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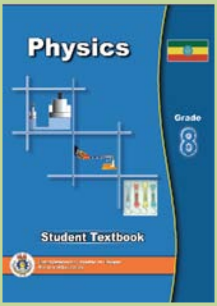

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Table of Content

Preface

This text book is written for students studying physics in grade 8. It will guide you through the basic concepts and skills with *readings, activities, questions* and *illustrations* to support the text. Each unit begins with the unit outcomes and followed by an introduction (overview).

The objectives of the lesson are listed at the beginning. Basic definitions of the topic which represents the MLCs are in a **blue background box**. This is to help you in identifying the MLCs sentences easily. All **"activities"** are in a box and consecutively numbered. You will find photographs or pictures which illustrate the topic you are studying.

Each section has set of questions **(Check points)** linked to the MLCs. At the end of each unit there is a **summary** of what you have read. And also there are a unit review questions and problems to enable you to test your knowledge and understanding of the unit's content. Each unit is set out in the same way with unit title and number at the top of the page. The title is written on each page as a header.

This book is just one resource which you will use to learn/ study introductory physics. Information to support this book will be located with your teacher, on the plasma programs, in other reference books and documents and with people in your communities.

UNIT 1

PHYSICS AND MEASUREMENT

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to basic measurements;
- ✓ develop skills of measuring area, volume and density;
- ✓ develop skill in producing and evaluation of a design project applying the laws of physics in its construction
- ✓ appreciate the interrelatedness of all things;
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

Introduction

One of the most important skills you need to learn in physics is measurement. In grade 7 you learnt how to measure length, time and mass. Different measuring instruments for length, time and mass has also been studied. Traditional units and standard units of measurements were differentiated. Also, you learnt that basic physical quantities are measurable. But plenty of physical quantities are expressed in terms of these basic quantities and they are called derived quantities. In this unit you will study how to measure and calculate areas of different surfaces, volumes of different bodies and the densities of substances.

1.1. Measuring Area

In this section you will learn how to measure areas of different surfaces.

Activity 1.1

Measure the length and width of the following materials

	Material	Length (m)	Width (m)	$\ell \times w$	Unit of $\ell \times w$
1	Gr-8 Physics .text				
2	Your class room				

Do you have any idea about the product $\ell \times w$ from your mathematics subject? What does it describe?

All forms of surfaces, whether they are regular or irregular shaped have lines that bound them.

Area of a surface is the space bounded by a certain line. The SI unit of area is square meter. i.e. m^2.
Other units are cm^2, mm^2, and km^2.

Table 1.1 Relationships between SI and non SI units of area

$1m^2$	$10,000cm^2$
$1m^2$	$1,000,000\ mm^2$
$1m^2$	$100\ dm^2$

Activity 1.2

1. Change $1m^2$ into cm^2, mm^2 and km^2.
2. Change $1cm^2$, $1mm^2$ and $1km^2$ into m^2

Calculating area

Activity 1.3

Find hard paper and cut it into pieces of 1cm × 1cm. Totally produce up to 100 pieces of square centimeter.

Paste these pieces of square centimeters in a regular way without leaving any space between them, on your textbook.

- How many pieces have you used to cover the whole surface of the textbook?
- Compare this number of pieces with product $\ell \times w$ of your textbook.

The method used for measuring surface area is derived directly from the method for measuring distances. Areas are measured by choosing some convenient square units. Determining how many of these units are contained in the surface we know the area. This is done by measuring the **length** and **width** of the surface and then finding the product of these measurements.

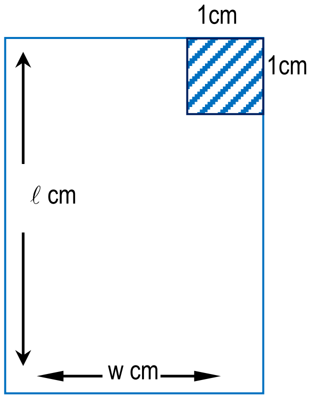


Fig 1.1 1cm × 1cm square

Areas of some common surfaces have simple mathematical relations with the enclosing curves. You have already learnt in mathematics how to find the area of a rectangle, square, triangle and circle. The followings are revisions of finding areas of different surfaces.

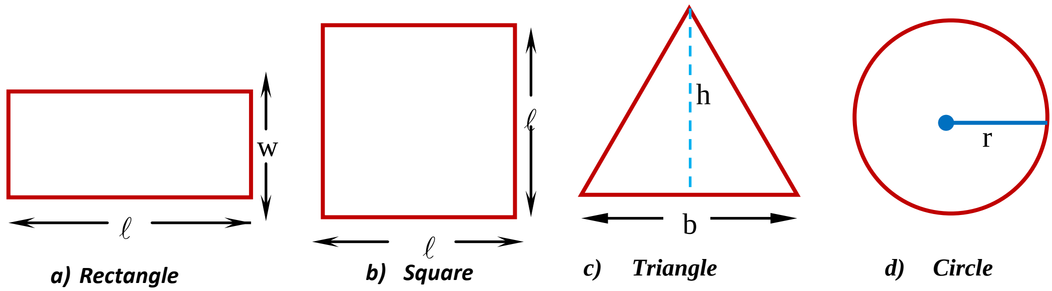


Fig 1.2. Area of different shapes

1. Area of a rectangular surface is given by the product of its **length** and **width.**

$$\text{Area} = \text{Length} \times \text{Width}$$

$$A = \ell \times w$$

2. Area of a square surface is given by the product of two sides.

$$\text{Area} = \text{Length} \times \text{Length}$$

$$A = \ell^2$$

3. Area of a triangular surface is given by the product of half of its base and height.

$$\textbf{Area} = \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2} \times b \times h = \frac{1}{2} bh$$

4. Area of a circular surface is given by:

$$\text{Area} = \pi \times (\text{radius})^2$$

$$A = \pi r^2$$

Table 1.2 Formula for finding areas of different surfaces

Surfaces	Formula of Area
Rectangular	$A = \ell \times w$
Square	$A = \ell \times \ell = \ell^2$
Triangle	$A = \frac{1}{2} \ell \times h$
Circle	$A = \pi r^2$

Example 1.1

What is the surface area of a table, if the length is 120 cm and its width is 80 cm?

Given	Required	Solution
ℓ = 120 cm	A = ?	$A = \ell \times w$
w = 80 cm		= 120cm × 80cm
		= 9600 cm^2 or 0.96m^2

Example 1.2

What is the area of a square surface if its sides are 2m each?

Given	Required	Solution
ℓ = 2m	A = ?	Area of square = ℓ^2
		= $(2m)^2$
		= $4m^2$

Example 1.3

Find the base area of a glass. If its base is circular with a diameter of 4 cm. (take π=3.14)

Given	Required	Solution
Diameter = 4cm	A= ?	Area of a circle = πr^2
∴ r =		= 3.14× $(2cm)^2$
= = 2cm		= (3.14× 4) cm^2
		= 12.56 cm^2

Challenging questions

How can you calculate the surface areas of a cube, rectangular block, and cylinder?

Check point 1.1

1. What is an area? How can you measure it?
2. Write the equations for finding the areas of a rectangle, a square, a triangle and a circle.
3. Explain the relation between the diameter and the radius of a circle.
4. Express the relation between m^2 and other units such as cm^2, mm^2 and km^2.

1.2 Measuring Volume

Next, you will learn how to measure the volume of regular shaped bodies, liquids, and irregular shaped bodies.

All physical bodies around you occupy a certain amount of space. Different materials occupy different space. The space occupied by a body is called the **volume** of the body.

The volume of a body is the space occupied by the body. The SI unit of volume is cubic meter (m^3).

The volume of an object can also be expressed in cubic decimeter (dm^3), cubic centimeter (cm^3), cubic millimeter (mm^3) and so on.

One unit can be converted into another using the relations in Table 1.3.

Table 1.3 Relationships between SI and non SI units of volume

$1m^3$	$1,000,000cm^3$
$1dm^3$	$1,000cm^3$
$1cm^3$	$1, 000mm^3$

Example 1.4

How many cm^3 are there in $0.8m^3$?

Given	Solution
$V = 0.8m^3$	$1m^3 = 1000, 000cm^3$ $0.8m^3 = ?$ $\therefore$ V in $cm^3 = \frac{0.8m^3 \times 1000,000cm^3}{1m^3}$ $= 800, 000\ cm^3$

Bodies are found in solid, liquid or gas forms. Moreover solid bodies are either regular or irregular in shape. Liquids do not have a definite shape. They take the shapes of their containers. Therefore different methods are used to determine the volumes of solids, liquids and gases.

Challenging questions

Explain the differences between solid, liquid and gases in terms of their volumes.

Activity 1.4

Discuss with your friends and write short notes on how to measure the volume of:

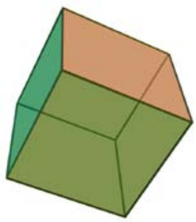
a) a match box.
b) air in your class room.
c) any liquid.
d) any irregularly shaped stone.

1.2.1 Measuring Volumes of Regular Shaped Solid Bodies

Solids have definite shape and volume. The shape of a solid can be regular or irregular.

Measuring volume of regular - shape solid is performed in a similar way as a surface area. The length, width and height of the body need to be measured. Then its volume is calculated using the product of the three sides (Fig 1.3 shows a rectangular block, cube and cylinder).


a) Rectangular block


b) Cube


c) Cylinder

Fig 1.3 Regular- shaped solids

I. Volume of a rectangular block

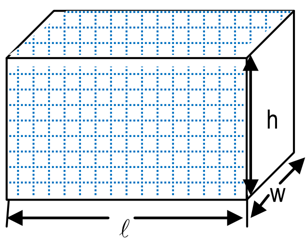


Fig 1.4 A rectangular block with sides ℓ, w and h

The volume (V) of a rectangular block having length (ℓ), width (w) and height (h) is given by:

$V = \ell \times w \times h$

$V = \ell wh$

Example 1.5

A chalk box has a length of 4cm, a width of 5cm and height of 6cm.

a) What is the volume of the chalk box?

b) How many unit chalks are needed to fill it, if each unit chalk is $2cm^3$?

Given	Solution
ℓ = 4cm	a) volume of chalk box = ℓwh
w = 5 cm	= 4cm×5cm×6cm
h = 6 cm	= $120cm^3$
Volume of unit chalk = $2cm^3$	b) The volume of unit of chalk is $2cm^3$, Therefore number of chalks needed can be calculated by dividing the volume of the box by the volume of chalk i.e.

$$\text{Number of chalks needed} = \frac{\text{volume of box}}{\text{volume of unit chalk}}$$

$$= \frac{120cm^3}{2cm^3} = 60$$

∴ The box can contain 60 chalks

II. The volume of a cube

A cube is rectangular block having all its sides equal. That means

length = width = height = ℓ

Therefore **Volume = ℓ^3**

1.2.2 Measuring Volume of Liquids

Liquids have no definite shape. When you pour liquids into differently shaped containers, they will have the shape of their containers. However liquids have definite volume.

Since liquids take the shape of their containers, the volume of a liquid is determined by considering their containers. The volume of a liquid can be measured by graduated measuring cylinder. (Fig 1.5).

The common unit for measuring the volume of liquid is liter (L)

.

Fig 1.5 A measuring graduated cylinder

Fig 1.6 Different plastic bottles containing different volume of water.

Activity 1.5

Pour a glass of water into a measuring cylinder. If the measuring cylinder is graduated in milliliter (mL), read the volume of the water in the measuring cylinder.

Table 1.4	
1 L =	1000 mL
1 mL =	$1 cm^3$
$1 m^3$ =	1000 L
1L =	$1 dm^3$

Example 1.6

1. A small swimming pool is 600 cm long, 300 cm wide and 200 cm deep. What is the volume of the water contained in the pool in cubic meters (m^3)?

Given	Required	Solution
$\ell = 600cm$ $w = 300cm$ $h = 200cm$	Volume in m^3 = ?	$V = \ell \times w \times h$ But first convert the unit of each dimension (size) into meter. i.e. $\ell = 600cm = 6m$; $w = 300cm = 3m$ and $h = 200cm = 2m$. Therefore, $V = 6m \times 3m \times 2m$. $= \mathbf{36\ m^3}$

1.2.3 Measuring the Volume of an Irregular shaped Body

Have you noticed the over flow of tea as spoons of sugar are put into a cup filled with tea? What is the cause of the over flow?

Activity 1.6

- Pour water into a measuring cylinder. Take carefully the reading (level) of the water and call it V_1. (see Fig 1.8a)
- Tie a stone with a thread and gradually immerse the piece of stone (irregular shape) into the water in the measuring cylinder. Notice the new level of the water. Again take the reading of the cylinder and call this volume V_2.
- Calculate $V_2 - V_1$ and explain what this value mean.

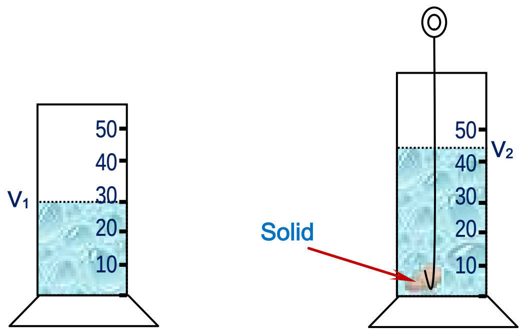
Steps to determine the volume of irregular shaped bodies

Step 1: Pour some amount of water into the measuring cylinder. Record its volume and let it be V_1

Step 2: Put an irregular- shaped body into the measuring cylinder. Record again the volume of water and irregular shaped body. Let it be V_2

Step 3: volume of the irregular shaped body (V) = $V_2 - V_1$

Fig 1.7 An irregular shaped stone



a) Volume of water only **b) Volume of water plus volume of irregular shaped stone**

Fig 1.8 Measuring the volume of an irregular shaped stone.

Two bodies do not occupy the same space at the same time. For example, immerse a stone in a vessel filled with water. You can observe the over flow of water. This is because the stone and water do not occupy the same space at the same time. The water has to leave some spaces for the stone. Hence the stone displaces the water. See Fig 1.8 and 1.9. The volume of displaced water is equal to the volume of the immersed solid body.

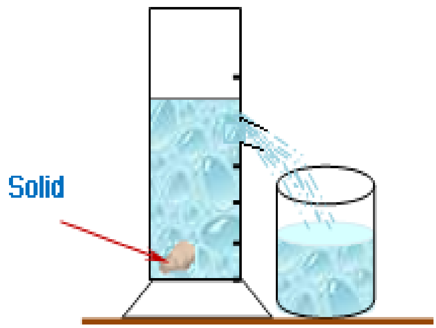


Fig 1.9 Measuring the volume of an irregular shaped body by displacement method.

Check point 1.2

1. Explain the method of calculating volume of a regular shaped body.
2. How can you measure the volume of a cylinder?
3. Explain how you can measure the volume of a liquid.
4. Describe the difference between solids, liquids and gases in relation to volume.
5. Describe the method for measuring volume of an irregular shaped body.
6. Write down the units of volume of a solid and liquid body.

1.3 Measuring the Density of a Substance

Activity 1.7

Hold blocks of wood and iron of the same volume. Consider their heaviness or lightness. Which one of them is heavier? Measure their mass and volumes.

Object	Mass	Volume	Mass/ volume
Iron block			
Wooden block			

- What do you understand by the quantity mass/volume?
- Which object does have the bigger mass/volume?
- How much mass of iron is there in a unit of volume?
- How much mass of wood is there in a unit of volume?
- What do you call the ratio of mass to volume of body?

In the above activity you determined the mass per unit volume of a wood and an iron. Comparing these quantities of mass per unit volume of iron with that of wood you find that iron has more mass in a unit volume than wood.

The secret of iron being heavier than wood of the same volume is, due to greater amount of mass per unit volume in it. This quantity is defined as the density of an iron.

Density is the amount of mass in a unit volume. Or, it is the ratio of mass to its volume. The symbol which stands for density is a Greek letter 'ρ' read as *roe*

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}; \quad \rho = \frac{m}{V}$$

m = mass of the body

V = volume of the body

You can also rearrange and get formula for 'm' and 'V'. i.e.

$$m = \rho . V \qquad \text{and} \quad V = \frac{m}{\rho}$$

The SI unit of density is kilogram per cubic meter (kg/m^3). For example the density of water is $1000 kg/m^3$. Different substances have different densities. Table 1.5 gives the densities of different substances.

Table 1.5 Densities of different substances			
Liquid		Solids	
Substance	Density (g/cm^3)	Substance	Density (g/cm^3)
Water	1.0	Aluminum	2.2
Kerosene	0.8	Copper	8.9
Petrol	0.7	Gold	19.3
Salty Water	1.2	Iron	8.0
Mercury	13.6	Rubber	1.5
		Lead	11.3
		Ice	0.9
		Silver	10.5
		Tin	7.3

Use Table 1.5 to answer the following questions

a) Among the given substances which one is the most dense?

b) Do you know why ice floats on water? Explain it using the concept of density.

c) What is the lightest metal among the given metallic substances?

Challenging questions

1. What substances have higher densities than iron?
2. What substances are denser than water?
3. What is the substance that has the greatest density of all?
4. What is the density of water in: a) Kg/m^3 b) g/cm^3?

Measuring the density of an irregular shaped solid body

You have already learned how to measure the density of a regular shaped solid body.

To measure the density of an irregular-shaped solid body, you need to measure the mass and the volume of the irregular shaped solid body.

Challenging questions

1. How do you measure the mass of an irregular shaped solid body?
2. How do you measure the volume of an irregular shaped solid body?

You measure the mass using a beam balance. To measure the volume of an irregular shaped solid body, you use a displacement method as in Fig 1.9. The density of an irregular shaped solid body equals the mass of the irregular solid body divided by the volume of water displaced. That is the volume of the irregular shaped solid body.

Density of irregular shaped body= $\frac{\text{Mass of irregular shaped body}}{\text{final volume} - \text{initial volume}}$

$$\boldsymbol{\rho} = \frac{m}{V_2 - V_1}$$

Measuring the density of liquid

You already know that a liquid doesn't have a regular shape. It takes the shape of its container. To measure the density of a liquid, you need to know its mass and volume.

Challenging question

How do you measure the mass of a liquid and volume of a liquid?

The following steps are used to measure the density of liquid

1. Measure the mass of an empty container using a beam balance and denote it as m_1.
2. Pour the liquid of a given volume into the container and measure the mass of the container and liquid together. Denote this as m_2.
3. The difference between m_2 and m_1 is the mass of the liquid (m_2- m_1).
4. Density of liquid = $\frac{\text{mass of liquid } (m_2 - m_1)}{\text{volume of liquid (V)}}$

Example 1.7

1. Figure 1.10 shows a cylinder graduated in cm^3. When an irregularly-shaped piece of metal is placed in the cylinder the water level rises as shown. If the mass of the metal is 150 g, what is the density of the solid metal?

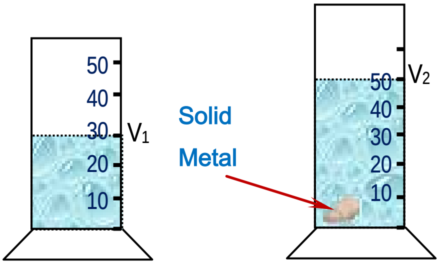


Fig 1.10 Displacement method for measuring volume

Given	Required	Solution
mass of the solid =150g	Density of the solid?	$\text{density} = \frac{\text{Mass}}{\text{Volume}} = \frac{150\text{g}}{20\ \text{cm}^3}$

$V_1 = 30\text{cm}^3$

$V_2 = 50\text{cm}^3$

$\Rightarrow V = V_2 - V_1 = 50\text{cm}^3 - 30\text{cm}^3$

$= 20\ \text{cm}^3 = \text{volume of metal}$

$= 7.5\text{g/cm}^3$

Hydrometer

Activity 1.8

1. Discuss with your class mates. How you can measure the density of a liquid. How do people know whether a given milk is waterish or not?
2. What is a hydrometer?

The density of a liquid is measured by using an instrument called a **hydrometer.** A hydrometer is a glass cylinder with a weight at the bottom and a thin calibrated tube at the top.

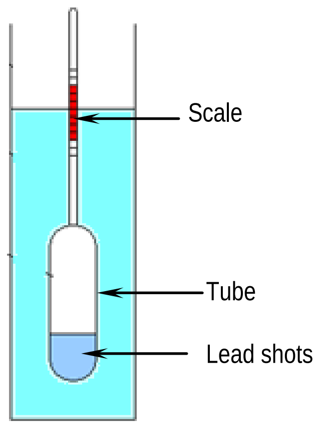


Fig 1.11 A Hydrometer

To measure the density of a liquid you let the hydrometer float in the liquid and note the depth to which it sinks. For example, the density of milk can be measured using a hydrometer.

The denser the milk the lesser the depth to which the hydrometer sinks. The smaller the density of the milk the more the depth to which the hydrometer sinks. (The milk is waterish when the density is small, and is fatty when the density is bigger).

Significance of knowing the density of materials:

1. Airplanes, moving parts of engines, bodies of buses etc. must be strong but not heavy. They are made of substances with low densities. For example aluminum has a density of 2.7 g/cm^3 which is lighter than steel (ρ_s = 7.7g/cm^3).
2. Density is important to identify pure substance from mixtures. For example the density of gold is 19.3 g/cm^3. Gold mixed with other metals has a lower density.
3. Civil engineers also use the idea of density to determine the durability of their building.

From your daily life mention some activities in which you apply the idea of density.

Check point 1.3

1. **What is density?**
2. **Describe the relationship between mass, volume and density of a body.**
3. **How can you measure the density of**
   - **a) a regular shaped solid body?**
   - **b) an Irregular shaped solid body?**
   - **c) Liquid?**
4. **Explain how a hydrometer works.**

1.4 Dimensional Expression of a Physical Quantity

The dimensions of a physical quantity refer to the fundamental unit or units contained in it.

Any quantity which can be measured in a mass unit is said to have the dimension of a mass. This is expressed by the symbol [M]. Similarly, any quantity which can be measured in length unit is said to have the dimension of length [L].

Every physical quantity can be expressed interms of the basic or fundamental quantities. For the system of units, the quantities M, L, T are used to represent mass, length, time respectively. The power to which the fundamental units are raised to obtain any physical quantity are called the dimensions of that quantity. For example, the dimensions of area = length × length; are $[L^2]$.

The dimensions of a physical quantity show how the quantity is related, through its defining equation, to the basic quantities.

For example, if we write the physical quantity speed as $[v] = [LT^{-1}]$ we indicate that speed is measured by dividing a length by a time.

Some quantities are described by a number which is independent of the units such quantities are said to be **dimensionless.**

For example, a relative density of a substance is dimensionless. It does not have a unit. Mechanical advantages and velocity ratio are dimensionless quantities in machines. Can you name other physical quantities that are dimensionless?

Table 1.6 Dimensional Expression of some physical quantities

Fundamental units			Derived units		
Phy.Quan	Unit	Dimension	Phy. Quan	Unit	Dimension
Mass	kilogram	[M]	Area	m^2	$[L^2]$
Length	meter	[L]	Volume	m^3	$[L^3]$
Time	second	[T]	Density	$\frac{kg}{m^3}$	$[ML^{-3}]$
			Speed.	m/s	$[LT^{-1}]$
			Force	$kg.m/s^2$	$[MLT^{-2}]$

The derived units are based on the fundamental units. In many cases, they involve more than one fundamental units.

In such a case the dimensions of such units are expressed in general as $K(M)^x (L)^y (T)^z$. Where K is a number. x, y and z indicate how many times the particular unit is involved.

For example, a force of 10 N can be rewritten as: 10 MLT^{-2}
Here K = 10, x = 1, y = 1 and z = -2

The values of x, y and z can be found from the definition of the physical quantities involved. The power to which the fundamental units are raised to obtain the derived units are called the dimensions of the derived units.

Table 1.7 The dimensions of some important physical quantities

Physical quantity	Dimension
Velocity	$[LT^{-1}]$
Momentum	$[MLT^{-1}]$
Acceleration	$[LT^{-2}]$
Energy	$[ML^2 T^{-2}]$
Frequency	$[T^{-1}]$
Power	$[ML^2 T^{-3}]$
Charge	[AT]

Example 1.8

1. **Area:** The area of a square whose sides are 1m each is 1m × 1m = $1m^2$. Thus the unit of area is the square of unit of length. Since the dimension of length is (L), the dimensions of area is (L) × (L) = L^2. Thus, area has two dimensions in length.
2. **Volume:** The volume of a unit cube = 1m × 1m × 1m = $1m^3$ i.e. the unit of volume is the cube of unit of length. So the dimensions of volume is [L] [L] [L] = $[L]^3$. Thus volume has 3 dimensions in length.

3. **Density:** $[M]^1 [L]^{-3}$

Since density is $\frac{\text{mass}}{\text{volume}}$

The dimension of density is $\frac{[M]}{[L^3]}$

$[M]^{+1}[L]^{-3}$

The uses of dimensions

Each term in a correct physical equation must have the same dimensions. Use of this fact is called the method of dimensions.

In a correct physical equation we can equate both number and unit for each term that appears. If we could not equate the unit, then a change of the system of units might result in the numbers changing by different factors, which would invalidate an equation whose numbers were previously equal.

i) Conversion of units

When several system of units are in common use, the method of dimension gives a quick way of converting units for complex derived quantities from one system to another.

ii) To check equations

Since physical equations are dimensionally homogeneous, terms which are incorrect can quickly be detected.

iii) Dimensional analysis

This enables us to predict how physical quantities may be related.

Check point 1.4

1. What do you understand by "dimensional expression"?
2. Express the dimensions of area, volume, density, speed, acceleration, force, work, and power.

1.5 Scientific Notation

Activity 1.9

Measure the height, width and length of your classroom in cm and calculate the volume of the class room in:

i) m^3 ii) mm^3 iii) km^3

Have you noticed any problem in expressing the volume of the room in the above units?

- Explain the advantage and disadvantage of writing the volume in the above units?
- Do you know any other option of writing this volume?

Obviously when you are doing Activity 1.9 you may have come across many problems. The problems are:

- The numbers are long and tiresome to write.
- The numbers may take up a lot of space.
- Errors may easily be made in reading the number of zeros. etc.

Suppose the distance from the sun to the earth is about 150 million km. This is fully written as:

s = 150,000,000 km where 's' stands for distance.

This distance is written in terms of other units, as

in meter, s = 150,000,000,000 m

in centimeter, s = 15,000,000,000,000 cm,

in millimeter, s = 150,000,000,000,000 mm

Do you notice the space you are taking to write such big numbers? And can you read the numbers in centimeters and millimeters?

Similarly to write very small numbers, you need to put as many zeros as possible before a numeral.

Using such numbers repeatedly in operations will finish the pages of your notebook very soon. Therefore, a simple method of writing small and large numbers is needed. The **scientific notation** is such a method.

The scientific notation is a way of writing very large and very small numbers using a power of 10. Remember your mathematics knowledge of writing numbers in power of 10.

Scientific notation is representation of a quantitiy in the form of $a \times 10^n$. Where 'a' is a number lying between 1 and 10 and 'n' is an integer number

In the scientific notation, only one non-zero number (digit) remains to the left (in front) of the decimal point. To compensate for the places the decimal point is shifted. To do this, you use power often. The numbers in the above examples can be written using the scientific notions.

$s = 1.5 \times 10^8 km$

$s = 1.5 \times 10^{11} m$

$s = 1.5 \times 10^{13} cm$

$s = 1.5 \times 10^{14} mm$

Challenging questions

Convert the following numbers into scientific notation

a) 300,000,000 cm

b) 0.000,000,000,000,128 cm

Prefixes

You have learnt that there is only one unit for basic or derived quantities. Scientists have felt that the powers of ten in the scientific notion are not suitable for writing. Therefore, they have given symbols for some of the powers of ten.

Prefixes involve power of ten which are multiples and sub multiplies. The symbols for the powers of ten are called prefixes. The word ''prefix'' means something put in front of another. As its name indicates, prefixes are put in front of units.

Table 1.8 shows the prefixes for some common multiples and submultiples.

For example in the quantity 5 km, m is the symbol of meter. The letter ‘k’ is a prefix. ‘k’ stands for 10^3. Thus, 5km = 5×10^3 m.

Table 1.8. Prefixes of units			
Prefix	symbol	Factor by which the base unit is multiplied	
tera	T	10^{12}	multiplies
giga	G	10^{9}	
mega	M	10^{6}	
kilo	k	10^{3}	
hector	h	10^{2}	
deca	da	10^{1}	
deci	d	10^{-1}	sub multiplies
centi	c	10^{-2}	
milli	m	10^{-3}	
micro	μ	10^{-6}	
nano	n	10^{-9}	
pico	p	10^{-12}	

Check point 1.5

1. **What do we mean by a ‘scientific notation’?**
   Write 1,000,000 w
   1,000 m
   0.001 cm using scientific notation
2. **Explain the use of scientific notation**
3. **Give some practical examples where prefixes are used**
4. **What are the prefixes used to write**
   a) 1,000,000 (1 million)
   b) 1,000,000,000 (1 billion)
   c) $\frac{1}{1,000,000}$
   d) $\frac{1}{1,000}$

SUMMARY

In this unit you learnt that:

- area of a surface is the region bounded by a certain curve. The methods used for measuring surface area are derived directly from the methods for measuring distances. Area of some regular shaped bodies:-
  1. Area of a rectangular surface = Length × width
  2. Area of a square = ℓ^2
  3. Area of a triangular surface = ½ (bh)
  4. Area of a circular surface = πr^2.
- the SI unit of area is square meter (m^2).
- volume of a body is the space occupied by the body. The SI unit of volume is cubic meter (m^3).
- volume of rectangular block = ℓwh.
- volume of cube = ℓ^3.
- volume of a liquid can be measured using a measuring cylinder. Volume of irregular shaped bodies can be measured by using displacement of a liquid.
- density is the amount of mass per unit volume. The formula of density is $\rho = m/V$.
- the density of regular shaped bodies can be obtained by measuring the mass and volume of the bodies.
- hydrometer is an instrument used to measure the density of liquids.
- the dimensions of a physical quantity shows, how the quantity is related to the basic quantities. Scientific notation is a convenient way of representing values of measurements in order to perform mathematical operations. Prefixes are powers of 10, written before units.

Review Questions and Problems

I. Write 'true' if the statement is true and 'false' if the statement is false.

1. One square meter (m^2) is equal to ten thousand square centimeters (10,000 cm^2).
2. Measuring cylinder is used to measure the volume of a liquid.
3. The volume of irregular-shaped bodies is determined by using beam balance.
4. Hydrometer is a devise used to measure the volume of a liquid.

II. Answer the following questions.

1. Define the following terms and phrases.
   a. Area
   b. Volume
   c. density
   d. dimensional expression
   e. scientific notation
2. Describe how you can determine:
   i) Surface area of a. a rectangle b. a triangle
   ii) Volume of an irregular shape solid body
   iii) Density of a liquid.
3. What is the use of a hydrometer?
4. Explain the advantage of using scientific notation.
5. What are the prefixes used to write multiples of numbers?

III. Work out problems.

1. A box is 30 cm wide, 40 cm long and 25 cm high Calculate:
   a. the area of its base.
   b. the volume of the box.
2. When 10 similar coins are dropped into a graduated cylinder the level of the water in the cylinder raised from 75mL to 100mL. What is the average volume of each coin?
3. What is the area of a rectangular plate whose sides measure 27.3cm by 17.5cm?

4. Compute the following operations in scientific notation. (Use your mathematical knowledge)
   a. $2.7 \times 10^{2}N \div 3.6 \times 10^{-4}m^{2}$
   b. $3.9 \times 10^{-2}m - 2.3 \times 10^{-3}m$
5. Write the followings in i) the scientific notation,
   ii) prefixes
   a. 15,000,000,000 kg
   b. 0.00000189 m
   c. 0.000,000,000,000,000,000,0030 second
   d. 6000,000,000,000,000,000,000,000 km
6. Carry out the following computation
   $(8.60 \times 10^{5}) \times (6.17 \times 10^{-2}) \div (1.79 \times 10^{-4})$. Write your answer in scientific notation with one digit to the left of the decimal. (use your mathematical knowledge)
7. Compute the dimensions of gravitational constant G; where
   $F = \frac{Gm_1m_2}{r^2}$.
8. Check the dimensional consistencies in the following equations
   a. $s = v_o t + \frac{1}{2}at^2$
   b. $v^2 = v^2_o + 2\,as$, where s is the distance moved in time t, v_o and v are the initiate and final velocities and 'a' is the acceleration.

UNIT 2

MOTION IN ONE DIMENSION

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to force and uniform motion;
- ✓ develop skill of manipulating problems related to statics and uniform motion;
- ✓ appreciate the interrelatedness of all things;
- ✓ use a wide range of possibilities for developing knowledge of the major concepts within physics.

Introduction

In grade 7 physics, you learnt the basic concepts in motion and identified four different types of motion. You also learnt how to compute derived quantities from the fundamental quantities.

''A moving object has a natural tendency to come to rest''
Aristotle (2500B.C)

This unit presents to you concepts in motion where you just extend your previous knowledge and skills in motion to greater depth.

2.1 Forces in Physics

Activity 2.1

- From your grade 7 physics lessons describe the concept 'Force' in general and 'Force' in physics in particular.
- List the types of force you know.

Force is a very important physical quantity. It is used to describe interactions between different bodies in nature. For example, when you kick a ball, tear a piece of paper, hold your exercise book, walk on the floor, close or open a door, you apply forces.

Frictional force and gravitational force are some of the forces that you deal with in day to day life. Frictional force helps you walk and gravitational force helps in the flow of water from higher level to lower level and in kicking ball up in the air and receiving it back.

What is a force?

Force is a push or pull exerted on a body.
The SI unit of force is newton (N) and it is measured by a device called a newton-meter.

Fig 2.1 Newton-meter

Challenging question

Can you name some effects of forces?

Particularly in physics, the concept of force is used to describe how a body changes its velocity or accelerates. It is not possible to describe a force as we can describe some material object such as a chalk, pen, orange, etc. You can only tell what a force does.

A force has the following major characteristics: **Magnitude**, **point of application** and **direction**. Thus, a force is a vector quantity.

Types of forces

In physics there are a number of different forces that you need to study. These are:

- Gravitational force,
- Friction force
- Magnetic force,
- Electric force,
- Elastic force,
- Forces from collisions,
- Centripetal force,
- Buoyancy.

Activity 2.2

Identifying types of forces. Consider the following four cases

Case 1. Two bar magnets attracting each other.

Case 2. A stone (ball) dropping from air to ground.

Case 3. Pushing and pulling a table on the floor.

Case 4. A box moving (sliding) over another box.

i) What are the basic differences between these forces?

ii) Have you noticed that forces can be exerted on objects in two ways?

a. By a physical contact of two objects.

b. Without physical contact of two objects.

Using Activity 2.2, you can classify forces as **contact forces** and **non-contact forces.**

Contact forces are forces that are exerted only when two objects are in contact. e.g frictional forces and pushing a table.

Other examples of contact forces:

1. The force exerted by a stretched or compressed spring,
2. The upward force exerted by a table on a book resting on it, and
3. The force exerted on a bone by a contracting muscle are some example of contact forces. Mention some other contact forces.

A *non-contact* force is a force applied to an object by another body that is not in contact with it. e.g magnetic forces, gravitational force, and electric force.

The most common examples of a non-contact forces are

i) Gravity (gravitational force)

ii) Magnetic force

iii) Electric force

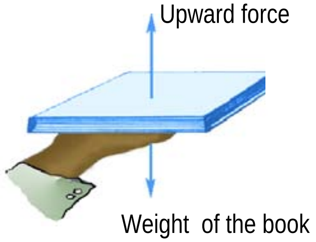
Revising Newton's laws of Motion

Activity 2.3
Discuss the three laws of motion with your friends.

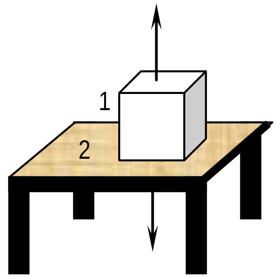
You have learnt **'Newton's first law'** of motion in grade 7. Therefore you remember that an object at rest will not change its position unless a net force causes it to do so.

Newton's first law implies that a net external force must act on an object to speed it up, slow down, or change its direction of motion or to start motion. The first law implies that a force is required to produce change in velocity or acceleration.

From Newton's first law, you observe that the states of **''no motion''** and of **''uniform motion''** are similar as long as there is no net force acting on a body.



a) Holding a book



b) A box resting on a table.

Fig 2.2 Action and reaction forces.

Activity 2.4

1. Hold up your textbook as show in Fig 2.2 (a)
   - Is there any force acting on the textbook you are holding?
   - Is there any force acting on your hand while you are holding the text?
   - Can you mention the number of forces? What are the forces?

While you are holding the textbook on your palm forces occur in pair.

For every action there is equal and opposite reaction Newton's third law

For any two objects a force that is applied to object 1 due to the action of object 2 is accompanied by a force applied to object 2 due to the reaction of object 1. Fig 2.2 illustrates different action and reaction forces. What are the action and reaction forces in Fig 2.2 b? This idea is described by **Newton's third law**. This law implies that action and reaction forces are equal and opposite.

Challenging question

- State and explain the three Newton's laws of motion.

Check point 2.1

1. **How could you explain a force in physics?**
2. **Describe different types of forces in nature.**
3. **What are contact forces and non-contact forces?**
4. **Explain the principles behind the first and third laws of Newton.**
5. **How would you explain the state of 'no motion' and 'balanced forces'?**

2.2 Motion in One Dimension

Motion is one of the most important features of the world around us. Every day, you walk from home to your school and see moving objects in your surroundings. In this unit you will further learn about average speed, velocity, acceleration, uniform motion and uniformly accelerated motion in a straight line. Motion in a straight line is called motion in one dimension. Do you remember what you have learnt in grade 7 about uniform motion and uniformly accelerated motion? (Revise your notes).

Activity 2.5

i) What is motion?
ii) Explain the different types of motion.
iii) What does it mean by "motion in one dimension"? Explain its properties.
iv) Define the following terms:
    - Average speed.
    - Average velocity
    - Acceleration.
    - Uniform motion.
    - Uniformly accelerated motion.

2.2.1 Uniform Motion

Challenging question

What does a uniform motion mean?

The type of motion where the moving object covers equal distance in equal time interval is called **uniform motion.** For uniform motion in a straight line, the speed of a moving body is constant.

Activity 2.6

How long does it take you to move around a foot ball field in your school? Five minutes, ten minutes or more? Record the time required to move around the field at least for three different trials.

Trials	Distance (s)	Time (t)	s/t
1			
2			
3			

The distance around the football field remains constant while for many practical reasons the time may not be constant. Sometimes you walk quickly and another time you may run. Therefore, your speed may not be constant. Similarly the motion of bodies, for example a car or a truck will not be uniform. To describe such kinds of motions we use the concept of average speed.

$$\text{Average speed} = \frac{\text{Total distance travlled}}{\text{Total time taken}}$$

$$v_{av} = \frac{s_T}{t_T}$$

The SI unit of average speed is meter per second (m/s). Other non SI units such as kilometer per hour (km/hr), cm/s, etc. can also be used as units of speed.

The concept used to describe a speed that has direction is called a **velocity.** Velocity tells us how fast a body is moving in a given direction.

Velocity is a vector quantity. It depends on the displacement made between final and initial positions. For examples, if you walk from your home to school and back to home your displacement is zero. But your distance traveled is not zero.

$$\textbf{Average velocity} = \frac{\text{Total displacement}}{\text{Total time}}$$

$$\vec{v}_{av} = \frac{\vec{s}}{t}$$

In section 2.1. you have seen that, if there is no net force acting on an object, it will remain at rest, if it was moving with constant speed in a straight line, it will continue to move with its uniform speed.

Generally, the motion of bodies starts and ceases. Bodies increase in motion or slow down, or change their directions. In all these cases the velocities of moving bodies are changing. The causes of these changes in the state of motion are forces exerted on the bodies. Bodies do not change their states of motion without the action of forces.

Newton's second law of motion describes the interrelations of force and motion.

Example 2.1

A bus is travelling from Addis Ababa to Ambo. It travels 43 km in the first hour, 40 km in the second hour, and 46 km in the thirds hour of its journey .What is its average speed?

Given	Required	Solution
$s_1 = 43$ km, $t_1 = 1$hr	**Speed (v_{av}) =?**	$v_{av} = \frac{\text{total distance}}{\text{total time}}$
$s_2 = 40$km, $t_2 = 1$ hr		$v_{av} = \frac{129\text{km}}{3\,\text{hr}}$
$s_3 = 46$ km, $t_3 = 1$ hr		

Total distances $S_T = S_1 + S_2 + S_3 = 129$ km **v_{av} = 43 km /hr**

Total time taken $t_T = t_1 + t_2 + t_3 = 3$ hr

Example 2.2

A car moved 2.4 km due east for 120 second. What is its average velocity?

Given	Required	Solution
s = 2.4 km due east	$\vec{v}_{av} = ?$	$\vec{v}_{av} = \frac{\text{displacement}}{\text{time taken}}$
= 2400 m, due east		$\vec{v}_{av} = \frac{2400\text{m}}{120\text{s}}$ East
t = 120 s		$\vec{v}_{av}$ = 20m/s, due East

2.2.2 Uniformly Accelerated Motion

Velocity is a speed with direction

A body that starts to move from rest may increases in motion or slows down or change its direction of motion. In such situations, velocities of moving bodies change. That is, acceleration is produced.

Acceleration is the time rate of change of velocity.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$\Rightarrow \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

$\vec{v}_f$ is final velocity at t_f, $\vec{v}_i$ is initial velocity at t_i

The SI unit of 'a' is m/s^2 (ms^{-2})

If the velocity of a body changes equally for equal interval of time then the motion of the body is said to be *uniformly accelerated motion.*

The phrase **uniformly accelerated motion** means

i. The magnitude of the acceleration is constant (uniform)
ii. The motion is along a straight line. i.e, the direction is fixed. Hence distance and displacement and speed and velocity can be used interchangeably.

Example 2.3

A car starts from rest and reaches a speed of 20 m/s in 5 seconds. What is the acceleration of the car?

Given	Required	Solution
$v_i = 0$ $v_f = 20\text{m/s}$ $t = 5\text{ s}$	$\vec{a} = ?$	$\vec{a} = \frac{v_f - v_i}{t} = \frac{20\text{m/s} - 0}{5\text{ s}}$ $= \mathbf{4\ (m/s^2)}$

Freely Falling Bodies

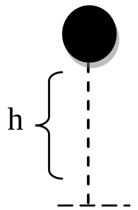


Fig 2.3 Freely falling body

The most common natural example of a uniformly accelerated motion is the motion of a freely falling body. Freely falling body in air means a body which is falling under the action of its weight alone.

For a freely falling bodies you have

$$\vec{v}_i = 0$$
$$\vec{a} = \vec{g} = 9.8\text{m/s}^2, \quad \vec{v}_f = gt$$
$$s = \text{height (h)}$$

Check Point 2.2

1. **What kind of motion is one dimensional motion?**
2. **What is an average speed?**
3. **What is the difference between a speed and a velocity for one dimensional motion?**
4. **What is acceleration?**
5. **Write the equation of acceleration for uniformly accelerated motion.**

2.3 Representation of Uniform Motion and Uniformly Accelerated Motion Using Tables and Graphs

Uniform velocity

When an object moves equal displacement in an equal time interval, then its velocity is said to be uniform velocity or constant velocity.

- Uniform velocity is unchanging velocity.
- If the velocity is uniform then the average and instantaneous velocities are the same.

A motion with constant velocity (i.e constant speed and fixed direction) is said to be **uniform motion**

Uniform motion can be described in v against t and s against t graphs;

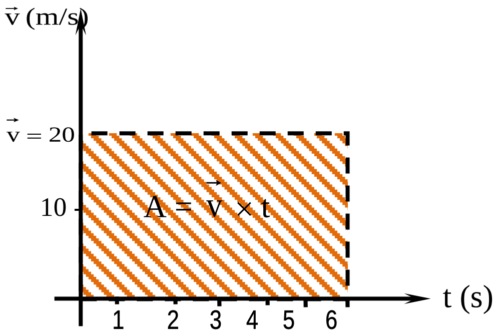


Fig 2. 4 v against t graph for motion with constant velocity.

In Fig 2.4 the v against t graph is given and the slope is a horizontal straight line which shows no change in the velocity as time goes on.

By definition s = v × t = 20 m/s × 6 sec = 120 m. But from Fig, 2.4 the area (A) under the slope equals v × t. $\Rightarrow$ 20 m/s × 6s= 120 m. This means distance equals the area of the v against t graph.

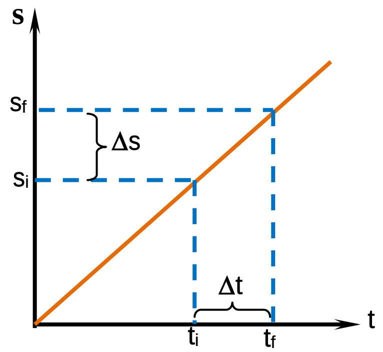


Fig 2.5 s against t graph for motion with constant velocity.

The velocity at a given instant of time can be found from the s against t graph by determining the slope of the graph. The slope of a graph at any point is equal to $\frac{s_f - s_i}{t_f - t_i}. = \frac{\Delta s}{\Delta t}$

Let us start with motion at constant velocity. Consider the v against t graph, Fig 2.6. This graph represents the velocity of a car traveling along a straight level road in a direction of north. For the first 2 hours, the car maintains a constant speed of 40 km/hr, then remains at zero velocity for 1 hour, and finally moves opposite in direction to its original velocity (a negative velocity) at 80 km/hr in a direction due south. What information does this graph give?

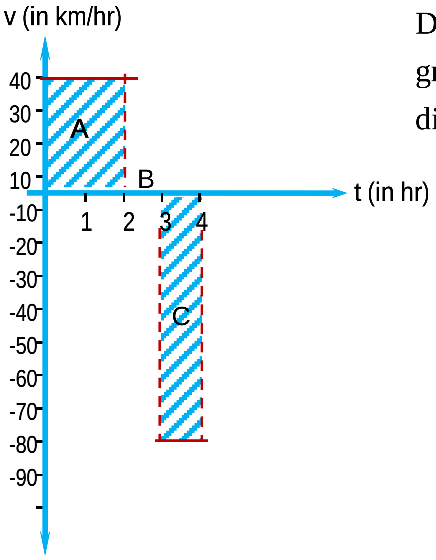


*Fig 2.6 **v against t** graph a car traveling along a straight, level road in a constant direction.*

During the first 2 hours (section A of the graph), When the speed is 40 km/hr the displacement is

$$\vec{s} = \vec{v} \times t$$

$= 40$ km/hr north $\times$ 2 hr

$= 80$ km, north

The graph does not tell where the car starts, but only that its position changes by 80 km during the 2 hours travel. As you can see, this 80 km is represented by the area under section A.

During the third hour (section B of the graph), the velocity is zero and there is no change in the position of the car, so the area under B is zero.

During the third hour (section C of the graph), the velocity is 80 km/hr due south for 1 hour. The displacement in C is – 80 km /hr × 1hr or 80 km south. This -80 km is represented by the area under section C of the graph.

The total displacement for the 4 hours is zero. The distance traveled by the car, however, is the sum of the magnitude of the displacements and equals

(80km) + (80km) = 160km.

The s against t graph in Fig 2.6 is a straight line graph, whose slope = $\frac{\Delta \vec{s}}{\Delta t}$. But by definition, $\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$. Hence slope equals velocity in the s against t graph.

Fig 2.7. is a graph of s against t, for the above object, whose v against t is shown in Fig. 2.6

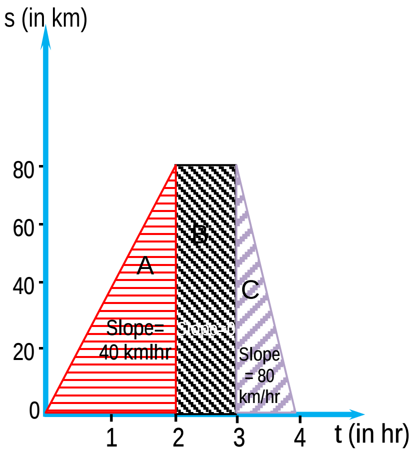


Fig 2.7 $\vec{s}$ against t graph

In section A of the graph, distance increases uniformly with time, in section B, there is no change in distance; and, finally, in section C the displacement is downward rather than upward. Since the negative displacement is equal in magnitude to the positive displacement, the net, or total, displacement is zero. Thus, we see that the velocity for a given time can be found by determining the slope of the displacement time curve for that interval of time.

Uniformly accelerated motion

The v against t graph for a uniformly accelerated motion is a straight line graph. Fig 2.8 illustrates the graph of a uniformly accelerated motion. From the graph you observe that;

i. Slope = $\frac{\Delta \vec{v}}{\Delta t} \Rightarrow$ slope $= \vec{a}$ (acceleration

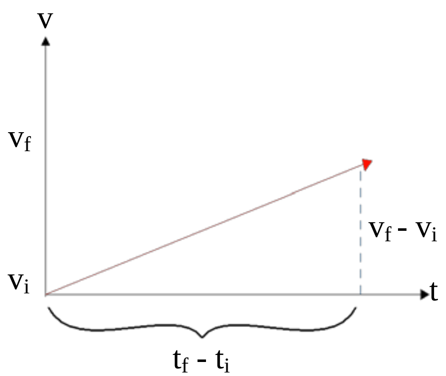


Fig 2.8 v against t graph for changing velocity

ii. The area under the slope of $\vec{v}$ against t graph equals to the displacement of the body. The area (A) under the graph = $\frac{1}{2} \times \Delta t \times \Delta v$. if $v = a\Delta t$, then distance (s) = $\frac{1}{2}at^2$.

Check Point 2.3

1. The motion of a toy is recorded as in table below

t (s)	1	2	3
v (m/s)	10	20	30

   a) What is the acceleration of the toy?
   b) What is the velocity attained at time t = 10 seconds?

2. A car accelerates from rest to 20 m/s in 5 seconds.
   a) What is the acceleration of the car?
   b) If it continued accelerating at this rate, how fast would it go after i) 2 seconds? ii) 10 seconds?

3. A car starts from rest and reaches a velocity of 10 m/s in 10 s.
   a) Draw the v against t graph for the motion of the car?
   b) From the graph find:
      i) the slope of the graph.
      ii) Area of the v against t graph bounded by the slope, and x- axis.
   c) What are the slope and area of v against t graph equal to respectively?

SUMMARY

In this unit you learnt that:

- when two bodies interact with each other, forces are produced between them. Force is a push or a pull exerted between bodies.
- force has magnitude and direction. It is measured by a Newton meter.
- forces are classified as contact and non- contact forces Newton's first law of motion states that a body at rest remains at rest or a body moving with a uniform velocity continues to move at that velocity, unless an external force is applied.
- the states of no motion and uniform motion remain the same in the absence of a force.
- uniform motion in a straight line is illustrated with a constant velocity. The s against t graph uniform motion is a straight line graph.
- the slope of the S against t graph equals the velocity.
- uniformly accelerated motion in a straight line is illustrated with a changing velocity. The v against t graph for an accelerated motion is a straight line.
- the slope of the v against t graph equals the acceleration. The area of the v against t graph equals the distance traveled for the time 't'.

Review Questions and Problems

1. The motion of a car is drawn is v against t graph as in Fig 2.8.

   a) What is the acceleration of the car?

   b) What is the distance travelled by the car in60 s?

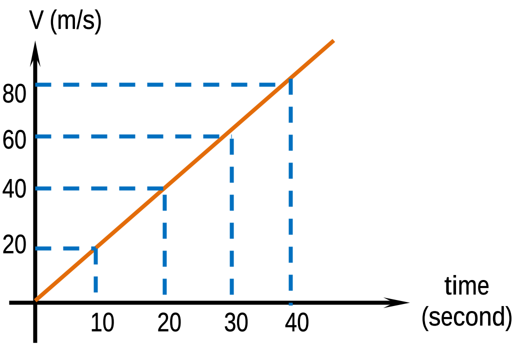


Fig 2.9. v against t graph

2. I rode my bicycle to grandmother's house at 6 km/h in a flat road for 5 min before reach a hill. I went at 2 km/h up the hill for 3minutes. I met a friend and stopped to talk for 5 minutes. I went on at 2 km/h to my grandmother's house. Draw (plot) the v against t graph for this motion.
3. An object is moving along a straight road at the speed of 6 km/h.
   a) How further away is the object every one hour?
   b) How further away is the object every half (½) hr?
   c) How further away is the object every 1/3 hr? Plot (draw) the s against t graph for its motion
4. Athlete Mesert Defar runs at 10 m/s. How long will it take her to go
   a) 1 m   b) 5 m   c) 20 m   d) 100 m
5. Draw a speed v against time graph by guessing of the values of your trip to school this morning. Show how this graph can be used to determine distance.
6. A car traveling due north at 60 km/hr increased its velocity to 80 m/s due south in 20 seconds.

   Draw

   i) speed against time graph,

   ii) acceleration against time graph.

UNIT 3 PRESSURE

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to pressure;
- ✓ develop skill of manipulating problems related to pressure;
- ✓ appreciate the interrelatedness of all things;
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

Introduction

In grade 7 physics, you learnt about force and its effects. Do you remember some of the effects of forces? In this unit you will study another effect of force known as **pressure**.

You begin first studying the concept of pressure using solid materials. Then you will learn about liquid pressure, atmospheric pressure, measuring atmospheric pressure, Pascal's principle and finally some applications of pressure.

3.1 Definition and Unit of Pressure

Activity 3.1
Discuss the following questions with your friends or parents. 1. What is a force? What is an area? 2. Explain the effect of force on a unit area. 3. What do you call this effect?

In Activity 3.1, most likely you recognized the difference between pressure and force.

Force is a push or a pull which changes the shape of a body; but pressure means force per unit area. Without changing the magnitude of the force you can have different pressures, just by changing the area on which the force acts. (see Fig 3.1).

a) Vertically arranged blocks ***b) Horizontally arranged blocks***

Fig 3.1. Effects of area on pressure

Activity 3.2 Observing the dependence of pressure on an area
Material required: blocks of wood (or books), a ruler, and a supporting body *Procedure:* Place the ruler between two supporting bodies. - Place the blocks of wood, one by one on the ruler. (Fig 3.1) the blocks could be placed a) Vertically (Fig. 3.1a) one over the other and the effect of the weight of the blocks on the ruler will be seen. What do you observe? b) Horizontally (Fig. 3.1b) next to each other. Compare the effect of the weight of the blocks on the ruler. In which cases is the ruler bent more? Explain the reason. - What can you conclude about the dependence of pressure on an area?

From Activity 3.2 you have noticed that, the pressure exerted by the block of wood on the ruler depends on the area on which the blocks were resting. The pressure is higher when the blocks are vertically placed than when they are arranged horizontally.

Pressure is an effect which occurs when a force is applied on a surface. Pressure is the amount of force acting on a unit area. The symbol of pressure is P.

$$\text{Pressure} = \frac{\text{Force exerted}}{\text{Area}} \Rightarrow P = \frac{F}{A}$$

The SI unit of pressure is Newton per square meter (N/m^2), and this unit is also called Pascal and is represented by P_a.

Where 1 P_a = 1N/m^2.

Other non-SI units are the bar, millibar and the torr.

1 millibar = 100pa
1 bar = 100,000pa
1 torr = 1mm of Hg
= 0.1 cm of Hg
1.01 bar=1010 millibars
= 760 torrs
= 101,000 pa and it is known as Standard Atmospheric Pressure (SAP).

From the definition of pressure one can understand that the pressure of the system increases with an increase of a force.

From the Activity 3.2; you have observed that pressure depends on the area on which the force is applied.

Challenging questions

1. Do you know an elephant? What about its hoof? Is it large or small?
2. What would happen to the elephant if it had a small hoof similar to a goat?

Nature seems to be aware of the factors affecting pressure. The hoof of an elephant covers a wide area. When it walks, its large weight is spread over a wide area of its hoof. So, its pressure or force per unit area is less. This helps the elephant to walk over soft ground without sinking much into it.

Dimension of pressure

If F is in N and N = kg m/s^2, its dimension is [MLT^{-2}], and

if A is in m^2 its dimension is [L^2]

Therefore, the dimension of pressure is $\left[\frac{MLT^{-2}}{L^2}\right]$ = [ML^{-1}T^{-2}]

Challenging question

Can you explain why tractors have tires of large area than an automobile?

Examples 3.1

1. Calculate the pressure exerted at a point while a nail tip of area $0.1cm^2$ is hammered into a wooden block with a force of 20N.

Given	Required	Solution
F = 20N A = 0.1cm^2 = 0.00001m^2	P = ?	$P = {}^{F}/_{A} = \frac{20\text{ N}}{0.00001\text{m}^2}$ = 2,000, 000 N/m^2 or 2,000,000 pa

2. What force is required to produce a pressure of 20,000 N/m^2 when the surface area is 2m^2?

Given	Required	Solution
P = 20,000$^{N}/_{m^2}$ A = 2m^2	F = ?	$P = \frac{F}{A} \Rightarrow F = P\times A$ $= 20{,}000\ \frac{N}{m^2}\times 2m^2$ $\Rightarrow F = 40{,}000N$

3. A rectangular block of mass 50 kg lies with a side 2m by 1m on a table. What is the pressure exerted by its weight on the table? (Fig 3.2)

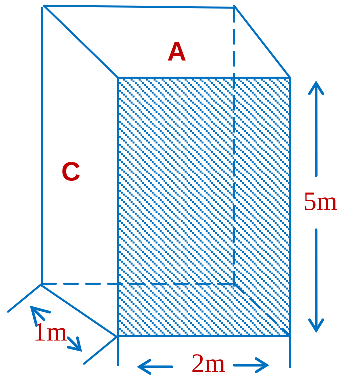


Fig 3.2 A block of sides 1m × 2m× 5m

Given	Required
Mass of block = 50 kg Sides of block = $2m\times1m\times5m$ $g = 10\ m/s^2$	$P_A = ?$

Solution

From your discussion in unit one, you already learnt how to calculate the area of any surface. Hence area of the block on surface 'A' = $1m \times 2m = 2m^2$

Weight of the block $W = m_b \times g = 50kg \times 10m/s^2 = 500N$

The maximum pressure is exerted when the block is resting on the smallest surface, which is the minimum area. i.e. $P_A = \frac{F}{A} = \frac{W}{A} = \frac{500N}{2m^2}$ 250 N/m^2. On the contrary, when the surface area is maximum, the corresponding pressure will be minimum.

$P = \frac{F}{A} = \frac{W}{A}$ $\quad$ $P = \frac{500\ N}{10\ m^2}$ $\quad$ $P = 50\ N/m^2$

Check point 3.1

1. **What is pressure?**
2. **What are the dimensions of pressure? Discuss the units of pressure.**
3. **Explain how pressure varies with change of area.**

3.2 Liquid Pressure

To understand the nature of pressure in liquids, you need to remember some common characteristics of liquids.

Activity 3.3

Discuss with your friends.

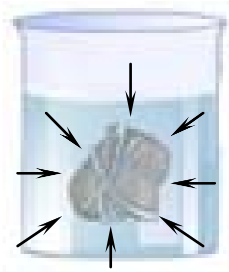
1. The differences and similarities between solid and liquid in terms of: (shape, volume, weight, density, etc)
2. Consider a plastic bag containing water. If it is pierced in different sides, what will happen to the water? (Fig 3.3)

In your discussion in Activity 3.3, you might have talked that:

- Liquids have no definite shape; they take the shape of their containers.
- Liquids have definite volume, mass and weight.
- Compared to molecules of solids, the molecules of liquids are relatively free to move. The densities of solids are greater than densities of liquids.

This and some other activities show that liquids exert pressure on the walls of the container in all direction. As shown in Fig 3.3 when a plastic bag filled with water is pierced, then water flows in all directions.

a) Plastic bag filled with water.



b) Water pressures is the same in all directions *on the object submerged*

Fig 3 .3 Pressure in liquid acts in all directions

Activity 3.4

Containers of different shapes and sizes are half filled with the same liquid. They will rise to the same level.

i. What will be the pressure of the liquid at the bases of the containers?
ii. Is the pressure the same or different in different containers?
iii. Do the shapes of the containers affect the pressure?

Fig 3.4 Containers having different shapes filled with liquid to the same height.

Fig 3.5 illustrates the dependency of liquid pressure on height of the liquid in a container. The container has outlets 1, 2 and 3. The liquid coming out from outlet 3 travels longest distance while liquid coming from outlet 2 travels longer distance than outlet 1. This shows that the pressure at outlet 3 is greater than pressures at 1 and 2. Activity 3.4 helps you to observe that, liquid pressure is independent of the shape of the container and the base area of the container.

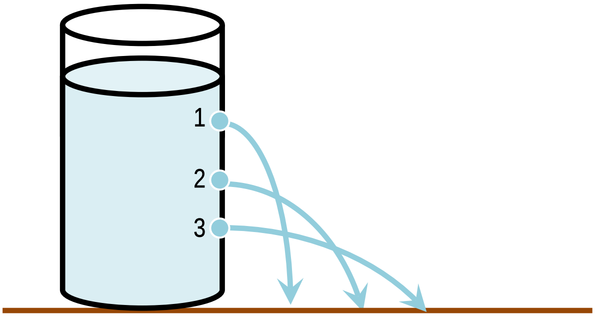


Fig.3.5 Pressure in liquids depends on the depth

This means, the liquid pressure depends only on the:-

i) Depth (h) from the top surface of the liquid,

ii) Density of the liquid. The more denser the liquid the greater the pressure at any given depth.

Consider a liquid of density (ρ) in a container. At a certain depth (h), the force exerted by the liquid is equal to the weight of the liquid.

Thus the pressure, $P = \frac{F}{A} = \frac{mg}{A}$, where m is the mass.

But m= ρV, by substituting the two equations, you get

$P = \frac{F}{A} = \frac{mg}{A} = \frac{\rho Vg}{A}$,

Since the volume is the product of height and base area, (V = Ah) then

$$\Rightarrow P = \frac{\rho Ahg}{A} \quad \Rightarrow P = \rho gh$$

Consequently, the pressure exerted by a given liquid at a certain location is given by the equation $P = \rho gh$;

Where p = pressure of liquid in N/m^2

ρ The density of liquid in kg/m^3

g = gravitational acceleration in m/s^2

h = depth of the liquid. (Height of the liquid above the point)

You can calculate the pressure exerted by water in a container, ocean, swimming pool, etc on an object, at any point (depth) of the water, using the equation of pressure, ($P = \rho gh$).

Activity 3.5

Neglecting air pressure: find the pressure at a depth of 10m, 100m, 1000 m and at the bottom of the ocean (2000 m.) Consider density of ocean water $1030kg/m^3$ and $g = 10m/s^2$.

Properties of pressure in a liquid at rest:

1. Pressure exists at every point within the liquid.
2. The pressure is the same at all points at the same level within a single liquid.
3. The pressure is directly proportional to the height (depth below the surface) and density of the liquid (ρ)
4. The force on the bottom of a container is the pressure at that level times the area of the bottom. ($F = PA$). This principle is used in the constructing of water dams.

Examples 3.2

1. A certain container is filled with water of density $1000kg/m^3$ to a height of 50cm. How much pressure is exerted on the base of the container? (take $g = 10m/s^2$).

Given	Required	Solution
$\rho = 1000kg/m^3$ $h = 50cm = 0.5m$ $g = 10m/s^2$	$p = ?$	$P = \rho gh$ $P = 1000kg/m^3 \times 0.5m \times 10m/s^2$ $= 5000N/m^2$ $= 5000P_a$

2. Water is poured into a vessel up to a height of 2m. (Calculate the pressure of water on the base of the vessel. (Take g = 10m/s^2, density of water ρ_ω = 1000kg/m^3).

Given	Required	Solution
h = 2m,	P = ?	P = ρgh =1000kg/m^3 × 10m/s^2 × 2m
g =10m/s^2		= 2 × 10^{4}N/m^2
ρ_ω= 1000kg/m^3		= 2× 10^4p_a

Check point 3.2

1. **Describe the Factors that affect liquid pressure.**
2. **Explain how liquid pressure varies with depth.**

3.3 Pascal's Principle

Activity 3.6

Can pressure be transmitted through a fluid? How?

A liquid can transmit any external pressure applied to it to all its parts. This property of liquid pressure is used in the hydraulic press, hydraulic brakes, to produce a large force from a small force.

A hydraulic press is consisted of a narrow cylinder connected to a wide cylinder both containing liquid (e.g. oil), and fitted with pistons A and B (as shown in Fig.3.6).

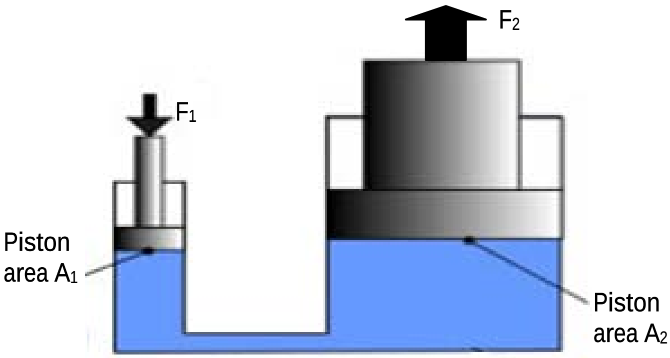


Fig 3.6 A- hydraulic press

Challenging question

Can you mention some other applications of hydraulic press principles?

Liquids and gases can flow and are called fluids. If an external pressure is applied to a confined fluid, the pressure will be transmitted to every point in the fluid. This principle is known as Pascal's principle.

Pascal's principle states that "a pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid."

Apply a force F_1 on the smaller piston of cross sectional area A_1, directly on the liquid such as oil. Then the pressure is $P_1 = \frac{F_1}{A_1}$. This pressure is transmitted undiminished through the oil to the larger cylinder, which has area of A_2. Since the pressure must be the same on both sides;

$P_1 = P_2$ where $P_2 = \frac{F_2}{A_2}$. The force exerted on piston A_2 is $P_2 A_2 = F_2$. The force F_2 is much greater than F_1. Thus, Pascal's principle is expressed mathematically as

$$P_1 = P_2$$

$$\Rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\text{or } F_2 = \frac{A_2}{A_1} \times F_1$$

Pascal's principle is applied in technological devices which are used to produce great forces as in the case of hydraulic-press and brakes.

Consider Fig 3.6, which illustrates the working principle of a hydraulic press.

Examples 3.3

1. In a hydraulic press the small piston has an area of 8 cm^2 while the large piston has an area of 400cm^2. If a force of 20N is applied on the small piston, what is the force on the larger piston?

Given	Required	Solution
$A_1 = 8cm^2$ $= 0.0008m^2$ $A_2 = 400cm^2$ $= 0.04\ m^2$ $F_1 = 20N$	$F_2 = ?$	$\frac{F_1}{A_1} = \frac{F_2}{A_2} \Rightarrow F_2 = \frac{A_2 \times F_1}{A_1}$ $= \frac{0.04m^2 \times 20N}{0.0008m^2}$ $= 1000N$

2. What should be the area of the large piston of a hydraulic press, if it is to lift a load of 20,000N when a force of 200N is applied on the small piston of area $1cm^2$?

Given	Required	Solution
$F_1 = 200N$ $F_2 = 20{,}000N$ $A_1 = 1cm^2$	$A_2 = ?$	$\frac{F_1}{A_1} = \frac{F_2}{A_2}$ $\Rightarrow A_2 = \frac{F_2}{F_1} \times A_1$ $= \frac{20{,}000N}{200N} \times 1$ $= 100cm^2$

3. In a hydraulic press the small piston has an area of $6cm^2$ while the large piston has an area of 300 cm^2. If a force of 30N is applied on the small piston, what load can it lift up (support)?

Given	Required	Solution
$A_1 = 6cm^2$ $A_2 = 300cm^2$ $F_1 = 30N$	$F_2 = ?$	$\frac{F_1}{A_1} = \frac{F_2}{A_2}$ $\Rightarrow F_2 = \frac{F_1}{A1} \times A_2$ $= \frac{30N}{6cm^2} \times 300cm^2$ $= 1500N$

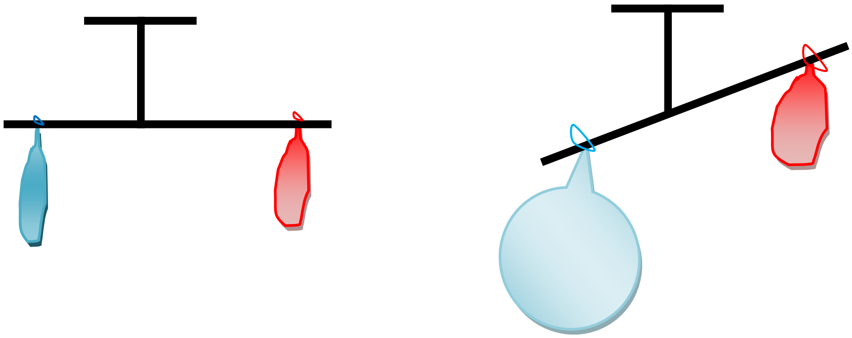
Check point 3.3

1. **State Pascal's principle.**
2. **Draw a hydraulic press diagram and describe how it functions.**

3.4 Atmospheric Pressure-Air Pressure

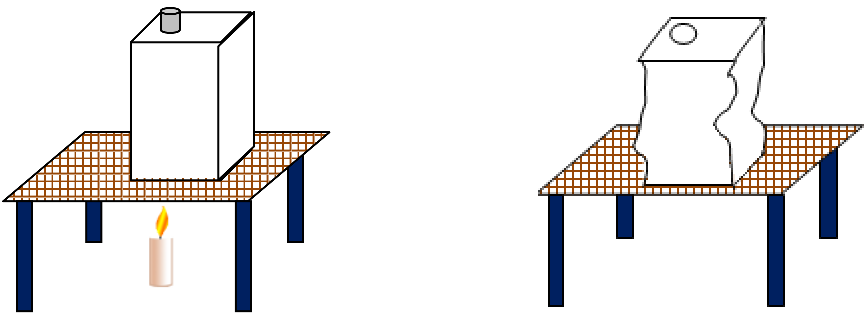
The earth is surrounded by a huge mass of air called the **Atmosphere**.

The force of gravity acts on air. Fig 3.7 illustrates that inflated balloon weighs more than empty balloon. Thus, air has a weight. The weight of atmosphere exerts pressure on bodies found on the earth's surface. This pressure is called **Atmospheric pressure**.



a) Both empty balloons ***b) One balloon filled with air***

Fig 3.7 Air has a weight



a) Heating water in a can b) Water in a can is cooled by pouring cold water

Fig 3.8. Crushing can experiment

Activity 3.7 Crushing can experiment

To observe the effect of atmospheric pressure. (Fig 3.8)

Materials required: Metal can, air tight stopper (cork), and small quantity of water, heat source (candle or Bunsen burner).

Procedure 1. Pour a small quantity of water in the can and boil it for a few minutes until steam is driven out.

2. Fit the cork tightly and remove the heat source away.

3. Pour cold water over the can so that the steam inside partly condenses into water and water vapor at low pressure.

Write a short report about your observation by answering the following questions;

1. What crushed the can?
2. What was the function of the heat and the steam inside the can?
3. What changed: mass, volume, density, temperature? Which quantity increased? decreased? Or remained the same?

From Activity 3.7 you see that, the can gets crushed inwards as in Fig.3-8 (b). This is due to the atmospheric pressure.

Activity 3.8 The U-tube experiment

Materials required: U-tube that contains water, rubber tube.

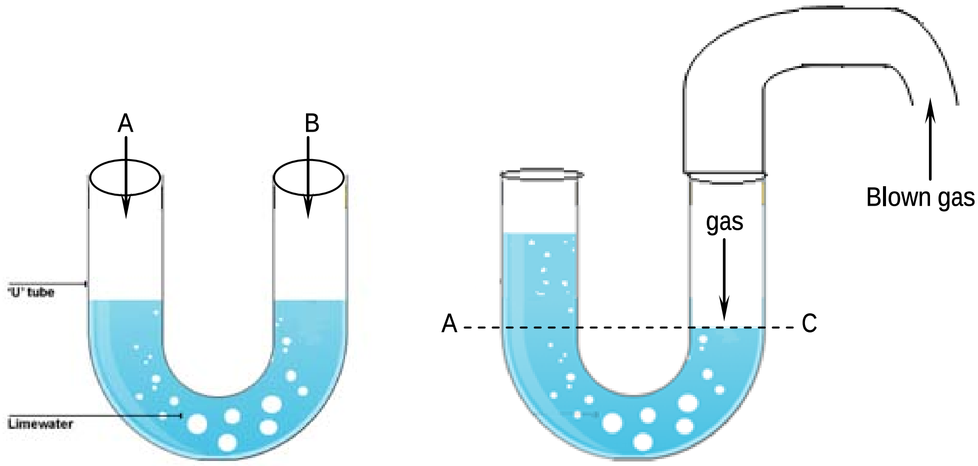
Procedure: 1. Pour water into the U-tube and mark the level.

2. By connecting the rubber tube with the U-tube, blow air into it and mark the level of water you raised.

i. What do you observe about the level of water in the two steps?

ii. Are the marks in the same level? Ask your friend to do the same and record the level of water raised.

iii. Explain what causes the level difference.



a) Equal pressure keeps the water level equal.

b) Extra pressure supports a column of liquid.

Fig 3.9. The U-tube experiment

In Activity 3.8 the water levels were the same before you blow air into the U-tube (Fig.3-9(a)). This is because; the same atmospheric pressure was exerted on sides A and B. But when air is gently blown into one of the tubes, say tube B, the level of water changes on the other side until the pressure at C becomes equal to the blown air pressure. Thus the blown air pressure supports a column of liquid in the other tube.

Challenging question

Explain why water comes to your mouth when you suck water in a glass using drinking straw?

Air pressure varies from place to place. If we travel up a mountain or go up in a hot air balloon, for example, the air pressure gets lesser and lesser as we go higher and higher.

Each layer of air above the earth presses down on the layers below, and so the greatest pressure is at the ground level, where we have the maximum amount of air above.

Atmospheric pressure is the force per unit area exerted on a surface by the weight of the atmosphere above that surface. It is caused by the weight of atmosphere above the measurement point. Low pressure areas have less atmospheric mass above their location, where as high pressure areas have more atmospheric mass above their location. Similarly, as elevation increases there is less overlying atmospheric mass, so that pressure decreases from sea level to the top of the atmosphere.

Challenging question

Explain how liquids are drawn into a syringe tube when the plunger is pulled out.

If we go up into the sky and reach the outer layer of the atmosphere called the stratosphere, the pressure will decrease until it reaches about zero. At this height there is hardly any air above it.

Check point 3.4

1. **Does the air around us exert pressure? Explain and give examples**
2. **What is atmospheric pressure?**
3. **What is the main purpose of doing "crushing can experiment? "**
4. **Explain how atmospheric pressure varies with the change of altitudes.**

3.5 Measuring Atmospheric Pressure

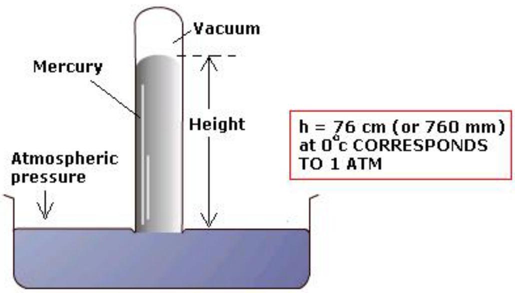
So far, you learnt the existence of atmospheric pressure. The next step is to ask how much strong this pressure is. To know the strength of atmospheric pressure, we need to measure it.

Atmospheric pressure is measured using an instrument called barometer. There are different kinds of barometers, but here we discuss only the mercury barometer.

Manometer is an instrument used to measure air pressure.

Challenging question

Explain the difference between air pressure and atmospheric pressure.



a) Structure of mercury barometer

b) Actual Mercury barometer

Fig. 3.10 The mercury barometer

Mercury Barometer: A glass tube about 80 cm long is completely filled with clean dry mercury. It is then inverted in a basin of mercury under the surface of mercury (Fig. 3.10(a)). The level of mercury in the tube falls leaving an empty space (vacuum) at the top. This apparatus is called the mercury barometer.

The column of mercury in the tube is supported by the atmospheric pressure, P_A acting on the surface of the mercury in the open dish. The exact height of the mercury column depends on the pressure of the atmosphere. Therefore, atmospheric pressure is measured by the height of mercury it supports.

The atmospheric pressure at sea level supports 76 cm of mercury. This means that atmospheric pressure equals the pressure at the bottom of a column of mercury 76 cm high or 760 mm of mercury.

Sometimes atmospheric pressure is expressed in torrs, Where: 1 torr =1mm of Mercury (Hg)

To find the value of atmospheric pressure in the SI unit, we use $p = \rho gh$ where $g = 10 m/s^2$, $\rho = 1.36 \times 10^4 kg/m^3$, (the density of mercury) and $h = 0.76$ m,

Thus 76 cm of Hg equals $1 \times 10^5 N/m^2 = 1 \times 10^5 p_a$.

Standard atmospheric pressure is taken to support a 760 mm high column of mercury at sea-level. That standard pressure is defined as the pressure at the foot of a column of mercury 760 mm high, equal to 1.01×10^5pa.=1 atmosphere. Another unit of pressure used in weather is the millibar (mb). 1mb=100pa.

Relationships between different units of atmospheric pressure
1 millibar = 100pa
1 bar = 100,000 pa
1 torr = 1mm of Hg
= 0.1 cm of Hg
1.01 bar =1010 millibars
= 760 torrs
= 101,000 pa and it is known as SAP.

Activity 3.9

1. Explain why people don't use water barometer instead of mercury barometers?
2. Mention at least 3- disadvantages of using water in a barometer.
3. What are the major advantages of using mercury in a barometer?

Suppose we use a water barometer at sea level where atmospheric pressure is 76 cm of Hg. This means the atmosphere supports 76 cm of a column of mercury. Now let us calculate the height (h_w) of the water barometer that the atmosphere can support.

Let h_m and h_w be heights of mercury and water supported by the atmospheric pressure respectively (see Fig 3.11 a and b).

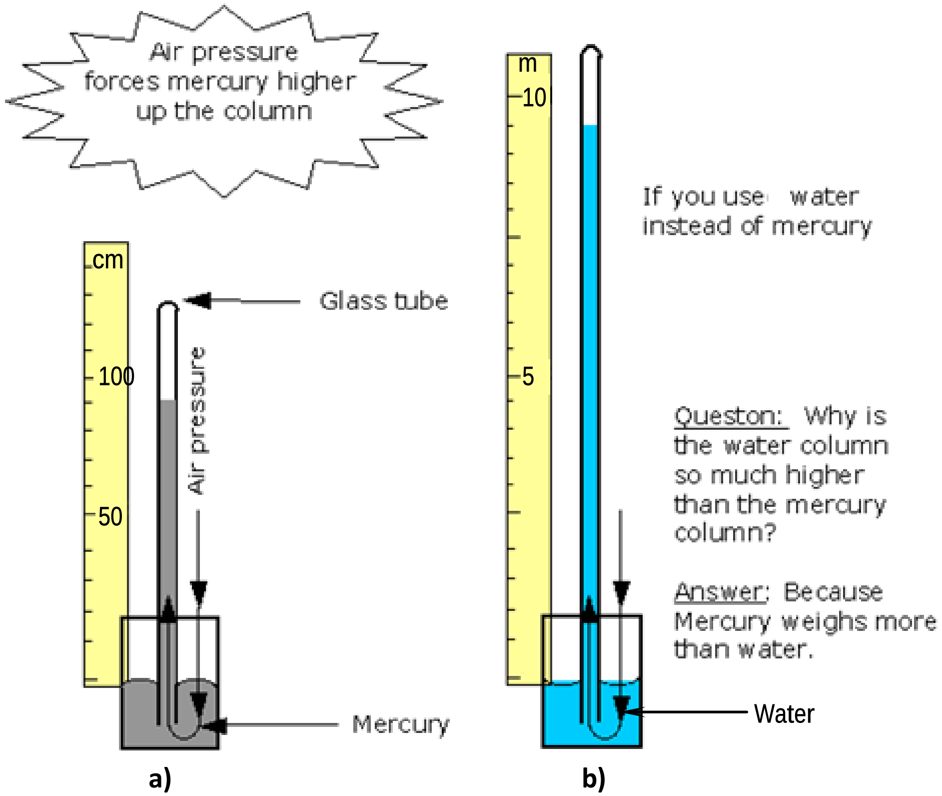


Fig 3.11. Comparison of mercury and water barometer

The atmosphere exerts the same pressure on the two barometers as they are placed at the same location. Hence the necessary height of water which is equivalent to 76 cm of Hg is 1034 cm or 10.34 m. That is, the water column rises up to 10.34 m through the tube. This means using water in a barometer requires us to have a tube taller than 10 m. Mercury barometers are small in size as the mercury rises only up to 76 cm.

Generally, mercury is selected for constructing a barometer due to the following advantages:

1. It is dense and therefore only a relatively short column of it is needed.
2. It is easy to see.
3. It doesn't freeze in very cold weather.
4. Very little is lost by evaporation.

Examples 3.4

1. What is the pressure in torr of a region whose atmospheric pressure is 64 cm-Hg?

Given	Required	Solution
P= 64 cm –Hg	P in 'torr' =?	Since 1cm =10mm, then P = 64 cm Hg = 640 mm-Hg. But 1mm Hg = 1 torr, hence 640mm- Hg = 640 torr

2. In a certain area the atmospheric pressure is 820 torr. Express this pressure in Pascal, bar and millibar.

Given	Required
P (in torr) = 820 torr	i) P(in Pascal)= ? ii) P (in bar) =? iii) P (in millibar) = ?

Solution

i) 760 torr = 101,000 pa

820 torr =?

$\Rightarrow$P(in pa) =

$$\frac{101{,}000\text{Pa} \times 820\cancel{\text{torr}}}{760\cancel{\text{torr}}}$$

108,933.68Pa=

ii) If 760 torr = 1.01 bars

then 820 torr = ?

$\Rightarrow$ P (in bar)

$$= \frac{1.01\ \text{bar} \times 820\ \text{torr}}{760\ \text{torr}}$$

= 1.08 bar

iii) Since 1bar

= 1000 millibar

$\Rightarrow$P (in millibar) =

1.08 $\times$ 1000 millibar

= 1080 millibar

Check point 3.5

1. Explain how atmospheric pressure is measured in terms of the columns of liquids it supports.
2. Discuss the units of atmospheric pressure.
3. What is a barometric reading for standard atmospheric pressure?

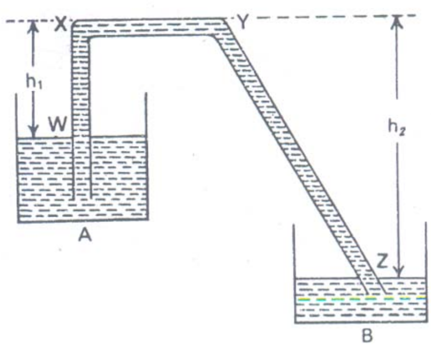
3.6 Applications of Atmospheric Pressure

There are many different devices that operate by the application of atmospheric pressure. Siphons, lift pumps, syringes and rubber-suckers are some technological gadgets that apply the atmospheric pressure.

1. Siphon

A siphon is one of the applications of the knowledge of atmospheric pressure.

A siphon is a device that transfers a liquid from a higher level to a lower level without disturbing the whole liquid or displacing the vessels.



a)

b)

Fig 3.12 Siphons

"Siphon" is a tube or pipe which allows water (or another liquid) to flow from a high place, over a higher point and then down to a lower level. Siphons are capable of raising water over a barrier. This is what makes them distinctive and interesting, as well as highly useful. A siphon is used in farm lands to move water from a reservoir to lower places.

It is also used to draw petroleum from a car tanker to a jerry can placed outside of a car. Try to observe such usages of siphon in your locality.

Challenging questions

Siphon experiment.

1. If we connect two containers with different amounts of water by a siphon, what will the result be, after a very long time? Suck the water with your mouth from one end.
2. What will happen if you raise one end of the tube too high?

Working conditions of a siphon

i) A siphon cannot work in vacuum.

ii) The siphon tube must be filled with a liquid.

iii) The vertical height h_1 of the top most point x of the shorter limb from the liquid level of the vessel A must be less than the barometric height of the liquid. (Fig 3.12a)

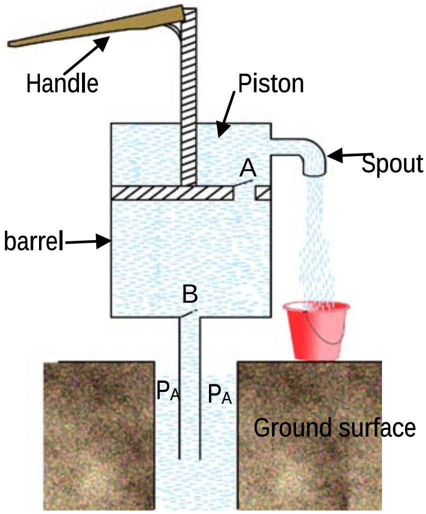
iv) The liquid level of the vessel from which the liquid is transferred must be higher than that of the other.

v) If there is an opening in the longer limb yz (Fig. 3.12(a)) below the level of the liquid in A, the siphon will work although the flow of the liquid will be slow.

2. Lift pump

A lift pump is a widely used device in different regions of our country. You might have observed it in the television set, when the rural people of Ethiopia are using it to pump water from deep well. It is very useful to our community as shown in Fig 3.13.

A lift pump has two valves, one on the piston and the other at the bottom of the barrel.



a) Structure of lift pump

b) The lift pump in action

Fig 3.13 Lift pump

To start the pump working, move the handle downwards so that valve 'B' closes and water inside the pump passes upward through valve A. When the handle moves up, valve A is closed and valve B is opened and water is pushed up the pipe through the valve 'B' by the atmospheric pressure. As the handle moves up and down continuously the atmospheric pressure pushes out the water through the spout.

Activity 3.10 Project work: Constructing a lift pump

Material required: bamboo tubes, pail of water, and threads

Procedures.

i. Visit a local water supply station that works with a lift pump.
ii. Study the structure of this pump and how it operates.
iii. Construct your own lift pump using the indicated material.
iv. Explain how a lift pump is useful for a community.

3. The syringe

You are all familiar with a syringe from your early childhood. You used to play with it.

A syringe is used by doctors and nurses to give injection. It consists of a tightly fitted piston in a barrel.

The barrel will be filled by putting the nozzle under the liquid and drawing back the piston. This reduces the air pressure in the barrel and atmospheric pressure forces the liquid up into it. Pushing down the piston drives the liquid out of the nozzle. You can check how a syringe works by yourself.

Fig 3.14 The syringes

4. The rubber sucker

A simple and a very useful application of atmospheric pressure is found in a circular shallow rubber-cup known as **sucker**. Rubber suckers are used for attaching pictures on shops and car windows (Fig 3.15a). You might have observed these suckers in the windows of a taxi where picture are hung when you come to school. When the sucker is moisture to obtain a good air seal and pressed on a smooth flat surface, the cup is flattened and air is squeeze out from the sucker. Then atmospheric pressure holds the sucker firmly on to the surface.

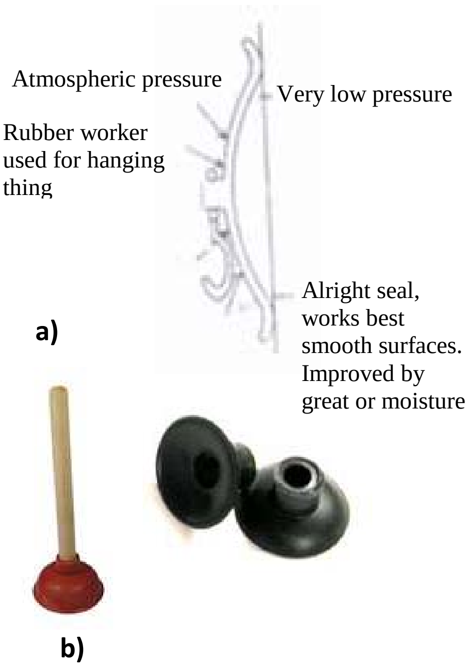


Fig 3.15. The Rubber sucker

Rubber suckers are also used in kitchen sinks to get rid of materials that block the flow of water. (Fig 3.15 b)

5. Drinking straw

Drinking straw shown in Fig 3.16 works with the help of atmospheric pressure. When you suck the air in the straw into your mouth you create a vacuum in it. The atmospheric pressure on the surface of the juice in the glass forces the juice to flow into the straws. As you continue to suck the air, the juice reaches your month.

Fig 3.16. Drinking straw

Check point 3.6

1. **Mention some practical applications of atmospheric pressure.**
2. **Explain how siphons, pumps, syringes, rubber suckers function.**

SUMMARY

In this unit you learnt that:

- pressure is force per unit area P=F/A. Its SI unit is N/m^2 or Pascal Pa. One Pascal of pressure is a force of one Newton being exerted on an area of one square meter.

  i.e 1 pa = $1N/m^2$
- pressure in solids depends on the area where the force is being exerts. Pressure in liquid at rest acts in all directions. Pressure in liquids depends on the depth of the liquid and the density of the **liquid.(P=ρgh)**
- Pascal's law states that "the pressure applied to a confined fluid is transmitted undiminished to every point of the fluid". Its application is the hydraulic press.

  i.e. $\frac{F_1}{A_1} = \frac{F_2}{A_2}$
  - the air surrounding us has weight and exerts pressure on the surface of the earth. This pressure is called atmospheric pressure. A barometer is a device used to measure atmospheric pressure. The standard atmospheric pressure is 76 cm of Hg (mercury) or

    760 mm Hg = 1 atm; where 1 atm = 1.01×10^5 pa
- atmospheric Pressure plays a very important role in devices called pumps, siphon and rubber suckers. They operate themselves by the decrease and increase of pressure produced within the fluid.

Review Questions and Problems

I. Fill in the blank spaces with appropriate word or phrase.

1. The SI unit of pressure is ____________ .
2. The two main factors affecting pressure in a liquid are ___and ___.
3. The instrument used to measure atmospheric pressure is __________.
4. Standard atmospheric pressure is equal to ____ Pa or _____cm of Hg.

II. Short answer Questions

1. What is a pressure?
2. On what factors do pressure depend?
3. What mathematical expression do you use to calculate the pressure due to liquid at a given depth? Explain each term.
4. Describe the working principle of a hydraulic press using Pascal's principle.
5. List some applications of atmospheric pressure.
6. Draw a lift pump diagram and explain how it operates.

III. Solve the following problems

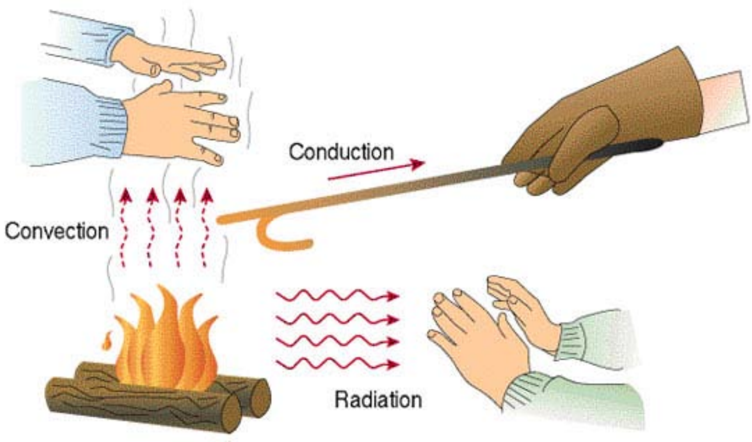
1. A metal box of weigh 20 N rests on its 1 m by 0.6m side on floor. How much is the pressure exerted by the metal box on the floor? Take g= 10 m/s^2.
2. A rectangular container of base 50 cm by 30 cm is filled with water to a depth of 5 cm. How much is the pressure exerted at the base? (Take ρ_w= 1000 kg/m^3 and g =10 m/s^2)
3. How much is the pressure exerted at a point where a ball- pointed – pen of area 1mm^2 is pushed against the paper with a force of 24 N?
4. Suppose a scientist was able to construct a barometer with a liquid being twice denser than mercury, then how high would the liquid raise at standard pressure?
5. A cylindrical container is filled with oil to a depth of 32 cm. if the pressure exerted at the base of the container is known to be 2560pa then, how much is the density of the oil?

UNIT 4

HEAT ENERGY

Unit out comes: After completing this unit you should be able to:

- ✓ understand concepts related to heat energy.
- ✓ develop skill of manipulating problems related to heat energy.
- ✓ appreciate the interrelatedness of all things.
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.



Introduction

In grade 7 physics, you learnt about temperature and heat. You learnt the differences between temperature and heat. Further more you studied about temperature scales, measuring temperature, types of thermometers and some effects of heating a body.

In this grade and this unit you will learn about heat transferring methods and the quantity of heat energy gained or lost by a substance.

Under heat transfer you will learn the three basic mechanisms of heat transfer namely **conduction**, **convection** and **radiation** and be introduced to different practical activities which help you to understand these heat transfer mechanisms.

The diagram on page 68 shows the different ways bodies get heat from a burning wood. Can you explain the different ways shown in the diagram?

When you deal with quantity of heat you will learn how to calculate heat lost or gained by a body. The relation between quantity of heat and change in temperature and nature of the substance will be your main focus. You will also be introduced to the concept of "Specific heat capacity".

Activity 4.1 Discuss with your friends on the following points.

i) What is temperature? And how is it related to heat?
ii) Explain the interrelationship between heat and molecular energy of a body.
iii) Is heat transferable? How do bodies get heat from different source?

4.1 Transfer of Heat

- Temperature is the measure of hotness or coldness of a body.
- It is the measure of the average molecular kinetic energy.
- It is an indication of the direction of heat flow.
- Kelvin is the SI uint of temperature.
- Thermometer is the instrument used to measure temperature

In grade 7 physics, you learnt about '*temperature*' and '*heat*'. Can you, explain them? The term temperature is one of the fundamental physical quantities. It is the measure of hotness or coldness of a body. Heat is a form of energy. Heat energy is directly related with the kinetic energy of molecules of a body. The kinetic energy of the atoms and molecules of matter gives rise to heat energy.

Heat transfer is the movement or flow of heat energy from a hotter body to a colder one.

Heat transfer occurs whenever there is a temperature difference between two bodies or between two parts of the same body. The movement of heat stops when the temperature of each object becomes the same. There are three ways by which heat moves from one body to another. These are Conduction, Convection and Radiation.

i. Conduction

Activity 4.2 Observing the transfer of heat by conduction

Material required: A metal rod, a source of heat (candle) wax, and paper pins.

Procedures: Fix the paper pins into wax around the metal rod.

i. Hold one end of the metal rod, and place its other end into a burning candle. (As shown in Fig 4.1)
ii. After a period of time, the wax near the candle melts and the pin falls.
iii. How did the heat move from the source to the metal rod?
iv. What do we call this method of heat transfer?

Heat energy can be transferred by conduction from one substance to another when they are in direct contact.

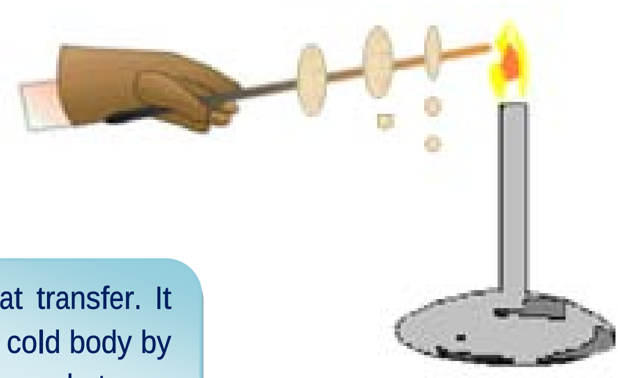


Fig 4.1Conduction of heat in a metal

Conduction is one way of heat transfer. It takes place from a hot body to cold body by means of successive collisions between neighboring particles.

Conduction is mainly seen with in solid objects; however it can happen when any material comes into contact with a source of heat. When you hold a cup of hot water, your hand gets heat by conduction from the hot water.

Activity 4.3 Classifying materials as conductors and insulators of heat

Materials required: The same materials as in Activity 4.2, and different materials like copper, steel, aluminum, wood, glass, plastic, etc.

Procedure: Use the procedure indicated in Activity 4.2 for different materials.

Fill in the table below

Materials	Good conductor	Poor conductor (insulator)
Copper		
Steel		
Wood		
Glass		

The degree with which heat flows within matter varies greatly.

Some materials are better conductors of heat than others. For example, metals are good conductors of heat, while a material like wood isn't. Metal heated on one end will soon be hot on the other end too, while this is not true with a piece of wood. Good conductors of electricity are often good conductors of heat.

Conduction is good in solid and it is poor within gases, because the atoms and molecules are not in close contact with each other.

Since the atoms in solid are closer to each other, solids conduct heat better than liquids or gasses. This means that two solid materials in contact would transfer heat from one to the other better than a solid in contact with a liquid.

Materials which allow heat to flow through them are called heat *conductors*. Iron, copper and other metals are examples of heat conductors.

Materials which do not allow heat to pass through them are called heat *Insulators*. Wool, wood, water glass, etc are examples of heat insulators.

What happens in conduction?

Heat flows from a hotter part of a body to colder part of a body. During heating, the molecules at the hot end of the material increase their vibrations since the temperature on the region is increased. As a result they collide with their slowly moving neighbors and their kinetic energy is transmitted successively from one particle to the next, until it reaches the colder region. Hence heat energy is transmitted from one end to the other while the particles are fixed in their original position except for their violent vibration about their original position.

Methods of controlling heat loss

Heat conduction is important in our daily lives. In cold weather, we wear clothes that stop the conduction of heat from our warm bodies to the cold air. For example, we wear head cap, hand gloves, cotton jacket, and wear socks to keep heat in our body.

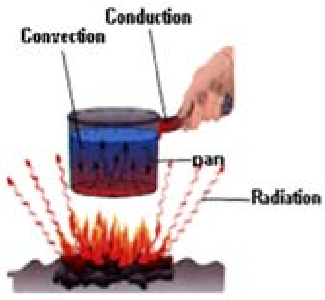


Fig 4.2 Heating a pan

Activity 4.4 Practical work

i. Put a pan on a hot stove. Can you touch the pan after some seconds? Why?
ii. Why do you think the handle of a pan is made of wood or plastic?
iii. Explain why people use carpets and rugs in their room.
iv. Stand on your bare feet on a ceramic tiled floor. What do you feel?

From Activity 4.4 and Fig. 4.2 you will notice that, when a pan is placed on hot stove, the bottom of the pan is in contact with a hot burner. The heat flows through the metal and soon raises the temperature of all parts of the pan.

Similarly, when you step on a carpets very little heat is transferred away from your feet, so you stay warm. But when you step bare feet on cement floor or ceramic tiled floor, more heat is transferred from your feet. So you feel cold.

Handles on metal pan are often made of wood or plastics to stop the conduction of heat from the burner to your hand as shown in Fig 4.3.

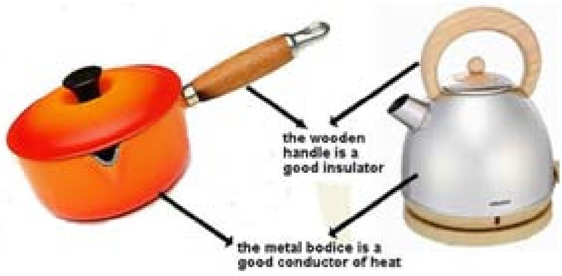


Fig 4.3 Examples of good conductors and poor conductors

Carpets and rugs are also used to reduce loss of heat by conduction.

Activity 4.5

How do your families keep heat in foods (drinks) at home? Discuss this question with your parents.

ii. Convection

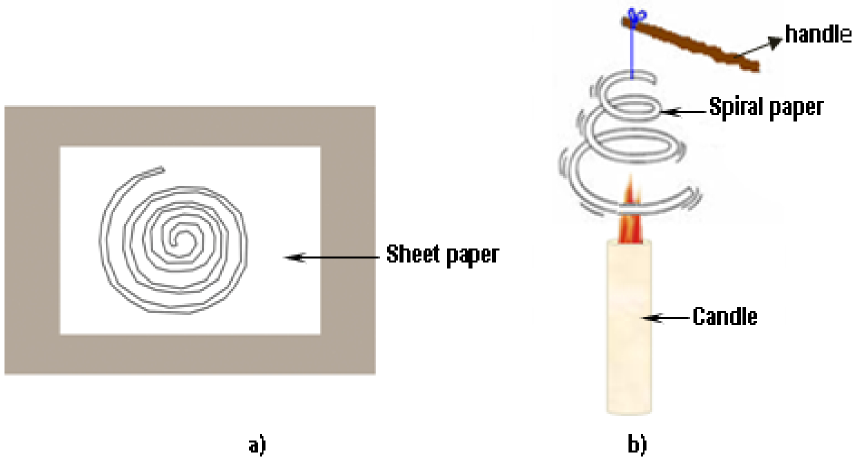


Fig 4.4 Observing the effect of heat transfer by convection

Activity 4.6 Observing heated air rises

Material: A sheet of paper, scissors, and thread.

Procedure: Cut the paper along the line spirally. (Fig. 4.4(a))

i. Hang the cut spiral paper by passing a string (thread) along it center.
ii. Put a burning candle under heating the spiral paper.(Fig. 4.4(b))
iii. Observe and explain what happens to the paper.
iv. Explain what causes it to rotate.

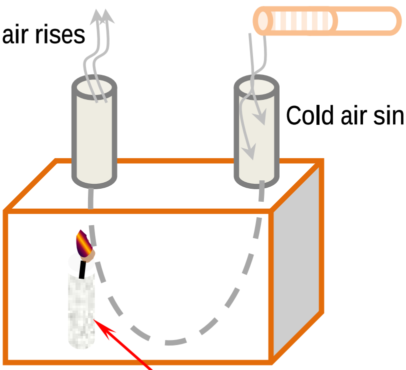


Fig 4.5 Convection in air (Smoke box)

Activity 4.7 Observing convection in air

Material required: A cardboard box with one side covered with transparent plastic sheet.

i. A source of heat
ii. Two tubes made from paper sheet.
iii. A smoking paper

Procedure: Assemble the materials as shown in Fig 4.5. Observe and explain what happens to the smoke.

- Explain the process of convection in this demonstration.

In Fig 4.4 and 4.5, the air gets heated by the burning candle. The heated air rises because it expands and become less dense than the air around it. Cooler air, which is heavier, goes down and replaces the hot air place. This cold air in turn is heated. Fig 4.4 and Fig 4.5 shows transfer of heat by convection in air.

The transfer of heat from one place to another by the actual movement of particles of the medium is called convection. Convection takes place primarily in fluids (gas and liquids). It is caused by the expansion of fluid particles when it is heated. As fluid particles expand, its density decreases. Thus the lighter portion of the fluid rises, and cold fluids takes its place and get heated. In convection, heat is carried by the moving medium. Convection can occur only in liquids and gases.

Transfer of heat by convection is applied in home, industry and in nature.

1. Air conditioner, chimney and boiling water in a dish use convection.
2. Land and sea breezes also work with convection. Wind blows from sea to land during the night, while wind blows from land to sea during the day because of temperature difference
3. The balloon shown in Fig 4.6 uses convection. A hot air balloon contains heated air having less density than the surrounding air. Thus the heated air rises up taking the balloon with it. For what purpose is a hot air balloon used?

Fig 4.6. Uses of convection in a balloon

iii. Radiation

Activity 4.8
Discuss: i) How does the heat from the sun reach our earth? ii) How does the sunlight change into heat on the earth's surface? iii) What do you call this type of heat transfer?

Heat transferred by radiation is also called **heat radiation**. Heat radiation is carried by an electromagnetic wave called **infra-red wave**. This wave is not visible to human eyes.

All objects emit heat radiation. For example, if an object is hotter than its surroundings, then it will give out heat radiation. In doing so, it will lose heat and cool down. Heat from electric heater and heat from a burning charcoal reaches its surrounding by radiation. For example, when we sit around a fire we feel warm. Conduction or convection is not responsible here. Since air is a poor conductor of heat and the warm air rises upwards. The heat reaches to our body from the fire by radiation. Heat can be transmitted by radiation through vacuum or a material medium.

Radiation is the transfer of heat from one place to another without a material medium. The heat of the sun reaches the earth by the process of radiation. Heat can be transferred by radiation in vacuum.

Types of surfaces will affect how quickly the object heats up. A rough and black surface is a good emitter and absorber of heat radiation while shiny and polished flat surface is a poor emitter and absorber of heat radiation.

Activity 4.9 Discuss the following with your friends.

- What do you know of the terms: absorber, reflector and emitter of heat? Describe them and give examples related to heat absorption, reflection and emission.

Activity 4.10 To observe which materials are good absorbers of heat radiation.

Material required: Two identical cans; one painted white and the other painted black, thermometer, the sunlight.

Procedure: Fill the two cans with equal volume of water

- Put a thermometer in each can and leave both cans in the sunlight.
- Measure the temperature of water in both cans, and record the reading data

at an interval of time, as shown in Fig 4.7.

- Draw the graph of temperature versus time taken for both cans.
- Which material (can) absorbed more heat radiation?

Heat radiation is controlled in house construction, in types of clothes worn, and thermos flask. For example, houses built in very cold climate use special materials for flooring, walls and roofing. The heat supplied to warm the house is absorbed by good absorbers and emitted back to warm the room (house). People living in hot areas wear white clothes to reflect the heat radiation because white clothes are poor heat absorbers.

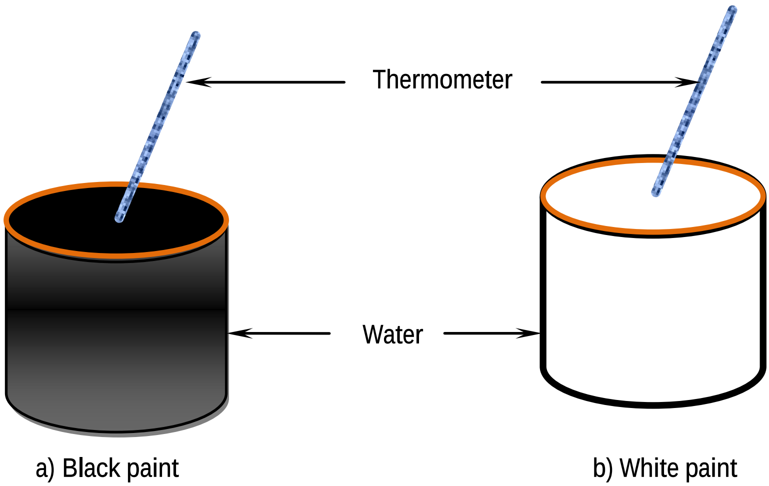


Fig 4.7 Observing good absorbers of heat radiation

Check point 4.1

1. Under what condition, does heat flow from one body to another?
2. State the three ways of heat transfer.
3. Distinguish between conduction and convection of heat transfer methods.
4. Explain what good and poor conductors of heat are.
5. How does heat radiation from the sun reach the earth?

4.2 Quantity of Heat

The important concepts you will learn under this section are the quantity of heat and the specific heat capacity of substances.

Activity 4.11 *Dependence of heat on the mass of a body.*

Material: Source of heat, two metallic balls (small and big) a tong, wax and vessel with water

i. Put the two metallic balls in water
ii. Heat the water with the balls until it boils
iii. Take large and very small pieces of metallic objects from boiling water and place them on a large piece of wax.
iv. Which metallic objects melted more wax?
v. Which object has more heat energy?
vi. What does this show?

When a substance cools, it loses heat energy. When a substance is heated it gains heat energy. A body can receive some heat from different sources.

We cannot actually measure the total amount of heat energy that a body contains. But, we can measure how much energy is gained or lost by a body. How do we measure the quantity of heat lost or gained by a body?

Specific heat capacity

The amount of heat energy needed to raise the temperature of 1kg mass of a substance by 1^0C is called the *specific heat capacity* of the substance.

Table 4.1 gives the values of specific heat capacity of some liquids and metals. The unit of specific heat capacity is Joule/kg °C. (Joule /kg K)

For example, 1kg of aluminum would need 900 J of heat to raise its temperature form 27 ^{0}C to 28 ^{0}C. If the temperature of the aluminum falls from 28 ^{0}C to

27 ^{0}C, it will give out 900 J of energy. So, the general formula for calculating heat energy transferred is:

Heat energy = mass × specific heat capacity × temperature change.

$Q = m \times c \times (T_2 - T_1)$

Where Q is the heat gained or lost

m is the mass of the body

c is the specific heat capacity

($\Delta T = T_2 - T_1$) is the temperature change.

Table 4.1 The specific heat capacity of some substances	
Substances	c (in J/kg0c)
• Water	4200
• Brine (salty water)	3000
• Aluminum	900
• Iron	480
• Copper	385
• Lead	130

From Table 4.1 you notice that specific heat capacities of solids are much less than those of the liquids. For example, water needs nearly five times as much heat as the same mass of aluminum.

Example 4.2

1. How much heat is required to raise the temperature of 500g of iron from 50 °C to 250 °C? (c = 480J/kg °C)

Given	Required	Solution
m=500g = 1/2 kg	Q = ?	$Q = mc\,\Delta T$
T_i = 50 °C		= 0.5kg × 480J/kg °C ×200 °C
T_f = 250 °C		= 48,000J

c = 480J/kg °C = 48 kJ

2. How much heat is lost by a copper bar weighing 2000g when it cools from 100 °C to 40 °C? c = 385 J/kg °C?

Given	Required	Solution
m = 2000g=2kg	Q = ?	$Q = mc\,\Delta T$
$T_i = 100\ ^0C$		$= 2kg \times 385 J/kg\ °C \times -60^0C$
$T_f = 40\ ^0C$		= - 46,200 J
C = 385 J/kg °C		

Note: The negative sign indicates heat lost.

3. A 200 g of copper is cooled from 100 °C to 0 °C. How much heat is given off? (c = 385 J/kg °C)

Given	Required	Solution
m = 0.2kg	Q = ?	$Q = mc\,\Delta T$
$T_i = 100$ °C		$\Delta T = T_f - T_i$
$T_f = 0$ °C		= 0 °C – 100 °C
c = 385 J/kg °C		= – 100 °C
		$Q = 0.2kg \times 385 J/kg\ °C \times (-100\ °C)$
		= - 7700 J

Check point 4.2

1. What is heat?
2. When do we say a body has gained heat?
3. Name the factors on which heat gained or lost depends on?
4. Write the equation of specific heat capacity for a given substance.
5. Define specific heat capacity.

SUMMARY

In this unit you learnt that:

- heat is a form of energy and is expressed in unit of joules (J); while temperature is the measure of the hotness or coldness of a body.
- heat transfer is the transmission of heat energy from a body at higher temperature to a body at lower temperature. The three mechanisms (ways) of heat transfer are:
  - i) Conduction
  - ii) Convection
  - iii) Radiation
- heat conductors are materials which allow heat flow through them. Heat Insulators are materials which do not allow heat to pass through them.
- the quantity of heat which is lost or gained by a body is directly proportional to mass of the substance, temperature rise and nature of the substance. The quantity of heat is given as

  $Q = mc\Delta T$
- the specific heat capacity of a substance is the heat required to raise the temperature of 1 kg of it through 1 ^{0}C. The SI unit of specific heat capacity is J/ kg ^{0}C or J/kg K. Water has a highest specific heat capacity of all liquids.

Review Questions and Problems

I. Fill in the blanks with the proper term or phrase.

1. _________ is the measure of the average kinetic energy of particles in a body.
2. __________ is the SI unit of heat energy.
3. __________ is the transfer of heat between two bodies by contact.
4. Materials that do not allow heat to pass through them are called_________.
5. _________ is the heat required to raise the temperature of 1kg mass of a substance by (1°C)

II. Short answer questions.

1. Explain a conventional method of heat transfer.
2. Give practical examples (3 examples) where poor conductors (insulators) of heat are used in our daily life to protect heat lost.
3. State the three methods of heat transfer.
4. Define the term specific heat capacity of a substance and state its unit.
5. Explain the formula $Q= mc (T_2-T_1)$ in words.

III. Word problems

1. The temperature of a body of mass 0.5 kg is raised from 15 °C to 20 °C. What is the heat taken by the body if its specific heat capacity is 400 J/kg °C?
2. How much heat energy must be supplied to raise the temperature of 2 kg of water by 20 °C? (c of water =4200 J/kg °C).
3. If 5400 J of energy is supplied to 3 kg of aluminum, by how much will the temperature rise? (c of aluminum is 900 J/kg °C)

UNIT 5 ELECTRICITY AND MAGNETISM

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to electricity and magnetism;
- ✓ develop skill of manipulating problems related to electricity and magnetism;
- ✓ appreciate the interrelatedness of all things;
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

Introduction

You learnt about electricity and magnetism in grade 7 physics. You will continue to learn more about this topic in this grade and in this unit. The relationship between electricity and magnetism and its uses for our country's economic and social development will be learnt.

5.1 Modeling Electric Current, a Circuit Loop and Voltage

Activity 5.1

Discuss the following questions with your friends or parents:

- **a)** How is electric current generated?
- **b)** What is the function of a voltage (battery)?
- **c)** What is an electric circuit?
- **d)** Identify the similarities and differences between water flow in pipe and electron flow in a wire. (Fig 5.1)

In this unit you will focus on motion of charges or current electricity. The flow of charge in an electric circuit is much like the flow of water through a closed path (See Fig 5.1). The power supply (battery) corresponds to the water pump and the resistance corresponds to the narrow segment of pipe. The pressure on the output side of the pump is much like the voltage on the ‘’+’’ terminal of the power supply. The electric current corresponds to the rate of flow of the water.

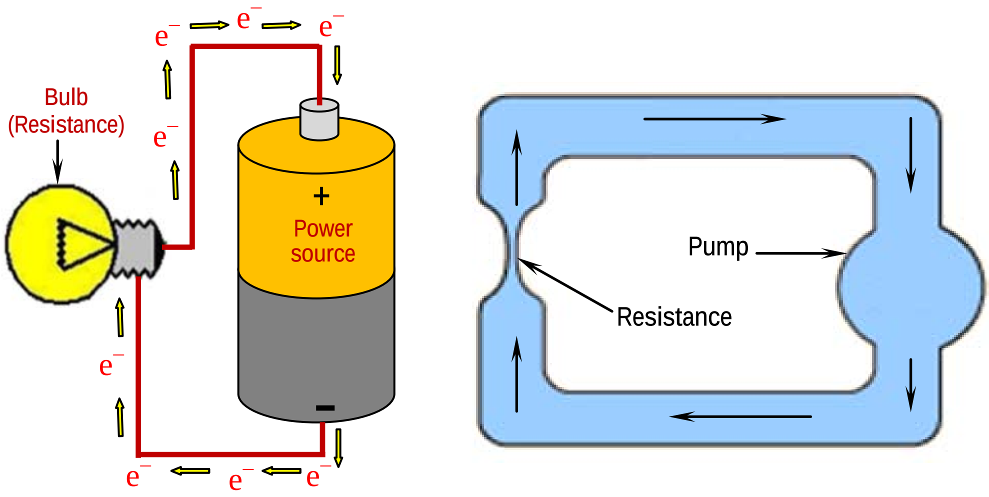


Fig. 5.1 Comparing water flow in pipe and electron flow in wire

To develop a reliable understanding of the concepts: **current, circuit loop** and **voltage** modeling human being as the "human wire" would be an interesting activity.

Modeling motion of charge in a conductor

The whole students in the class can become a model for motion of charges in a conductor. Let us start with one row of students (front to back) becomes one wire. A box at the front of the class models the battery. The box has "battery" painted on it with negative on one end and positive on the other. Assume, in the box there are about 100 small stones the sizes of marbles. They can be labeled with an "e" on them. They represent the electrons.

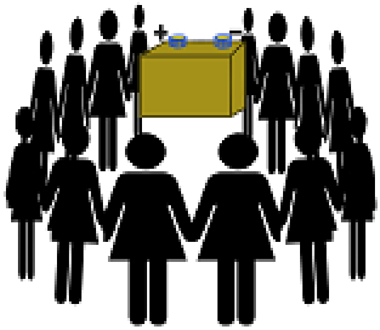


Fig. 5.2 Modeling motion of charge

A student stands at the box and pushes all of them to the minus side. That student is the model for the electromotive force (EMF). EMF is a potential energy that does work by separating charges and making them available for travel else where. For a battery, the potential difference comes from a chemical reaction that separates charges and pushes electrons to the negative end. The potential differece could be a generator or a photovoltaic cell.

To begin the current a student nearest to the "battery" gets a stone electron. The potential difference person hands out the stone electrons one after another. The first student passes the stone along the row of students. This process continues until the "human wire" has brought stone electrons back to the positive side of the box where the electron is placed. The potential difference quickly pushes the electron from the positive end to the negative end. Here, we assume that the conductor is full of free electrons. As one electron comes out of the negative end automatically another electron enters the positive end of the battery. The "human wire" models the motion of electrons in a conductor, as it occurs in an electric circuit.

Conventionally, current is taken as the flow of positive charges. When current was defined centuries ago nothing was known about electrons. Scientists guessed that positive charges move in a wire; but they don't. You should note that current is a flow of negative charges. Though by convention, we take electric current as the flows of positive charges from the positive side of the battery. You should appreciate the role of the potential difference as the separator of charges and the role of the initiator of charge concentration.

Modeling a broken Electric Circuit

The connected students from the negative terminal to the positive terminal is a path for the electron flow. This path is called electric circuit. The circuit is closed if there is no break/opening along the line of students. (see Fig 5.3)

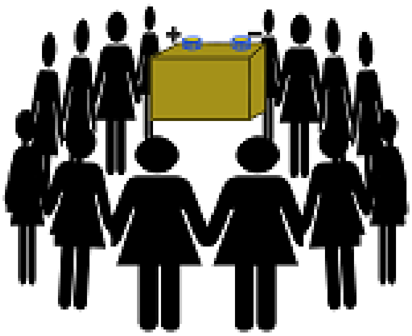


Fig. 5.3 Modeling a closed circuit

The circuit is broken if there is break/opening along the line of students. (see Fig 5.4)

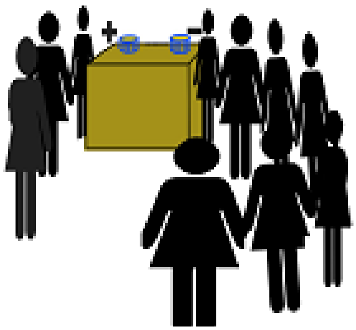


Fig 5.4 Modeling a broken electric circuit

Modeling thicker wires

Now consider two rows of students to form the human wire, instead of one row. (see Fig 5.5)

Fig 5.5 modeling thicker wires

The electrons pushed by the EMF at negative terminal are transferred by two students at a time. Here, electrons are transferred faster than in one row. Having thicker wire means having faster flow of electrons in an electric circuit.

Electric circuits

An electric circuit is a complete path for the flow of electric current. It may consist of different items like a source of potential difference, switches connecting wires, lamp, etc. You can represent any complicated circuit using symbols. The standard electric symbols are used to draw electric circuit diagrams.

Modeling a parallel circuit

Next, consider the two rows of student to split into two branches, to form two paths. The two rows of students accept the electrons from negative terminal and transfer them to the positive terminal of the EMF. This model demonstrates that electrons pushed by the EMF at the negative terminal have two options to travel/flow through the conductor. Again these electrons combine at the positive terminal. (See Fig.5.6)

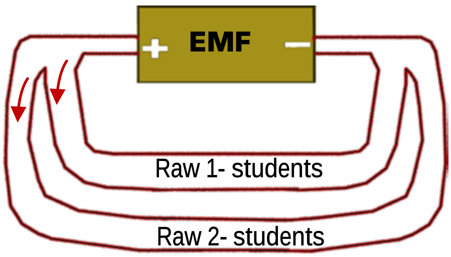


Fig 5.6 Modeling a parallel circuit

Check point 5.1.

1. **Describe how an electric current flows through a conductor. (use human beings as a wire)**
2. **State the role of an electromotive force (EMF) in a current flow.**
3. **Draw**
   a) closed electric circuit
   b) a broken electric circuit and explain their differences.

5.2 Modeling an Electric Light Bulb

Activity 5.2

Investigating what light bulb looks like.

1. Take a burnt (useless) electric bulb.
2. Study the parts of the electric lamp. Identify-filaments, screw base, tip and support posts
3. Draw the diagram of the bulb and label its parts.
4. Explain the importance of the filament
5. When do you say the bulb is burnt? or not working?

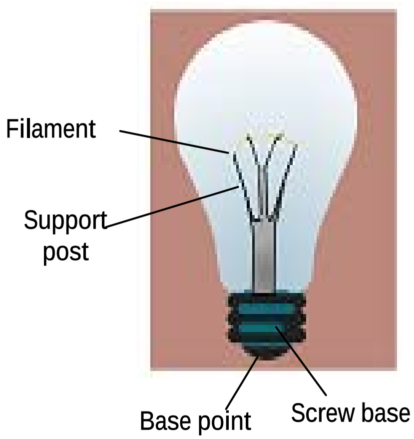


Fig 5.7 Electric bulb

Filaments are made from metallic substance called **tungsten**. Tungsten has the highest melting point. The filament is much thinner than the support posts. In a bulb, the filaments are connected to the support posts. One of the posts is connected to the screw base and the other post to the base point. A functioning bulb makes complete circuit when connected to a battery (see Fig 5.7).

Modeling a fuse

- Construct an electric circuit using a bulb, 12V battery, switch, connecting wires and different wires thick, thin and very thin.
- Leave a gap in the circuit to insert the different wires.
- The bulb gives light when the switch is closed for the different thick and thin wires.

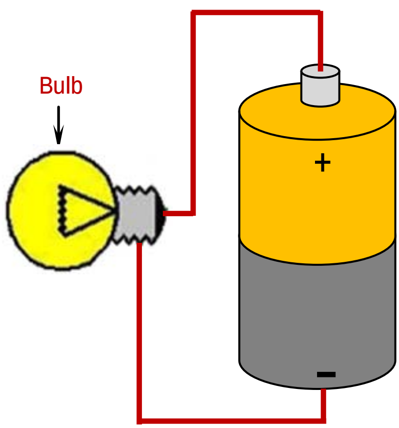


Fig 5.8 Modeling circuit flow in a bulb

- When the thinnest wire (very thin wire) is inserted in the gap it glows and melts. At this time the bulb stops giving light.
- A piece of wire made of metal alloy having low melting point is called a **fuse**. A fuse melts and breaks the circuit when excess current flows through it.

A fuse makes a circuit open (incomplete) in a high flow of current.

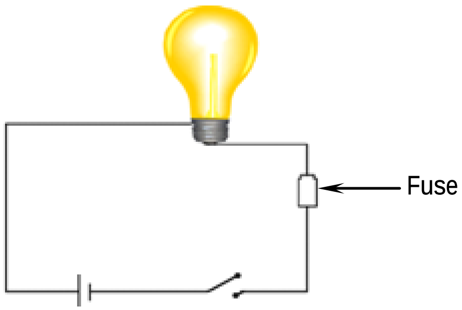


Fig 5.9 Modeling a fuse

Parallel Circuit

Activity 5.3

Building a parallel circuit (see Fig 5.10)

1. What happens to the brightness of the light when both bulbs are on?
2. What happens to the brightness when one of the bulbs is removed out?
3. Why does the difference in brightness happen?

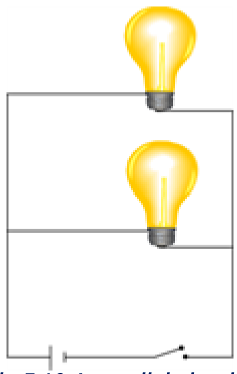


Fig.5.10 A parallel circuit

Check point 5.2

1. What effects of an electric current does a bulb use?
2. Draw the structure of a real light bulb and label its parts.
3. Describe the role of a fuse.

5.3 Relationship of Current, Voltage and Resistance

Electric current

In grade 7, you studied how electric charges are produced and how they are distributed on conductors. When a potential difference is applied across a conductor free electrons in the conductor start to move. For instance, if a dry cell or battery is connected between the end points of a conducting wire, a systematic transfer of charged particles occur from one terminal to another. This ordered motion of charged particles is said to set up an **electric current.**

Electric current is the rate of flow of electric charges across a given cross-sectional area in a conductor.

$$\text{Electric current} = \frac{\text{charge moved}}{\text{time taken}}$$

In symbols, $I = \frac{Q}{t}$ where I is electric current

Q is charges moved

t is time taken.

Current is a scalar quantity.

Challenging question

- Do you remember the unit of electric current? Name it.

The unit of electric current is Ampere (A) named after the French scientist Andre **'Marie Ampere.**

$$1\ \text{Ampere} = \frac{1\ \text{coulomb}}{1\ \text{second}}\ ; \qquad 1\text{A} = \frac{1\text{C}}{1\ \text{s}} = 1\ \text{C/s}$$

One ampere is equal to one coulomb of charge per second;

An electric current of one Ampere is obtained when a charge of one coulomb (6.25$\times 10^{18}$ electrons) passes a point through a conductor in one second. Electric current can also be measured in smaller units such as milliAmpere and micro Ampere,

1milliAmpere = 0.001A = 10^{-3}A = 1 mA

1microAmpere = 0.000,001A = 10^{-6}A = 1μA

Worked Example 5.1

1. What constant current is transferred when a charge of 120 C passes through a conductor in 1minute?

Given	Required	Solution
Q = 120C	I = ?	$I = \frac{Q}{t}$
t = 1minute = 60 s		$= \frac{120c}{60s}$
		= 2C/s
Therefore, the current is 2 C/s = 2A		= 2A

2. If a current of 90 milliAmpere (mA) flows for 150 s, then what is the charge transferred?

Given	Required	Solution
I = 90mA = 0.09A	Q = ?	$I = \frac{Q}{t}$, then Q = It
t = 150s		Q = (0.09A) (150s)
		= (0.09 C/s) (150s)
		= 13.5C

The charge transferred is = 13.5C

Voltage

Voltage is a measure of the ability to do work. It is a scalar quantity. It can be taken as a "potential push" or "pressure" in an electric circuit. It is not a force. Voltage is supplied by some sources of electromotive force (EMF) like a battery or a generator or a photovoltaic cell. An EMF is used in an electric circuit as a separator of charges and as an initiator of charge concentration.

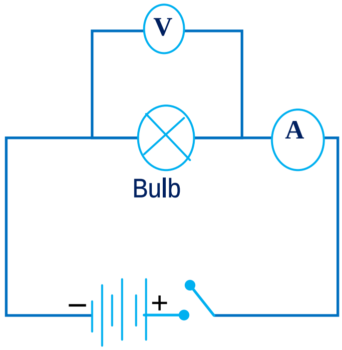


Fig 5.11 Circuit diagram for Ohm's law

Relation between current and voltage

Activity 5.4

Investigating the relationship between current and voltage

Material Required: 4 dry cells (1. 5V each), voltmeter, ammeter, a bulb, switch and connecting wires.

Procedure:

i) Connect the suggested materials as shown in Fig.5.11
ii) Connect one cell first and take the readings of the voltmeter and Ammeter.
iii) Repeat the above procedure each time for two, three and four cells being in series.
iv) Fill in the table below from the reading of the meters.
v) Calculate the ratio of voltage (V) to current (I). for each trial

Number of cells connected in series	1	2	3	4
Potential difference (in V)				
Current, I (in A)				
Ratio $\frac{V}{I}$				

vi) Draw the graph of V versus I.
vii) Compare the ratio and the slope of your graph. (Fig 5.12)
- What do you observe?
- How does the current increase or decrease with an increase or decrease in voltage?

The current in the Activity 5.4 increases with an increase in potential difference and decreases with the decrease of the potential difference.

George Simon Ohm, a German physicist measured electric current through a conductor by applying different potential differences across it and arrived at a law called "**Ohm's law**".

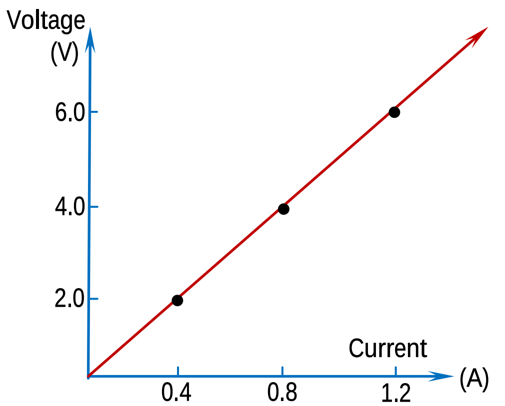


Fig 5.12 Graph of voltage against current

Ohm's law states that:
"The current flowing through a metallic conductor at a constant temperature is directly proportional to the voltage between the two ends."

Mathematically Ohm's law is expressed as: $\frac{\text{Voltage}}{\text{Current}}$ **= constant**

The proportionality constant is a peculiar property of the metallic conductors. This constant is called the resistance of a conductor.
What is a resistance?

Resistance is defined as the measure of the opposition to the flow of current through the conductor. From your Activity 5.4,
The resistance of a conductor is defined as the ratio of voltage to current.
In symbols, $R = \frac{V}{I}$ where V= voltage in volt (V)
I = current in ampere (A)
R = resistance is ohm (Ω)
The unit of resistance is ohm (Ω read as omega)

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

In a circuit diagram a resistor is represented by
a symbol  or  or 

Ohm's law is valid only under certain condition. That is, it is valid for metallic conductors kept at a constant temperature.

Worked Example 5.2

1. What is the resistance of a lamp that draws 0.5A current when connected to 2V dry cell?

Given	Required	Solution
V = 2V	R = ?	$R = \frac{V}{I}$
I = 0.5A		$R = \frac{2V}{0.5A}$ = 4 ohms (4Ω)

∴ The resistance of the lamp is = 4Ω

2. What current flows when a 10 Ω resistor is connected to a 2V supply?

Given	Required	Solution
R = 10 Ω	I = ?	V = IR
V = 2V		$I = V/R = \frac{2v}{10\Omega}$
∴ The currant is 0.2A		I = 0.2A

3. When a 200Ω resistance is joined to a mains supply the current is 1.15A. What is the mains voltage?

Given	Required	Solution
R = 200Ω	V = ?	V = IR
I = 1.15A.		V = 1.15A × 200Ω
		V = 230V

∴ The main voltage is 230V

Check point 5.3

1. Define the following terms
   a) Electric current.
   b) Voltage
   c) Ampere
   d) Resistance
2. What is the other name for a voltage?
3. State Ohm's law
4. Fill the units and symbols for both physical quantities in the table below.

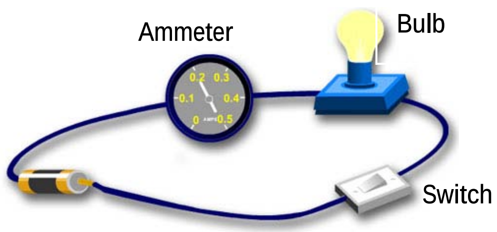
	Physical quantities	Unit	Symbols of quantity	Symbol of Unit
1	Electric current			
2	Voltage			
3	Resistance			

5.4 Measuring Electric Current, Voltage and Resistance

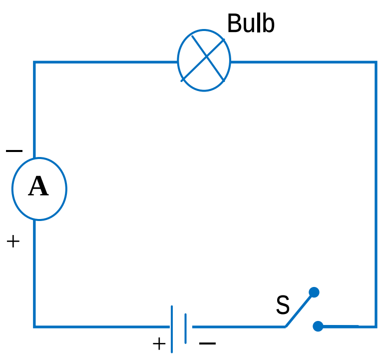
You have noticed that the important electrical quantities are current, voltage and resistance. You can measure these quantities in an electric circuit using different instruments.

Measuring electric current with an ammeter

The electric current in a circuit is measured by an instrument called ammeter.



a) Physical circuit diagram



b) Symbolic circuit diagram

Fig. 5.13 connecting an ammeter

In using an ammeter:

- Connect it in series to a resistor or an appliance as shown in Fig 5.13.
- Never connect it across the ends of a battery without having at least a resistor (electrical appliance) in series with it.
- Never connect in parallel to a resistor.

Activity 5.5

Measuring electric current is parallel circuits (Fig 5.14)

Materials required: An ammeter, 2 light bulbs, and 6v battery.

1. Connect the ammeter at position 1 to measure the current that comes out of the battery.
2. Connect the ammeter to measure the current in each of the branch (positions 2 and 3).
3. What do you observe (conclude) about the current in positions 1, 2 and 3
4. Which part of the parallel circuit has more current? Why?

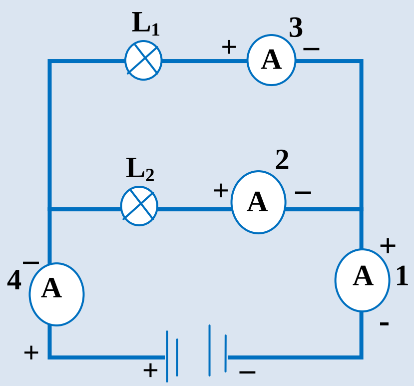


Fig. 5.14 Measuring current in parallel circuit

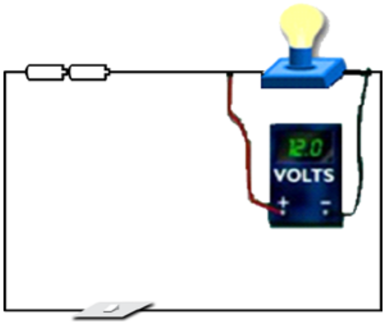
The sum of the currents in the parallel circuit is the same as the current from the battery.

Measuring voltage with a voltmeter

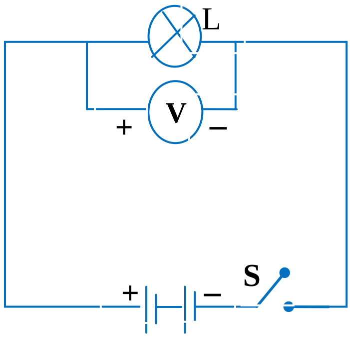
The potential difference across any two points in a circuit is measured by an instrument called **voltmeter**.

In using a voltmeter:

- Connect it in parallel to a resistor to measure the voltage across the resistor.
- Connect it in parallel to a battery or a cell whose voltage you want to measure. As in Fig 5.15.
- Never connect it in series with resistors or voltage source.



a) Physical circuit diagram



b) symbolic circuit diagram

Fig. 5.15 Connecting a voltmeter

Activity 5.6 Measuring voltage in parallel circuit (Fig 5.16)

Materials required: a voltmeter, 2 light bulbs and 6V battery.

1. Connect the voltmeter across the battery. Record its readings.
2. Connect the voltmeter across each of the bulbs in the parallel circuit separately. Record their readings.
3. Compare the voltages across each of the bulb.

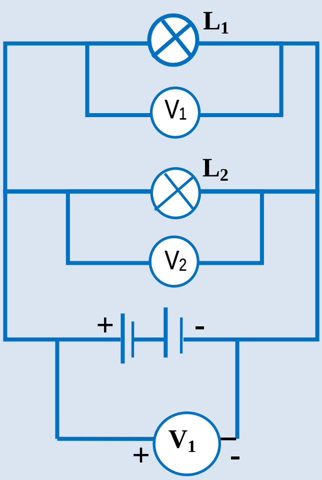


Fig.5.16 Measuring voltage in parallel circuit

The voltages across each of the bulbs in parallel circuits are the same.

Voltmeters and ammeters work making use of the magnetic effect of electric current. In using these instruments, their positive (+) terminals must be connected to the positive terminals of the source of EMF and their negative (-) terminals to the negative terminal of the source of EMF. As shown in Fig 5.13a and Fig 5.15b

Measuring resistance with a voltmeter and an ammeter

The resistance of a bulb can be measured using a combination of voltmeter, an ammeter and Ohm's law. From ohm's law, you can measure the resistance of the bulb. (See Fig 5.17)

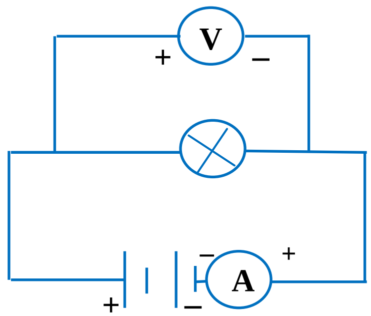


Fig.5.17 Measuring the resistance of a bulb

Activity 5.7

Measuring the resistance of a bulb

Materials required: different bulbs, ammeter, voltmeter, 6V battery and connecting wires.

Procedure:

1. Connect the ammeter, voltmeter, bulb and the battery by connecting wires. As shown in Fig 5.17
2. Measure the current in the circuit and record its reading.
3. Measure the voltage across the bulb using the voltmeter and record its reading.
4. Calculate the ratio of the voltage to the current using Ohm's law.

The ratio of the voltage to the current through the bulb gives the resistance of the bulb filament. Different bulbs have different resistances.

Resistors are electrical devices made to resist an electric current. There are many resistors in your electrical appliances. Example: in radio or television. Most resistors are made from a wire having a certain length, or from layer of carbon. (See Fig 5.18)

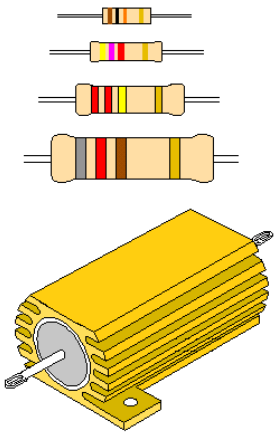
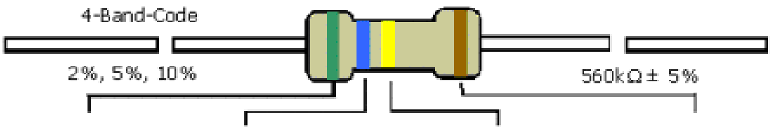


Fig 5.18 Different types of resistor

Color coding of resistors

Values of a resistor is some time shown using color mark. Fig 5.19 shows color marking of a resistor.

The value of the resistance of resistors given at the top of Fig 5.19 is calculated as: Green is 5, blue is 6, Yellow is 10kΩ thus the resistance of the resistor 560kΩ (560, 000Ω). Similarly you can find the resistance of the resistor given at the bottom of Fig 5.19.



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Fig 5.19 color markings of resisters

Factors affecting the resistance of conductors

The resistance of a conductor depends on the nature of materials, lengths and cross-sectional areas provided the temperature remains constant. The following factors affect the resistance of a conductor.

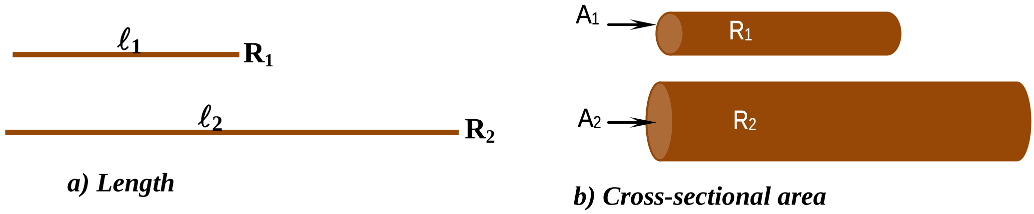


Fig 5.20 Factors affecting resistance

i) *Length:* The resistance of a conductor is directly proportional to the length of the conductor (wire). That is the longer the wire, the higher its resistance is and the shorter the wire, the lower its resistance is for a given material and cross-section area.

This relation can be explained using the collision of free electron in a conductor.

As the length of the conductor increases, the number of collisions that electrons make in traveling through the conductor also increases. Thus, current is slower in long wires and is faster in short wire (Fig 5.20 (a))

ii) *Cross-sectional area:* The resistance of a conductor is inversely proportional to its cross-sectional area i.e. The cross-sectional area indicates the thickness of the conductor. The thicker a wire is, the wider the cross sectional area is. The resistance of a conducting wire increases as the cross-sectional area is small. The resistance of a conducting wire decreases as the cross-sectional area is wide. (Fig 5.20 (b)).

You can compare this relationship to the human wiring model learnt in section 5.1.

In our homes thick wires are used for “mitad” electric iron and welding machines. While thin wires are used for electric bulbs, radio, television, battery charger, etc.

iii) *Nature of the conducting material:* The nature of material also determines the resistance of the conductor i.e. Different conducting materials have different ability to conduct electric currents.

iv) *Temperature*: The resistance of a conductor depends upon its temperature. As the temperature of the conductor increases, its resistance increases. However, Ohm’s law holds true for a material whose temperature does not change.

Check point 5.4

1. **Describe how to connect ammeters and voltmeters in a circuit.**
2. **Draw a circuit diagram using symbols of an ammeter and voltmeter.**
3. **Explain how you can measure the resistance with a voltmeter and an ammeter.**
4. **Describe the color coding of resistors.**
5. **What are the factors that affect the resistance of a conductor?**

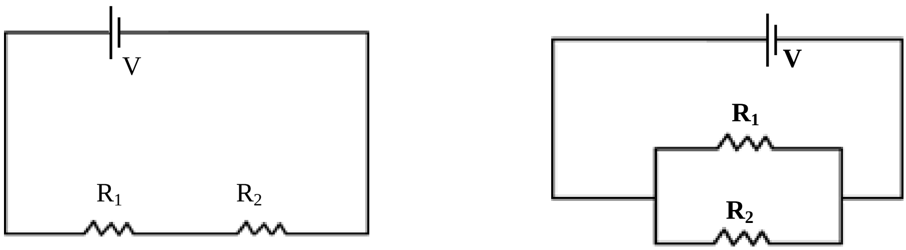
5.5 Formulae to Calculate Series and Parallel Combinations of Resistors

Activity 5.8

- Explain what is meant by series and parallel connections of bulbs?
- How are light bulbs in your home connected?
- Can you turn-on or turn off all the bulbs in your home using one switch only? Explain how.

Many electrical appliances in our homes are products of combined circuit system. Ohm's law is used to find the current in a circuit or part of a circuit. When conductors are connected together to make up a circuit they may all be connected together like a chain as shown in (Fig.5.21 (a) or some may be connected in parallel as shown in Fig. 5.21 (b). The way in which parts of a circuit are arranged affects the flow of current through the circuit. Basically there are two types of circuits. These are **Series circuit and Parallel circuit.**

- In Fig 5.21 (a) resistors R_1 and R_2 are connected is series and
- In Fig 5. 21 (b) resistors R_1 and R_2 are connected in parallel.



a) Series connection of R_1 and R_2 **b) Parallel connections of R_1 and R_2**

Fig 5.21 connections of resistors

Resistors in Series Circuit

A circuit without any branch is called a series circuit. Resistors are connected one after another.

When resistors are connected in series, current passes through each resistor one after the other.

Fig 5.22 shows a series connection of two bulbs.

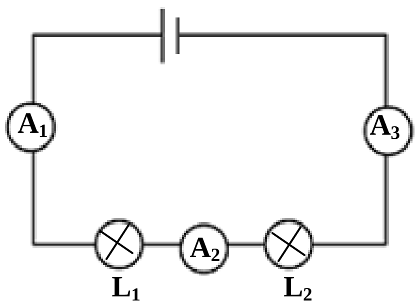


Fig.5.22 Current in series circuit is the same

The current through each resistor is the same for series connection. That is, from Fig. 5.22 the ammeters A_1, A_2 and A_3 read the same current.

Activity 5.9

To show that current in series circuit is the same.

Materials Required: 2 voltmeters, an ammeter, two flashlight bulbs, connecting wire, and 2 dry cells (1.5V each).

Procedure: 1. Connect the bulbs (L_1 and L_2) and the voltmeters as shown in the Fig.5.23.

2. By placing the ammeter in different points (like in a, b and c) take the values of the currents.
3. Take the values of the voltage drops across lamp L_1 and lamp L_2. (Fig 5.23)
   - Is the value of the current the same or different?
   - compare the sum of the voltage across each lamp with the total voltage

If you perform Activity 5.9 properly, you will then get the following important results.

1. The current flowing through each resistor or bulbs is the same for series connection. i.e. $I_1 = I_2 = I$
2. In a series circuit the sum of the voltages across each resistor equals the total voltage i.e. $V= V_1 + V_2$

Now based on the above two equations and the definition of resistance from ohm's law, you can calculate for the equivalent or effective resistance of a series combination of resistors.

If $V= V_1+V_2$, $R_1 = \frac{V_1}{I}$ and $R_2 = \frac{V_2}{I}$

then $V_1 = R_1 I$ and $V_2 = R_2 I$

$\Rightarrow V = R_1 I+R_2 I$ since $V = I R_t$

$\Rightarrow IR_t = I(R_1+R_2)$

$$R_t = R_1 + R_2$$

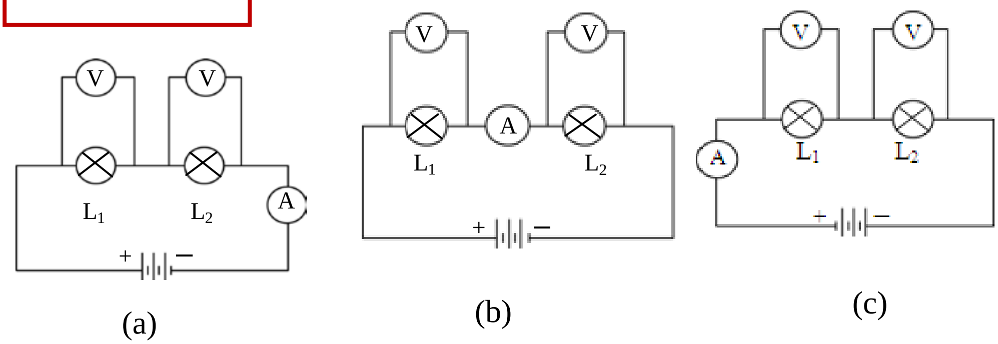


Fig.5.23 Measuring current in series circuit

In a series circuit, the total resistance (equivalent resistance) equals the sum of the resistances of each resistor. This means, the two resistors can be replaced by one equivalent resistor.

Worked Example 5.3

1. Two resistors of 6Ω each are connected in series to a battery which provides 36V. For this circuit, calculate
   a) the total resistance,
   b) the current through the circuit.

Given	Required	Solution
$R_1 = R_2 = 6\Omega$ $V = 36V$	a) R_t = ? b) I = ?	a) For series circuit, $R_t = R_1 + R_2$, $\Rightarrow R_t = (6+6)\Omega = 12\Omega$ ∴ The equivalent resistance is 12Ω b) According to ohm's law $V = IR$ and $I = \frac{V}{R_t} \Rightarrow I = \frac{36V}{12\Omega} = 3A$ ∴ The current through the circuit is 3A

2. For the circuit diagram shown in Fig.5.24, find out;
   1. the total resistance
   2. the ammeter reading
   3. the voltmeter's readings

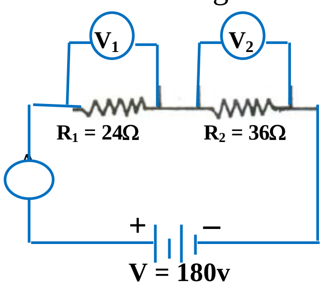


Fig. 5.24 Resistors in series combination

From Fig 5.24 we see that R_1=24Ω, R_2= 36V and V=180V are in series. Thus

a) The total resistance $R_t = R_1 + R_2 = 24\Omega + 36\Omega = 60\Omega$

b) The ammeter reads the same current I through the circuit

Thus $I = \frac{V}{R} = \frac{180V}{60\Omega} = 3A$

c) The voltages across R_1 equals $V_1 = IR_1 = (3A)(24\Omega) = 72V$

$V_2 = I_2R_2 = (3A)(36\Omega) = 108V$

Resistors in Parallel Circuit

A circuit that branches out into two or more branches is called a parallel circuit. For example two resistors are said to be connected in parallel when they are placed side by side and their corresponding ends are joined together. Fig.5.25 shows parallel connection of two resistors.

In Fig 5.25 the total current (I) is split into I_1 and I_2 at a junction point A. and I_1 and I_2 join together at point B to give back the total current.

That is $I = I_1 + I_2$

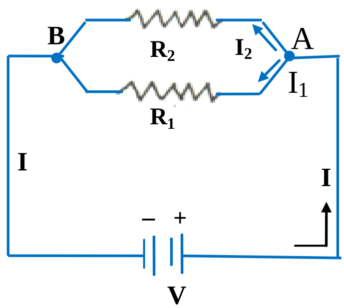


Fig. 5.25 parallel connection of two resistors

Activity 5.10 To measure current in every branch of the parallel resistor

Materials Required: Two cells of 1.5V each, connecting wires, two flashing bulbs, and ammeter.

Procedure:

1. Connect the bulbs in parallel.
2. Take the readings of the ammeter by placing it in different positions as shown in Fig 5.26
3. Compare the total current with the sum of the currents through the two bulbs. Is the sum of the currents through the two bulbs the same as that of the total current?

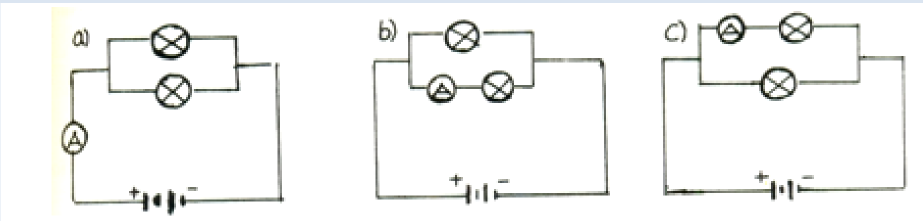


Fig. 5.26 Measuring current in parallel circuit

Activity 5.11 To measure the voltage across each resistor

Materials Required: Two cells of 1.5V each, connecting wires two flash light bulbs, and a voltmeter.

Procedure: 1. Connect the bulbs in parallel

2. Place the voltmeter across each resistor turn by turn as shown in Fig 5.27

3. Take the readings of the voltmeter and compare it with the total voltage of the cells.

- Is the voltage across each resistor the same?
- Is the voltage across each resistor the same as that of the total voltage of the cells?

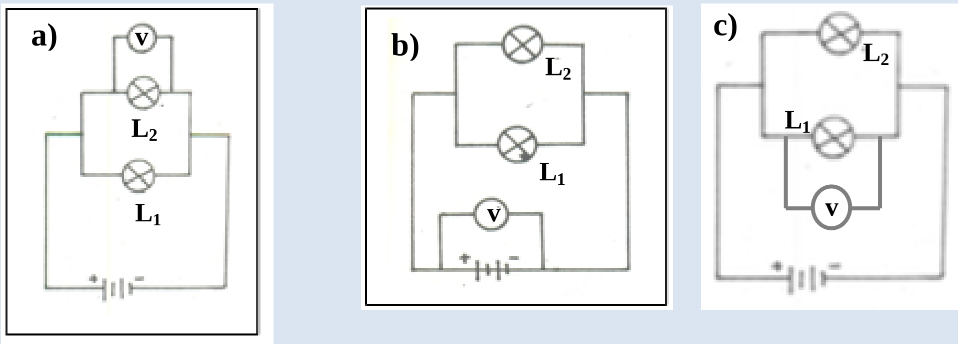


Fig 5.27 Measuring voltage in parallel circuit

If Activities 5.10 and 5.11 are done correctly then you will have the following results.

1. The sum of the currents flowing through the two bulbs is equal to the total current. That is:

   $I = I_1 + I_2$

2. The voltage across each bulb is the same as that of the total voltage supply. That is

   $V = V_1 = V_2$

3. Using Ohm's law and the above equations you can find an important relationship for the total resistance of two resistors connected in parallel.

   If $I = I_1 + I_2$ and $I = \frac{V}{R_t}$ (ohm's law)

Where $I_1 = \frac{V_1}{R_1}$ and $I_2 = \frac{V_2}{R_2}$ then;

$I = \frac{V}{R_t} = \frac{V_1}{R_1} + \frac{V_2}{R_2}$ But $V_1=V_2=V$

Thus $\frac{V}{R_T} = v\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

Or $$\boxed{\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}}$$

Total resistance of two resistors R_1 and R_2 connected in parallel is less than the resistance of each resistor. Connecting resistors in parallel reduces the equivalent resistance and increases the total current. Use the following simplified form to find the equivalent resistance R_t.

$$R_t = \frac{R_1 R_2}{R_1 + R_2}$$

This formula works only for two resistors in parallel and you can use the mathematical method of adding fractions to get the value of R_t.

Worked Examples 5.4

1. Two resistors of 9Ω and 18Ω are connected in parallel across a 24V supply. For this circuit calculate;

   a) The total resistance b) The total current

Given	Required	Solution
$R_1 = 9\Omega$	a) R_t = ?	a) from equation above
$R_2 = 18\Omega$	b) I = ?	$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{9\Omega} + \frac{1}{18\Omega}$
V= 24V		$R_t = \frac{9\Omega \times 18\Omega}{9\Omega + 18\Omega} = \frac{162\Omega^2}{27\Omega} = 6\Omega$
		$\therefore R_t = 6\Omega$
		b) From ohm's law we have
		$I = \frac{V}{R} = \frac{24v}{6\Omega} = 4A$
		That is; I = 4A

2. Two resistors of 12Ω and 24Ω are connected in parallel across a 48V battery (see Fig. 5.28). For this circuit system, calculate;
   a) the total resistance,
   b) the total current,
   c) the currents I_1 and I_2,
   d) compare the sum of I_1 and I_2 with I,

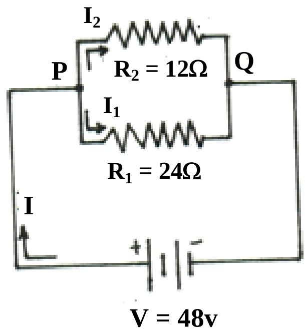


Fig 5.28 Resistors in parallel

Given	Required
$R_1 = 9\Omega$	a) R_t =?
$R_2 = 12\Omega$	b) I = ?
V = 48V	c) I_1 = ?, I_2 = ?
	d) $I = I_1 + I_2$ =?

Solution

a) Equivalent resistance in parallel combination is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \text{ Thus, } \qquad \frac{1}{R} = \frac{1}{12\Omega} + \frac{1}{24\Omega}$$

$$\frac{1}{R} = \frac{2+1}{24\Omega} = \frac{3}{24\Omega} = \frac{1}{8\Omega}$$

$$\frac{1}{R} = \frac{1}{8\Omega}$$

∴ The equivalent resistance R =8Ω

b) From Ohm's law, $I = \frac{V}{R_t}$

$$I = \frac{48V}{8\Omega} = 6A$$

$$I = 6A$$

c) For parallel connection of resistors

$$V_1 = V_2 = V$$

$$\text{Thus } I_1 = \frac{V}{R_1} = \frac{48V}{24\Omega} = 2A$$

$$I_2 = \frac{V}{R_2} = \frac{48V}{12\Omega} = 4A$$

d) $I = I_1 + I_2 = 2A + 4A = 6A$

Total current is the sum of currents in each resistor.

Energy and Power in an Electric Circuit

Many electrical appliances are used in our homes to convert electrical energy into other forms of energy. For example, a torch is used to convert electrical energy into light and electric heater converts electric energy into heat.

The amount of energy drawn from an electrical appliance depends on how long (time) it is used. Thus, it is preferred to talk about the amount of energy transferred every second. The energy transferred per second is called **power**.

$$\text{Power} = \frac{\text{Energy transeferred}}{\text{time taken}}$$

$$P = \frac{E}{t}, \; E = Pt$$

Challenging question

Does the power in an electric circuit depend on the voltage and current?

Think about a 3V battery connected to a lamp as shown in Fig.5.29. The current in the circuit is 2A. This means that 2 coulombs of charge flow per second through the lamp. Now the voltage is 3V. This means that each coulomb transfer 3J of energy as it flows through the lamp. Since 1volt is equal to the energy used to move 1C of charge across the terminal points.

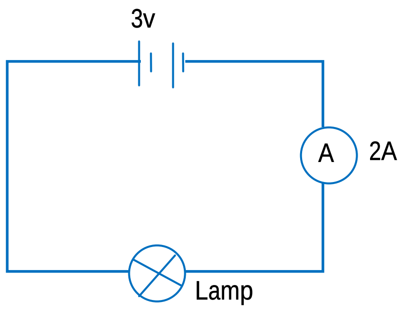


Fig 5.29 Power depends on voltage and current

If there are 2C per second, and each coulomb transfers 3J, how many Joules are transferred each second?

The answer is 6 J /s, so, the power is 6 J/s or 6W.

The unit of electric power is Watt represented by W where 1W = 1J/s.

Electric power is the product of voltage and current.

$$P = IV$$

Using Ohm's law V = IR, we can express P in terms of R, V, and I.

$$\text{Thus, } P = I^2R \text{ where } (V = IR)$$

$$P = \frac{V^2}{R} \text{ where } (I = \frac{V}{R})$$

Worked Examples 5.5

1. A bulb uses 1,500J of energy in 25 second. What is its power?

Given	Required	Solution
E = 1500J	P = ?	$P = \frac{E}{t}$
t= 25second		$P = \frac{1500J}{25s} = 60W$

∴ The power of the bulb P = 60 W

2. An electric lamp is labeled as 220V, 60W.
   a) What do these numbers mean?
   b) What is the current produced when the lamp is connected to 220V?
   c) What is the resistance of the lamp filament?

Solution

a) 220V is the voltage across which the lamp has to be connected. This means 220J of energy is transferred whenever one coulomb of charge flows.
60W is the electric power. It means 60Joules of electrical energy will be converted into light every second when connected to 220 V supply.

b) To calculate the current in the lamp.

$$P = IV,\ I = P/V = \frac{60W}{220V} \Rightarrow I = 0.27A$$

c) The resistance of the lamp

$$P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{220V \times 220V}{60W} = 806.6\ \Omega$$

Check Point 5.5

1. Write the advantages and disadvantages of connecting lamps (a) in series and (b) in parallel.
2. a) Draw Fig 5.30 into your exercise book and name the way in which the lamps are connected and answer questions b and c
   b) If A_3 read 0.2A, what do the other two ammeters read?
   c) If one of the lamps is removed explain what would happen to the other lamp.

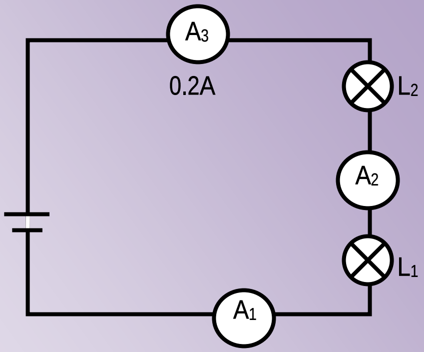


Fig 5.30 Reading of ammeter in series circuit

3. Draw Fig 5.31 into your exercise book, and answer the following questions.
   a) Name the way in which the lamps (bulbs) are connected.
   b) If the lamps are identical and A_3 reads 0.4 A, show on your diagram what the other ammeters read.
   c) What would the ammeter A_4 read?
   d) If the lamp next to A_3 is removed, what would happen to the other lamp?

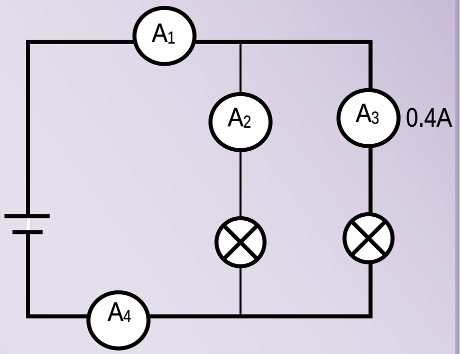


Fig 5.31 Reading of ammeter in parallel circuit

4. Describe series and parallel connections of resistors by drawing their diagram.
5. What happens to the resistance of two resistors when connected in a) series and b) parallel?
6. Define electric power in terms of current and voltage.

5.6 Electromagnetism

The interaction between electricity and magnetism is called **electromagnetism**. In this section you will study the magnetic effect of an electric current and its applications. However, you need to revise some properties of magnetism.

Activity 5.12

Discuss the following questions with your friends. (Revise your grade 7 physics on magnetism).

1. What is a magnetic field? How do you represent a magnetic field?
2. Draw and describe the magnetic field lines around a bar magnet.
3. What is a compass? What is it used for?

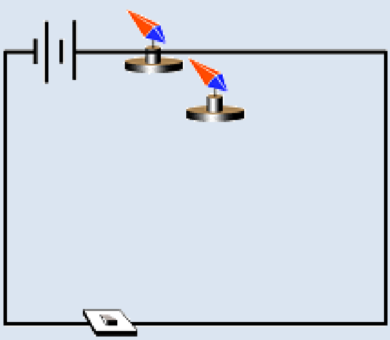
Magnetic effect of a current

In grade 7 physics you learnt that electric current can produce magnetism. The easiest way to show the magnetic effect of electric current is to hold a compass near a current carrying wire. Do the following activity.

Activity 5.13 Observing the magnetic effect of an electric current

Do the practical activity and answer the questions followed.

Materials required: Dry cell, switch, a resistor, a compass and a long connecting wire.



Hans Christain Oersted

Fig. 5. 32 Circuit connection for Oersted experiment

Procedures

1. Connect the resistor, switch and dry cells in series, as in Fig 5. 32
2. Close the switch and keep the compass below the wire. Observe the direction of deflection of the compass.
3. Then exchange the terminals connected to the battery. Keeping the compass needle below the wire, observe its direction of deflection.
4. Repeat steps (2) & (3) keeping the compass needle above the wire.
   - What do your observations show?
   - How would the electric current affect the magnetic field of the surrounding like a compass?
   - Can you conclude that magnetic field exists around a current carrying conductor?

From Activity 5.13 you observe that the compass needle is deflected from its original position when electric current flows through a wire placed on or below the compass. Thus, an electric current produces a magnetic field. This effect was first discovered by a Danish scientist called **Hans Christain Oersted.**

An electric current passing through a conductor produces a magnetic field in the surrounding. This phenomenon is called the magnetic effect of electric current.

Challenging question

Can you name other effects of electric current?

Magnetic field due to a straight current carrying wire

An electric current in a long straight wire produces magnetic lines which are circular in planes at right angles to the wire.

Activity 5.14

To observe the direction of magnetic field around a straight current carrying *conductor.*

Materials required: Dry cells, straight wire, a resistor, iron filings, switch, compass needle and cardboard

Procedure:

1. Connect the straight wire in series with the resistor, the switch and the battery (as shown in Fig 5.33. Stand the straight wire in a vertical direction.

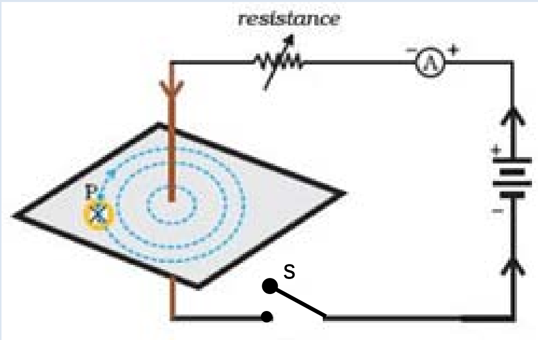


Fig 5.33

2. Mount the card board to the straight wire and attach it to the stand.
3. Gently sprinkle iron filings on the card board. Observe the pattern of the iron filings on the card board.
4. Remove the iron filings from the card board and place the compass on the card board. Slowly move the compass on the card board around the current carrying wire. Observe the direction of the needle at each point.
5. Sketch the direction of the compass needle on the card board. The direction of the compass indicates the magnetic field lines around a straight wire carrying current.
6. Exchange the connection of the terminals of the battery and repeat step 4 and 5

Activity 5.14 shows that magnetic field lines around current carrying straight conductor are circular. You might have observed that the direction of the magnetic field lines depends on the direction of current. The direction of the field lines due to a straight current-carrying conductor can be easily shown using the "Right Hand" rule.

Right–hand rule for a straight current carrying conductor

Grasp the current carrying conductor in your right hand with the thumb extended in the direction of current. The fingers will then point in the direction in which the field lines encircle the wire (see Fig 5.34).

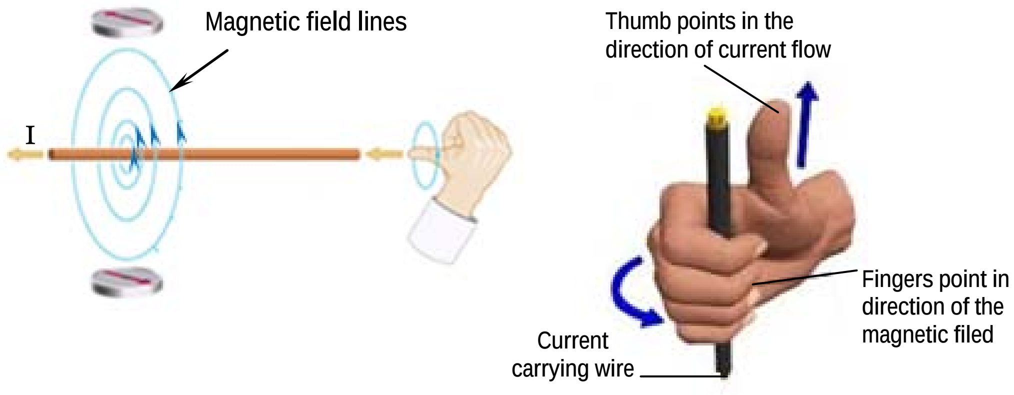


Fig 5.34 A schematic diagram showing the right-hand -rule

Using this rule, you can determine the

1) direction of magnetic field lines, if the directions of current is known,
2) direction of current, provided the direction of magnetic field lines are known.

Now you will examine what factors affect the magnitude (strength) of magnetic field around current carrying conductor. In Activity 5.14 you might have observed the region where the density of iron filings is more and sparse. Did you notice that the iron filings are concentrated near the wire? This shows that the magnetic field near the wire is stronger than that at a further distances. (Fig 3.34).

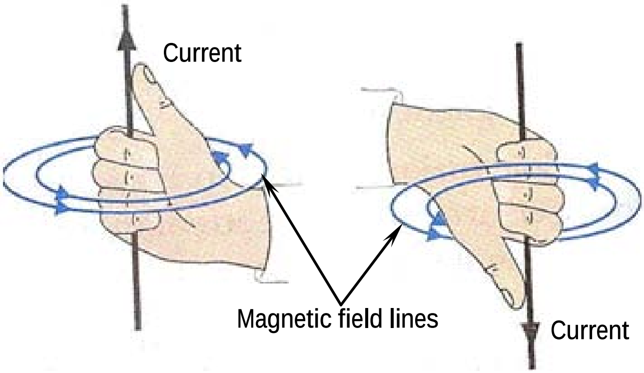


Fig 5.35 The directions of magnetic field lines around straight wires carrying current

Does the field strength depend on the current? Yes it does. To observe this repeat Activity 5.14 for different numbers of cells. A larger number of cells corresponds to stronger current. Did you notice that density of iron filings in a particular region increases as current increases? Thus, magnetic field of stronger current is stronger than that of weaker current.

The magnitude of the magnetic field of a current carrying wire depends on:
- i) the magnitude of the electric current, and
- ii) the distance from the wire.

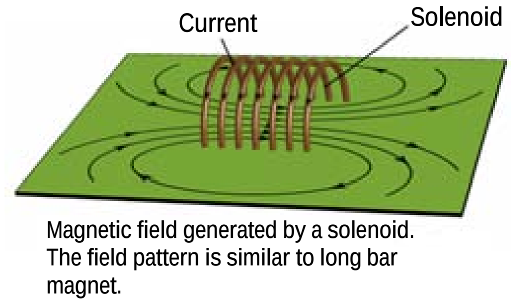
Magnetic field around a solenoid

What is a solenoid? **Solenoid** is a coiled wire with a large number of turns. It is cylindrical in shape as shown in Fig 5.36 a) and b).

Fig 5.36 Solenoid

The magnetic field strength of a current carrying solenoid depends on;
- i) the number of windings (turns),
- ii) the magnitude of current passing through the solenoid and
- iii) the types of core material inside the solenoid,

The magnetic field in the interior of a solenoid is nearly uniform. The magnitude of the magnetic field surrounding a current carrying solenoid increases when the solenoid has an iron core.



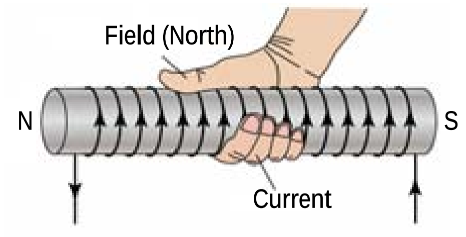


Fig 5.37 Magnetic field line in solenoid

As shown in Fig 5.37 the magnetic field lines due to each loop of wire help each other, inside the solenoid. Therefore, magnetic field inside a solenoid is stronger than that of the magnetic field outside a single loop.

The magnetic field of a solenoid increases as the number of turns and current in the coils increases. In addition to this the magnetic felid of a solenoid also increases when an iron core is inserted inside the solenoid.

Electromagnet

An electromagnet is a solenoid with an iron core. It consists of an insulated wire wound around an iron core. The coil can have different shapes. It can be wound in the shape of a bar or a horse-shoe shape or a nail. Fig 5.38 shows an electromagnet made from iron nail.

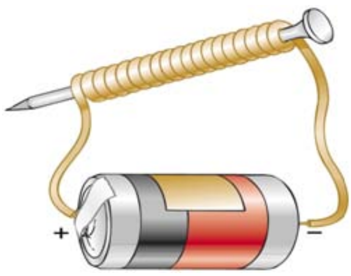


Fig.5.38 An electromagnet

Electromagnets are very useful in lifting iron materials. It serves as a temporary magnet. When the current in the coils is turned off the iron core loses its magnetism.

The magnetic field of an electromagnet depends on the following factors.

- The current passing through the coil.
- The number of turns of the coils.
- The types of core material inside the coil.

To determine the direction of the magnetic field lines of an electromagnet you need to apply, the right-hand rule for each loop. That is, grasp the solenoid inside your right hand and point the fingers in the direction of the current. Then the thumb points in the direction of the north pole of the electromagnets.

Similarities and differences between an electromagnet and bar magnet (Fig 5.39)

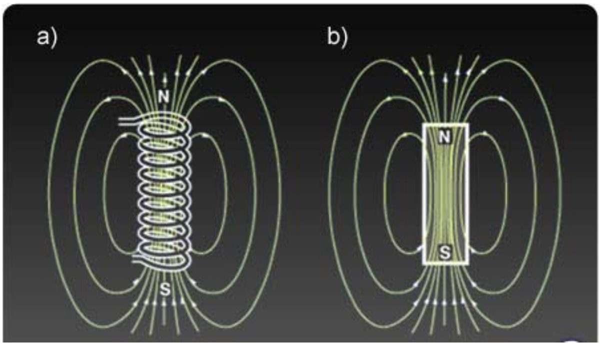


Fig. 5.39 Similarities between an electromagnet and a bar magnet

A. Similarity between electromagnet and a bar magnet

1. Both have the magnetic properties.
2. Both have similar magnetic field line patterns
3. Both have North and South poles.
4. Both attract metals.

B. Differences between electromagnet and bar magnet

Electromagnet	Bar magnet
- Magnetism is temporary - The field strength can be increased or decreased - The polarities can be changed - The magnetic field disappears when the current is turned off.	- Magnetism is permanent - The field strength cannot be changed. - The polarities are fixed.

Check point 5.6

1. Explain the shape of a magnetic field lines around a straight current carrying wire.
2. Fig 5.40 shows a current carrying straight wire. Draw the magnetic field line around it.

Fig 5.40 Current carrying straight wire

3. What is a solenoid?
4. Draw the magnetic field lines inside and around a current carrying solenoid.
5. Write down the factors that make an electromagnet strong.
6. Draw the magnetic field lines around a bar magnet and a current carrying solenoid. Describe their similarities and differences.

5.7 Electric Motor

An electric motor is a device that rotates when current passes through it. It is used to convert electrical energy into mechanical energy (kinetic energy.)
How does an electric motor works? What principle does it apply?

A current carrying wire in an external magnetic field experiences a force. The direction of the magnetic force on the wire depends on the direction of the current in the wire and the direction of the magnetic field lines.

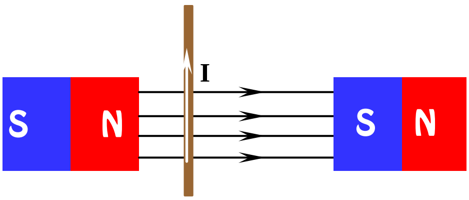
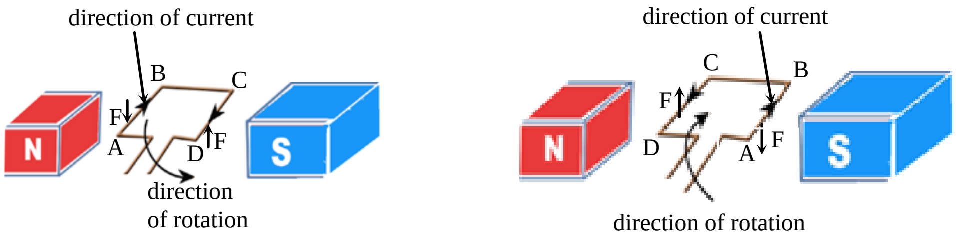


Fig 5.41 Current carrying wire crossing a magnetic field

We use the Right hand rule to indicate the direction of the force. Point your right hand thumb in the direction of the current and the remaining fingers in the directions of magnetic field. Then the palm of your hand shows the direction of the force. Fig 5.42 illustrates a force exerted on current carrying wire found inside a magnetic field.

In grade 7 physics, you also learnt that a force applied to a body produces a turning effect called torque. Thus, a torque produced in opposite direction causes bodies to rotate around an axis. This principle is applied in the working principle of an electric motor.



a) Force on AB is downward and force on CD is upward

b) After half cycle force on CD is upward and force on AB is downward,

Fig. 5.42 Rotations of a coil in magnetic filed

An electric motor consists of a strong permanent magnet and a flat coiled wire. The rotation of the coil obeys the principle of torque as the above example. The principle is that two opposing forces act on opposite segments of the flat current carrying coil. Then, the coil rotates about an axis. The forces are perpendicular to the plane of the segments.

Consider the rectangular coil shown in Fig 5.42a.

The segments $\overline{AB}$ and $\overline{CD}$ are perpendicular to the magnetic lines of force. The arrows on the segments show direction of current through the coil. A conductor kept perpendicular to the magnetic field experiences a force (when current flows). The direction of the force depends on direction of the current. The direction of current in $\overline{AB}$ is opposite to that in $\overline{CD}$. Therefore, opposing forces act on these two segments. This causes rotation of the coil.

After a half cycle (Fig 5.42b) the force on each segment is still the same as before. But, the positions of the segments are exchanged. Therefore, the direction of rotation is reversed.

The main parts of an electric motor are: the commutator or split ring brushes, magnetic field and armature or coiled wire.

To make the motor rotate in one direction a commutator is used. A commutator is a pair of half rings (split ring) insulated at the separation. The terminals of the coil rotate inside the half rings. One of the terminals of battery is connected to one half ring and the other terminal to the second half ring. As a result, the direction of current in each segment is reversed after a half cycle. This causes rotation of the coil in one direction. This is illustrated in Fig 5.43. What are the main parts of an electric motor? Name them using Fig 5.43.

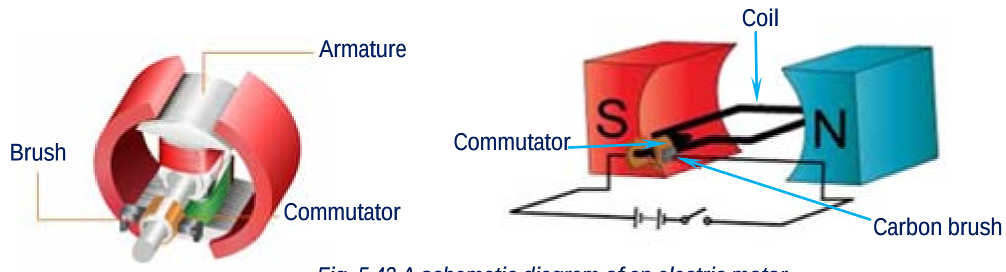


Fig. 5.43 A schematic diagram of an electric motor

To increase the speed of an electric motor you can do one of the followings.

1. **Wind the coil on a soft-iron core.** The iron core is called an armature. This increases the magnetic field strength.
2. **Increase the number of turns of the coil.** Slot the iron core and wind more turns on the slots. This helps for smooth turning.
3. **Use an electromagnet instead of a permanent magnet**

Where do you find electric motors in use? Electric motors are found in our every day life. They are used in video players, in electric singers (sawing machine), in drilling machine, in ventillaters, in cars,etc.

Project work

Construct a simple electric motor in group with your friends.

Materials required:

1) An electromagnet (a horse-shoe or a bar magnet can also be used).
2) A long insulated wire

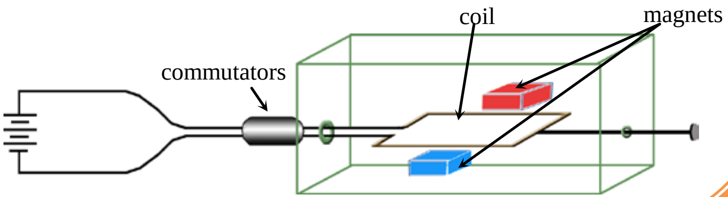
3) A metal ring
4) Battery (dry cells)
5) Iron slabs (three in number)
6) Brushes (made of insulators)
7) A box (wooden or metal) for enclosure

Procedure

1) Bisect the metal ring through its diameter. Insulating, at the cuts mount them together to the hole on the box. These are your commutators mentioned in step 4.
2) Slot one of the iron slabs and wind insulated wire in the slots (in a rectangular shape). Each wire has to be wound once. The terminals of all wires, which are to one side of the axis of the coil(see fig 5.41) should be connected together. (you can find some pieces of iron in a mechanic's shop) you may also use a single coil without a slab.
3) Use the remaining two slabs as cores for the electromagnet. The wire wound around the electromagnet should be insulated. The electromagnet has to be fixed to the bottom of the box. Leave a space, which is slightly larger than the width of the coil (between the two slabs). Connect the circuit as shown in Fig 5.42. The coil is connected to the battery in parallel with the electromagnet. The electromagnet and the coil can both be connected from the commutator. The terminals of the coil are pushed gently to the inner surface of the commutator by using brushes. The brushes should freely rotate inside the commutator.

   Instead of the electromagnet you can use a horse-shoe magnet, the north and South Pole of which are very close to each other. Or you may also use two bar magnets.
4) Make two holes on the box at a height half the width of the electromagnet (magnet) measured from the bottom of the box. Fix the commutators to one of the holes. Connect a straight wire to the center of the coil (as shown in Fig 5.43) pass the wire through the other hole on the box.

   You can use a switch between one terminal of the battery and the commutator. When the switch is closed you will observe that the wire, which is connected to the rectangular coil, rotates.



A model-type simple electric motor

An electric motor is a device that converts electrical energy into mechanical energy. There are several other devices which operate by the magnetic effect of electric current'. Some of these are electrical measuring instruments, such as; voltmeter, ammeter, ohmmeter, galvanometer, etc.

Check point 5.7

1. **Indicate the direction of a force on a current carrying wire in a magnetic field shown in fig 5.44.**
2. **Draw an electric motor diagram and label its parts.**
3. **Name some electrical appliances that have electric motors.**

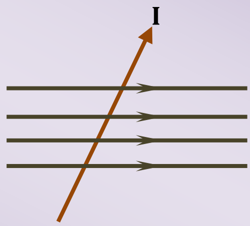


Fig 5.44 Magnetic field

5.8 Electromagnetic Induction

In the previous sections you learnt that an electric current in a conductor produces a magnetic field. How about the reveres action? Does magnetic field produce an electric current?

Activity 5.15

Observing magnetic lines of force cutting a conductor produces an electric current through the conductor.

Materials required: A sensitive centre zero galvanometer, a conducing wire, and U-shaped magnet.

Procedure

1. Connect the end points of the conductor, to the terminals of a galvanometer. A galvanometer is sensitive electrical instrument used to measure the presence of an electric current.

2. Move the magnet down ward and observe in which direction the galvanometer deflects. What does the deflection show?
3. Move the magnet up wards and observe the direction of deflection of the galvanometer.
   What do you observe about the deflection?
4. Now move the magnet horizontally, keeping the wire between the poles. Is there any deflection of galvanometer pointer? Why?

In the above activity, in step 2, when the magnet moves downward, the galvanometer deflects. This deflection shows that current is created in the conductor.

In step 3, when the magnet is moved upwards, the galvanometer deflects in opposite direction of the previous deflection.

When the magnet is kept horizontally, and moved, there is no deflection.
You will notice similar effects when you move a conductor in a magnetic field. Follow the next activity.

Instead of the U-shaped magnet, you can use two bar magnets. Keep the opposite poles of the two magnets close to each other. Connect the end points of a straight wire to the terminals of zero galvanometer. Move the wire upward, downward and horizontally between the poles. Vary the speed of motion of the wire. In each case observe the deflection on the galvanometer.

If the motion of the conductor is parallel to the magnetic lines, there is no effect observed
In this activity you could have observed that;

1. There is no deflection when the wire moves parallel to the magnetic field lines.
2. The deflections change in directions when the wire moves upward and down ward.
3. The induced current is stronger when the conductor moves faster.

You will observe similar effects when you move a bar magnet inside a solenoid.
Generally, a current is produced in a conductor whenever it cuts (move) across magnetic lines of force. This phenomenon is known as the **electromagnetic**

induction. Michael Faraday was the first scientist who demonstrated the generation of an electric current from a magnet. Activity 5.15 is known as Michael Faraday's experiment.

Electromagnetic induction is the process of inducing EMF in a coil by moving it relative to a magnet.

The current produced in the coil is called *induced current* and the EMF is called *induced EMF*

In the process of an electromagnetic induction, mechanical energy is converted to electrical energy. The mechanical work done in moving the coil or the magnet relative to one another results in inducing an electric current in the coil.

The direction of the induced current changes when the direction of the magnetic field changes.

Check point 5.8

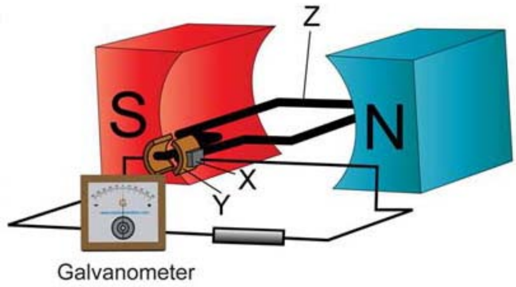
1. Define the terms a) electromagnetic induction
b) induced current

2. Describe the generation of electricity by the movement of a magnet with in a coil of wire or a solenoid.

5.9 Generator

In the previous section you learnt that current is induced in a coil that moves in a magnetic field. The strength of induced current is weak in a single coil. In real life, many turns of rectangular coils are used. In addition, these turns are wound out of a single wire on slotted iron-core. A coiled wire around the iron-core is known as an **armature**. A shaft links the armature with a source of mechanical energy. The **armature** then rotates in a magnetic field. As a result, current is induced in the coil. Such a device is called a **generator**.

A generator is a device used to convert mechanical energy into electrical energy. It makes use of the principle of electromagnetic induction.



X = Brush
Y = Slip ring (Commutator)
Z = Armature (Coil)

Fig 5.45 The structure of an ac generator

When a coil of wire is rotated inside a magnetic field or when a magnet is made to rotate around a stationary coil, current is induced in the coil. The induced current in the coil is supplied to the external circuit by means of slip-rings and brushes.

The slip rings are fastened tightly to the coil and rotate with it. The slip rings and the external circuits are in contact by means of brushes.

The main parts of a generator are the **armature, brushes, slip rings and magnetic field.**

- **An armature** is a coiled wire around an iron core.
- **Slip ring** is a metallic ring splitted into two half. It is attached to the armature.
- **Brushes** are carbon rods used to attach the external circuit to the armature.

When the coil makes half a turn, the direction of the currents is reversed. A current that changes its direction with time is called an alternating current (AC). A generator that produces alternating current is called an AC generator.

A current that does not change its direction with time is called a direct current (DC). For example, a dry cell and a car battery are sources of direct current.

A bicycle dynamo is an electric motor that produces direct current when it rotates with the wheel of a bicycle. In this case, an electric motor acts as a D.C generator.

Check point 5.9

1. **What is a generator?**
2. **Draw an AC generator and label its parts.**
3. **Explain the differences between AC and DC current**

5.10 Transformer

A transformer is a device that transfers electrical energy from one circuit to another by the process of electromagnetic induction. It is used on an alternative currents (AC) only not on a DC current.

A transformer consists of two coils of wire, wound on an iron core. The two coils of wire are called **primary coil** and **secondary coil,** as shown in Fig 5.46. When an alternating current is passed through the primary coil, the changing magnetic field gives rise to induced alternating current in the secondary coil.

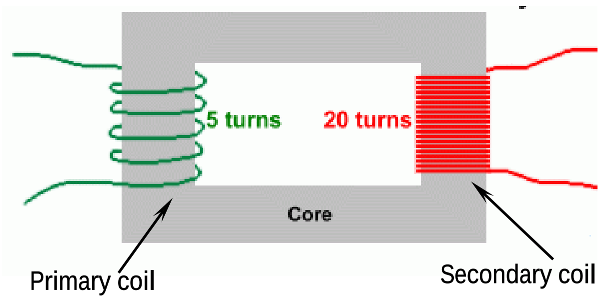


Fig 5.46 Structure of a transformer

Fig 5.47 A transformer

A transformer in which the output coils (secondary coils) have more turns than the input coils (primary coils) is called a step-up transformer. **A step-up** transformer changes a voltage to a higher value and it has more numbers of turns in its secondary coil than in its primary coil ($N_s > N_p$).

A transformer in which the output coils have fewer turn is called a step-down transformer. **A step-down** transformer changes a voltage to a lower value and it has more number of turns in its primary coil than in its secondary coil ($N_p > N_S$).

In an ideal transformer the electric power is the same in both primary and secondary coils.

Electric power in primary coil; $P_p = I_P V_P$ and the electric power in secondary coil $P_s = I_S V_S$.

Since the power $I_p V_p$ going into a transformer must be equal to the power $I_s V_s$ going out where I_p and I_s are the primary and secondary currents respectively. The ratio of turns;

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

$$\frac{\text{Primary voltage}}{\text{Secondary voltage}} = \frac{\text{Primary turns}}{\text{Secondary turns}} \Rightarrow \frac{v_p}{v_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

Examples

1. A transformer is being designed to have a 600-volt output with a 120-volt input. If there are to be 800 turns of wire in the input coil, how many turns must there be in the output coil?

Given	Required	Solution
$V_p = 120\ V$	$N_s = ?$	$\frac{V_p}{V_s} = \frac{N_p}{N_s}$
$V_s = 600\ V$		$\frac{120\ V}{600\ V} = \frac{800}{N_2} \Rightarrow 800 \times 5 =$
N_2		
$N_p = 800$		$\Rightarrow$ Number = 4,000
		The number of turns in the Secondary coil $N_s = 4{,}000$

Uses of Transformers

Electric power transmission lines use transformers to either step-up or step-down the generated electric power. You probably have a number of transformers in your home. Your mobile telephone charger is a transformer. It operates at 9V voltage. It transforms 240 V from the main to 9 V. Your cassette player, computer, radio, etc have transformers in them.

Transformers play a significant role in distribution of electrical energy over wide areas in the country. This is done by means of high voltage lines carrying relatively small current to avoid losses caused by heating the lines.

Check point 5.10

1. **What is a transformer?**
2. **Name the two kinds of transformers. Explain the functions of each type of transformer.**
3. **Draw a transformer and label its parts.**
4. **Write down some electric appliances in life that have transformers.**

5.11 Power Transmission

Ethiopia is using hydroelectric power plants to supply electrical energy to cities to light roads, industries, homes and other sectors.

Can you name some hydroelectric power plants in your locality? From where does your city /town or village get electric energy? The main hydroelectric power stations in our country are given in Table 5.3

Activity 5.17 Observation

Make a visit to a nearby electric power station (plant)

1. Identify the voltages stepped up or stepped down along the transmission process.
2. For what purposes are the voltages stepped down?

Let us see how an electric energy is transmitted from the power station to our home. Let us say, Koka Electric Power Plant generates 25kV at the station. This voltage is stepped up by a transformer to about 270kV or 400kV at different points. High voltage is used to reduce the electric energy loss as it travels long distances. As it reaches towns the 400 kV is stepped down by a transformer to 11kV for industries and to 240 V for homes, schools, shops, etc. Fig 5.48 illustrates electric power transmission from a power station.

Fig 5.48 Electric power Transmission lines

At home, the 240V mains are stepped down to 110V or 9V as required.

Table 5.3

Name of some hydro electric power plants	Power being transmitted	Where it is found
1. Melka wakana	150MW	Oromia Reginal state
2. Koka	43.2MW	Oromia Reginal state
3. Fincha	100MW	Oromia Reginal state
4. Tekeze	300MW	Tigrai Regional state
5. Tanabeles	460MW	Amhara Regional state
6. Tise Abai	11.5MW	Amhara Regional state
7. Gelgel Gibe I	180MW	Oromia Regional state
8. Gilgel Gibe II	420MW	SNNPR state

Check point 5.11

1. What is the function of a transformer?
2. Draw the symbol of a transformer.
3. Why is a high voltage used to transmit electricity?

Electrical Safety Rules

Electricity is very useful to people. It could become a curse due to people's ignorance and carelessness. You need to know electrical safety rules so that you can protect yourself and others and properties from the dangers of electricity. Some of the precautions which should be taken as a safety rule are stated below.

- Don't plug something in or unplug something unless you have your teachers'/parents' permission.
- Never touch appliances, electrical outlets or switches with wet hands.
- Only trained people should install and repair electrical wirings.
- Bare wires should be well insulated or replaced.
- Make a change in the wiring only after the mains has been put off.
- Every circuit must be fused with the proper size. Fuse is used to protect the line or instrument in the circuit from damage.
- Tell your teacher or parent about any damaged electrical cords so they can be replaced right away.
- Never climb an electric pole or tower.

SUMMARY

In this unit you learnt that:

- an electric circuit is a complete path for the flow of electric current. It may consist of different items like a source of potential difference, switches connecting wires, and a lamp.
- the structure of an electric bulb and the function of a fuse. A fuse makes a circuit open (incomplete) in a time of high flow of current.
- electric current is the rate of flow of electric charges across a given cross-sectional area in a conductor.
- electron current is the flow of electrons from negative terminal to positive terminal of the source. Conventional current is a theoretically assumed current that flows to opposite direction to that of an electron current.
- voltage is a measure of the ability to do work.
- Ohm's law states the relationship between current and voltage. It states that: ''The current flowing through a metallic conductor at a constant temperature is directly proportional to the voltage between the two ends."
- measuring electric current, voltage and resistance in a given circuit, using voltmeter and ammeter. An electric current passing through a conductor produces a magnetic field in the surrounding.
- a current carrying wire in an external magnetic field experiences a force.
- an electric motor is a device that converts electrical energy into mechanical energy (kinetic energy.)
- electromagnetic induction is the process of inducing EMF in a coil by moving it relative to a magnet.
- a generator is a device used to convert mechanical energy into electrical energy. It makes use of the principle of electromagnetic induction.
- a transformer is a device that transfers electrical energy from one circuit to another by the process of electromagnetic induction. Transformers are of two types: step up and step down.
- the major source of electrical energy is hydroelectric power. In hydroelectric power stations potential energy of falling water is converted in to electrical energy.

Review Questions and Problems

I. Say True or False for the following statements.

1. The current through two resistors in series branches out (splits).
2. The sum of potential differences across each resistor in series is the same as that of the voltage of the source.
3. The sum of currents through two equal resistors in parallel are equal to the total current.
4. For two resistors in parallel the voltage across each resistor is the same as that of the voltage of the source.
5. If two resistors are in parallel then the reciprocal of net (total) resistance is the sum of reciprocal of the two resistances.
6. A current carrying wire produces a magnetic field around it.
7. A current carrying conductor experiences no force when found in an external magnetic field.
8. An electric motor converts electric energy in to energy of motion.
9. Magnetic field in an electromagnet is not affected by the number of turns of the coil.
10. A transformer transfers energy from one body to another.

II. Choose the best answer among the given alternative answers.

1. Two opposite forces acting perpendicular to an axis cause
   a. Back and forth motion
   b. Rotation
   c. Sliding motion
   d. No motion (at rest)
2. The part of an electric motor that reverses current in a segment of the coil is.
   a. Armature
   b. Commutator
   c. Brushes
   d. Battery

III. Choose the proper word from the given options that makes the statement true.

1. A current carrying conductor is aligned (parallel/perpendicular) to magnetic lines of forces so as to experiences force.
2. After a half cycle a motor without a commutator rotates (forward/ backward).
3. Electric motor converts (electrical/mechanical) energy to (electrical/mechanical) energy.

IV. Solve the following problems

1. A current of 15 A flowed through a conductor for 1hr. What amount of charge would move through the conductor in this time?
2. Two resistors of 40Ω each are connected in series across a 120V supply.
   a) What is the total resistance of the circuit?
   b) What is the current through the circuit?
   c) What is the potential difference across each resistor?
3. A 75Ω lamp and 150Ω heater are connected in parallel across a 150V potential difference.
   a) What is the equivalent resistance of the two items?
   b) Find the currents flowing through the two items.
   c) What current flows through the entire circuit?
   d) Compare the sum of the currents through the lamp and heater with total current.
4. Calculate the total resistances and the current through each resistor. Fig 5.49

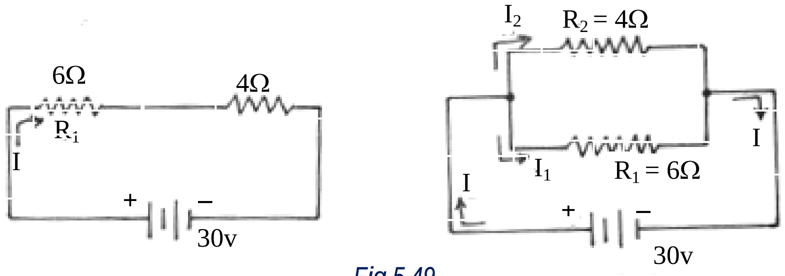


Fig 5.49

(a) (b)

V. Answer the following questions

1. What is the use of insulation between the half rings of a commutator?
2. What is the purpose of winding many turns of wire on an armature?
3. Using a diagram, describe how an electric motor works.
4. State and demonstrate the right hand rule for current carrying wire in a magnetic field
5. Explain Faraday's Experiment using a coil and a magnet
6. State an electromagnetic induction
7. What is meant by a step up transformer and a step down transformer?
8. What is a fuse? How does it work?

UNIT 6

LIGHT

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to light.
- ✓ develop skill of manipulating problems related to light.
- ✓ appreciate the interrelatedness of all things.
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

6.1 What is Light?

Activity 6.1
• Describe what light is. What sense organ do you use to see light? • Explain different sources of light. • How does light travel from its source to your eyes?

We are sometimes afraid to walk in the dark, because we cannot see our surrounding. The greater part of what we know about the world around us is the result of our vision. Light helps us to see things around us by producing a sensation of sight through our eyes and brain. Fig 6.1 shows a boy seeing his cattle using the sun light and his eyes.

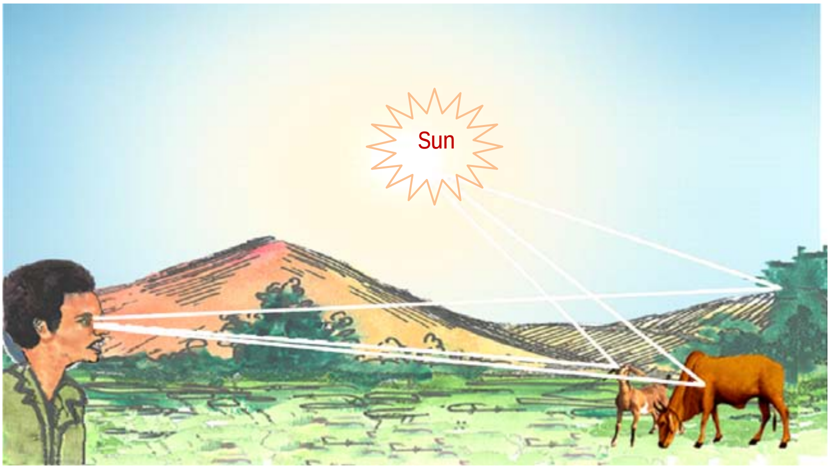


Fig. 6.1 Light helps us see things around us

The branch of physics which studies the nature, properties and all other aspects of light is called optics.

How does light also affects our life? Light helps us see things around us. It also makes plants to grow and produce the food we eat. Plants store energy which is produced from the sunlight. This stored energy is converted to fuels such as charcoal and fire woods.

Light is an electromagnetic wave which is emitted from a hot body. It produces sensation of sight on human eyes. To produce light, some other forms of energy have to be converted to light energy. For example, in an electric lamp electrical energy is changed to heat and light.

What are the sources of light?

The sources of light are bodies which generate and emit light energy of their own. These bodies are called *luminous bodies*. For example, the sun, fire, burning lamps and burning candles are luminous bodies. They are sources of light.

Most bodies do not generate light of their own. Such bodies are visible only when they receive light from some luminous body and reflect it to our eyes. Bodies on which light is falling are called **illuminous bodies**.

For example a wall, a person, a tree, a book, the moon and mountains are illuminous bodies. Why is not the moon the source of light?

Check point 6.1

1. **What is light?**
2. **Describe luminous and illuminous bodies. Give examples for each of them.**
3. **Name some local sources of light in your area.**

6.2 How Does Light Travel?

Activity 6.2 Observing how light travels.

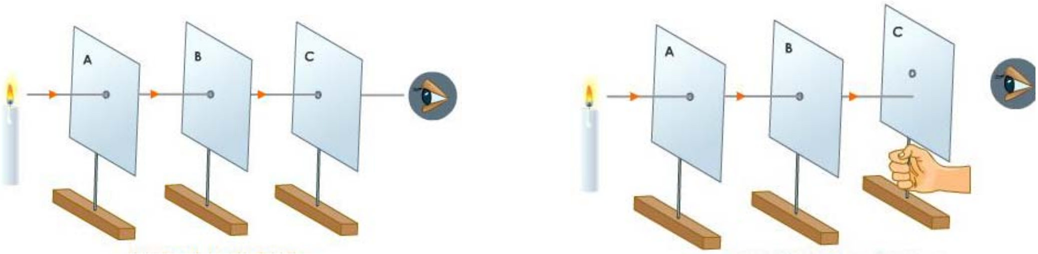
Form a group with your friends and do the following practical activity and describe how light travels. Is it in a straight line or zigzag (curved) path?

Materials required: 3 cardboards mounted on blocks (see Fig 6.2) source of light (candle or lamp).

The 3 cardboards need to have small holes at their centers exactly at the same level.

Procedure:

1. Arrange the cardboards as shown in Fig 6.2
2. Pass string through the holes and pull it tight to make sure that the holes are in a straight line.
3. Place a lighted candle at one end of the 3 cardboards. Try to look the burning candle flame through the other end as shown in the Fig.6.2. (you should be able to see the candle flame though the holes)
   i. Can you see the flame through the holes?
   ii. If any of the cards is moved slightly from their position, can you still see the flame?
   iii. What do you conclude about the motion of light? Does light travel around a corner



a) Straight holes b) Disordered holes

Fig. 6.2 Propagation of light

From Activity 6.2 you might have noticed that when the holes of each card are exactly at the same level you can see the light of the candle (Fig 6.2(a)). But if one of the cards is moved (disordered) slightly out of the line the light will not be seen, because the light from the flame is blocked by the surface of the displaced card (Fig. 6.2(b)). Light does not move around a corner. This activity shows that light travels in a straight line.

Let us take other practical examples in our life.

If you open a window facing sunlight or walk through trees at sunrise or sunset you will see light streaming through in straight lines as it passes through the window to the opposite wall or between the branches of trees to the ground.

The same effect is also observed in cinema halls as light travels from the projector to the screen. These events suggest that light travels in straight lines.

Actually, we see the light because it hits particles in its path and reflect to our eyes. The direction of the path followed by the light is called a **ray** and is represented by a straight line with an arrow. A group of rays of light is called a **beam of light**. There are different types of beams of light: parallel, diverging and converging beams as shown in Fig 6.3

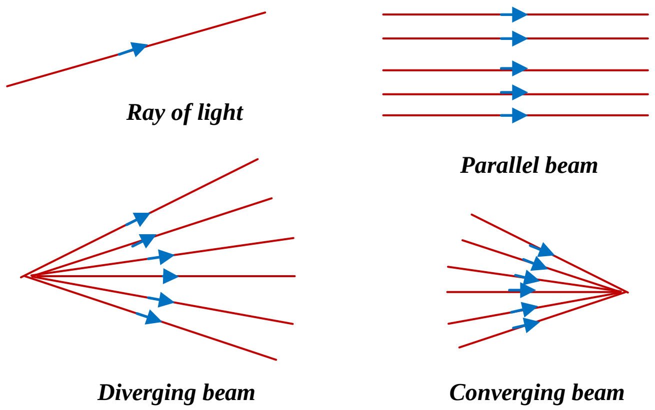


Fig 6.3 Types of rays.

Kinds of light transmission

Light travels in a straight line. It can travel through a vacuum and through some materials.

Some objects like the wall, do not allow light to pass through them at all. Such objects are called **opaque**.

Other objects allow light to pass through them partially. Such objects are said to be **translucent**. Special glasses used in toilet and bathroom windows and water are examples of such material. Materials like air and ordinary window glasses allow light to pass through them. You can see things through them clearly. Such objects are said to be **transparent**. They serve as media for the propagation of light. What is a medium?

> Opaque materials reflect light falling on them completely, while translucent materials reflect light partially.

Pin-hole camera

A pinhole camera consists of a closed box with a small hole on one face and screen on the opposite side. The screen could be made from oiled paper or plastic sheet or white pieces of cloth as shown in Fig 6.4.

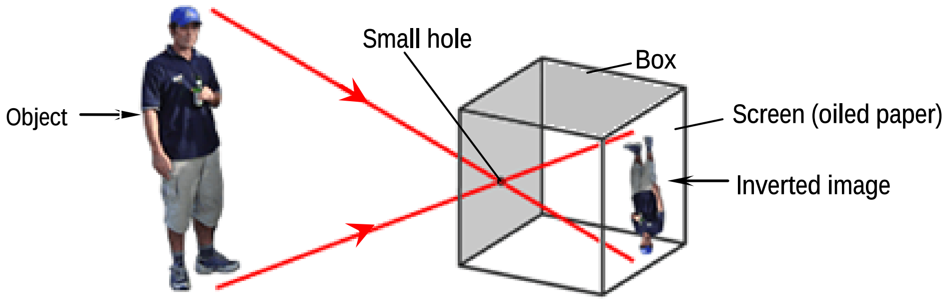


Fig 6.4 Pin-hole Camera

Activity 6.3 To Construct a pinhole camera

Materials required: A paper box, silver color plastic sheet (oiled paper), a pin and scotch tape.

Procedure: Make a hole with a pin on one side of the box.

- Remove the opposite side of the box, and replace it with the oiled paper or plastic sheet.
- Seal the sides of the box with the scotch tape, not to allow light inside the box. (Fig 6.4)
- Use the pinhole camera you prepared to observe things around you like a flag, a burning candle, or a tree placed in the sunshine.
- Explain the image formed by the pinhole camera.

The image formed on the screen will be seen more clearly if the observation is done in a darkened room.

Geometrical optics is a branch of optic which deals with the properties of light by using a light 'ray' model.

Since light travels in a straight line, each point of the image on the screen will be illuminated only by the light travelling in a straight line from a particular point source. The tiny particles of light from the object combine to form an inverted (upside down) image of the object as shown in the figure. If the hole is enlarged, the image becomes blurred. You get clear picture when the hole is very small like a pinhole.

We can think of a bigger hole as equivalent to a group of small holes close together. Each hole produces its own image and the overlap of these causes the image to appear blurred. (not clearly identified)

Shadows

When an opaque object is place between a source of light and a screen, a shadow is formed on the screen. This is because light travels in a straight line and so will not be able to go round the object. The formation of a shadow is a practical example that show light travels in a straight line. When the source is very small, i.e a point source, the shadow produced is sharp and equally dark all over. When the source is large, however, the shadow has one central dark patch the umbra surrounded by a lighter ring called penumbra. Some rays of light are able to reach the penumbra but none reaches the umbra.

Check point 6.2

1. **Explain how light propagates.**
2. **What is a pin-hole camera? Describe its uses.**
3. **Explain the nature of the image formed by the pinhole camera.**
4. **What is meant by the terms translucent, transparent and opaque materials? Give examples for each of them.**

6.3 Reflection of Light

Light travel in all directions from a source. This propagation of light is represented by rays of light.

Light travels in straight line in a given medium. When light reaches the boundary of another medium through which it does not travel, some changes may happen. These are;

i. Some amount of light is absorbed by the boundary medium.
ii. The rest is turned back into the first medium. If the surface is polished and glazed like a mirror, most of the light is turned back from the surface. This phenomenon of light is known as the **reflection of light**.

Reflection of light is the turning back or bouncing of light rays when it encounters a different medium.

When a light ray hits an opaque material it totally reflects.

Can you see any relationship between the angle at which the light ray hits the opaque material and the angle at which it is reflected?

There are two kinds of reflection:

i. *Regular reflection:* is a reflection from regular, shining and smooth surface. Example a mirror. (Fig 6-5 a)

ii. *Diffuse reflection:* is a reflection from irregular and rough surfaces (Fig 6-5 b)

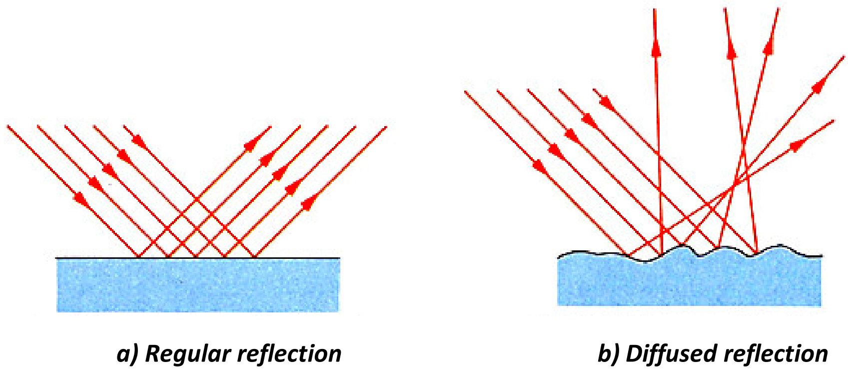


Fig 6.5 Regular and diffuse reflections

The rays that strike the surface are called **incident** rays while the rays that are bouncing back from the surface are called **reflected** rays.

When you look at yourself in the mirror, incident rays from your face hit the mirror and return as reflected rays. As these rays enter your eyes you see the picture of yourself behind the mirrors. This picture is called an **image**.

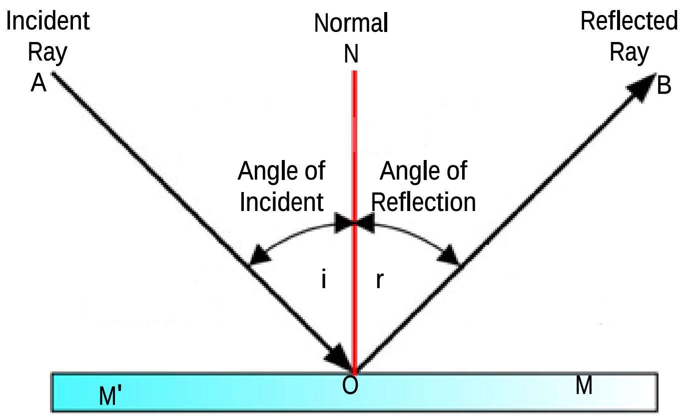


Fig 6.6 Terms used in reflection of light ray

MM' is the reflecting surface of a plane mirror.

AO is the direction in which the light from the object (or source) falls on the reflecting surface and is called the **incident ray**. The point **O** is the point of incidence and **OB** is the reflected ray. The line **NO** is perpendicular to **MM'** and it is called the **normal**.

The angle formed by the **incident ray** and the normal is called the **angle of incidence**. The angle formed by the reflected ray and the normal is called **the angle of reflection**. They are represented as $\hat{\imath}$ and $\hat{r}$ respectively, where

$\hat{i}$ = The angle of incidence.

$\hat{r}$ = The angle of reflection.

Activity 6.4 Observing the law of reflection

Obtain a white sheet of paper and draw a straight horizontal line about its center. Place the paper on a piece of soft cardboard or a horizontal table and use four pins to hold the paper to the cardboard (table).

Place a strip of plane mirror vertically so that its silvered surface (i.e. the back of the mirror) is on the line you have drawn. Label this line MM'. Stick two pins P_1 and P_2 on the paper in front of the mirror, so that the line joining p_1 and p_2 is at an angle to MM'. The pins p_1 and p_2 should be 5 or 6 cm apart.

With the eye at a convenient point, observe the images of p_1 and p_2 of the two pins (i.e P_1' and P_2'). Stick two other pins p_3 and p_4 in a straight line with these images. The set-up is shown in Fig.6.7. Now remove the mirror and the pins. Draw the line p_1p_2 and p_4 p_3 to cut MM'.

If you did the experiment carefully, you would find that the lines meet at a point on MM'; call this point O and draw a perpendicular to MM' as shown.

Measure the angel P_2ON ($\hat{i}$) and P_4ON ($\hat{r}$) and record your results. Repeat the experiment for different angles and tabulate your results as shown below.

On Table 6.1. Angles i and r are the angles of incidence and reflection respectively.

Table 6.1

Experiment number	Angle of incidence (i)	Angle of reflection (r)
1	10^0	-
2	20^0	-
3	30^0	-
4	45^0	-
5	60^0	-

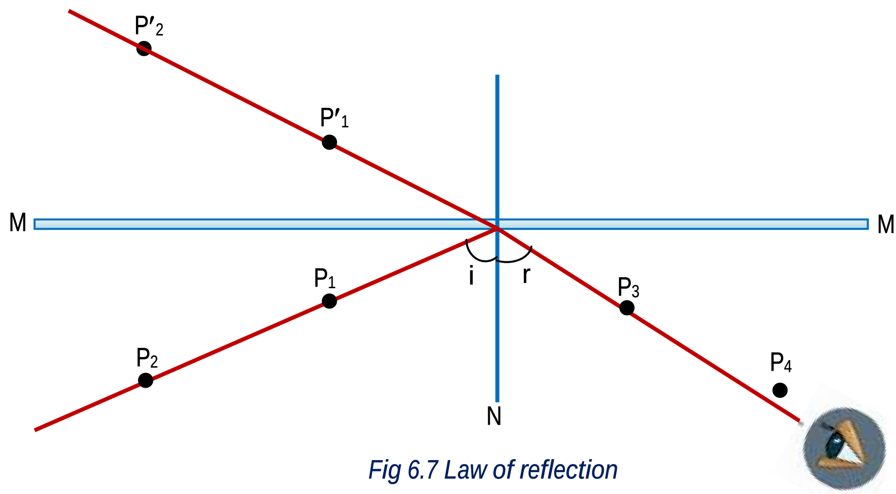


Fig 6.7 Law of reflection

The results obtained from this experiment can be summarized as laws of reflection.

Laws of reflection

The angle of incidence is equal to the angle of reflection.

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

Worked Example

An incident ray strikes the surface of a mirror at angle of 30°. What are

a) The angle of reflection and

b) The angle between the reflected ray and the mirror?

Solution

- Draw the normal lie at the point where the incident ray strike the mirror

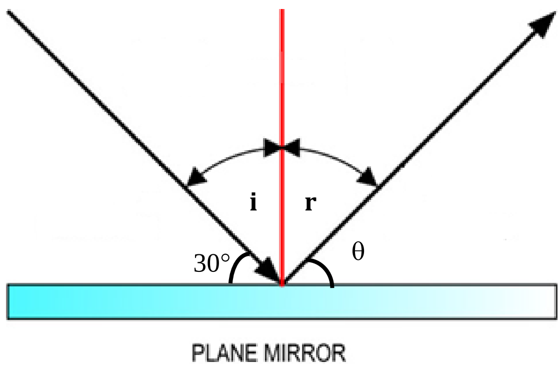


Fig 6.8

a) The angle between the incident ray and the normal

$= 90° - 30° = 60°$

Therefore, the angle of reflection = 60° since $\hat{i} = \hat{r} = 60°$.

b) The angle between the reflected ray and the mirror is

$90° = \hat{r} + \theta° \Rightarrow \theta° = 90 - \hat{r}$

If $r = 60°$ then $\theta° = 90° - 60° = 30°$

Diffuse and regular reflection can now fulfill one of the laws of reflection When a parallel beam strikes a rough surface at an angle, all the rays in the beam will be incident at different angles of incidence from the others. So the angles of reflection for the different rays will be different resulting in reflection in all direction.

Image formation by a plane mirror

A plane mirror is a glass plate whose one of its side is painted black or silver. The reflecting surface is the surface that is not painted. Rays of light falling on a mirror are reflected in a definite direction. The reflection of an object in a mirror is called an **image**.

Fig 6.9 Image in a plane mirror

Activity 6.5 Observing your image in a plane mirror

Material required: a plane mirror.

Procedure: Take a plane mirror and place it in front of your face.

- Observe the type of image you receive on the mirror.
- Is your image enlarged, inverted, and sides exchanged in the mirror and how is its position from the mirror? Fig 6.9
- Can you receive your image on a screen (paper) and touch it with your hand?
- What do you call such images?

Consider a point object **O**, such as the tip of a candle flame, placed in front of a mirror. Two rays **OA** and **OB**, strike the mirror at A and B as show in Fig 6.10 After reflection they appear to the eye as if they were originating from I. The eye sees an image at I in such a way that ON is equal to **IN** and **ONI** is perpendicular to the mirror.

As no rays actually come from I, the image is described as a virtual image. It cannot be seen on a screen placed at I.

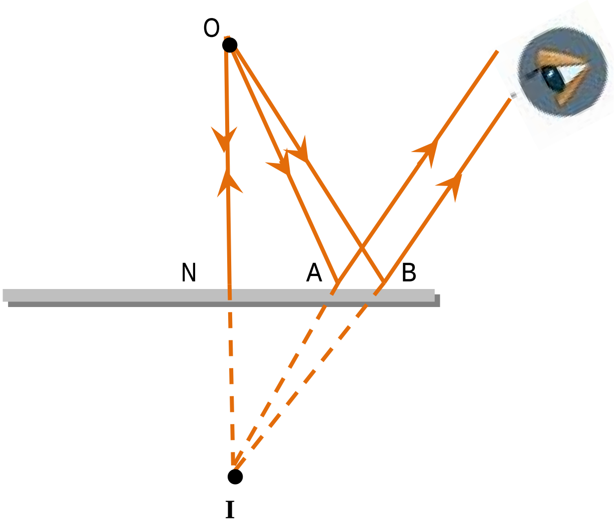


Fig 6.10 Construction of an image using a ray diagram

The image formed in a plane mirror has the following characteristics;

i. It is erect, not upside down.
ii. It is of the same size as the object
iii. It is laterally inverted. (i.e. Sideways reversed)
iv. Has the same distance behind the mirror as the object is in front i.e. the image formed in a plane mirror appears to be as far behind the mirror as It is a virtual image.

A virtual image is one through which rays of light do not pass but which is nevertheless visible to the eye. A virtual up right image is an optical illusion. A real image is one through which rays of light pass if a screen is placed at the position of a real image, the image is seen on the screen.

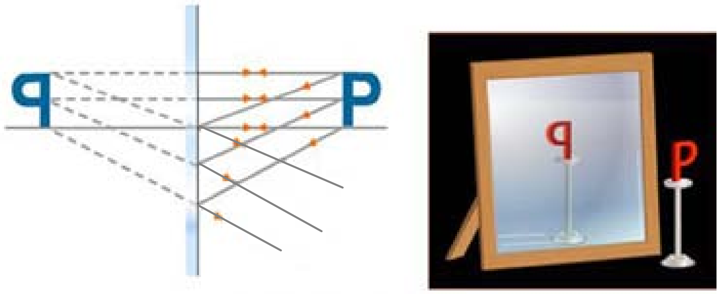


Fig 6.11 Image of a letter P in a plane mirror

A periscope

A periscope is a device that helps an observer to see over or around an opaque material. Using a periscope you can see a football game being behind a tall wall.

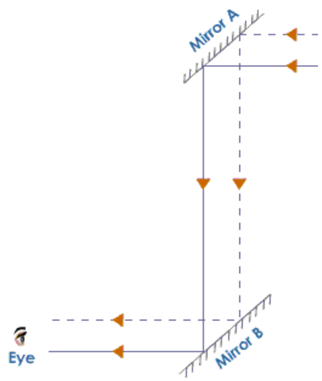


Fig 6.12 A periscope

A periscope uses two plane mirrors placed in a long tube as shown in Fig 6.12. The mirrors are placed at each end of the tube at 45° to the direction to be observed. The image formed by the top mirror is observed through the bottom mirror.

Image formed in two mirrors

When two mirrors are inclined at angle θ° (angle teta) a number of images are formed by a number of reflections.

$$\text{Number of images} = \frac{360^\circ}{\theta} - 1$$

E.g. Images formed in two mirrors inclined at 90° are: $\frac{360^\circ}{90^\circ} - 1$ = 3 images.

Parallel mirrors: An infinite number of images are formed for an object placed between two parallel mirrors. These images lie on a straight line through the object perpendicular to the mirrors.

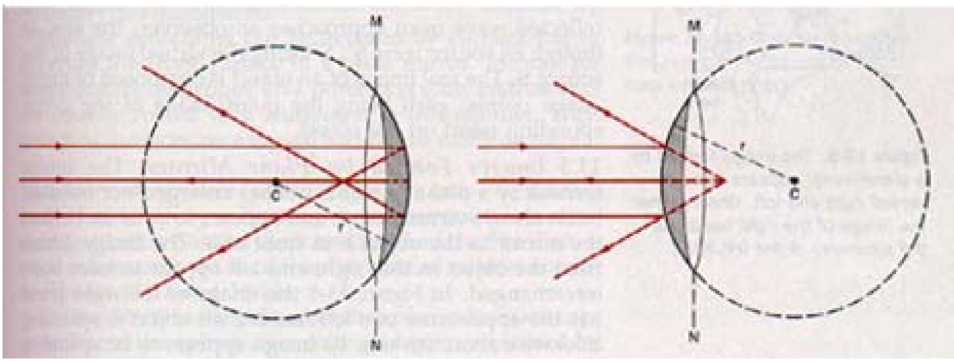
The position of the images may be found by the usual construction, remembering that each image seen in mirror will act as a virtual object and produce an image in the mirror.

Check point 6.3

1. **What is reflection of light?**
2. **What is the difference between regular and diffuse reflection?**
3. **Define the terms incident ray, reflected ray, angle of reflection, angle of incidence and normal line (demonstrate pictorially.)**
4. **State and describe the law of reflection.**
5. **What is the angle between incident ray and reflected ray if the angle of incidence is 40°?**
6. **Describe the nature of images formed by a plane mirror.**
7. **Explain the difference between real and virtual images.**
8. **What is a periscope? Describe how to make it.**

6.4 Image Formation by Curved Mirrors

Curved mirrors are made up of a spherical shaped body. Consider the cover of a hollow sphere of glass. We could produce a curved surface by cutting out the part of this spherical cover. If we reflect light from the outside of this surface, we produce a **convex mirror**. If we reflect light from the inside surface we have a **concave mirror**. Such mirrors are called **curved mirrors**.



a) Concave mirror *b) Convex mirror*

Fig. 6.13 Curved mirror.

When the reflecting surface of mirrors is curved rather than plane, the law of reflection holds true. But the size and position of the image formed are quite different from those of the image formed by a plane mirror.

Because of the curved nature of these mirrors, they do not produce images in the same way as the plane mirrors discussed earlier in this unit.
Concave mirrors are used in torches and car head-lights, in reflecting telescopes and as showing mirrors.

Convex mirrors are often used as driving mirrors (i.e. as rear-view mirrors in cars) and to see round corners in Supermarket.

To study the images formed by curved mirrors we need to define some terms used in connection to these mirrors. See Fig. 6.14.

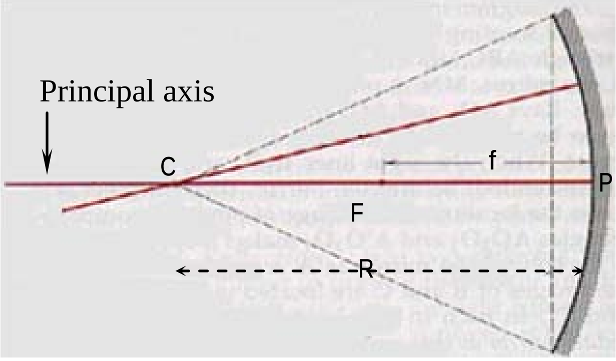


Fig. 6.14 A plane diagram for defining terms used with curved mirrors.

1. The **pole (p)** of the mirror is the midpoint of the mirror
2. The **center of curvature (C)** is the center of the sphere of which the mirror forms a part.
3. The **principal axis** is the line that passes through the pole and the center of curvature of the mirror.
4. The distance from P to C is the **radius of curvature** (R). It is the radius of the sphere from which the mirror was cut out. The action of a curved mirror depends on the radius of curvature.
5. The **principal Focus (F)** of a concave mirror is the point where rays that are parallel to the principal axis converge after reflection. Fig.6.15 (a) illustrates

that when a beam of light is incident on a concave mirror, the rays are reflected to converge or come together at a point F called a **principal focus**.

6. The **principal focus (F)** of a convex mirror is the point from which rays parallel and close to the principal axis appear to diverge after reflection. With a convex mirror, the rays appear to diverge or move out from the point F behind the mirror after reflection. See Fig.6.15 (b). With a concave mirror, the rays converge to a point which we can actually obtain on a screen placed in front of the mirror as a bright spot of light.

   The focus of a concave mirror is therefore a real focus. In the case of a convex mirror, the reflected rays do not actually pass through the focus but only appear to do so.

7. The **focal Length (f)** of curved mirrors is the distance from the principal focus F to the pole P. The focal length is found experimentally to be equal to half of the radius of curvature.

   That is $f=R/2$

   For example, if the radius of curvature is 40 cm, the focal length of the mirror $f= 40/2=20$cm.

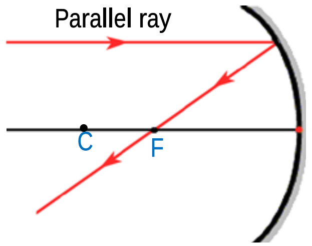
Ray diagrams for Image formation

When an object is placed in front of a mirror, we can't know where the image will be and what kind of image it is. Our general problem is that if light rays start from a point on an object, what happens to them after reflection by the mirror? We make the problem easier for ourselves by taking rays whose directions after reflection are known and can easily be drawn. The followings are rays whose direction is known.

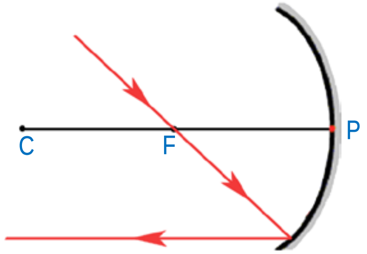
i. A ray parallel to the principal axis passes through the principal focus (F) after reflection Fig.6.15(a)
ii. A ray through the principal focus (F)is reflected parallel to the principal axis fig 6.15(b)
iii. A ray through the center of curvature (C) is reflected back along its path, fig 6.15(C)

Any intersection of the reflected rays of at least the above two rays form the image of the object placed in front of the mirrors.

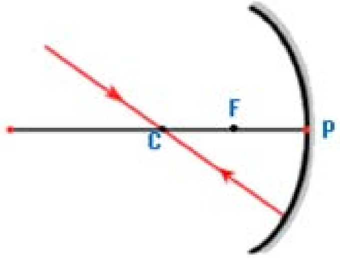
Images formed by Concave and Convex mirrors



a) Any ray parallel to the principal axis is reflected through F.



b) Any ray through F is reflected parallel to the principal axis



c) Any ray through C hits the mirror at right angles and is reflected straight back

Fig.6.15 Construction of rays for a concave mirror

Activity 6.6 Observing images in

a) Concave mirrors

b) Convex mirrors

Materials: Concave and Convex mirrors (locally available like polished metallic surfaces).

Procedure:

a) concave mirror

- Stand in front of a concave mirror at a distance. Try to observe your image in the mirror.
- Come closer to the mirror slowly, observing the type of image formed.
- And finally come very close to the mirror

Explain the types of image observed as you move closer to the mirror.

b) convex mirror

Repeat the steps you followed for a concave mirror above.

Explain the types of image (s) observed as you move from a distance to closer to the convex mirror

i. Images formed by Concave mirrors

The nature and position of the image formed by a concave mirror varies with the position of the object in front of the concave mirror. This can be observed by drawing a ray diagram to scale. Ray diagrams in Fig 6.16 illustrate the different images formed for different distant objects.

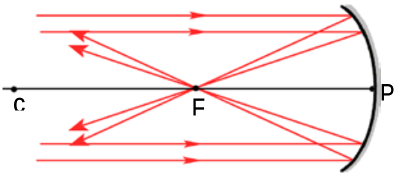
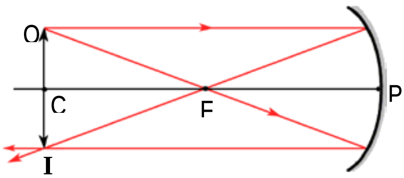
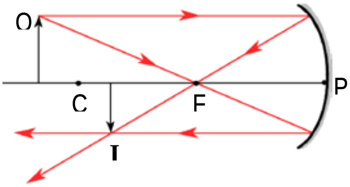
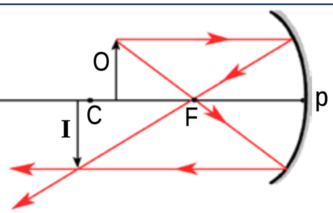
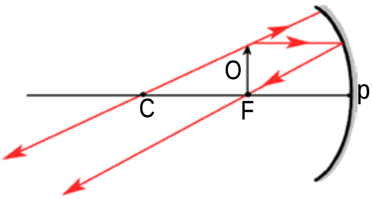
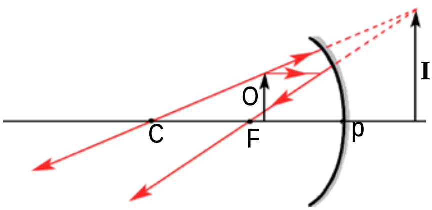
a) 	Object at infinity (Very far)	The image is 1. At F 2. Real 3. Inverted 4. Smaller than object
b) 	Object at C (S_0=2F)	The image is 1. Real 2. Inverted 3. Same size 4. At C
c) 	Object beyond C ($s_0 > 2f$)	The image is 1. Real 2. Inverted 3. Smaller than object 4. Between C and F
d) 	Object between F and C ($2f > s_0 > f$)	The image is 1. Real 2. Inverted 3. Large than object 4. Beyond C
e) 	Object at F ($s_0 = f$)	No image is observed (it is at infinity)
f) 	Object between F and P ($f > s_0$)	The image is (1) Virtual (2) Larger than object (3) Erect (4) Behind the mirror

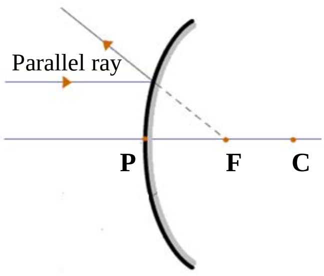
Fig. 6.16 Image formed by a concave mirror

Fig 6.16 shows the image positions for various object positions. In a concave mirror we get both a real image and a virtual image A real image is formed by the actual rays of light and can be received on a screen.

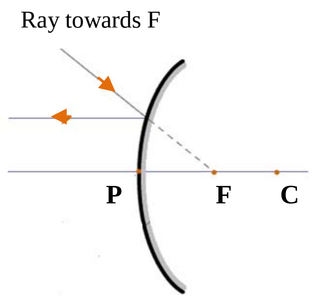
In concave mirrors

1. If an object is placed beyond focal point, the image is real and inverted. The size and position depend on the distance of the object from the mirror.
2. If an object is placed between the focal point and the mirror, the image is virtual, erect and larger than the object.

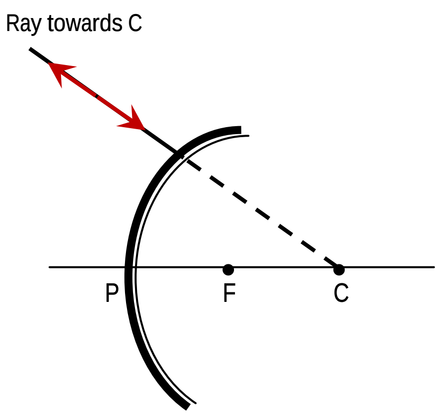
i) Images formed by a convex mirrors



a) Any ray parallel to the principal axis is reflected so that it appears to come from F.



b) Any ray going towards the principal focus is reflected parallel to the principal axis.



c) Any ray towards C is reflected straight back

Fig.6.17 Construction of rays for a convex mirror

Fig 6.17 illustrates construction of ray diagrams for a convex mirror. The image formed in a convex mirror does not depend on the distance between object and mirror.

The points to which these reflected rays appear to diverge represents the required image. In practice, however, the tracing of any two of these rays will enable us to find the position of the image.

For the convex mirror the image is always erect, diminished, virtual and behind the mirror for all object positions. (fig 6.18)

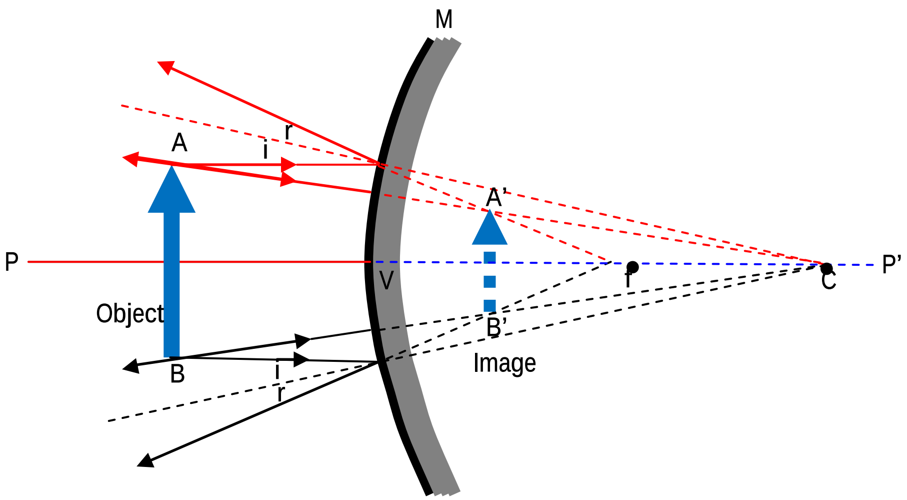


Fig.6.18 Construction of rays for a convex mirror

Most driving mirrors are convex. They gather in light from a wide area and distant objects around and direct the ray to the driver's eyes. In this way he or she can see diminished size of the objects and the whole road behind him/her.

Activity 6.7 Discuss the following questions with your friends

1. What is the difference between real and virtual images?
2. Use the images formed by a concave, convex and plane mirrors to explain the question.

Object and image are represented by O and I respectively. Fig 6.14 and Fig 6.18 show the position and nature of the image produced by curved mirrors. Where the rays diverge, do not meet, you extend them backward. The image formed where the reflected rays actually meet is called **real image**. The image formed where the extension of the reflected rays meet is called **virtual image**.

Check point 6.4

1. **Describe curved mirrors (Give examples for convex and concave mirrors).**
2. **Define the terms**
   - **Principal axis**
   - **Focal point**
   - **Focal length,**
   - **Radius of curvature**
   - **Vertex (pole) of mirror**
3. **Describe the nature and position of images formed by curved mirrors using ray diagrams, when the object is placed at different location.**

6.5 Refraction of Light

Activity 6.8 Observing refraction of light in different media.

Materials required: a torch, a card board with a pinhole, water in a plastic bag, and a glass plate.

Procedure: (Do this activity in dim or dark place)

- Arrange the torch as shown in Fig6. 16 so, a single ray could be produced.
- Direct the ray to the surface of water or glass at an angle.
- Observe what happens to the ray as it hits boundary between the air and water (or glass).
- To which direction does the light ray bends in the water medium (glass medium)?
- Follow the ray as it comes out of the glass or water. Observe how it is bending.

In the previous section you learnt that light travels in straight line in a given medium. But this is true only when light travels through a substance which has the same optical density throughout.

Optical density is a property of any transparent material, and it is the measure of the speed at which light travels through that material.

For example the speed of light through water is very nearly ¾ of the speed of light through air, so water has an optical density ¾ times that of air.

When a ray of light traveling in one transparent medium enters another different transparent medium, its direction is suddenly changed at the surface separating the two media. This happens only if the light strikes the separating surface obliquely (slantingly). Light travels in a straight line when it enters a new medium perpendicularly. The change in the direction of the light ray is known as **refraction of light**.

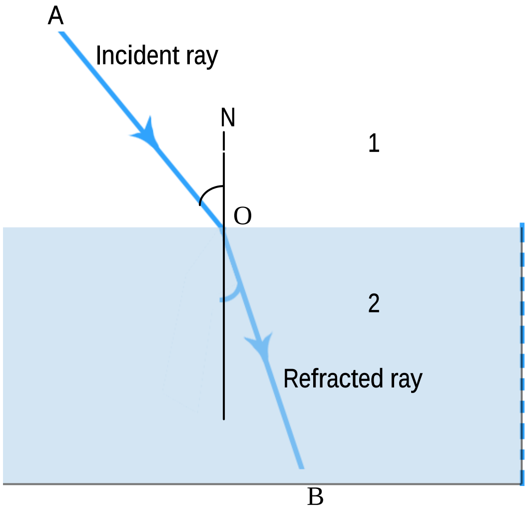


Fig.6.19 Refraction of light rays

Therefore refraction of light occurs when light travels from air to glass, from air to a liquid, from glass to air and from a liquid to air. Refraction happens due to the difference in the velocity of light in the different media.

Refraction of light is the bending of a light ray as it passes from one medium to another. It occurs because light travels at slightly different velocities in different media.

The incoming ray is called the incident ray. After bending in a new medium it becomes the refracted ray. A line perpendicular to the boundary of the two media at the point where the incident ray entries is called the normal.

The phenomenon of refraction explains why a swimming pool or water in any container appears shallower than it actually is. It also explains why a pencil appears to bend when part of it is immersed in a glass of water or any other liquid.

Fermat's least time principle

The path taken by a ray of light between any two points in a medium is always the path that takes the least time. This principle leads to the law of the rectilinear propagation of light and the laws of reflection and refraction. It was discovered by the French mathematician Pierre de Fermat (1901-1965)

Definition of terms

Consider a ray of light travelling from medium 1 to 2 using Fig 6.19 we make use of the following terms.

1. **The incident ray**: is the path along which the light travels in the first medium.
2. **The refracted ray**: is the path along which the light travels in the second medium.
3. **The angle of incidence**: is the angle between the incident ray and the normal to the surface.
4. **The angle of refraction**; is the angle between the refracted ray and the normal to the surface.

In Fig 6.19 it is shown that the refracted ray is bent towards the normal. This occurs when the ray enters a denser medium. If the same ray had started from medium 2, it would have followed the same path. That is BO would have been the incident ray and OA the refracted ray. In this case the ray entering the less denser medium would bend away from the normal. In other words a ray travelling from the denser to the less denser medium bends away from the normal as it crosses the surface of the separation of the two media;

These can be summarized as the law of refraction

Laws of Refraction

The laws of refraction are stated as follows:-

- The incident ray, the normal at the point of incidences and the refracted ray lie in the same plane.
- Light bends towards the normal in denser medium and bends away from the normal in lighter medium.

Check point 6.5

1. **What is refraction of light?**
2. **Draw and explain ray diagrams to illustrate how light travel from one medium to another.**
3. **Explain Fermat's least time principle.**

6.6 Lenses

Activity 6.8 Individual work

i) What is a lens?
ii) Describe what lenses do to parallel rays.
iii) Mention some applications of lenses.
iv) What does the hole in a pinhole camera represent

A lens is a piece of transparent medium, usually glass, bounded by two curved surfaces or by one plane and one curved surface. The word 'lens' 'lentil' was given first to convex lens because of its similarity in shape to lentil seeds.

Lenses are used in many instruments. They are used inside cameras, eye glasses projectors, microscopes, telescopes and others. (Explain the different uses of lenses indicated in (Fig 6.20)

a) Camera   b) Night vision goggles   c) Glasses

d) Over head Projector   e) Telescope   f) Microscope

Fig 6.20 Different uses of lenses

Lenses produce either real images or virtual images.

Types of Lenses

There are two types of lenses. These are:

1. Convex lens
2. Concave lens

1. Convex Lenses

These lenses are thicker at the middle and thinner at the edges. Convex lenses are also called **converging lenses**. (Fig 6.21)

A convex lens makes parallel rays of light originating from a source converge to a point called a **Focus.** It produces both real and virtual images. The virtual images are magnified but the real images can be either magnified or diminished depending on the object's distance from the lens.

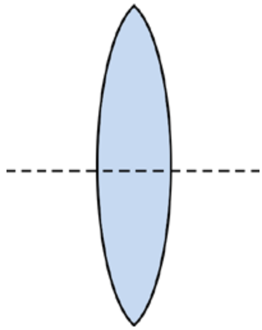


Fig 6.21 Convex lens is a converging lens.

2. Concave Lenses

These lenses are thinner at the middle and thicker at the edges. A concave lens is also called **diverging lens**. (Fig 6.22)

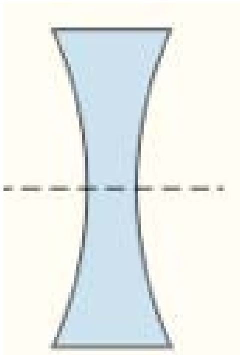


Fig 6.22 Concave lens is a diverging lens.

A concave lens makes parallel rays of light which pass through it spread out or diverge.

When you look through a concave lens, you always see a diminished and upright image.

Terms used in lenses

1. The **principal axis** of a lens is an imaginary line joining the centers of curvature of its surfaces.
2. For every lens there is a point through which rays of light pass without being bent by the lens. This point is called the **optical center** of the lens.
3. **The principal Focus (F)** of a converging lens is the point to which all rays parallel to the principal axis actually converge after refraction through the lens.

4. **The principal focus** (F) of a diverging lens is the point from which all rays parallel to the principal axis appear to diverge after refraction though the lens.
5. **The focal length** (f) is the distance between the optical center (O) and the principal focus (F) of the lens
6. **Center of curvature** (C): the center of curvature of a lens surface is the center of the sphere of which the surface forms a part.

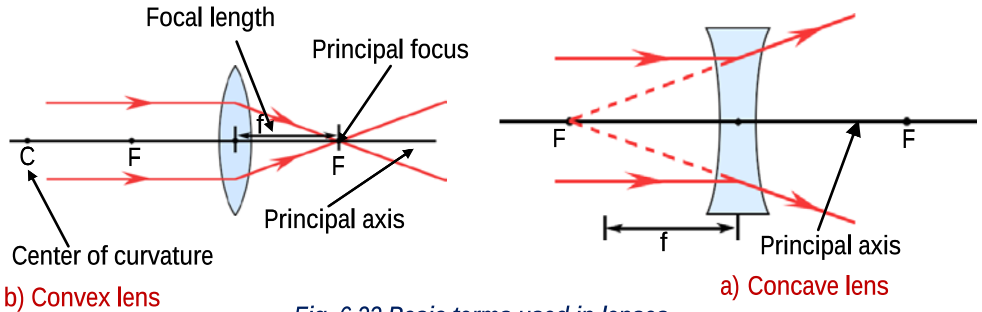


Fig. 6.23 Basic terms used in lenses

Ray diagrams used to determine nature and position of images in lenses.

As in the construction of ray diagrams for curved mirrors, three rays are used to obtain the position and nature of images formed by lenses. These rays are:

a. Rays parallel to the principal axis to it, pass through the principal focus after refraction.

b. Rays through the principal focus emerge parallel to the principal axis after refraction

c. Rays through the optical center pass through the lens unrefracted, i.e. their direction is unchanged.

Formation of images by a convex lens

Image of an object formed by lenses is located at a point where at least two of the refracted rays intersect.

When constructing ray diagrams we represent the object and the image by a perpendicular line with an arrow at the head.

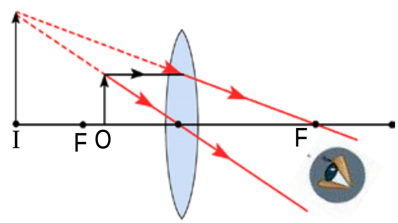
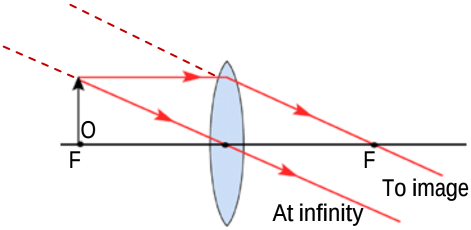
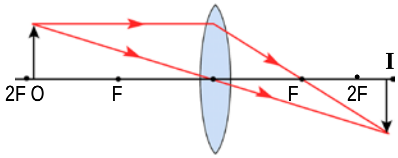
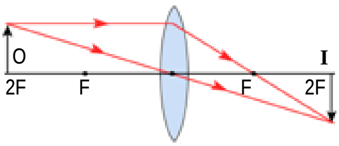
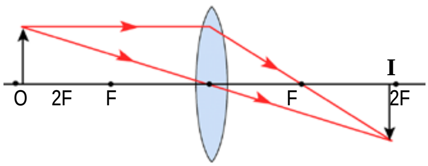
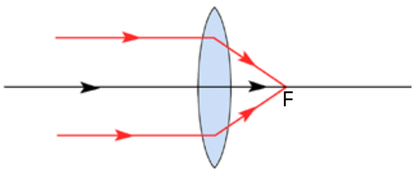
	Object Between Lens and F	The image is **1. Behind the object** **2. Virtual** **3. Erect** **4. Larger than the object**
	Object at F	No image is formed the image is at infinity
	Object Between F and 2 F	The image is **1. Behind 2F** **2. Real** **3. Inverted** **4. Larger than the object**
	Object at 2F	The image is **1. At 2 F** **2. Real** **3. Inverted** **4. Same size as object**
	Object beyond 2F	The image is **1. Between F and 2F** **2. Real** **3. Inverted** **4. Smaller than the object**
	Object at infinity (Very Far)	The image is **1. At F** **2. It is a point image.**

Fig 6.24 Formation of images by a convex lens

Activity 6.10

How do the images in convex lens vary with the

a) Distance of the object beyond and at F?

b) Between F and the lens?

As for curved mirrors, we distinguish between real and virtual images. To repeat once again, a real image is one that can be received or projected on a screen. Actual light rays pass through it. A virtual images is one through which the light rays forming it only appear to pass, without actually doing so. A virtual image cannot therefore be projected on a screen.

Images formed by a concave Lens

For all position of the object, the image formed by a concave lens is always virtual, erect, diminished and located between the principal focus 'F' and the optical center of the lens 'O'. Fig 6.25. shows the path taken by a ray travelling parallel with the principal axis and one passing though the optical center 'O' of the lens. These rays can be used to predict the image position.

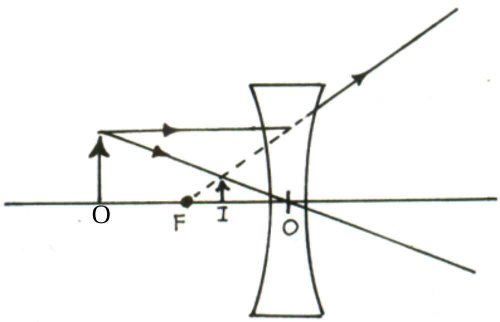


Fig. 6.25 Image formed by concave lens

Types of lens	Position of an object	Position and nature of Image formed	Uses
1. Convex lens (Converging lens)	• Object beyond 2F	- Real, - inverted, - diminished	- camera - Telescope - Projector - Magnifying glass
	Object at 2F	- Real, - inverted, - same size	
	Object between 2F and F	- Real, - inverted, - magnified	
2. Concave lens (Diverging lens)	Any position in front of the lens.	- Virtual, - erect - diminished	- spectacles (eye glasses)

A convex lens has a real focus but a concave lens has a virtual focus.

Mirage

People, who travel in a still sunny day, see inverted images of distant objects in a nonexistent pool of water. Have you ever seen a mirage? Ask your friends or parents about mirages. Mirage can be observed on asphalted road in hot days. Mirage is formed by the refraction of light traveling between hot and cold air.

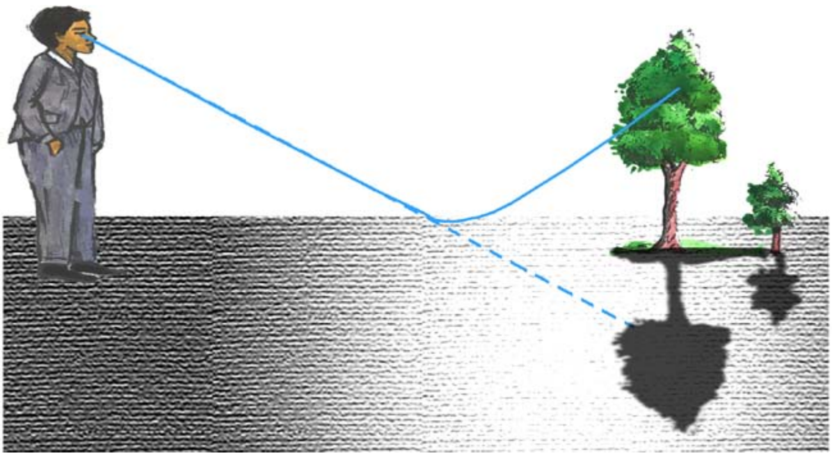


Fig. 6.26 Mirage

Dispersion of Light

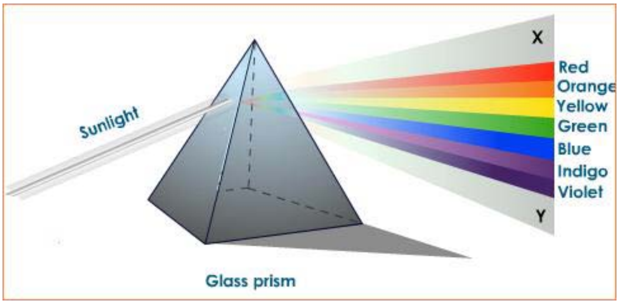
Activity 6.11

Observing white light is made up of different colors.

What is a rainbow? How is it formed? How many colors are found in a rainbow?

The band of colors you see on a screen xy is called a spectrum. The splitting of white light into different colors is called dispersion of light. It is caused by the refraction of white light at different angles to the glass prism as in Fig 6.27.

The fastest color light bends most, while the slowest color light bends least. The order of the colors of the spectrum is as follows. Red is on top followed by orange, yellow, green, blue, indigo and violet at the bottom. The violet is the most refracted while the red light is the least refracted. Thus, white light is made up of seven colors.



a) Dispersion of light in a glass prism

b) Rainbow

Fig 6.27 Dispersion of light

A rainbow is a band or spectrum of colors. It is formed by the refraction of light by drops of water in the sky.

Check point 6.6

1. What is a lens?
2. Explain the difference between convex and concave lenses.
3. Define the optical center, focal length, focal point, radius of curvature and principal axis of lenses.
4. Describe the nature of image formed by concave and convex lenses using ray diagrams.
5. What is the importance of lenses in technology?
6. Describe dispersion of light and name the spectrum of light (colors).
7. What is mirage? Describe it by comparing with refraction.

SUMMARY

In this unit you learnt that:

- light is an electromagnetic wave, that emits from a hot body
- Sources of light are the sun, burning lamp, candles and electric torch
- light travels in a straight line in a single medium.
- light travels completely through transparent materials and partially through translucent. It does not pass through opaque materials. They are either absorbed or reflected.
- reflection of light is the returning of light when it encounters an opaque or translucent material.
- the law of reflection states that the angel of incidence equals the angle of reflection.
- the image formed by a plane mirror is virtual, erect, the same size as the object and behind the mirror.
- curved mirrors are of two types; concave and convex mirrors.
- concave mirror forms real and inverted images. The size and position depends on the distance of the object from the mirror. For an object placed between the focal point and the mirror. The image is virtual, erect and larger than the object.
- the image formed by a convex mirror is always erect, diminished, virtual and behind the mirror.
- refraction of light is the bending of light as it passes from one medium to another.
- lenses are of two types: Convex and concave lenses. Convex lens converge parallel rays into a point called focal point (principal focus). While concave lens diverges parallel rays.
- the splitting of light into different colors is called dispersion. White light is made up of seven colors.

Review Questions and Problems

I. Choose the best answer among of the given alternatives

1. Which of the following is/are true about the image formed by a pinhole camera? The image is always.
   a. diminished
   b. inverted
   c. magnified
   d. a and b
2. If a pin – hole camera was made longer without changing the size of pinhole, the image would be
   a. Smaller and less bright
   b. Larger and less bright
   c. Smaller and brighter
   d. Larger and brighter
   e. The same size and brighter
3. The image formed in a plane mirror is
   a. Real and the same size as the object
   b. Real and nearly the same size as the object
   c. Virtual and the same size as the object
   d. Virtual and nearly the same size as the object
4. A convex mirror is usually used as an out side rear-view mirror on a car because
   a. It has a wide field of view
   b. It has a narrow field or view
   c. The image is always magnified
   d. The image is always real
   e. The image appears the same size as the object

II. Answer the following questions

1. Complete the following table with examples

Material	Examples (3 each)
Transparent	1 2 3
Translucent	1 2 3
Opaque	1 2 3

2. **Write the names of the indicated types of light rays in the given space. (Fig 6.28)**

   a. ______________________________

   b. ______________________________

   c. ______________________________

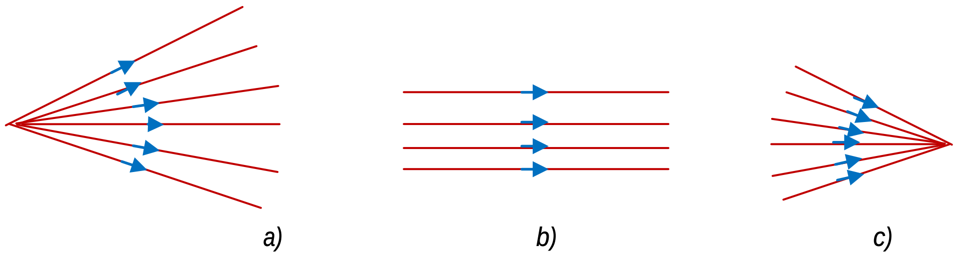


Fig 6.28 Types of light rays

3. **Explain how light travels by giving practical examples.**
4. **The parts of the reflection of light from a mirror are labeled. on Fig 6.29 what do the letters stand for?**

   A ______________________

   B ______________________

   C ______________________

   <**α** ______________________

   <**β** ______________________

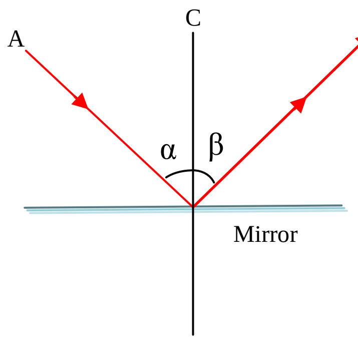


Fig 6.29 Reflection of light rays

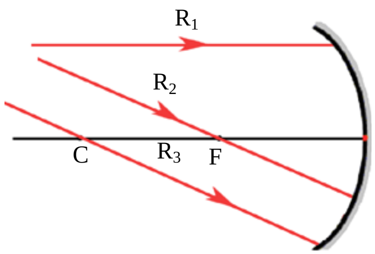
5. **Define a) Reflection of light**

   b) Refraction of light

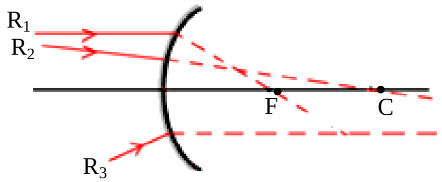
   c) Dispersion of light
6. **Explain what concave and convex mirrors do to parallel rays directed to their surfaces.**
7. **Construct a ray diagram to find the image of a burning candle in front of a plane mirror.**
8. **Describe the nature of the image formed by convex and concave lenses. Fill in the Table given below.**

Types of lens	Natures of Image
Convex lens	
Concave lens	

9. What is the difference between virtual and real images?
10. Draw the reflected rays for the given incident rays on



a) Concave mirror



b) Convex mirror

Fig 6.30 Incident rays R1,R2, & R3.

11. A convex lens has a focal length of 12 cm. what is the distance between the optical center and the center of curvature (c)?
12. The radius of curvature (R) of a concave mirror is 30cm. what is the focal length of this mirror?
13. A man is standing at a distance of 2m from a large plane mirror. He moved 1m farther away from the mirror. How far is his image now from him?
14.

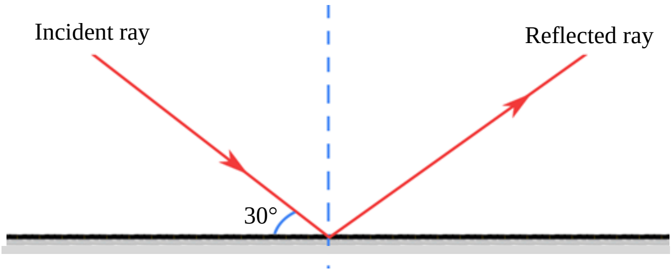


Fig 6.31 reflection on a plane mirror.

In Fig 6.31 the angle between the plane mirror and the incident ray is 30°. Find the

a. Angle of incidence
b. Angle of reflection