semiconductors with pentavalent impurity.

Nuclear Fission is a nuclear reaction in which a heavy nucleus splits into small nuclei with the emission of large amount of energy.

Nuclear Fusion is a nuclear reaction in which two nuclei are combined or fused together to form a larger nucleus and emit large amount of energy.

Nuclear Radiations are the rays that originate in the nuclei of atoms

Nucleons are the particles found inside nucleus (i.e., protons and neutrons).

Nucleus is the region consisting of protons and neutrons at the center of an atom.

Nuclide is a type of atom whose nucleus has specific numbers of protons and neutrons.

Ohm's Law states that the amount of electric current in a circuit depends upon the potential difference while keeping temperature constant.

Optical Fibers are the doubly refractive indices concentric tubes of glass or plastic which are used for transmission of light using the phenomenon of total internal reflection.

Optics is the science of light and its interaction with matter.

Parallel Combination of Resistors include connecting resistors side by side across the same voltage source, allowing multiple current paths.

Pentavalent impurities such as phosphorus, arsenic, antimony, and bismuth have five valance electrons and belong to group V-A of periodic table.

Perspex Block is a tough transparent plastic block which is used instead of glass blocks.

Photon is a tiny massless particle from which the light is composed of.

Pitch is the perception of frequency of sound; greater the frequency, greater will be the pitch and shriller will be the sound.

Potential barrier is the value of potential barrier for Ge crystal is 0.3 V and for Si crystal is 0.7 V.

Potential difference is the amount of work done in moving a unit positive charge from one point to another inside an electric field.

Potential divider is a circuit arrangement used to divide a voltage into smaller fractions using resistors connected in series.

Pressure is Force on unit area on an object perpendicularly.

Pressure of gas is the measure of force exerted by the gas particles on unit area of the walls of the container perpendicularly.

Projector is an optical device which use single lens to enlarge the image of an object.

P-Type semiconductors are semiconductors with trivalent impurity.

Quality is number and relative intensity of multiple sound frequencies.

Quantization of charge is the principle that electric charge exists in discrete units called electrons and protons.

Quantum computing uses phenomena in quantum physics to create new ways of computing.

Radiation is the mode of transfer of heat due to

electromagnetic waves. It does not require material medium for its motion.

Radiation Pressure is the phenomenon in which due to transfer of momentum light can exert pressure on objects.

Radio Waves are the range of longest wavelengths in the family of electromagnetic waves is the radio waves and can travel at the speed of light and can be used in radio transmission, television transmission and in astronomy.

Radioactive Dating is an application of radioactive decay in which the age of a material is determined by the amount of radioactivity of a particular type that occurs.

Radioactive Decay is the process by which an atomic nucleus of an unstable atom loses mass and energy by emitting ionizing particles.

Radioactive Substance is a substance or object that emits nuclear radiation.

Real volume expansion is thermal expansion in volume of liquid when it is heated directly.

Reflection is the throwing back by a body or surface of light, heat, or sound without absorbing it.

Reflection of light is when a ray of light approaches a smooth polished surface and bounces back is called reflection.

Refraction is the change in direction of a wave passing from one medium to another caused by its change in speed.

Refraction of light is the phenomenon in which the light ray's direction changes when it enters from one medium to another.

Refractive index is the measure of bending of a light ray when passing from one medium to another.

Refrigerant is a material used to produce cooling in refrigerator.

Relay is an electrically operated switch that open and close the circuits by receiving electrical signals from outside sources.

Resistance is the opposition to the flow of charges or opposition to electric current.

Resistivity is the resistance of unit length and unit area.

Resistor is an electrical component that limits the flow of electric current in a circuit, measured in ohms (Ω).

Reverberation is the reflected sound that cannot be distinguished from original sound (is heard before 0.1 s of the original sound).

Reverse biased is when potential at anode (p-type) is smaller than the potential at cathode (n-type), the diode is said to be reverse biased and the current is blocked.

Scattering of Light is the reflection of light waves in different directions from the particles of the medium.

Second law of reflection states that the angle of incident ray is equal to the angle of the reflected ray.

Seismic waves are caused by the sudden movement of materials within the Earth, such as slip along a fault during an earthquake.

Series Combination of Resistors include connecting resistors end-to-end in a single path so that the same current flows through each.

Shielding is a technique to limit radiation exposure.

Short-sightedness or Myopia is the condition in which a person can see near objects clearly but distant objects appear blurry to him.

Solar Sail is a spacecraft propulsion method that utilizes a curious quirk of photons.

Sound intensity level is a unit less quantity that tells about the level of sound relative to a fixed standard.

Sound is a disturbance of matter that is transmitted from its source to outwards and which produces sensation of hearing in ear.

Specific Heat Capacity is the amount of heat required to raise the temperature of one gram of a substance by 1 °C or 1 K.

Spectroscopy is the branch of physics which is used

to study the ways different electromagnetic waves interact with matter.

Step-down Transformer is used to decrease the incoming voltage.

Step-up Transformer is used to increase the incoming voltage.

Sublimation is a phenomenon in which solids change directly into gases.

Superconductor are those material through which current flows without resistance.

Temperature Coefficient of Resistance (α) is a measure of how a material's resistance changes with temperature.

Thermal expansion means increase in size of matter on heating.

Total internal reflection is the phenomenon in which a light ray travelling in denser medium bounces back to the same medium after striking the boundary of a rarer medium.

Transformer is an electrical device which is used to increase or decrease the value of an alternating voltage.

Transistor is a device that acts as both a transmitter and resistor and is made in two types: PNP and NPN.

Transverse waves are the waves in which particles of the medium vibrate/oscillate perpendicular to the direction of motion of waves.

Trivalent impurities such as boron, aluminum, indium, and gallium have three valance electrons and belongs to group III-A of periodic table.

Tsunamis are a series of enormous ocean waves caused by earthquakes, underwater landslides, volcanic eruptions or asteroids.

Two Long Parallel Wires carrying a current in same direction attract each other.

Ultrasound waves are the sound waves having frequency greater than 20 kHz, which human cannot hear.

Universal Logic Gates are the logic gates NAND and NOR because they can be used to make all the other gates.

Vaporization is the phenomenon in which a liquid is converted into gas (vapours) upon boiling.

Visible Light is the narrow segment of the electromagnetic spectrum to which the normal human eye responds.

Voltmeter is a device used to measure potential difference across any device.

Volume thermal expansion of solids is increase in volume of substance on heating.

Wave is the energy transfer mechanism without the transport of material media.

Wildfires is an unplanned, unwanted fire burning in a natural area, such as a forest or grassland.

Winter Storms is an event in which the main types of precipitation are snow, sleet or freezing rain.

X-rays of low range overlaps with the ultraviolet and high energy x-rays overlaps gamma rays (in low energy region) and its applications are in medical, technological and social applications some of them are use in medical imaging, security scanners, killing cancerous cells and engineering applications such as detecting cracks in metal etc.

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BIBLIOGRAPHY

ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management (AHA Centre). (n.d.). Retrieved September 25, 2024, from https://ahacentre.org

BBC Education - Bitesize. (n.d.). Retrieved September 29, 2024, from https://www.bbc.co.uk/bitesize

Brian, H., Nowikow, I., T. Howes, C., Mantha, J., P. Smith, B., & Bemmel, H. M. (2002). Physics: Concepts and Connections . Toronto: Irwin Publishing Ltd.

Climates to Travel. (n.d.). Climate of Pakistan. Retrieved October 6, 2024, from https://www.climatestotravel.com/climate/Pakistan

D. Cutnell, J., & W. Johnson, K. (2012). PHYSICS. Hoboken: John Wiley & Sons, Inc.

Freedman, R. A., & Young, H. D. (2020). University Physics with Modern Physics . Harlow: Pearson Education Limited.

Freepik. (n.d.). Retrieved October 15, 2024, from https://www.freepik.com

Giancoli, D. C. (2014). Physics for Scientists & Engineers with Modern Physics. Essex: Pearson Education Limited.

Hawkes, R., Iqbal, J., Mansour, F., Milner-Bolotin, M., & Williams, P. (2019, 2014). Physics for Scientists and Engineers: An Interactive Approach, Second Edition. Toronto: by Nelson Education Ltd.

Herman, S. L. (2011). Delmar's Standard Textbook of Electricity, 5th Edition. New York: Delmar, Cengage Learning.

Hewitt, P. G. (2014). Conceptual physics (12th ed.). Pearson.

HowStuffWorks. (n.d.). Environmental Science: Oceanography. Retrieved October 10, 2024, from https://science.howstuffworks.com/environmental/earth/oceanography

https://www.nasa.gov. (2024, May 29). Retrieved from NASA: https://www.nasa.gov

Internet Geography. (n.d.). Retrieved September 30, 2024, from https://www.internetgeography.com

Khan, A. U., Jan, A. M., Elahi, M., Khaliq, M. I., & Ahmad, E. (2022). Physics Grade 09. Islamabad: National Book Foundation (NBF).

Khan, A. U., Jan, M. A., Elahi, M., Khaliq, M. I., & Ahmad, E. (2022). Physics Grade 10. Islamabad: National Book Foundation.

Krane, K. S. (2020). Modern Physics, Fourth edition . Hoboken: John Wiley & Sons, Inc.

National Ocean and Atmospheric Organization. (n.d.). Retrieved October 5, 2024, from https://www.noaa.gov

Pakistan Meteorological Department (PMD). (n.d.). Retrieved October 2, 2024, from https://www.pmd.gov.pk

Robertson, C. R. (2008). Fundamental Electrical and Electronic Principles. Slovenia: Elsevier.

Save My Exams. (n.d.). Retrieved October 28, 2024, from https://savemyexams.com

Serway, R. A., & Faughn, J. S. (2006). Physics. New York: Holt, Rinehart and Winston.

U.S. Energy Information Administration. (n.d.). Retrieved September 20, 2024, from https://www.eia.gov

Urone, P. P., & Hinrichs, R. (2020). Physics - High School. Texas: Texas Education Agency (TEA).

Walker, J., Halliday,, D., & Resnick, R. (2014, 2011, 2008, 2005). Fundamentals of physics. Hoboken: John Wiley & Sons, Inc.

William H. Hayt, Jr., & John A. Buck. (2012). Engineering Electromagnetics, Eighth Edition. New York: McGraw-Hill Companies, Inc.

Zemansky, M. W., & Dittman, R. H. (1997, 1981, 1968, 1957, 1951, 1943, 1937). Heat and Thermodynamics - An intermediate textbook. New York: McGraw Hill Companies.

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