

Based on National Curriculum of Pakistan 2022-23

# Model Textbook of

# Physics

## Grade

9

National Curriculum Council

Ministry of Federal Education and Professional Training



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as  
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Islamabad



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**Model Textbook of Physics  
for Grade 9**



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## Preface

This Model Textbook for Physic Grade 9 has been developed by NBF according to the National Curriculum of Pakistan 2022-2023. The aim of this textbook is to enhance learning abilities through inculcation of logical thinking in learners, and to develop higher order thinking processes by systematically building the foundation of learning from the previous grades. A key emphasis of the present textbook is creating real life linkage of the concepts and methods introduced. This approach was devised with the intent of enabling students to solve daily life problems as they grow up in the learning curve and also to fully grasp the conceptual basis that will be built in subsequent grades.

After amalgamation of the efforts of experts and experienced authors, this book was reviewed and finalized after extensive reviews by professional educationists. Efforts were made to make the contents student friendly and to develop the concepts in interesting ways.

The National Book Foundation is always striving for improvement in the quality of its textbooks. The present textbook features an improved design, better illustration and interesting activities relating to real life to make it attractive for young learners. However, there is always room for improvement, the suggestions and feedback of students, teachers and the community are most welcome for further enriching the subsequent editions of this textbook.

May Allah guide and help us (Ameen).

**Dr. Raja Mazhar Hameed**  
Managing Director

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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

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# PHYSICAL QUANTITIES AND MEASUREMENT

UNIT

1

Which unit  
was used by  
ancient Egyptians  
while building  
pyramids?

## Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-A-01] Differentiate between physical and non-physical quantities
- [SLO: P-09-A-02] Explain with examples that physics is based on physical quantities
- [SLO: P-09-A-03] Differentiate between base and derived physical quantities and units.
- [SLO: P-09-A-04] Apply the seven units of System International (SI)
- [SLO: P-09-A-05] Analyse and express numerical data using scientific notation
- [SLO: P-11-A-06] Analyse and express numerical data using prefixes.
- [SLO: P-09-A-07] Differentiate between scalar and vector quantities.
- [SLO: P-09-A-08] Justify that distance, speed, time, mass, energy, and temperature are scalar quantities.
- [SLO: P-09-A-09] Justify that displacement, force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength are vector quantities.
- [SLO: P-09-A-10] Determine, by calculation or graphically, the resultant of two vectors at right angles
- [SLO: P-09-A-11] Make reasonable estimates of physical quantities
- [SLO: P-09-A-12] Justify and illustrate the use of common lab instruments to measure length.
- [SLO: P-09-A-13] Justify and illustrate the use of measuring cylinders to measure volume.
- [SLO: P-09-A-14] Justify and illustrate how to measure time intervals using lab instruments.
- [SLO: P-09-A-15] Determine an average value for an empirical reading.
- [SLO: P-09-A-16] Round off and justify calculational estimates.
- [SLO: P-09-A-17] Critique and analyze experiments for sources of error.
- [SLO: P-11-A-09] Differentiate between precision and accuracy.
- [SLO: P-09-A-19] Determine the least count of a data collection instrument (analog) from its scale.

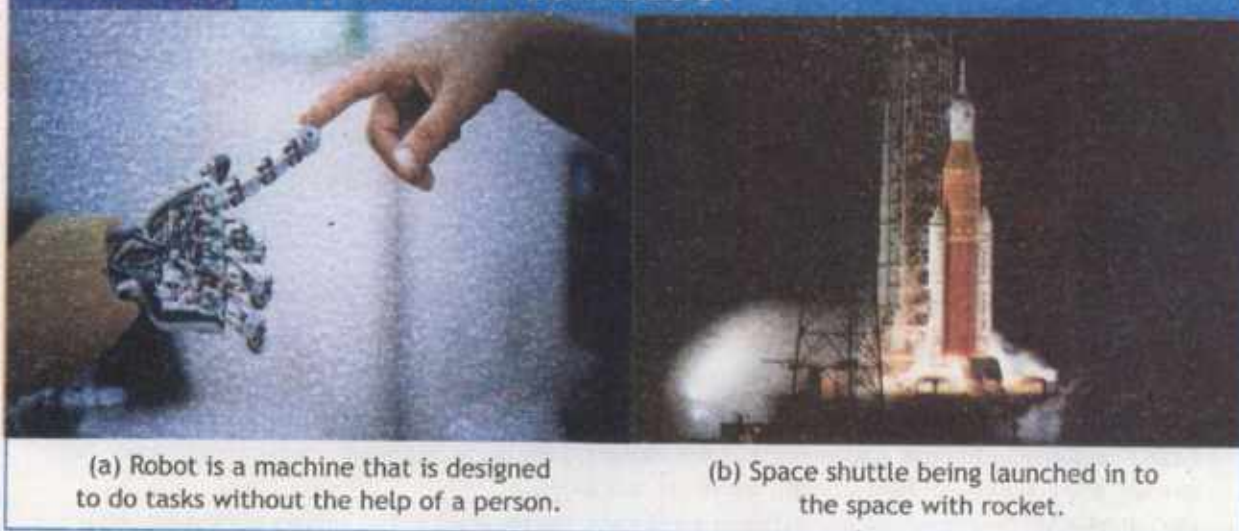
Measurements are not confined to science. They are part of our lives. They play an important role to describe and understand the physical world. Over the centuries, man has improved the methods of measurements. In this unit, we will study some of physical quantities and a few useful measuring instruments. We will also learn the measuring techniques that enable us to measure various quantities accurately.

## 1.1 INTRODUCTION TO PHYSICS

In the nineteenth century, physical sciences were divided into five distinct disciplines; physics, chemistry, astronomy, geology and meteorology. The most fundamental of these is the Physics. In Physics, we study matter, energy and their interaction. The laws and principles of Physics help us to understand nature.

**Physics in Science:** Physics is the most fundamental of all the sciences. In order to study biology, chemistry, or any other natural science, one should have a firm understanding of the principles of physics. For example, biology uses the physics principles of fluid movement to understand how the blood flows through the heart, arteries, and veins. Chemistry relies on the physics of subatomic particles to understand why chemical reactions take place.

FIGURE 1.1 - PHYSICS AND TECHNOLOGY



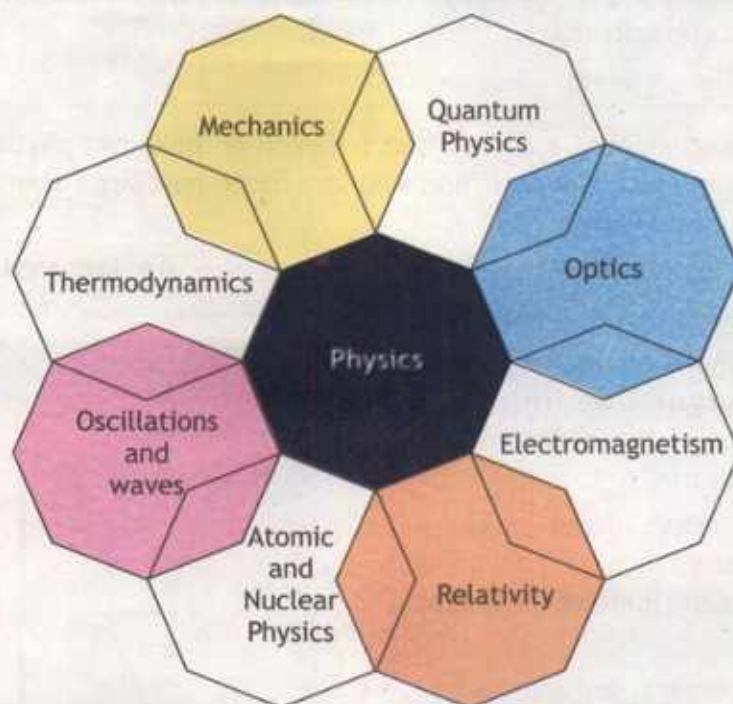
**Physics and Technology:** What are the technological devices that we use on a regular basis? Computers, smart phones, MP3 players, and internet come to our mind. What are technologies that you have only heard of? Rockets and space shuttles, Magnetically levitating trains, and microscopic robots that fight cancer cells in our bodies. All of these technologies, whether common place or exciting, are based on the principles of physics.

Physics is behind every technology and plays a key role in further development of these technologies, such as airplanes, computers, PET scans and nuclear weapons.



## 1.1.1 BRANCHES OF PHYSICS

Physics is vast and is therefore further subdivided in many other branches. These branches of physics are increasing as the technology is progressing, however the major branches of physics include mechanics, optics, oscillation and waves, thermodynamics, electromagnetism, astrophysics, quantum physics, atomic physics and nuclear physics.



The cubit was the measurement unit used by Egyptians to build the pyramid. The cubit is the measure from your elbow to the tip of your middle finger when your arm is extended.



Physics has strong connection with mathematics, to understand the nature physics we use mathematics as a tool. Therefore learning physics requires mathematical knowledge.



## 1.2 PHYSICAL AND NON-PHYSICAL QUANTITIES

“Physical quantities are those quantities which can be measured whereas non physical quantities are those quantities which can not be measured”.

Quantities like length, mass, time, density, temperature, can be defined and measured, therefore they are termed physical quantities while taste, feeling and color can not be measured so they are non physical quantities

### POINT TO PONDER



Measurement is a comparison between an unknown physical quantity (like length, mass, time etc) and standard to see how large or small it is compared to that standard.

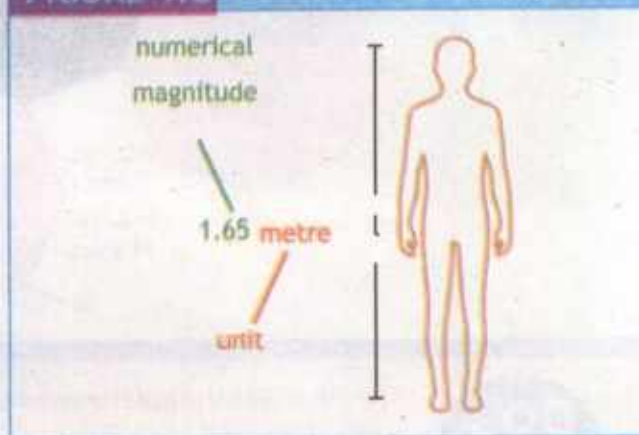
Unit is standard with which physical quantities are compared.

Measurement of a physical quantity consists of numerical magnitude (number representing the size of the quantity) and unit in which it is measured.

For example if the length of the person is 1.65 metres (5 foot and 5 inches), 1.65 is the numerical magnitude and meter is the unit as shown in figure 1.2.

To record a measurement, an appropriate unit is chosen and the size of quantity is then found with an instrument having a proper scale (like measuring tape).

FIGURE 1.2 LENGTH MEASUREMENT



### 1.2.1. BASE AND DERIVED PHYSICAL QUANTITIES

Base (or fundamental) physical quantities (like mass, length and time) are selected as the simplest form of physical quantities, such that all other physical quantities can be derived from them. The physical quantity obtained by multiplying or dividing base physical quantities are termed as the derived physical quantities.

## 1.3 INTERNATIONAL SYSTEM OF UNITS

‘A complete set of units for all physical quantities is called system of units’.

The international system of units is termed as System International (abbreviated as SI), a short form of the French name ‘Système International d’ Units’ which means ‘International System of Units’.



## 1.3.1. SYSTEM INTERNATIONAL (SI) BASE UNITS

In System International (SI) seven (07) physical quantities are chosen as base and their units are defined and standardized. These units are called base units. Each SI unit is defined carefully so that accurate and reproducible measurements can be made. The seven basic physical quantities, their SI base units and the symbols of SI units are given in the table 1.1.

| TABLE 1.1 BASE UNITS FOR INTERNATIONAL SYSTEM OF UNITS |                |              |        |
|--------------------------------------------------------|----------------|--------------|--------|
| SI Base Quantity                                       |                | SI Base Unit |        |
| Name                                                   | Symbol         | Name         | Symbol |
| length                                                 | l              | meter        | m      |
| mass                                                   | m              | kilogram     | kg     |
| time                                                   | t              | second       | s      |
| electric current                                       | I              | ampere       | A      |
| temperature                                            | T              | kelvin       | K      |
| amount of substance                                    | n              | mole         | mol    |
| light intensity                                        | I <sub>v</sub> | candela      | cd     |

## 1.3.2. SYSTEM INTERNATIONAL (SI) DERIVED UNITS

Units of derived quantities are obtained by multiplying and/or dividing base quantities. In SI units all other physical quantities can be derived from the seven base units.

For example, the unit for area is ' $m \times m = m^2$ ', in this example base unit of length is used. Similarly the unit for velocity is ' $m/s$ ' and acceleration is ' $m/s^2$ '. Some derived units are given special names and symbols. For example force has derived units of ' $kg\ m/s^2$ ' which is given special name as 'newton' and represented as 'N'. Some derived quantities with derived units in terms of base units are given in table 1.2.

**EXPLORE**

<https://www.bipm.org/en/>

**The BIPM is...**  
the international organization established by the Metre Convention in 1875 through which Member States act together to

TABLE 1.2 DERIVED UNITS FOR 'INTERNATIONAL SYSTEM OF UNITS'

| Derived Quantity |        | SI Derived Unit          |                                |
|------------------|--------|--------------------------|--------------------------------|
| Name             | Symbol | Name                     | Symbol                         |
| area             | A      | square meter             | $\text{m}^2$                   |
| volume           | V      | cubic meter              | $\text{m}^3$                   |
| speed, velocity  | v      | meter per second         | $\text{ms}^{-1}$               |
| acceleration     | a      | meter per second squared | $\text{ms}^{-2}$               |
| density          | $\rho$ | kilogram per cubic meter | $\text{kgm}^{-3}$              |
| force            | F      | newton (N)               | $\text{kgms}^{-2}$             |
| pressure         | P      | pascal (Pa)              | $\text{kgm}^{-1}\text{s}^{-2}$ |
| energy           | E, U   | joule (J)                | $\text{kgm}^2\text{s}^{-2}$    |

## 1.4 STANDARD FORM / SCIENTIFIC NOTATION

In physics we deal with numbers that are either very small or very large, for example, the width of the observable universe is approximately 880,000,000,000,000,000,000,000 metres (88 with 25 zeros). If we use this number often, it is not only time consuming but there are chances of reporting it wrong.

Scientific notation is an easy method of writing very large or small numbers in power of ten.



Standard form or scientific notation represents a number as the product of a number greater than 1 and less than 10 (called the mantissa) and a power of 10 (termed as exponent):

number = mantissa  $\times 10^{\text{exponent}}$

Therefore the width of the observable universe can scientifically be written compactly as  $8.8 \times 10^{26}$  metres, where '8.8' is the mantissa and '26' is the exponent. Similarly the mass of earth is 5,980,000,000,000,000,000,000,000 kg which is written as  $5.98 \times 10^{24}$  kg and the diameter of hydrogen nucleus is about 0.0000000000000017 metres, which is  $1.7 \times 10^{-15}$  m.



## 1.5 PREFIXES TO POWER OF TEN

A mechanism through which numbers are expressed in power of ten that are given a proper name is called prefix.

Prefixes makes standard form or scientific notation further easier. Large numbers are simply written in more convenient prefix with units.

The thickness of a paper can be written conveniently in smaller units of millimetre instead of metre. Similarly the long distance between two cities may be expressed better in a bigger unit of distance, i.e., kilometre. Some prefixes in SI to replace powers of 10 are given in table 1.3.

TABLE 1.3 PREFIXES

| Prefix | Decimal Multiplier | Symbol | Prefix | Decimal Sub-multiplier | Symbol |
|--------|--------------------|--------|--------|------------------------|--------|
| Exa    | $10^{18}$          | E      | deci   | $10^{-1}$              | d      |
| Peta   | $10^{15}$          | P      | centi  | $10^{-2}$              | c      |
| Tera   | $10^{12}$          | T      | milli  | $10^{-3}$              | m      |
| giga   | $10^9$             | G      | micro  | $10^{-6}$              | $\mu$  |
| Mega   | $10^6$             | M      | nano   | $10^{-9}$              | n      |
| kilo   | $10^3$             | k      | pico   | $10^{-12}$             | p      |
| hecto  | $10^2$             | h      | femto  | $10^{-15}$             | f      |
| deca   | $10^1$             | da     | atto   | $10^{-18}$             | a      |

For example

- the number of seconds in a day are:  
 $86400 \text{ s} = 8.64 \times 10^4 \text{ s} = 86.4 \times 10^3 \text{ s} = 86.4 \text{ ks}$
- the distance to the nearest star alpha centauri is:  
 $4.132 \times 10^{16} \text{ m} = 41.32 \times 10^{15} \text{ m} = 41.23 \text{ Pm}$
- the thickness of the page of this book is about:  
 $4.0 \times 10^{-5} \text{ m} = 40 \times 10^{-3} \text{ m} = 40 \text{ mm}$
- the mass of grain of salt is:  
 $1.0 \times 10^{-4} \text{ g} = 100 \times 10^{-2} \text{ g} = 100 \text{ mg}$



Volume is a derived quantity

$$1 \text{ L} = 1000 \text{ mL}$$

$$1 \text{ L} = 1 \text{ dm}^3$$

$$= (10 \text{ cm})^3$$

$$= 1000 \text{ cm}^3$$

$$1 \text{ mL} = 1 \text{ cm}^3$$



## CAN YOU TELL?

Can you write the number in power of ten and choose prefix to the following numbers

- The mass of Sun is about 1,970,000,000,000,000,000,000,000 kg.
- radius of a hydrogen atom, is about 0.00000000005 m.
- The age of earth is about 143,300,000,000,000 s.

Can you express the following in terms of powers of 10.

- The thickness of sheet of paper is about 100,000 nanometers.
- Pakistan has a total installed power generation capacity of over 40,000 megawatt.
- A single hard disk capacity of computers has exceeded 30 terabyte.

## EXAMPLE 1.1: SCIENTIFIC NOTATION

Convert the following numbers in Standard form / scientific notation.

- 149,530,000,000 m which is the average distance between earth and Sun.
- 0.0008 g which is the average mass of human hair.
- The number of seconds in a day.



## SOLUTION

(a) For Standard form / scientific notation we can write the term as

$$\text{Distance} = 149530000000.0 \times 10^0 \text{ m}$$

For Standard form / scientific notation, in order to get mantissa (M), we have to move the decimal 11 digits towards left. Therefore, the power of 10 will be positive 11, that is

$$\text{Distance} = 1.4953 \times 10^{11} \text{ m}$$

Answer

Which is the average distance between earth and sun in standard form / scientific notation

(b) In Standard form / scientific notation we can write the term as

$$\text{Mass of hair} = 0.0008 \times 10^0 \text{ g}$$

$$\text{Mass of hair} = 8 \times 10^{-4} \text{ g}$$

Answer

(c) We know that there are 24 hours in a day, 60 minutes in an hour, and 60 s in a minute. These three relationships are conversion factors. As

$$1 \text{ d} = 86,400 \text{ s}$$



For Standard form/scientific notation we can write the term as:

$$1 \text{ d} = 86,400.0 \times 10^0 \text{ s}$$

$$1 \text{ d} = 8.64 \times 10^4 \text{ s}$$

Answer

## EXAMPLE 1.2: PREFIXES

Write the numbers in standard/scientific notation and also represent using appropriate prefix.

(a) One ton of rice in gram

(b) The diameter of neutron is  $0.0000000000000018 \text{ m}$ .

### SOLUTION

(a) One ton is equal to a mass of 1000 kilograms

$$1 \text{ ton} = 1000 \text{ kg}$$

As we know that:  $1 \text{ kg} = 1000 \text{ g}$ , therefore  $1 \text{ ton} = 1000 \times 1000 \text{ g}$

$$1 \text{ ton} = 1,000,000 \text{ g} = 1,000,000.0 \times 10^0 \text{ g}$$

In scientific form: For Standard form / scientific notation in order to get mantissa (M), we have to move the decimal 6 digits towards left.

Therefore, the power of 10 will be positive 6, given by:

$$1 \text{ ton} = 1.0 \times 10^6 \text{ g}$$

Answer

Using prefix: As  $10^6 = \text{Mega}$ , therefore

$$1 \text{ ton} = 1.0 \text{ Mg}$$

Answer

(b) The diameter of proton is  $0.0000000000000017 \text{ m}$ , which can be written as

$$\text{Diameter of proton} = 0.0000000000000017 \times 10^0 \text{ m}.$$

$$\text{Diameter of proton} = 1.7 \times 10^{-15} \text{ m}$$

Answer

Using prefix:  $10^{-15} = \text{femto}$ , therefore

$$\text{Diameter of proton} = 1.7 \text{ fm}$$

Answer





## 1.6 SCALARS AND VECTORS

Does direction of wind matter when you fly a kite? You need to know the direction in which the air is blowing; otherwise, it will be difficult for you to keep your kite flying. Some physical quantities require direction to be specified completely. Therefore these directional properties can be used to categorize physical quantities as scalars and vectors.

### 1.6.1. SCALAR QUANTITIES OR SCALARS

Physical quantities which can be completely described only by its numerical magnitude (or size) with proper unit are termed as scalar quantities or simply scalars. Foreexamples distance, speed, time, mass, energy, and temperature etc are scalar quantities.

consider a man travels a distance of 4.5km but its direction is not specified but only this magnitude is given so it is said to be scalar quantity similarly we say that time is a scalar quantity, because when we say that time measurement is 30 s, here '30' is the numerical magnitude and 's' is proper unit. We does not need to state the direction of time.

Scalar quantities can be added, subtracted and multiplied by using ordinary rules of algebra. For example if we took 5 s to reach the door of the classroom and another 20 s to reach the gate of school, the total time we took is (5 s + 20 s) 25 seconds.

### 1.6.2. VECTOR QUANTITIES OR VECTORS

Physical quantities which require not only numerical magnitude (or size) with proper unit, but also the direction are termed as vector quantities or simply vectors. Vector quantities, such as displacement, force, weight, velocity, acceleration, momentum, electric field strength, and gravitational field strength, require both numerical magnitude and direction. When we refer to a vector quantity, we not only mention its numerical magnitude and unit, but also its direction. To fully describe a vector, its direction must be specified.

Since vector quantities are associated with direction, they cannot be added, subtracted, or multiplied using the usual rules of algebra. They follow their own set of rules known as vector algebra.

#### POINT TO PONDER



A coordinate system is used to locate the position of any point and that point can be plotted as an ordered pair (x, y) known as Coordinates. The horizontal number line is called 'X-axis' and the vertical number line is

called 'Y-axis' and the point of intersection of these two axes is known as the origin and it is denoted as 'O'. The reference frame is the coordinate system from which the positions of objects are described.

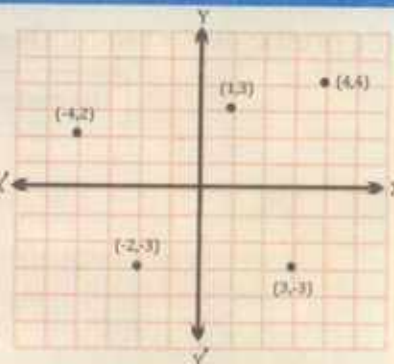


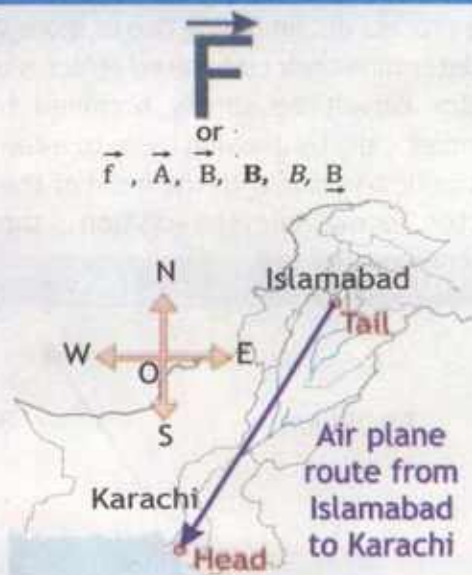


**FIGURE 1.3 VECTOR REPRESENTATION**

Symbolically a vector can be represented by a letter either capital or small. (e.g F and f or A and B) with an arrow over it.

Graphically a vector is represented by an arrow, the length of the arrow gives the magnitude with proper unit (under certain scale) and the arrow head points the direction of the vector. To use vectors we place them in coordinate axis.

Aeroplane route from Islamabad to Karachi is shown as a vector in figure. Here a Geographical Coordinate System having directions as North (N), East (E), West (W) and South (S) is used.



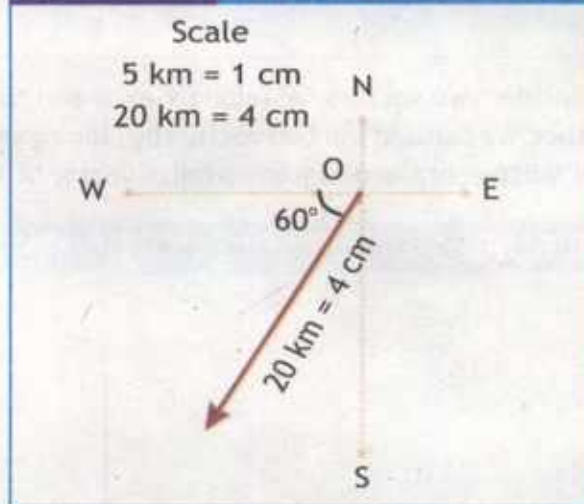
## Steps to Represent a Vector in Coordinate System

The following method is used to represent a vector

1. Choose and draw a coordinate system.
2. Select a suitable scale.
3. Draw a line in the fixed direction. Cut the line equal to the magnitude of the vector according to the chosen scale.
4. Put an arrow along the direction of the vector.

For example the representation of helicopter as it moves to 20 km from origin towards  $60^\circ$  south of west is shown in the figure 1.4.

**FIGURE 1.4 HELICOPTER MOTION**



Since displacement, force, weight, velocity, acceleration, momentum, electric field strength, and gravitational field strength are vector quantities or vectors. They will require to follow the rules of vector addition. This means that when we combine two vectors, the resulting value must also result as a vector.

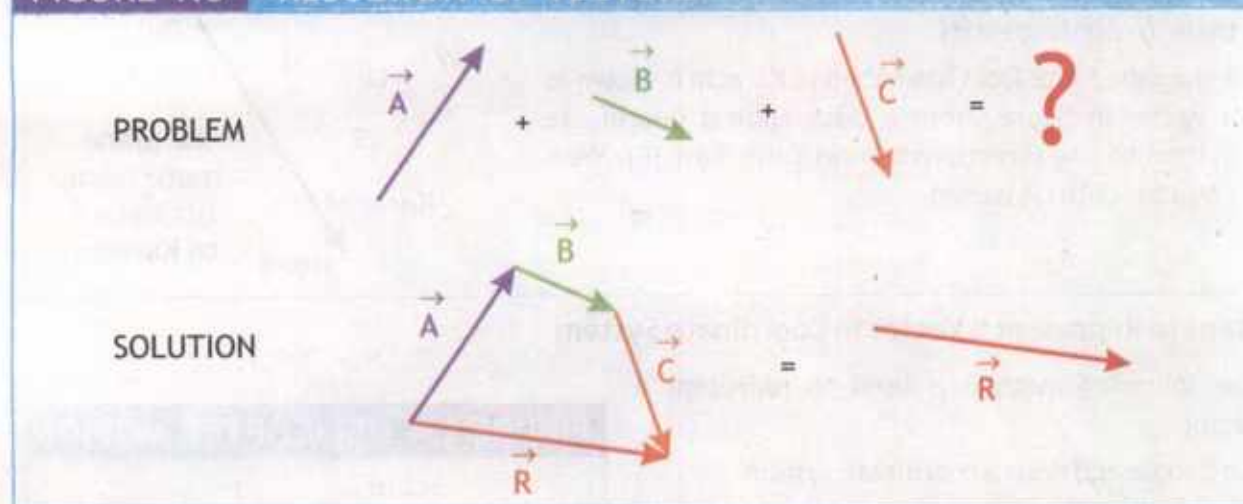


## UNIT 1 PHYSICAL QUANTITIES AND MEASUREMENT

### 1.6.3. ADDING VECTOR QUANTITIES

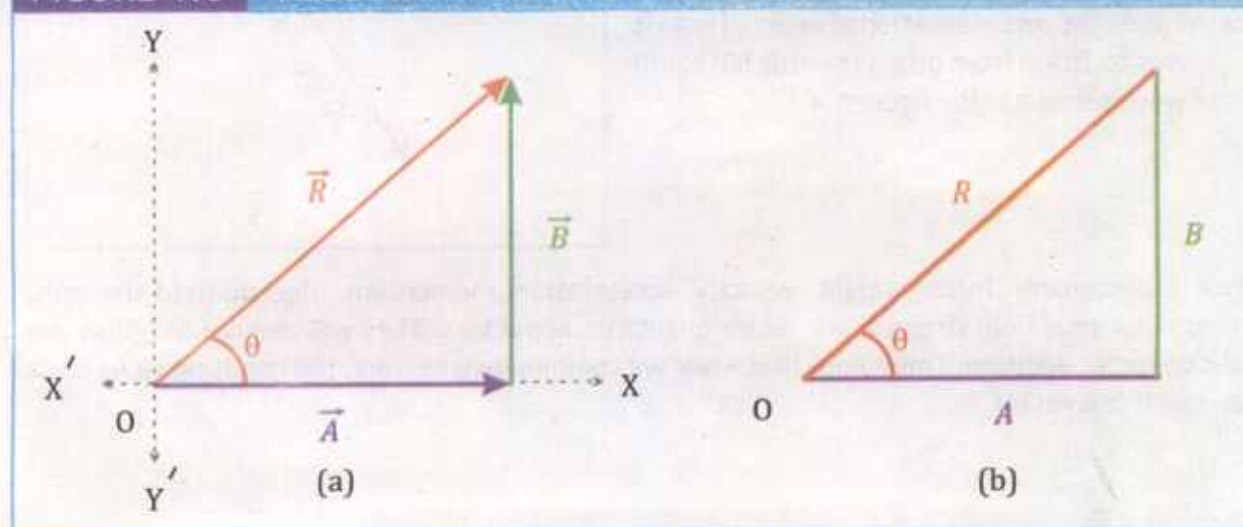
The process of combining two or more vectors into a single vector (called as resultant vector) to determine their cumulated effect is termed as vector addition. In vector algebra, the resultant vector cannot be simply obtained by adding vector values. Vectors may be added geometrically by drawing them to a common scale and placing them head to tail. Joining the tail of the first vector with the head of the last will give another vector which will be its **resultant vector**. For example, the addition of three vectors is shown in figure 1.5.

FIGURE 1.5 RESULTANT OF VECTORS



Consider two vectors ' $\vec{A}$ ' (along x-axis) and ' $\vec{B}$ ' (along y-axis), which are perpendicular to each other. We can add the two vectors by placing vector ' $\vec{B}$ ' on head of vector ' $\vec{A}$ ', the resultant vector ' $\vec{R}$ ' will be obtained by joining tail of vector ' $\vec{A}$ ' with head of vector ' $\vec{B}$ ', as shown in figure 1.6.

FIGURE 1.6 RESULTANT OF TWO VECTORS





## POINT TO PONDER



Does vector addition depends on the order? Will it make any difference if we add vector ' $\vec{A}$ ' with vector ' $\vec{B}$ ' or vector ' $\vec{A}$ ' with vector ' $\vec{B}$ '.

## 1.7 MEASURING INSTRUMENTS

Physics is built on definitions that are expressed in terms of measurements. For measurements of physical quantities we need devices termed as measuring instruments. These range from simple objects such as rulers and stopwatches to Atomic Force Microscope (AFM) and Scanning Tunneling Electron Microscope (STEM).

All measuring instruments have some measuring limitations.

Least count is the minimum value that can be measured on the scale of measuring instrument. The measurement of every instrument is therefore limited to its least count.

### 1.7.1 METRE RULE AND MEASURING TAPE

We use ruler to draw margin lines on our notebooks. Have you ever used the scale on it to draw the lines with exact lengths? A meter rule is a physics laboratory tool, used to measure the length of objects.

Metre rules are one metre long (as compared to the standard metre). Metre Rulers usually have 1000 small divisions on them called millimetres. Such metre rulers have least count of 1 mm as shown in figure 1.7.

These instruments have similar scale on it as drawn on our rulers, principally rulers are shorter version of metre rule.

FIGURE 1.7 METRE RULE



A measuring tape is a flexible ruler used to measure larger distance or length. It consists of a ribbon of cloth, plastic, metal, or fiberglass with linear measurement markings on it. The tape is usually housed in a compact case, and it can be pulled out and locked in place to measure distances. The most common units of measurement on a measuring tape are inches and centimeters. Measuring tapes come in various lengths, typically ranging from a few feet to several meters.

## POINT TO PONDER



Can you measure distances smaller than 1 mm on metre rule? Why?

## CAN YOU TELL?



Some metre rulers like the one shown in the figure 1.7 are marked with inches and feet? What is the least count of metre rule on this scale?



## ACTIVITY



In this activity the students will determine their height in metres and millimetres by making a paper scale and pasting it on the wall. The paper scale should be 2 m large with marking in metre, centimetre and millimetre.

They can form pair to measure each other heights, with paper scale.

## 1.7.2 VERNIER CALIPER

In physics sometimes we need to measure a length smaller than 1 mm. A vernier calliper can help take smaller than a millimetre reading.

'Vernier caliper is a device used to measure a fraction of a smallest division on scale by sliding another scale over it'.

It can be used to measure the thickness, diameter or width of an object and the internal, external diameter of hollow cylinder.

FIGURE 1.8 VERNIER CALLIPERS



There are two scales on vernier callipers.

A main scale which has markings of usually of 1 mm each and it contains jaw on its left end.

A sliding scale called vernier scale which has markings of some multiple of the marking on the main scale.

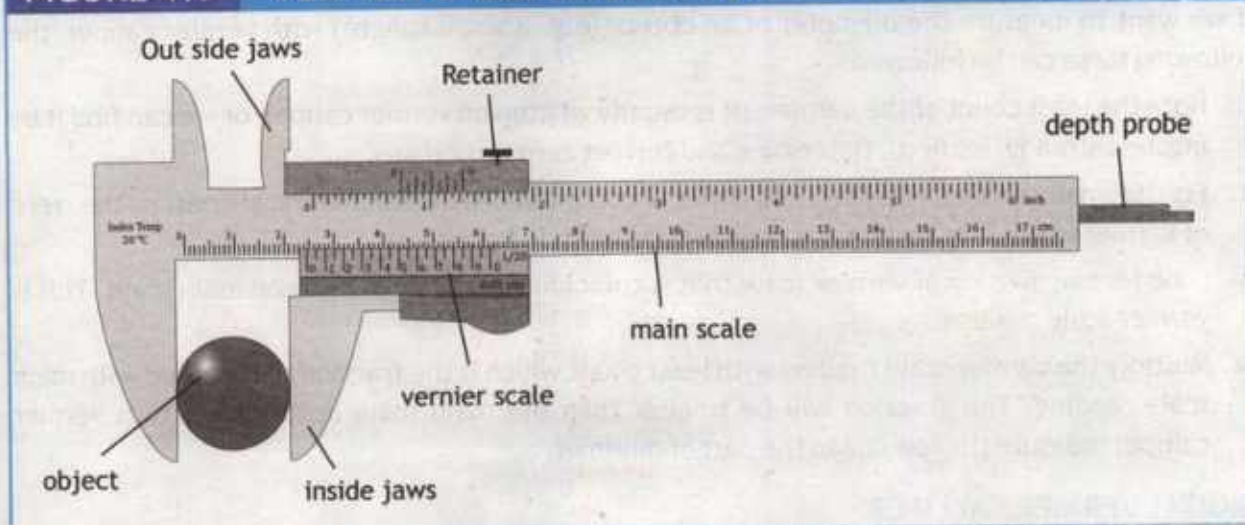
Minimum length which can be measured accurately with the help of a vernier callipers is called least count (vernier constant) of vernier callipers.

Least count can be obtained from dividing the value of smallest division on main scale by total number of divisions or vernier scale.

$$\text{Least Count} = \frac{\text{Smallest division on main scale}}{\text{Total number of divisions on vernier scale}}$$



FIGURE 1.9 VERNIER CALLIPER DIAGRAM



If the smallest main scale division is 1 mm and vernier scale division has 10 division on it then the least count of vernier caliper is:

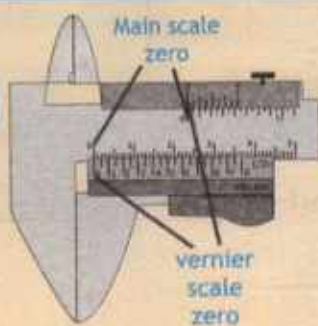
$$\text{Least Count} = \frac{1 \text{ mm}}{10} = 0.1 \text{ mm}$$



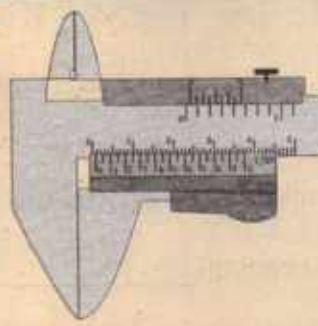
### CAN YOU TELL?

What is the length of the object measured by metre rod if it is 20.14 cm measured by vernier callipers?

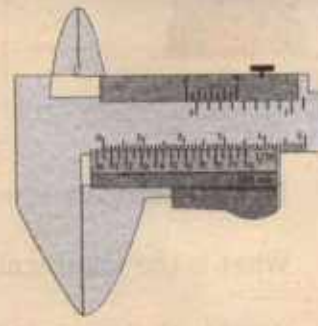
On closing the jaws of the vernier calipers, the zero of the vernier scale should coincide with the zero of the main scale. If their zeros does not coincide, there is an error in the instrument, called zero error. The zero error can be corrected which you will learn in laboratory work.



(a) There is no zero error as the zero line of vernier scale is coinciding with the zero of vernier scale.



(b) Zero error is positive as vernier scale is towards the right of the zero of main scale.



(c) Zero error is negative as vernier scale is towards the left of the zero of main scale.

## TAKING MEASUREMENT WITH VERNIER CALLIPERS

If we want to measure the diameter of an object (e.g. a small sphere) with vernier caliper, the following steps can be followed.

- Note the least count of the vernier, (it is usually written on vernier caliper, or we can find it by method already learned). Determine and correct zero error if any.
- Fix the small sphere in the jaws and note the complete divisions of main scale past by the zero of vernier scale. This is main scale reading as shown in figure 1.6.
- Look for the division of vernier scale that is coinciding with any division on main scale. This is vernier scale reading.
- Multiply the vernier scale reading with least count which is the fraction to be added with main scale reading. This fraction will be smaller than the main scale least count, thus vernier caliper measure the reading to the part of millimetre.

## DIGITAL VERNIER CALLIPER

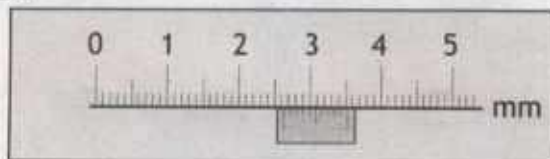
Digital Vernier Callipers has greater precision than mechanical vernier Callipers. Least count of Digital Vernier Callipers is 0.01 mm.



## ACTIVITY



Read the following Vernier Caliper measurement, and answer the following questions.



If the main scale is in millimetre, what is the least count? \_\_\_\_\_

What is the main scale reading? \_\_\_\_\_

What is the vernier scale reading? \_\_\_\_\_

What is total reading of the measurement? \_\_\_\_\_



## 1.7.3 SCREW GAUGE

Screw gauge is also length measuring device and is used for measurements even smaller than vernier callipers. 'Screw Gauge is a device used to measure a fraction of a smallest division on scale by rotating circular scale over it'.

The distance traveled by the circular scale on linear (or main) scale in one rotation is called the pitch of the screw gauge.

The minimum length which can be measured accurately by a screw gauge is called least count of the screw gauge. The least count of screw gauge is found by dividing its pitch by the number of circular scale divisions.

**FIGURE 1.10 SCREW GAUGE**

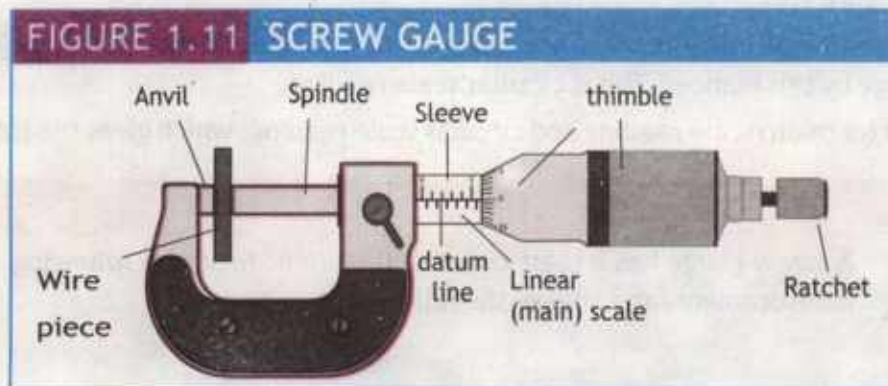


$$\text{Least Count} = \frac{\text{Pitch of Screw Gauge}}{\text{Total Number of Divisions on Circular Scale}}$$

If the pitch of the screw gauge is 0.5 mm and the number of divisions on circular scale is 50 then

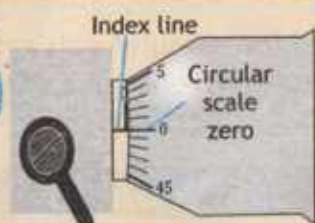
$$\text{Least Count} = \frac{0.5 \text{ mm}}{50} = 0.01 \text{ mm}$$

**FIGURE 1.11 SCREW GAUGE**

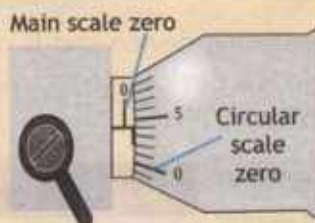


### ZERO ERROR IN SCREW GAUGE

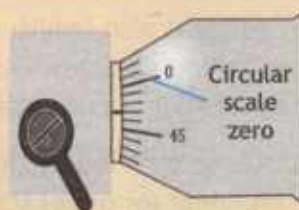
Turn the thimble until the anvil and spindle meet, datum line of the linear scale must meet with the zero on the thimble scale. If the zero mark on the thimble scale (or circular scale) does not lie directly opposite the datum line of the main scale we say that there is zero error. The zero error and its correction will be discussed in laboratory work.



(a) As zero of circular scale is exactly on the index line hence there is no zero error.



(b) Zero error is positive if zero of circular scale has not reached zero of main scale.



(c) Zero error is negative if zero of circular scale has passed zero of main scale.

### TAKING MEASUREMENT WITH SCREW GAUGE

If we want to measure the diameter of an object (e.g a wire piece) with screw gauge, the following steps can be followed.

- Note the pitch and least count of the screw gauge and determine the zero error (if any).
- Place the object (e.g a wire piece) between with spindle and anvil. Now gently close the gap between the spindle and the anvil by turning the ratchet.
- Turn the ratchet until it starts to click. The ratchet prevents the user from exerting too much pressure on the object.
- Read the main scale reading, which is the reading shown (or unblocked) by circular scale as shown in figure 1.8.
- Identify the line of circular scale aligned with datum line, now multiply the least count of screw gauge by this number. This is circular scale reading.
- Add linear (or main) scale reading and circular scale reading, which gives the total reading.

### ACTIVITY



A screw gauge has a least count of 0.01 mm. Read the following screw gauge measurement, and answer the following questions.



What is the main scale reading? \_\_\_\_\_

What is the circular scale reading? \_\_\_\_\_

What is total reading of the measurement? \_\_\_\_\_



## CAN YOU TELL?



You have to measure the thickness of page and internal diameter of a beaker which instrument would you use vernier calliper or screw gauge? Why?

## FOR YOUR INFORMATION

Least count of ruler is 1mm. It is 0.1mm for Vernier Callipers and 0.01mm for micrometer screw gauge.

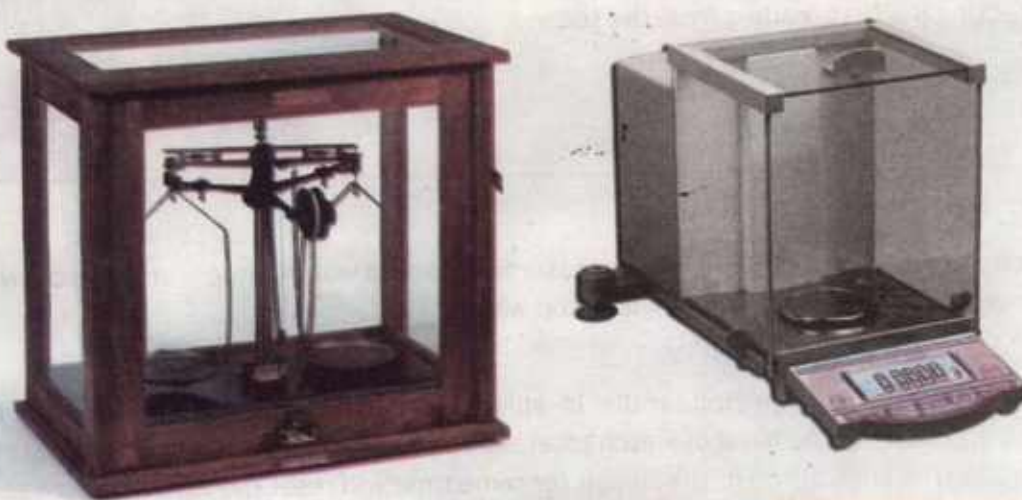
Thus measurements taken by micrometer screw gauge are the most precise than the other two.

### 1.7.4 PHYSICAL BALANCE

The balance (also balance scale, beam balance and laboratory balance) was the first mass measuring instrument invented. A physical balance as shown in figure 1.12 (a) is a very sensitive common balance which can measure weights in milligram order. It consists of a vertical pillar having a horizontal beam, resting on knife edge with two pans. A long pointer is attached to the middle of the beam.

Leveling screws are used to level the physical balance, while the pointer is set at the center of the scale by adjusting screws. It is placed in a protective glass case so that even dust and wind can not affect the accuracy of the instrument. A weight box containing standard weights comes with the balance. The mass of a body is found by placing the body in one pan, placing some standard weights in the other, and then calculating it from the standard weights placed and the resting point of the pointer.

FIGURE 1.12 PHYSICAL BALANCE

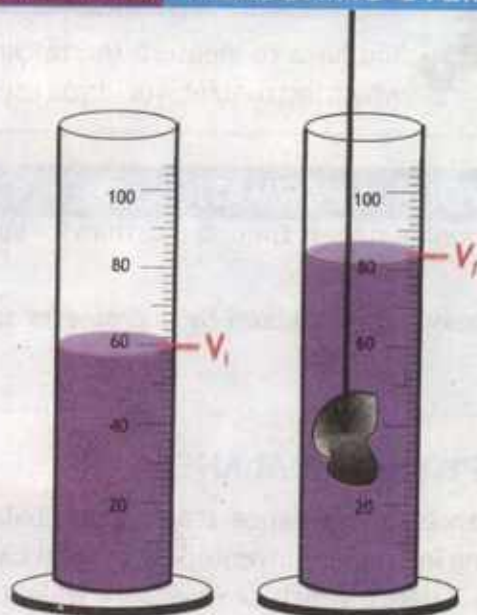




### 1.7.5 MEASURING CYLINDER

A measuring cylinder is a tool used in laboratories to measure the volume of liquids, chemicals, or solutions. It is also known as a graduated cylinder. Measuring cylinders are typically made of transparent plastic or glass and have a vertical scale in milliliters (ml) or cubic centimeters ( $\text{cm}^3$ ). The volume of a liquid can be determined by measuring the height of the liquid in the cylinder. The least count of a measuring cylinder is usually  $1 \text{ cm}^3$ , meaning that any volume change smaller than this cannot be measured. Measuring cylinders come in various sizes, ranging from small capacities of a few milliliters to larger capacities of several liters. The choice of cylinder size depends on the volume of the liquid being measured.

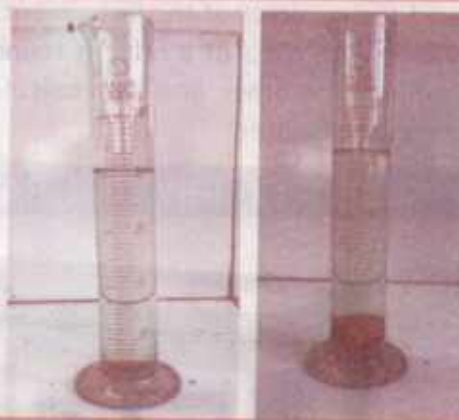
FIGURE 1.13 MEASURING CYLINDER



#### ACTIVITY



Measuring cylinder can be used for measuring the volume of an irregular solid body such as metallic bob as shown in figure. When the object is completely immersed the volume of the water is read again. The volume of the object is found by subtracting the first reading from the second.



### 1.7.6 STOP WATCH

The duration of specific interval of time is measured by a stop watch. Stop watch are of two main types i.e. mechanical stop watch and digital stop watch.

#### MECHANICAL / ANALOGUE STOP WATCH

It has two circular dials, a large circular dial in which a second hand of watch rotates and a small minute hand in which minute hand of watch rotates as shown in figure 1.14. The watch starts and stops by pressing the knob at top it, pressing it for some time will reset the watch back to zero.



**FIGURE 1.14 MECHANICAL AND DIGITAL STOP WATCH**



Generally the least count of analogue stop watch is 1 s and digital stop watch is 0.1 s

## DIGITAL STOP WATCH

Digital stop watch are usually controlled by two buttons on the case as shown in the figure. Pressing the left button starts the timer and by pressing it again the time stops, thus the elapsed time is shown in the figure 1.14.

Pressing the right button resets the stopwatch to zero. The right button is also used to record split times or lap times.

## 1.8 ERRORS

**Every measurement, no matter how carefully taken, has a certain amount of doubt known as error. Error is simply the uncertainty that arises during measurement.** This means that all measurements are only approximate due to the presence of errors.

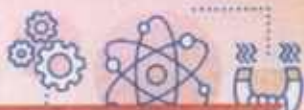
There are two main types of errors in measurement: systematic errors and random errors.

### 1.8.1 SYSTEMATIC ERRORS

Systematic errors tend to occur consistently in one direction, either positive or negative. Some sources of systematic errors include:

- (a) Instrumental errors, which result from imperfections in the design or calibration of the measuring instrument, as well as zero errors.
- (b) Imperfections in the experimental technique or procedure, such as changes in external conditions like temperature, humidity, or wind velocity, which can systematically affect the measurement.
- (c) Personal errors, which arise from an individual's bias, improper setup of the apparatus, or carelessness in taking observations without following proper precautions.

Systematic errors can be reduced by improving experimental techniques, choosing better instruments, and minimizing personal bias as much as possible. These errors can be estimated to some extent for a given setup, and the necessary adjustments can be made to the measurements.

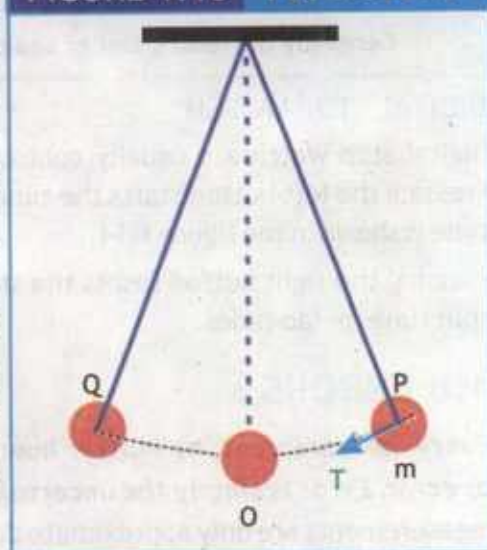


### 1.8.2 RANDOM ERRORS

Random errors are unpredictable and uncontrollable errors that can happen irregularly. These errors can be caused by fluctuations in experimental conditions or imperfections in measuring instruments. The person conducting the measurements can also introduce variability due to factors like reaction time or technique. Because of this, if the same person repeats an observation multiple times, they are likely to get different readings each time. To minimize random errors, it is important to take repeated measurements and use statistical analysis to account for the variability.

During measurements, it is always a good idea to take multiple of the same measurement and find the mean, as it reduces errors. A simple pendulum is simply a mass that swings back and forth about a fixed point as shown in figure 1.15. One single oscillation of a pendulum is when it swings back to the exact same position and achieves the same state of motion that it started at. For example, if the pendulum started swinging from its right most point (from its position of maximum amplitude), the mass would have to swing towards the left and then come back all the way to the right to complete one oscillation. The time taken to complete a single oscillation is called a period. To measure the period of a pendulum, you usually measure the time taken for ten oscillations and then calculate the mean.

FIGURE 1.15 PENDULUM



That is, you divide the total length of time by 10, to get the period of one oscillation. This will reduce the error in measurement as human reflexes are usually too slow to be completely accurate, and that inaccuracy can have a major impact on something as small as a period.

### 1.9 PRECISION AND ACCURACY

Precision and accuracy are both important factors in determining the reliability and validity of measurements and experimental results. While precision focuses on the consistency and repeatability of results, accuracy is concerned with how close the measured values are to the true or accepted values.

Precision can be thought of as the degree of agreement between repeated measurements of the same quantity. If a set of measurements consistently yields similar results, with little variation or scatter, then it is considered to be precise. This indicates that the measurement process is reliable and consistent, and that the results can be reproduced under the same conditions. For example, a scale that always gives the same weight within a margin of 0.1 kg is precise, even if it consistently overestimates the true weight by 0.5 kg (not accurate).



Accuracy, on the other hand, refers to how close a measured value is to the true or accepted value. It is a measure of the absence of systematic errors or biases in the measurement process. An accurate measurement is one that is close to the true value, regardless of whether it is consistently reproducible. For example, thermometer that consistently reads 2 degrees Celsius higher than the actual temperature is not accurate, even if its readings are very precise (always 2 degrees above).

precision focuses on the consistency and reproducibility of measurements, while accuracy assesses how close the average of those measurements is to the true value.

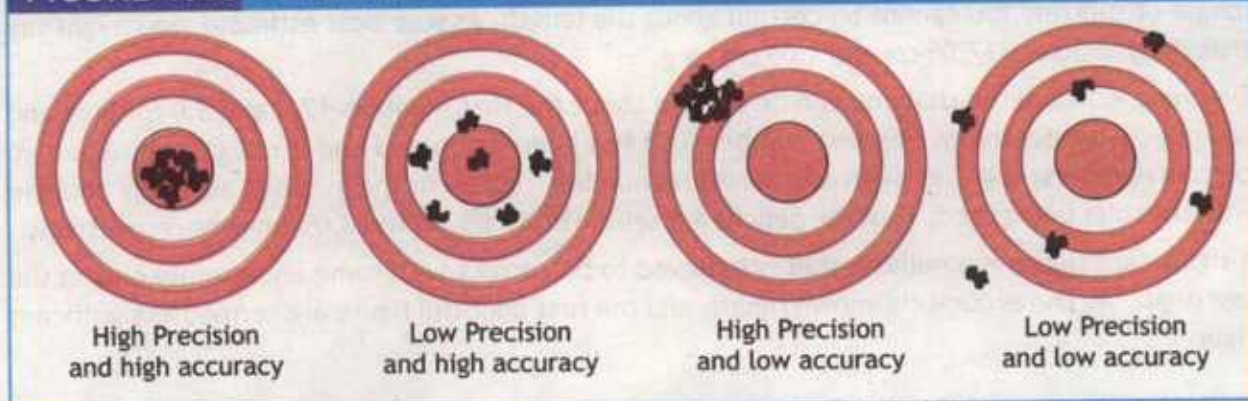
Imagine throwing darts at a target as shown in figure 1.16. If your darts land close to the center of the target (hitting the bullseye is ideal) your aim will be referred as accurate. Your darts are grouped tightly together, even if they're not in the center (a tight cluster off-center) your aim will be termed as precise, therefore, it's possible for something to be:

**Accurate and precise:** Your darts hit the bullseye and are tightly grouped.

**Accurate but not precise:** Your darts land near the center, but they're scattered all over the place.

**Precise but not accurate:** Your darts are tightly grouped, but they're all off-center in the same direction.

**FIGURE 1.16 PRECISION AND ACCURACY**



## CAN YOU TELL?

Books in a library were counted one by one. There were a total of 57,000 books in the library. How many significant digits are there in the result? Will the result change if the books are measured in the packets of 10?

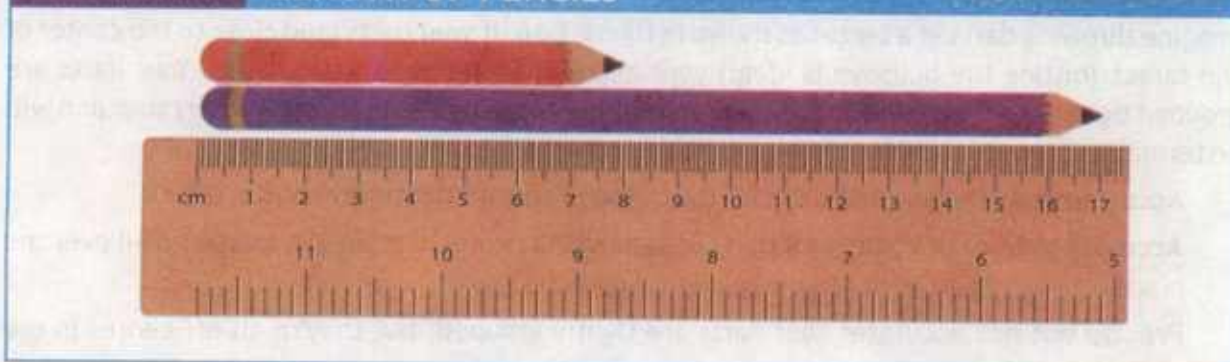
In practice, both precision and accuracy are desirable qualities in measurements. A measurement can be precise but not accurate, or accurate but not precise. Ideally, measurements should be both precise and accurate, meaning that they are both consistent and close to the true value. Achieving both precision and accuracy often requires careful calibration of instruments, control of experimental conditions, and consideration of sources of error.

## 1.10 SIGNIFICANT FIGURES

There are two types of values, exact and measured. Exact values are those that are counted clearly. For example while reporting 3 pencils or 2 books, we can indicate the exact number of these items.

The numerical value of any measurement will always contain some uncertainty. Suppose, for example, that you are measuring the length of two pencils as shown in figure 1.17.

**FIGURE 1.17 LENGTH OF PENCILS**



It seems clear that the length of blue pencil is greater than 17 cm but shorter than 17.1 cm, similarly the length of red pencil is greater than 8 cm but shorter than 8.1 cm. But how much longer or shorter? You cannot be certain about the length. As your best estimate, you might say that the pencils are 17.05 cm and 8.05 cm long.

Everyone would agree that you can be certain about the first numbers 17.0 and 8.0 for blue and red pencils respectively. The last number 0.05 has been estimated and is not certain. The two certain numbers, together with one uncertain number, represent the greatest accuracy possible with the ruler being used. Thus the pencils are said to be 17.05 cm and 8.05 cm long respectively.

A significant figure is a number that is believed to be correct with some uncertainty only in the last digit. 'All the accurately known figures and the first doubtful figure are termed as significant figures'.

### MINI-LAB



Measure the length, width and thickness of physics textbook and report your observations in significant figures. Does your reading depends upon the instrument you used for measurement?

#### 1.10.1 GENERAL RULES FOR WRITING SIGNIFICANT FIGURES

There are a few simple rules that help us determine how many significant figures are contained in a reported measurement:

1. All digits reported as a direct result of a measurement are significant.



- The reported NONZERO digits (all digits from 1 to 9) are always significant. For example the number of significant figures in 23.457 is 5.
- In figures reported as larger than the digit 1, the digit 0 is not significant when it follows a nonzero digit to indicate place. For example, in a report that '29,000 spectators watched a cricket match'. The digits 2 and 9 are significant but the zeros are not significant. In this situation, the 29 is the measured part of the figure, and the three zeros tell you an estimate of how many watched the match. If this figure is a measurement rather than an estimate, then to avoid confusion it is written in scientific notation with exact number of significant figures as in measurement e.g  $2.90 \times 10^5$  showing three significant figures or  $2.900 \times 10^5$  showing four significant figures or even  $2.9000 \times 10^5$  showing 5 significant figures.
- In figures reported as smaller than the digit 1, zeros after a decimal point that come before nonzero digits are not significant and serve only as place holders. For example, 0.0029 has two significant figures: 2 and 9. The zeros after a nonzero digit indicate a measurement, so these zeros are significant. The figure 0.00290, for example, has three significant figures.

## EXAMPLE 1.3: SIGNIFICANT FIGURE

Find the number of significant figures in each of the following values. Also express them in scientific notations.

a) 100.8 s

b) 0.00580 km

c) 210.0 g

### SOLUTION

a) All the four digits are significant. The zeros between the two significant figures 1 and 8 are significant. To write the quantity in scientific notation, we move the decimal point two places to the left, thus

$$100.8 \text{ s} = 1.008 \times 10^2 \text{ s}$$

b) The first two zeros are not significant. They are used to space the decimal point. The digit 5, 8 and the final zero are significant. Thus there are three significant figures. In scientific notation, it can be written as

$$5.80 \times 10^{-3} \text{ km.}$$

c) The final zero is significant since it comes after the decimal point. The zero between last zero and 1 is also significant because it comes between the significant figures. Thus the number of significant figures in this case is four. In scientific notation, it can be written as

$$210.0 \text{ g} = 2.100 \times 10^2 \text{ g}$$

## 1.10.2 ROUNDING OFF NUMBERS AND SIGNIFICANT FIGURES

Rounding off numbers is an essential practice in scientific and quantitative contexts as it allows for the presentation of numbers with the appropriate level of precision. In these fields, accuracy and precision are crucial, and rounding off numbers helps to achieve this.



When dealing with measurements or calculations, it is often necessary to express the result in a more manageable or meaningful form. Rounding off numbers allows scientists and researchers to simplify complex figures without sacrificing the overall accuracy of the data.

Significant figures play a vital role in determining which digits in a number are reliable and meaningful. They indicate the precision of a measurement or calculation by identifying the digits that are known with certainty. By using significant figures, scientists can convey the level of uncertainty associated with a particular value. For example, consider a scientific experiment that measures the length of an object to be 3.5678 centimeters. While this measurement may be precise, it is not practical to report it with such detail. Rounding off the number to three significant figures, we can express it as 3.57 centimeters, which provides a more concise representation without compromising the accuracy of the measurement.

Rounding numbers is the act of approximating a number to a simpler value that is easier to use, understand, or work with. It includes reducing the number of digits while maintaining an appropriate level of accuracy for the situation.

**A. Rounding rules for whole numbers:** When rounding to a specific whole number of significant figures, we follow these steps:

1. Always choose the smaller place value for an accurate final result. Find the next smaller place to the right of the number being rounded off. For example, if rounding off a digit from the tens place, look at the digit in the ones place.
2. If the digit in the smallest place is less than 5, leave it as it is. Any digits after that become zero, which is called rounding down.
3. If the digit in the smallest place is greater than or equal to 5, add +1 to that digit. Any digits after that become zero, which is called rounding up.

**B. Rounding rules for decimal numbers:** The rules for rounding decimal numbers are as follows:

1. Find the digit you want to round and look at the digit to its right.
2. If the digits to the right are less than 5, treat them as zero.
3. If the digits to the right are 5 or greater, add 1 to that digit and treat all other digits as zero.

### EXAMPLE 1.4: ROUNDING OFF

Round off the following numbers to

- (a) Two decimal points      i) 3.876      ii) 657.873      iii) 0.0857  
(b) Three significant digits      i) 24.68      ii) 0.07683      iii) 7,847

#### SOLUTION

a) In order to round off a number to two decimal points, we will drop all digits after the decimal except two.

- i) 3.876: Here the dropping digit is 6, which is greater than 5, so, it will be dropped by increasing the next digit 7. So, the answer is 3.88.



- ii) 657.873: Here the dropping digit is 3, which is smaller than 5, so, it will be dropped without any change to the next digit. So, the answer is 657.87.
- iii) 0.0857: Here the dropping digits are 5 and 7. After dropping 7 (which is greater than 5), the next digit will become 6 to get 0.086. Now by dropping 6, the next digit will become 9. So, the answer is 0.09.
- b) In order to round off a number to three significant digits, we will drop or replace with zero all digits except three significant digits.
- i) 24.68: Here we will drop the digit 8, which is greater than 5, so it will increase the next digit to 7. So, the answer is 24.7.
- ii) 0.07683: Here we will drop the digit 3, which is smaller than 5, so it will not change the next digit. So, the answer is 0.0768.
- iii) 7,847: As this is a whole number so, the digit 7 is replaced by zero. As it is greater than 5, so it will increase the next digit to 5. So, the answer is 7,850

## SUMMARY

**Physics** is the branch of science which deals with the study of matter and energy.

**Physical quantities** are measurable quantities

**System International (SI)** is the system of units which consists of seven base units and a number of derived units.

**Seven Base SI Units** are metre (length), kilogram (mass), second (time), ampere (current), candela (luminous intensity), Kelvin (temperature) and mole (amount of substance).

**Scientific Notation** is an internationally accepted way of writing numbers in which numbers are recorded using the power of ten and there is only one non zero digit before the decimal.

**Vernier calliper** is a device used to measure a fraction of smallest scale division by sliding another scale over it.

**Screw Gauge** is a device used to measure a fraction of smallest scale division by rotatory motion of circular scale over it.

**Stop Watch** is an instrument used for measurement of time interval

**Significant Figures** are the accurately known digits and first doubtful digit in any measurement.



## EXERCISE



## MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option.

- Which one of the following unit is not a derived unit?  
A. pascal                      B. kilogram                      C. newton                      D. watt
- Amount of a substance in terms of numbers is measured in:  
A. gram                      B. kilogram                      C. newton                      D. mole
- The number of significant figures in 0.00650 s are:  
A. . 2                      B. . 3                      C. 5                      D. 6
- Which of the following numbers show 4 significant digits?  
A. 9000.8                      B. 4                      C. 5174.00                      D. 0.001248
- Which of following prefix represents a largest value?  
A. mega                      B. pico                      C. peta                      D. kilo
- Micrometer can be used to measure:  
A. current                      B. force                      C. length                      D. mass
- The instrument best measures the internal diameter of a pipe is:  
A. screw gauge                      B. vernier caliper                      C. metre rule                      D. measuring tape
- Least count of screw gauge is 0.01 mm. If main scale reading of screw gauge is zero and third line of its circular scale coincides with datum line then the measurement on the screw gauge is:  
A. 0 mm                      B. 3 mm                      C. 0.03 mm                      D. 0.3 mm
- $9.483 \times 10^3$  m is the standard form of  
A. 94.83 m                      B. 9.483 m                      C. 948.3 m                      D. 9483 m
- Which of the following is a base unit?  
A. pascal                      B. coulomb                      C. meter per second                      D. mole
- The numbers having one significant digit is:  
A. 1.1                      B. 6.0                      C. 7.1                      D.  $6 \times 10^2$
- Ratio of millimetre to micrometre is:  
A. 1000 metre                      B. 0.001 metre                      C. 1000                      D. 0.001
- 0.2 mm in units of meters is:  
A. 0.0002 m                      B.  $2 \times 10^{-4}$  m                      C. both A and B                      D. none



## SHORT RESPONSE QUESTIONS

**QII. Give a short response to the following questions**

1. How physics plays an important role in our life?
2. Estimate your age in minutes and seconds
3. What base quantities are involved in these derived physical quantities; force, pressure, power and charge.
4. Show that prefix micro is thousand times smaller than prefix milli.
5. Justify that displacement is a vector quantity while energy is a scalar quantity.
6. Screw gauge can give more precise length than vernier calipers. Briefly explain why?
7. Differentiate between mechanical stop watch and digital stop watch.
8. How measuring cylinder is used to measure volume of an irregular shaped stone?
9. What precaution should be kept in mind while taking measurement using measuring cylinder?
10. Why do we need to consider significant digits in measurements?
11. How random error can be reduced?
12. Differentiate between precision and accuracy.

## LONG RESPONSE QUESTIONS

**QIII. Give a detailed response to questions below.**

1. Define Physics. Describe its revolutionary role in technology.
2. List with brief description of different branches of physics.
3. What are physical quantities? Distinguish between base physical quantities and derived physical quantities. Give at least three examples to show that derived physical quantities are derived from base physical quantities.
4. What do you mean by unit of a physical quantities? Define base units and derived units.
5. What are prefixes? What is their use in measurements?
6. What is scientific notation or standard form of noting down a measurement? Give at least five examples.
7. Describe construction and working of vernier calipers in detail.
8. What is screw gauge? What is its pitch and least count? How is it used to measure thickness of thin copper wire?
9. Define error. Differentiate between random and systematic error. How can these errors be reduced?
10. Differentiate between scalars and vectors. Justify that distance, speed, mass and energy are scalars while displacement, velocity, acceleration and force are vectors.
11. Justify and illustrate the use of a measuring cylinder to measure the volume of a liquid.
12. Differentiate between precision and accuracy.



## NUMERICAL RESPONSE QUESTIONS

**QIV. Solve the questions given below.**

1. Write the following numbers in scientific notations

a. 1234 m

b. 0.000023 s

c.  $469.3 \times 10^5$  m

d.  $0.00985 \times 10^7$  s

2. Express the followings measurements using prefixes

a.  $27.5 \times 10^{-10}$  m

b.  $0.00023 \times 10^{-2}$  s

3. If a boy has age of 15 years 2 months and 10 days, convert his age in

a. seconds

b. milli seconds

c. mega seconds

4. How many kilometers are there in 25 micrometers?

5. What is pitch and least count of:

a. Vernier calipers if smallest division on main scale is 1mm and total divisions on vernier scale are 20.

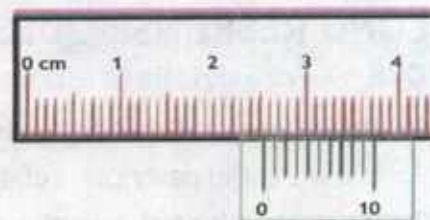
b. Screw gauge if smallest division on its main scale is 0.5 mm and its movable scale has 50 divisions.

6. Look at the measurement of vernier calipers:

a. What is its main scale reading?

b. What is its coinciding division on vernier scale?

c. Calculate total reading on the vernier calipers?

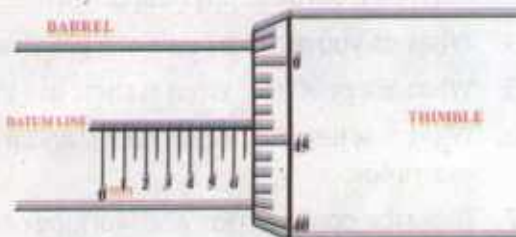


7. Look at the figure of screw gauge, let a small steel ball is place between its thimble and anvil then:

a. What is its main scale reading?

b. What is coinciding division of circular scale?

c. Calculate the total diameter of the ball?



# KINEMATICS

UNIT  
2



How fast the  
bullet move?

## Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-01] Differentiate between different types of motion.
- [SLO: P-09-B-02] Differentiate between distance and displacement, speed and velocity.
- [SLO: P-09-B-03] Define and calculate speed.
- [SLO: P-09-B-04] Define and calculate average speed.
- [SLO: P-09-B-05] Differentiate between average and instantaneous speed.
- [SLO: P-09-B-06] Differentiate between uniform velocity and non-uniform velocity.
- [SLO: P-09-B-07] Define and calculate acceleration.
- [SLO: P-09-B-08] Differentiate between uniform acceleration and non-uniform acceleration.
- [SLO: P-09-B-9] Sketch, plot and interpret distance-time and speed-time graphs.
- [SLO: P-09-B-10] Use the approximate value  $9.8\text{ m/s}^2$  for free fall acceleration near Earth to solve problems.
- [SLO: P-09-B-11] Justify how the gradient of a distance vs time graph gives the speed.
- [SLO: P-09-B-12] Analyse the distance traveled in speed vs time graphs.
- [SLO: P-09-B-13] Derive how the area beneath a speed vs time graph gives the distance traveled.
- [SLO: P-09-B-14] Calculate acceleration from the gradient of a speed-time graph.
- [SLO: P-09-B-15] Justify how the gradient of the speed vs time graph gives the acceleration.
- [SLO: P-09-B-16] State that there is a universal speed limit for any object in the universe that is approximately  $3 \times 10^8 \text{ ms}^{-1}$ .

Mechanics is the study of motion. Everywhere we look, objects are moving. We see people moving on roads, some using vehicles. Actually, everything we know is constantly in motion. Celestial objects and our Earth are always moving. Even objects that appear to be still have atoms and molecules that vibrate in continuous motion.

Our formal study of physics starts with kinematics, which is the study of motion without considering its causes. The term "kinematics" comes from Greek and means motion. In this unit, we will only focus on the motion of objects, without concerning ourselves with the forces that cause or change their motion.

## 2.1 REST AND MOTION

If with passage of time an object does not change its position then it is at rest with respect to an observer and if it is changing its position then it is in motion.

When we look around us, we observe that many objects do not change their position. Thus we consider them at the state of rest. For example a bench in a park fixed under a tree is at rest as there is no change in its position with respect to us while standing near it with the passage of time. On the other hand we also observe that many objects do change their position from one place to another. Hence we consider them to be in the state of motion. For example a car is in motion if there is change in its position with time.

### POINT TO PONDER



Interestingly objects can be at rest and in motion at same time. It looks simple to distinguish the rest from motion, for example a car starts, it changes its position with reference to its surrounding, we say that car is moving.

However, we know that Earth is spinning on its axis, so the car along with its road is also in motion. Not only this but Earth is also moving around the sun and the sun along with the rest of the solar system are also moving through our milky way galaxy. Apart from this our galaxy is also traveling through space. How can

we say that our car is at rest? This is why when we state an object to be at rest or motion, we specify it reference to some observer.

### 2.1.1 TYPES OF MOTION

Looking at the motion of object we see that objects move differently. These different types of motion can be broadly categorized in three types translatory motion, rotatory motion and vibratory motion.

**A. Translatory motion:** If all points of a moving object move uniformly in the same direction, such that there is no change in the object's orientation the object is said to be undergoing translatory motion (also termed as translational motion).

**FIGURE 2.1** TRANSLATORY MOTION



A basketball is shown in figure 2.1 as an example of translatory motion. All the three points ' $P_1$ ', ' $P_2$ ' and ' $P_3$ ' moves parallel to each other and there is no change in its orientation relative to a fixed point.

**B. Rotatory motion:** When an object rotates on its own axis (a line passing through the object), the object is said to be undergoing rotatory motion (also termed as rotational motion). A basketball in figure 2.2 is again shown as an illustration of rotational motion.

**FIGURE 2.2 ROTATORY MOTION**



The point ' $P$ ' is rotated around an axis of rotation passing through the center of it.

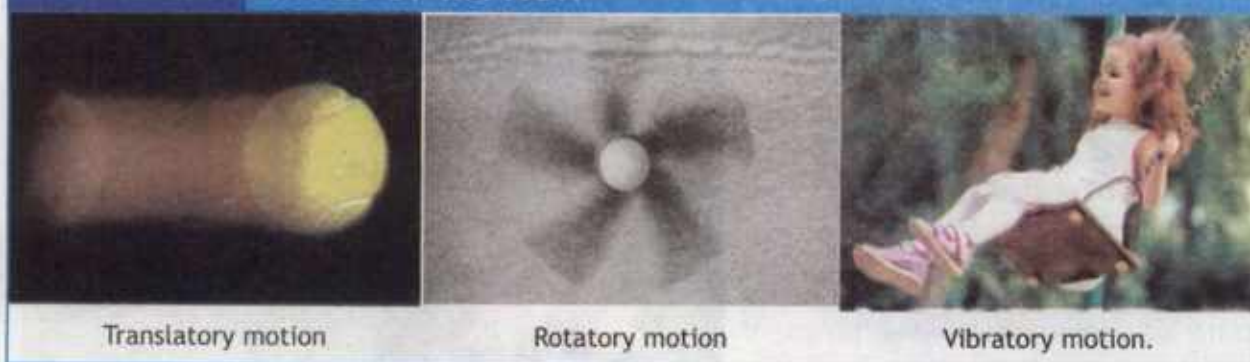
**C. Vibratory motion:** When an object is moving forward and backward repeatedly about mean position (certain fixed position), the object is said to be undergoing vibratory motion (also termed as vibrational motion). A basketball in figure 2.3 is shown as an example of vibrational motion.

**FIGURE 2.3 VIBRATORY MOTION**



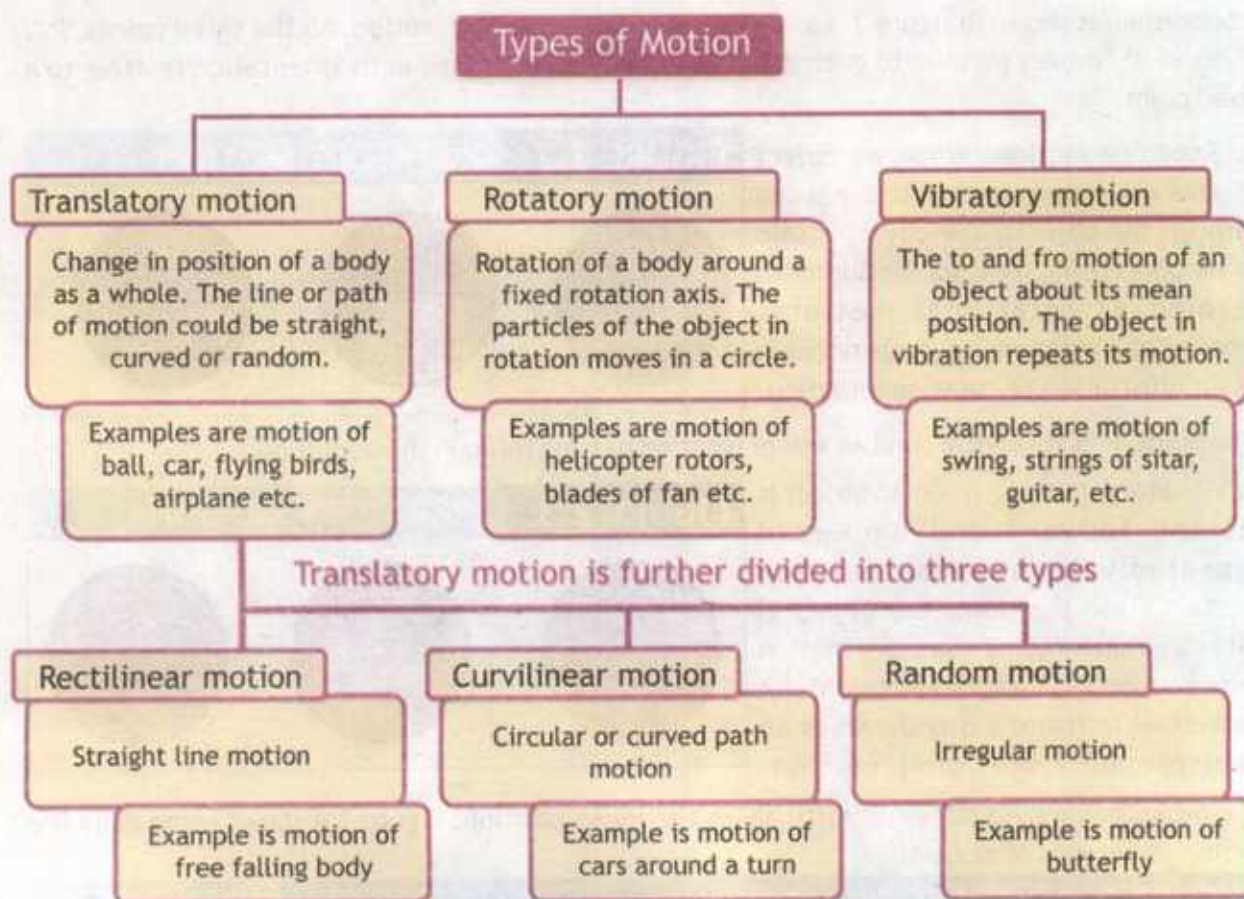
The basketball moves back and forth about the mean position. Figure 2.4 shows some daily life examples of types of motion.

**FIGURE 2.4 TYPES OF MOTION**



Translatory motion is further divided into three types.

- **Rectilinear motion** is the translatory motion of the object in straight line path. For example the motion of train on track, motion of gun shot and motion falling apple.
- **Circular motion** is the translatory motion of an object in which it moves in a curved path. For example the motion of a football when kicked, the motion of roller coaster and the motion of a vehicle in a turn are examples of curvilinear motion. Circular motion is a special case of curvilinear motion in which the radius of rotation remains constant and object moves along a circular path.

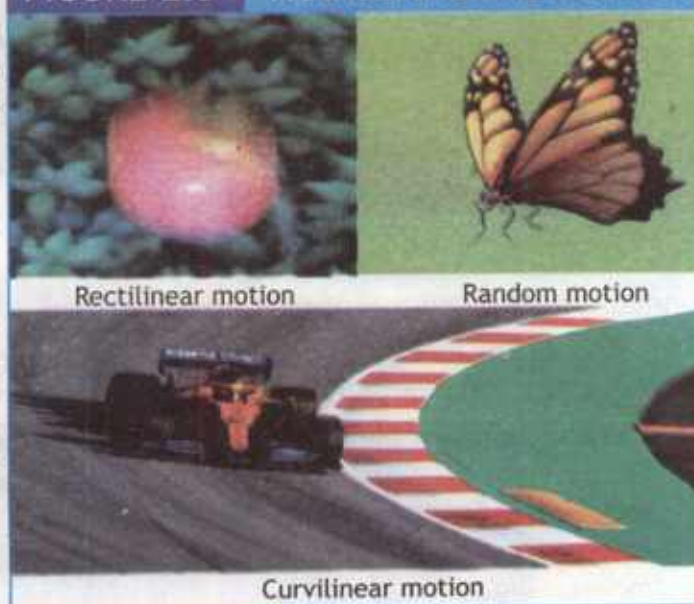


An object can have any combination of these types of motion.

- **Random Motion** is the translatory motion of an object with no specific path. For example kites flying through sky, motion of clouds and the motion of butterfly.

Translational motion is seen in various scenarios, covering a wide range of situations. Whether in engineering, physics, or everyday life, objects frequently display this type of motion. It is crucial to comprehend the specific motion type in order to accurately analyze and describe the behavior of moving objects.

**FIGURE 2.5 – TRANSLATIONAL MOTION**



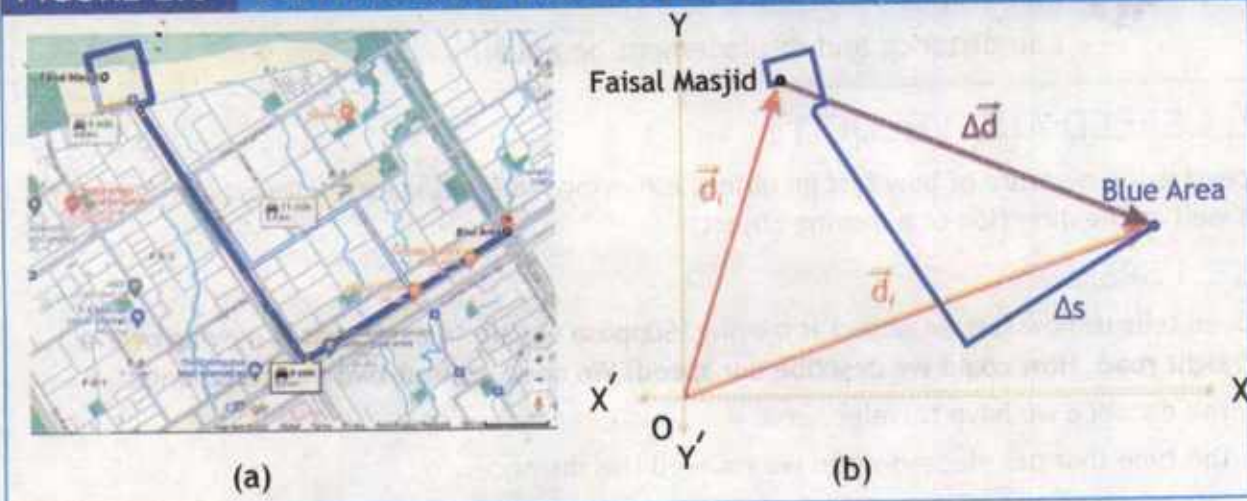
## 2.2 DISTANCE AND DISPLACEMENT

If we are at Faisal Masjid, Islamabad and we want to move to Blue area, Islamabad by searching on google map as shown in figure 2.5 (a), we get a twisted path, showing us the way to reach our destination. However, the straight path as shown in figure 2.5 (b) can be shorter.

**'The length of path traveled between two positions is called distance'.**

Distance has no direction and therefore it is a scalar quantity. Distance is usually denoted by  $\Delta x$ ,  $\Delta r$ ,  $\Delta s$ ,  $\Delta d$  or  $\Delta l$ , and has SI unit as metre (m).

**FIGURE 2.6 DISTANCE AND DISPLACEMENT**



**'The shortest distance from initial position to final position (or straight directed distance) is called displacement'.**

Displacement has direction and therefore it is a vector quantity. Displacement has SI unit as metre (same as length).

If an object moves then the object's position changes. This change in position vector ' $\Delta \vec{d}$ ' of an object, from initial position ' $\vec{d}_i$ ' to final position ' $\vec{d}_f$ ' is known as displacement as shown in figure 2.6 (b). Mathematically:

$$\Delta \vec{d} = \vec{d}_f - \vec{d}_i$$

### POINT TO PONDER



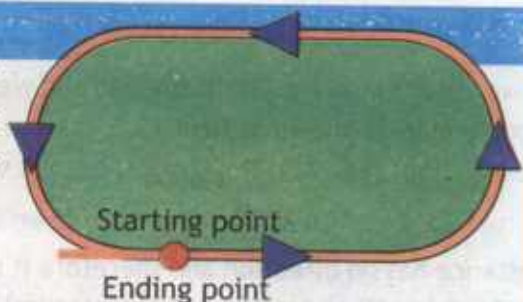
Here we used symbol  $\Delta$  (Greek letter delta) for change in position; however, it is used to represent a 'change in' any quantity. For example elapsed time  $\Delta t$  is the change in (or the difference between) the ending time  $t_f$  and beginning time  $t_i$ .

$$\Delta t = t_f - t_i$$



## CAN YOU TELL?

If on a 400 m running track your starting point and ending point is same. How much distance you have covered? What is your displacement?



## CAN YOU TELL?

Can displacement be greater than distance?

Can distance and displacement be equal?

## 2.3 SPEED AND VELOCITY

Speed is the measure of how fast an object is moving, whereas velocity describes the speed as well as the direction of a moving object.

### 2.3.1 SPEED

Speed tells us how fast an object is moving. Suppose we are in a car that is moving over a straight road. How could we describe our speed? We need at least two measurements:

- the distance we have traveled, and
- the time that has elapsed while we covered this distance.

'Measure of the distance covered ( $\Delta s$ ) with passage of time ( $\Delta t$ ) is called speed (denoted by  $v$ )'. Mathematically:

$$\text{speed} = \frac{\text{distance}}{\text{elapsed time}} \quad \text{or} \quad v = \frac{\Delta d}{\Delta t} \quad \text{or} \quad v = \frac{s_f - s_i}{t_f - t_i} \quad \text{--- 2.1}$$

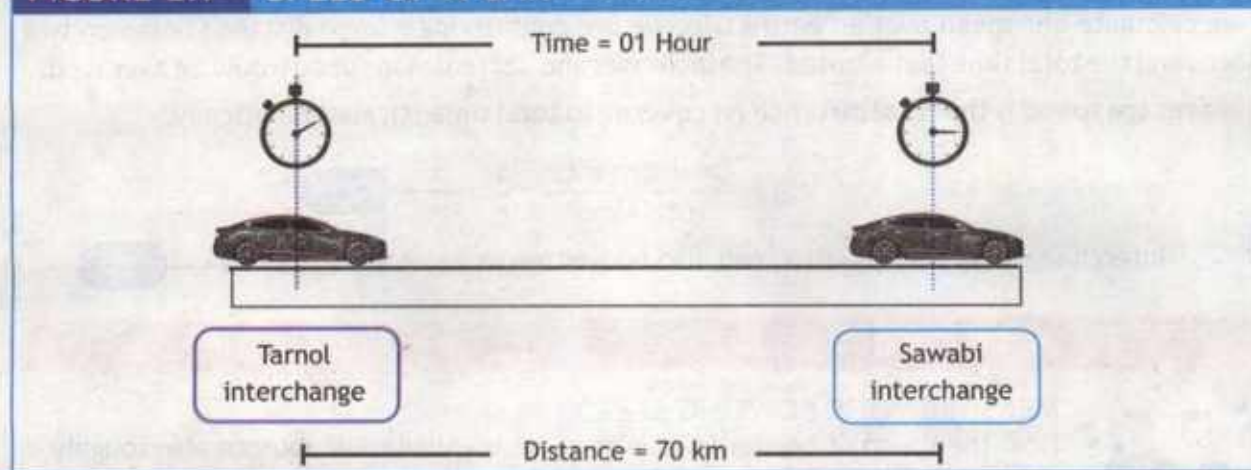
Speed of an object show us the rate at which the object is moving. Speed is a scalar quantity having SI unit of metre per second ( $\text{m/s}$  or  $\text{ms}^{-1}$ ). The speed will be one 'metre per second' if an object cover one metre distance in one second.

Speed tells us how fast an object is moving. An object is fast if it cover large distance in a short time. For example while going from Islamabad to Peshawar through motor-way M1, we leave at Tarnol interchange at 2:00 pm and cross Sawabi interchange at 3:00 pm as shown in figure 2.7. Since Sawabi interchange is about 70 km from Tarnol interchange and it took us one hour therefore our speed can be obtained as:

$$v = \frac{70 \text{ km}}{1 \text{ hr}} = 70 \text{ km/hr}$$

A fast-moving object covers a relatively large distance in a given amount of time and thus has a high speed. Whereas a slow-moving object covers a relatively small amount of distance in the same amount of time and therefore has a low speed.

FIGURE 2.7 SPEED OF A CAR



## POINT TO PONDER



## SOME INTERESTING SPEED FACTS

Who is the fastest man on earth? Yes, Usain Bolt. He finished a 100-metre sprint in just 9.58 seconds back in 2009. In that instance, his speed was 10.44 m/s or 37.58 km/h.



The slowest animal in the world, the crown goes to the 3-toed sloth. And, the average speed of them is about 0.00134112 m/s or 0.0048 km/h. You would have seen garden snails or turtles moves which is faster than this rate.



The fastest animal in the world is Peregrine Falcon, it can attain a maximum speed of up to 108.333 m/s or 390 km/h. Cheetah is the fastest animal in the land can reach a fastest speed of 33.33 m/s or 120 km/h.

This means that our car is moving at 70 km/hr neither speeding up nor slowing down. However, it is usually difficult to maintain a same speed. Other cars and distractions can cause us to reduce speed or at times we have to increase speed of our car.

## A. AVERAGE SPEED

If we calculate our speed over an entire trip, we are considering a large distance between two places and the total time that elapsed. The increases and decreases in speed would be averaged.

The average speed is the total distance (s) covered in total time (t). Mathematically,

$$v_{ave} = \frac{\text{total distance}}{\text{total time}} = \frac{s}{t} \quad \text{--- 2.2}$$

Interchangeably this equation can also be written as

$$s = v_{ave} t \quad \text{--- 2.3}$$

## ACTIVITY



### MEASURE YOUR BOWLING SPEED

How the speed of bowler in cricket game is calculated? You can also roughly calculate your bowling speed. First carefully measure the length of the cricket pitch in metres from bowlers delivery stride mark to where the batter is standing. Now give a stop watch to your friend and ask him to start the stopwatch as you release the ball and stop it once it reaches the batter. To get the speed in m/s divide the length of the pitch by the time in the stop watch. For comparison with speed of international bowlers, we would require to convert this speed to kph or pmh.

## B. INSTANTANEOUS SPEED

We see sign boards on road reading, sharp turn ahead reduce speed 'speed limit 70 km/hr'. Certainly this sign board does not refer to our average speed, but the speed at which we are moving at that particular instant of time. The speed at any specific instant of time is called the instantaneous speed.

If we are not looking at the speedometer of car we only have a rough idea of how fast we are moving, and how much we should reduce speed. However, looking at the speedometer, on the other hand, we will know exactly how fast we are going at that instant of time.

## C. UNIFORM AND VARIABLE SPEED

'If an object covers equal distances in equal intervals of time we say that the object is moving with uniform speed'. In uniform speed object does not get slower or faster and maintains the same speed.

FIGURE 2.8 SPEEDOMETER OF A CAR



DO YOU KNOW?

When it comes to fastest measured speed, the limit is set by the laws of physics themselves as the 'speed of light'. Albert Einstein realized that, a light ray appears to move at the same speed, regardless of whether it's moving towards us or away from us. No matter how fast you travel or in what direction, all light always moves at the same speed. Moreover, anything that's made of matter can only approach, but never reach, the speed of light. If you don't have mass, you must move at the speed of light; if you do have mass, you can never reach it.



The speed of light in a vacuum is about 299,792,458 m/s or 299,792 km/s (which is approximately  $3 \times 10^8 \text{ ms}^{-1}$ ). At this speed, you can revolve around the Earth 7.5 times in a second. In comparison the speed of sound in the air is roughly 343 m/s or 767 mph or 1235 km/h. That means the speed of light is so much faster than the speed of sound.

### EXAMPLE 2.1: REACTION TIME OF BATSMAN

Shoaib Akhtar made a record in World cup 2003 against England by bowling at a speed of 161.3 km/h. If the batsman is at a displacement of 17.5 m from the bowler, what should be the reaction time for the batsman to play such a delivery?

**GIVEN**

$$\text{Speed of ball } v = 161.3 \text{ km/h} = \frac{161.3 \times 1000 \text{ m}}{3600 \text{ s}} = 44.8 \text{ m/s}$$

**REQUIRED**

time  $t = ?$

Distance covered by ball  $s = 17.5 \text{ m}$

**SOLUTION**

From the definition of average speed, equation 2.2 we have

$$v_{\text{ave}} = \frac{\text{total distance}}{\text{total time}} = \frac{s}{t}$$

$$t = \frac{s}{v_{\text{ave}}} \quad \text{Putting values} \quad t = \frac{17.5 \text{ m}}{44.8 \text{ m/s}}$$

Hence

$$t = 0.39 \text{ s}$$

Answer

The batsman should react in just 0.39 seconds to play this delivery. These are typical reaction times player deal in game of cricket.

DO YOU KNOW?

Pakistani Cricketer Shoaib Akhtar bowled the fastest recorded ball in the history of cricket in the World Cup match at Newlands South Africa. This match was played between Pakistan and England and the ball was faced by Nick Knight (former England opener).



## EXAMPLE 2.2: FASTEST TRAIN IN THE WORLD

Shanghai's Maglev, the fastest train, travelled a distance of 30 kilometres in 7 minutes and 30 seconds. What is its speed? Convert the speed to km/h.

### GIVEN

Distance travelled 'Ds' = 30 km = 30 × 1000 m = 30,000 m

Time taken 'Dt' = 7 min 30 s = (7 × 60) s + 30 s = 420 s + 30 s = 450 s

### SOLUTION

From the definition of speed, equation 2.1 we have:  $v = \frac{\Delta s}{\Delta t}$

Putting values  $v = \frac{30,000 \text{ m}}{450 \text{ s}}$

Hence  $v = 66.67 \text{ m/s}$  — Answer

### Conversion in km/h

Converting m to km and s to h

$$v = \left[ 66.67 \frac{\text{m}}{\text{s}} \right] \times \left[ \frac{3600 \text{ s}}{1 \text{ h}} \right] \times \left[ \frac{1 \text{ km}}{1000 \text{ m}} \right] = 240.01 \text{ km/h}$$

$v = 240.01 \text{ km/h}$  — Answer

This is a much greater speed as compared to the speed limits on motor ways (120 km/h)



Maglev is a system of train transportation that uses two sets of electromagnets: one set to repel and push the train up off the track, and another set to move the elevated train ahead, taking advantage of the lack of friction.

## 2.3.2 VELOCITY

Velocity is similar to speed, but a direction is needed for the description of velocity. **'Measure of displacement ( $\Delta \vec{d}$ ) with passage of time ( $\Delta t$ ) is called velocity (denoted by  $\vec{v}$ )'. Mathematically**

$$\text{velocity} = \frac{\text{displacement}}{\text{elapsed time}} \quad \text{or} \quad \vec{v} = \frac{\Delta \vec{d}}{\Delta t} \quad \text{or} \quad \vec{v} = \frac{\vec{d}_f - \vec{d}_i}{t_f - t_i} \quad \text{--- 2.4}$$

Velocity is a vector quantity having same direction as displacement vector. The SI unit of velocity is metre per second (m/s). When we know both the speed and the direction of an object, we simply call it as velocity.

For straight-line motion in one direction, speed and velocity have same magnitudes because the lengths of the distance and the displacement are the same. The distinction between them in this case is that a displacement direction must be specified for the velocity.



### A. AVERAGE VELOCITY

The average velocity is the total displacement ( $\vec{d}$ ) covered in total time ( $t$ ). Mathematically,

$$\vec{v} = \frac{\vec{d}}{t} \quad \text{2.5}$$

### B. INSTANTANEOUS VELOCITY

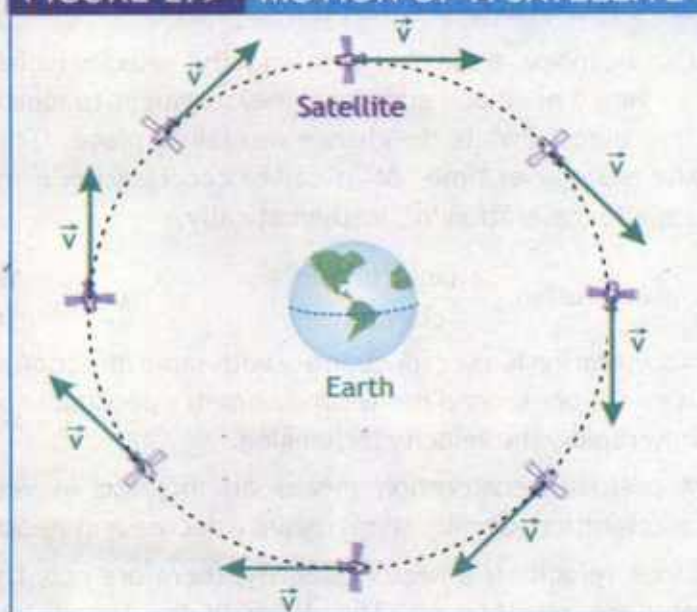
If velocity is measured by keeping the time interval small, such velocity is termed as instantaneous velocity. To calculate velocity both the speed and direction for that moment of time need to be specified.

### C. UNIFORM AND VARIABLE VELOCITY

*'If an object covers equal displacements in equal intervals of time we say that the object is moving with uniform velocity. Uniform velocity is the velocity that does not change otherwise it is called variable velocity.'*

To produce variable velocity (a change in velocity), either the speed or the direction is changed (or both are changed). A satellite moving with a constant speed in a circular orbit around Earth does not have a constant velocity since its direction of movement is constantly changing as shown in figure 2.9.

**FIGURE 2.9 MOTION OF A SATELLITE**



### EXAMPLE 2.3: VELOCITY OF A CAR

A car travels a curvy track of length 800 metres in 40 seconds. The straight path is about 600 metres between starting point and ending point, which the same car travels in 36 seconds.

What is the car's (a) average speed and (b) average velocity?

**GIVEN**

Length of curvy track = Distance  $\Delta d = 800$  m

Time taken ' $\Delta t$ ' = 40 s

Length of straight path = Displacement  $\Delta d = 600$  m

Time taken ' $\Delta t$ ' = 40 s

**REQUIRED**

(a). Average speed  $v_{ave} = ?$

(b). Average Velocity  $\vec{v}_{ave} = ?$

## SOLUTION

From the definition of speed and velocity, we have

$$(a). \text{Average Speed} = v_{ave} = \frac{\text{Total distance}}{\text{Total time}} \Rightarrow v_{ave} = \frac{s}{t}$$

Putting vales:  $v_{ave} = \frac{800 \text{ m}}{40 \text{ s}} \Rightarrow v_{ave} = 20 \text{ m/s}$  Answer

$$(b). \text{Average Velocity} = \vec{v}_{ave} = \frac{\text{Total displacement}}{\text{Total time}} \Rightarrow \vec{v}_{ave} = \frac{\vec{d}}{t}$$

Putting values:  $\vec{v}_{ave} = \frac{600\text{m}}{36\text{s}} \Rightarrow \vec{v}_{ave} = 16.67 \text{ m/s}$  Answer

## 2.4 ACCELERATION

Can we measure the change in velocity? Velocity is changed by changing speed, direction or both, we would need one additional measurement to measure change in velocity, which is how much time elapsed while the change was taking place. 'The measure of change in velocity ' $\Delta \vec{v}$ ' with the passage of time ' $\Delta t$ ' is called acceleration ' $\vec{a}$ '. (or) Time rate of change in velocity ' $\Delta \vec{v}$ ' is called acceleration ' $\vec{a}$ '. Mathematically:

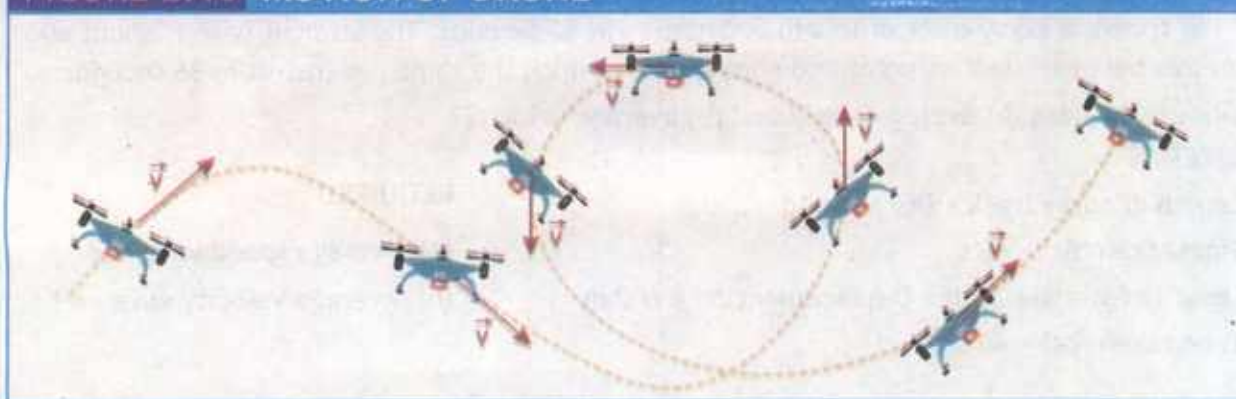
$$\text{acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}} \quad \text{or} \quad \vec{a} = \frac{\Delta \vec{v}}{\Delta t} \quad \text{or} \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \quad \text{2.6}$$

Acceleration is a vector quantity with same direction as change in velocity. SI Unit of acceleration is metre per second per second or metre per square second ( $\text{m/s}^2$ ). Acceleration is a measure of how rapidly the velocity is changing.

A positive acceleration means an increase in velocity with time, whereas the negative acceleration (deceleration) means a decrease in velocity with time.

Since velocity is a vector quantity, therefore only the change in direction of velocity can also produce acceleration. The drone in the figure 2.10 is accelerating because it is changing directions.

**FIGURE 2.10 MOTION OF DRONE**



**Uniform and Non-uniform Acceleration:** When an object is changing its velocity at the same rate each second we call it uniform acceleration. A body has uniform acceleration if it has equal changes in velocity in equal intervals of time.

Non-uniform acceleration occurs when an object's velocity changes, but this change is not steady over time. In simple terms, the rate at which the object's velocity changes is not the same throughout its movement. Acceleration, which is the measure of velocity change, is therefore not constant in non-uniform acceleration. Understanding non-uniform acceleration is important in physics to explain the movement of objects affected by changing forces. This is a common and practical situation since many real-life scenarios involve forces that vary over time, resulting in non-uniform acceleration.



### CAN YOU TELL?

The initial velocity  $\vec{v}_i$  and final velocity  $\vec{v}_f$  of a tennis ball at two different points in time is shown below. The direction of the ball is indicated by the arrow. For each case, indicate if there is an acceleration and show the direction of acceleration.

|                                                                                                      |                                                                                                      |                                                                                                      |
|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| <p>A</p> <p><math>\vec{v}_i = 2 \text{ m/s}</math></p> <p><math>\vec{v}_f = 2 \text{ m/s}</math></p> | <p>B</p> <p><math>\vec{v}_i = 2 \text{ m/s}</math></p> <p><math>\vec{v}_f = 4 \text{ m/s}</math></p> | <p>C</p> <p><math>\vec{v}_i = 3 \text{ m/s}</math></p> <p><math>\vec{v}_f = 1 \text{ m/s}</math></p> |
| <p>D</p> <p><math>\vec{v}_i = 2 \text{ m/s}</math></p> <p><math>\vec{v}_f = 2 \text{ m/s}</math></p> | <p>E</p> <p><math>\vec{v}_i = 1 \text{ m/s}</math></p> <p><math>\vec{v}_f = 3 \text{ m/s}</math></p> | <p>F</p> <p><math>\vec{v}_i = 4 \text{ m/s}</math></p> <p><math>\vec{v}_f = 2 \text{ m/s}</math></p> |

### EXAMPLE 2.4: ACCELERATION OF CHEETAH

Cheetah (fastest land animal) can accelerate its speed from zero to 26.8 m/s in just three seconds. Suppose the Cheetah has started running towards East, find its acceleration.

#### GIVEN

Initial velocity  $\vec{v}_i = 0 \text{ m/s}$  (East)

Final velocity  $\vec{v}_f = 26.8 \text{ m/s}$  (East)

Time taken  $\Delta t = 3 \text{ s}$

#### SOLUTION

From the definition of acceleration, equation 2.6 we have  $\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$

Putting values  $\vec{a} = \frac{26.8 \text{ m/s} - 0 \text{ m/s}}{3 \text{ s}}$

$\vec{a} = 9.93 \text{ m/s}^2$

Answer

That is a big value, as typical cars have accelerations of only 3 to 4 m/s<sup>2</sup>

**CAN YOU TELL?**


The car is depicted after equal time intervals, can you determine that in which picture A, B, C and D, the car is

at rest

speeding up

moving at a constant speed

slowing down

A



B



C



D


**POINT TO PONDER**


The first scientist to measure speed as distance over time was Galileo. He dropped various objects of different masses from the leaning tower of Pisa. He found that all of them reach the ground at the same time. The acceleration of freely falling bodies is called gravitational acceleration or acceleration due to gravity denoted by 'g'.


**2.5 MOTION DUE TO GRAVITY**

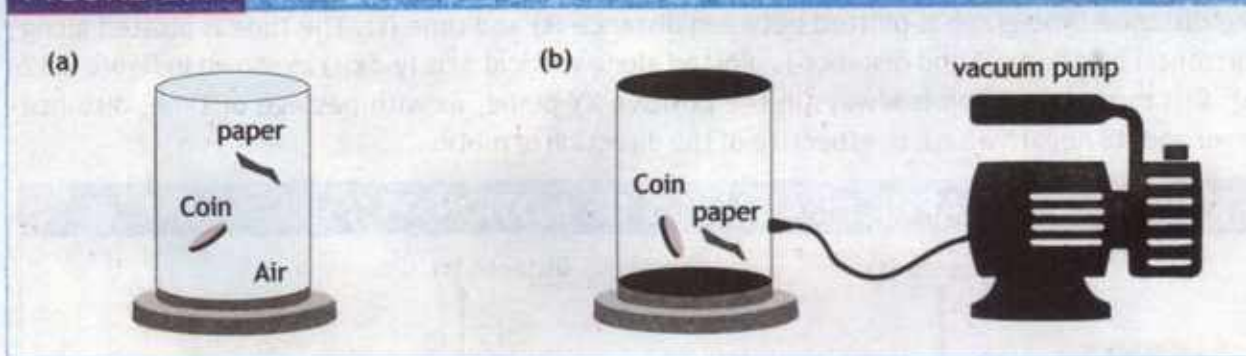
If you drop a ball and large stone from the roof of your school building, which of them will reach the bottom first? All the freely falling objects have the same acceleration called the acceleration due to gravity (g) and is independent of their masses.

The acceleration due to gravity is directed downward, toward the center of the earth. Near the earth's surface, g is approximately

$$g = 9.80 \text{ m/s}^2 \text{ or } 32.2 \text{ ft/s}^2$$

For large object the presence of air resistance is neglected, however if we drop a small piece of paper and coin. The coin will fall faster than a sheet of paper due to air resistance as in Figure 2.11 (a). However, when air is removed, as in Figure 2.11 (b), the coin and the paper will experience the same acceleration due to gravity, and both the coin and the paper will fall at same rate.

**FIGURE 2.11 FREE FALL EXPERIMENT**



When an object moves with the gravity acceleration due to gravity is taken as positive (+g) and when object moves against gravity (like an object thrown up), acceleration due to gravity is taken as negative (-g).

### EXAMPLE 2.5 ACCELERATION DUE TO GRAVITY

A block of mass 2 kg is left from the top of a building. How much time will the block take to reach the ground if it strikes the ground with a speed of 78.5 m/s? (Ignore air resistance).

#### GIVEN

Mass of the block ' $m$ ' = 2 kg

Initial speed ' $v_i$ ' = 0 m/s

Final speed ' $v_f$ ' = 78.5 m/s

Acceleration due to gravity ' $g$ ' = 9.8 m/s<sup>2</sup>

#### SOLUTION

From the definition of acceleration, acceleration due to gravity can also be written as

$$g = \frac{v_f - v_i}{\Delta t} \quad \text{rearranging for time} \quad \Delta t = \frac{v_f - v_i}{g}$$

$$\text{Putting values} \quad \Delta t = \frac{78.5 \text{ m/s} - 0 \text{ m/s}}{9.8 \text{ m/s}^2}$$

Therefore,

$$\Delta t = 8 \text{ s}$$

**Answer**

So, the block will reach the ground in 8 seconds.

## 2.6 GRAPHICAL ANALYSIS OF MOTION

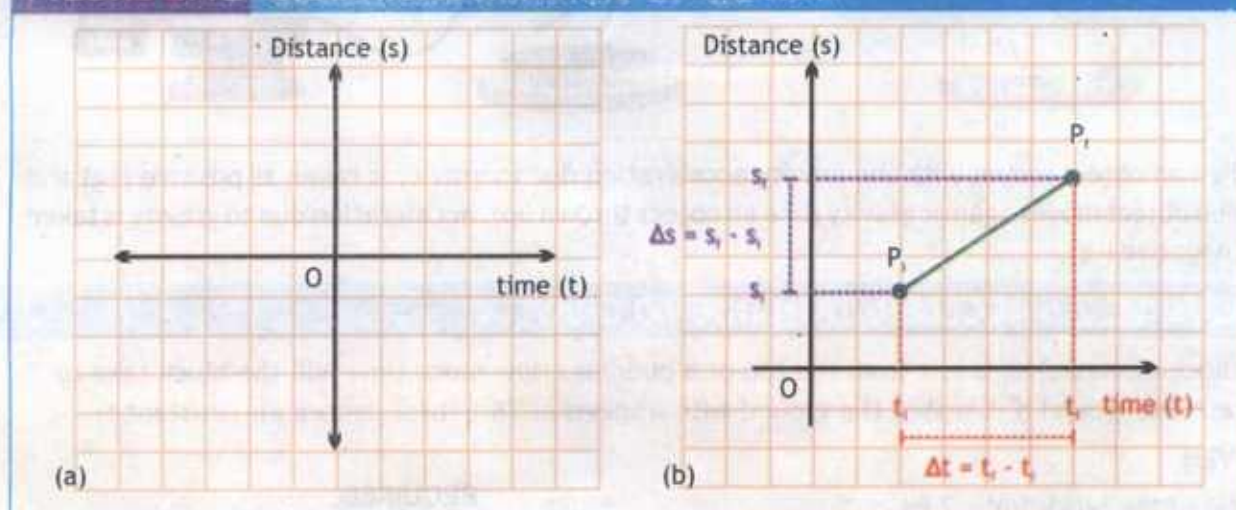
Graph (horizontal and vertical lines at equal distances) is an efficient method to show relationship between physical quantities. Graph use coordinate systems to show relationship in various quantities.



## 2.6.1 DISTANCE-TIME GRAPH

The distance-time graph is plotted between distance ( $s$ ) and time ( $t$ ). The time is plotted along horizontal axis (x-axis) and distance is plotted along vertical axis (y-axis) as shown in figure 2.12 (a). Distance time graph is always in the positive XY plane, as with passage of time, distance never goes to negative axis, irrespective of the direction of motion.

**FIGURE 2.12** GRAPHICAL ANALYSIS OF MOTION



The gradient (or slope) of distance time curve gives speed. The gradient of the graph means vertical coordinate difference divided by horizontal coordinate difference. The gradient in distance-time graph can be calculated as

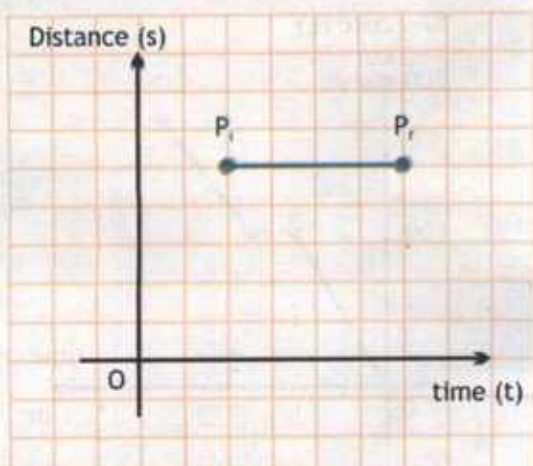
1. Choose two points  $P_1$  and  $P_2$  for which the gradient is to be determined.
2. Determine the coordinates  $P_1(t_1, s_1)$  and  $P_2(t_2, s_2)$ , by drawing perpendicular on each axis from both points as shown in figure 2.11 (b).
3. Determine the difference between horizontal-coordinates ( $\Delta t = t_2 - t_1$ ) and vertical-coordinates ( $\Delta s = s_2 - s_1$ ).
4. Dividing the difference in vertical-coordinates ( $\Delta s = s_2 - s_1$ ) by difference in horizontal-coordinates ( $\Delta t = t_2 - t_1$ ) gives gradient. Mathematically

$$\text{gradient} = \frac{\Delta s}{\Delta t} = \frac{s_2 - s_1}{t_2 - t_1} = v \quad \text{--- 2.7}$$

from equation 2.1 it is definition of speed, therefore  $\text{gradient} = v$

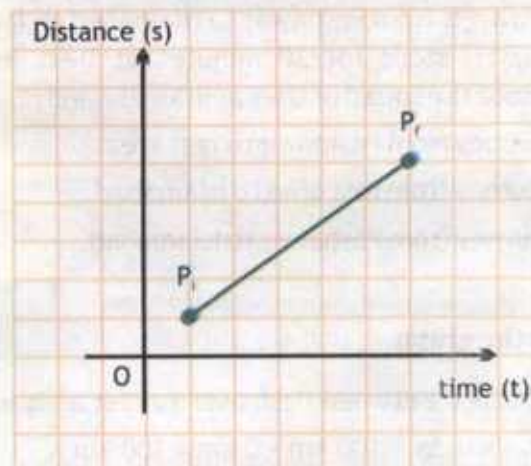
Thus by looking at the graph we get the idea about the speed of a body, shown in figure 2.13.

**FIGURE 2.13 DISTANCE - TIME GRAPH**



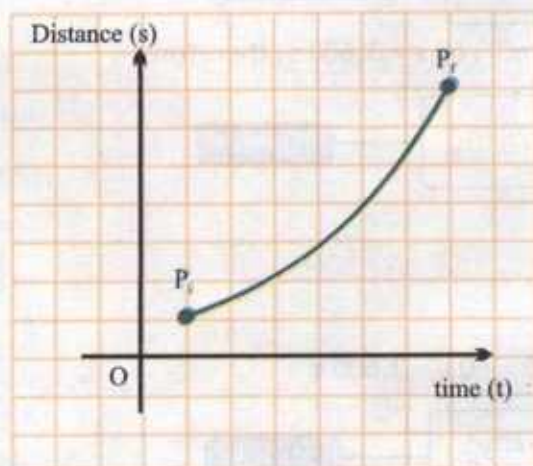
**(a) BODY AT REST (ZERO SPEED)**

Time is passing and no change in distance is seen. It means the body is at rest. Since there is no slope so the speed is zero.



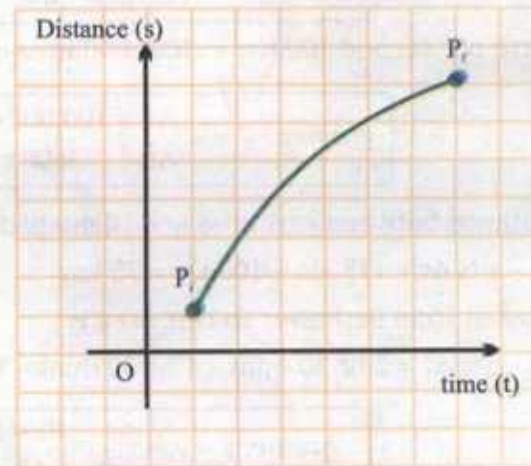
**(b) BODY MOVING WITH CONSTANT SPEED**

The distance is increasing linearly with time. The slope is constant therefore object is moving with uniform speed.



**(c) BODY MOVING WITH VARIABLE SPEED**

**Increasing speed (accelerating):** The distance is changing non-linearly with time (curving up). The slope is increasing therefore object is increasing its speed.



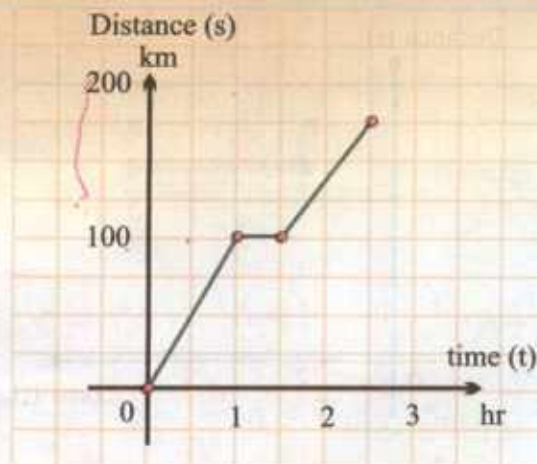
**(d) BODY MOVING WITH VARIABLE SPEED**

**Decreasing Speed (decelerating):** The distance is changing non-linearly with time (curving down). The slope is changing therefore object is decreasing its speed.

## EXAMPLE 2.5: PESHAWAR TO ISLAMABAD THROUGH M1

A car travels from Peshawar to Islamabad on Motorway (M1), stops for 30 minutes at 'rest area'. Calculate the speed of the car in km/hr and m/s for

- Journey from Peshawar to rest area.
- Journey from rest area to Islamabad.
- Journey from Peshawar to Islamabad.



**From the graph**

(a) Distance between Peshawar to rest area is

$$\Delta s = s_f - s_i \text{ is } \Delta s = 100 \text{ km} - 0 \text{ km} = 100 \text{ km}$$

time taken from Peshawar to rest area is

$$\Delta t = t_f - t_i \text{ is } \Delta t = 1 \text{ hr} - 0 \text{ hr} = 1 \text{ hr}$$

$$\text{gradient} = v = \frac{\Delta s}{\Delta t} = \frac{100 \text{ km}}{1 \text{ hr}} = 100 \text{ km/hr}$$

Answer

In metre per second  $100 \text{ km} = 100,000 \text{ m}$  and  $1 \text{ hr} = 60 \times 60 \text{ s} = 3,600 \text{ s}$ , therefore

$$\text{gradient} = v = \frac{\Delta s}{\Delta t} = \frac{100,000 \text{ m}}{3600 \text{ s}} = 27.78 \text{ m/s}$$

Answer

(b) Distance between rest area and Islamabad is

$$\Delta s = s_f - s_i \text{ is } \Delta s = 175 \text{ km} - 100 \text{ km} = 75 \text{ km}$$

time taken from Peshawar to rest area is

$$\Delta t = t_f - t_i \text{ is } \Delta t = 2 \text{ hr } 30 \text{ mins} - 1 \text{ hr } 30 \text{ mins} = 1 \text{ hr} = 60 \times 60 \text{ s} = 3,600 \text{ s}$$

$$\text{gradient} = v = \frac{\Delta s}{\Delta t} = \frac{75 \text{ km}}{1 \text{ hr}} = 75 \text{ km/hr}$$

Answer

In metre per second  $75 \text{ km} = 75,000 \text{ m}$  and  $1 \text{ hr} = 60 \times 60 \text{ s} = 3,600 \text{ s}$ , Therefore

$$\text{gradient} = v = \frac{\Delta s}{\Delta t} = \frac{75,000 \text{ m}}{3600 \text{ s}} = 20.83 \text{ m/s}$$

Answer

(c) Distance from Peshawar to Islamabad is:

$$\Delta s = s_f - s_i \text{ is } \Delta s = 175 \text{ km} - 0 \text{ km} = 175 \text{ km}$$

time taken from Peshawar to Islamabad is

$$\Delta t = t_f - t_i \text{ is } \Delta t = 2 \text{ hr and } 30 \text{ mins} - 0 \text{ hr} = 2.5 \text{ hr}$$

$$\text{gradient} = v = \frac{\Delta s}{\Delta t} = \frac{175 \text{ km}}{2.5 \text{ hr}} = 70 \text{ km/hr}$$

Answer

In metre per second

175 km = 175,000 m

and 2 hr and 30 mins = 2 (60 ' 60) s + (60 ' 30) s = 7,200 s + 1,800 s = 9,000 s

$$\text{gradient} = v = \frac{\Delta s}{\Delta t} = \frac{175,000 \text{ m}}{9,000 \text{ s}} = 19.44 \text{ m/s}$$

Answer

## 2.6.2 SPEED - TIME GRAPH

Speed-time graph is the graph plotted between speed ( $v$ ) and time ( $t$ ). In this graphical analysis the speed is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Speed time graph serve two purposes

- Slope of the graph gives magnitude of acceleration
- Area under the graph gives distance traveled.

The slope of speed time curve gives magnitude of acceleration. As discussed in the graph for the distance graph, the slope of velocity time graph gives by definition the magnitude (value) of acceleration

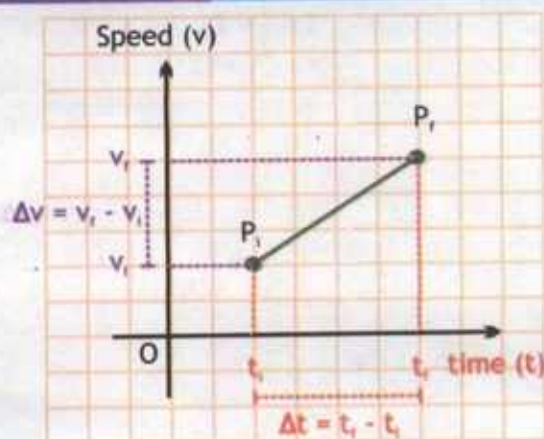
**The gradient (or slope) of speed time curve gives magnitude of acceleration.** The gradient of the graph means vertical coordinate difference divided by horizontal coordinate difference. The gradient in distance-time graph can be calculated as:

1. Choose two points ' $P_i$ ' and ' $P_f$ ' for which the gradient is to be determined.
2. Determine the coordinates ' $P_i(t_i, v_i)$ ' and ' $P_f(t_f, v_f)$ ', by drawing perpendicular on each axis from both points as shown in figure 2.9 (b).
3. Determine the difference between horizontal-coordinates ( $\Delta t = t_f - t_i$ ) and vertical-coordinates ( $\Delta v = v_f - v_i$ ).
4. Dividing the difference in vertical-coordinates ( $\Delta v = v_f - v_i$ ) by difference in horizontal-coordinates ( $\Delta t = t_f - t_i$ ) gives gradient. Mathematically

$$\text{gradient} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = |a| \quad \text{2.8}$$

From equation 2.8 we can conclude that the gradient of velocity - time graph gives the magnitude of acceleration.

**FIGURE 2.13 SPEED TIME GRAPH**



**B. Area under speed time graphs represent the distance traveled:** If the motion of a body represented by the speed time graph is symmetric shape then the area can be calculated using appropriate formula for geometrical shapes.

For example consider the figure 2.14 in which the speed time graph of the object in motion is represented by a rectangle. The area of rectangle is

$$\text{Area} = \text{width} \times \text{length}$$

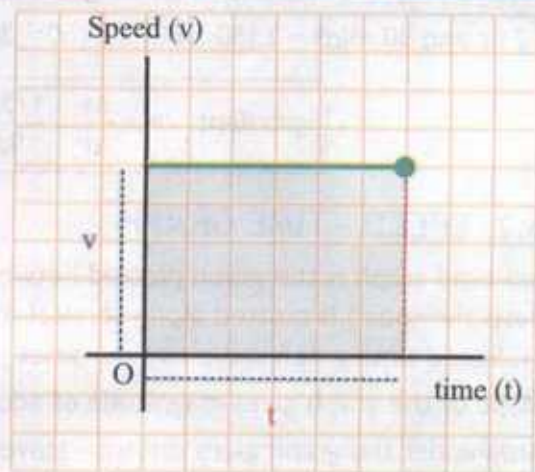
$$\text{Area} = v \times t$$

The distance by average speed is given by equation 2.3, is also

$$s = v t$$

Thus the area under speed time graphs represent the distance traveled.

**FIGURE 2.14 RECTANGULAR AREA**



Similarly consider the figure 2.15 in which the speed time graph of the object in motion is represented by a triangle. The area of triangle is

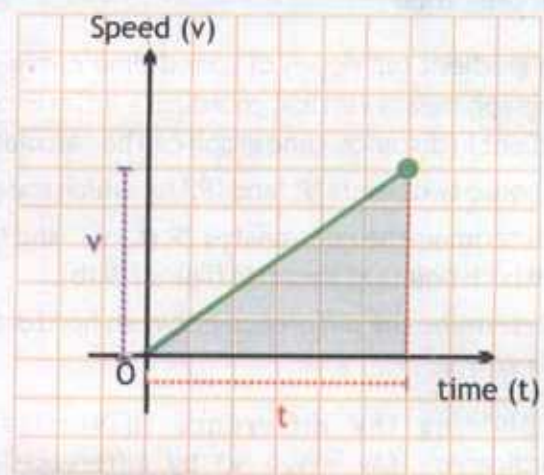
$$\text{Area} = \frac{1}{2} \text{width} \times \text{length}$$

$$\text{Area} = \frac{1}{2} v \times t$$

The distance by average speed is given by equation 2.4, is again

$$s = \frac{1}{2} v t$$

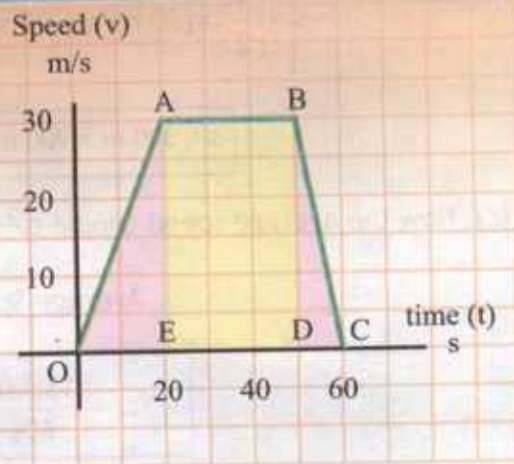
**FIGURE 2.15 TRIANGULAR AREA**



## EXAMPLE 2.6: GRAPHICAL REPRESENTATION OF SPEED OF CAR

A car increases its speed from zero to a 30 m/s in 20 s. Then it moves with uniform speed for the next 30 seconds and then the driver applies brakes and the speed of the car decreases uniformly to zero in 10 s. The graph is plotted for the journey, use this graph to calculate:

- (a). magnitude of acceleration (i) in first 20 s (ii) from 20 s to 50 s and (iii) in last 10 s (b). total distance covered (c). average speed



- (a) The slope of the graph will give magnitude of acceleration.

$$\text{Slope} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \text{Magnitude of acceleration}$$

- (i) For the first 20 seconds, OA line represents the slope

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{(30 - 0) \text{ m/s}}{(20 - 0) \text{ s}} = \frac{30 \text{ m/s}}{20 \text{ s}}$$

$$|\vec{a}| = 1.5 \text{ m/s}^2 \quad \text{Answer}$$

- (ii). From 20 s to 50 s, the slope is represented by line AB

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{(30 - 30) \text{ m/s}}{(50 - 20) \text{ s}} = \frac{0 \text{ m/s}}{30 \text{ s}}$$

$$|\vec{a}| = 0 \text{ m/s}^2 \quad \text{Answer}$$

- (iii). In the last 10 seconds, the slope is represented by BC

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{(0 - 30) \text{ m/s}}{(60 - 50) \text{ s}} = \frac{-30 \text{ m/s}}{10 \text{ s}}$$

$$|\vec{a}| = -3 \text{ m/s}^2 \quad \text{Answer}$$

The negative sign shows that the car is slowing down.

- (b). Now the total distance covered is equal to the area under the speed-time graph.

Total distance covered = Area of triangle OAE + Area of rectangle ABDE + Area of triangle CBD

$$s = \left[ \frac{1}{2} \times (30 \text{ m/s} \times 20 \text{ s}) \right] + [30 \text{ m/s} \times 30 \text{ s}] + \left[ \frac{1}{2} \times (30 \text{ m/s} \times 10 \text{ s}) \right]$$

$$s = 300 \text{ m} + 900 \text{ m} + 150 \text{ m} = 1350 \text{ m}$$

Answer

(c). Now the average speed can be calculated when distance  $s$  is divided by total time  $t$

$$\text{Average Speed} = \frac{\text{Total distance covered}}{\text{Total time}}$$

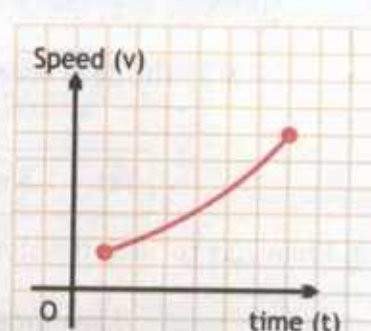
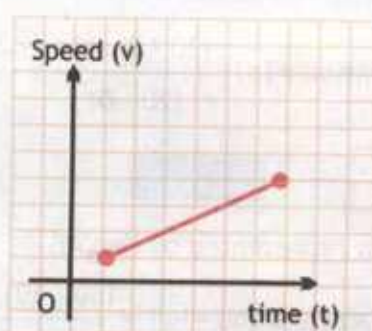
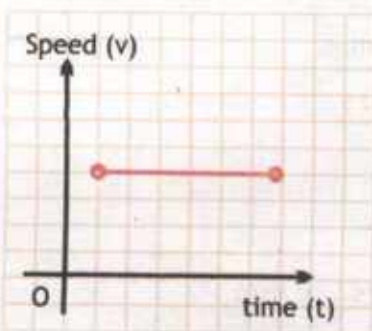
$$v_{\text{ave}} = \frac{1350 \text{ m}}{60 \text{ s}} = 22.5 \text{ m/s}$$

Answer



## CAN YOU TELL?

What does the slope of these graphs tell about acceleration?



## SUMMARY

**Position** is the distance and direction of a body from a fixed reference point.

**Distance** is the length of a path traveled by an object.

**Displacement** is the shortest distance from the initial and final position of a body.

**Speed** is time rate of change of distance and is a scalar quantity.

**Velocity** is the time rate of change of displacement and is a vector quantity.

**Acceleration** is the time rate of change of velocity and is a vector quantity.

**Gradient of distance-time graph** gives speed of the body.

**Gradient of speed-time graph** gives acceleration of the body.

**Area under the speed-time graph** gives distance travelled by the body.



## EXERCISE

### MULTIPLE CHOICE QUESTIONS

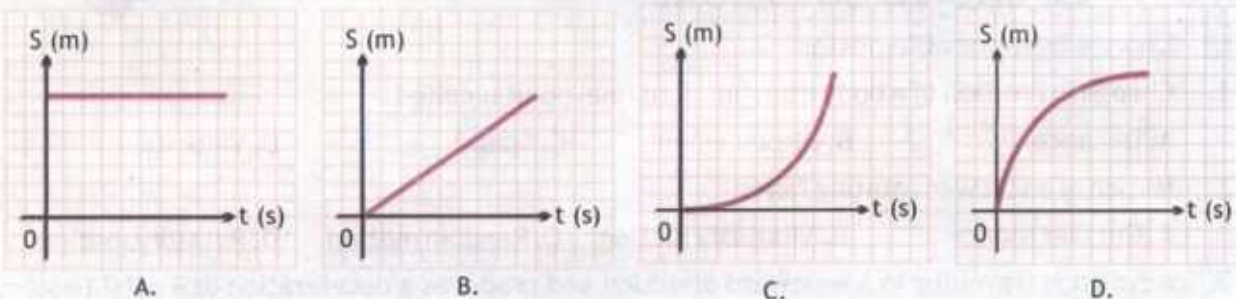
Q1. Choose best possible option:

1. Change in position of a body from initial to final point is called:  
A. Distance                      B. Displacement                      C. Speed                      D. Velocity
2. Motion of a screw of rotating fan is:  
A. Circular motion                      B. Vibratory motion                      C. Random motion                      D. Rotatory motion
3. A cyclist is travelling in a westward direction and produces a deceleration of  $8 \text{ m/s}^2$  to stop. The direction of its acceleration is towards  
A. North                      B. East                      C. South                      D. West
4. A girl walks 3 km towards west and 4 km towards south. What is the magnitude of her total distance and displacement respectively?  
A. 7 km, 7 km                      B. 1 km, 7 km                      C. 7 km, 1 km                      D. 7 km, 5 km
5. A rider is training a horse. Horse moves 60 metres towards right in 3 seconds. Then it turns back and travels 30 metres in 2 seconds. Find its average velocity?  
A. 6 m/s                      B. 18 m/s                      C. 35 m/s                      D. zero
6. If a cyclist has acceleration of  $2 \text{ m/s}^2$  for 5 seconds, the change in velocity of the cyclist is  
A. 2 m/s                      B. 10 m/s                      C. 20 m/s                      D. 15 m/s
7. A car is moving with velocity of 10 m/s. If it has acceleration of  $2 \text{ m/s}^2$  for 10 seconds. What is final velocity of the car?  
A. 30 m/s                      B. 20 m/s                      C. 10 m/s                      D. 15 m/s
8. When the slope of a body's displacement-time graph increases, the body is moving with:  
A. increasing velocity                      B. decreasing velocity  
C. constant velocity                      D. all of these
9. A ball is thrown straight up, what is the magnitude of acceleration at the top of its path?  
A. zero                      B.  $9.8 \text{ m/s}^2$                       C.  $4.9 \text{ m/s}^2$                       D.  $19.6 \text{ m/s}^2$
10. Slope of distance-time graph is:  
A. velocity                      B. acceleration                      C. speed                      D. displacement
11. Area under speed-time graph is equal to \_\_\_\_\_ of moving body:  
A. distance                      B. change in velocity                      C. uniform velocity                      D. acceleration



## UNIT 2 KINEMATICS

12. In 5 s a car accelerates so that its velocity increases by 20 m/s. The acceleration is  
 A.  $0.25 \text{ m/s}^2$       B.  $4 \text{ m/s}^2$       C.  $25 \text{ m/s}^2$       D.  $100 \text{ m/s}^2$
13. Ball dropped freely from a tower reaches ground in 4 s, the speed of impact of ball is:  
 A.  $0 \text{ m/s}$       B.  $2.45 \text{ m/s}$       C.  $19.6 \text{ m/s}$       D.  $39.2 \text{ m/s}$
14. Which of following distance time graphs represents increasing speed of a car?



### SHORT RESPONSE QUESTIONS

#### QII. Give a short response to the following questions

- In a park, children are enjoying a ride on Ferris wheel as shown. What kind of motion the big wheel has and what kind of motion the riders have?
- A boy moves for some time, give two situations in which his displacement is zero but covered distance is not zero?
- A stone tied to string is whirling in circle, what is direction of its velocity at any instant?



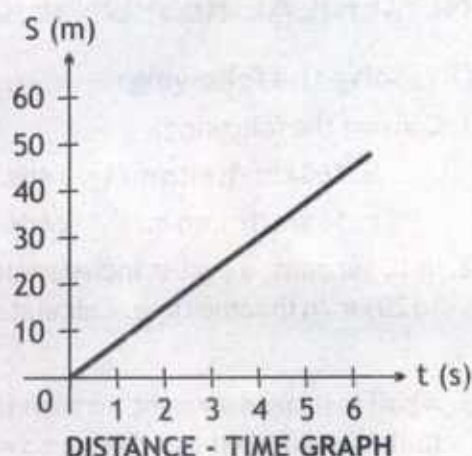
Side view



Top view

- Is it possible to accelerate an object without speeding it up or slowing it down?
- Can a car moving towards right have direction of acceleration towards left?
- With the help of daily life examples, describe the situations in which:
  - acceleration is in the direction of motion.
  - acceleration is against the direction of motion.
  - acceleration is zero and body is in motion.

7. Examine distance-time graph of a motorcyclist (as shown), what does this graph tell us about the speed of motorcyclist? Also plot its velocity-time graph.



8. Which controls in the car can produce acceleration or deceleration in it?
9. If two stones of 10 kg and 1 kg are dropped from a 1 km high tower. Which will hit the ground with greater velocity? Which will hit the ground first? (Neglect the air resistance)
10. A 100 g ball is just released (from rest) and another is thrown downward with velocity of 10 m/s, which will have greater acceleration? (Neglect the air resistance)

## LONG RESPONSE QUESTIONS

**QIII. Give a detailed response to questions below.**

1. Differentiate between rest and motion. With the help of example, show that rest and motion are relative to observer?
2. What are different types of motion? Define each type of motion with examples from daily life.
3. What are scalars and vectors? Give examples. How are vectors represented symbolically and graphically?
4. Define the term position. Differentiate between distance and displacement.
5. Differentiate between speed and velocity. Also define average speed, uniform and variable speeds, average velocity, uniform and variable velocities.
6. What are freely falling bodies? What is gravitational acceleration? Write down sign conventions for gravitational acceleration? Write three equations of motion of a freely falling body?
7. Draw distance-time graphs for rest, uniform speed, increasing speed and decreasing speed.
8. Draw speed-time graphs for zero acceleration, uniform acceleration, uniform deceleration. Also show that area under speed time graph represents distance covered by the body.



## NUMERICAL RESPONSE QUESTIONS

## QIV. Solve the following

1. Convert the following:

- a. 160 km/h into m/s (Ans. 44.44 m/s)    b. 36 m/s into km/h (Ans. 129.6 km/h)  
c. 15 km/h<sup>2</sup> into m/s<sup>2</sup> (Ans. 0.001 m/s<sup>2</sup>)    d. 1 m/s<sup>2</sup> into km/h<sup>2</sup> (Ans. 12,960 km/h<sup>2</sup>)

2. In 10 seconds, a cyclist increases its speed from 5 km/h to 7 km/h, while a car moves from rest to 20 km/h in same time. Calculate and compare acceleration in each case.

(Ans. 0.055 m/s<sup>2</sup> and 0.55 m/s<sup>2</sup>)

3. A ball is thrown straight up such that it took 2 seconds to reach the top after which it started falling back. What was the speed with which the ball was thrown up? (Ans. 19.6 m/s)

4. A car is moving with uniform velocity of 20 m/s for 20 seconds. Then brakes are applied and it comes to rest with uniform deceleration in 30 s. Plot the graph to calculate this distance using speed time graph? (Ans. 1 km)

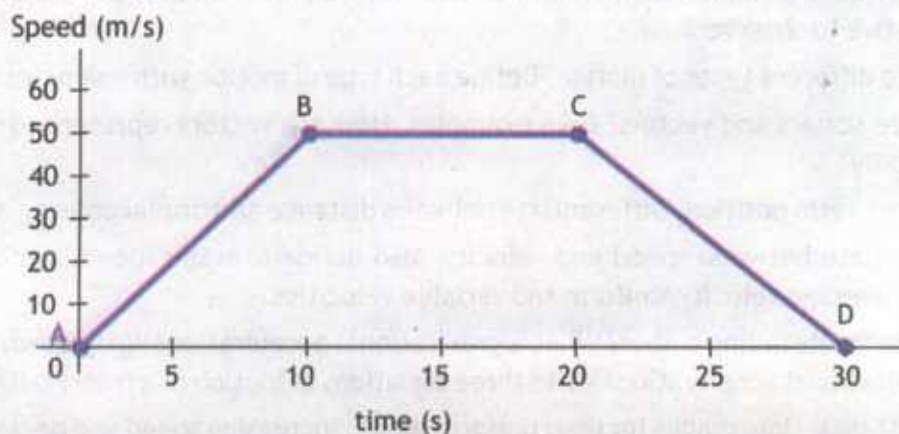
5. A girl starts her motion by a racing bicycle in a straight line at a speed of 50 km/h. Her speed is changing at a constant rate. If she stops after 60 s, what is her acceleration? (Ans. 0.23 m/s<sup>2</sup>)

6. Consider the following speed time graph. Tell:

a. Which part of the graph is showing acceleration, deceleration and zero acceleration?

b. Calculate covered distance from 10 seconds to 20 seconds from the graph.

(Ans. (a) OA, BC, AB, (b) 500 m)



SPEED - TIME GRAPH

# DYNAMICS - 1

UNIT  
3

What force enable us to hold rope tightly?

## Student Learning Outcomes (SLOs)

### The students will

- [SLO: P-09-B-17] Illustrate that mass is a measure of the quantity of matter in an object.
- [SLO: P-09-B-18] Explain that the mass of an object resists change from its state of rest or motion (inertia).
- [SLO: P-09-B-19] Define and calculate weight.
- [SLO: P-09-B-20] Define and calculate gravitational field strength.
- [SLO: P-09-B-21] Justify and illustrate the use electronic balances to measure mass.
- [SLO: P-09-B-22] Justify and illustrate the use of a force meter to measure weight.
- [SLO: P-09-B-23] Differentiate between contact and non-contact forces.
- [SLO: P-09-B-24] Differentiate between different types of forces.
- [SLO: P-09-B-25] State that there are three fundamental forces and describe them in terms of their relative strengths.
- [SLO: P-09-B-26] Represent the forces acting on a body using free body diagrams.
- [SLO: P-09-B-27] State and apply Newton's first law.
- [SLO: P-09-B-28] Identify the effect of force on velocity.
- [SLO: P-09-B-29] Determine the resultant of two or more forces acting along the same straight line.
- [SLO: P-09-B-30] State and apply Newton's second law in terms of acceleration.
- [SLO: P-09-B-31] State and apply Newton's third law.
- [SLO: P-09-B-32] Explain with examples how Newton's third law describes pairs of forces of the same type acting on different objects.
- [SLO: P-09-B-33] State the limitations of Newton's laws of motion.
- [SLO: P-09-B-39] Define and calculate momentum.
- [SLO: P-09-B-40] Define and calculate impulse.
- [SLO: P-09-B-41] Apply the principle of the conservation of momentum to solve simple problems in one dimension.
- [SLO: P-09-B-42] Define resultant force in terms of momentum.

In kinematics we have discussed how motion is described in terms of velocity and acceleration. Now we deal with the questions like: How an object at rest begin to move? What causes an object to accelerate or decelerate? What makes an object to move in a curved path? The simple answer to all these questions is force. In this Chapter, we will study the connection between force and motion, which is the subject called dynamics.

Every motion you observe or experience is related to a force as shown in figure 3.1. We can start moving a trolley by simply applying force on it, we can use this force to speed it up or slow it down and we can even change its direction.

**FIGURE 3.1 FORCE**



## 3.1 FORCE

Force is vector quantity which changes or tends to change state of body; start or stop its motion, speed it up or slow it down and can change the direction of its motion.

### 3.1.1 TYPES OF FORCES

Forces are broadly classified as contact and non contact forces.

#### A. CONTACT FORCES

The force acting between two objects that are in physical contact are termed as contact forces. For example, in game of cricket a batter hitting a cricket ball (Figure 3.2) is a contact force since there is physical contact between the bat and the ball.

**FIGURE 3.2 CONTACT FORCE**



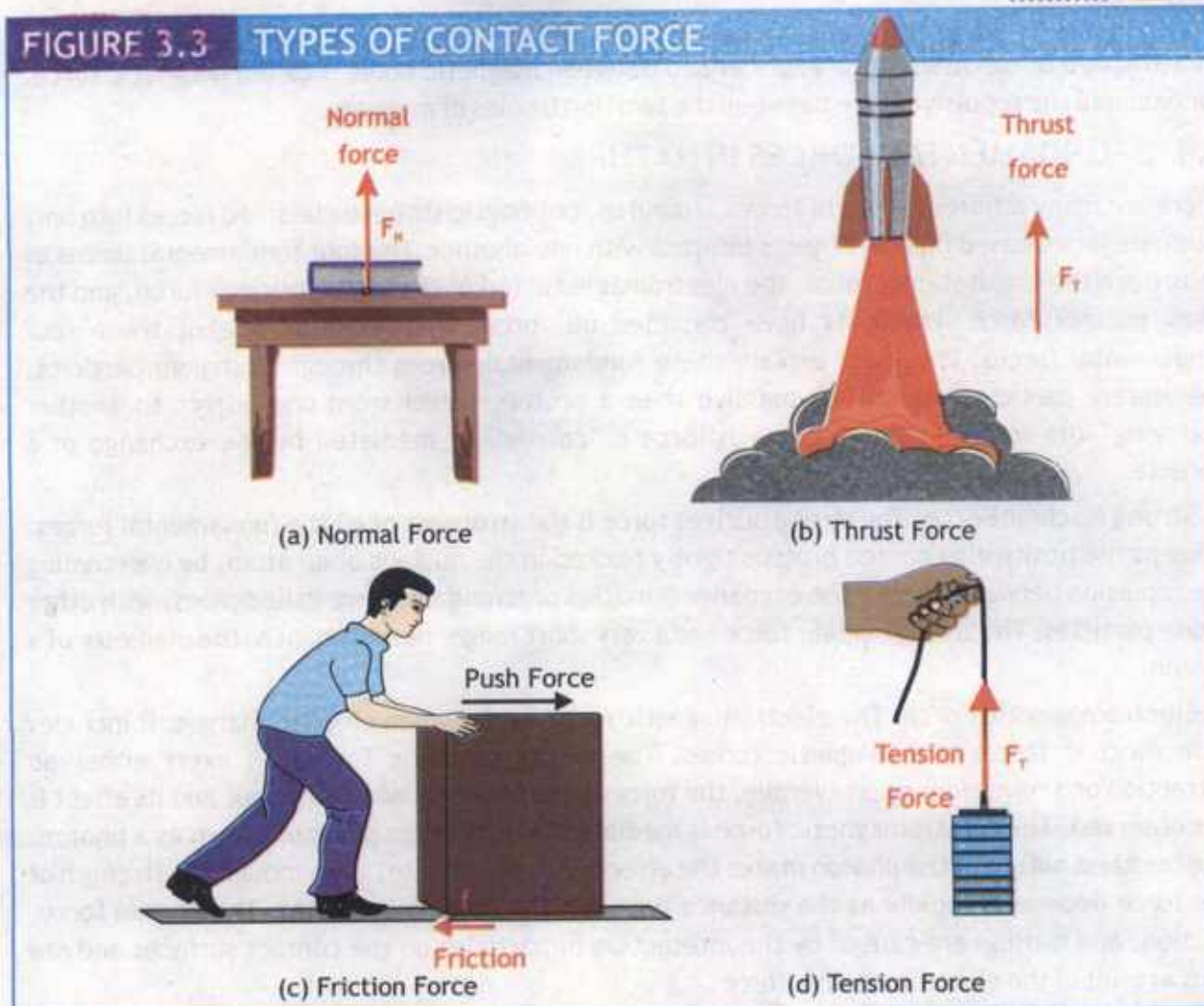
A force perpendicular to the contact surface that keeps objects from passing through each other is called the **normal force** and is represented as  $F_n$ . (In geometry, normal means perpendicular). For example the book lying on table, the force perpendicular to the table is normal force figure 3.3 (a).

The force that propels a flying machine in the direction of motion is termed as **thrust**. For example engines produce thrust, the thrust of engine of car cause it to accelerate as shown in figure 3.3 (b).

Force that resist the relative motion of solid surfaces, fluid layers, and material elements in contact and sliding against each other is called **friction**. Friction on an object acts in a direction opposite to the direction of the object's motion or attempted motion figure 3.3 (c).

For example air resistance is also a frictional force which occurs between air and an object. It is the force that the object experiences as it passes through the air. It is a kind of the drag force which resists the motion of a body with fluid.

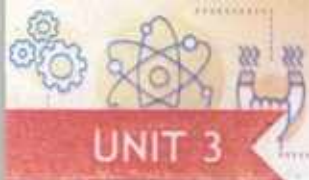
FIGURE 3.3 TYPES OF CONTACT FORCE



The forces exerted by two or more physical objects that are in contact, through string, rope, cable or spring, we call such force as **tension**. For example tension keeps spider web together consists of numerous fine strands that pull on one another. The tension in cord attached to a string is shown in the figure 3.3 (d). The forces that an object exerts to resist a change in its shape are called **elastic forces**; they arise from forces between the particles in the material. For example when force is applied to a spring or rubber band it will stretch and at same time resists being stretched. It must be noted that the tension is the elastic only during extension not compression.

### B. NON-CONTACT FORCES

Have you seen magnets exerting push or pull on other magnets at some distance? The force which acts at a distance, without any physical contact between bodies is termed as non-contact force. This force acts even if the objects involved are not touching, also termed as action at a distance force. The attractive force between two objects with mass is called **gravitational force**. For example, the force experienced by moon because of earth. An attractive or repulsive force experienced by charged objects is called **electrostatic force**. For example the attractive force between a positively charged nucleus and negatively charged electron.



An attractive or repulsive force experienced between magnetic poles is called **magnetic force**. For example the repulsive force between the two North poles of magnets.

### 3.1.2 FUNDAMENTAL FORCES IN NATURE

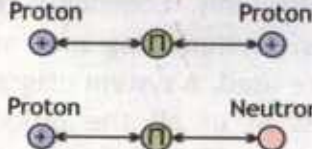
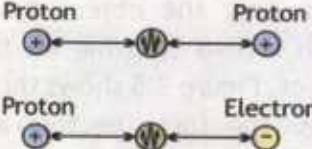
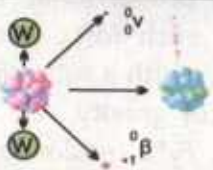
There are many different types of forces around us, but physicists have classified forces into only four categories based on how objects interact with one another. The four fundamental forces of nature are the gravitational force, the electromagnetic force, the strong nuclear force, and the weak nuclear force. Physicists have classified all forces that exist as one of these four fundamental forces. Physicists explain these fundamental forces through exchange particles. Elementary particles, much less massive than a proton, travel from one object to another "carrying" the force. In this way, each force is 'carried' or mediated by the exchange of a particle.

**A. Strong Nuclear Force:** The strong nuclear force is the strongest of all the fundamental forces. It keeps the positively charged protons tightly packed in the nucleus of an atom, by overcoming the repulsion between them. The exchange particles of strong force are called pions, with other heavy particles. The strong nuclear force has a very short range, nearly equal to the diameter of a proton.

**B. Electromagnetic Force:** The electromagnetic force act between electric charges. It includes both electric forces and magnetic forces. The electromagnetic force can exert either an attraction or a repulsion, so on average, the forces tend to cancel each other out and its effect is not observed. The electromagnetic force is mediated by a massless particle known as a photon. **The massless nature of the photon makes the effective range infinite, even though the strength of the force decreases rapidly as the distance between the objects increases.** The normal force, friction, and tension are caused by the interaction of particles on the contact surfaces and are thus a result of the electromagnetic force.

**C. Gravitational Force:** The gravitational force, or the force of gravity, is the force of attraction between all objects in the universe. Gravity is by far the weakest of the four fundamental forces (with least relative strength), the force of gravity between two objects is noticed only if at least one of the objects has a large mass such as stars, planets, and moons. It holds them together and controls their motions in the same way that it controls the motion of falling objects here on Earth. Gravitational force is theorized to be an exchange force with a massless mediating particle 'graviton'. The massless nature of the graviton allows gravity to have infinite range similar to the electromagnetic force. However, the graviton is the only exchange particle not detected yet.

**D. Weak Nuclear force:** The weak nuclear force is very weak, 10 000 times weaker than the strong nuclear force and has the shortest range of any of the fundamental forces. Despite this, the weak nuclear force plays a major role in the structure of the universe. It is an exchange force mediated by the exchange of three different particles called vector bosons. The weak nuclear force is responsible for radioactive decay. Specifically, the weak force changes the flavour (type) of an elementary particle called a quark. When this process occurs, a neutron in the nucleus transforms into a proton.

| TABLE 3.1: FUNDAMENTAL FORCES IN NATURE |                                    |                      |                                                                                     |                                          |
|-----------------------------------------|------------------------------------|----------------------|-------------------------------------------------------------------------------------|------------------------------------------|
| Fundamental Force                       | Range (metre)                      | Relative strength    | Function                                                                            | Exchange Particles                       |
| Strong Force                            | $10^{-15}$<br>(diameter of proton) | 1                    |   | Pions ( $\pi$ ) or others                |
| Electromagnetic Force                   | infinite                           | $7.3 \times 10^{-3}$ |   | Photons (massless)                       |
| Weak Force                              | $10^{-17}$                         | $10^{-6}$            |   | $W^+$ , $W^-$ , $Z_0$<br>(vector bosons) |
| Gravitational Force                     | infinite                           | $6 \times 10^{-39}$  |  | graviton<br>(not yet detected)           |

For years physicists have sought to show that the four basic forces are simply different manifestations of the same fundamental force. The most successful attempt at such a unification is the electroweak theory, proposed during the late 1960s by Abdus Salam (Pakistani physicist), Steven Weinberg, and Sheldon Lee Glashow. This theory, which incorporates quantum electrodynamics (the quantum field theory of electromagnetism), treats the electromagnetic and weak forces as two aspects of a more-basic electroweak force that is transmitted by four carrier particles, the so-called gauge bosons.

**FIGURE 3.4 ABDUS SALAM**



One of these carrier particles is the photon of electromagnetism, while the other three—the electrically charged  $W^+$  and  $W^-$  particles and the neutral  $Z_0$  particle—are associated with the weak force. Unlike the photon, these weak gauge bosons are massive, and it is the mass of these carrier particles that severely limits the effective range of the weak force.



### 3.1.3 FORCE DIAGRAMS

In order to study forces and their effects on the objects, we should familiarize ourselves with the skill of drawing force diagrams. Commonly two types of force diagrams, 'system diagrams' and 'free-body diagrams', are used. A system diagram (SD) is a visual expression of all the objects required. A free-body diagram (FBD) is a schematic representation in which only the object being analyzed is drawn, with arrows showing all the forces acting on the object. Figure 3.5 shows three examples SDs and FBDs: the force vectors are drawn with their lengths proportional to the magnitudes of the forces; each force vector is labelled with the symbol ' $\vec{F}$ ', with a subscript (for example, ' $\vec{F}_g$ ' is the force of gravity, ' $\vec{F}_N$ ' is the normal force, ' $\vec{F}_f$ ' is friction, ' $\vec{F}_T$ ' is tension, and ' $\vec{F}_A$ ' is the applied force).

### 3.1.4 CONCEPT OF NET FORCE

Different forces can affect an object, and the net force is the total effect of all these forces. It is calculated by adding up all the forces acting on the object.

The net force helps us determine if the forces on the object are balanced or unbalanced. If the net force is 0 N, it means the forces are balanced, and there will be no change in the object's motion.

FIGURE 3.5 FORCE DIAGRAMS

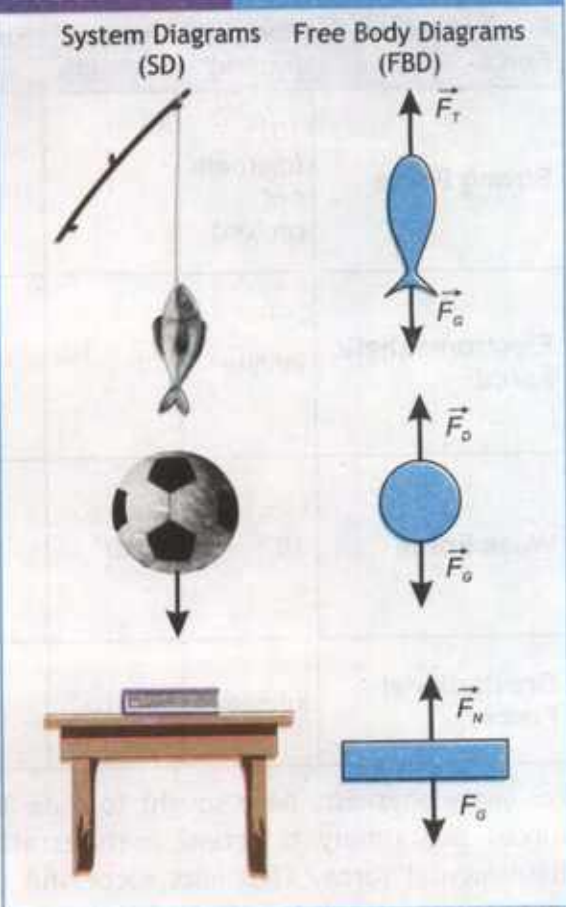


FIGURE 3.6 NET FORCE



For example, in a tug of war shown in figure 3.6 (a) the forces ' $\vec{F}_1$ ' and ' $\vec{F}_2$ ' are equal in magnitude and opposite in direction, the forces cancel the effect of each other and there is no net force. However, when the net force on an object is not 0 N, the forces are unbalanced and produce a change in motion of an object. For example, for tug of war in figure 3.6 (b) one force ' $\vec{F}_2$ ' exceeds the other force ' $\vec{F}_1$ ', and there is a net force ' $\vec{F}_{net}$ ' to the right.

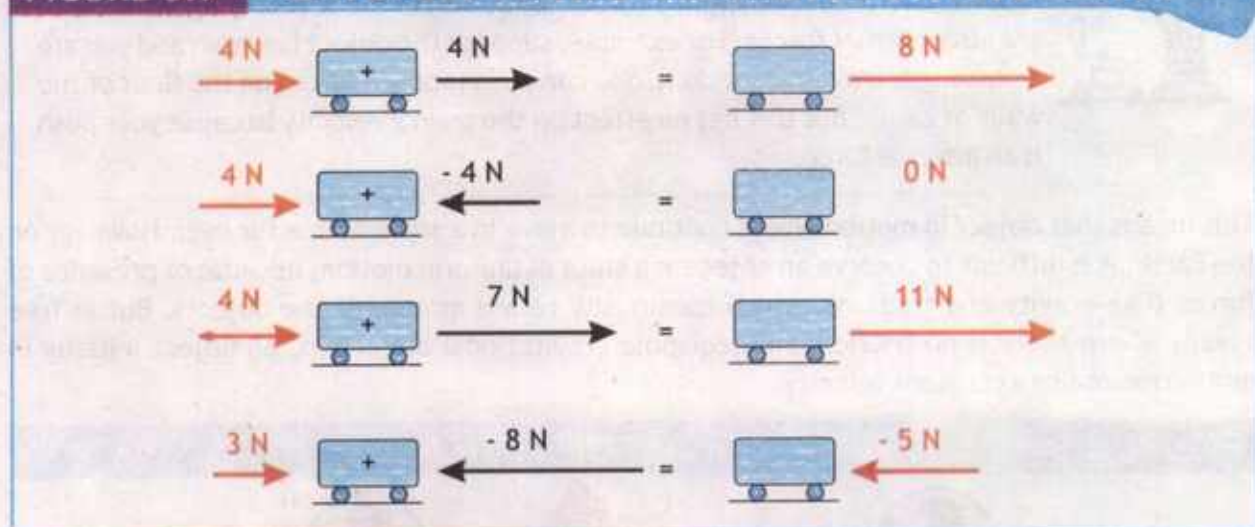


### FREE-BODY DIAGRAMS AND RESULTANT (NET) FORCES

To study the effects of forces acting on any object, we can apply the skill of drawing force diagrams. Since force is a vector quantity, the vector sum of all the forces acting on an object is the resultant force. The resultant force can also be called the net force. These two terms can be used interchangeably. They will be represented by the same symbol, ' $\vec{F}_{net}$ ', in this text.

The net force or resultant force can be obtained by simply adding forces. A resultant force is a single force that has the same effect as the combined effect of all the forces to be added. Forces are vector quantities which require both magnitude with proper unit as well as direction for its complete description. Therefore it is required that we should draw the forces to a common scale as vectors (arrow diagrams). Simply add the magnitudes of vectors in case of like parallel forces and subtract the magnitudes of vectors in case of unlike parallel forces. Few examples are shown in the figure 3.7.

FIGURE 3.7 NET FORCE FOR LIKE AND UNLIKE PARALLEL FORCES

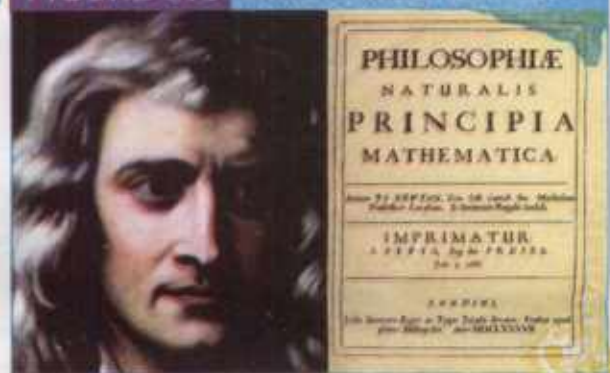


However, we cannot make such algebraic addition of vectors when vectors are making certain angle. In such cases we draw vectors on a coordinate axis and then according to the same scale we can add them by head to tail rule of vector addition.

### 3.2 NEWTON'S LAWS OF MOTION

In 1686 English Scientist Sir. Isaac Newton (1642-1727) presented his three laws of motion in a book *Philosophiae Naturalis Principia Mathematica* (English: Principles of Natural Mathematics) as shown in the figure 3.8. This book is considered as the greatest scientific work ever written.

FIGURE 3.8 SIR. ISAAC NEWTON



## 3.2.1 NEWTON'S FIRST LAW OF MOTION

In a soccer game, players kick the ball to each other. When a player kicks the ball, the kick is an unbalanced force. It sends the ball in a new direction with a new speed. What keeps the ball rolling? To answer we have to look into statement of Newton's first law of motion.

If the net external force acting on an object is zero, the object will maintain its state of rest or uniform motion (constant velocity).

It means that in absence of external net force, an object at rest, it will remain at rest; While an object in motion will continue to move with constant velocity (no change in velocity or no acceleration). Mathematically,

$$\vec{F}_{\text{net}} = 0 \quad \text{then} \quad \Delta \vec{v} = 0 \quad \text{or} \quad \vec{a} = 0$$



## SCIENCE TIDBITS

An external force is an applied force, applied on to the object or system. There are also internal forces. For example, suppose the object is a train and you are a passenger traveling inside it. You can push (apply a force) on the floor or the walls of cabin, but this has no effect on the train's velocity because your push is an internal force.

This means that object in motion would continue to move in a straight line for ever. However on the Earth, it is difficult to observe an object in a state of uniform motion, because of presence of forces (like gravity and friction), which continually retard motion of the objects. But in free space, where there is no friction and negligible gravitational attraction, an object initially in motion maintains a constant velocity.

FIGURE 3.9 NEWTON'S FIRST LAW OF MOTION



An object at rest will remain at rest



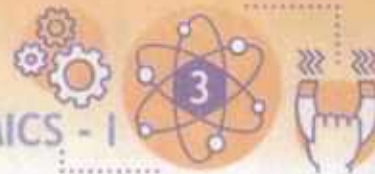
Unless acted on by an unbalance force



The object will continue to move at constant speed and direction



Unless acted upon by another unbalance force



An object can continue to move when the unbalanced forces are removed. For example, when a soccer ball is kicked, it experiences an unbalanced force. The ball keeps rolling on the ground until another unbalanced force alters its movement as shown in figure 3.9.

### POINT TO PONDER



**Why is it more difficult to push large man on swing compared to a small child?**

There is a difference in the resistance to a change in motion between the man and the child. Also, when you try to stop their motions, you would again notice a difference in the resistance to a change in motion. Because large man has more inertia due to more mass.

First law of motion specifies that there is a natural tendency of an object to remain in a state of rest or in uniform motion in a straight line termed as **inertia**. Does all objects have equal tendency to resist its state of rest or uniform motion? Absolutely not, the object with more mass (the measure of the amount of matter in a body) has greater resistance to change (inertia), is the reason why it is difficult to move massive objects. Mass is a quantity that is dependent on inertia (the greater the mass of an object, the greater its inertia, and vice versa).

### ACTIVITY



Place a stack of coins over a small sheet of paper. Quickly remove the sheet without toppling the stack of coins. Increase the number of coins and see who wins the game.



Newton's first law of motion is applied when we ride standing in the aisle of a bus holding a pole as shown in figure 3.10 (a). As the bus begins to move, we tend to remain at rest, therefore we feel a push to back (as our lower body start moving with the bus, but the upper part of body maintains the state of inertia). The same principle is again at work when the bus start to slow down or stops, we feel to move forward due to inertia as shown in the figure 3.10 (b).

**FIGURE 3.10 INERTIA AND SUDDEN MOTION OF BUS**



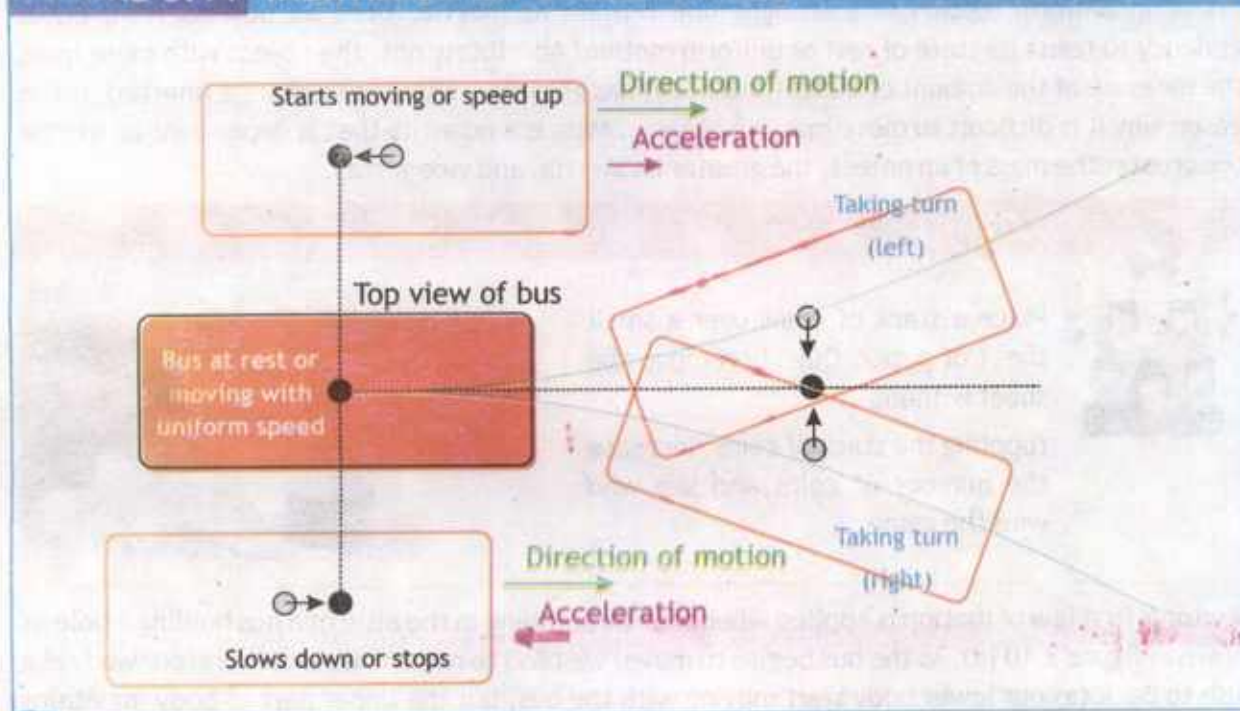


## ACTIVITY



Place a card on top of a glass, and put a coin above this arrangement. If you quickly flick the card horizontally, the inertia of the coin will keep it at rest horizontally. The vertical force of gravity will pull it straight down into the glass.

FIGURE 3.11 INERTIA ON AN OBJECT IN BUS



As the bus starts moving with uniform speed if we hold on to the pole, it supplies the forces needed to give us the same motion as the bus, we no longer feel pushed. But when the bus goes around a curve, again we feel a tendency to move to the side of the bus. The bus has changed its straight line motion, but we tend to move straight ahead. The same principle is again at work when the bus starts to slow down or stops, we feel to move forward as shown in the figure 3.11. Thus the forces we feel when the bus starts moving, speeds up, slows down or turn around a corner are a result of our tendency to remain at rest or follow a straight path.



### 3.2.2 NEWTON'S SECOND LAW OF MOTION

What causes acceleration (change in velocity)? We can get this answer from Newton's first law of motion as 'external, unbalanced net force is required to produce a change in velocity'. Newton went further and related acceleration to inertia (or mass), that it tends to reduce this acceleration.

The acceleration produced by a net force acting on an object (or mass) is directly proportional to the magnitude of the force ( $a \propto F_{\text{net}}$ ) and in the direction of the force (the  $\propto$  symbol is a proportionality sign). In other words, the greater the unbalanced net force, the greater the acceleration.

The acceleration of an object being acted on by a net force is inversely proportional to the mass of the object ( $a \propto 1/m$ ). That is, for a given unbalanced net force, the greater the mass of an object, the smaller the acceleration.

Combining these effects of net force and mass on acceleration gives

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}}$$

Using appropriate units we can write

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

This is Newton's second law of motion which can be formally stated as, The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

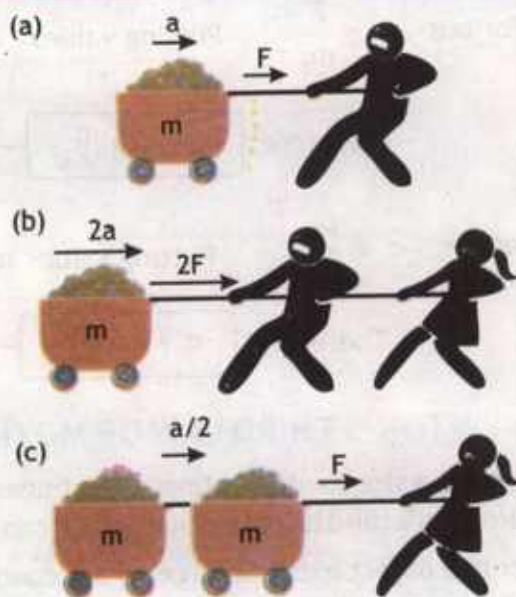
Commonly written in terms of force in magnitude form, we have Newton's second law of motion:

$$\vec{F}_{\text{net}} = m\vec{a} \quad \text{--- 3.1}$$

As an example consider the figure 3.12 (a), mass  $m$  is the mass of the system, when net force acts it produces an acceleration ' $a$ '. In figure 3.12 (b) the force is doubled by keeping the mass same, the acceleration also doubles where as in figure 3.12 (c) the mass is doubled while force is kept the same the acceleration is halved.

Newton's second law of motion also enable us to define System International (SI) unit of force newton represented by symbol N.

FIGURE 3.12 NEWTON'S SECOND LAW



One newton is defined as the force that produces acceleration of one meter per second squared ( $a = 1 \text{ m/s}^2$ ) in a body of mass one kilogram (1 kg).

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2 \quad \text{or} \quad \text{N} = \text{kgm/s}^2$$

### EXAMPLE 3.1: BUS AND CAR ACCELERATIONS

If the same engine is installed in a bus and car that applies a force of 3000 N. What acceleration will this engine produce in a bus of mass 12,000 kg and a car of mass 1200 kg?

GIVEN

Mass of bus  $m_b = 12000 \text{ kg}$

Mass of Car  $m_c = 1200 \text{ kg}$

Force  $F = 3000 \text{ N}$

REQUIRED

Acceleration in bus  $a_b = ?$

Acceleration in car  $a_c = ?$

SOLUTION:

From Newton 2nd law of motion  $a = \frac{F}{m}$

For bus  $a_b = \frac{F}{m_b}$       Putting values  $a_b = \frac{3000 \text{ N}}{12000 \text{ kg}} = \frac{3000 \text{ kgm/s}^2}{12000 \text{ kg}}$

Therefore  $a_b = 0.25 \text{ m/s}^2$  ——— **Answer**

For car  $a_c = \frac{F}{m_c}$       Putting values  $a_c = \frac{3000 \text{ N}}{1200 \text{ kg}} = \frac{3000 \text{ kgm/s}^2}{1200 \text{ kg}}$

Therefore  $a_c = 2.5 \text{ m/s}^2$  ——— **Answer**

### 3.2.3 NEWTON'S THIRD LAW OF MOTION

When we press a stone with our finger, the finger is also pressed upon by the stone. The reason is given by Newton's third law of motion, which can be stated as

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.

When an object 'A' exerts force on object 'B' written as ' $\vec{F}_{AB}$ ', object 'B' also exerts equal force on object 'A' written as ' $\vec{F}_{BA}$ ' but in opposite direction:

$$\vec{F}_{AB} = - \vec{F}_{BA} \quad \text{—————} \quad \text{3.3}$$

Here the negative sign shows that force ' $\vec{F}_{BA}$ ' is opposite to force ' $\vec{F}_{AB}$ '.

These two forces are termed as action - reaction pair. Action and reaction cannot cancel each other because they act on different bodies (action on one body and reaction on another body). When we kick a football as shown in figure 3.13, the foot exerts the action force  $F_{AB}$  on the football and as a reaction the foot ball exerts an equal and opposite force  $F_{BA}$  on our foot. Both these forces are equal in magnitude and opposite in direction.

**FIGURE 3.13 NEWTON'S THIRD LAW OF MOTION**



Examples of Newton's third law of motion are present every where, because when we talk of force we also consider its reaction.

For example, when we jump, our legs apply a force to the ground, and the ground applies an equal and opposite reaction force that pushes us into the air. When we punch an object or kick something as an action, we also get a force onto our hands and legs as a reaction force. That is why we feel pain when punching a wall, or falling on the ground. The exhaust from the rocket creates a downward force which creates an equal and opposite thrust in the upward direction as shown in figure 3.14. Applying Newton's third law of motion allow us to explore two important forces normal force and tension force.

**FIGURE 3.14 NEWTON'S THIRD LAW**



### 3.2.4 LIMITATIONS OF NEWTON'S LAWS OF MOTION

Although Newton's laws of motion are a fundamental set of principles and are applied in variety of situations. While they are very useful for describing the behavior of everyday objects, there are some limitations to their applicability.

- Newton's laws are not readily applied on the very small scale: As one goes to extremely low energies on the atomic scale, position and acceleration are not well defined, where the concepts of quantum mechanics takes over.

- Newton's laws are not applied for objects moving at high speed (speeds close to the speed of light) relativistic effects complicate the dynamics at high speeds and high energies. In such situations we would require to use relativistic mechanics.

However, Newton's laws are not exact but provide a good approximation on the large (macroscopic) scale and over the vast range of practical energies and forces. Newton's laws are still work spectacularly well in physics and engineering.

## 3.3 MASS AND WEIGHT

In our daily life we use the term mass and weight in almost the same meaning. However, mass is the amount of matter an object contains (and a measure of inertia). Weight is the gravitational force acting on a mass or object. Newton's second law can be used to relate the two quantities.

On the surface of the Earth, where the acceleration due to gravity is relatively constant ( $g = 9.80 \text{ m/s}^2$ ), the weight  $W$  is

weight = mass  $\times$  acceleration due to gravity

$$\vec{w} = m\vec{g} \quad \text{--- 3.2}$$

Note that this equation is a special case of  $\vec{F} = m\vec{a}$  where different symbols,  $W$  and  $g$ , have been used for force and acceleration.

### 3.3.1 MEASURING FORCE AND MASS:

Two devices used to measure force in the laboratory are the spring scale and the force sensor, as shown in figure 3.15.

Spring scale is a device used for measuring the force acting on an object. It consists of a spring which gets stretched when a force is applied to it. Stretching of the spring is measured by a pointer moving on a graduated scale. The reading on the scale gives the magnitude of the force.

The force sensor uses an electronic gauge to measure force measure force with a high degree of accuracy. It gives a digital readout or a graph of the forces when interfaced with a computer.

Weight is the effect that gravitational force has on an object. Mass is the amount of matter in an object irrespective of the gravitational force. If we to move to the Moon, our weight would be reduced roughly by 5/6, but our mass would stay the same.

However by using Newton's laws convert our weight into mass easily.

**FIGURE 3.15 FORCE AND MASS MEASUREMENT**





Equation 3.2 can be written as:

$$m = \frac{\vec{W}}{g}$$

Thus if we somehow measure the force of gravity as weight 'W' and divide the value by acceleration due to gravity 'g' we could easily find our mass 'm'. Weighing-scales (actually force-measurers) as shown in figure 3.16 are therefore graduated in kg to show mass. Thus every time you stand on weight machine it gives your mass in 'kilograms', not your weight in 'newtons'.

FIGURE 3.16 WEIGHT MACHINE



Weight machine can be calibrated to measure mass

### EXAMPLE 3.2: WEIGHT OF SCHOOL BAG ON EARTH AND MOON

Mass of your school bag is 8 kg. How much will it weigh (a) here on Earth and on (b) the surface of moon? [Take acceleration due to gravity for Earth as  $g_e = 9.8 \text{ m/s}^2$  and for Moon as  $g_m = 1.625 \text{ m/s}^2$ ]

#### GIVEN

Mass of school bag 'm' = 8 kg

acceleration due to gravity for Earth  $g_e = 9.8 \text{ m/s}^2$  and  
acceleration due to gravity for Moon as  $g_m = 1.625 \text{ m/s}^2$

#### REQUIRED

- (a). Weight on surface of Earth  $w_e = ?$   
(b). Weight on surface of Moon  $w_m = ?$

**SOLUTION:** Weight of a body is given by:  $W = mg$

(a) The weight on surface of earth is  $W_e = m g_e$

Putting values  $W_e = 8 \text{ kg} \times 9.8 \text{ m/s}^2$

$$W_e = 78.4 \text{ kg m/s}^2 = 78.4 \text{ N}$$

Answer

(b) The weight on surface of Moon is  $W_m = m g_m$

Putting values  $w_m = 8 \text{ kg} \times 1.625 \text{ m/s}^2$

$$w_m = 13 \text{ kg m/s}^2 = 13 \text{ N}$$

Answer

Due to low value of "g" on Moon's surface, it will be much easy for you to carry your bag to school. Similarly, it will be easy for you to do the routine works and will not get tired easily on Moon's surface.

### 3.4 GRAVITATIONAL FIELD

The region around a non contact forces where a magnetic force is operative is termed as force field. Whereas the region around a massive object (such as earth, sun etc.) where gravitational force is operative is termed as gravitational field.

The gravitational field strength is the amount of force per unit mass acting on objects in the gravitational field. The value of 'g' is equal to the magnitude of the gravitational force exerted on a unit mass at that point, mathematically

$$g = F_g / m.$$

The gravitational field strength (g) is a vector with a magnitude of 'g' that points in the direction of the gravitational force.

The gravitational field strength 'g' for earth is shown in the figure 3.17. Since, from newton's second law of motion:

$$\vec{a} = \frac{\vec{F}}{m}$$

similarly  $\vec{a}_g = \frac{\vec{F}_g}{m} = \vec{g}$  — 3.3

In SI units, gravitational field strength is measured in newton per kilogram (N/kg). It is a vector quantity that has the direction downward or toward the centre of Earth.

Since the gravitational field strength and the acceleration due to gravity are equal in magnitude, the same symbol,  $\vec{g}$ , is used for both. Therefore, on Earth's surface,  $\vec{g} = 9.8 \text{ N/kg} [\downarrow]$ , or  $\vec{g} = 9.8 \text{ m/s}^2 [\downarrow]$ .

The gravitational field strength is not the same everywhere. Gravitational force decrease as we move away from the surface of earth, therefore gravitational field strength also decreases. Also on different planets we have different gravitational field strengths as shown in table 3.2.

FIGURE 3.17 FIELD STRENGTH

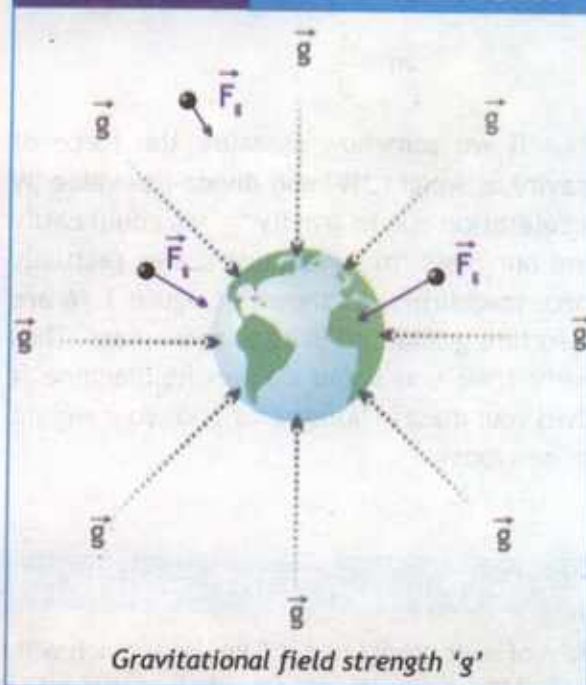


TABLE 3.2: GRAVITATIONAL FIELD STRENGTH IN THE SOLAR SYSTEM

| Planet  | g (N/kg) |
|---------|----------|
| Mercury | 3.7      |
| Venus   | 8.9      |
| Earth   | 9.8      |
| Mars    | 3.7      |
| Jupiter | 24.7     |
| Saturn  | 9.0      |
| Uranus  | 8.7      |
| Neptune | 11.0     |
| Sun     | 274      |



### EXAMPLE 3.2: WEIGHT OF SCHOOL BAG ON EARTH AND MOON

A box weighs 400 N on earth while 150 N on an unknown planet. Find the gravitational field strength on that planet.

#### GIVEN

Weight on Earth ' $W_E$ ' = 400 N  
 unknown planet ' $W_N$ ' = 150 N

Gravitational field strength on Earth ' $g_E$ ' = 9.8 N/kg

#### REQUIRED

Gravitational field strength on the  
 unknown planet ' $g_N$ ' = ?

#### SOLUTION

Since, weight of a body is the product of its mass and acceleration due to gravity, given by:

$$W = mg \quad \text{or} \quad m = \frac{W}{g}$$

Since, mass of a body remains constant, therefore,

$$\frac{W_E}{g_E} = \frac{W_N}{g_N} \quad \text{or} \quad g_N = \frac{W_N}{W_E} \times g_E$$

Putting values  $g_N = \frac{150 \text{ N}}{400 \text{ N}} \times 9.8 \text{ N/kg}$

Hence

$$g_N = 3.675 \text{ N/kg}$$

Answer

The value 3.675 agrees with the numerical value of gravitational field strength on the surface of Mars. So, the unknown planet is Mars (red planet), the nearest planet to earth.

### 3.5 MOMENTUM

The product of the object's mass ' $m$ ' and velocity ' $\vec{v}$ ' is called momentum, denoted by ' $\vec{p}$ '. Mathematically

$$\vec{p} = m\vec{v} \quad \text{--- 3.4}$$

Momentum is a vector quantity that points in the same direction as the velocity. SI Unit of momentum is kilogram-meter per second (kgm/s), or newton-second (Ns). Newton's second law is used to relate force and momentum.

## EXAMPLE 3.4: GOLF BALL MOMENTUM

A golfer hits a ball having mass 45 g. If after the shot, the ball travels with a speed of 80 m/s, what magnitude of momentum does the golfer imparted to ball?



## GIVEN

Mass of ball ' $m$ ' = 45 g = 0.045 kg

Velocity of ball ' $v$ ' = 80 m/s

## REQUIRED

Momentum of ball ' $P$ ' =?

## SOLUTION

From the mathematical form of linear momentum:  $p = mv$

for magnitude ignoring the vector signs:  $p = mv$

putting values  $p = 0.045 \text{ kg} \times 80 \text{ m/s}$

Therefore

$$p = 3.6 \text{ kg m/s}$$

Answer

In order to increase the speed of ball, the golfer needs to impart a greater momentum to the ball.

## 3.5.1 FORCE AND CHANGE IN MOMENTUM

A force ' $\vec{F}$ ' produces acceleration ' $\vec{a}$ ' in a body of mass ' $m$ '. By Newton's second law of motion it is written as

$$\vec{F}_{\text{net}} = m\vec{a} \quad \text{--- (1)}$$

The acceleration produced changes the velocity of the body from initial velocity ' $\vec{v}_i$ ' to final velocity ' $\vec{v}_f$ ' during time interval ' $\Delta t$ '. Then by definition of acceleration

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad \text{--- (2)}$$

Putting equation 2 in equation 1

$$\vec{F}_{\text{net}} = m \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad \text{or} \quad \vec{F}_{\text{net}} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t}$$

FIGURE 3.18 CATCHING





Hence  $\vec{F}_{net} = \frac{\vec{p}_f - \vec{p}_i}{\Delta t} = \frac{\Delta \vec{p}}{\Delta t}$  — 3.5

The time rate of change of linear momentum of a body is equal to the net force acting on the body. This means that for sudden change in momentum force is large and vice versa.

For example, catching a ball with your bare hands will hurt depending on the force of the ball. However, if you allow your hands to move with the ball as you catch it, duration of time ' $\Delta t$ ' will increase, and force will be smaller, and your hands will hurt less.

### EXAMPLE 3.5: FORCE REQUIRED TO STOP A TRUCK AND CAR

What is difficult to stop if their brakes fail and are travelling from an inclined road:

- (a) A car of mass 1200 kg moving with a velocity of 8 m/s in 5 seconds,
- (b) A truck of mass 10,000 kg moving with the same velocity in the same time?

#### GIVEN

Mass of car  $m_c = 1200$  kg

Mass of truck  $m_t = 10,000$  kg

Initial Velocity  $v_i = 8$  m/s

Change in time  $\Delta t = 5$  s

Final Velocity  $v_f = 0$  m/s (As both car and truck have to stop finally)

#### REQUIRED

(a) Average force required to stop car  $F_c = ?$

(b) Average Force required to stop truck  $F_t = ?$

#### SOLUTION

From the relation between force and momentum:

$$F_{net} = \frac{\Delta p}{\Delta t} = \frac{mv_f - mv_i}{\Delta t} \quad \text{--- 1}$$

Putting Values in equation 1 for car:  $F_c = \frac{(1200 \text{ kg})(0 \text{ m/s}) - (1200 \text{ kg})(8 \text{ m/s})}{5 \text{ s}}$

Therefore,

$$F_c = -1920 \text{ N}$$

Answer

(b) Putting Values in equation 1 for truck:  $F_t = \frac{(10,000 \text{ kg})(0 \text{ m/s}) - (10,000 \text{ kg})(8 \text{ m/s})}{5 \text{ s}}$

Therefore,

$$F_t = -16,000 \text{ N}$$

Answer

The negative sign shows that force is applied opposite to the direction of motion i.e., velocity.

### 3.5.2 IMPULSE AND CHANGE IN MOMENTUM

Newton's second law enable us to write force and change in momentum relation as:

$$\vec{F}_{net} = \frac{\vec{p}_f - \vec{p}_i}{\Delta t} = \frac{\Delta \vec{p}}{\Delta t}$$

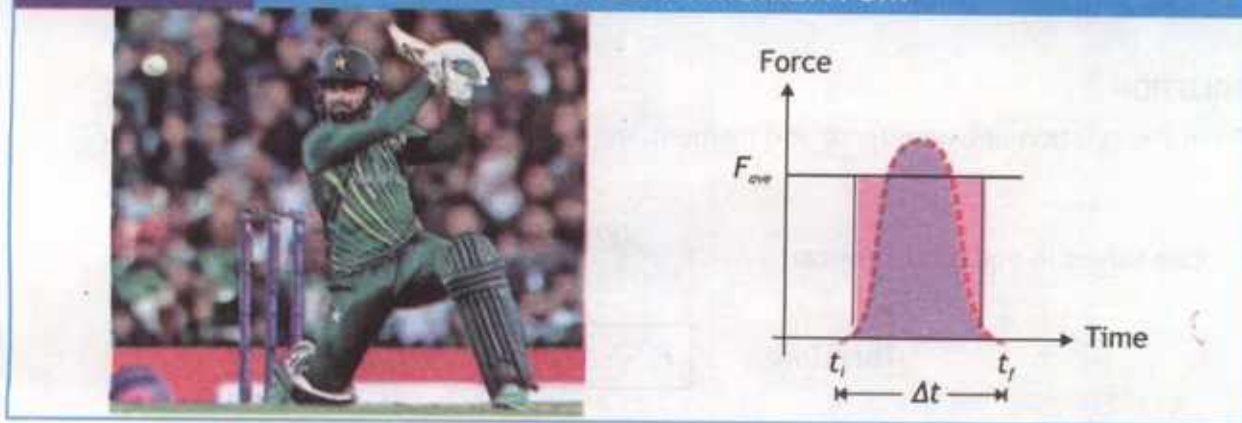
$$\vec{F}_{net} \times \Delta t = \Delta \vec{p} \quad \text{--- 3.6}$$

Equation 3.6 enable us to define a new quantity termed as 'impulse'. Impulse is the product of the force exerted on an object and the time interval over which the force acts, and is often given the symbol 'J'. Impulse is a vector quantity, and the direction of the impulse is the same as the direction of the force that causes it, and have the same SI units as momentum.

In many situations, the net force on the object is not constant and the force applied to an object changes non-linearly during its time of application. The equation 3.8 still applies, provided the net force ' $F_{net}$ ' is equal to the average force acting on the object over the time interval  $\Delta t$ .

For example, when a batter hits a cricket ball, initially the force is very small. Within milliseconds, the force is large enough to deform the ball. The ball then begins to move by return to its original shape and the force soon drops back to zero. Graph in figure 3.19 shows how the force changes with time. We can find the impulse by calculating the area under the curve in force versus time graph.

FIGURE 3.19 IMPULSE AND CHANGE IN MOMENTUM



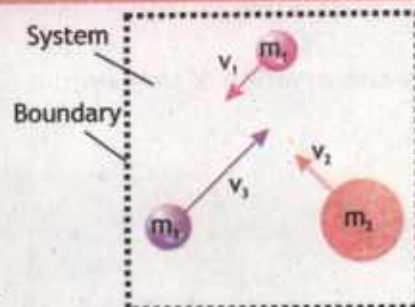
In many collisions, it is difficult to make the precise measurements of force and time that you need in order to calculate the impulse. The relationship between impulse and momentum provides an alternative approach to analyzing such collisions, as well as other interactions. By analyzing the momentum before and after an interaction between two objects, we can determine the impulse.



### SCIENCE TIDBITS

Group of bodies or particles, under study separated by a boundary is called as a system. If the net external force on the system is zero, it is termed as isolated system.

An isolated system is a collection of bodies that can interact with each other but whose interactions with the environment have a no effect on their properties is termed as an isolated system.



### 3.5.3 NEWTON'S LAWS AND CONSERVATION OF MOMENTUM

For an isolated system there is no net force acting ' $F = 0$ ', therefore Newton's second law in terms of momentum (equation 3.) can be written as

$$0 = \frac{\Delta \vec{P}}{\Delta t} \quad \text{or} \quad 0 = \frac{\vec{P}_f - \vec{P}_i}{\Delta t}$$

therefore  $\vec{P}_f = \vec{P}_i$  or  $m_f \vec{v}_f = m_i \vec{v}_i$  ——— 3.8

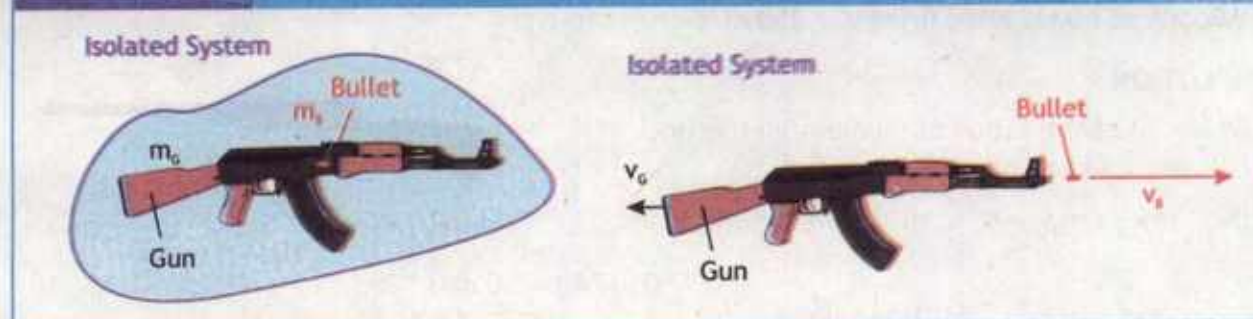
In the absence of external force (isolated system) the final momentum ' $\vec{P}_f$ ' of the system must be equal to initial momentum ' $\vec{P}_i$ '. If no net external force acts on a system of particles, the total momentum of the system cannot change.

This enable us to write the law of conservation of momentum which states:

**'The momentum of an isolated system remains constant'.**

Consider an isolated system of bullet of mass  $m_b$  and gun of mass  $m_g$ . Such that before firing the total initial momentum ( $p_i = 0$ ) of the system is zero as shown in figure 3.20.

**FIGURE 3.20 RECOIL OF GUN**



After firing the bullet moves with velocity ' $v_b$ ' in one direction and the rifle recoils with velocity ' $v_g$ ' in the other direction such that the total final momentum ( $P_f = 0$ ) is again zero.

By conservation of momentum  $\vec{p}_f = \vec{p}_i = 0$  or  $m_b \vec{v}_b + m_g \vec{v}_g = 0$   
or  $m_g \vec{v}_g = -m_b \vec{v}_b$

Hence  $\vec{v}_g = -\frac{m_b \vec{v}_b}{m_g}$  — **3.9**

Negative sign indicates that velocity of the gun is opposite to the velocity of the bullet, i.e., the gun recoils. Since mass of the gun is much larger than the bullet, therefore, the recoil is much smaller than the velocity of the bullet.

### POINT TO PONDER



How rockets accelerate in space as there is no air in space to push against such that as a reaction rocket pushed forward?

In rockets, hot gases produced by burning of fuel rush out with large momentum. The rockets gain an equal and opposite momentum, thereby causing them to accelerate.



### EXAMPLE 3.6: RIFLE RECOIL

Ahmad fired a bullet of mass 17 g from his hunting gun, of mass 3 kg. If the velocity of the bullet were 350 m/s, what would be the recoil velocity of the air gun?

#### GIVEN

Mass of Rifle  $m_g = 3$  kg

Mass of bullet  $m_b = 17$  g = 0.017 kg

Velocity of bullet after firing  $v_b = 350$  m/s

#### REQUIRED

Velocity of Rifle after firing (Recoil speed)  $v_g = ?$

#### SOLUTION

By law of conservation of momentum the final momentum must be zero, therefore

$$m_b v_b + m_g v_g = 0 \quad \text{or} \quad m_g v_g = -m_b v_b$$

Hence  $v_g = -\frac{m_b v_b}{m_g}$

Putting values  $v_g = -\frac{0.017 \text{ kg} \times 350 \text{ m/s}}{3 \text{ kg}}$

Therefore

$v_g = -1.98 \text{ m/s}$

**Answer**



Negative sign is for direction opposite to that of bullet's velocity.

The gun will move in the opposite direction but with a smaller velocity as compared to the bullet because of its greater mass than the bullet..

## SUMMARY

**Dynamics** is the branch of mechanics in which we discuss the motion of bodies along with causes of motion of bodies.

**Force** is a physical quantity which moves or tends to move a body, stops or tends to stop a moving body or which tends to change the speed and direction of a moving body.

**Newton's First Law of Motion** states that every body continues in its state of rest or uniform motion in a straight line unless an external net force acts upon it.

**Newton's Second Law of Motion** states that whenever a net force acts on a body, it produces acceleration in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass of the body.

**Newton's Third Law of Motion** states that to every action there is an equal and opposite reaction.

**Mass** is the quantity of matter in a body.

**Weight** is the downward force with which the earth pulls a body towards its center.

**Gravitational Field Strength** is defined as the force per unit mass that earth exerts on a body.

**Momentum** is the product of mass and velocity. It is a vector quantity.

**Law of Conservation of Momentum** states that if there is no external force applied to a system, the momentum of that system remain constant.

## EXERCISE



### MULTIPLE CHOICE QUESTIONS

**Q1. Choose the best possible option.**

1. Inertia of a body is related to which of the following quantities

- |         |          |           |             |
|---------|----------|-----------|-------------|
| A. mass | B. force | C. weight | D. friction |
|---------|----------|-----------|-------------|

2. A force of 5N is applied to a body weighing 10 N. Its acceleration in  $\text{m/s}^2$  is:

- |        |      |      |       |
|--------|------|------|-------|
| A. 0.5 | B. 2 | C. 5 | D. 50 |
|--------|------|------|-------|

3. SI unit of linear momentum is:

- |                                    |                                 |        |                         |
|------------------------------------|---------------------------------|--------|-------------------------|
| A. $\text{kg m}^{-1}\text{s}^{-1}$ | B. $\text{kg m}^2\text{s}^{-1}$ | C. N m | D. $\text{kg m s}^{-1}$ |
|------------------------------------|---------------------------------|--------|-------------------------|



4. The rate of change of momentum of free falling body is equal to its:  
A. momentum      B. velocity      C. weight      D. size
5. Change in momentum of a body is equal to:  
A. (force) (velocity)      B. (force) (time)      C. (mass) (time)      D. force
6. A book of mass 5 kg is placed on the table, the magnitude of net force acting on the book is:  
A. 50 N      B. 5N      C. 25 N      D. 10 N
7. Thrust force is a consequence of which law of motion:  
A. First      B. second      C. third      D. fourth
8. A force acts on a body for 2 seconds and it produces 50 kgm/s change in its momentum. The force acting on the body is:  
A. 100 N      B. 50 N      C. 25 N      D. 2 N
9. At the fairground, the force that balances your weight is:  
A. gravitational force      B. centripetal force  
C. electrostatic force      D. frictional force
10. When a hanging carpet is beaten by stick. Dust flies off the carpet. It is mainly due to:  
A. Action force on carpet      B. Reaction force by carpet  
C. Inertia of dust      D. Rate of change of momentum of carpet
12. A bucket having some water is revolved in vertical circle. Water does not spill out, even the bucket is upside down, due to:  
A. Weight of water  
B. Centrifugal force on water  
C. Inertia of water  
D. Action and Reaction balance each other
13. The force which moves the car is:  
A. Force developed by engine      B. Force of friction between road and tyre  
C. Weight of car      D. Water spilt on the road
14.  $\text{N kg}^{-1}$  is equivalent to:  
A.  $\text{m s}^{-1}$       B.  $\text{m s}^{-2}$       C.  $\text{kg m s}^{-1}$       D.  $\text{kg s}^{-2}$
15. An object of mass 1 kg placed at earth's surface experiences a force of:  
A. 1 N      B. 9.8 N      C. 100 N      D. any value
16. Net force on the body falling in air with uniform velocity is equal to \_\_\_\_\_.  
A. Weight of the body      B. air resistance on the body  
C. difference of weight of body and air resistance on it      D. zero





## SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. When a motor cyclist hit a stationary car, he may fly off the motor cycle and driver in the car may get neck injury. Explain
2. In autumn, when you shake a branch, the leaves are detached. Why?
3. Why it is not safe to apply brakes only on the front wheel of a bicycle?
4. Deduce Newton's first law of motion from Newton's second law of motion.
5. Action and reaction are equal but opposite in direction. These forces always act in pair. Do they balance each other? Can bodies move under action - reaction pair?
6. A man slips on the oily floor; he wants to move out of this area. He is alone. He throws his bag to move out of this slippery area. Why is it so?
7. How would you use Newton's 3rd law of motion and law of conservation of momentum to explain motion of rocket?
8. Why are cricket batter gloves padded with foam?
9. Where will your weight be greater, near earth or near moon? What about mass?
10. When Ronaldo kicks the ball, at the highest point of ball both Earth and ball attract each other with the same magnitude of force. Why then the ball moves towards Earth and not the Earth?

## LONG RESPONSE QUESTIONS

QIII. Give a an extended response to the following questions

1. State first law of motion. Explain with the help of examples. Why is it called law of inertia?
2. Define inertia. Why is it important to have knowledge of inertia in our daily life? Elaborate your answer with examples.
3. State and prove Newton's second law of motion. Deduce Newton's second law of motion from its first law?
4. State Newton's 3rd law of motion. Explain with examples from daily life.
5. State the limitations of Newton's laws of motion.
6. Differentiate with examples between contact and non-contact forces. Also, explain fundamental forces and the role of Dr. Abdus Salam from Pakistan in unifying two fundamental forces.
7. Represent the forces acting on a body using free body diagrams.
8. Define momentum. What is its formula and unit? Is it a scalar or vector quantity? Show that units of momentum, Ns and kgm/s are equal.
9. Differentiate between mass and weight of body.



10. What are gravitational field and gravitational field strength? Explain.
11. Justify and illustrate the use of electronic balances to measure mass.
12. State and prove Newton's second law of motion in term of momentum.
13. Define isolated system. State law of conservation of linear momentum. Explain with example.

## NUMERICAL RESPONSE QUESTIONS

### QIV. Solve the following numerical questions.

1. A boy is holding a book of mass 2 kg. How much force is he applying on the book? If he moves it up with acceleration of  $3 \text{ m/s}^2$ , how much should he apply total force on the book?  
(Ans. 19.6 N, 25.6 N)
2. A girl of mass 30 kg is running with velocity of 4 m/s. Find her momentum.  
(Ans. 120 N)
3. A 2 kg steel ball is moving with speed of 15 m/s. It hits with bulk of sand and comes to rest in 0.2 second. Find force applied by sand bulk on the ball.  
(Ans. - 150 N)
4. A 100 grams bullet is fired from 5 kg gun. Muzzle velocity of bullet is 20 m/s. Find recoil velocity of the gun.  
(Ans. 0.4 m/s)
5. A robotic car of 15 kg is moving with 25 m/s. Brakes are applied to stop it. Brakes apply constant force of 50 N. How long does the car take to stop?  
(Ans. 7.5 s)

# DYNAMICS - II

UNIT

4

How bottle opener helps to open soda bottle more easily?

## Student Learning Outcomes (SLOs)

### The students will

- [SLO: P-09-B-34] Describe and identify states of equilibrium.
- [SLO: P-09-B-35] Analyse the dissipative effect of friction.
- [SLO: P-09-B-36] Analyse the dynamics of an object reaching terminal velocity.
- [SLO: P-09-B-37] Differentiate qualitatively between rolling and sliding friction.
- [SLO: P-09-B-38] Justify methods to reduce friction.
- [SLO: P-09-B-43] Differentiate between like and unlike parallel forces.
- [SLO: P-09-B-44] Analyze problems involving turning effects of forces.
- [SLO: P-09-B-45] Analyse objects in equilibrium using the principle of moments.
- [SLO: P-09-B-46] Justify experiment to verify the principle of moments.
- [SLO: P-09-B-47] State what is meant by center of mass and center of gravity.
- [SLO: P-09-B-48] Describe how to determine the position of the center of gravity of a plane lamina using a plumb line.
- [SLO: P-09-B-49] Analyse, qualitatively, the effect of the position of the center of gravity on the stability of simple objects.
- [SLO: P-09-B-50] Propose how the stability of an object can be improved.
- [SLO: P-09-B-51] Illustrate the applications of stability physics in real life.
- [SLO: P-09-B-52] Predict qualitatively the motion of rotating bodies.
- [SLO: P-09-B-53] Describe qualitatively motion in a circular path due to a centripetal force.
- [SLO: P-09-B-54] Identify the sources of centripetal force in real life examples.
- [SLO: P-09-F-01] Define and calculate average orbital speed.
- [SLO: P-09-F-02] Interpret and compare given planetary data.



## UNIT 4 DYNAMICS - II

In Dynamics I, we learnt about the force and Newton's laws of motion. Here in Dynamics II, we will study different effects of force on a body including its resistive nature, turning effect and its ability to rotate a body in a circle. We will also know about the stability of different bodies and the role of centre of mass and centre of gravity.

### 4.1 FORCES ON BODIES

Some times we need to extend the direction in which the force acts. The line along which a force acts is called the line of action of the force as shown in figure 4.1.

Multiple forces may act on bodies at same time, under such condition we have to determine the net force ' $F_{net}$ '. However in such situations the line of action of these forces become important. Suppose you are trying to move a heavy piece of furniture, if a friend helps and you both push together, now the ease at which the furniture will depend on the line of action of both forces on the object.

FIGURE 4.1 LINE OF ACTION OF FORCE



If the directions of forces are parallel to each other, even if they are in opposite direction, those forces are called parallel forces. If they are in the same direction they are called 'Like parallel forces'. If they are in the opposite direction they will be known as 'Unlike parallel forces'. For example, when we push a cart with both hands, we are applying like parallel forces from each support as shown in the figure 4.2 (a) and when we apply force with our both hands on handle of a bike to turn it the force from one hand may be greater or equal, we are applying unlike parallel forces as shown in the figure 4.2 (b).

FIGURE 4.2 PARALLEL FORCES



### 4.2 MOMENT OF A FORCE

Force can be used to produce rotation in an object, for example in opening a door or tightening a nut with spanner or wrench.

Turning effect produced in a body about a fixed point due to applied force is called moment of force (or torque).

Moment of force or torque is a vector quantity and have the SI unit as N m.

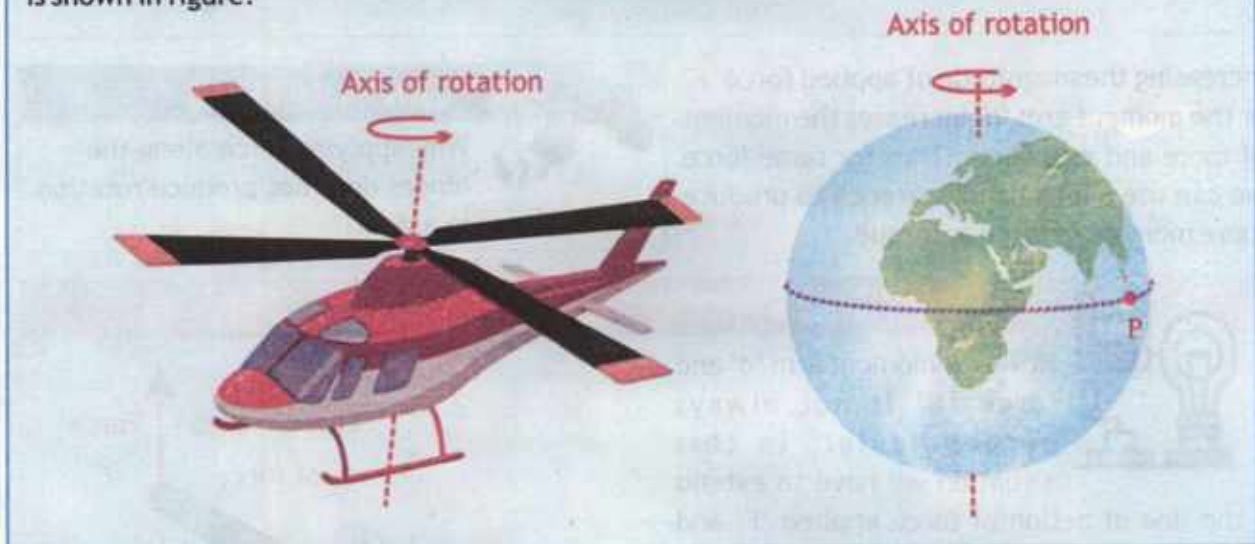


Just like force causes change in motion, moment of force causes change in rotation. This means that moment of force play the same role in rotational motion as force in translational motion. It implies that an object at rest tends to remain at rest, and an object that is rotating (or spinning) tends to spin with a constant angular velocity, unless it is acted on by a nonzero net external moment of force. Similarly, the moment of force tend to produce acceleration in rotational (or spinning) motion.

## FOR YOUR INFORMATION

### AXIS OF ROTATION

Rotational motion is the turning or spinning motion of an object about an axis that passes through it. Axis of rotation is a line about which rotation takes place. This line remain fixed during rotational motion, while the other points of the body move in circles about it. it may be a pivot, hinges or any other support. The axis of rotation for earth and helicopter rotor spinning is shown in figure.



The moment of force or torque ' $\vec{\tau}$ ' is equal to the magnitude of the force ' $F$ ' multiplied by the perpendicular distance from the axis of rotation to the line of action of force ' $d$ '. mathematically

$$\vec{\tau} = F \times d \quad \text{--- 4.1 ---}$$

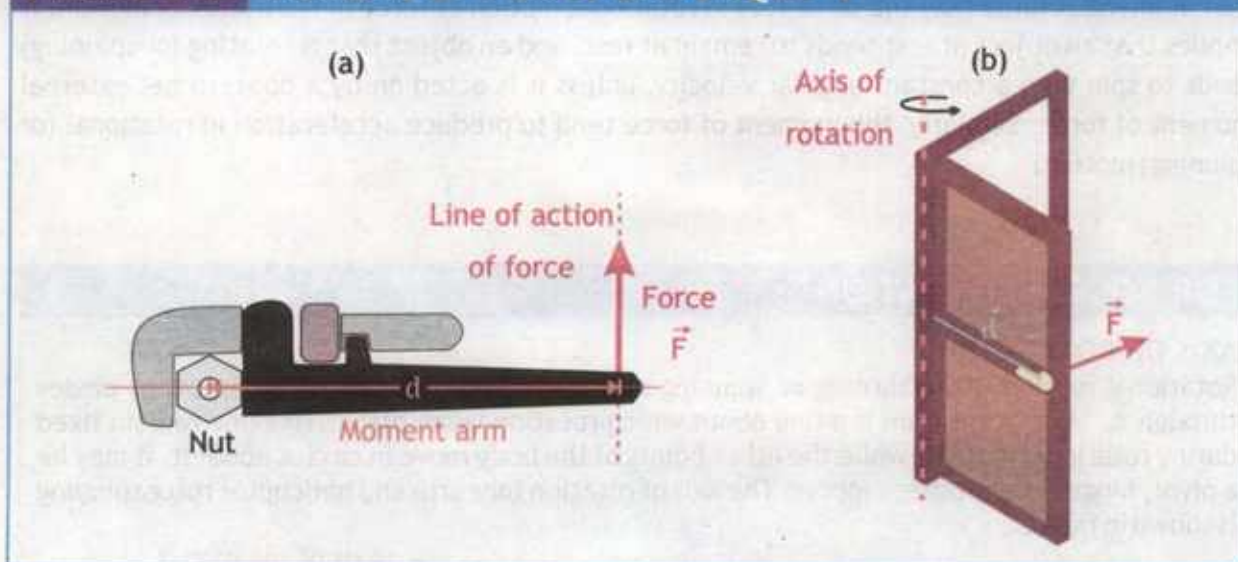
Here the perpendicular distance from the axis of rotation ' $d$ ' is termed as moment arm. So we can redefine moment of force as the **product of force and moment arm**.

Moment of force can cause rotation in a wrench to tighten a nut, for a wrench the axis of rotation is at the center of the nut as shown in the figure 4.3 (a). Similarly moment of force can cause the rotation in a door, for door the axis of rotation is at its hinges as shown in the figure 4.3 (b).



## UNIT 4 DYNAMICS - II

**FIGURE 4.3 MOMENT OF FORCE OR TORQUE 'T'**



Increasing the magnitude of applied force ' $F$ ' or the moment arm ' $d$ ' increases the moment of force and vice versa. Thus for same force we can use a long handle wrench to produce more moment of force or torque.



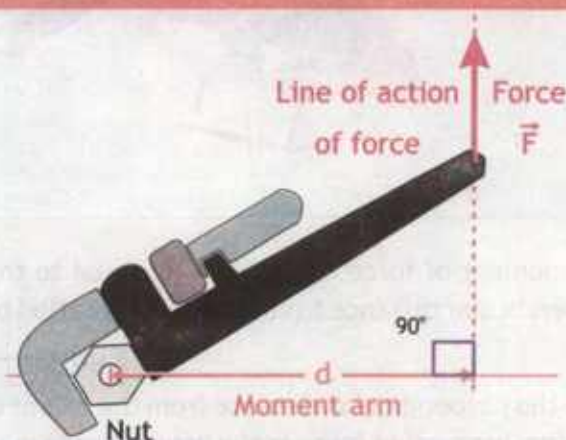
### CAN YOU TELL?

Why applying force along the hinges does not produce rotation in a door?



### SCIENCE TIDBITS

However moment arm ' $d$ ' and force ' $F$ ' is not always perpendicular, in this situation we have to extend the line of action of force applied ' $F$ ' and take the moment arm ' $d$ ' as perpendicular distance from the axis of rotation to the line of action of force as shown in figure.



Moment arm is key to the operation of the lever, pulley, gear, and many other simple machines.

There are two senses of rotation. If the force is capable of rotating the body in clockwise direction, the moment is known as **clockwise moment**. Similarly, the force is capable of producing rotation in the anti-clockwise direction, the torque is known as **anti-clockwise moment**.

Conventionally, clockwise moment is taken as negative, whereas anticlockwise moment is taken as positive.

Newton's laws when applied to rotating bodies we see that moment of force is rotational analogue for force. It implies that an object at rest tends to remain at rest, and an object that is rotating (or spinning) tends to spin with a constant angular velocity, unless it is acted on by a nonzero net external moment of force. Similarly the torque tends to produce acceleration in rotation (or spinning).

### EXAMPLE 4.1: TORQUE

A Physics teacher was explaining the role of moment arm in torque by performing an experiment. The teacher applied a force of 60 N to open a door. The force is applied at three different points perpendicularly and their distances from the axis of rotation are: (a)  $d_A = 0.40$  m, (b)  $d_B = 0.20$  m and (c)  $d_C = 0.0$  m. Find the torque produced in each case.

#### GIVEN

Force ' $F$ ' = 60 N

Moment arm ' $d_A$ ' = 0.40 m

Moment arm ' $d_B$ ' = 0.20 m

Moment arm ' $d_C$ ' = 0.0 m

#### REQUIRED

(a) Torque ' $\tau_A$ ' = ?

(b) Torque ' $\tau_B$ ' = ?

(c) Torque ' $\tau_C$ ' = ?

#### SOLUTION

In each case the moment arm is the perpendicular distance between the axis of rotation and the line of action of force.

(a). Using the definition of torque  $\tau_A = d_A \times F$

Putting values  $\tau_A = 0.40 \text{ m} \times 60 \text{ N}$

Therefore

$$\tau_A = 24.0 \text{ N m}$$

Answer

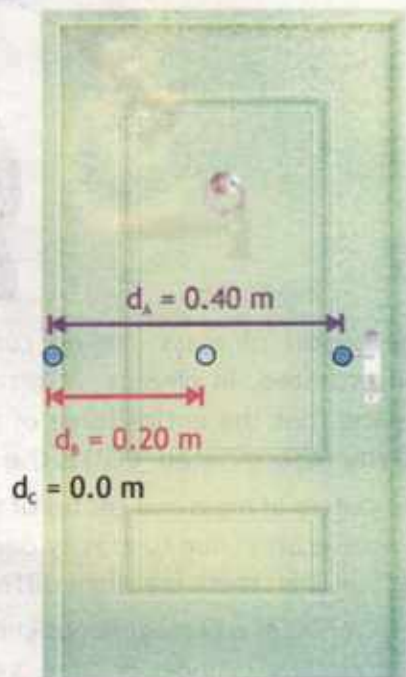
(b). Using the definition of torque  $\tau_B = d_B \times F$

Putting values  $\tau_B = 0.20 \text{ m} \times 60 \text{ N}$

Therefore

$$\tau_B = 12.0 \text{ N m}$$

Answer





(c). Using the definition of torque  $\tau_c = d_c \times F$  Putting values  $\tau_c = 0 \text{ m} \times 60 \text{ N}$

Therefore

$$\tau_c = 0 \text{ N m}$$

Answer

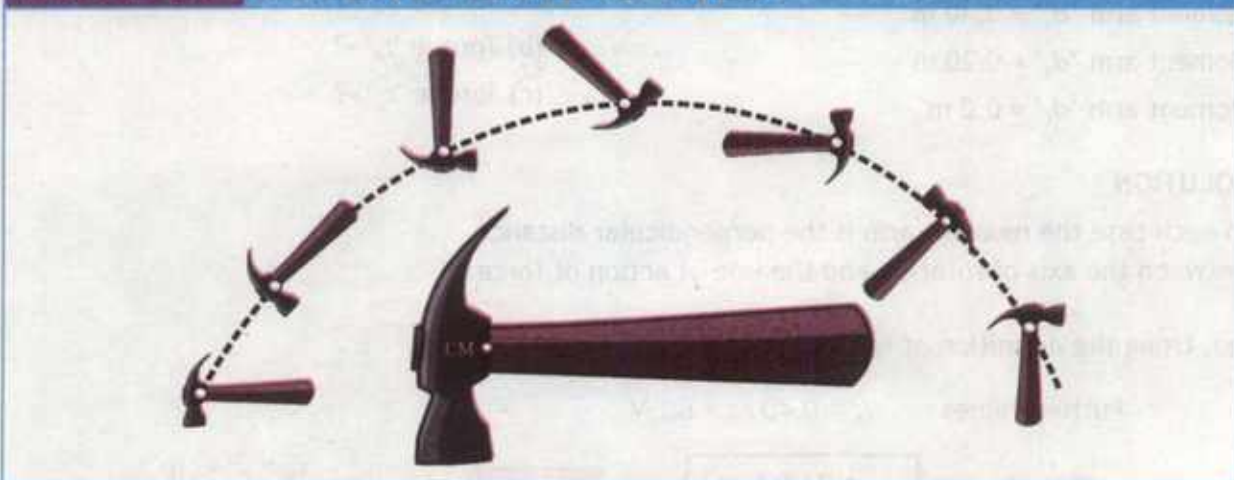
In parts a and b, the torques are positive since the forces tend to produce an anti-clockwise rotation of the door. In part c the line of action of force passes through the axis of rotation (the hinge). Hence the moment arm is zero, and the torque is zero.

### 4.3 CENTER OF MASS

A rigid body (a body that does not deform or change shape) is made of large number of small interconnected particles. The center of mass (abbreviated CM) of a rigid body is the point about which mass is equally distributed.

If the line of action of force pass through the center of mass of a body it will not produce any rotation in it. As an example, consider the motion of the center of mass of the hammer as shown in Figure 4.4. When the hammer is thrown from handle the center of mass follows a smooth parabolic path while other points in the rotating hammer travel along more complicated paths.

FIGURE 4.4 MOTION OF CENTER OF MASS

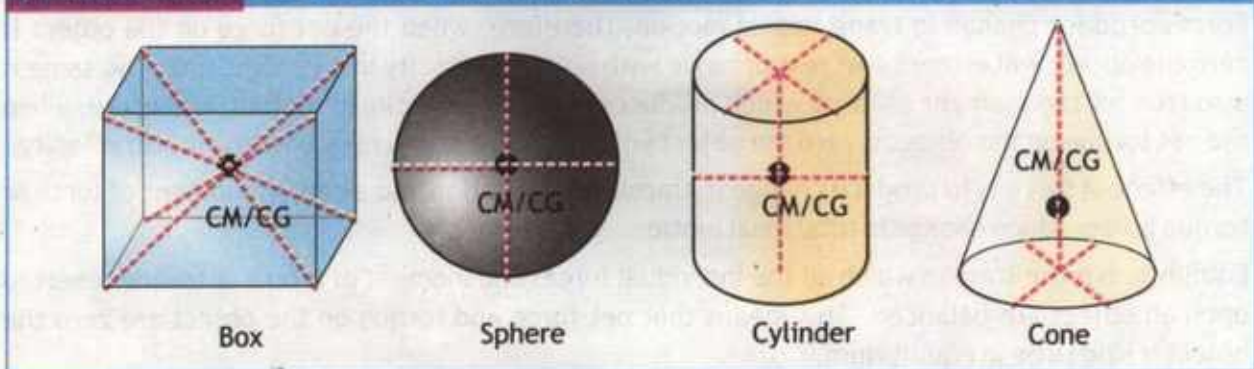


The center of mass can be considered as a point at which all the mass of an object is concentrated. In physics we often deal with weight (the force of gravity). Therefore we can assume that the entire force of gravity (weight) is concentrated at one point. The center of gravity (abbreviated 'CG') is the point where whole weight of the body appear to act.

The center of mass and center of gravity (CM/CG) are same for small objects. But since the value of acceleration due to gravity decrease with altitude, therefore for tall objects (like mountains and building) there is a slight difference.

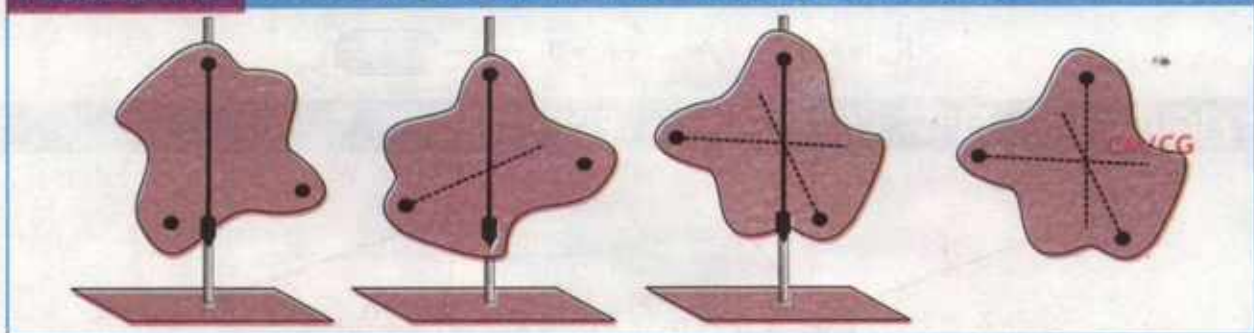
The CM/CG of a homogeneous cube or sphere is at its geometric center, whereas the CM/CG of a right circular cylinder or cone is on the axis of symmetry, and so on as shown in the figure 4.5. Similarly the CM/CG of a uniform wooden rod is at its mid-point, and therefore it can be balanced from its center.

**FIGURE 4.5 CENTER OF MASS OF SYMMETRICAL OBJECTS**



For irregular objects one way to determine the center of gravity is to hang it randomly from at least three different points, and then connecting vertical lines drawn with the help of plumb line. These line will meet each other at a common point which will be the center of gravity CG of the irregular object (sheet) as shown in figure 4.6.

**FIGURE 4.6 CENTER OF GRAVITY OF IRREGULAR OBJECT**

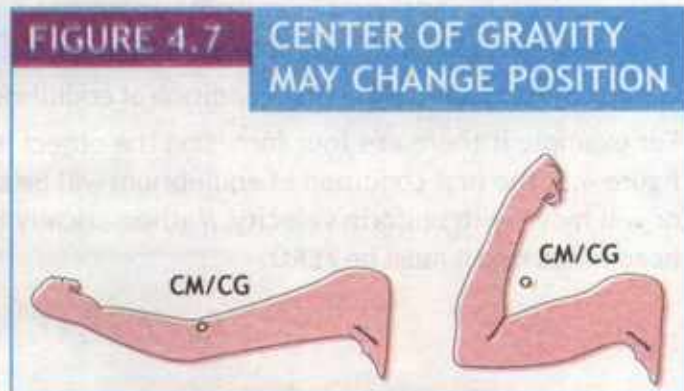


The CM/CG doesn't always lie inside the mass and may change its location depending upon the orientation of the object. For example the arm is stretched out the CM/CG lies inside the mass distribution, but when the arm is bent, the CM/CG shifts to the new location outside the mass distribution as shown in figure 4.7.

**CAN YOU TELL?**



Is there any difference between center of mass and center of gravity? When would the center of mass of object be different than its center of gravity?





## UNIT 4 DYNAMICS - II

### 4.4 EQUILIBRIUM

Forces produce change in translational motion, therefore, when the net force on the object is zero the object will either be at rest or move with uniform velocity in a straight line. The same is also true for the moment of force which produces change in rotational motion, therefore, when the net torque on the object is zero the object will not rotate or will rotate with uniform velocity.

The effect of force is to produce change in translational motion and effect of moment of force or torque is to produce change in rotational motion.

Equilibrium is the state in which all the individual forces and moment of forces or torques exerted upon an object are balanced. This means that net force and torque on the object are zero the object is said to be in equilibrium.

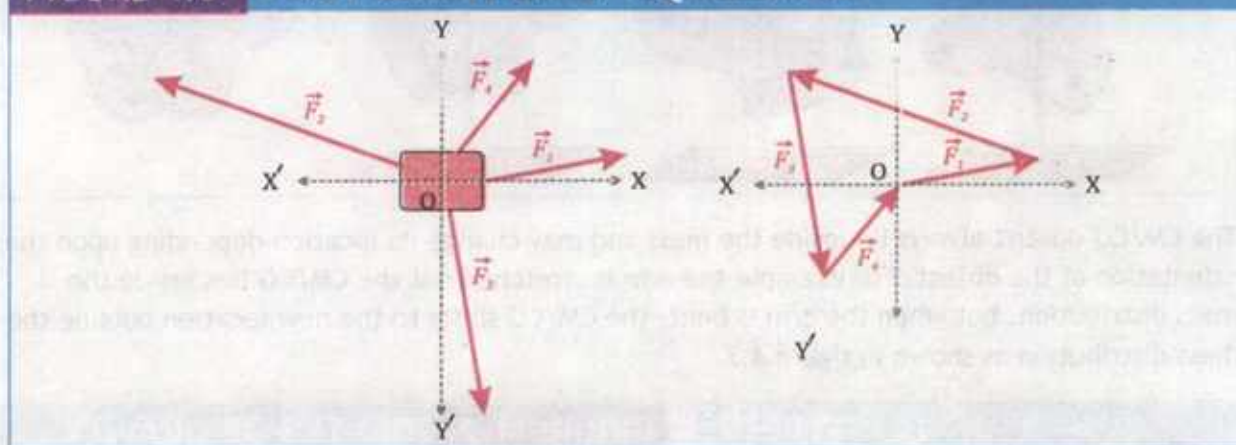
#### 4.4.1 CONDITION OF EQUILIBRIUM

Therefore for complete equilibrium two conditions must be met.

**A. First Condition of Equilibrium:** When the vector sum of all the forces acting on the body is ZERO then the first condition of equilibrium is satisfied. Mathematically if  $\vec{F}_{net}$  is the sum of forces  $\vec{F}_1, \vec{F}_2, \vec{F}_3, \dots, \vec{F}_n$  then

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots + \vec{F}_n = 0 \quad \text{--- 4.2}$$

**FIGURE 4.8 FIRST CONDITION OF EQUILIBRIUM**



For an object to satisfy the first condition of equilibrium the force polygon must close.

For example if there are four forces on the object and their vector sum is zero as shown in the figure 4.8, the first condition of equilibrium will be satisfied and the object will either be at rest or will move with uniform velocity. Mathematically if  $\vec{F}_{net}$  is the sum of forces  $\vec{F}_1, \vec{F}_2, \vec{F}_3$ , and  $\vec{F}_4$  by head to tail rule it must be ZERO.

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4 = 0$$



**B. Second Condition of equilibrium:** When the vector sum of all the torques acting on the body is ZERO then the second condition of equilibrium is satisfied. If  $\vec{\tau}_{\text{net}}$  is the sum of torques  $\vec{\tau}_1, \vec{\tau}_2, \vec{\tau}_3, \dots, \vec{\tau}_n$  then mathematically

$$\vec{\tau}_{\text{net}} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \dots + \vec{\tau}_n = 0 \quad \text{4.3}$$

For complete equilibrium both the first and second conditions of equilibrium must be satisfied.

#### 4.4.2 PRINCIPLE OF MOMENTS

Second condition of equilibrium is also called the principle of moments, which states that

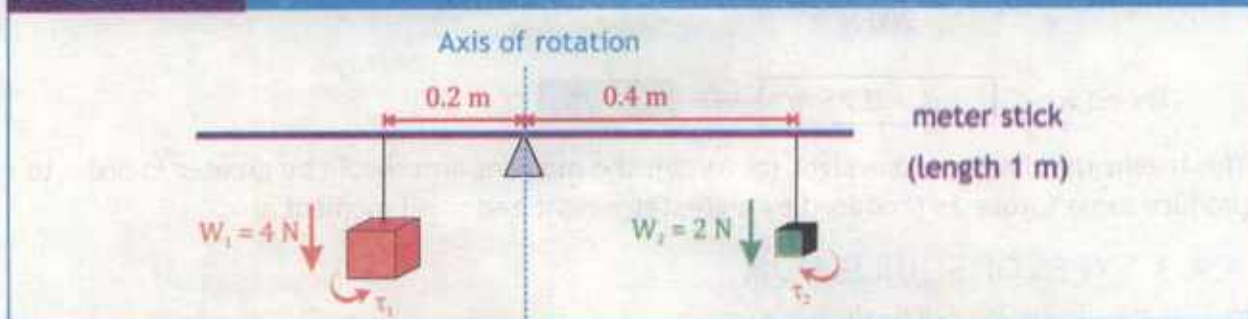
**'For an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of anti-clockwise moments taken about the same pivot'.**

To balance torques or moment of force, the perpendicular distance from the axis of rotation play an important role.

By convention the anticlockwise torques are taken as positive while clockwise torques are taken as negative, which leads to second condition of equilibrium that the sum of both these torques must be zero.

For example, Let a uniform meter stick is balanced from center. Now if we suspend weight of 4 N at 0.1 m from the pivot, it exerts the same torque as 2 N weight at 0.4 m from the fulcrum. A uniform meter stick will balance on pivot under these conditions as shown in the figure 4.9.

**FIGURE 4.9 VERIFICATION OF PRINCIPLE OF MOMENTS**



Anticlockwise  
torque (positive)

$$\begin{aligned}\tau_1 &= W_1 \times d_1 \\ \tau_1 &= 4 \text{ N} \times 0.2 \text{ m} \\ \tau_1 &= 0.8 \text{ N m}\end{aligned}$$

Clockwise  
torque (negative)

$$\begin{aligned}\tau_2 &= - (W_2 \times d_2) \\ \tau_2 &= - (2 \text{ N} \times 0.4 \text{ m}) \\ \tau_2 &= - 0.8 \text{ N m}\end{aligned}$$

$$\tau_{\text{net}} = \tau_1 + \tau_2 = 0.8 \text{ N m} - 0.8 \text{ N m}$$

$$\tau_{\text{net}} = 0 \text{ N m}$$

Similarly three or more torques around a pivot (as axis of rotation) can also balance each other.



## UNIT 4 DYNAMICS - II

### EXAMPLE 4.2: SEESAW BALANCE

Kamil and Bilal are sitting on a seesaw at F9 Park Islamabad. Kamil, weighing 250 N, is sitting at a distance of 0.6 m from the pivot. At what distance from the pivot should Bilal, weighing 200 N sit in order to balance the seesaw?

#### GIVEN

Weight of Kamil ' $W_k$ ' = 250 N

Moment arm of Kamil ' $d_k$ ' = 0.6 m

Weight of Bilal ' $W_b$ ' = 200 N

#### REQUIRED

Moment arm of Bilal ' $d_b$ ' = ?

#### SOLUTION

Kamil's weight is producing anticlockwise moment, while Bilal's weight is producing clockwise moment, Therefore, by principle of moments:

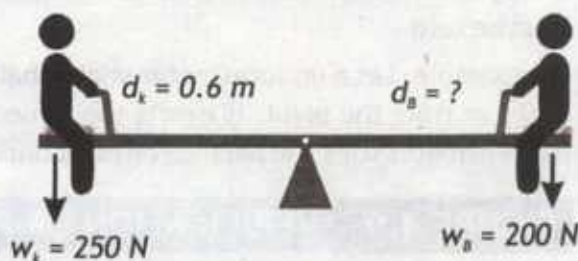
$$\tau_{\text{anticlockwise}} = \tau_{\text{clockwise}}$$

$$\text{OR } \tau_k = \tau_b$$

$$\text{Hence } d_k \times W_k = d_b \times W_b$$

$$\text{or } d_b = \frac{d_k \times w_k}{w_b}$$

$$\text{Putting values } d_b = \frac{0.6 \text{ m} \times 250 \text{ N}}{200 \text{ N}}$$



Therefore

$$d_b = 0.75 \text{ m}$$

Answer

This means that having less weight (or force), the moment arm should be greater in order to produce same torque as produced by a greater weight and small moment arm.

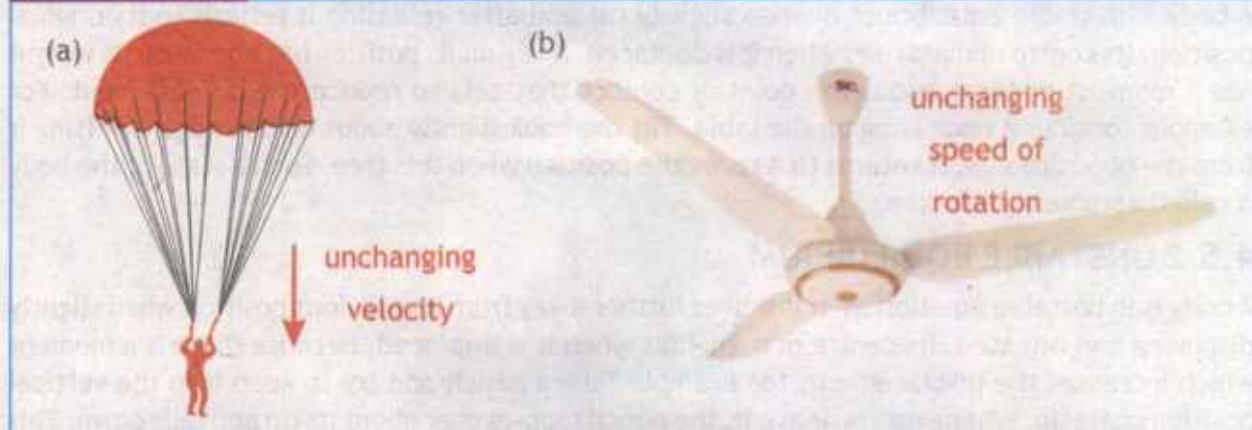
### 4.4.3 TYPES OF EQUILIBRIUM

The equilibrium is divided into two types

**A. Static equilibrium:** When a body is at rest under the action of several forces acting together and several torques acting the body is said to be in static equilibrium. For example a book resting on the table is in static equilibrium, the weight  $mg$  of the book is balanced by a normal reaction force from the table surface.

**B. Dynamic equilibrium:** When a body is moving at uniform velocity under the action of several forces acting together the body is said to be in dynamic equilibrium. It is further divided in to two types.

**I. Dynamic Translational Equilibrium:** When a body is moving with uniform linear velocity the body is said to be in dynamic translational equilibrium. For example a paratrooper falling down with constant velocity is in dynamic translational equilibrium as shown in figure 4.10 (a).

**FIGURE 4.10 DYNAMIC EQUILIBRIUM**

**II. Dynamic Rotational Equilibrium:** When a body is moving with uniform rotation the body is said to be in dynamic rotational equilibrium. For example when the ceiling fan is rotating with unchanging speed as shown in figure 4.10 (b).

## 4.5 STABILITY

'A measure of the ability of an object to return to its original position when the force that changed its position is removed is called stability'. Stable objects are very difficult to topple over, while unstable objects topple over very easily.

The position of the Center of gravity or center of mass (CG/CM) of a body affects whether or not it topples over easily. This is important in the design of such things as tall vehicles (which tend to overturn when rounding a corner), racing cars, reading lamps and even drinking glasses.

**FIGURE 4.11 STABILITY OF VEHICLES**



### 4.5.1 STABLE EQUILIBRIUM

A body is in stable equilibrium if when slightly tilt and after releasing it returns to its original position. Its centre of mass rises when it is displaced. It regain its position back because its weight has a moment of force about the point of contact that acts to reduce the displacement. For example consider a book lying on the table. Tilt the book slightly about its one edge by lifting it from the opposite side. It returns to its previous position when sets free. Such a state of the body is called a stable equilibrium.

### 4.5.2 UNSTABLE EQUILIBRIUM

A body is in unstable equilibrium if it moves further away from its previous position when slightly displaced and released. Its centre of mass falls when it is displaced, because there is a moment which increases the displacement. for example Take a pencil and try to keep it in the vertical position on its tip. Whenever you leave it, the pencil topples over about its tip and falls down. This is called an unstable equilibrium.

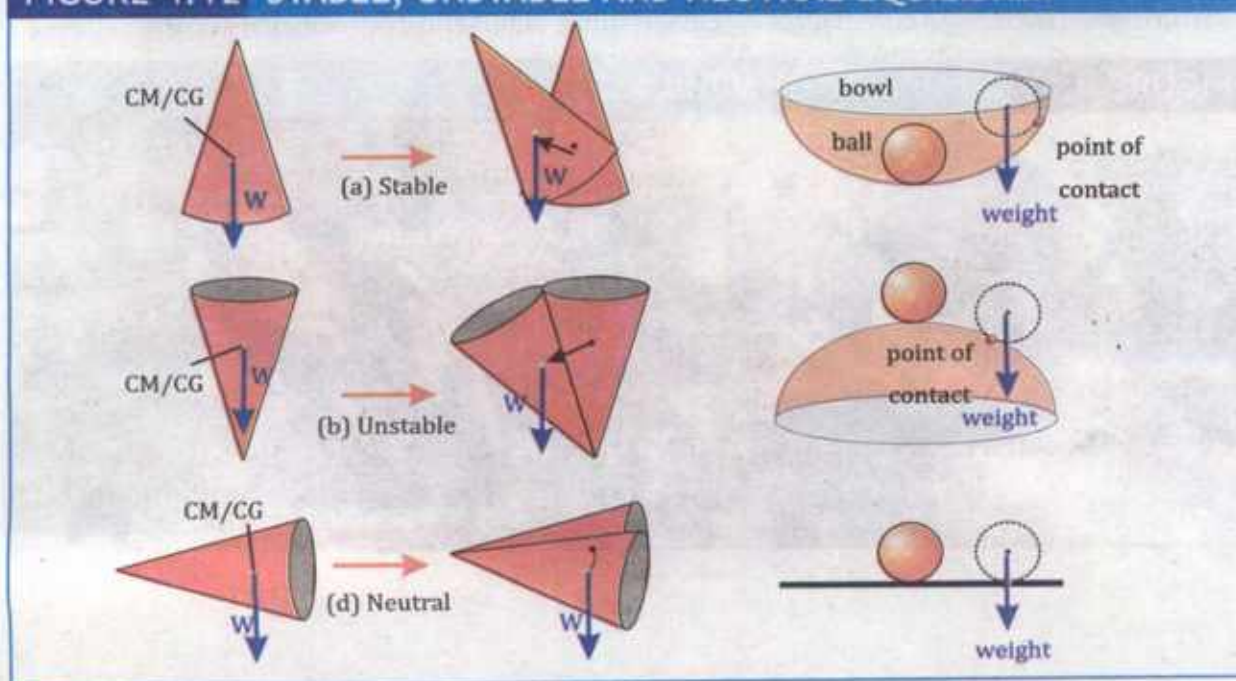
### 4.5.3 NEUTRAL EQUILIBRIUM

A body is in neutral equilibrium if it stays in its new position when displaced. Its center of mass does not rise or fall because there is no moment to increase or decrease the displacement.

For example take a ball and place it on a horizontal surface. Roll the ball over the surface and leave it after displacing from its previous position. It remains in its new position and does not return to its previous position. This is called a neutral equilibrium.

The illustrations in figure 4.12 shows the three states of equilibrium for the cone and ball and bowl.

FIGURE 4.12 STABLE, UNSTABLE AND NEUTRAL EQUILIBRIM



**An object's stability can be improved by:**

- (a) lowering the center of mass; or
- (b) increasing the area of support; or
- (c) by both.

When the object's center of mass is directly beneath the point of support, it is in a stable equilibrium state. The center of mass represents the average position of the mass distribution within the object. In simple terms, "vertically below" means that the center of mass is aligned vertically beneath the point of support.

When an object is in stable equilibrium, it means that if it is slightly disturbed or tilted, it has a tendency to return to its original position. This is because the gravitational force acting on the object causes it to rotate around the point of support, and the object's weight acts through its center of mass. As a result, the object naturally realigns itself to maintain its stable equilibrium state.

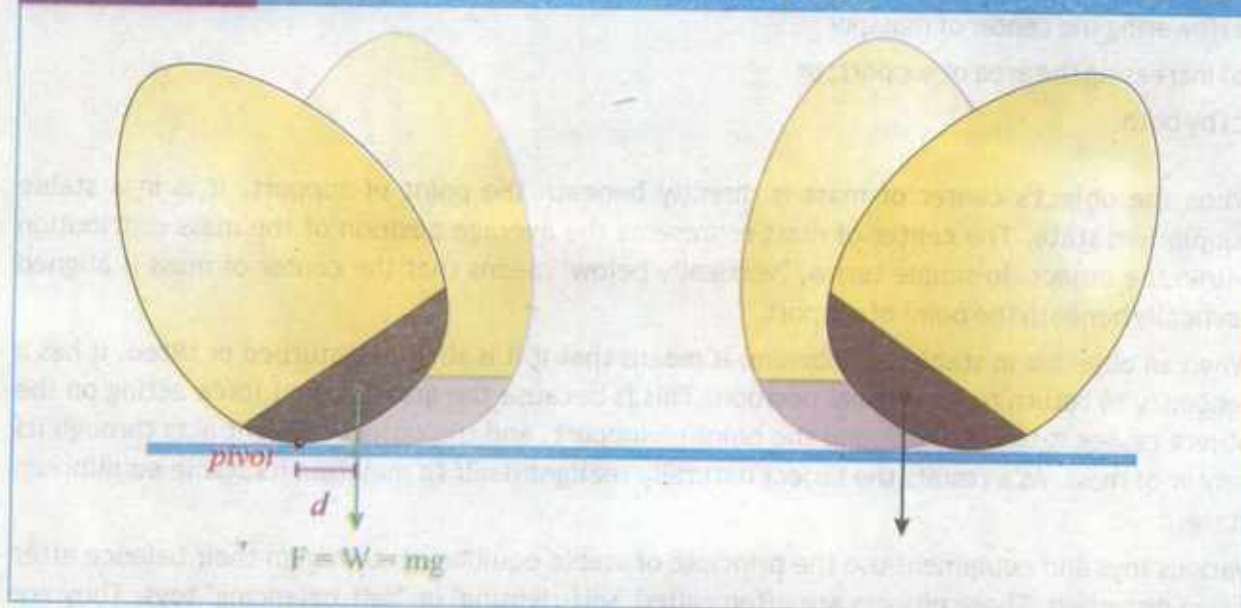
Various toys and equipment use the principle of stable equilibrium to regain their balance after being disturbed. These objects are often called "self-righting" or "self-balancing" toys. They are designed with their center of mass below the support point and have a specific weight distribution that helps them restore their original position. These objects might include balancing birds, wobbling dolls, or weighted-bottom drinking cups, all of which exhibit the stable equilibrium principle as shown in figure 4.13.

**FIGURE 4.13 SELF BALANCING TOYS**



Once such toy is of shape of an egg, when it is tilted, the position of the pivot changes because of its round bottom. In figure 14.14 (a), when tilted to the left, the weight 'W' from the center of gravity (CG) is to the right of the pivot with moment arm (perpendicular distance) 'd'. This creates a clockwise moment that makes the toy turn clockwise. Due to inertia, the toy will go past the vertical position and tilt to the right, as shown in the figure 14.14 (b). Similarly, since the weight is to the left of the pivot, it creates an anti-clockwise moment.

FIGURE 4.14 EGG SHAPED SELF BALANCING TOY



Therefore, this toy always has a restoring mechanism that brings it back to its vertical position, where the weight is directly above the pivot. In this position, the weight passing through the pivot does not create any moment (no perpendicular distance). Hence, the toy will be at rest.

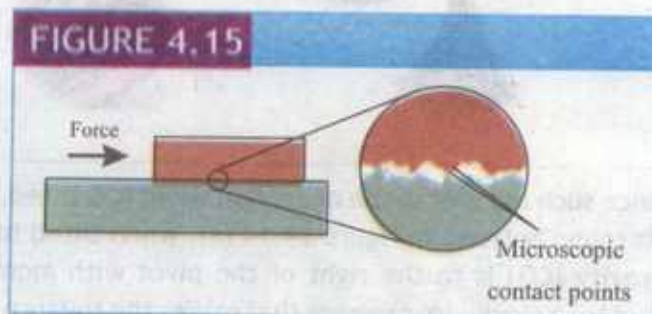
## 4.6 FRICTION

Friction (denoted by letter ' $f$ ') is the resistance to relative motion that occurs whenever two materials are in contact with each other, whether they are solids, liquids, or gases. Since it is a force therefore it is a vector quantity and has unit as newton (N).

Friction always acts in a direction to oppose motion. If you push a solid block along a floor to the right, the force of friction on the block will be to the left. When an object falls downward through the air, the force of friction, air resistance, acts upward.

### 4.6.1 Microscopic description of friction

Every surface is rough, even surfaces that appear to be highly polished can actually look quite rough when examined under a microscope as shown in figure 4.15. There is no such thing as a perfectly flat surface. As a result the two surfaces that are touching are not really touching across the entire area that appears to be touching.



Thus roughness of both surfaces interlock which makes friction.

Sliding friction is the resistance created by any two objects when sliding against each other. It is the sliding friction between the brake pads and our bike rims, that slows the rolling wheels so we can stop our bike in time.

Rim brakes, are the most effective and most popular bicycle brakes, as they provide adequate braking power without too much maintenance. They are controlled by hand levers which are attached to the actual brake by a cable. When the rider pulls on the brake lever the cable attached to it moves the two pads, one on each side of rim. These pads attached to break leather press against the rim, causing the wheel to slow down due to friction as shown in figure 4.16.

**FIGURE 4.16 BICYCLE BREAKS**



### 4.6.2 ADVANTAGES AND DISADVANTAGES OF FRICTION

Friction is required in many situations, for example

- Friction between the soles of our shoes (or feet) and the ground help us walk.
- Friction between tyre and road helps to drive cars.
- Friction holds the screw and nails in wood.

Friction can sometime be a hindrance, for example

- It slows down moving objects and causes heating of moving parts in machinery.
- Energy is wasted to overcome friction in machinery.
- Produce wear and tear.

### 4.6.3 METHODS OF REDUCING FRICTION

There are many ways to reduce unwanted friction, few are discussed below.

- **By polishing:** If we polish the rough surfaces, they become smooth and friction is reduced.
- **By using Ball Bearing:** This method converts the sliding friction is converted into rolling friction by use of ball bearings.
- **By applying Lubricants (oil or Grease) to surfaces:** Friction of certain liquids is less than that of solid surfaces, therefore, oil or grease is applied between the parts of machinery.

#### ACTIVITY



Take the book and slide it on the table now place book on few pencils and roll it you will see that less effort is required.



## UNIT 4 DYNAMICS - II

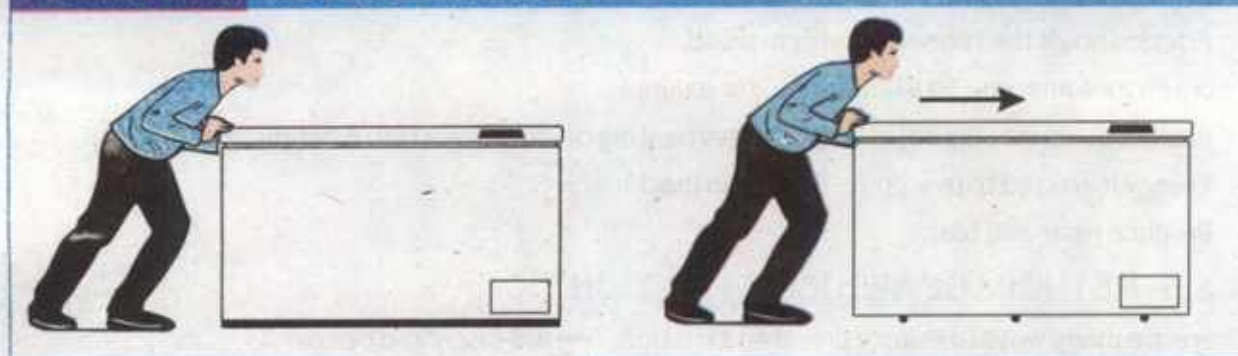
FIGURE 4.17 METHODS TO REDUCE FRICTION



### 4.6.4 ROLLING FRICTION

If we set a heavy spherical ball, ring or cylinder rolling, it experiences an opposing force called rolling friction. When a body rolls over a surface, the force of friction is called rolling friction. For the same weight, rolling friction is much smaller (even by 2 or 3 orders of magnitude) than static or sliding friction.

FIGURE 4.18 ROLLING FRICTION



This is the reason why discovery of the wheel has been a major milestone in human history. It is rolling friction that helps a heavy deep freezer with wheels to easily move as shown in figure 4.18.

### 4.6.5 FLUID FRICTION

A fluid is a collection of molecules that are held together by weak cohesive forces and the forces exerted by the walls of container. Both liquids and gases are fluids as they can flow and can exert force on the walls of their container.

When an object moves through a fluid, the fluid exerts a retarding force that tends to reduce the speed of the object. The moving body exerts a force on the fluid to push it out of the way. By Newton's third law, the fluid pushes back on the body with an equal and opposite force. This retarding force experienced by an object moving through a fluid is called the drag force, which is the result of fluid friction.



### POINT TO PONDER



**Does wider tyres increase friction and thus road grip of our car?**

It seems intuitive that wider tyres will provide more friction, however, the friction is same for narrow and wide tyres of same weight. It is because friction does not depend on the area of contact. The wider tyre simply spreads the weight of the car over more surface area thereby reducing heat and wear.

Similarly treads (traction) on tyres also does not increase friction. These treads are much larger compared to microscopic roughness which lock the contact surfaces together and produce friction while sliding. The treads are made in the tyre only to displace water from the road to avoid skidding. Many racing cars use tires without treads because they race on dry days.



Friction resists sliding



For example when you extend your hand out of the window in a moving vehicle as shown in figure 4.19. If you set the palm of your hand in the direction of motion you can observe the fluid friction and the drag force it exerts on your palm. You can also see variation in the drag force by changing its orientations.

The drag force depends upon the

- Size, shape and orientation of the object
- Type (Properties) of the fluid
- Speed of the object relative to the fluid

Skydivers and swimmers change their effective size and orientation by bending, twisting and stretching their body parts. This allow them to manipulate drag and thereby allowing them to control speed and direction of motion.

During free fall the objects does not speed up indefinitely. The speed of free falling object initially increases because of weight of the object, but as the speed increases the drag force also increase, slowing the object down.

A point reaches where both the weight and drag force become equal and dynamic translational equilibrium is achieved. The object has now attained its maximum velocity termed as **terminal velocity**. At terminal speed, the diver's acceleration is zero; in other words, the speed remains constant.

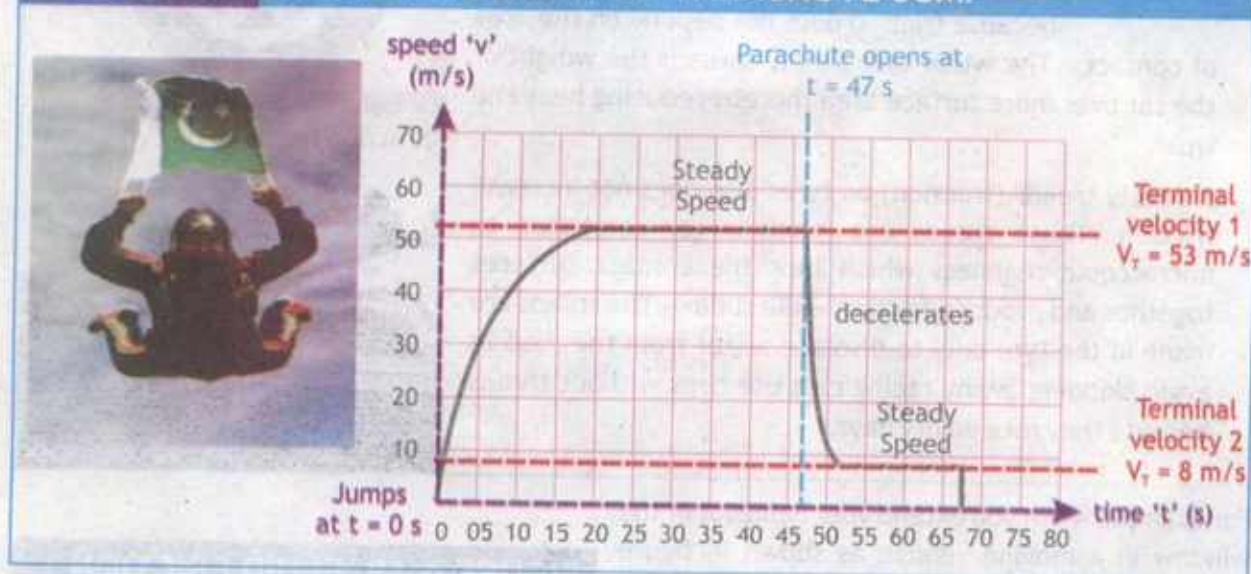
**FIGURE 4.19 FLUID FRICTION**



The constant maximum velocity that is attained and maintained by an object while falling through air (or any other resistive medium) is called terminal velocity.

For humans, terminal speed in air is about 53 m/s or 190 km/h. After the parachute opens, the terminal speed is reduced to between 5 m/s and 10 m/s, as shown in figure 4.20.

**FIGURE 4.20 SPEED TIME GRAPH OF PARACHUTE JUMP**



## 4.6.6 FRICTIONAL DISSIPATION

Dissipative force decreases the mechanical energy in a system. Dissipative forces acting on an object always oppose the motion of the object. For example in case of the sky diver, when the parachute opened some energy is dissipated into the air thereby increasing its temperature. The sky diver safety depends on air resistance as a dissipative force.

**FIGURE 4.21 FRICTIONAL DISSIPATION**



In winter when we rub our hands together we feel the sensation of warmth as shown in figure 4.21 (a). It is because friction causes the increase in the temperature our hands, which makes our

hands warm. Similarly you would have noticed shooting stars (a small piece of rock or dust that hits Earth's atmosphere from space) as shown in figure 4.21 (b). When they plow through the atmosphere, meteors are heated, and they glow. A meteor compresses air in front of it. The air heats up, in turn heating the meteor. The intense heat vaporizes most meteors, creating what we call shooting stars.

## 4.7 CENTRIPETAL FORCE

When the speed of the moving object does not change as it travels in the circular path is called uniform circular motion.

The speed of the object may remain constant however the direction is continuously changing, giving rise to a change in velocity and an acceleration as shown in figure 3.22. This acceleration is perpendicular (or at a right angle) to the velocity. In uniform circular motion, it is towards the center of the circle called centripetal acceleration.

Now there must be some unbalanced force acting on the object which is pulling it towards the center.

The force that pulls an object out of its straight-line path and into a circular path is called centripetal (center-seeking) force.

Consider a communications satellite that is moving at a uniform speed around Earth in a circular orbit as shown in figure 4.23. According to the first law of motion there must be some unbalanced force acting on the satellite that is pulling it out of a straight-line path. This unbalanced force is termed as centripetal force.

The magnitude of the centripetal force ' $F_c$ ' of an object with a mass ' $m$ ' that is moving with a velocity ' $v$ ' in a circular orbit of a radius ' $r$ ' is:

$$F_c = -\frac{mv^2}{r} \quad \text{--- 4.4}$$

Equation 4.4 gives the magnitude of centripetal force, where negative sign indicates that force is directed towards the center of the circular path.

**FIGURE 4.22 CIRCULAR MOTION**

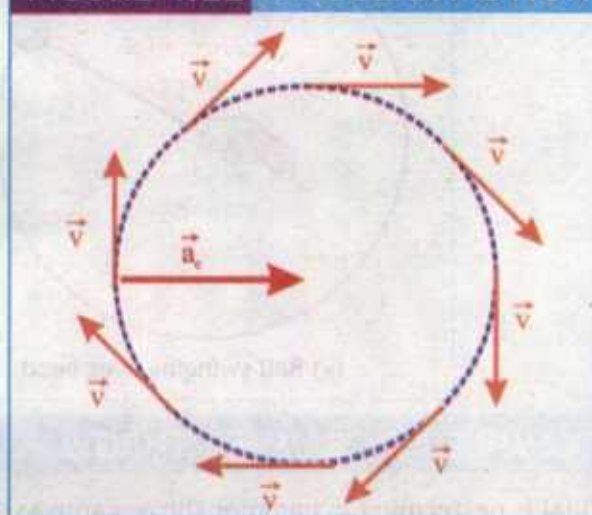
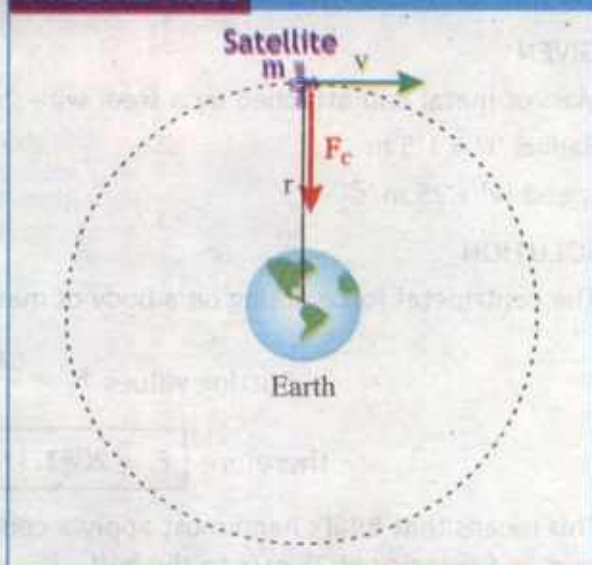
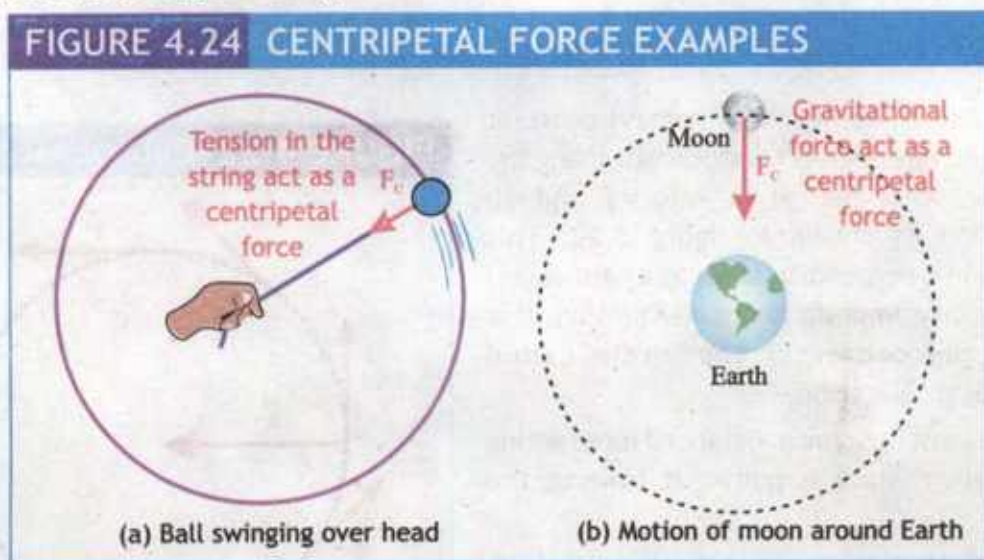


**FIGURE 4.23 SATELLITE**



Perhaps you have swung a ball on the end of a string in a circle over your head. Once you have the ball moving, the tension on the string keeps it moving in a circular path as you twirl it. That tension is centripetal force, which pulls the ball from its natural straight-line path into a circular path as shown in figure 4.24 (a). The force that keeps a planets in orbit around sun is centripetal force, which, in this case is the 'gravitational force'. This center is exactly where the Sun is located. In the case of the Moon, the centripetal force acting on it is directed towards the center of the Earth as shown in figure 4.24 (b).



### EXAMPLE 4.3: HAMMER THROW

Bilal is performing in hammer throw game as shown in the figure. Mass of the metal ball is 5 kg and length of the string is 1.5 m. What centripetal force must Bilal apply to get a speed of 25 m/s?

#### GIVEN

Mass of metal ball attached by a steel wire ' $m$ ' = 5 kg

Radius ' $r$ ' = 1.5 m

speed ' $v$ ' = 25 m/s

#### SOLUTION

The centripetal force acting on a body of mass " $m$ " is given by:  $F_c = \frac{mv^2}{r}$

$$\text{Putting values } F_c = \frac{5 \text{ kg} \times (25 \text{ m/s})^2}{1.5 \text{ m}}$$

$$\text{therefore } F_c = 2083.3 \text{ N} \quad \text{Answer}$$

#### REQUIRED

Centripetal force  $F_c = ?$



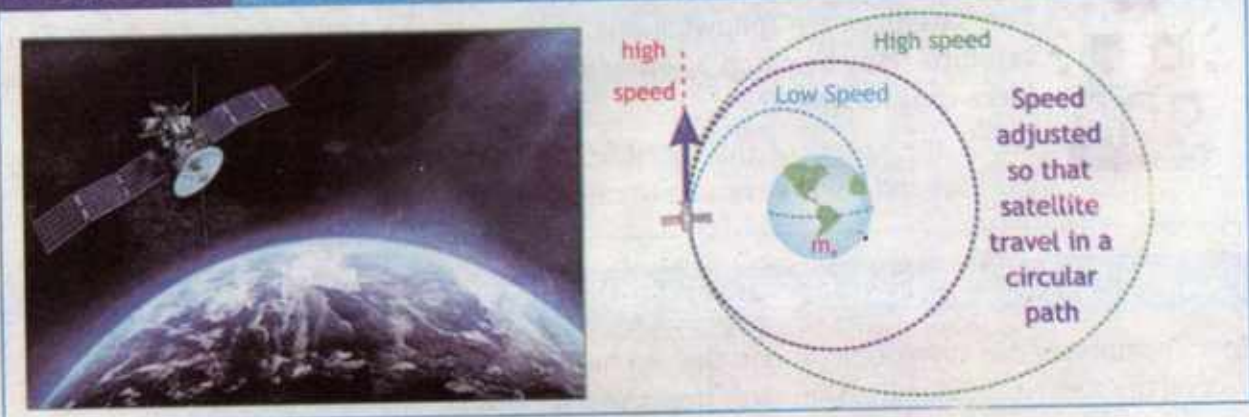
This means that Bilal's hand must apply a centripetal force of 2083.3 N on the metal in order to give a velocity of 25 m/s to the ball.

## 4.8 ORBITAL MOTION

An orbit is a regular, repeating path that one object in space takes around another one. An object in an orbit is termed as a satellite. A satellite can be natural, like Earth or the moon. Objects orbit each other because of gravity. Many planets have moons that orbit them, and many stars have planets, comets, asteroids and other objects that orbit them. A satellite can also be man-made, like the International Space Station. Such man-made satellites are termed as artificial satellites.

To put an artificial satellite into orbit, first we move it to high altitude and then accelerate it to a required tangential speed using rockets, as shown in Figure. 4.25. If the speed is too high, the spacecraft either move in elliptical orbit or will escape, never to return. If the speed is too low, it will fall back to Earth. Satellites are typically put into circular (or nearly circular) orbits.

**FIGURE 4.25 MOTION OF ARTIFICIAL SATELLITE**



### 4.8.1 AVERAGE ORBITAL SPEED OF SATELLITE

The orbital speed of the body is the speed at which it orbits around the center of the system. This system is usually around a massive body.

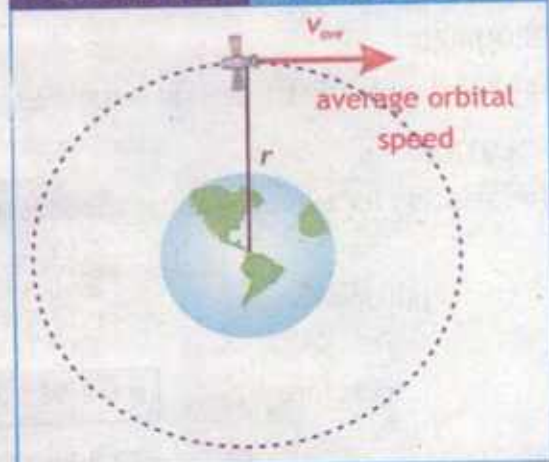
The relationship between speed, distance and time is:

$$\text{Average speed} = \frac{\text{distance}}{\text{time}} \quad \text{--- 1}$$

This means that in one orbit, a satellite travels a distance equal to the circumference of a circle (the shape of the orbit). This is equal to ' $2\pi r$ ' where ' $r$ ' is the radius a circle, thus:

$$\text{Distance} = 2\pi r \quad \text{--- 2}$$

**FIGURE 4.26 SPEED IN ORBIT**





## UNIT 4 DYNAMICS - II

The time it takes for an object to orbit around another object is called its orbital period 'T'. Earth completes its orbital period around the sun every 365 days. The further away a planet is from the sun, the longer its orbital period. The planet Neptune, for example, takes almost 165 years to orbit the sun.

$$\text{time} = \text{Orbital period} = T \quad \text{--- 3}$$

putting equation 2 and equation 3 in equation 1, the average orbital speed ' $v_{ave}$ ' is:

$$v_{ave} = \frac{2\pi r}{T} \quad \text{--- 4.5}$$

Which means that for particular distance from the center of earth, all the satellite should have the same orbital speed irrespective of the size of satellite.



### QUIZ

Two satellites are following one another in the same circular orbit. If one satellite tries to catch another (leading one) satellite, can it be done by increasing its speed?

No, if the speed of the satellite is somehow increased, its radius will also increase and it will be unable to catch up the leading satellite.

### EXAMPLE 4.4: ORBITAL SPEED OF EARTH

Earth completes one revolution around the sun in 365.25 days. Find the orbital speed of Earth around the sun if it is 150 million km away from the sun.

#### GIVEN

Orbital period ' $T$ ' = 365.25 days =  $365.25 \times 24 \times 60 \times 60 \text{ s} = 3.16 \times 10^7 \text{ s}$

Radius ' $r$ ' = 150 million km =  $150 \times 10^6 \times 10^3 \text{ m} = 1.5 \times 10^{11} \text{ m}$

#### REQUIRED

Orbital speed of Earth around sun  $v = ?$

#### SOLUTION

The relation for average orbital speed is given by:  $v_{ave} = \frac{2\pi r}{T}$

putting values  $v_{ave} = \frac{2 \times 3.14 \times 1.5 \times 10^{11} \text{ m}}{3.16 \times 10^7 \text{ s}}$

therefore

$$v = 2.98 \times 10^4 \text{ m/s}$$

Answer

or  $v = 29.8 \text{ km/s}$  or  $v = 107,280 \text{ km/h}$



This is a huge speed as compared to the speeds of our daily life objects. The reason we do not feel it is that we are relatively at rest i.e. we also move with the earth.

## 4.9 PLANETARY DATA

An astronomical body orbiting a star or stellar remnant that is massive enough to be rounded by its gravity, is termed as planet. There are more planets in our galaxy than stars.

Our solar system consists of our star, the Sun, and everything bound to it by gravity - the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune; dwarf planets such as Pluto; dozens of moons; and millions of asteroids, comets, and meteoroids. Table 4.1, summarizes the physical parameters of the planets in solar system.

TABLE 4.1: SELECTED DATA FOR THE SOLAR SYSTEM

| Planet  | Distance from Sun (Gm) | Mass ( $10^{24}$ kg) | g (N/kg) | Orbital Period (yr) | Density ( $\text{kg/m}^3$ ) | Average Surface temperature ( $^{\circ}\text{C}$ ) |
|---------|------------------------|----------------------|----------|---------------------|-----------------------------|----------------------------------------------------|
| Mercury | 57.9                   | 0.330                | 3.7      | 0.241               | 5429                        | 167                                                |
| Venus   | 108.2                  | 4.87                 | 8.9      | 0.615               | 5243                        | 464                                                |
| Earth   | 149.6                  | 5.97                 | 9.8      | 1                   | 5514                        | 15                                                 |
| Mars    | 228.0                  | 0.642                | 3.7      | 1.88                | 3934                        | - 65                                               |
| Jupiter | 778.5                  | 1898                 | 24.7     | 11.9                | 1326                        | - 110                                              |
| Saturn  | 1432.0                 | 568                  | 9.0      | 29.4                | 687                         | - 140                                              |
| Uranus  | 2867.0                 | 86.8                 | 8.7      | 83.8                | 1270                        | - 195                                              |
| Neptune | 4515.0                 | 102                  | 11.0     | 164                 | 1638                        | - 200                                              |
| Sun     | 5906.4                 | 1,990,000            | 274      | -                   | 1408                        | 5,600                                              |

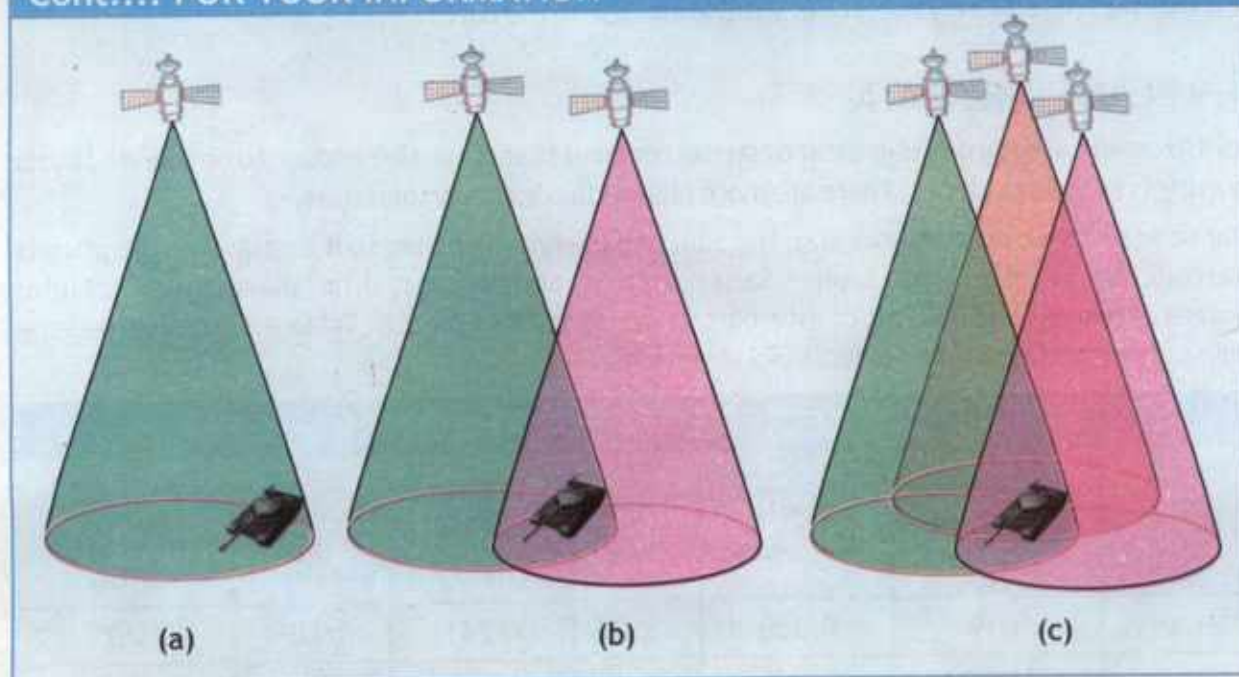
### FOR YOUR INFORMATION

#### INFORMATION: GLOBAL POSITIONING SYSTEM (GPS)

Many applications of satellite technology affect our lives. An increasingly important application is the network of 24 satellites called the Global Positioning System (GPS), which can be used to determine the position of an object. Figure illustrates how the system works, by locating position of enemy tank. A measurement using a single satellite locates the tank somewhere on a green circle, as Figure (a) shows, while a measurement using a second satellite locates the tank on another circle. The intersection of the circles reveals two possible positions for the tank, as in Figure (b). With the aid of a third satellite, a third circle can be established, which intersects the other two and identifies the tank's exact position, as in Figure (c).



## Cont.... FOR YOUR INFORMATION



## SUMMARY

**Moment of a force or Torque** is the measure of an object tendency to rotate about some point O.

*Moment of a force = force  $\times$  perpendicular distance of the force to the point.*

**Principle of moments** states that for an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of the anti-clockwise moments taken about the same pivot.

**Centre of mass** of the body is the point about which mass is equally distributed in all directions.

**Centre of gravity** is a single point where the whole weight of an object appears to act.

**Stability** of an object refers to the ability of the object to return to its original position when the force that changed its orientation is removed.

**Frictional force** is the force that resists motion of objects on a surface.

**Terminal velocity** is the maximum constant velocity that a body can achieve while passing through a resistive (viscous) medium.

**Centripetal force** is the force that compels a body to travel a circular path. It may be electric, gravitational, or any other force.

**Orbital velocity** is the speed of an object revolving around another heavy object in an orbit.



## EXERCISE



### MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option.

1. A seesaw balances perfectly with two children of equal weight sitting at equal distances from the fulcrum. If one child moves closer to the fulcrum:
  - A. The seesaw remains balanced.
  - B. The seesaw tips towards the child who moved closer.
  - C. The seesaw tips towards the child who stayed further away.
  - D. The seesaw topples.
2. When line of action of the applied force passes through its pivot point then moment of force acting on the body is:
  - A. maximum
  - B. minimum
  - C. zero
  - D. infinite
3. If a body is at rest or moving with uniform rotational velocity, then torque acting on the body will be
  - A. maximum
  - B. minimum
  - C. zero
  - D. infinite
4. A body in equilibrium must not have:
  - A. speed
  - B. quantity of motion
  - C. velocity
  - D. acceleration
5. A uniformly rotating fan is said to be in:
  - A. static equilibrium only
  - B. dynamic equilibrium only
  - C. both in static and dynamic equilibrium
  - D. not in equilibrium
6. You throw a weighted fishing net into a calm lake. As the net sinks, it opens fully underwater, spreading out its mesh evenly. Compared to the moment it left your hand, where is the net's center of mass now?
  - A. Higher in the water column.
  - B. Lower in the water column.
  - C. At the same depth but slightly shifted horizontally.
  - D. Unchanged from its position when thrown.
7. A tightrope walker is carrying a long pole while walking across a rope. The stability of the walker is affected if the pole is
  - A. long and placed vertically
  - B. long and placed horizontally
  - C. short and placed vertically
  - D. short and placed horizontally
8. It is more difficult to walk on a slippery surface than on a nonslippery one because of:
  - A. reduced friction
  - B. increased friction
  - C. high grip
  - D. lower weight



## UNIT 4 DYNAMICS - II

9. For an object moving with terminal velocity, its acceleration:
- A. increases with time
  - B. decreases with time
  - C. is zero
  - D. first increases then decreases
10. The correct order of comparison for the terminal speeds of a raindrop, snowflake, and hailstone is:
- A. Raindrop > Snowflake > Hailstone
  - B. Hailstone > Raindrop > Snowflake
  - C. Snowflake > Raindrop > Hailstone
  - D. Raindrop = Snowflake = Hailstone
11. You are trying to loosen a nut using a spanner, but it is not working. In order to open the nut, you need to:
- A. insert a pipe to increase length of spanner
  - B. use a spanner of small length
  - C. use plastic and soft spanner
  - D. tie a rope with spanner
12. The force that always changes direction of velocity and not its magnitude is called:
- A. gravitational force
  - B. electric force
  - C. centripetal force
  - D. friction
13. The reason that a car moving on a horizontal road gets thrown out of the road while taking a turn is:
- A. the reaction of the ground
  - B. rolling friction between tyre and road
  - C. gravitational force
  - D. lack of sufficient centripetal force
14. A car drives at steady speed around a perfectly circular track.
- A. The car's acceleration is zero.
  - B. The net force on the car is zero.
  - C. Both the acceleration and net force on the car point outward.
  - D. Both the acceleration and net force on the car point inward.
15. A satellite of mass ' $m$ ' is revolving around the earth with an orbital speed ' $v$ '. If mass of the satellite is doubled, its orbital speed will become:
- A. double
  - B. half
  - C. one fourth
  - D. remain the same

### SHORT RESPONSE QUESTIONS

#### QII. Give a short response to the following questions

1. Why long spanner is used to open or tight nuts of vehicle's tyre? While tightening a small nut, extra-long wrench is not suitable. Why?
2. Why door knobs are fixed at the edge of door? What will happen if the door knob is at the middle of the door?
3. If you drop a feather and a bowling ball from the same height, which one will reach the terminal velocity first? Which one of them will hit the ground first?
4. Why do ice skates effortlessly slide on ice, while your shoes cause skidding?
5. Explain why it's easier to push a car on flat tyres than inflated ones. What happens to the frictional force between the tyres and the road?



6. When standing on a crowded school bus, which stance would provide better stability and prevent you from being pushed over: legs joined or legs spread apart?
7. Why a moving bicycle is easier to balance? Relate this to the principles of rotational motion.
8. Why is a pencil standing on its tip unstable, and what factors affect the stability of an object balanced on a point?
9. While driving what happens if the driver take the curve too fast? How does centripetal force play a role in keeping the car from skidding off the road?
10. Consider a situation where you swing a ball connected to a string in a circle. How does the tension in the string vary as the ball moves across different points in its circular path, and what forces are involved?
11. Why is it important for communication satellites in geostationary orbit to maintain a specific speed?

## LONG RESPONSE QUESTIONS

QIII. Give an extended response to the following questions

1. Differentiate between like and unlike parallel forces.
2. What is moment of force or torque? On what factors it depends? Write its mathematical formula
3. Define center of mass. What is effect of mass distribution in a body on its center of mass?
4. What is center of gravity? Where will be center of gravity of these regular shaped bodies; circular plate, rectangular and square shaped plate, triangular shaped plate, cylinder, sphere (also draw figures to support your answer). Differentiate between center of mass and center of gravity.
5. How can you find center of gravity of an irregular shaped thin sheet of plastic?
6. What is equilibrium? Describe the conditions of equilibrium. State and explain principle of moments.
7. Propose how the stability of an object can be improved. Illustrate the applications of stability physics in real life.
8. Define force of friction. What causes friction? What are advantages and disadvantages of friction? Explain with examples. How can friction be reduced?
9. Compare rolling friction and sliding friction. How are they different in terms of contact surfaces, motion, and forces involved? Explain with examples.
10. Analyse the dynamics of an object reaching terminal velocity.
11. Define centripetal force. Describe the motion of a body in a circular path under the action of centripetal force.
12. Identify different sources of centripetal force in real life examples.
13. Define orbital velocity. How do scientists use the concept of orbital speed to launch satellites into specific orbits? What factors influence the chosen speed?



## UNIT 4 DYNAMICS - II

### NUMERICAL RESPONSE QUESTIONS

#### QIV. Solve the following questions.

1. Calculate the torque acting on spanner of length 20 cm to loosen a nut by a force of 50 N. If the same nut is to be loosen up by force of 100 N, what should be length of spanner?

(Ans. 10 N m and 10 cm)

2. A long uniform steel bar of length 1.0 m is balanced by a pivot at its middle. Two mass  $m_1$  and  $m_2$  are suspended at a distance of 0.2 m and 0.3 m respectively from the pivot. Ignoring mass of the steel bar, if mass  $m_1 = 0.6$  kg find mass  $m_2$ .

(Ans. 0.4 kg)

3. Two masses, 250 g and 100 g, are hanging at positions 65 cm and 80 cm, respectively, on a uniform meter rod, pivoted at 50 cm mark as shown. Where should a third mass of 400 g be positioned to balance the rod?



(Ans. 33.1 cm)

4. A car weighing 1200 kg enters a roundabout with a diameter of 60 meters at a speed of 25 km/h. Calculate the centripetal force acting on the car as it navigates the curve.

(Ans. 693.3 N)

5. A geostationary satellite revolves around earth in an orbit of radius 42000 km. Find orbital speed of the satellite at this height.

(Ans. 3.052 km/s)

# PRESSURE AND DEFORMATION IN SOLIDS

UNIT  
5

Why it is difficult to cook food at high altitudes?

## Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-55] Illustrate that forces may produce a change in size and shape of an object.
- [SLO: P-09-B-56] Define and calculate the spring constant.
- [SLO: P-09-B-57] Sketch, plot and interpret load-extension graphs for an elastic solid and describe the associated experimental procedures.
- [SLO: P-09-B-58] Define and use the term 'limit of proportionality' for a load-extension graph.
- [SLO: P-09-B-59] Illustrate the applications of Hooke's law.
- [SLO: P-09-B-77] Define and calculate pressure.
- [SLO: P-09-B-78] Describe how pressure varies with force and area in the context of everyday examples.
- [SLO: P-09-B-79] Analyse in situations how pressure at a surface produces a force in a direction at right angles to the surface.
- [SLO: P-09-B-80] Justify that the atmosphere exerts a pressure.
- [SLO: P-09-B-81] Describe that atmospheric pressure decreases with the increase in height above the Earth's surface.
- [SLO: P-09-B-82] Explain that changes in atmospheric pressure in a region may indicate a change in the weather.
- [SLO: P-09-B-83] Analyse the workings and applications of a liquid barometer.
- [SLO: P-09-B-84] Justify why and analyse quantitatively how pressure varies with depth in a liquid.
- [SLO: P-09-B-85] Analyse the workings and applications of a manometer.
- [SLO: P-09-B-86] Define and apply Pascal's law.



## UNIT 5

## PRESSURE AND DEFORMATION IN SOLIDS

Matter is made up of atoms and molecules. Applying external forces like weight, pressure, heat, etc., causes the deformation of the matter, which in turn changes the matter's shape, dimension, and orientation.

Solid matter is made up of atoms and molecules which are packed closely. The intermolecular space between the atoms is significantly less than in liquid and gas. Because of this property of solids, they retain their original shapes easily, and the atoms or molecules return to equilibrium after removal of force.

In the case of liquid and gaseous matter, the atoms and molecules are loosely packed, and the deformation of this matter takes less force as compared to solids. Liquids and gaseous matter do not retain their equilibrium state unless an external force is applied again. Some examples include a stretched rubber band as shown in figure 5.1, a bent metal rod and a shattered glass as shown in figure 5.2.

FIGURE 5.1 RUBBER BAND



FIGURE 5.2 BENT METAL ROD AND SHATTERED GLASS



### 5.1 ELASTICITY

'The ability of a deformed body to return to its original shape and size when the deforming forces are removed is called elasticity'.

When a stretched spring is released, it comes back to its original form. When a tennis racket hits a tennis ball, the shape of the ball is distorted or deformed, but it regains its original shape when it bounces off the tennis ball. Similarly, when an archer shoots an arrow, she bends the bow which comes back to its original form after the arrow is released as shown in figure 5.3.

Not all materials return to their original shapes when a deforming force acting on it is removed. Materials that do not return to their original shapes after being distorted are said to be inelastic. Examples of inelastic materials are plasticine, clay and dough.

Most materials are elastic up to a certain limit known as the elastic limit. Beyond the elastic limit a material will not return to its original dimensions when the deforming force is removed.



**FIGURE 5.3 ELASTICITY**



## 5.1.1 HOOKE'S LAW

When a spring is stretched or compressed (within elastic limit), the extension or compression is directly proportional to the applied force (Figure 5.4). This relationship is known as Hooke's law which states that **within elastic limits the extension (or compression)  $x$  is directly proportional to the restoring force  $F_{res}$** , i.e.

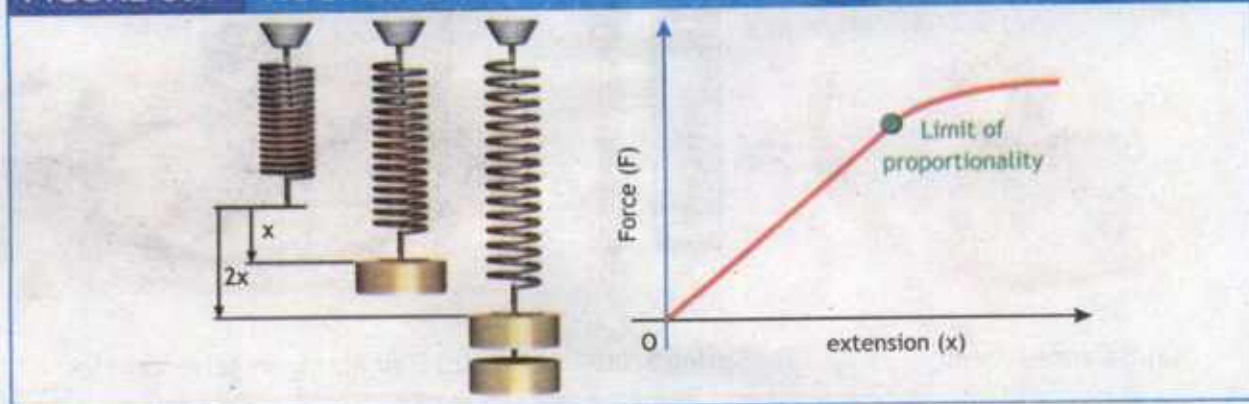
$$F_{res} \propto -x \quad \text{or} \quad F_{res} = -kx$$

$$\text{therefore } k = \frac{-F_{res}}{x} \quad \text{--- 5.1}$$

where 'k' is the ratio of restoring force to the extension and is known as the force constant or spring constant having units  $\text{N m}^{-1}$ . The negative sign shows that force is directed against displacement. This relationship is also true for a wire under tension. Provided that the limit of proportionality is not exceeded, a graph of stretching force against extension is a straight line through the origin, as shown in figure 5.4.

The gradient of the line  $F/x$  is the spring constant 'k'. Hooke's Law is obeyed up to the limit of proportionality. Beyond this point, stretching force and extension are no longer directly proportional and the graph begins to curve.

**FIGURE 5.4 HOOKES LAW**



### 5.1.2 APPLICATIONS OF HOOKE'S LAW

Hooke's law has many important practical applications, with one being the creation of a balance wheel, which made possible the creation of the mechanical clock, the portable timepiece. Hooke's law is also used as a fundamental principle behind spring scale. It is also used as the foundation for diving boards and car suspension systems, seismology, acoustics molecular mechanics and even in medical science. The spring is a marvel of human engineering and creativity, still in use in many modern day instruments.

**A. Balance wheel of the mechanical watches:** A balance wheel is the timekeeping device used in mechanical watches. It is a weighted wheel that rotates back and forth, being returned toward its center position by a spiral torsion spring or hairspring as shown in figure 5.5 (a). It is driven by the escapement, which transforms the rotating motion of the watch gear train into impulses delivered to the balance wheel. Each swing of the wheel (called a 'tick' or 'beat') allows the gear train to advance a set amount, moving the hands of watch forward. The combination of the mass of the balance wheel and the elasticity of the spring keep the time between each oscillation or 'tick' very constant.

**B. Spring Scale:** A spring scale (spring balance) is a type of mechanical force measuring instrument that make use of spring. This device is mainly used to weigh items or objects by connecting them to a hook at it bottom as shown in figure 5.5 (b). Since by Hooke's law the force or weight that extends a spring is directly related to the distance that the spring is extended from its initial position. The spring scale converts this extension to measuring weight using an analog or digital gauge attached to the device.

**C. Galvanometer:** Galvanometer is a device used for detecting current or voltage. It make use of the hair spring which not only electrical connection to coil and restoring the pointer back, but also make the deflection proportional to the force according to Hooke's law as shown in figure 5.5 (c). And since the force is proportional to the current, it permits us to draw an analogue scale under the pointer and measure the current.

FIGURE 5.5 APPLICATIONS OF HOOKE'S LAW





### MINI-LAB



What would happen to the reading if two or more spring balances are hung one below the other in series?

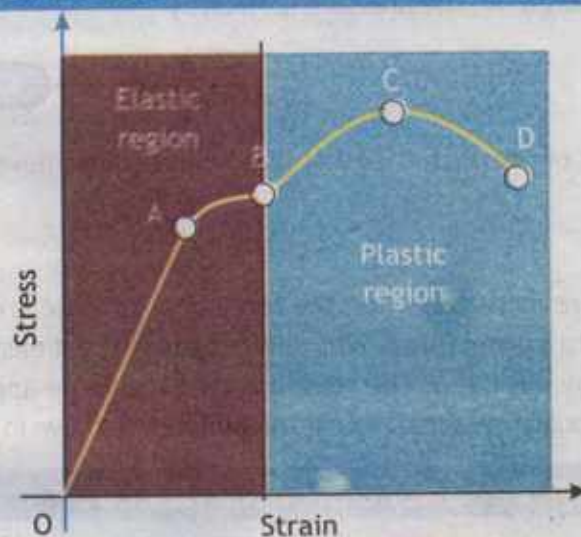


**Stress and strain curves:** Stress and strain curves are measured by stress tester, one such machine Rockwell hardness tester is shown in the figure 5.6 (a). The applied stress is increased and the change in length is noted. The values are then printed on graph. A typical graph for metal is shown in the figure 5.6 (b). Here, Point, A, is the limit of proportionality, the limit up to which Hooke's law is obeyed called **proportional limit**. Point, B, is the elastic limit, the limit up to which material shows elastic behavior also called **yield strength**, point C is the maximum stress a material can bear before fracture (breaking) called **ultimate stress** and point D, is the breaking point, where material breaks.

FIGURE 5.6 STRESS STRAIN ANALYSIS



(a) Hardness testing machine



(b) typical stress - strain curve

### EXAMPLE 5.1: SPRING CONSTANT OF A SPRING CHAIR

Kamil sits on a spring chair as shown in the figure. If Kamil's weight is 50 kg and compresses the spring by about 10 cm, when he sits on the chair, find the spring constant of this chair's spring.

**GIVEN**

Mass of Kamil ' $m$ ' = 50 kg

Extension in spring ' $x$ ' = 10 cm = 0.1 m

**REQUIRED**

Spring constant ' $k$ ' = ?

**SOLUTION:**

The force stretching the spring is equal to weight of the body, given by:

$$W = F = mg = 50 \text{ kg} \times 9.8 \text{ m/s}^2 = 490 \text{ N}$$

From Hook's law:  $F = kx$  or  $k = \frac{F}{x}$  Putting values:  $k = \frac{490 \text{ N}}{0.1 \text{ m}}$

Therefore,

$$k = 4,900 \text{ N/m}$$

**Answer**

So, the given chair spring has a spring constant of 4,900 N/m.



## 5.2 PRESSURE

Pressure is defined as force per unit area. Pressure is represented by letter ' $P$ ', if force ' $F$ ' is applied on area ' $A$ ', the pressure is given by

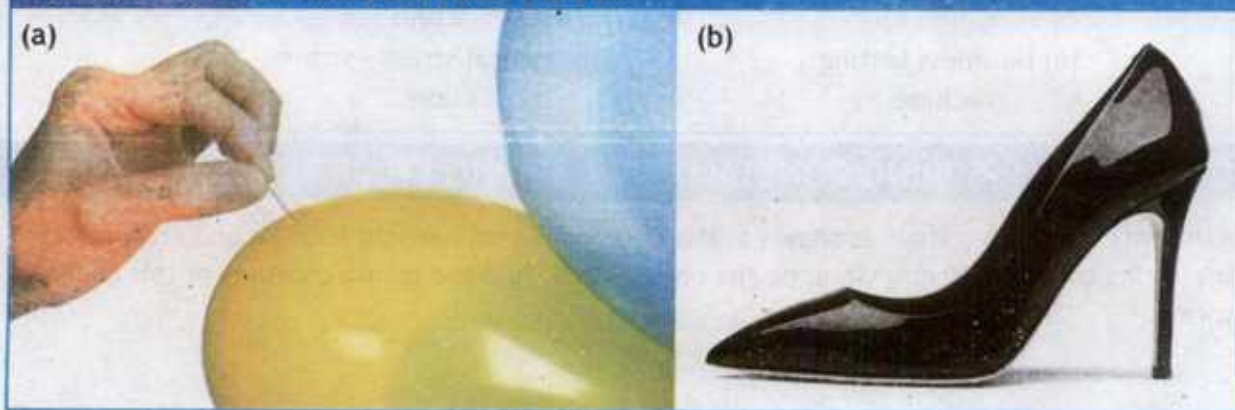
$$P = \frac{F}{A} \quad \text{--- 5.2}$$

The SI unit of pressure is pascal (Pa) which equals newton per square meter ( $\text{N/m}^2$ ).

$$1 \text{ Pa} = \frac{1 \text{ N}}{1 \text{ m}^2}$$

The pressure increases when the force on a specific area is increased or when a smaller area is subjected to a given force. Why does a balloon burst easily when pricked with a pin, but not when squeezed by our hand? The reason is that the force applied to the small area of the needle tip creates enough pressure to burst the balloon as shown in figure 5.7 (a).

**FIGURE 5.7 BALLOON AND HEELS**

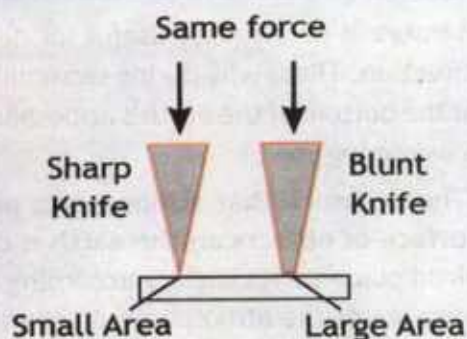




Getting stepped on by a high-heeled shoe hurts more than getting stepped on by a flat one. This is because the weight of the body is concentrated on a smaller area with a pencil heel shoe, as illustrated in figure 5.7 (b).

Have you ever wondered why a blunt knife cannot cut meat easily? When you apply the same force on sharp and blunt knife, the sharp knife offers little surface area thereby increasing pressure, which help to cut meat easily as shown in figure 5.8.

**FIGURE 5.8 SHARP AND BLUNT KNIFE**



## EXAMPLE 5.2: WEIGHT AS PRESSURE ON GROUND

Abdurrahman was standing at the stage of a hall for a speech. What pressure does he apply on the stage if his two feet cover an area of  $400 \text{ cm}^2$ ? (b). If for a while he stands on one foot, what will be the pressure under that foot? (Take his mass  $50 \text{ kg}$ ).

### GIVEN

Mass of Abdullah ' $m$ ' =  $50 \text{ kg}$

Area of two feet ' $A_1$ ' =  $400 \text{ cm}^2 = 400 \times 10^{-4} \text{ m}^2 = 0.04 \text{ m}^2$

Area of one foot ' $A_2$ ' =  $A_1/2 = 0.04 \text{ m}^2/2 = 0.02 \text{ m}^2$

### SOLUTION:

Weight of Abdurrahman will be given by:  $W = mg = 50 \text{ kg} \times 9.8 \text{ m/s}^2 = 490 \text{ N}$

$$P = \frac{F}{A} = \frac{W}{A} \quad \text{--- 1}$$

(a) For both feet the equation 1 can be written as:  $P_1 = \frac{W}{A_1}$

$$\text{Putting values } P_1 = \frac{490 \text{ N}}{0.04 \text{ m}^2}$$

Therefore  $P_1 = 12,250 \text{ N/m}^2 = 12,250 \text{ Pa} = 12.25 \text{ kPa}$

**Answer**



(b) For one foot the above equation can be written as  $P_2 = \frac{W}{A_2}$

$$\text{Putting values } P_2 = \frac{490 \text{ N}}{0.02 \text{ m}^2}$$

Therefore

$$P_2 = \frac{490 \text{ N}}{0.02 \text{ m}^2} = 24500 \text{ N/m}^2$$

Answer

Thus, for the same force (or weight), if area is halved pressure becomes double.

### 5.3 ATMOSPHERIC PRESSURE

Pressure is particularly useful for dealing with liquids and gases, as it exerts pressure in every direction. That's why during swimming we feel pressure on all parts of our body. Similarly we live at the bottom of the earth's atmosphere, which pushes inward on our bodies just like the water in a swimming pool.

'The pressure that atmospheric particles exert on the surface of earth and all over the surface of objects on the earth is called atmospheric pressure'. The pressure of the air at a given place varies slightly according to the weather and height from sea level. At sea level, the pressure of the atmosphere on average is  $1.013 \times 10^5 \text{ Nm}^{-2}$  (or  $1.013 \times 10^5 \text{ Pa}$ ). This value lets us define a commonly used unit of pressure, the atmosphere (abbreviated atm), such that

$$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

Another unit of pressure sometimes used (in meteorology and on weather maps) is the bar, which is defined as

$$1 \text{ bar} = 1.000 \times 10^5 \text{ Pa.}$$

How a suction cup gets its sticking force? It is because of the atmospheric pressure. When we push the cup against a smooth wall, we actually force the air out of the cup, allowing atmospheric pressure to hold it to the wall. Another example of atmospheric pressure can be seen when we pump the air out of sealed can, atmospheric pressure produces an inward force that is unopposed, this results in the collapse of the can (figure 5.9).

FIGURE 5.9 SUCTION CUP AND AIR EVACUATED FROM SEALED CAN





## POINT TO PONDER



In 17th century Otto Von Guricke (German physicist) fitted two hollow bronze hemispheres together and removed the air from the resulting sphere with a pump. Two eight horse teams were unable to pull the halves apart, even though the hemispheres fell apart when the air was readmitted.

### 5.3.1 MEASUREMENT OF ATMOSPHERIC PRESSURE

A liquid barometer is a device that measures atmospheric pressure using the principles of hydrostatics and the behavior of liquids. The most common type of liquid barometer is the mercury barometer.

The liquid barometer works on the principle of hydrostatic equilibrium, which states that the pressure at any point in a fluid at rest is the same at all depths.

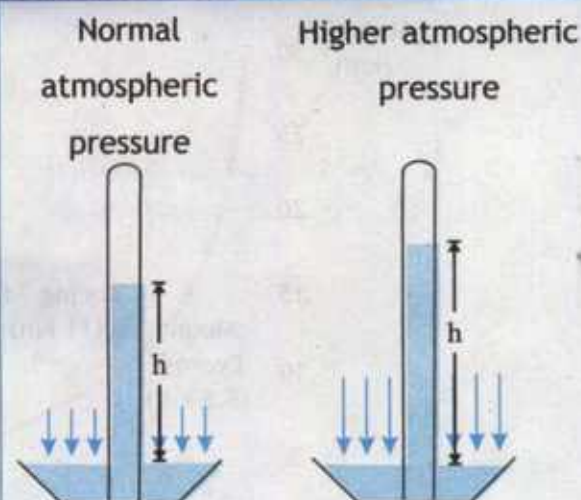
In a mercury barometer, a tube filled with mercury is inverted into a container of mercury. The mercury in the tube seeks a level where the weight of the mercury column is balanced by atmospheric pressure on the surface of the mercury in the container. The height of the mercury column in the tube represents the atmospheric pressure as shown in the figure 5.10. At sea level, the atmosphere will push down mercury in the tub and make it rise up in a tube to a height of approximately 760 millimeters (mmHg) or 29.92 inches.

$$1 \text{ atm} = 760 \text{ mmHg} = 101.325 \text{ kPa}$$

The torr is another unit of pressure, equivalent to 1 mmHg.

$$1 \text{ atm} = 760 \text{ torr}$$

**FIGURE 5.10 BAROMETER**





Changes in pressure cause the mercury level to rise or fall, indicating pressure variations associated with altitude and local weather conditions.

Mercury barometers are precise, but they can be harmful to health because of the toxic nature of mercury. When safety is a priority, aneroid or digital barometers are commonly chosen as alternatives.

Liquid barometers have various applications:

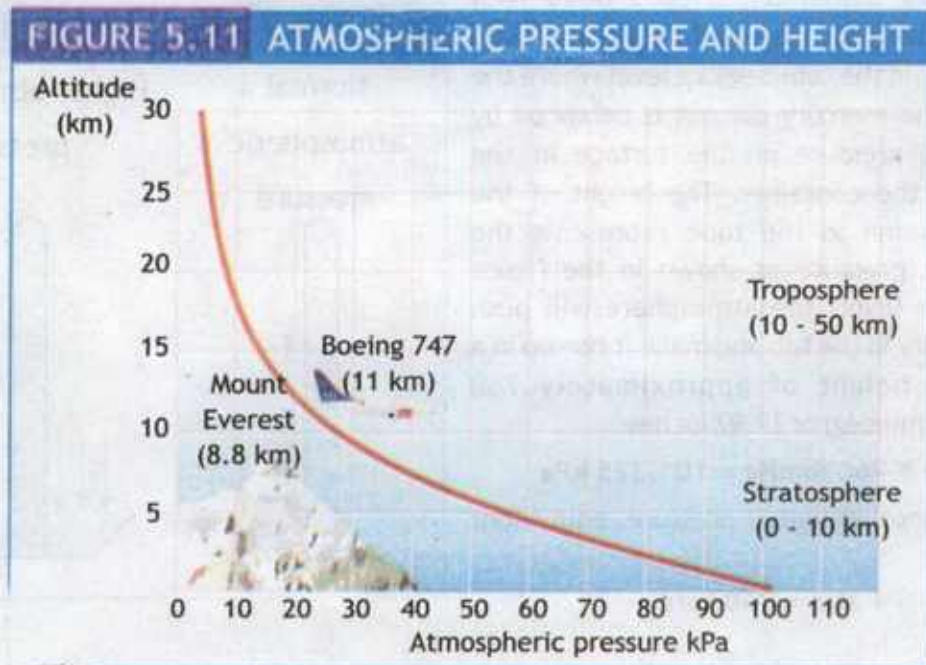
**A. Altitude Measurement:** Liquid barometers (including mercury barometers), can estimate altitude. As atmospheric pressure decreases with increasing altitude, the height of the mercury column decreases, allowing for altitude calculations. They are essential instruments in aviation for altitude measurements and setting aircraft altimeters.

**B. Weather Forecasting:** They are used in meteorology to measure atmospheric pressure, which is associated with weather changes. A falling barometer may indicate an approaching storm, while a rising barometer suggests improvement in weather conditions.

**C. Industrial Applications:** Liquid barometers are used in industrial settings where precise pressure measurements are needed for specific processes or equipment.

### 5.3.2 ATMOSPHERIC PRESSURE AND HEIGHT FROM SURFACE OF EARTH

The atmospheric pressure decreases as we go up from the surface of earth. On mountains the atmospheric pressure is lower than at sea level, decreasing gradually to zero. The climbers at high altitudes encounter lower atmospheric pressure due to the thinner air. The thinner air causes breathing difficulties due to the lower level of oxygen. The graph in figure 5.11 shows that at Mount Everest (height of 8.8 km above sea level) the atmospheric pressure is only 33 kPa, and where Boing 747 flies the atmospheric pressure is around 23 kPa.



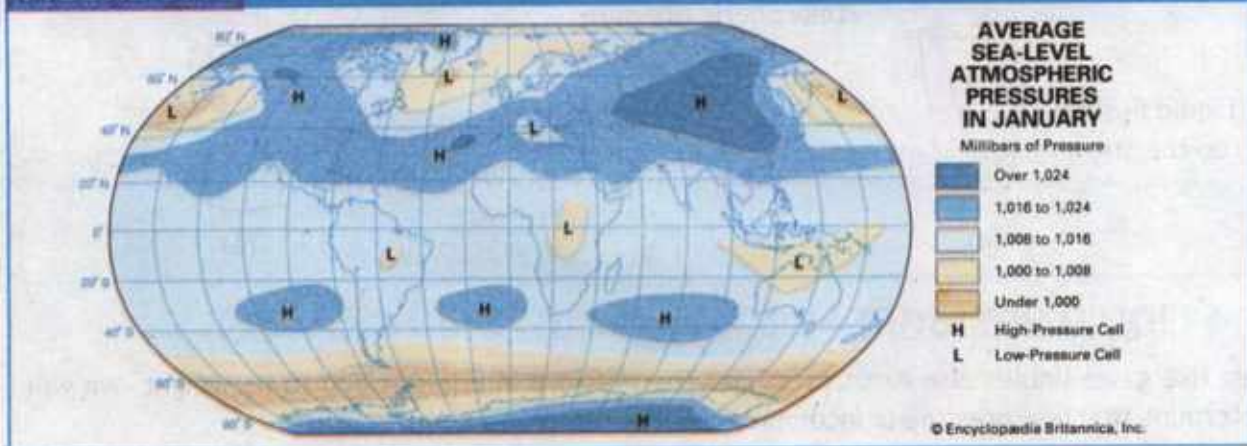


## 5.3.3 ATMOSPHERIC PRESSURE AND WEATHER

Barometers that are kept in the same place at the same height above sea level show some variation in atmospheric pressure from day to day. These pressure variations are shown on weather maps (fig. 5.12). The lines in the map joining all those places with the same atmospheric pressure are called isobars. The unit for pressure used in weather maps is the millibar (mbar).

$$1 \text{ mbar} = 100 \text{ Pa}$$

**FIGURE 5.12 PRESSURE MAP**



Usually the range of atmospheric pressure varies from the very high pressure of 1040 mbar to as low as 950 mbar. Winds move from high pressure regions to low pressure regions. The strength of the wind is determined by the pressure difference. From the weather map, when the isobars are packed closely together, it indicates a high pressure difference.

## 5.3.4 APPLICATIONS OF ATMOSPHERIC PRESSURE

**(A) DRINKING BY STRAW:** The drinking through straw is possible by lowering the pressure in the mouth below atmospheric pressure as shown in figure 5.13 (a). The action of sucking increases the volume of lungs, thereby reducing the air pressure in the lungs and the mouth. The atmospheric pressure acting on the surface of the liquid will then be greater than the pressure in the mouth, thus forcing the liquid to rise up the straw into the mouth.

**(B) DRAWING LIQUID BY SYRINGE:** We can draw liquid up the syringe, as shown in Figure 5.13 (b), the piston of the syringe is drawn back upwards. This decreases the pressure within the cylinder. Atmospheric pressure acting on the surface of the liquid drives the liquid into the cylinder through the nozzle of the syringe.

### POINT TO PONDER



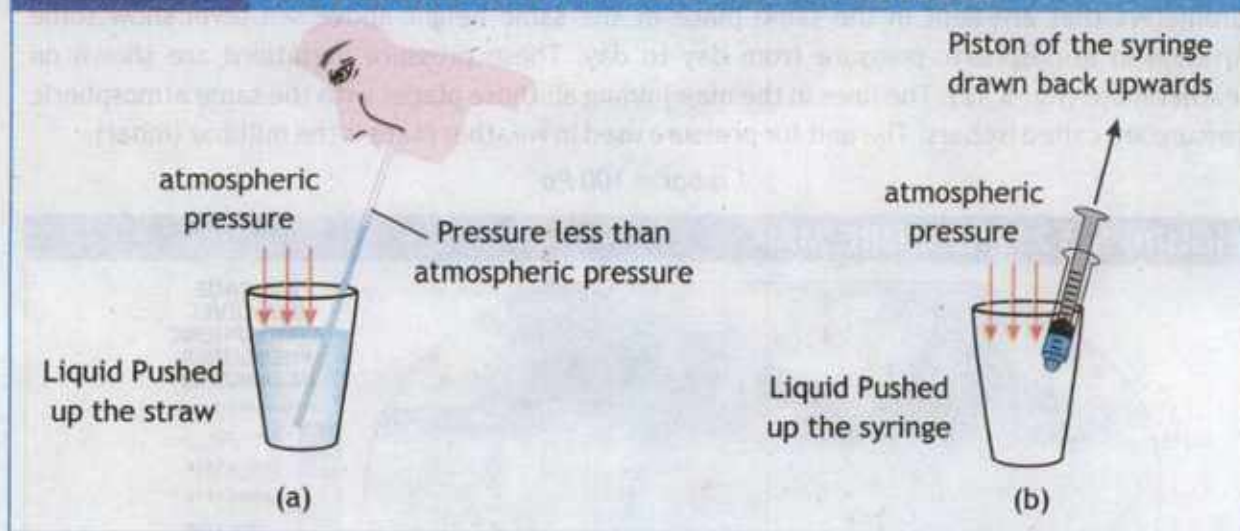
**Why it is difficult to cook food at high altitudes?**

As altitude increases and atmospheric pressure decreases, the boiling point of water decreases. To compensate for the lower boiling point of water, the cooking time must be increased. Turning up the heat will not help cook food.





FIGURE 5.13 APPLICATIONS OF ATMOSPHERIC PRESSURE



## 5.4 LIQUID PRESSURE

Just like gases liquids also exert pressure. The pressure in liquid is due to its weight. We will determine that how pressure of incompressible liquid increases with depth.

Consider a column of liquid of height 'h', base area 'A' at the bottom of a tank in liquid and density 'ρ' as shown in figure 5.14. The force acting on a base area is the weight of the cylindrical column of liquid of mass 'm' is,

$$F = W = mg \quad \text{--- 1}$$

The mass 'm' of the cylindrical liquid, in terms of density 'ρ' is given by,

$$\rho = \frac{m}{V} \quad \text{or} \quad m = \rho V \quad \text{--- 2}$$

Since the fluid forms a cylindrical volume V shown by dotted lines in the figure which has height h and area of cross section A. Therefore

$$V = Ah \quad \text{--- 3}$$

putting equation 3 in equation 2, we get

$$m = \rho Ah \quad \text{--- 4}$$

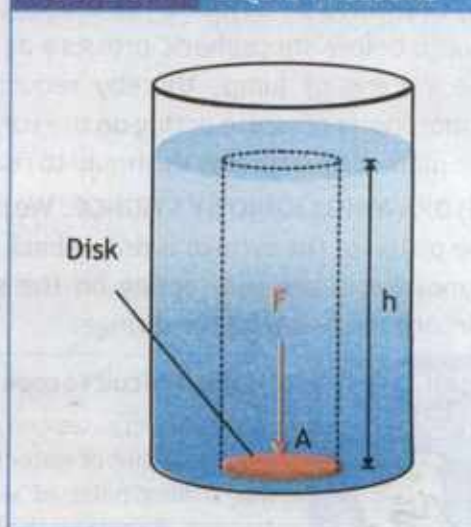
putting equation 4 in equation 1, we get

$$F = \rho Ahg \quad \text{--- 5}$$

Since pressure is defined as  $P = \frac{F}{A}$  --- 6

putting equation 5 in equation 6, we get  $P = \frac{\rho Ahg}{A}$

FIGURE 5.14 LIQUID PRESSURE



## PRESSURE AND DEFORMATION IN SOLIDS



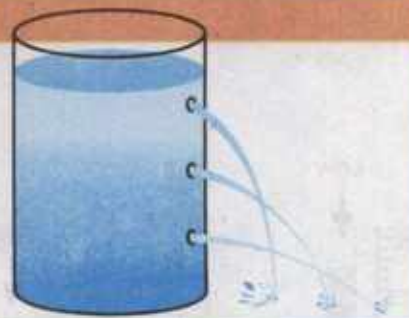
therefore  $P = \rho hg$  — **5.3**

from equation 7.3 we deduce that the pressure in a liquid depends on the depth and density of the liquid.

**ACTIVITY**



Drill holes at different heights on a can as shown in the figure and fill it with water. Water will spurt out fastest and furthest from the lowest hole and slowest and nearest from the highest hole. This means that the pressure in a liquid increases with depth because the further down you go, the greater the weight of liquid above it.



### EXAMPLE 7.3: LIMITS ON SUBMARINE DEPTH

A submarine was moving in the Pacific Ocean (the largest and deepest ocean) at a depth of 8.5 km. How much pressure is exerted upon the submarine if density of water is  $1000 \text{ kg/m}^3$ ?

#### GIVEN

Depth = height  $h = 8.5 \text{ km} = 8500 \text{ m}$

Density of water  $\rho = 1000 \text{ kg/m}^3$

Acceleration due to gravity  $g = 9.8 \text{ m/s}^2$

#### REQUIRED

Pressure  $P = ?$

#### SOLUTION:

The pressure exerted on a body inside a liquid, can be given by:  $P = \rho gh$

Putting values  $P = (1000 \text{ kg/m}^3) \times (9.8 \text{ m/s}^2) \times (8500 \text{ m})$

Therefore  $P = 8.55 \times 10^7 \text{ N/m}^2 = 8.55 \times 10^7 \text{ Pa}$  — **Answer**

The water will exert a pressure of  $8.33 \times 10^7 \text{ Pa}$  or  $83.3 \text{ MPa}$  on the submarine.

## 5.5 MANOMETER

A manometer can be defined as a device that is used to measure the pressure in a fluid using fluid dynamics. The fluid can be a gas or a liquid.

In other words, we can define it as a gauge that is used to measure pressure present in the fluids. Also, it is used in laboratory experiments to demonstrate the pressure of air on a liquid column or vice versa



## UNIT 5

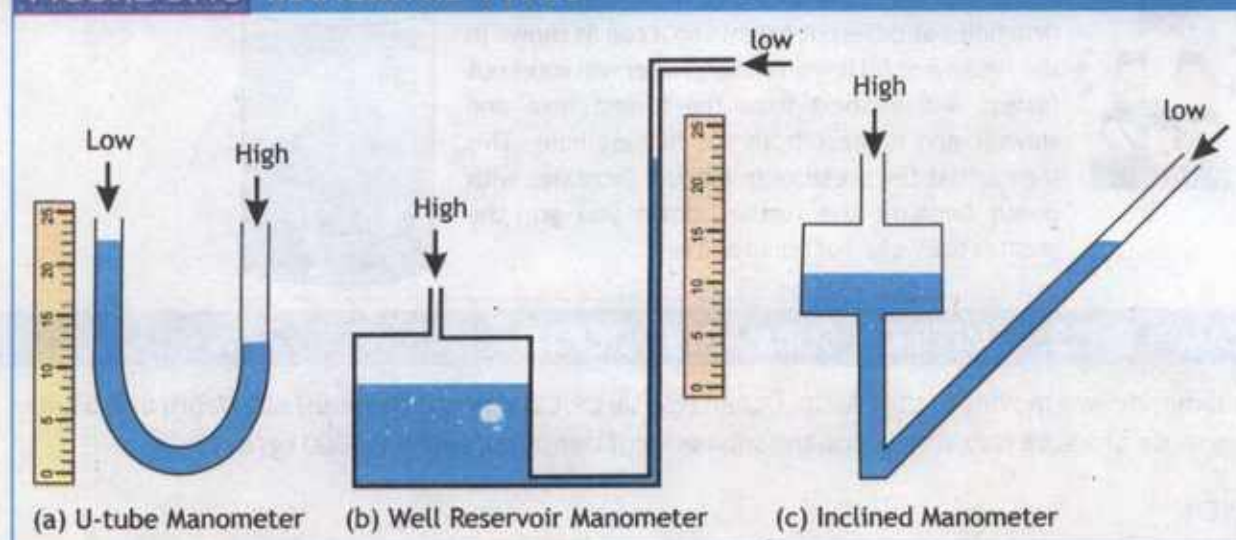
## PRESSURE AND DEFORMATION IN SOLIDS

The formula of a manometer is as follows:

$$P = \rho gh \quad \text{5.4}$$

Where ' $P$ ' is the pressure of the fluid, ' $\rho$ ' is the density of the fluid, ' $g$ ' is the gravitational acceleration exerted by the earth, and ' $h$ ' is the height till which the fluid rises in a manometer.

FIGURE 5.15 MANOMTRE TYPES



The working principle of a manometer is that one end is connected to a seal-tight gas to measure the source of pressure. Whereas, its other end is left open to the atmospheric pressure of the earth. If the pressure present in it is greater than 1 atm then the fluid present in the column will be forced down by that pressure. However, it will cause an increase in equal amounts in the present column.

### 5.5.1 APPLICATION OF MANOMETER

- It is used to measure the pressure of the fluids using mechanical properties of fluids.
- It is also used to measure vacuum.
- It is also used to measure the flow of the fluid.
- It is used to measure the filter pressure drop of the fluids.
- It is also used for meter calibrations.
- It is used to measure leak testing.
- It is also used to measure the liquid level present in a tank.



TABLE 5.2: DIFFERENCE BETWEEN MANOMETER AND BAROMETER

| Manometer                                                                                                                          | Barometer                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| It is a device that is used to measure the pressure of the fluid but that of a liquid concerning the earth's atmospheric pressure. | It is a device that is used to measure fluid pressure but that of air as it can differ with distance when it's below or above sea level |
| It comes in different forms                                                                                                        | It comes only in one basic design for all its types                                                                                     |
| These are filled with mercury or any heavy liquid material but in some cases, they can be filled with a lighter liquid material    | In all its cases, these are only filled with mercury or any heavy liquid material                                                       |

## 5.6 PASCAL'S PRINCIPLE

When we pump a bicycle tire, we apply a force on the pump that in turn exerts a force on the air inside the tyre. The air responds by pushing not only against the pump but also against the walls of the tyre. As a result, the pressure increases by an equal amount throughout the tyre as shown in figure 5.16.

FIGURE 5.16 AIR FILLING IN BICYCLE



In general, if the pressure in a fluid is increased at any point in a container (such as at the valve of the tyre), the pressure increases at all points inside the container by exactly the same amount. Blaise Pascal (1623-1662) noted this fact, what is now called Pascal's principle (or Pascal's law):

**An external pressure applied to an enclosed fluid is transmitted unchanged to every point within the fluid.**



## UNIT 5

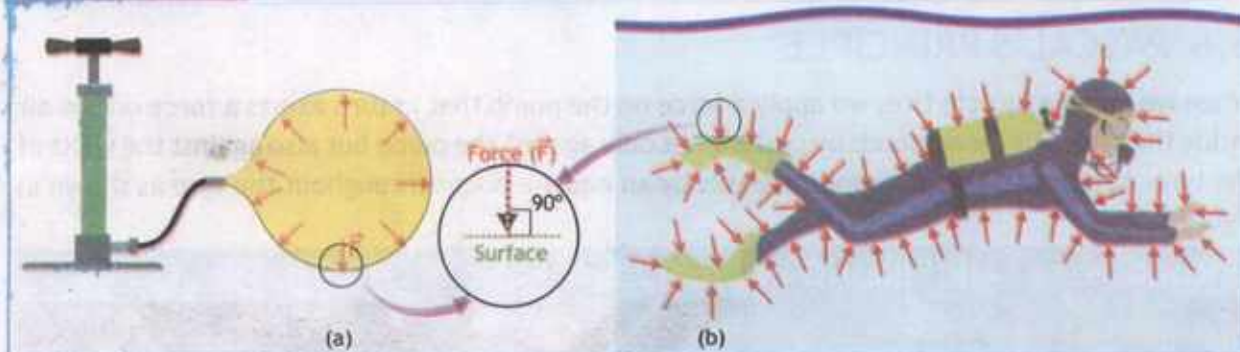
## PRESSURE AND DEFORMATION IN SOLIDS

The relationship between pressure and force on a surface is described by Pascal's Principle, which explain how pressure at a surface produces a force in a direction perpendicular (at right angles) to the surface.

Since pressure is transmitted equally in all directions, the force generated ( $F = P \times A$ ) is also distributed equally in all directions. The force acts perpendicular to the surface because the pressure is acting uniformly in all directions. If there were a component of force parallel to the surface, the object would exert force on the fluid parallel to it as a consequence of Newton's third law. This would result in an uneven distribution of forces, contradicting the principles of Pascal's Principle.

When you blow up a balloon, the pressure inside the balloon goes up. This pressure spreads out evenly in all directions. The force from the pressure pushes outward and goes straight across the surface of the balloon, making it get bigger as shown in figure 5.17 (a).

FIGURE 5.17 FORCE ACTS PERPENDICULARLY



As you dive deeper underwater, the pressure increases due to the weight of the water above. The force exerted by this pressure is perpendicular to the surface of your body. This is why divers feel pressure on their ears, and it also explains why deep-sea divers need specialized suits to counteract the pressure as shown in figure 5.17 (b).

### 5.7.1 HYDRAULIC LIFT

Pascal's principle at work in hydraulic lift, which is shown schematically in Figure 5.18. Here we see two cylinders, one of cross-sectional area  $A_1$  and the other of cross-sectional area  $A_2$  (such that  $A_2 > A_1$ ). The cylinders, each of which is fitted with a piston, are connected by a tube and filled with a Hydraulic fluid. Initially the pistons are at the same level and exposed to the atmosphere.

Now, suppose we push down on piston 1 with the force  $F_1$ . The pressure  $P_1$  exerted by this piston is:

$$P_1 = \frac{F_1}{A_1} \quad \text{--- 1}$$



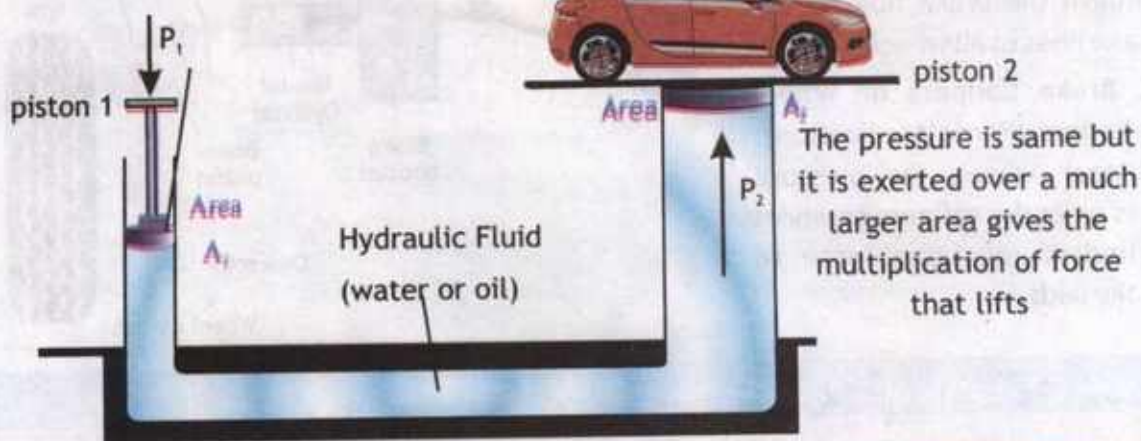
Similarly, the pressure on the piston lifting vehicle is  $P_2$ , which can be written as

$$P_2 = \frac{F_2}{A_2} \quad \text{--- 2}$$

By pascal's principle  $P_2 = P_1 \quad \text{--- 3}$

**FIGURE 5.18 HYDRAULIC ELEVATOR OR LIFT**

Pressure exerted on fluid in cylinder with small cross sectional area



putting values from equation 1 and equation 2 in equation 3 and rearranging for  $F_2$ , we get

$$F_2 = \frac{A_2}{A_1} F_1 \quad \text{--- 5.5}$$

Equation 5.5 shows that depending on the ratio  $A_2/A_1$ , the force  $F_2$  can be as large as possible. To be specific, let's assume that  $A_1$  is 100 times greater than  $A_2$ . Then, by pushing up on piston 1 with a force  $F_1$ , we push up on piston 2 with a force of  $F_2 = 100 F_1$ . Our force has been magnified 100 times! Hence a relatively small effort can be used to overcome a much larger load.

**FIGURE 5.19 HYDRAULIC CAR LIFT**





## UNIT 5

## PRESSURE AND DEFORMATION IN SOLIDS

### 5.7.2 HYDRAULIC CAR BRAKE SYSTEM

The operation of hydraulic car brake system as shown in figure 5.20 is based on Pascal's principle, in the brake system:

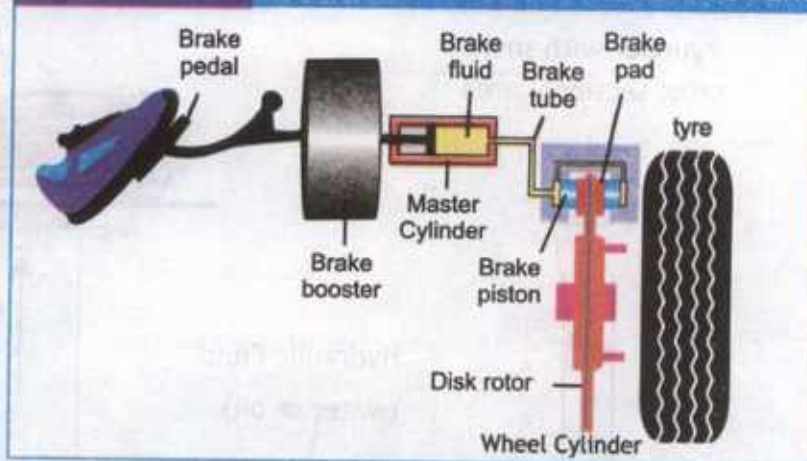
A. Brake Pedal (Force Input): When we press the brake pedal, it exerts force on the master cylinder's piston.

B. Master Cylinder (Pressure Increase): The force on the piston increases the pressure in the brake fluid.

C. Brake Lines (Pressure Transmission): The increased pressure is transmitted equally through the brake fluid in the brake lines to all wheels.

D. Brake Calipers or Wheel Cylinders (Force Application): At each wheel, the pressure acts on brake calipers or wheel cylinders, applying force to brake pads.

FIGURE 5.20 HYDRAULIC CAR BRAKE SYSTEM



#### EXAMPLE 7.4: PASCAL'S PRINCIPLE

A hydraulic lift has  $0.002 \text{ m}^2$  narrow cylinder area while  $0.9 \text{ m}^2$  wider cylinder area. How much force must be applied at the narrow cylinder if a car weighing  $1800 \text{ kg}$  is to be lifted?

#### GIVEN

Area of narrow cylinder ' $A_1$ ' =  $0.002 \text{ m}^2$

Area of wider cylinder ' $A_2$ ' =  $0.9 \text{ m}^2$

Mass of car ' $m$ ' =  $1800 \text{ kg}$

#### REQUIRED

Force at narrow cylinder  $F_1$  = ?

**SOLUTION:** First we will find weight of the car as this will be the force applied on car:

$$w = mg = F_2 = 1800 \text{ kg} \times 9.8 \text{ m/s}^2 = 17,640 \text{ N}$$

From Pascal's principle  $F_1 = \frac{A_1}{A_2} F_2$  Putting values  $F_1 = \frac{0.002 \text{ m}^2}{0.9 \text{ m}^2} \times 17,640 \text{ N}$

Therefore

$$F_1 = 39.2 \text{ N}$$

Answer

That is why we use hydraulic lifts to lift heavy weights with much smaller force than their weight.



## SUMMARY

**Elasticity** is the property of a body, which enables the body to regain its original dimension when the deforming force acting on it is removed.

**Hooke's law** states that within elastic limits the extension (or compression) is directly proportional to the force applied.

**Pressure** is force applied per unit area.

**Atmospheric Pressure** or barometric pressure is the force exerted by the air (its weight) on unit area.

**Barometer** is a device used to measure atmospheric pressure.

**Monometer** is one of the most accurate devices for measuring pressure, including atmospheric pressure in the lower ranges.

**Pascal's Principle** states that if the pressure at one point of a confined fluid is increased by an amount, the pressure increases by the same amount at all other parts throughout the fluid.

## EXERCISE



### MULTIPLE CHOICE QUESTIONS

**Q1. Choose the best possible option.**

1. The most elastic material of the following is:
 

A. Rubber
B. Wood
C. Glass
D. Steel
2. Hooke's law hold good up to:
 

A. proportional limit
B. yield limit

C. elastic limit
D. plastic limit
3. A mass of 2 kg is hung by spring, which displaces it through 5 cm. The spring constant is:
 

A. 400 N/m
B. 40 N/m
C. 4 N/m
D. 4000 N/m
4. Materials which does not regain its original shape after removal of the load producing deformation are termed as:
 

A. Elastic materials
B. Plastic materials

C. Rigid materials
D. Hooke's materials
5. SI unit of pressure is:
 

A. bar
B. newton
C. psi
D. pascal
6. Which will exert greater pressure?
 

A. 3 g needle of tip area  $1\text{mm}^2$ 
B. 4000 kg elephant of total feet area  $0.5\text{ m}^2$

C. A girl of mass 40 kg wearing high heel shoes of cross-sectional area  $0.5\text{ cm}^2$ 
D. A loaded ship of mass  $2.2 \times 10^7\text{ kg}$  having area  $600\text{ m}^2$



7. Pressure of 1000 mbars is equivalent to:  
A. 0.1 kPa      B. 1 kPa      C. 10 kPa      D. 100 kPa
8. Pressure of 1 mm Hg is equal to:  
A.  $1.316 \times 10^{-3}$  atm      B. 1 atm      C. 133.29 atm      D.  $1.316 \times 10^5$  atm
9. Atmospheric pressure is commonly measured using a:  
A. hygrometer      B. barometer      C. manometer      D. thermometer
10. Pressure of liquid in a container increase with:  
A. base      B. volume      C. depth      D. mass
11. The atmospheric pressure will be smaller at:  
A. Islamabad      B. Peshawar      C. Lahore      D. Murree
12. A girl of mass 50 kg wears heels with an area of  $2 \text{ cm}^2$  in contact with the ground. The pressure she exerts on ground is:  
A.  $4 \times 10^3$  Pa      B.  $4 \times 10^4$  Pa      C.  $4 \times 10^4$  Pa      D.  $4 \times 10^5$  Pa
13. Divers wear special suits in order to protect them from:  
A. low pressure      B. high pressure  
C. low temperature      D. high temperature
14. In a stationary fluid, the local pressure of the fluid vary:  
A. with depth only      B. horizontally only  
C. both with depth and along horizontal direction  
D. neither with depth nor along horizontal direction
15. The pressure exerted by a man on the surface of earth will be smaller when he:  
A. stands on both feet      B. sits on the ground  
C. stands on one leg      D. sleeps on the ground

### SHORT RESPONSE QUESTIONS

#### QII. Give a short response to the following questions

1. While walking on a trampoline. Do you feel more pressure when you stand still or jump up and down? Why does pressure change with movement?
2. How does the shape of a thumb pin help it penetrate surfaces easily?
3. If you blow up a balloon and then tie it closed, why does it stay inflated even though you stop blowing? How does pressure play a role here?
4. Why an inner airtight layer of a space suit is designed to maintain a constant pressure around the astronaut?
5. If a liquid has density twice the density of mercury, what will be height of liquid column in barometer?
6. Why we wouldn't be able to sip water with a straw on the moon?



7. How are we able to break a metal wire by bending it repeatedly?
8. A spring, having spring constant  $k$  when loaded with mass ' $m$ ', is cut into two equal parts. One of the parts is loaded with the same mass  $m$  again. What will be its spring constant now?
9. Why do static fluids always exert a force perpendicular to the surface?
10. How can a small car lifter lift load heavier than itself?



## LONG RESPONSE QUESTIONS

QIII. Give an extended response to the following questions

1. Define elasticity and elastic limit. Show that a force may produce change in size and shape of solids.
2. What is Hook's law? Illustrate its applications. Also, define and calculate spring constant.
3. Draw and explain force-extension graph for elastic solids.
4. Define and explain pressure. What is effect of area on pressure acting on surface?
5. Explain the term atmospheric pressure along with its units. How atmospheric pressure is measured with liquid barometer? Explain its construction and applications.
6. Explain with examples how atmospheric pressure varies with altitude. What kind of weather change is indicated by variation in the atmospheric pressure? What are different applications of atmospheric pressure?
7. Show that liquid in a container exerts pressure equal to  $P = \rho g h$ . What is effect of depth on pressure of liquid?
8. State Pascal's law? Describe working principle of hydraulic lift using Pascal's law? What do you mean by force multiplier?

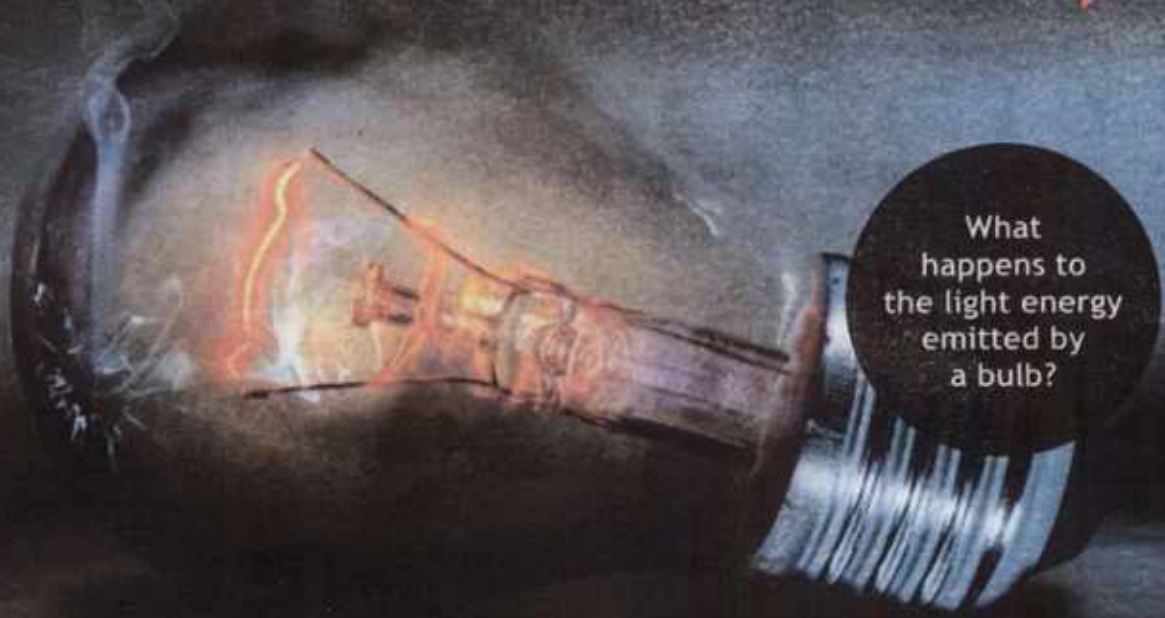
## NUMERICAL RESPONSE QUESTIONS

**QIV. Solve the following numerical questions.**

1. Consider a spring with a spring constant of  $8000 \text{ N/m}$ . If a force of  $500 \text{ N}$  is applied to the spring, what will be the displacement of the spring?  
(Ans.  $6.25 \text{ cm}$ )
2. In a force multiplier, small piston has diameter of  $15 \text{ cm}$  and large piston has diameter of  $30 \text{ cm}$ . If  $250 \text{ N}$  force is applied on the small piston then how much force will produce on large piston?  
(Ans.  $1000 \text{ N}$ )
3. A hydraulic car lift lifts a car of mass  $1000 \text{ kg}$  when we apply force of  $50 \text{ N}$  on small piston. Radius of its small piston is  $20 \text{ cm}$ . Find the radius of its large piston.  
(Ans.  $78.4 \text{ cm}$ )
4. Water column in a beaker is  $70 \text{ cm}$ . Find the pressure of water in beaker. Take density of water as  $1000 \text{ kg/m}^3$ .  
(Ans.  $6.86 \text{ kPa}$ )
5. How much force should be applied on an area of  $20 \text{ cm}^2$  to get a pressure of  $4500 \text{ Pa}$ ?  
(Ans.  $9 \text{ N}$ )

# WORK AND ENERGY

UNIT  
6



## Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-60] Define work done.
- [SLO: P-09-B-61] Use the equation work done = force  $\times$  distance moved in the direction of the force  $W = F \times d$  to solve problems
- [SLO: P-09-B-62] Define energy as the ability to do work.
- [SLO: P-09-B-63] Explain that energy may be stored.
- [SLO: P-09-B-64] Prove that Kinetic Energy  $E_k = \frac{1}{2} mv^2$ .
- [SLO: P-09-B-65] Prove and use the formula for gravitational potential energy.
- [SLO: P-09-B-66] Use the formulas for kinetic and gravitational potential energy to solve problems involving simple energy conversions.
- [SLO: P-09-B-67] Describe how energy is transferred and stored during events and processes.
- [SLO: P-09-B-68] State and apply the principle of the conservation of energy.
- [SLO: P-09-B-69] Justify why perpetual energy machines do not work.
- [SLO: P-09-B-70] Differentiate between and list renewable and non-renewable energy sources.
- [SLO: P-09-B-71] Describe how useful energy may be obtained from natural resources.
- [SLO: P-09-B-72] Describe advantages and disadvantages of methods of energy generation.
- [SLO: P-09-B-73] Define and calculate power.
- [SLO: P-09-B-74] Define and calculate efficiency.
- [SLO: P-09-B-75] Apply the concept of efficiency to simple problems involving energy transfer.
- [SLO: P-09-B-76] State that a system cannot have an efficiency of 100% due to unavoidable energy losses that occur.



## UNIT 6 WORK AND ENERGY

In our daily life work means “to do anything”. But in science, work has specific meaning, i.e. when force is applied and some distance is covered. For example, a man carrying a physics book is doing work but he is not doing work if he is not moving while keeping the physics book on his head. Scientifically, work is done only when an effort or force moves an object. When work is done, energy is used. Thus, work and energy are related to each other. The concept of energy is an important concept in Physics. It helps us to explain the changes that occur when work is done. This unit deals with the concepts of work, energy and power.

### 6.1 WORK

Work is said to be done when a force displaces a body in its own direction.

When an object moves distance  $S$  in the direction of applied force  $F$  (figure 6.1), then work done  $W$  is given mathematically as

$$\text{Work - done} = \text{Force} \times \text{Displacement}$$

$$W = F \times d \quad \text{--- 6.1}$$

FIGURE 6.1 WORK DONE

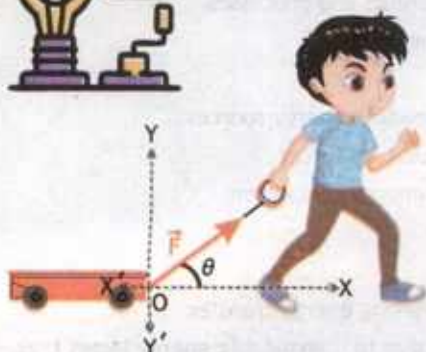


Work is a scalar quantity and in the International System of Units (SI), work is measured in joules (J). One joule is equal to the work done by a one-newton (1 N) force acting over a one-metre (1 m) distance.

$$1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$$



### SCIENCE TIDBITS



### VECTOR REPRESENTATION

Force is not always applied perfectly in the direction of motion. For example consider a toy car which is moving in horizontal direction and force ‘ $F$ ’ is applied making certain angle ‘ $\theta$ ’ with the horizontal. In such situations the force is resolved into its rectangular components as shown in figure 6.2.



## CAN YOU TELL?

A man is pushing the truck but truck is at rest, is he doing work? Explain.

## EXAMPLE 6.1: WORK DONE

Muhammad Tuaha was pushing a box with a force of 100 N on a flat frictionless surface. How much work he does on the box if he pushes it through a displacement of 200 m?

## GIVEN

Force ' $F$ ' = 100 N

Distance ' $d$ ' = 200 m

## REQUIRED

Work ' $W$ ' = ?

## SOLUTION

By the definition of work:  $W = F \times d$       Putting values:  $W = 100 \text{ N} \times 200 \text{ m}$

Therefore,

$$W = 20,000 \text{ J} = 20 \text{ kJ}$$

Answer

Muhammad Tuaha does 20 kJ of work on the box.

## 6.2 ENERGY AND ITS FORMS

We can identify things around us that are capable of doing work, that is, exerting a force to move an object.

- A boy is pushing a toy car. The boy exerts a force on the toy car to move on floor. The work done on toy car is transfer of energy from boy to the toy car.
- A Sharpening a pencil by a child is due to energy transfer to the sharpener.
- Riding a bicycle is possible due to transfer of energy to bicycle by a person.

So energy is defined as 'the capacity of a body to do work'.

Energy has many different forms as shown in table 6.1

## UNIT OF ENERGY

The unit of energy is the same as that of work i.e joule (abbreviated  $\text{J} = \text{Nm}$ ).

**TABLE 6.1 TYPES OF ENERGY**

| TYPE                   | DESCRIPTION                                                                                     | EXAMPLE                                                                                                                      |
|------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Chemical Energy        | The energy contained within the bonds between atoms.                                            | These bonds can take many different forms, including energy derived from carbohydrates in food to energy stored in gasoline. |
| Electromagnetic Energy | Electromagnetic energy (or radiant energy) is energy from light or electromagnetic waves.       | Electromagnetic energy from the Sun supplies Earth with all of the energy required to sustain life.                          |
| Electrical Energy      | The energy associated with charges.                                                             | Electrons moving from negatively to positively charged objects.                                                              |
| Sonic Energy           | The energy of sound waves. Sound waves travel through the air or another medium.                | Sound vibrations cause a person's eardrums to vibrate.                                                                       |
| Nuclear Energy         | Nuclear energy is energy resulting from changes in the atomic nuclei or from nuclear reactions. | Nuclear power stations use nuclear energy to generate electric energy.                                                       |

All forms of energy (Heat, electrical, light, chemical, nuclear and sound) can be classified as one of two types, either potential energy (stored) or kinetic energy (due to motion) collectively termed as mechanical energy.

### 6.2.1 KINETIC ENERGY

**The energy possessed by a body due to its motion is called Kinetic energy.**

A moving bullet is able to do work by overcoming forces when it strikes something e.g. wood. Similarly kinetic energy is felt during a collision.

A football is kicked by a boy it moves because it possesses Kinetic energy. Now think a tennis ball and a football moving with same speed. Which possess greater ability to do work? Of course it is the football with larger mass, which is difficult to stop. Similarly now two footballs are approaching you with different speeds, which can do more work? Again it is easy to answer as the football with greater speed is difficult to stop. Thus the object's mass and its speed contribute to its Kinetic energy. Like all energies Kinetic energy is also a scalar quantity.

Consider a constant force ' $F$ ' is acting on an object of mass ' $m$ ' and as a result the object moves on a frictionless surface. The kinetic energy of an object will be equal to work done.

The work done on force-displacement graph can be calculated by finding area of figure under force-displacement graph as shown in figure 6.2.



Change in kinetic energy ( $E_k$ ) = Work done =  $F \cdot d$

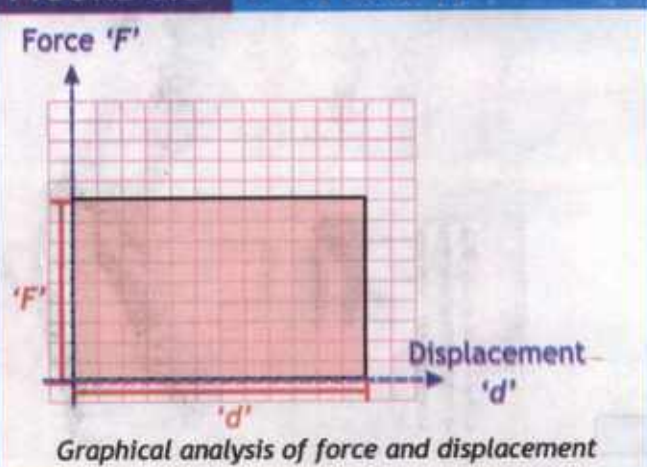
Work done = area under force displacement graph

Here the area under force displacement graph is the area of rectangle, thus:

Change in kinetic energy ( $E_k$ ) = Area of rectangle = width  $\times$  length =  $(F)(d)$

or  $E_k = (ma)(v_{av} t)$  — 1

**FIGURE 6.2 F - D GRAPH**



here  $v_{ave} = \frac{v_i + v_f}{2}$

As the speed is increasing its velocity from  $v_i = 0$  to  $v_f = v$ , therefore the average speed  $v_{ave}$  is therefore

$v_{ave} = \frac{0 + v}{2} = \frac{v}{2}$  — 2

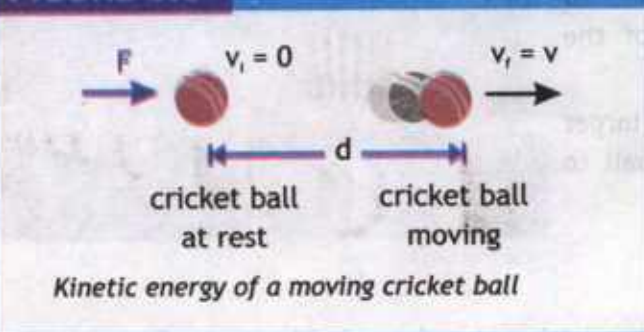
And acceleration can also be written as:

$a = \frac{v}{t}$  — 3

Putting equation 2 and equation 3 in equation 1, we get  $E_k = m \frac{v}{t} \cdot \frac{1}{2} vt$

$E_k = \frac{1}{2} mv^2$  — 6.2

**FIGURE 6.3 KINETIC ENERGY**



By solving equation 6.2 kinetic energy for cricket ball can be found, For example, a 100 g cricket ball moving with a speed of 2.0 m/s has a Kinetic energy of 0.2 J as shown in figure 6.3.

Equally important, it demonstrate the work kinetic energy theorem which

states that the work done on an object is equal to change in energy i.e  $W = \Delta E$ , Where 'W' is the work done and ' $\Delta E$ ' is the change in energy.

**EXAMPLE 6.2: SPEED OF CRICKET BALL**

Babar Azam hits a cover drive by giving kinetic energy of 50 J to the ball by his bat. At what speed will the ball go to the boundary if mass of the ball is 120 g?

**GIVEN**

Mass of ball ' $m$ ' = 120 g = 0.12 kg

Kinetic energy of ball ' $E_k$ ' = 50 J

**REQUIRED**

Speed of cricket ball ' $v$ ' = ?

**SOLUTION**

Kinetic energy is given by:  $E_k = \frac{1}{2}mv^2$

For velocity:  $v^2 = \frac{2E_k}{m}$

Taking square root on both sides:  $v = \sqrt{\frac{2E_k}{m}}$

Putting values:  $v = \sqrt{\frac{2 \times 50 \text{ J}}{0.12 \text{ kg}}}$

Therefore,  $v = 28.9 \text{ m/s}$

**Answer**



At this speed, the ball will touch the boundary line in just 2.5 seconds, which is about 72 m long

**DO YOU KNOW**


The light emitted by the bulb is converted into other forms of energy like kinetic energy of the surrounding molecules etc.

This means that a football will need a much larger amount of kinetic energy than a cricket ball to make it move at the same speed.

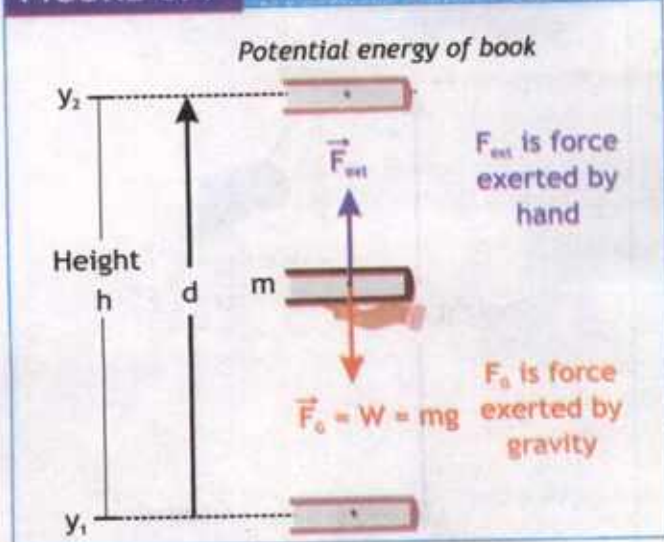

**6.2.2 POTENTIAL ENERGY**

The energy possessed by a body by virtue of its position (in a force field or in configuration) is called potential energy'.

Consider the work you do on a book when you lift from the floor and place it on the top shelf. The work you did on your book is now stored in the book by virtue of its position.



**FIGURE 6.4** STORED ENERGY



By doing work against the force of gravity, you have given your book a special form of potential energy called gravitational potential energy (figure 6.4). If you release book from the top shelf it will accelerate, gaining kinetic energy, thus gravitational potential energy is released and have the ability to do useful work. Gravitational potential energy is only one of several forms of potential energies.

For example, doing work on an elastic spring by stretching it stores elastic potential energy in elastic spring, (slingshot, shock absorber, winding spring in toys and watches are all example of

elastic potential energy). Chemical potential energy stored in the food you eat. A battery contains both chemical and electrical potential energy during working of battery. Similarly, in a capacitor, which consists of two conductive plates with opposite charges, electrostatic potential energy is stored in the electric field between the plates.

**FIGURE 6.5**



Mathematically, Gravitational potential energy is the product of mass 'm', the acceleration due to gravity 'g', and the change in height 'h'.

$$E_{p,grav} = mgh$$

Like all energies potential energy is also a scalar quantity. For example if we lift a stone of mass 5 Kg from the ground to 20m high the work is done against the force of gravity, this work appears as 980 J of potential energy.



## UNIT 6 WORK AND ENERGY

Consider an object of mass ' $m$ ' being lifted vertically by a force ' $F$ ' to ' $h$ ' as shown in figure 6.6. The work done by the force  $F$  is given by equation.

$$W = E_{p,grav} = FS \quad \text{--- 1}$$

Since the force in this case is equal to its weight

$$F = W = mg \quad \text{--- 2}$$

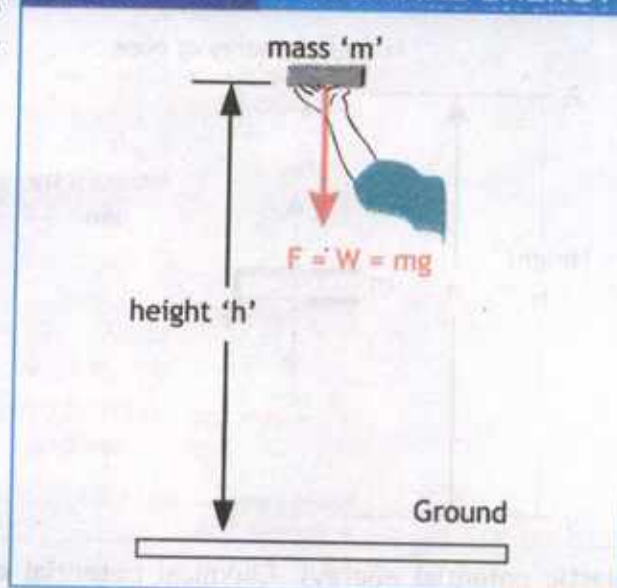
Here the distance moved is the height ' $h$ '

$$S = h \quad \text{--- 3}$$

putting equation 2 and 3 in equation 1, we get

$$E_{p,grav} = mg \times h = mgh \quad \text{--- 6.3}$$

FIGURE 6.6 POTENTIAL ENERGY



### EXAMPLE 6.3: POTENTIAL ENERGY

At School sports gala, Kamil made a record in high jump at his school. He jumped 1.5 m high. What will be his potential energy if his mass is 60 kg? From where does this potential energy come?

#### GIVEN

Mass ' $m$ ' = 60 kg      Height ' $h$ ' = 1.5 m

Acceleration due to gravity ' $g$ ' =  $9.8 \text{ m/s}^2$

#### REQUIRED

Potential Energy ' $E_{p,grav}$ ' = ?

#### SOLUTION

Potential energy is given by:  $E_{p,grav} = mgh$

Putting values:  $E_{p,grav} = 60 \text{ kg} \times 9.8 \text{ m/s}^2 \times 1.5 \text{ m}$

Therefore,

$$E_{p,grav} = 882 \text{ J}$$

Answer



This gravitational potential energy comes from pushing himself upward with kinetic energy of 882 J.



### 6.2.3 ENERGY CONVERSION AND CONSERVATION

Think of a book lying on a shelf. The book has gravitational potential energy when it is on the shelf. What happens if the book falls off the shelf? Its potential energy changes into kinetic energy. This change in energy from one form to another is conversion of energy. For example consider the following examples

**A. Generation of electricity:** Potential energy of water which is stored at a certain height is converted into kinetic energy by making it fall on turbine to produce electricity as shown in figure 6.7.

**FIGURE 6.7 ENERGY CONVERSION**



**B. A cyclist going up to the top of a hill:** Stored chemical energy in the body of cyclist allows him to do work against gravity (see figure 6.7). At the top of the hill, he will possess gravitational potential energy which will allow him to go down the hill with increasing kinetic energy even without pedaling.

When current passes through bulb, electrical energy is converted into light energy and thermal energy. In a car driven with petrol the chemical energy stored in the fuel is converted into kinetic energy of car. Engineers are concerned with the technologies associated with transformation from sources such as fossil fuels into conveniently used forms such as electrical energy and heating.

**FIGURE 6.8 ALTERNATE ENERGY SOURCES**



It must be noted that during this conversion process all the energy is not converted into useful forms. Scientists term this lost energy as dissipated energy. For example, in an automobile driven with petrol only a small portion (17 to 21%) of the chemical energy of gasoline is converted into energy that moves the car. The remaining portion (80%) is lost to the environment as heat and other forms of energy. Electric cars are far more energy efficient than internal combustion engine cars.

Energy cannot be destroyed or created it is only converted from one form to the other.

The law of conservation of energy states that,

**'Energy can neither be created nor destroyed in any process. It can be converted from one form to another, but the total amount of energy remains constant'.**

This means that if the work done 'W' is zero then, the change in energy ' $\Delta E$ ' is also zero.

$$\Delta E = 0$$

If the total energy at final stage is  $E_{Tf}$  and the total energy at initial stage is  $E_{Ti}$ , then by conservation of energy principle

$$E_{Tf} - E_{Ti} = 0$$

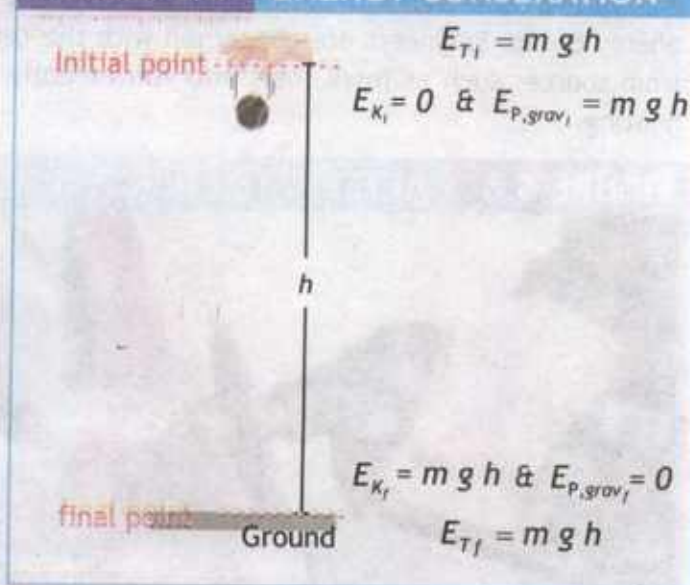
$$E_{Tf} = E_{Ti} \quad \text{--- 6.4}$$

Thus the initial energy of a system is equal to its final energy. However, some time this principle appears to be violated. For example, when electrical energy is provided to fan some of this energy is used in rotating the fan, the remaining energy is not lost or destroyed but converted into other forms of energy (such as thermal energy). In this way, the total energy remains constant.

In certain processes, both the total energy and the total mechanical energy are conserved, meaning they stay the same. An example of this can be seen in Figure 6.9, where a ball is falling. The ball starts from a rest position and drops from a height 'h', above the ground. As the ball falls, its gravitational potential energy is converted into kinetic energy, causing it to move faster. However, its mechanical energy remains constant. This can be expressed mathematically as:

$$E_{K_i} + E_{P,grav_i} = E_{K_f} + E_{P,grav_f} \quad \text{--- 1}$$

**FIGURE 6.9 ENERGY CONSERVATION**





As energy at initial point is totally because of gravitational potential energy ' $E_{p, grav}$ ' Which is totally transformed into kinetic energy ' $E_k$ ' at final point, therefore equation 1 can be:

$$E_k = E_{p, grav} \quad \text{--- 2}$$

When the frictional forces, such as air resistance acts between initial and final points, the gravitational potential energy ' $E_{p, grav}$ ' at initial point apart from converting into kinetic energy ' $E_k$ ' ' $E_k$ ' is dissipated into work done against friction ' $W_{fr}$ '. Thus equation A can be written as

$$E_k + W_{fr} = E_{p, grav} \quad \text{--- 6.5}$$

### EXAMPLE 6.4: FOOTBALL KICK

A player kicks the football of mass 450 g is thrown vertically upward at a speed of  $22 \text{ ms}^{-1}$ .

(a) Neglecting air resistance how high would it reach. (b) If due to air friction the ball only rises to 20 m, what is the work done against air resistance?

**GIVEN**

Mass ' $m$ ' = 450 g = 0.45 kg

Speed ' $v$ ' =  $22 \text{ ms}^{-1}$

Acceleration due to gravity ' $g$ ' =  $9.8 \text{ ms}^{-2}$

Height with air friction ' $h_{fr}$ ' = 20 m

**REQUIRED**

(a) Height ' $h$ ' = ? (without friction)

(b) Work by friction ' $W_{fr}$ ' = ?

**SOLUTION:** (a) Without frictional loss:

$$E_k = E_{p, grav}$$

$$\text{or } \frac{1}{2}mv^2 = mgh \quad \text{or } h = \frac{v^2}{2g} \quad \text{putting values } h = \frac{(22 \text{ ms}^{-1})^2}{2 \times 9.8 \text{ ms}^{-2}}$$

Hence

$$h = 24.7 \text{ m}$$

**Answer**



(b) Due to friction when the ball only raises to 20 m, then:

$$\text{loss in KE} + \text{Work against friction} = \text{gain in PE} \quad \text{or } E_k + W_{fr} = E_{p, grav}$$

$$\text{or } W_{fr} = E_{p, grav} - E_k \quad \text{Hence } W_{fr} = mgh_{fr} - \frac{1}{2}mv^2$$

$$\text{putting values } W_{fr} = 0.45 \text{ kg} \times 9.8 \text{ ms}^{-2} \times 20 \text{ m} - \frac{0.45 \text{ kg} \times (22 \text{ ms}^{-1})^2}{2}$$

Therefore,

$$W_{fr} = 88.2 \text{ J} - 108.9 \text{ J} = -20.7 \text{ J}$$

**Answer**

Where the negative sign shows that work done by friction retard the motion of the object.

So 20.7 J of energy is lost due to friction of 108.9 J of the available energy.

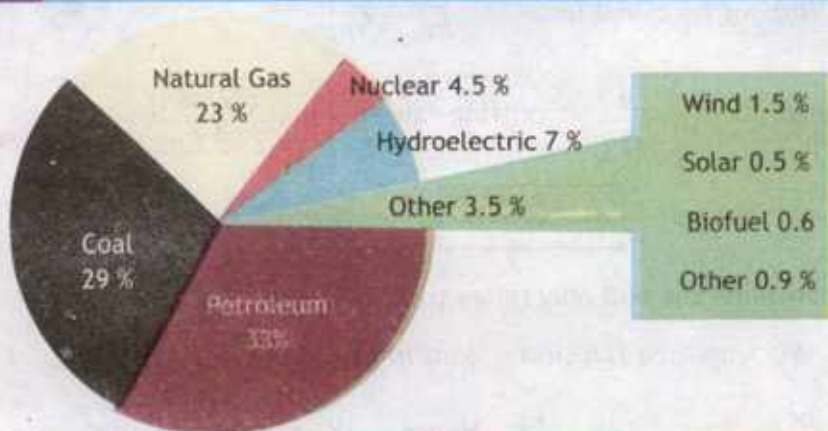
## 6.3 MAJOR ENERGY RESOURCES

The progress in science and technology has propelled society from a time when human strength was the primary source of energy, to a time where various forms of energy are harnessed. However, in every conversion of energy, there is always a loss of useful energy. It is evident that society cannot persistently consume increasing amounts of energy without taking into account the needs of future generations. The forthcoming challenge lies in the development of energy sources and processes that are sustainable. A sustainable resource is one that does not diminish over time and does not harm the delicate biosphere of the Earth, while still meeting the energy requirements of society. On this classification the energy resources are divided into two groups – renewable and nonrenewable.

**Non-renewable energy resource** is an energy resource that is limited and cannot be replaced naturally in short time. Most of the energy we use comes from non-renewable energy resources, for example fossil fuels like coal, natural gas and petroleum.

**Renewable energy resource** is an energy resource that is replaced rapidly by a natural process. Renewable energy resources capture their energy from an on-going natural processes, such as sunshine, wind, flowing water and biological processes. They are part of the planet's physical structure, which means they are constantly being renewed by natural means and cannot simply run out (technology not fuel). Apart from this advantage many renewable energy systems are better for the environment, compared to non-renewable energy sources.

**FIGURE 6.10 ENERGY CONSUMPTION**



Energy conversion involves transforming available energy resources into a useful form. These resources provide the raw materials or sources used to generate energy for various purposes, including electricity generation, transportation, heating, and industrial processes. Nowadays, many energy converters focus on converting energy into electrical form. This process is facilitated by various devices and systems known as energy converters. Achieving a sustainable and reliable energy supply requires us to increase the use of renewable energy sources, enhance energy efficiency, and create new technologies to minimize environmental impacts.



It is important to strike a balance between energy requirements and environmental and social concerns.

The impact on the environment caused by the electricity system is influenced by different factors such as the generation and distribution methods used. In general, the environmental effects can include:

- Emissions of greenhouse gases and other air pollutants, especially when a fuel is burned.
- Use of water resources to produce steam, provide cooling, and serve other functions.
- Discharges of pollution into water bodies, including thermal pollution (water that is hotter than the original temperature of the water body).
- Generation of solid waste, which may include hazardous waste.
- Land use for fuel production, power generation, and transmission and distribution lines.
- Effects on plants, animals, and ecosystems that result from the air, water, waste, and land impacts.

The use of energy resources raises various social concerns that involve impacts on communities, public health, and overall societal well-being. To tackle these social issues, it is important to take a holistic and inclusive approach. This involves involving the community, engaging stakeholders, and carefully considering the potential effects of energy projects. Policymakers, industry stakeholders, and communities need to collaborate in order to create sustainable and socially conscious energy solutions.

TABLE 6.2 ENERGY RESOURCES

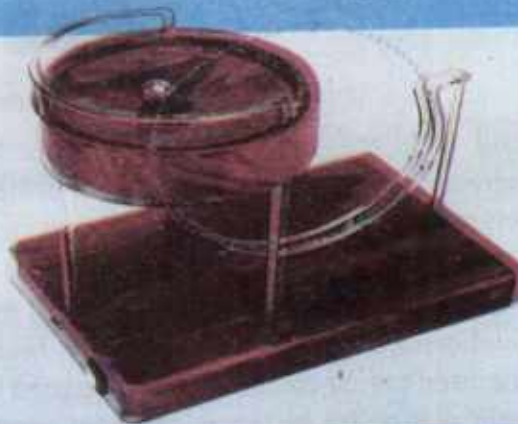
| NONRENEWABLE                                | RENEWABLE                |
|---------------------------------------------|--------------------------|
| Fossil Fuels<br>(Coal, Oil and Natural Gas) | Solar radiation          |
|                                             | Geothermal resources     |
|                                             | Winds                    |
|                                             | Bio-fuels                |
| Nuclear fuel                                | Tides                    |
|                                             | Waves in seas and oceans |
|                                             | Hydroelectric resources  |
|                                             | Waste as fuel            |

### FOR YOUR INFORMATION

**Perpetual motion** is the motion of bodies that continues forever in an unperturbed system.

A perpetual motion machine is a hypothetical machine that can do work infinitely without an external energy source.

This kind of machine is impossible, as it would violate either the first or second law of thermodynamics, or both.



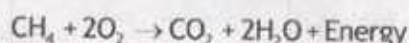


## UNIT 6 WORK AND ENERGY

### 6.3.1 FOSSIL FUELS

Fossil fuels are the remains of million year old plant life (now coal) or aquatic animal life (now gasoline and natural gas). Chemical energy stored in fossil fuels is obtained through a process called combustion. Fossil fuels, which include coal, oil, and natural gas, are rich in hydrocarbons—molecules made up of hydrogen and carbon atoms. When these hydrocarbons burn, they combine with oxygen from the air to create carbon dioxide, water, and energy.

The general chemical equation for the combustion of a hydrocarbon, such as methane ( $\text{CH}_4$ ) found in natural gas, is as follows:

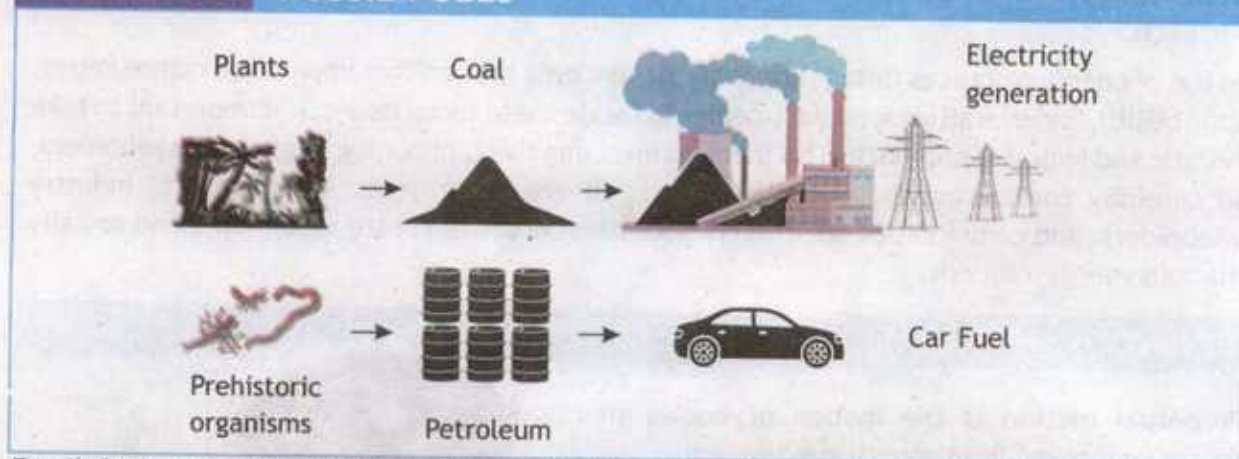


**A. COAL:** Coal, the most abundant fossil fuel globally, possesses an estimated reserve of one million metric tonnes. However, the combustion of coal leads to significant atmospheric pollution.

**B. OIL:** Crude oil undergoes refining processes to yield various energy products, including gasoline, jet fuel, and heating oil. Despite the limited global reserves of oil, it is favored over coal due to its higher energy output for the same quantity.

**C. NATURAL GAS:** Natural gas, often a byproduct of oil extraction, comprises a mixture of gases, primarily methane. One advantage of natural gas is its ease of transportation.

FIGURE 6.11 FOSSIL FUELS



Fossil fuels are extracted from the Earth through various methods. Coal is usually mined, whereas, oil and natural gas is often drilled and extracted from reservoirs. The extracted fossil fuels may undergo refining and processing to separate impurities and obtain usable forms of the fuel.

To extract energy fossil fuel is burned in the presence of oxygen, typically in a combustion chamber or engine. This combustion reaction releases energy in the form of heat. The heat generated during combustion can be used to produce steam, drive turbines, or power engines. In power plants, for instance, the heat produced is often used to generate steam, which in turn drives turbines connected to generators to produce electricity.



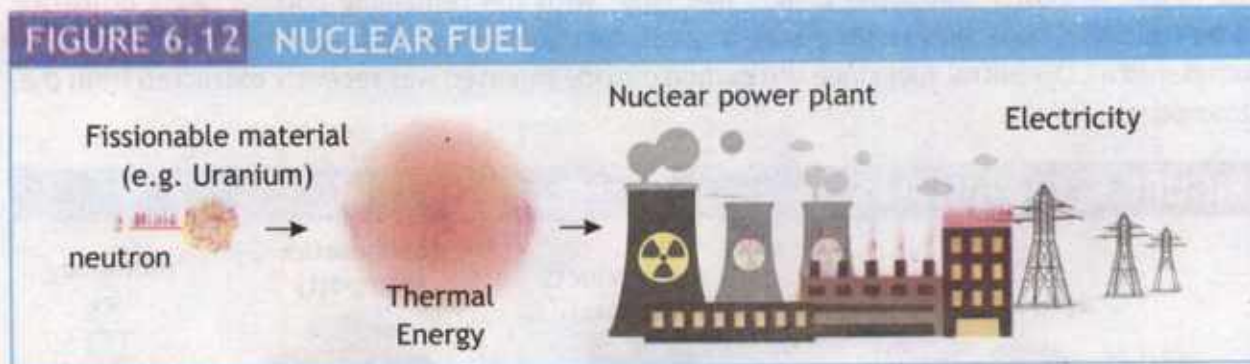
Fossil fuels serve as a significant energy resource due to their inherent value. The process of extracting them is relatively cost-effective. Furthermore, they possess the advantage of being easily stored, transported via pipelines, or shipped to any location across the globe. It is crucial to acknowledge that although fossil fuels play a significant role as an energy source, their combustion leads to the emission of carbon dioxide ( $\text{CO}_2$ ) and other harmful substances into the atmosphere. This contributes to environmental problems like air pollution and climate change. Consequently, there is an increasing focus on the advancement and implementation of cleaner and more sustainable energy alternatives.

### 6.3.2 NUCLEAR FUEL

Nuclear energy is often considered a nonrenewable energy source, even though nuclear energy itself is renewable. The material used in nuclear power plants, such as uranium, is not renewable. Nuclear power plants harness the energy in the nucleus of an atom through nuclear fission, where the atom's nucleus splits. These plants are complex machines that can control nuclear fission to generate electricity. While uranium is found in rocks worldwide, nuclear power plants typically use a rare type called U-235. Plutonium-239 is another material that can be used as nuclear fuel. It is often produced within nuclear reactors by irradiating U-238 which is common.

The process of nuclear fission involves splitting heavy atoms like uranium or plutonium, resulting in a significant amount of thermal energy. This heat is used to boil water, which then generates electricity.

FIGURE 6.12 NUCLEAR FUEL



Nuclear energy is a popular method for generating electricity globally because small amount of nuclear fuel can produce a large amount of energy and it doesn't pollute the air or emit greenhouse gases. These power plants can be constructed in rural or urban areas without harming the environment. Nevertheless, harnessing nuclear energy is challenging. Building and operating nuclear power plants is a complicated process that requires skilled scientists and engineers, which many communities lack.

However, nuclear energy produces radioactive waste, which is highly toxic and can cause severe health issues like burns, cancers, blood diseases, and bone decay.

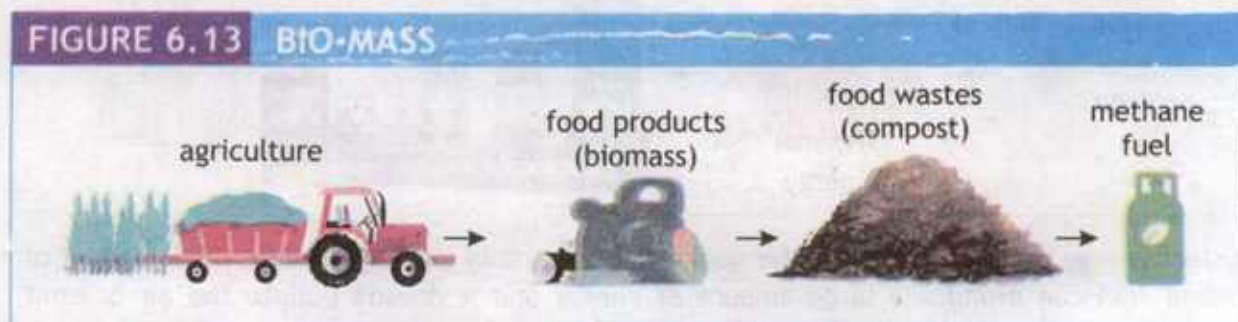
## 6.3.3 BIO-MASS FUEL

Bio-mass, refers to the material that provides bio-energy. The energy contained in biomass comes from the sun, as plants capture sunlight through photosynthesis and convert it into chemical energy, specifically carbohydrates. Only green plants and photosynthetic algae with chlorophyll can utilize solar energy. The most basic way to harness this energy is through consumption. Whenever you eat a fruit, vegetable, or a processed form of either, you are benefiting from the energy stored as biomass.

Bio-mass has many types, this includes logs, branches, wood chips, sawdust, and other by-products from forestry and wood processing. Agricultural residues such as straw, corn stalks, and rice husks can be used as biomass fuel. Certain crops, like switchgrass and miscanthus, are grown specifically for energy production. Livestock waste, such as dung, can be used as a biomass fuel.

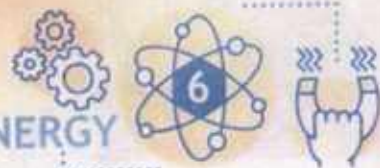
There are many methods currently used around the world to make the best possible use of biomass energy. Biomass can be burned directly to produce heat or used in combustion processes to generate steam, which drives turbines connected to generators for electricity production. It can also be used as biochemical conversion which involves the use of microorganisms or enzymes to break down biomass into biofuels, such as ethanol and biodiesel. Apart from this, processes like pyrolysis and gasification can convert biomass into gases (syngas), bio-oil, or charcoal.

Bacteria decompose decaying plants, resulting in the production of biogas. A tonne of food waste can generate 85 m<sup>3</sup> of biogas, consisting of methane, carbon dioxide, and hydrogen sulfide gas. The biogas is mostly composed of 60% methane, with the remaining portion being primarily carbon dioxide. This biogas serves as a great fuel source for heat and power plants. It is considered a CO<sub>2</sub> neutral fuel since the carbon dioxide released was recently extracted from the atmosphere.



Biogas is renewable energy system ideal for treating liquid manure and industrial wastes, providing nutrient-rich fertilizers from the residues. Implementing biogas systems for farm manure helps decrease nitrate pollution and the risk of water contamination by E-coli bacteria.

However the effectiveness of biogas systems depends on the collaboration between regional farmers and industrial sites to support a centralized plant, which can be challenging to accomplish.

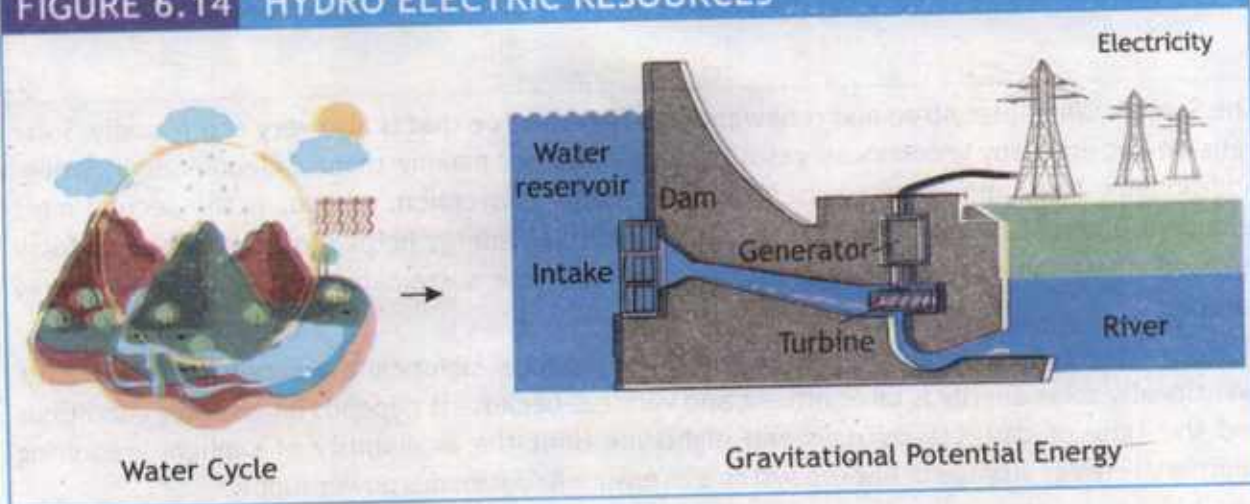


### 6.3.4 HYDRO ELECTRIC RESOURCES

Hydroelectric generation is the process of using the gravitational potential energy of water to generate electric energy. The force of gravity pulls the water down, giving it a lot of kinetic energy. This kinetic energy is then converted into electric energy by large turbines.

Sometimes, these large reservoirs flood a large area of farmland, thereby significantly changing the ecosystem, and we don't know what the consequences will be. In the past, engineers didn't have the technology to economically use smaller reservoirs for generating electricity. But now, with advancements in technology, smaller generation facilities are becoming more popular.

**FIGURE 6.14** HYDRO ELECTRIC RESOURCES



Hydroelectric power is renewable and efficient. Once the facilities are raised and running, they have minimal impact on the environment. However, generating power from water requires fast-flowing water, and it often causes ecological damage when using large facilities.

### 6.3.5 SOLAR RADIATION

The energy from direct sun light can be used to produce electricity. Today, solar cells are used to power everything from calculators and watches to small cities.

Solar radiation is harnessed in two main ways for energy. The first method involves solar photovoltaic cells, also known as solar cells, which directly convert sunlight into electricity. These cells are made of semiconductor materials like silicon, which generate an electric current when exposed to sunlight. Solar panels are created by connecting multiple solar cells together to form a module. These panels can be installed on rooftops, solar farms, or other locations with access to sunlight.

The second method is through solar thermal systems, which utilize the heat from sunlight for various applications such as electricity generation, water heating, and space heating. Concentrated Solar Power (CSP) systems concentrate sunlight onto a small area using mirrors or lenses.

The concentrated sunlight is then used to heat a fluid, like water or a heat transfer fluid, which in turn produces steam. This steam is used to drive a turbine connected to a generator for electricity production.

FIGURE 6.15 SOLAR SYSTEM



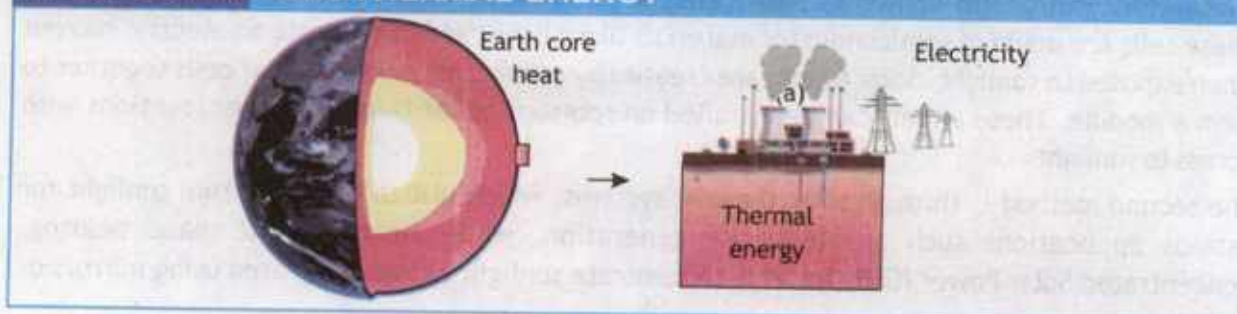
The Sun is a completely free and renewable energy resource that is also very eco-friendly. Solar cells do not emit any greenhouse gases during operation, making them a clean energy option. Additionally, the main material used in solar energy conversion, silicon, is the second most abundant element in the Earth's crust. The use of solar energy helps reduce reliance on fossil fuels, decrease greenhouse gas emissions, and promote sustainable and renewable energy sources.

However, Significant land area is required to produce significant amounts of electricity. Additionally solar energy is intermittent and variable because it depends on weather conditions and the time of day. Cloudy days and nighttime limit the availability of sunlight, requiring additional energy storage or backup systems to ensure a continuous power supply.

### 6.3.6 GEOTHERMAL RESOURCES

Geothermal energy comes from the Earth's core and is formed by the trapped energy from billions of years ago and the heat produced by decaying radioactive elements. It is, in fact, not considered a renewable energy source because the heat is extracted faster than it is replenished. However, due to the immense size of the Earth, it would take thousands of years to deplete this energy source, making it practically renewable.

FIGURE 6.16 GEOTHERMAL ENERGY





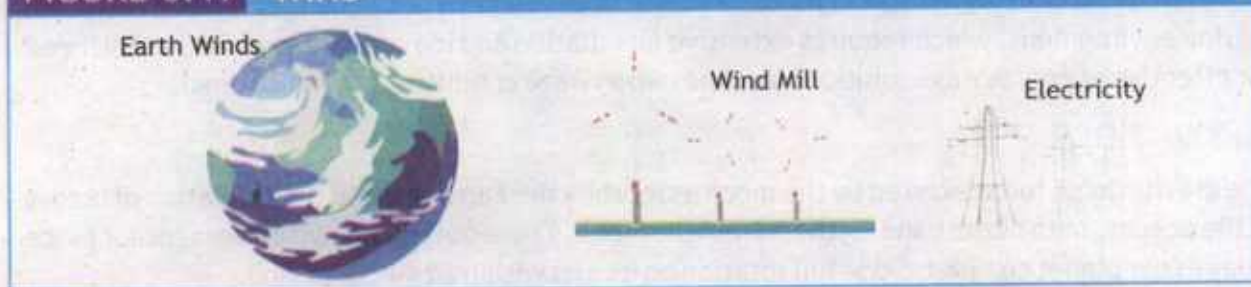
Geothermal energy is abundant and does not produce greenhouse gas emissions. It is a reliable source of power that is not affected by weather conditions. Nonetheless, it is only economically viable in certain locations on Earth, and the discharge of hydrogen sulfide gas can be toxic and even deadly in high concentrations.

### 6.3.7 WIND

The kinetic energy of the wind can be used to turn turbine which in turn produce electricity. Wind turbines are the main technology used to capture wind energy. They have big rotor blades connected to a hub, gearbox, and generator. The blades convert wind's kinetic energy into rotational energy. The design, length, and shape of the blades are important for the turbine's efficiency. Modern turbines usually have three blades that can be adjusted for better energy capture. Control systems are installed in wind turbines to adjust blade pitch or shut down the turbine in strong winds to prevent damage.

The generator converts the rotational energy into electricity, usually alternating current (AC). Wind turbines are often grouped together in wind farms to maximize energy production. These farms are strategically located in areas with consistent and strong winds, like coastal regions, plains, or mountain passes.

FIGURE 6.17 WIND



Generating electricity from wind is eco friendly and renewable energy source with zero greenhouse gas emissions and a low risk of accidents.

However, developing turbines to meet infrastructure needs is expensive. They are only viable in areas with constant and strong winds. Wind farms require a significant amount of open space.

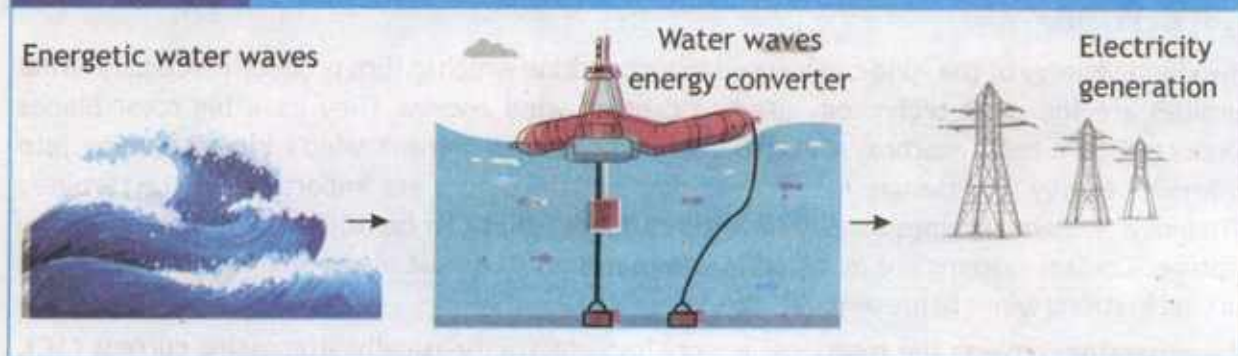
### 6.3.8 WAVES IN THE SEA

Wave energy, also called ocean wave energy, is obtained from the movement of surface waves on the ocean. Wave Energy Converters (WECs) are devices created to capture the kinetic energy of these waves. There are different types of WECs, each with its own design and working principle.

One type is point absorbers, which move up and down with the waves. This vertical motion powers a system that converts the mechanical energy into electricity, such as a hydraulic pump or an electrical generator. Another type is attenuators, which are long floating structures that move with the waves. The relative motion between the segments of the attenuator is used to generate electricity.

Oscillating water columns utilize the rising and falling motion of waves to create air movement in a chamber. This moving air is then used to drive a turbine connected to a generator, producing electricity. In this way, the mechanical motion of the waves is converted into electrical energy.

**FIGURE 6.18 WAVES IN SEA**



Wave energy has the advantage of being more predictable compared to some other renewable sources, as it is influenced by factors like wind patterns and ocean currents. Countries with access to an ocean can potentially harness wave power, which poses minimal threat to the environment.

However, the technology is still in its early stages of development. Challenges include the harsh marine environment, which requires extensive installation and maintenance, as well as the need for effective energy storage solutions for times when wave conditions are not optimal.

### 6.3.9 TIDES

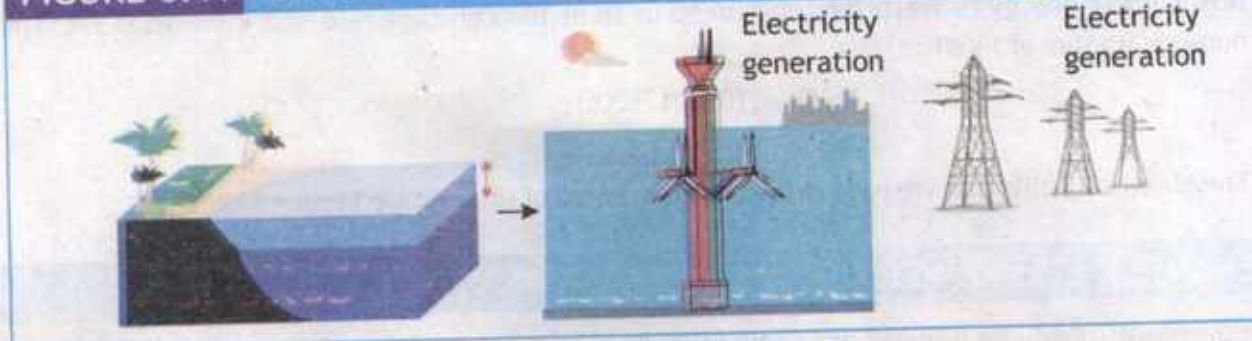
The gravitational force exerted by the moon as it orbits the Earth leads to the formation of bulges in the oceans, both closest and farthest from the moon. These bulges, known as tides, occur twice a day as our planet completes one full rotation on its axis within a 24-hour period.

There are primarily two main approaches to harnessing energy from tides. The first method involves utilizing tidal stream systems, also referred to as tidal current systems, which harness the kinetic energy generated by the movement of water caused by tidal currents. Specifically designed underwater turbines are strategically placed in areas with strong tidal currents to capture the kinetic energy and convert it into electricity. On the other hand, tidal range systems make use of the difference in height between high tide and low tide, known as the tidal range. To generate electricity, a tidal barrage or a dam-like structure is constructed across the entrance of a tidal basin. Sluice gates within the barrage allow water to flow into the basin during high tide and release it during low tide, thereby producing electricity. Another method involves capturing high-tide waters and releasing them through turbines during low tide to generate electrical power from the ocean.

Tidal energy systems, whether based on tidal streams or tidal ranges, are considered renewable sources of energy and possess the advantage of predictability due to the regular and cyclic nature of tides.



FIGURE 6.19 TIDES



Physicists have calculated that the rise and fall of tides dissipate energy at a rate of two to three million megawatts. However, only a small fraction of this energy, approximately 23,000 MW worldwide, or about 1%, is currently recoverable. The deployment of tidal energy technologies is hindered by challenges related to environmental impact and the high costs associated with installation. Furthermore, the viability of tidal facilities is limited to only a few locations across the globe.

## 6.4 POWER

The definition of work makes no reference to the passage of time. But often we need to know how fast is being done or how fast energy is being converted from one form to another. We describe this in terms of power. Power is the time rate at which work is done or the rate at which energy is consumed. Mathematically

$$P = \frac{W}{t} = \frac{E}{t} \quad \text{--- 6.6}$$

Like work power is a scalar quantity. The SI unit of power is watt (W), in honour of James Watt, a Scottish physicist who invented the first steam engine. From equation (6.7), the unit of power is given by

$$1 \text{ watt} = 1 \text{ joule} / 1 \text{ second}$$

$$\text{Or in symbols, } 1 \text{ W} = 1 \text{ Js}^{-1}$$

FIGURE 6.20 POWER RATING ON LIGHTING DEVICES



The power rating (sometimes called the "wattage") of a light bulb tells you how fast it will convert electric energy into heat and light. 100 W filament bulb and 40 W tube light are shown in the figure 6.20.

For practical purpose, a larger unit is often used, the horse power (hp). One horse power (hp) is defined as 550 ft.lb/s which equals 746 W.

$$1 \text{ hp} = 746 \text{ W}$$



## UNIT 6 WORK AND ENERGY

A unit of energy (work) can now be defined in terms of the unit of power. One kilowatt hour (kWh) is the energy converted or consumed in 1h at the constant rate of  $1 \text{ kW} = 1000 \text{ J/s}$ . The numerical value of 1 kWh is,

$$1 \text{ kWh} = (10^3 \text{ W})(3600 \text{ s})$$

$$\text{Or } 1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

The electricity bills that we pay are measured in terms of this unit i.e 1 unit = 1 kWh.

### EXAMPLE 6.5: POWER OF AN ENGINE

How powerful will be a Tesla Car's engine if it does  $3 \times 10^7 \text{ J}$  of work in 1 minute? What will be its power in hp?

#### GIVEN

$$\text{Work 'W'} = 3 \times 10^7 \text{ J}$$

$$\text{Time 't'} = 1 \text{ min} = 60 \text{ s}$$

#### REQUIRED

Power in horsepower 'P' = ?

#### SOLUTION

Power is given by the relation:  $P = \frac{W}{t}$

$$\text{Putting values: } P = \frac{3.69 \times 10^7 \text{ J}}{60 \text{ s}}$$

$$\text{Hence } P = 6.15 \times 10^5 \text{ W} = 615 \text{ kW}$$

$$\text{since, } 1 \text{ hp} = 746 \text{ watt} \quad \text{or} \quad 1 \text{ watt} = \frac{1}{746} \text{ hp}$$

$$\text{or } P = 6.15 \times 10^5 \times \frac{1}{746} \text{ hp}$$

Therefore,

$$P = 825 \text{ hp}$$

Answer



Thus, power of such an engine will be 615 kW or 825 hp.

### 6.5 EFFICIENCY

The principle of conservation of Energy suggests that energy can neither be created nor destroyed. That is the total energy output of a machine must be equal to its energy input.

However, it is found that the energy output is always less than the energy input. This is mainly due to the work that must be done against frictional forces.

A car engine is designed to convert chemical energy stored in the fuel into kinetic energy for the car. A light bulb is designed to convert electric energy into light energy. While the car engine and the light bulb are transforming some of the potential energy into the desired form of energy, part of its energy is 'lost'.



The lost energy is converted into form that does not serve the intended purpose. Often the lost energy is transformed into heat. The efficiency ' $\eta$ ' of a machine or device describes the extent to which it converts input energy or work into useful type of output energy or work.

Efficiency ' $\eta$ ' is the ratio of useful work output ' $W_o$ ' to the total work input ' $W_i$ '.

$$\text{efficiency} = \frac{\text{useful output work}}{\text{input work}} \quad \text{or} \quad \eta = \frac{W_o}{W_i} \quad \text{--- 6.7}$$

In terms of energy equation 6.4 can be written as:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \quad \text{or} \quad \eta = \frac{E_o}{E_i} \quad \text{--- 6.8}$$

Efficiency has no unit as it is the ratio of same quantities and therefore units cancels. The efficiency of an energy transformation is sometimes given in percentage as follows

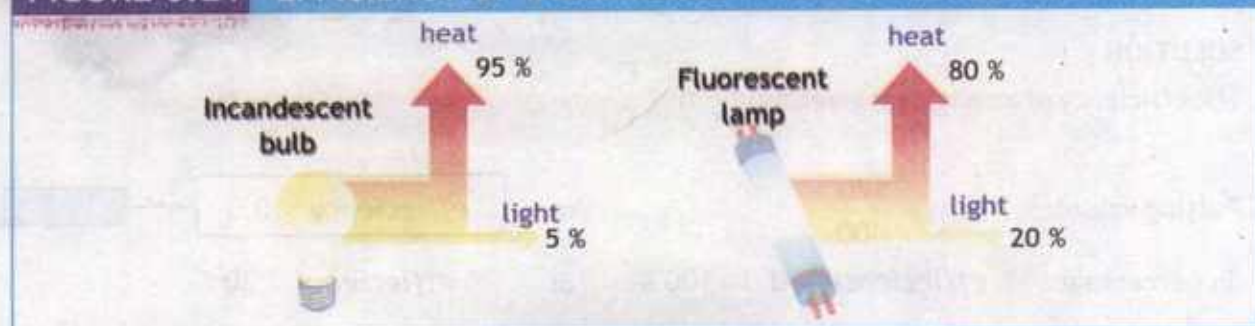
$$\eta = \frac{E_o}{E_i} \times 100\% \quad \text{--- 6.9}$$

The correlation between power and efficiency becomes apparent when considering the output power of an energy conversion process. The output power ' $P_{out}$ ' of a given system is directly proportional to its input power ' $P_{in}$ ' through the efficiency ' $\eta$ ' factor:

$$P_{out} = \eta \times P_{in} \quad \text{--- 6.10}$$

Equation 6.10 clearly demonstrates that the output power is a fraction of the input power, determined by the efficiency of the system. In the event that the system operates at 100% efficiency ( $\eta = 1$ ), the output power will be equivalent to the input power. However, in practical applications, energy is often dissipated as waste heat or in other forms, resulting in efficiencies lower than 100%.

**FIGURE 6.21 EFFICIENCY OF INCANDESCENT BULB AND FLORESCENT LAMP**





## UNIT 6

## WORK AND ENERGY

Efficiency maximization plays a pivotal role in energy systems as it allows for optimal utilization of resources while minimizing energy wastage.

An incandescent light bulb is designed to provide light energy. Unfortunately, it also produces a lot of thermal energy while in use.

In fact, only about 5% of the electrical energy delivered to the bulb transforms to light energy; the rest becomes waste thermal energy. We say that the incandescent light bulb is only 5% efficient. A fluorescent lamp is about 20% efficient of converting electrical energy into light as shown in the figure 6.21. It is not possible to have a machine with 100% efficiency, because friction lowers the efficiency of a machine. Work output is always less than work input, so an actual machine wasting some of input energy as heat (which is not required) cannot be 100% efficient. Typical efficiencies of energy transformation technologies are given in the table 6.3.

**TABLE 6.3 : TYPICAL EFFICIENCIES OF ENERGY TRANSFORMATION TECHNOLOGIES**

| DEVICE                    | EFFICIENCY (%) |
|---------------------------|----------------|
| electric generator        | 98             |
| hydroelectric power plant | 95             |
| large electric motor      | 95             |
| home gas furnace          | 85             |
| wind generator            | 55             |
| fossil fuel power plant   | 40             |
| automobile engine         | 25             |
| fluorescent light         | 20             |
| incandescent light        | 5              |

### EXAMPLE 6.6: EFFICIENCY

A petrol engine in-takes 400 J of fuel energy and does only 120 J of useful work. How efficient is this petrol engine?

#### GIVEN

Input energy = Input work  $E_{in} = 400 \text{ J}$

Output energy = Output Work  $E_{out} = 120 \text{ J}$

#### REQUIRED

Efficiency = ?



#### SOLUTION

The efficiency of an engine is given by:

$$\eta = \frac{E_o}{E_i}$$

Putting values:  $\eta = \frac{120}{400}$

or

$$\text{efficiency} = 0.3$$

Answer

In percentage: % efficiency =  $0.3 \times 100\%$

or

$$\% \text{ efficiency} = 30\%$$



Therefore, such a petrol engine will be 30 % efficient. This means that such an engine will only do about one quarter of useful work of the provided input fuel. Which means that such a petrol engine will be 25 % efficient. It will only do one quarter of useful work of the provided input fuel.

## SUMMARY

**Work** is force multiplied by distance moved in the direction of the force.

**Energy** is the capacity of a body to do work.

**Kinetic Energy** is the energy of an object due to its motion and is given by  $E_k = \frac{1}{2} m v^2$ .

**Potential Energy** is a form of energy that an object possesses due to its position or state.

**Gravitational Potential Energy** is a specific type of potential energy associated with an object's position in a gravitational field. It arises because of the gravitational attraction between the object and the Earth (or another massive celestial body) and is given by  $E_{p,grav} = mgh$ .

**Energy Conversion** refers to the process of changing one form of energy into another.

**Law of Conservation of Energy** is a fundamental principle in physics that states that the total energy of an isolated system remains constant over time. In other words, energy cannot be created or destroyed; it can only change forms.

**Energy Resources** are substances or systems from which we can extract energy for various purposes, such as electricity generation, heating, and powering machinery.

**Non-renewable Energy Resources** are finite sources of energy that cannot be easily replaced on a human timescale. Examples include fossil fuels (coal, oil, natural gas) and nuclear fuels.

**Renewable Energy Resources** are sources of energy that are naturally replenished on a human timescale. They include sunlight, wind, rain, tides, waves, geothermal heat, and biomass.

**Perpetual Motion Machine** is a hypothetical device that can operate indefinitely without an external energy source.

**Fossil Fuels** are hydrocarbons, primarily coal, fuel oil, or natural gas, formed from the remains of dead plants and animals over millions of years.

**Nuclear Fuel** is a material that can be used to generate nuclear energy through nuclear reactions, typically involving the release of energy from the nucleus of an atom.

**Hydroelectric Resources** involve the generation of electricity by harnessing the energy of flowing water, often from rivers or dams.

**Power** is the rate of doing work or rate of conversion of energy.  $P = W/t$ .

**Efficiency** is the ratio of useful energy or work output to the total energy or work input.



## EXERCISE

## MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option.

- The unit of work or energy joule (J) is equal to:  
A. horsepower      B. watt metre      C. watt second      D. newton second
- A car, an elephant and a cricket ball have same kinetic energies. Which of these will have a greater speed?  
A. Car      B. Elephant      C. Cricket ball      D. all have same speed
- A ball weighing 50 N is lifted to a height of 5 metre. The potential energy stored in it is:  
A. 10 J      B. 25 J      C. 45 J      D. 55 J
- What is the power utilized when 100 J of work is done in 5 s.  
A. 10 W      B. 20 W      C. 105 W      D. 500 W
- The SI unit of power is  
A. joule      B. watt      C. horsepower      D. erg
- A 4 kg body is thrown vertically upward from the ground with a velocity of 5 m/s. If friction is neglected its kinetic energy just before hitting the ground is  
A. 25 J      B. 50 J      C. 75 J      D. 100 J
- A ball is thrown downward with an initial velocity, its  
A.  $E_k$  increases &  $E_p$  decreases      B.  $E_k$  decreases &  $E_p$  increases  
C. Both  $E_k$  &  $E_p$  increases      D. Both  $E_k$  &  $E_p$  decreases
- The type of energy derived from heated ground water is:  
A. tidal energy      B. geothermal energy  
C. hydroelectric energy      D. nuclear energy
- A weight lifter of power 1960 watt lifts a load of mass 'M' from the ground to a height of 2 m in 3 second. 'M' is:  
A. 100 kg      B. 200 kg      C. 300 kg      D. 400 kg
- Which one is renewable source of:  
A. Coal      B. Natural gas      C. Sunlight      D. Uranium
- One unit of horsepower is equivalent to:  
A. 756 watt      B. 716 watt      C. 736 watt      D. 746 watt
- A practical engine cannot have an efficiency equal or greater than:  
A. 0      B. 0.5      C. 0.8      D. 1



13. A heavy and a lighter object have same momenta. The object with greater kinetic energy is:  
A. lighter      B. heavy      C. same kinetic energy      D. either a or b
14. A force is acting on body but causes no displacement. The work done on the body is  
A. positive      B. negative      C. zero      D. infinite
15. A box is taken to the second floor of a building by doing some work. This work converts to  
A. kinetic energy      B. potential energy      C. heat energy      D. sound energy

## SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. A car is moving with a constant speed along a straight road. Is there any work done on the car?
2. Does the work done in raising a box up in a building depend upon how fast it is raised up? Through which path? To how much height?
3. Work done on the body either speeds it up, slows it down. Keeping it mind, explain how much work is done by centripetal force on an orbiting satellite?
4. A car has Kinetic energy ' $E_k$ '. By what factor its kinetic energy would change, if its velocity is doubled?
5. A bullet is fired from gun, bullet penetrates into sand wall and it stops. Where does its kinetic energy used?
6. An LED light bulb has efficiency of 80%. Does it violate conservation of energy principle?
7. How does using renewable energy sources contribute to reducing environmental impact compared to non-renewable sources?
8. Will we eventually rely entirely on renewable energy sources? Why or why not?
9. How can increasing the power of a machine impact its energy consumption?
10. A perpetual engine has an efficiency equal to 1. Why it will not work?

## LONG RESPONSE QUESTIONS

QIII. Give an extended response to the following

1. Define work and its unit. Describe the conditions for maximum and minimum work.
2. What is kinetic energy? Derive its expression by using graphical analysis.
3. What is potential energy? What are its different types? Show that gravitational potential energy is equal to the product of mass ' $m$ ', gravitational field strength ' $g$ ' and height ' $h$ '.
4. What is meant by energy conversion and energy conservation.
5. Describe how useful energy may be obtained from natural resources.
6. Differentiate between renewable and non-renewable energy sources with examples. Write down advantages and disadvantages of each in reference to their availability and environmental impact.



7. Describe the processes by which energy is converted from one form to another with reference to fossil fuel energy, hydroelectric generation, solar energy, nuclear energy, geothermal energy, wind energy and biomass energy.
8. Describe the process of electricity generation by drawing a block diagram of the process from fossil fuel input to electricity output.
9. Define power. What is the relation of its SI unit with horse power?
10. What is efficiency. Why is it important for cars or electronic devices to be designed with high efficiency? Why efficiency of machines can never be unity or 100%?
11. Explain by drawing energy flow diagrams through steady state systems such as Filament lamp, a power station, a vehicle traveling at a constant speed on a level road.

## NUMERICAL RESPONSE QUESTIONS

### QIV. Solve the following.

1. Calculate the work done in pushing a box with 150 N through distance of 5m.  
(Ans. 750 J)
2. A boy weighing 75 N jumps up and gains 300 J of gravitational potential energy. Find the height to which the boy will rise.  
(Ans. 4 m)
3. A 5 kg steel ball is dropped from the top of a 12 m high tower. What is kinetic energy of the ball on hitting the ground? With what velocity will it hit the ground? (Neglect air resistance).  
(Ans. 588 J and 15.3 m/s)
4. A 2.0 kg rock is dropped from 20 m tall building. What is the Kinetic and gravitational potential energy when the rock has fallen 15 m.  
(Ans.  $E_k = 294$  J and  $E_{p, grav} = 98$  J)
5. A rocket with a mass of 800 g is launched vertically upward with an initial speed of 30 m/s. (a) Assuming no air resistance, calculate the maximum height the rocket would reach. (b) If, due to air friction, the rocket only rises to 25 m, determine the work done against air resistance.  
(Ans. (a) 45.92 m, (b) -164 J)
6. A 2 hp electric motor gives energy to a system that lifts a load of 100 kg to height of 10 m in 1.5 s. Calculate (a) Input (work done by motor on system) (b) Output (load lifted by system) and (c) Efficiency of the system.  
(Ans. (a) 2238 J, (b) 980 J and (c) 22.8 %)
7. What horsepower (hp) is required to pump up 2500 kg of water to 100 m height in 5 minutes?  
(Ans. 95 hp)

# DENSITY AND TEMPERATURE

UNIT  
7

What is the highest recorded temperature on earth??

## Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-C-01] Define and calculate density.
- [SLO: P-09-C-02] Justify and illustrate how to determine the density of a substance.
- [SLO: P-09-C-03] Describe, qualitatively, the particle structure of solids, liquids and gasses.
- [SLO: P-09-C-04] Describe plasma as a fourth state of matter.
- [SLO: P-09-C-05] Describe the relationship between the motion of particles and temperature.
- State that an increase in the temperature of an object increases its internal energy.
- [SLO: P-09-C-07] Explain, with examples, how a physical property which varies with temperature may be used for the measurement of temperature.
- [SLO: P-09-C-08] Justify the need for fixed points in the calibration of thermometers.
- [SLO: P-09-C-09] Illustrate what is meant by the sensitivity, range and linearity of thermometers.
- [SLO: P-09-C-10] Differentiate between the structures and function of liquid-in-glass and of thermocouple thermometers.
- [SLO: P-09-C-11] Analyze how the structure of a liquid-in-glass thermometer affects its sensitivity, range and linearity.



## UNIT 7 DENSITY AND TEMPERATURE

### 7.1 DENSITY

Density of a material tells us how much matter a substance has in its unit volume. The substance, which has more closely packed atoms, has more matter in a fix volume. Therefore, it is denser substance. Solids like metals; rocks etc. are denser materials because they have closely packed atoms in the given volume. Substances in which atoms are far from each other, they have small amount of matter in a fix volume, so they are less dense. It is the reason why liquids and gases have less density than solids. Density of solids is greater than liquids and density of liquids is greater than gases.

#### FIGURE 7.1 STATES OF MATTER

Solids have more atoms per unit volume than liquids and gases, so solids are denser than liquids and gases



Solids



Liquids



Gases

We define density of a material as:

“Mass per unit volume of the substance is called its density”.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Its symbol is so:  $\rho = \frac{m}{V}$  — 7.1

ts SI unit is kilogram per cubic metre ( $\text{kg/m}^3$ ). Smaller unit to measure density is gram per cubic centimetre ( $\text{g/cm}^3$ ). Density of liquids is usually measured in gram per millilitre ( $\text{g/mL}$ ). It is a scalar quantity.

Density of small amount of a substance is the same as the density of its bulk because density is calculated by the amount of matter in its unit volume. Density of a material changes with the temperature. Can you explain why?

DO YOU KNOW?

Osmium metal is the most dense material at room temperature and pressure. Its density is  $22.59 \text{ g/cm}^3$ . It is harder than diamond.



#### CAN YOU TELL?

Why are liquids denser than gases?

#### FOR YOUR INFORMATION

$$1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$$

To convert  $\text{g/cm}^3$  into  $\text{kg/m}^3$ , multiply  $\text{g/cm}^3$  by 1000. For example, the density of petrol,  $0.9 \text{ g/cm}^3$ , is multiplied by 1000 to write in units of  $\text{kg/m}^3$  as  $900 \text{ kg/m}^3$ .



| TABLE 7.1 DENSITIES |                              |
|---------------------|------------------------------|
| Material            | Density (kg/m <sup>3</sup> ) |
| Iron                | 7900                         |
| Gold                | 19300                        |
| Ice                 | 920                          |
| Plythene            | 900                          |
| Petrol              | 800                          |
| Pure water          | 1000                         |
| Mercury             | 13600                        |
| Air                 | 1.3                          |
| Carbon dioxide      | 2.0                          |



## CAN YOU TELL?

Write the followings in increasing order of densities:

Hydrogen, milk, mercury, gold

## EXAMPLE 7.1: DENSITY OF REGULAR SHAPE

You find a material in the shape of cube of side length 5 centimetre. Mass of this cube is 500 grams. Find the density of this material?

**Given:** Mass of the material = 500 g  
Side length of the cube of the given material = 5 cm

**Required:** Density of the material  $\rho = ?$

**Solution:** Volume of a cubic shape object is given by:  $\text{Volume} = (\text{side length})^3$

Putting values  $\text{Volume} = (5 \text{ cm})^3 = 125 \text{ cm}^3$

Now, we will find density of cube shaped object is:

$$\text{Density of cube shaped object} = \frac{\text{Mass of cube}}{\text{Volume of cube}}$$

Putting values  $\rho = \frac{500 \text{ g}}{125 \text{ cm}^3}$

Therefore,  $\rho = 4 \text{ g/cm}^3$



## 7.2 MEASURING DENSITIES OF DIFFERENT SUBSTANCES

To measure the densities of liquids, solids (regular shaped or irregular shape), we will follow some steps in each case, which we will explain below:

### Density of Liquids

To measure density of liquids, we need a graduated measuring cylinder to measure volume of liquid, a balance to measure mass of liquids. We will measure density of liquid using following steps:

1. Place the empty measuring cylinder on balance and measure its mass.
2. Add liquid in the measuring cylinder and measure its volume.
3. Subtract mass of empty cylinder from the mass of cylinder and liquid (measured in step-2).  
*Mass of liquid = Mass of measuring cylinder and liquid – Mass of empty cylinder*
4. Measure volume of liquid from the measuring cylinder.
5. To calculate the density of liquid, divide mass of liquid by its volume.

$$\text{Density of liquid} = \frac{\text{Mass of liquid}}{\text{Volume of liquid}}$$

7.2

FIGURE 7.2 FINDING VOLUME OF LIQUID



Step 1: Finding mass of empty measuring cylinder



Step 1: Finding mass of measuring cylinder and added liquid

Let us calculate density of liquid using this method



## EXAMPLE 7.2: DENSITY OF LIQUID

Mass of empty measuring cylinder is 145 g. We add a 60 mL liquid in it. Now, its mass becomes 205 g. Find density of the liquid?

**Given:** Mass of empty cylinder = 145 g

Mass of measuring cylinder and added liquid = 205 g

Volume of liquid = 60 mL

**Required:** Density of the liquid  $\rho = ?$

**Solution:** Mass of liquid is calculated

*Mass of liquid = Mass of measuring cylinder and liquid – Mass of empty cylinder*

Putting values *Mass of liquid = 205 g – 145 g*

Mass of liquid = 60 g

Density of liquid is calculated by:  $\rho = \frac{\text{Mass of liquid}}{\text{Volume of liquid}}$

Putting values  $\rho = \frac{60 \text{ g}}{60 \text{ mL}}$

Therefore,  $\rho = 1 \text{ g/mL}$

Density of liquid is 1 gram per milliliter. As this is the density of water (at 4°C). So, our liquid in the measuring cylinder is water.

### 7.2.1 DENSITY OF REGULARLY SHAPED SOLIDS

To find density of regularly shaped solids (like solid cubes, solid cuboids, solid sphere etc.), we will follow these steps:

1. Find mass of the solid regular shaped object using balance.
2. Calculate the volume of object using formula according to shape of the object.

For example, Volume of cuboid = Length  $\times$  Width  $\times$  Height

Volume of cube = (side length)<sup>3</sup>

$$\text{Volume of Sphere} = \frac{4}{3} \pi r^3$$

3. Finally calculate its density by using the formula:

$$\text{Density of Solid} = \frac{\text{Mass of Solid}}{\text{Volume of Solid}}$$

7.3

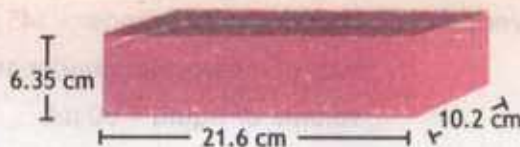


## UNIT 7 DENSITY AND TEMPERATURE

### EXAMPLE 7.3: DENSITY OF BRICK

Find the density of a solid brick of mass 3.30 kg as shown in the figure.

**Given:** Mass of brick = 3.30 kg  
 Length of brick = 21.6 cm = 0.216 m  
 Width of brick = 10.2 cm = 0.102 m  
 Height of brick = 6.35 cm = 0.0635 m



**Required:** Density of the solid object  $\rho = ?$

**Solution:** First, we calculate the volume of regular brick by:

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Height}$$

**Putting values:**

$$\text{Volume} = 0.216 \text{ m} \times 0.102 \text{ m} \times 0.0635 \text{ m} = 0.00140 \text{ m}^3$$

Now, we will find density of the brick using formula:

$$\text{Density of brick} = \frac{\text{Mass of brick}}{\text{Volume of brick}}$$

Putting values

$$\rho = \frac{3.3 \text{ kg}}{0.00140 \text{ m}^3}$$

Therefore,

$$\rho = 2358.773 \text{ kg/m}^3 = 2360 \text{ kg/m}^3$$

### 7.2.2 DENSITY OF IRREGULAR SHAPED OBJECT (DISPLACEMENT METHOD)

We can find the density of irregular shaped solid objects like stones which can sink in the water. We need graduated measuring cylinder to measure volume and balance to measure mass of object. We will follow these steps to find its density:

1. Find the mass of the irregular shaped stone
2. Add some water in measuring cylinder and measure its initial volume ( $V_i$ ).
3. Tie thread with the irregular shaped object e.g. stone and lower it in the measuring cylinder.
4. Water will rise (i.e. displace) in the measuring cylinder and measure final volume ( $V_f$ ). This final volume reading is the sum of volume of water and volume of object.
5. Subtract initial volume ( $V_i$ ) from final volume ( $V_f$ ) to get volume of object.

$$\text{Volume of object} = V_f - V_i$$

6. To find density of objects divide mass of object with its volume.

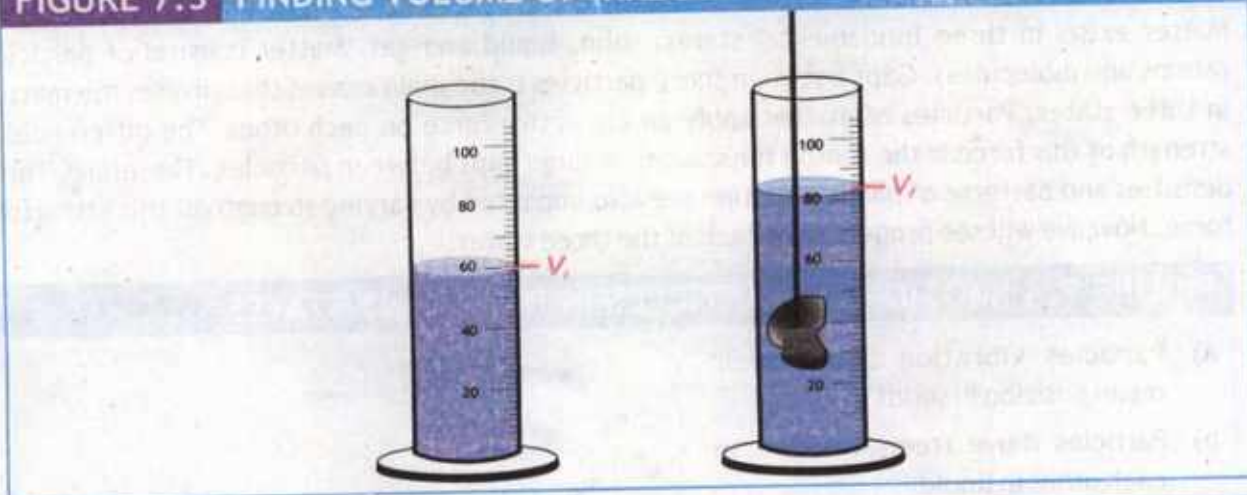
$$\text{Density of Solid} = \frac{\text{Mass of Solid}}{\text{Volume of Solid}}$$

7.4

We can find this method to find volume and density of any insoluble irregular shaped object.



**FIGURE 7.3 FINDING VOLUME OF IRREGULAR SHAPED STONE**



## EXAMPLE 7.4: VOLUME AND DENSITY OF IRREGULAR SHAPE

Mass of a rock is 80.52 grams. It was immersed in a measuring cylinder containing water. From the figure, find the initial and final volumes of water. Use this data to find volume of water and density.

**Solution:**

**Given:** Mass of rock = 80.52 g  
Initial volume of water = 18 mL  
Final volume of water = 46 mL

**Required:**

Volume of object = final volume - Initial volume  
Volume of object = 46 mL - 18 mL  
= 28 mL = 28 cm<sup>3</sup>

Density of irregular shaped stone is:

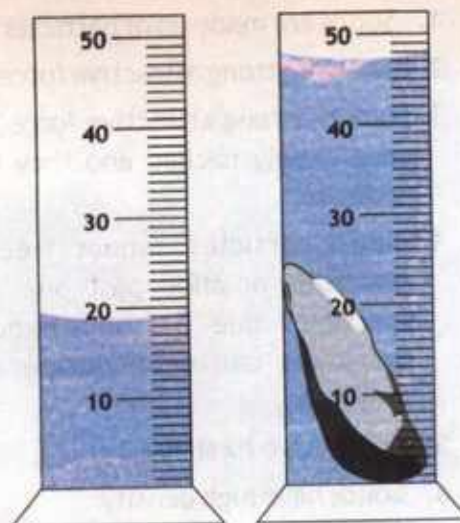
$$\text{Density of object} = \frac{\text{Mass of object}}{\text{Volume of object}}$$

Putting values

$$\rho = \frac{80.52 \text{ g}}{25 \text{ cm}^3}$$

Therefore,

$$\rho = 3.22 \text{ g/cm}^3$$



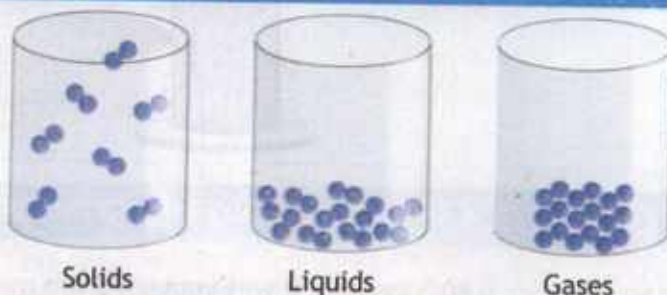


### 7.3 STATES OF MATTER

Matter exists in three fundamental states; solid, liquid and gas. Matter consists of particles (atoms and molecules). Gaps between these particles is the main reason that divides the matter in three states. Particles of matter apply an attractive force on each other. The difference in strength of this force is the reason for smaller or large gaps between particles. Therefore, Their densities and patterns of particle motion are also impacted by varying strength of this attractive force. Now, we will see properties of each of the three states:

**FIGURE 7.4 MOTION OF PARTICLES IN DIFFERENT STATES**

- Particles vibration about their mean position in solids
- Particles move freely relative to each other in liquid
- Particles move freely and quickly in gases



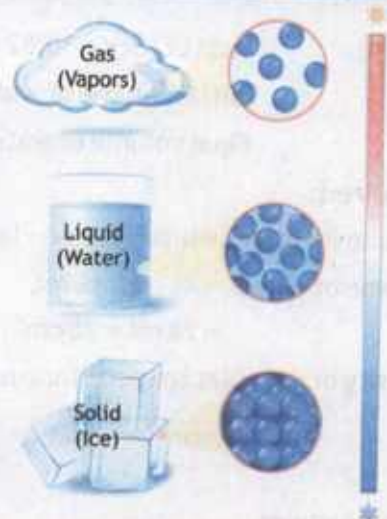
#### 7.3.1 SOLIDS:

- Solids are made up of particles (atoms or molecules).
- There is strong attractive force between particles.
- Due to strong attractive force, particles of solids are closely packed and they have fixed lattice pattern.
- Solid particles cannot freely move like gas particles or slide past one another like liquid particles due to their fixed location. Solids' particles can only vibrate about their mean positions.
- Solids have fix shape.
- Solids have high density.

#### LIQUIDS:

- Liquids are also made up of particles (molecules).
- The attractive force between particles is stronger than that of gases but weaker than that of solids.
- The distance between particles in liquids is greater than that in solids due to an intermediate attractive force, yet they are still close together.

**FIGURE 7.5 PARTICLES**



Different states of matter and arrangement of particles in each state



4. Liquid particles flow and glide over each other. Liquid particles keep changing their position.
5. Due to flowing particles, a liquid has no fix shape and can adopt the shape of the container.
6. A liquid has intermediate density (smaller than a solid and higher than a gas).

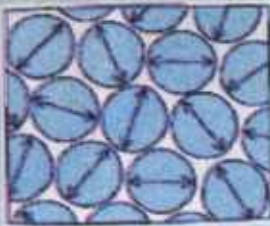
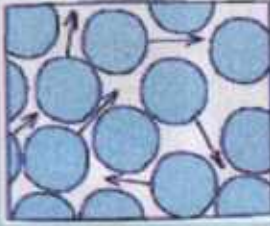
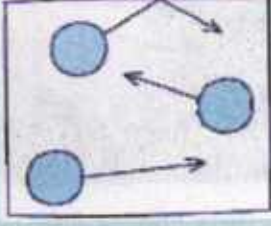
## GASES:

1. Gas is also composed of particles (atoms and molecules).
2. There is negligibly weak attractive force between gas particles.
3. Due to weak attractive force, distance between particles is larger as compared to the size of the particles.
4. Particles are in constant random motion and they constantly colliding with each other and with the walls of the container.
5. Forces between molecules are negligible, except during collisions.
6. Gas has no fix shape and volume. Gas spread out in the container and fill it, therefore its volume is equal to the volume of the container.
7. Gases are less dense than liquids and solids.

### FOR YOUR INFORMATION

Particles in liquids move freely but stay at the bottom of the container due to a relatively strong attractive force, while in gases, particles spread, fill the container and move freely in it.

TABLE 7.2 STATES OF MATTER

| State                    | Solid                                                                               | Liquid                                                                               | Gas                                                                                   |
|--------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Density                  | High                                                                                | Medium                                                                               | Low                                                                                   |
| Arrangement of particles | Regular pattern                                                                     | Randomly arranged                                                                    | Randomly arranged                                                                     |
| Movement of particles    | Vibrate around a fixed position                                                     | Move around each other                                                               | Move quickly in all directions                                                        |
| Energy of particles      | Low energy                                                                          | Greater energy                                                                       | Highest energy                                                                        |
| 2D diagram               |  |  |  |

**POINT TO PONDER**


Because liquids and gases do not maintain a fixed shape, they both have the ability to flow. Thus, they are collectively referred to as fluids.

## 7.4 PLASMA AS A FOURTH STATE OF MATTER

Plasma consists of positive ions, free electrons (negatively charged particles) and neutral atoms in gaseous state. Usually, plasma exists at very high temperature or at high pressure or at both. By using a high electric and magnetic field, a substance can also be transformed into plasma.

There is lot of plasma in the universe. Plasma exists in the Sun; stars glow because of plasma; nebulas and auroras at the south and north poles are due to plasma; neon light glows because of plasma; lightening in the sky forms plasma; etc. Plasma is gas that hot, bright and highly ionized. These characteristics together makes it different from the gas. 99% of visible universe is made up of plasma. That is why plasma is often called "the fourth state of matter," along with solid, liquid, and gas.

When a gas heated continuously K.E of gas molecules also continuously increases. Due to it, attractive molecules forces keep on decreasing as molecules go away from each other. The molecules and atoms start colliding with each other powerfully. Due to it, electrons of the atoms are removed and atoms become positive ion. This ionic state of matter is called plasma. It can highly conduct current because it has free electrons and moving ions.

**FIGURE 7.6** EXAMPLES OF PLASMA FROM DAILY LIFE



Neon Plasma Tube Light



Welding Arc Plasma



Plasma Lamps



FIGURE 7.7 EXAMPLES OF PLASMA IN NATURE



The Sun



Nebula



Aurora

### FOR YOUR INFORMATION

**AURORAS:** It is a solar phenomenon where coloured lights appear in the sky as a result of charged particles from the Sun striking the upper atmosphere. It is also called polar lights.

**NEBULAE:** It is a massive cloud of dust and gas that fills the space between stars. It is a Latin word, meaning "mist, fog etc". Nebulae are made up of dust, fundamental elements such as hydrogen and other ionized gases (i.e. plasma). Hot stars inside of the nebula heats these elements which emit radiation of reds, blues and greens.

## 7.5 RELATIONSHIP BETWEEN THE MOTION OF PARTICLES AND TEMPERATURE

Even though the water molecules in a pot are constantly moving, the movement is not powerful enough for us to notice it with our naked eyes. However, we observe water currents, or water molecules in motion at a higher temperature, when we place this pot on a stove that is burning. There is certain relationship between motion of molecules of a material and its temperature. In this section, we will understand this relationship.

When a material is heated, one of the two things may happen: (1) Strength of attractive force between particles can decrease and bonds between particles may break (as it happens during melting and boiling processes of a material) (2) it can speed up the particles and hence increase K.E. of the particles.

"The temperature of a substance is the measure of its hotness or coldness, and the temperature of a substance is directly proportional to the average K.E. of its particles."

When we heat a substance (at room temperature), the speed and kinetic energy of its particles increase. That is why the temperature of the substance will also increase. Conversely, when we remove heat from a substance (for example, by placing hot water on ice or in a refrigerator), the speed and kinetic energy of the particles will become slower and slower. Therefore, the temperature of the substance will also decrease.

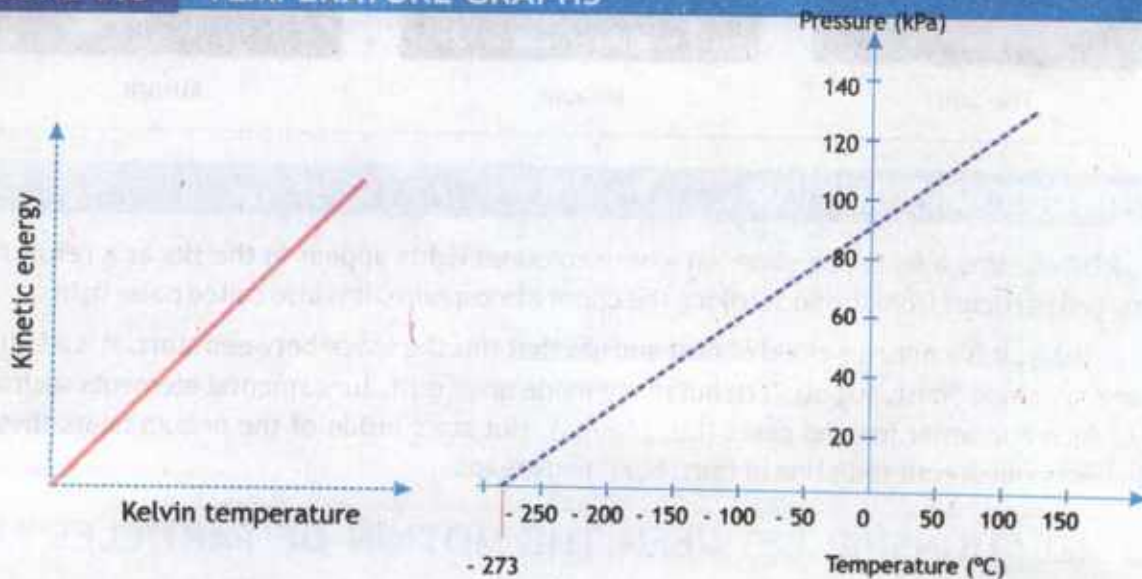


## UNIT 7 DENSITY AND TEMPERATURE

If we keep on removing the heat energy from a substance, its particles will keep on slowing down and hence keep on losing kinetic energy. By doing so, a stage will come when molecules will no longer be moving and they have least or no kinetic energy. Particles cannot collide with each other or with the container, therefore they cannot exert pressure ( $P=0$  Pa). At this point, temperature of the substance is called absolute zero.

"Absolute zero is the lowest possible temperature of a substance at which its particles have least kinetic energy".

FIGURE 7.8 TEMPERATURE GRAPHS



(a) Graph between temperature and kinetic energy of particles

(b) Graph between temperature and pressure of a substance showing absolute zero

Its value is zero kelvin (0K) while on the Celsius scale, it is  $-273.15^{\circ}\text{C}$ . At absolute zero, there is no heat energy available to move the particles of the substance.

### 7.6 INTERNAL ENERGY AND TEMPERATURE OF A SUBSTANCE

Internal energy of a substance is the total energy possessed by the particles of the substance. Internal energy is the total kinetic and potential energy of the particles of a substance. Potential energy of the particles of a substance is due to attractive force between them. These particles can have three forms of kinetic energies i.e. translational K.E., rotational K.E. and vibrational K.E. In case of ideal gas, it has only translational kinetic energy of particles. Therefore, its internal energy is only due to kinetic energy of particles.

In the previous topic, we have studied that temperature is directly proportional to average kinetic energy of the particles of a substance. When we heat a substance, it speeds up the particles and increases the kinetic energy of its particles. Hence, we can say that internal energy of the substance also increases. By increasing the temperature of a substance, its internal energy also increases.



A change in internal energy gives important information about the substance. For example, an increase in internal energy indicates an increase in temperature of the substance, which can be the result of energy given to particles by adding heat or by some other method. Can you name any method that can increase the internal energy of a substance without adding heat to it?

## 7.8 VARIATION IN PHYSICAL PROPERTIES AS A TOOL FOR MEASURING TEMPERATURE OF A SUBSTANCE

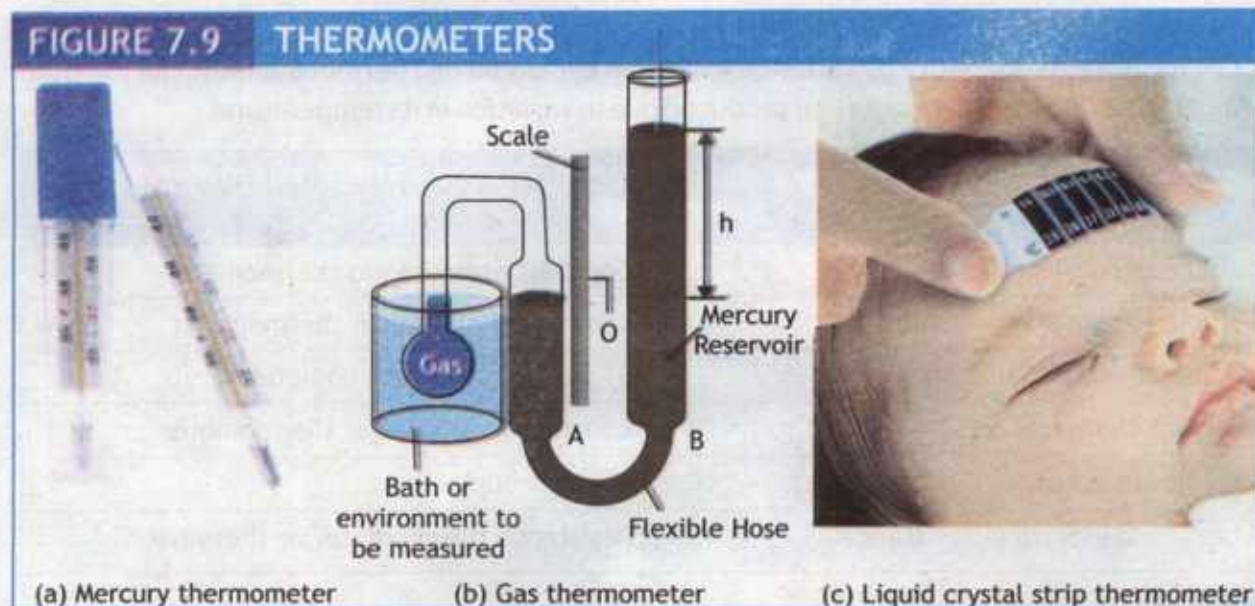
Now we know that when the temperature of a body increases, it increases the kinetic energy of its particles. These fast-moving particles can cause variations in different physical properties (volume, pressure, change in colour, electrical resistance etc.) in a predictable way. Variations in these physical properties may be used to measure the temperature of a body. These physical properties on the basis of which a thermometer works is called its thermometric property. Let us explain the concept in more detail.

### 7.8.1 EXPANSION OF LIQUIDS:

Most liquids expand upon heating. Liquids that expand on heating uniformly can be used as thermometric materials. We use this property for liquids in glass thermometers, which use mercury or alcohol as thermometric materials. When this thermometer is touched by a hot body, it absorbs heat from the body and causes the mercury to expand. This uniform expansion of mercury varies linearly with temperature when absorbing heat. The position of the mercury in the thermometer gives a reading of the temperature on the thermometer scale as in figure 7.9 (a).

### 7.8.2 VARIATION OF VOLUME AND PRESSURE:

When a gas is heated, its volume as well as pressure may change. These variations in volume and pressure are used in gas thermometers to measure temperature. There are two types of gas thermometers, constant pressure gas thermometer and constant volume gas thermometer.





## UNIT 7 DENSITY AND TEMPERATURE

A constant volume gas thermometer, as shown in figure 7.9 (b) uses the principle that the pressure of a gas is directly proportional to the temperature, while the volume of the gas is kept constant (Gay-Lussac's law). We touch the thermometer bulb with the body whose temperature is to be measured. When the temperature of the thermometer bulb increases, the K.E. of gas particles increases.

They collide with each other and the walls of the container more vigorously. This causes an increase in pressure. This variation in pressure is used to measure temperature. A constant-pressure gas thermometer uses the principle that the volume of a gas is inversely proportional to the temperature, while the pressure of the gas is kept constant (Charles's law). In this thermometer, the gas in its bulb expands and pushes a piston according to the increase in volume of the gas. This change in volume of the gas is used to measure its temperature.

### 7.8.3 VARIATION IN COLOUR OF CRYSTALS:

Liquid crystals are those materials that change colour with a change in temperature. Liquid crystals are packed inside a plastic strip. Liquid crystals are substances that change colour with a change in temperature. In these thermometers, a liquid crystal material is sealed in a plastic strip or patch. We touch it with the body whose temperature is to be measured. When its temperature changes, it also changes colour. By matching the colour to a temperature scale, we can determine the temperature of a body. These thermometers are often used as fever thermometers and for aquariums and baby bottles.

There are also other thermometers for example resistance thermometers, bimetallic thermometers, thermocouple etc.

### 7.8.4 RESISTANCE THERMOMETERS OR THERMISTORS

It can measure temperature due to change in its resistance (change in opposition to flow of current through it) due to variation of its temperature.

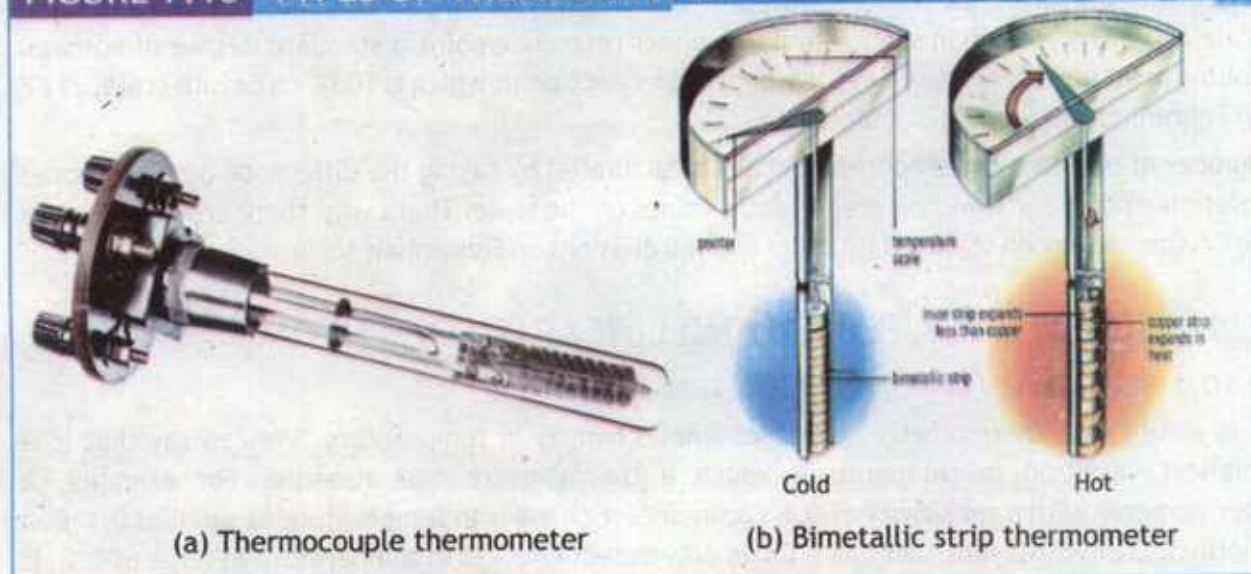
### 7.8.5 BIMETALLIC STRIP THERMOMETERS

It can measure temperature by variation in volume expansion of **Thermocouple**: It can measure temperature due to change in its emf produced due to variation in its temperature:

| TABLE 7.3 DIFFERENT TYPES OF THERMOMETRE AND THEIR THERMOMETIC PROPERTIES |                                      |
|---------------------------------------------------------------------------|--------------------------------------|
| Volume expansion of a gas                                                 | Constant pressure gas thermometer    |
| Volume expansion of a liquid                                              | Laboratory or clinical thermometer   |
| Volume expansion of a solid                                               | Bi-metallic strip thermometer        |
| Pressure change of a fixed mass of gas                                    | Constant - volume gas thermometer    |
| Changes in e.m.f                                                          | Thermocouple                         |
| Changes in electrical resistance                                          | Resistance thermometer or thermistor |



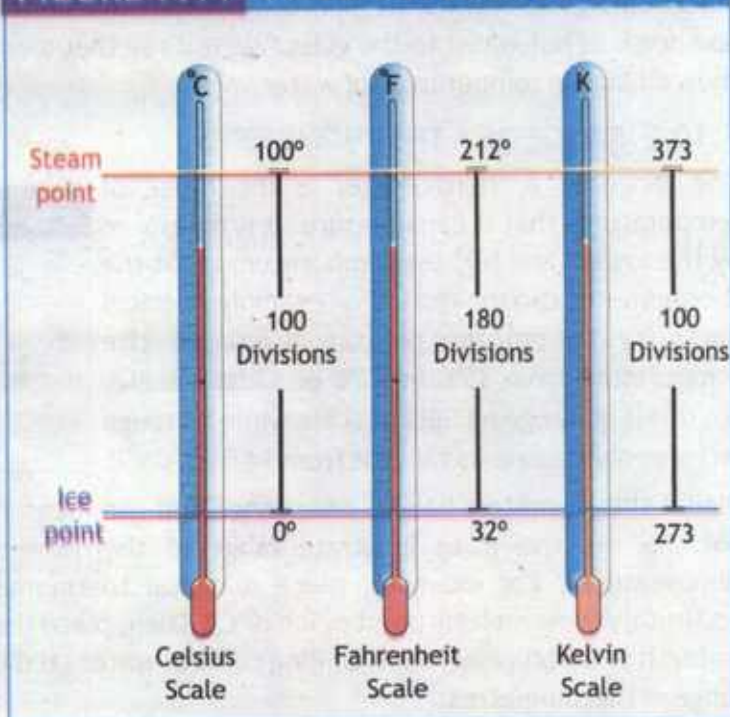
FIGURE 7.10 TYPES OF THERMOMETERS



## 7.9 FIXED POINTS IN CALIBRATION OF THERMOMETRE

When a thermometer is used to determine the temperature of a body, we measure its reading from the calibrated scale made on it. Without a temperature scale, a thermometer is valueless. We can measure the temperature accurately from thermometre if it is properly calibrated. To make a proper scale on thermometre, we need two fixed points. These two fixed points should be accessible and reproducible. These two fixed points are also called the reference points; lower reference points and upper reference points. Gap between these two points is divided into equal divisions. So, we cannot measure temperature accurately without deciding about these fixed points.

FIGURE 7.11 FIXED REFERENCE POINTS



A fixed point is a standard degree of hotness or coldness. In general, we have three scales; Celsius scale, Fahrenheit scale and Kelvin scale.



For these scales, lower reference point is a standard degree of coldness. Melting point of ice is taken as lower reference points for these scales which is  $0^{\circ}\text{C}$  on Celsius scale,  $32^{\circ}\text{F}$  on Fahrenheit scale and  $273\text{ K}$  for kelvin scale. Similarly, upper reference point is standard degree of hotness. Boiling point of water is taken as their upper reference point which is  $100^{\circ}\text{C}$  on Celsius scale,  $212^{\circ}\text{F}$  on Fahrenheit scale and  $373\text{ K}$  for Kelvin scale.

Number of divisions on temperature scale is calculated by taking the difference between upper reference point and lower reference point values on the scale. That's why, there are 100 divisions on Celsius and Kelvin scales while there are 180 divisions on Fahrenheit scale.

## 7.10 SENSITIVITY, RANGE AND LINEARITY OF THERMOMETRES

### 7.10.1 SENSITIVITY OF A THERMOMETER:

It is ability of a thermometre to detect small changes in temperature. We can say that it is smallest variation in temperature which a thermometre can measure. For example, a thermometer with a sensitivity of  $0.1^{\circ}\text{C}$  can detect changes in temperature as small as  $0.1^{\circ}\text{C}$ . A thermometer with a sensitivity of  $1^{\circ}\text{C}$  can only detect changes in temperature as large as  $1^{\circ}\text{C}$ . It cannot measure change in temperature less than  $1^{\circ}\text{C}$ . We can say that sensitivity is analogous to least count of a measuring instrument.

Mercury thermometre is a sensitive thermometre. To illustrate sensitivity of a thermometre, place it in a glass of water at room temperature and let it to set at room temperature. Then, add a few drops of hot water to the glass. We will see that mercury in thermometre will rise quickly to show change in temperature of water.

### 7.10.2 RANGE OF A THERMOMETER:

The range of a thermometer is the range of temperatures that it can measure. It is measured by the lowest and highest temperatures that the thermometer can measure. For example, clinical mercury thermometer can measure the temperature from  $35^{\circ}\text{C}$  to  $42^{\circ}\text{C}$  on Celsius scale. So, this is its range on Celsius scale while its range on Fahrenheit scale its range is from  $94^{\circ}\text{F}$  to  $108^{\circ}\text{F}$ .

FIGURE 7.12 RANGE



Digital thermometers have a wide range and can measure temperatures from very cold to very hot. So, we use it to illustrate range of thermometre by measuring lowest and highest temperatures. For example, place a digital thermometer in a glass containing ice. It will accurately show melting point of ice ( $0^{\circ}\text{C}$ ). Then, place the digital thermometer in a pot of boiling water. It will accurately show boiling point of water ( $100^{\circ}\text{C}$ ). This method can be used to measure range of thermometres.

### 7.10.3 LINEARITY OF A THERMOMETER:

Linearity tells us how equally and uniformly a thermometer shows the temperature variations. Thermometres scales have equally spaced marks on its scale.



If temperature changes and thermometre shows an increase of some divisions then it should same increase in divisions for same change in temperature at higher temperatures. For example, a linear thermometer will measure an increase in temperature from  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$  with the same accuracy as an increase of temperature from  $50^{\circ}\text{C}$  temperature of  $100^{\circ}\text{C}$ .

Bimetallic thermometers are linear thermometers and measure temperature equally accurately across their range. To illustrate this, place a bimetallic thermometer in a glass of water at room temperature. Then, gradually heat the water. The bimetallic thermometer will gradually respond to the change in temperature and the pointer on the thermometer will move.

## 7.11 STRUCTURES AND FUNCTION OF LIQUID-IN-GLASS AND THERMOCOUPLE THERMOMETRES

Liquid-in-glass thermometers and thermocouple thermometers are two different types of thermometers that are used to measure temperature.

### 7.11.1 LIQUID-IN-GLASS THERMOMETERS

A glass thermometer usually has a long, thin glass tube with a bulb at the end. The bulb contains mercury or alcohol as a liquid. The liquid expands as it warms and contracts as it cools.

Liquid-in-glass thermometers work by measuring the expansion and contraction of the liquid in the bulb. When the thermometer is placed in a warm atmosphere or touched with hot body, the liquid (mercury or alcohol) in the bulb expands and rises up the glass tube. When the thermometer is placed in a cold environment or touched with cold body, the liquid in the bulb contracts and falls down the glass tube.

Reading of temperature on the thermometre scale is measured. The scale is calibrated so that a certain temperature is represented by the height or position of the liquid inside the thermometre tube.

In homes, schools, and laboratories, liquid-in-glass thermometers are frequently used to measure temperature. They are also used in a few industrial applications.



### CAN YOU TELL?

Why does the temperature of a substance not change at its melting point and at its boiling point even after giving it heat?

The temperature of a substance remains the same at its melting point and boiling point during heating. The temperature of a substance is directly proportional to the average K.E. of its molecules. At the melting and boiling points, heat given to the substance only increases the gap between molecules by decreasing the intermolecular forces to change the state of the substance, and it is not used by molecules to increase their K.E. Hence, the temperature of the substance does change at its melting point and boiling point.

### 7.11.2 THERMOCOUPLE THERMOMETERS

Thermocouple thermometers have two wires made of different metals that are joined at one end. This junction is called the hot junction. The other ends of the wires, called the cold junctions, are connected to a measuring device, such as a voltmeter.

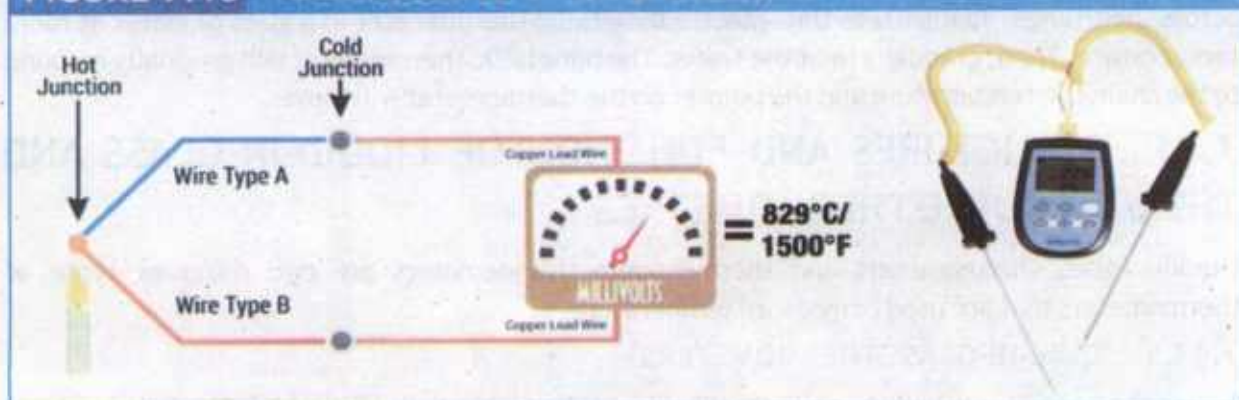


## UNIT 7

## DENSITY AND TEMPERATURE

Thermocouple thermometers work by measuring the voltage difference between the hot junction and the cold junctions. When the hot junction is heated, it causes free electrons in metals to flow across the junction and it creates voltage between hot and cold junctions. If we keep on heating hot junction then voltage difference between the hot junction and the cold junction increases.

**FIGURE 7.13 THERMOCOUPLE THERMOMETERS**



When the hot junction is cooled, the voltage difference between the hot junction and the cold junctions decreases. This shows the change in temperature in thermocouple is linearly proportional to change in voltage between hot and cold junctions. Thus, we can measure temperature by measuring this voltage. The voltmeter is calibrated so that the voltage difference between the hot junction and the cold junctions corresponds to a specific temperature.

Thermocouple thermometers are used to measure the temperature of furnaces, kilns, engines, and other industrial equipment. These are also used in the agriculture industry to measure the temperature of soil and water.

### 7.12 EFFECT OF STRUCTURE OF A LIQUID-IN-GLASS THERMOMETRE ON ITS SENSITIVITY, RANGE AND LINEARITY

The structure of a liquid-in-glass thermometer affects its sensitivity, range, and linearity in the following ways:

#### 7.12.1 EFFECT OF DIAMETER OF TUBE ON SENSITIVITY OF THERMOMETER:

Sensitivity of a thermometer is its ability to detect the smallest change in temperature. Liquid in glass thermometer has a long capillary tube of small diameter filled with liquid mercury or alcohol. The sensitivity of a liquid-in-glass thermometer is affected by the diameter of this tube. A thermometer with small diameter capillary tube can detect smaller change in temperature than the thermometer with large diameter of the tube. Narrower diameter tube will have smaller volume of liquid in it, which will react quickly to the absorbed heat and will rise quickly.

#### 7.12.2 EFFECT OF NATURE OF LIQUID USED IN THERMOMETER ON ITS SENSITIVITY:

Liquids like mercury and alcohol expand more than others when heated as compared to liquids like water. Therefore, we can say that thermometers having mercury or alcohol are more sensitive.



## 7.12.3 EFFECT OF SIZE OF BULB OF THERMOMETER ON ITS RANGE:

The range of a liquid-in-glass thermometer is affected by the volume of the bulb. If bulb has large size then it will contain more amount of liquid in it. So, this thermometer has large amount of liquid available to expand. Therefore, it can cover large range.

## 7.12.4 EFFECT OF NATURE OF LIQUID USED IN THERMOMETER ON ITS RANGE:

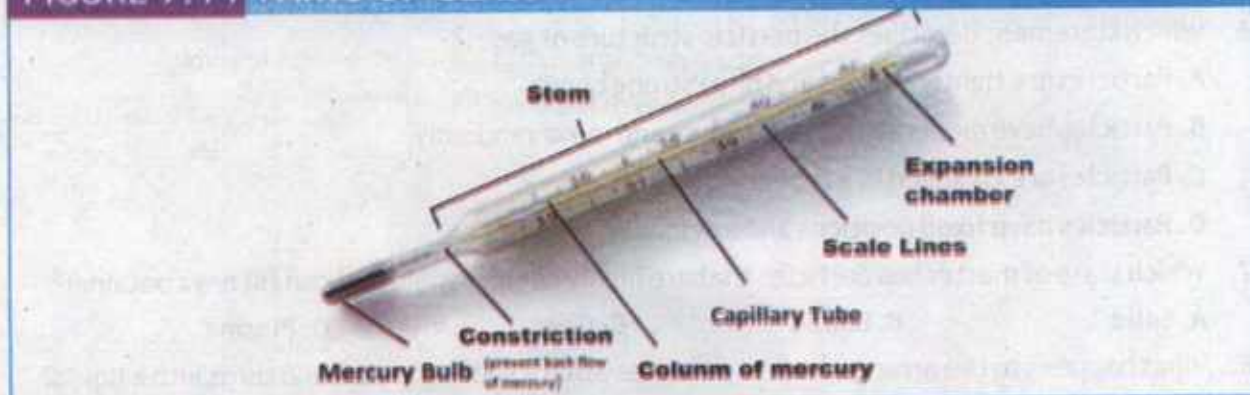
We use mercury in thermometer because of its smaller melting point and higher boiling point. Liquids with a wider boiling point range will have a wider range than liquids with a narrower boiling point range.

## 7.12.5 EFFECT OF TYPE OF GLASS USED IN THERMOMETER ON ITS LINEARITY:

The nature of the glass used in a thermometer can impact its linearity by affecting its expansion and contraction with temperature changes, transparency, chemical stability, uniformity, durability, and thermal conductivity.

Some types of glass, such as borosilicate glass, have a more linear expansion coefficient than others. Liquid-in-glass thermometer made with borosilicate glass will be more linear than a liquid-in-glass thermometer made with another type of glass, such as soda lime glass.

**FIGURE 7.14 PARTS OF GLASS THERMOMETER**



## SUMMARY

Density is mass per unit volume

States of matter are four, which are named as Solids, Liquids, Gases and Plasma.

Plasma is called fourth state of matter which is the ionized state of matter.

Thermometry is the branch of physics, which deals with the measurements of temperature.

Temperature is the measure of degree of hotness or coldness of a body.

Thermometer is a device which is used to measure temperature.

Heat is the form of energy which is transferred from one body to another body due to the difference in temperature.



## EXERCISE



## MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option.

- How many phases of matter are there?  
A. 1                      B. 2                      C. 3                      D. 4
- In which of the materials, particles have only vibrational motion?  
A. Solid                      B. Liquids                      C. Gas                      D. Plasma
- Which amount of water has greater density at room temperature?  
A. 100 g                      B. 1 kg                      C. 1 ton                      D. All have same density
- What is mass of a liquid of density  $50 \text{ kg m}^{-3}$  in a container of volume  $5 \text{ m}^3$ ?  
A. 200 kg                      B. 225 kg                      C. 250 kg                      D. 275 kg
- Gases and liquids are categorized as:  
A. Liquids                      B. Gases                      C. Fluids                      D. Solids
- Which statement describes the particle structure of gases?  
A. Particles are tightly packed and have strong bonds.  
B. Particles have moderate kinetic energy and move randomly.  
C. Particles are arranged in a repeating pattern.  
D. Particles have fixed positions and low kinetic energy.
- Which state of matter has particles that are highly compressible and can fill any container?  
A. Solid                      B. Liquid                      C. Gas                      D. Plasma
- What happens to the arrangement of particles when a solid is heated and turns into a liquid?  
A. Particles become more closely packed.      B. Particles move farther apart.  
C. Particles start vibrating in fixed positions.      D. Particles change their state from solid to gas.
- Which of the following is NOT a form of internal energy?  
A. Kinetic energy of the particles                      B. Potential energy of the particles  
C. Chemical energy of the bonds between the particles                      D. Light energy
- When an ideal gas is expanded keeping its temperature constant, its internal energy  
A. Increases                      B. Decreases  
C. Remains the same                      D. Cannot be determined
- Which of the following physical properties is used in a mercury thermometer?  
A. Electrical resistance      B. Pressure                      C. Volume                      D. Colour



12. Which of the following can increase the sensitivity of liquid in glass thermometer?
  - A. Use a bigger bulb which contains more amount of liquids
  - B. Use a longer capillary tube
  - C. Using long specific its
  - D. Changes colour on temperature.
13. Thermometre, which is most suitable for measuring rapid changing temperatures, is
  - A. Constant volume gas thermometer
  - B. Resistance thermometer
  - C. Liquid in glass thermometer
  - D. thermocouple
14. Mercury has uniform linear expansion in liquid in glass thermometers. A liquid in glass thermometer has a mercury level of 2cm at melting point of ice and a mercury level of 6cm at boiling point of water. What is the distance between every  $1^{\circ}\text{C}$  division on Celsius scale of thermometer?
  - A. 0.04 cm
  - B. 0.06 cm
  - C. 0.08 cm
  - D. 1.00 cm
15. Which thermometer uses voltage to measure temperature of a hot body?
  - A. Thermocouple
  - B. Resistance thermometer
  - C. Liquid in glass thermometer
  - D. gas thermometer

## SHORT RESPONSE QUESTIONS

**QII. Give a short response to the following questions**

1. Two liquids A and B, have densities 1 g/mL and 1.2 g/mL respectively. When both liquids are poured into a container, one liquid floats on top of the other. Which liquid is on top, and why?
2. Write a method to find the volume and density of a human body?
3. How is plasma the fourth state of matter? Give a reason
4. Why water is not used in liquid in glass thermometers?
5. Can we increase internal energy of a substance without increasing its temperature?
6. Why are fixed point scales required for thermometers? What difficulties are there when setting fixed points for thermometer scales?
7. Mercury is replaced with alcohol in liquid in glass thermometers. Discuss the possible change in sensitivity and range of thermometer?
8. Why  $-273.15^{\circ}\text{C}$  temperature is called absolute zero? Can we achieve this temperature?
9. Why thermocouple thermometer is suitable to measure high temperatures but not liquid in glass thermometer? Why is a thermocouple thermometer good for measuring high temperatures but a liquid in glass thermometer is not?
10. Can we increase the sensitivity of a liquid-in-glass thermometer without changing its range?
11. One student claims to have constructed a more sensitive liquid in glass thermometer. How can her claim be verified?



## LONG RESPONSE QUESTIONS

QIII. Give an extended response to the following

1. Define density. Describe methods to determine densities of regular and irregular-shaped solids, liquids and gases.
2. How would you distinguish between solids, liquids and gases on the basis of attractive forces between particles and the motion of particles?
3. Describe two different physical properties that vary with temperature and explain how these properties can be used to measure temperature.
4. Describe the construction and working of different types of gas thermometers.
5. Analyze how the structure of a liquid-in-glass thermometer can be modified to improve its performance. Give a detailed answer.

## NUMERICAL RESPONSE QUESTIONS

QIV. Solve the questions given below.

1. Sarah has two objects, a wooden block and a metal ball, with the following properties:  
(a) The wooden block has a mass of 300 g and a volume of  $150 \text{ cm}^3$ .  
(b) The metal ball has a mass of 500 g and a volume of  $50 \text{ cm}^3$ .  
Calculate the density of each object and determine which one is denser.  
(Ans. 2 g/mL, 10 g/mL)
2. You have a container with 500 milliliters of cooking oil, and it has a mass of 450 grams. Calculate the density of the cooking oil in grams per milliliter (g/mL).  
(Ans. 0.9 g/mL)
3. A 70cm 10cm 30cm plastic box has mass of 2500 g. Find the density of plastic.  
(Ans.  $0.12 \text{ g/cm}^3$ )
4. Aluminum has a density of  $2700 \text{ kg/m}^3$ . Find the mass of a solid 25 cm diameter aluminum ball.  
(Ans. 22 kg)
5. A cube of iron has a side length of 10 cm. What is volume of this cube? Mass of this iron cube is half kilogram. This cube has cavity inside it, find the volume of the cavity?  
(Ans.  $935.9 \text{ cm}^3$ )
6. Mass of an irregular shaped stone is 200 grams (g). When it is lowered in a measuring cylinder, it rises the water level from 40 mL to 73 mL. Find volume and density of this stone.  
(Ans. 33 mL, 6.1 g/mL)

# MAGNETISM

UNIT  
8

How Aurora  
(the dancing  
lights in the sky)  
forms at the  
poles?

## Student Learning Outcomes (SLOs)

The students will:

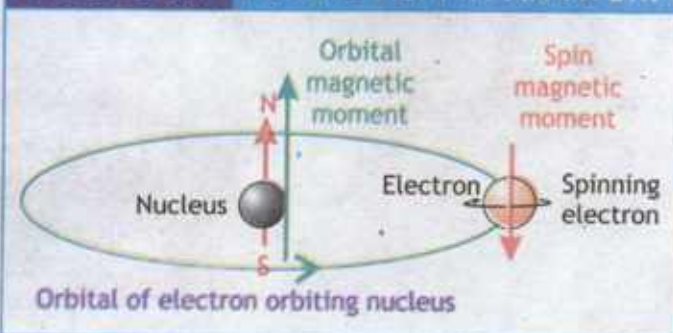
- [SLO: P-09-E-01] Describe the forces between magnetic poles and between magnets and magnetic materials.
- [SLO: P-09-E-02] Describe induced magnetism.
- [SLO: P-09-E-03] State the difference between magnetic and non-magnetic materials.
- [SLO: P-09-E-04] Differentiate between temporary and permanent magnets.
- [SLO: P-09-E-05] Describe magnetic fields.
- [SLO: P-09-E-06] Illustrate the plotting of magnetic field lines with a compass or iron filings.
- [SLO: P-09-E-07] Draw the pattern and direction of the magnetic field lines around a bar magnet.
- [SLO: P-09-E-08] State that the direction of the magnetic field at a point is the direction of the force on the N pole of a magnet at that point.
- [SLO: P-09-E-09] state that the relative strength of a magnetic field is represented by the spacing of the magnetic field lines.
- [SLO: P-09-E-10] Describe uses of permanent magnets and electromagnets.
- [SLO: P-09-E-11] Explain qualitatively in terms of the domain theory of magnetism how materials can be magnetized and demagnetized.
- [SLO: P-09-E-12] Differentiate between ferromagnetic, paramagnetic and diamagnetic materials.
- [SLO: P-09-E-13] Describe the nature of the Earth's magnetic field.
- [SLO: P-09-E-14] Analyze applications of magnets in recording technology.
- [SLO: P-09-E-15] State that soft magnetic materials (such as soft iron) can be used to provide shielding from magnetic fields.

Magnetism finds its history to times back to the 600 BC, when the early loadstone, attracting the iron was found in the region of magnesia, from where it takes the name 'magnet'. Though it dates long ago but man begun to understand magnetism in the twentieth century and started developing technologies on this understanding. Magnetism arises due to motion of charge particles like electrons moving around the nucleus in the atoms and charges moving in the wires in the form of electric current. Now a day we have a lot of technological applications of magnets and magnetism.

## 8.1 DOMAIN THEORY OF MAGNETISM

As we know everything around us is made up of atoms, having massive central body with positive charge known as nucleus and light particles with negative charge called electrons orbit around the nucleus. In late twentieth century we found that the basis of magnetism is the motion of charge particles. Electrons (charged particles) move around the nucleus in all atoms producing magnetism.

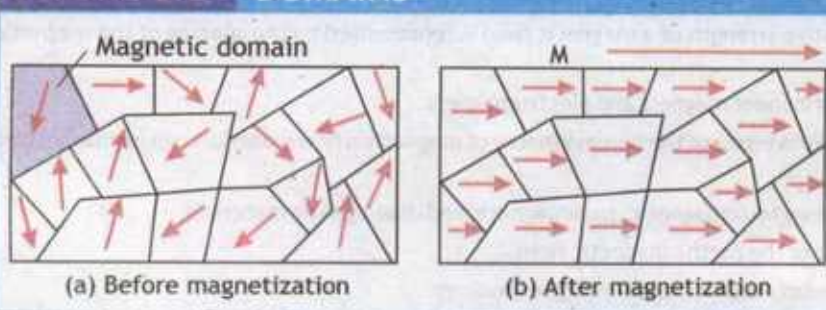
FIGURE 8.1 MAGNETISM IN AN ATOM



So for a single atom each electron produces a small amount of magnetism as shown in figure 8.1. For a single electron loop a tiny magnet is produced which has two poles called the north-pole (N pole) and the south-pole (S pole). Spinning nucleus also produces some amount of magnetic field but that is negligibly small and the spin motion of electron also produces a tiny magnetism, hence we take the magnetic field of atoms only due to orbital motion of electrons. In some atoms electrons are so oriented that they may add up their magnetic field to make the atom with net non-zero magnetic field, which makes the whole material as magnetic material.

In a sizeable piece of a material a group of atoms having parallel magnetic field make a 'domain' (of roughly  $10^{12}$  atoms and a size of few mm). In unmagnetized material the domains are randomly oriented while in a magnetized material (a material can be magnetized by placing it in external magnetic field) the domains are aligned, as shown in figure 8.2.

FIGURE 8.2 DOMAINS



### FOR YOUR INFORMATION

"A domain is the group of atoms in a material which have n-poles pointing in the same direction".

### 8.1.1 Force between magnetic poles:

As we seen above that a magnet, how small it may be, have an S-pole and N-pole. In magnets like poles repel each other while unlike poles attract each other. Similarly the materials which have magnetism are attracted by the opposite poles of a magnet. A magnetic material can also attract opposite poles of other magnetic materials as shown in figure 8.3.

FIGURE 8.3 MAGNET



### 8.2 MAGNETIC FIELD

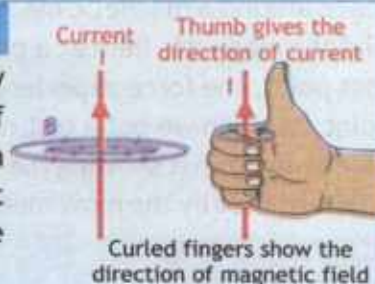
Mono-pole never exist in magnets, magnets are always bipolar i.e. they have two poles N-pole and S-pole. Every magnet has a space around it where it has its influence on other magnets in the form of attraction or repulsion.

**“The region or space around a magnet where it exerts a force on other magnetic poles is called magnetic field”.**

The intensity of magnetic field ( $B$ ) at any point in the field can be measured in the unit called tesla ( $T$ ). Graphically the magnetic field is represented by the field lines. The direction of the magnetic field of a material at any point can be found by the direction of force acting on the N-pole placed at that point. Magnetic field lines are curved in general, hence the direction of magnetic field on a point at such a curved line can be found by drawing a tangent at that point.

#### INFORMATION

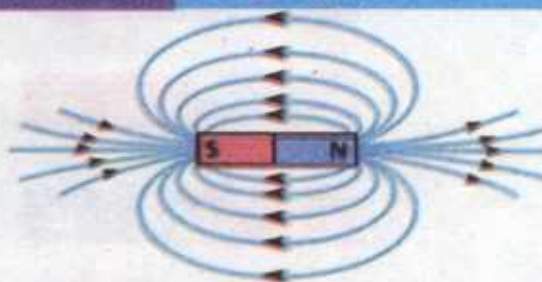
Magnetic field ( $B$ ) of a wire carrying a current ( $I$ ) can be found by placing iron filling around the wire. We get the magnetic field of current carrying wire as the concentric circles having centers in the wire. The direction of such field can be found by using right hand rule. Hold the current carrying wire in your right hand, the fingers will curve in the direction of magnetic field.



#### 8.2.1 Magnetic Field of a Bar Magnet:

A bar magnet is a rectangular part of a material which shows permanent magnetic properties. The magnetic field of a bar magnet can be found by placing the magnet on a plane sheet such that it has compass needles around it. You will notice that all the compass needles point in a particular manner, which shows the magnetic field pattern of the bar magnet, as shown in figure 8.4.

FIGURE 8.4 FIELD LINES



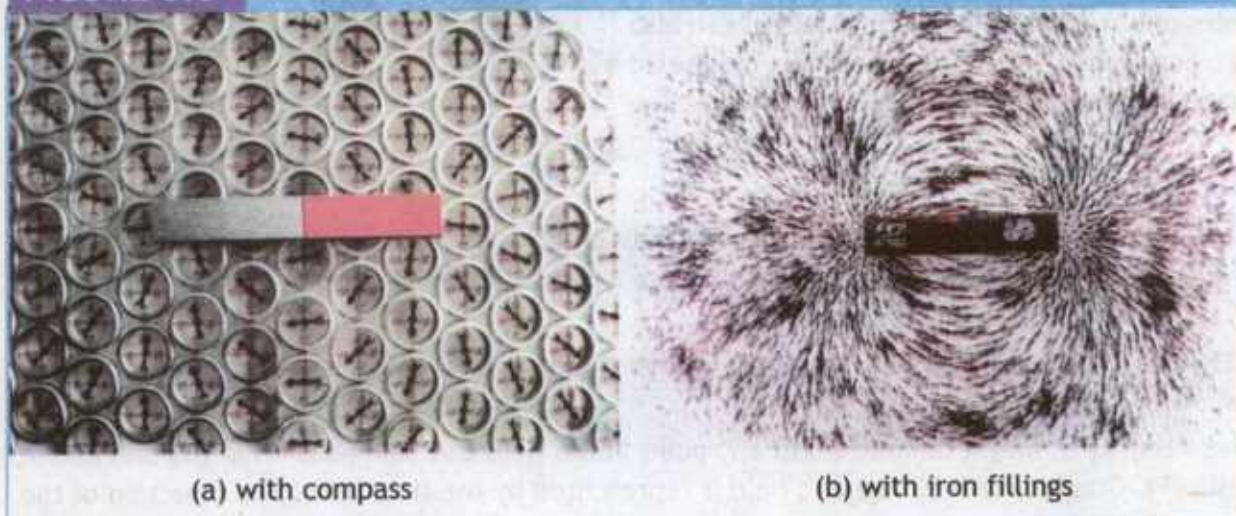
Magnetic field lines of a bar magnet



## UNIT 8 MAGNETISM

The field lines originate from N-pole and terminate at S-pole, while within the body of magnet these lines travel from S-pole to N-pole. This pattern of magnetic field of a bar magnet can also be found by putting the iron fillings around a bar magnet instead of compass needles. The iron filling arrange them in the same pattern as that of compass needle as shown in figure 8.5 (a) and 8.5 (b).

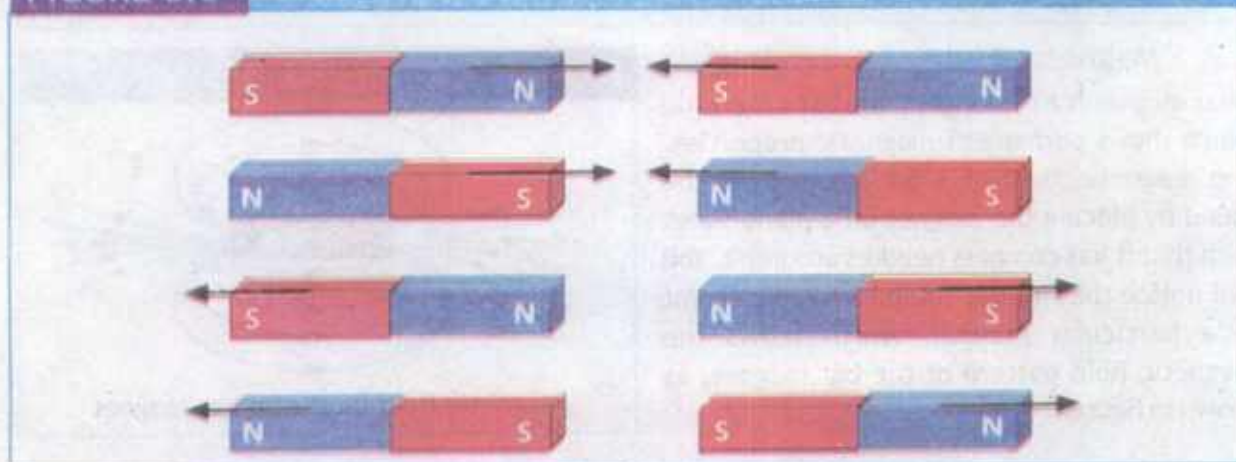
**FIGURE 8.5** MAGNETIC FIELD LINES OF A BAR MAGNET



### 8.2.2 Direction of magnetic Field at a point:

The magnetic field is the map that we use to describe how the magnetic force is distributed in the space around a magnetic material or magnet and even within a magnetic material or magnet. To find the magnetic field at a point due to some magnet, is determined by placing a north-pole at that point, the force experienced by the north-pole will be the strength of magnetic field at that point. As when we put a test north-pole near the north-pole of material, it repels the test north-pole away from it showing the direction of north-pole of material as outward. The magnetic force is determined by the movement of test magnet as shown in figure 8.6.

**FIGURE 8.6** DIRECTION OF MAGNETIC FIELD



### 8.2.3 Relative Strength of Magnetic Field:

The strength of magnetic field at any point due to a magnetic pole can be found by the field lines.

The field is stronger where the field lines are closer, while the field is weaker where the field lines are farther apart.

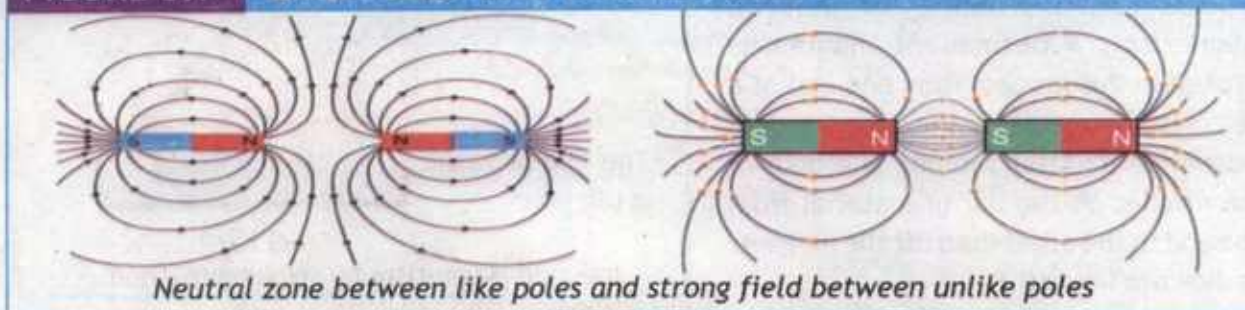


#### SCIENCE TIDBITS

"The relative strength of a magnetic field is the degree of closeness of the field lines".

Hence magnetic field lines give the direction and the strength of magnetic field. The relative strength of magnetic field due to like poles and unlike poles is shown in figure 8.7. By placing two N-poles close to each other we can decrease the field similarly by placing N-pole near an S-pole we can make magnetic field strengthen.

**FIGURE 8.7** LIKE POLES AND UNLIKE POLES



### 8.2.4 Magnetic Shielding:

There may be different orientation of magnetic field by suitably adjusting the magnets. We can find a field free region called 'neutral zone' by placing two N-poles side by side, such that their field lines seem to repel each other by making a field free region, this phenomenon is called shielding of magnetic field. In daily life we deal with a lot of devices which have to work in strong magnetic environment but this external magnetic field can alter the functioning of the device. So we have to shield the device from external magnetic field.



#### SCIENCE TIDBITS

Materials used for magnetic shielding are called shields. These materials are used for protecting sensitive circuits from unwanted parasitic magnetic fields including power inverters, magnetic immunity, magnetic sensors and EMI. The commonly used materials as shield are Iron, Nickel and Cobalt. Shields are usually made rounded corners because it is difficult for magnetic field lines to turn an angle of  $90^\circ$ .





## UNIT 8 MAGNETISM

### 8.3 INDUCED MAGNETISM

A material which is not a magnet in normal condition can be made a magnet with the help of some techniques and is called induced magnet and this phenomenon is called induced magnetism. Similarly a magnetic material can lose its magnetization.

There are many ways to make an object an induced magnet or a magnet to lose its magnetization like, by stroking the material with a magnet, by hammering the material in a magnetic field, by heating or by putting the material inside a coil from which direct current is flowing.

**STROKING METHOD:** This is the way of aligning the poles of a material by a process called stroking for induced magnetism. A permanent magnet is stroked in this process from one end of a bar of some metal to the other end to magnetize it. After rubbing one pole of the magnet on the bar of material from one end to the other then lift the magnet, as shown in figure 8.8.

**HAMMERING METHOD:** In this method a bar of metal is placed inside a strong magnetic field and hammered gently. The domains will begin to line up in the direction of applied magnetic field and hence metal bar becomes magnetized. This method is mainly used for magnetization of steel. The magnetization can be increased by heating the metal bar slightly before hammering. This method is shown in figure 8.9.

**HEATING METHOD:** This method is usually used to demagnetize a material, as heat speeds up the movements of already aligned domains which results in misalignment of domains and hence material loses its magnetization. However in recent past scientists have provided the evidences of generating magnetic field by the process of heating. This phenomenon is referred to as the 'magnetic Seebeck effect' or 'thermo-magnetism'.

### FOR YOUR INFORMATION

"A material that becomes a magnet when it is placed in a magnetic field is called induced magnet".

FIGURE 8.8 STROKING METHOD



FIGURE 8.9 HAMMERING METHOD



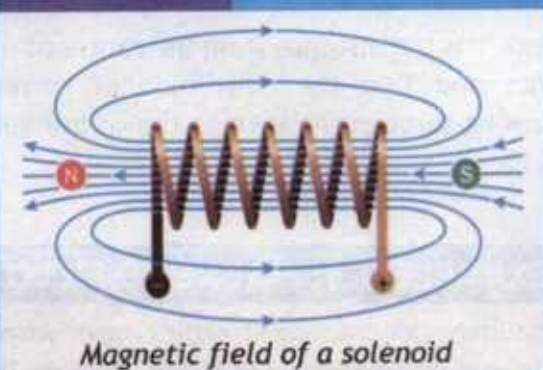
FIGURE 8.10 SOLENOID



**SOLENOID:** This is the most common method used for the magnetization of metals. A solenoid is a coil of wire wrapped around a cylindrical coil as shown in figure 8.10. The magnetic field of the solenoid resembles with the field of a bar magnet, as shown in figure 8.11. When we wrap a conducting wire (say a copper wire) around a metal with insulation the domains of the metal get aligned. In this process when a current flows through the wire it generates a magnetic field which behaves as external field to the domains of metal placed inside, which aligns the domains. The coil of wire acts as a magnet as long as the current is flowing through it. When current stops it no longer behaves as a magnet. For direct current (DC) the polarity of coil remains the same and hence it magnetizes the material in one direction.

For alternating current the polarity of solenoid changes after every half cycle and hence in first half cycle it magnetizes the material in one direction then demagnetizes it. In second half cycle it magnetizes the material in opposite direction and then demagnetizes it. Materials which easily magnetize and demagnetize are called soft magnetic materials (like soft iron), on the other hand materials which cannot magnetize and demagnetize easily are called hard magnetic materials (like steel).

**FIGURE 8.11 MAGNETIC FIELD**



### FOR YOUR INFORMATION

Electric motors used in hand-held hair dryers, electric razors, hair trimmers and many more such devices, work with the help of magnetic force. An electric motor generates magnetic field with electric current through the coil. The magnetic force then causes the movement or spinning that runs the motor.



The magnetic field of a solenoid can mathematically be given as:  $B = \mu_0 n I$  — **8.1**

Here 'B' is the strength of magnetic field having unit tesla (T) which is also equal to newton per ampere per meter ( $\text{N A}^{-1} \text{m}^{-1}$ ), while  $\mu_0$  is the permeability of the material (Permeability is the property of a material to its response towards a magnetic field, i.e. how much a material permits magnetic field to pass through it), 'I' is the current flowing through the solenoid and 'n' is the number of turns of the solenoid per unit length given by the relation as,

$$n = \frac{N}{L} \quad \text{— 8.2}$$

Here 'N' is the total number of turns of the solenoid and 'L' is the length of solenoid. The value of the permeability for vacuum ' $\mu_0$ ' is given as:

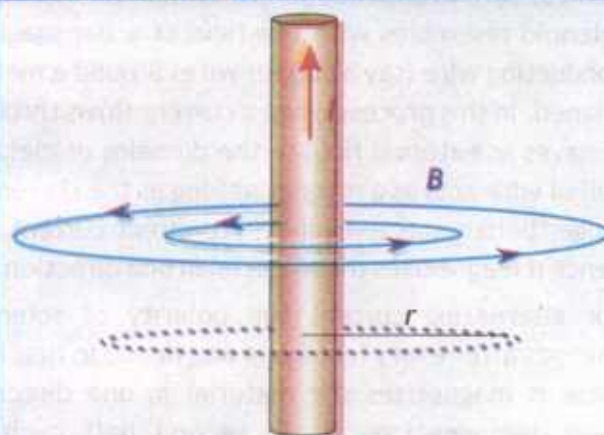
$$\mu_0 = 4\pi \times 10^{-7} \text{ N A}^{-2}$$

Similarly the magnetic field due to a wire carrying current can be given as:

$$B = \frac{\mu_0 I}{2\pi r}$$

Here 'r' is the distance from the center of the wire and 'I' is the magnitude of current flowing through the wire as shown in figure 8.12.

FIGURE 8.12 WIRE FIELD



Magnetic field around a wire

## EXAMPLE 8.1: MAGNETIC FIELD OF A SOLENOID

A student takes a long straight copper wire (with insulation on it) from his physics lab, he wraps the wire on an iron rod of 50 cm, to make it solenoid of 15 turns. He connects the ends of copper wire with the battery, which provides 1.2 A current. Find the magnetic field he produces in solenoid by doing so.

### GIVEN

Length 'L' = 50 cm = 0.5 m

Number of turns 'N' = 50

Current 'I' = 1.2 A

Permeability ' $\mu_0$ ' =  $4\pi \times 10^{-7} \text{ N/A}^2$

### SOLUTION

To find magnetic Field Strength we have to find number of turns per unit length first by using equation 8.2

$$n = \frac{N}{L} = \frac{50}{0.5} = 100 \text{ m}^{-1}$$

Now using equation 8.1

$$B = \mu_0 n I$$

Putting values:  $B = (4\pi \times 10^{-7} \text{ N A}^{-2})(100 \text{ m}^{-1})(1.2 \text{ A})$

Therefore,

$$B = 1.5 \times 10^{-4} \text{ T}$$

Answer

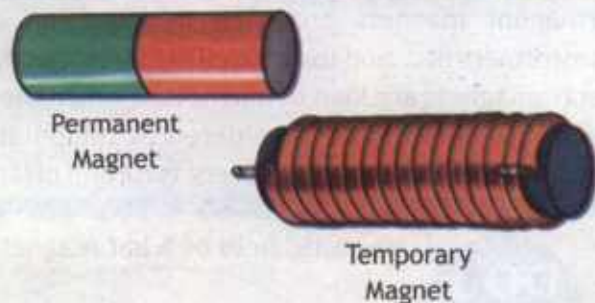
### FOR YOUR INFORMATION

"Magnetic materials which do not retain their magnetization after removal of external magnetic field or applied current (as in case of solenoid) are called temporary magnets".

### 8.3.1 TEMPORARY AND PERMANENT MAGNETICS:

The solenoid as stated earlier behaves like a magnet as long as a current flows through it, just after removal of current it loses its magnetic field, hence it is a temporary magnet. It is also called as electromagnet. Electromagnet is type of magnet in which the magnetic field is produced due to an electric current. Examples of temporary magnetics include iron nails, screws, metal bolts, kitchen utensils etc.

**FIGURE 8.13** MAGNET TYPES



Examples of permanent magnetic materials include iron ore, cobalt, nickel and Alnico. Temporary and permanent magnets are shown in figure 8.13. Some of the differences are listed below.

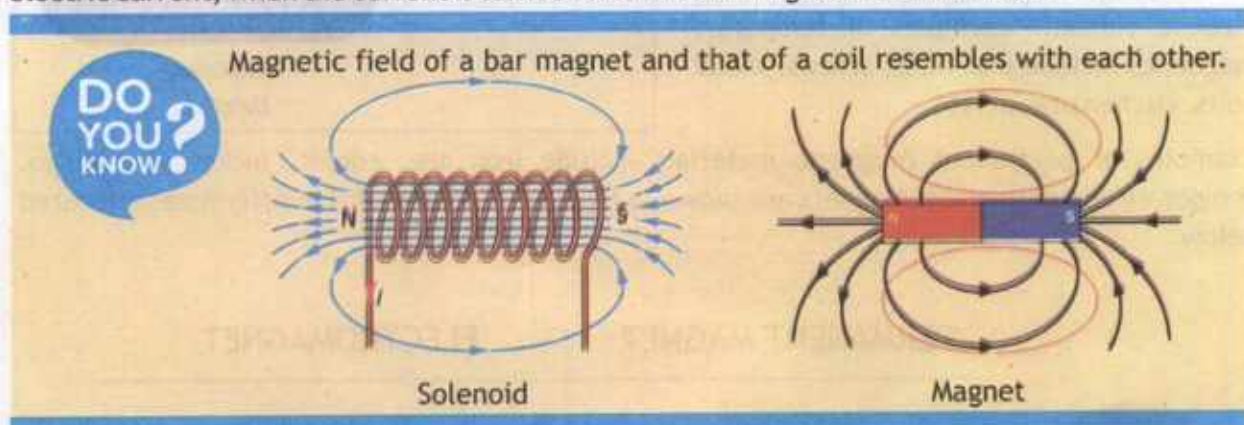
|                                                                                     | PERMANENT MAGNET                    | ELECTROMAGNET                                         |
|-------------------------------------------------------------------------------------|-------------------------------------|-------------------------------------------------------|
|  | Permanently magnetized              | Temporarily magnetized                                |
|  | Made of hard magnetic materials     | Made of soft magnetic materials                       |
|  | Magnetism does not vary in strength | Magnetism can be varied in strength according to need |
|  | Magnets' poles can not be altered   | Magnets' poles can be changed                         |



## UNIT 8 MAGNETISM

### 8.3.2 USES OF PERMANENT MAGNETS AND ELECTROMAGNETS:

Magnets are used in many fields, depending upon the need we can use permanent or electromagnets. A permanent magnet is made from a material which is magnetized once and does not lose its magnetization by itself and has its own magnetic field. As we know that permanent magnet does not require a continuous supply of electric energy for maintaining its magnetic field. Hence it is used in those applications where continuous supply of electricity is not available or cannot be maintain for long. Although magnetic field strength of permanent magnets are lower than those of electromagnets but they can have magnetic field even in the absence of electricity. Permanent magnets are used in induction cooker, MRI machines, particle accelerators, transformers etc. and in automotive, aerospace, medical, semiconductor and energy industries. Electromagnets are kind of magnets in which the magnetic field is created by an electric current. Electromagnets can be considered as temporary magnets that function only with the flow of electric current, when the current is turned off it loses its magnetization at once.

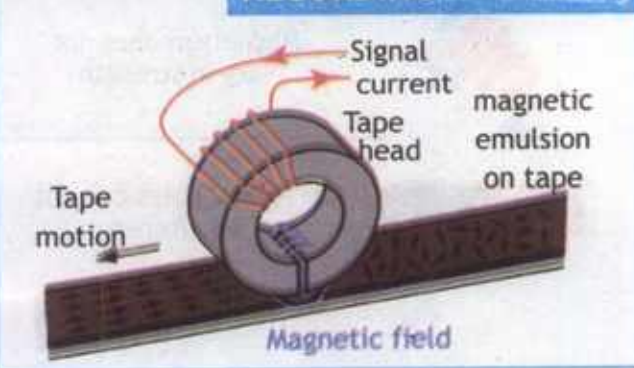


Electromagnets have a wide range of daily life applications like in electromechanical and electronics devices. Most of the home appliances use electromagnetism as the basic working principle, like electric fan, electric motors and door bells. In medical fields electromagnets are used in MRI scan. Electromagnets are also used in communication devices and power circuits.

### 8.3.2 APPLICATIONS OF MAGNETS:

**A. MAGNETIC RECORDING** is a method of saving sounds, pictures and data in the form of electrical signals by the process of selective magnetization of some portion of a magnetic material. For writing the data a magnetic tape head is moved onto the tape which is in motion the magnetic field of the tape head aligns the pattern of magnetic domains according to the applied current flowing through the tape head, as shown in figure 8.14.

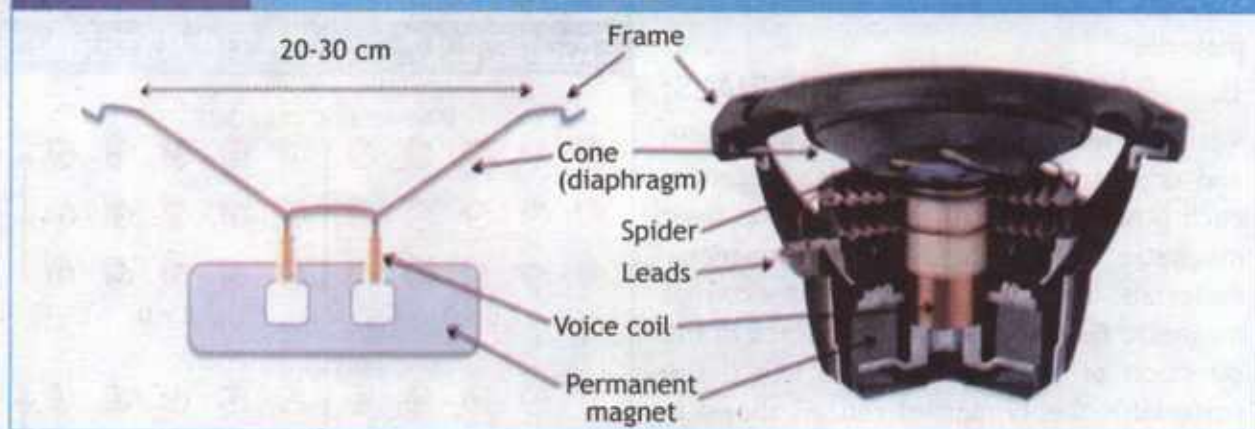
FIGURE 8.14 PROCESS OF MAGNETIC RECORDING



Similarly the reverse process is done for reading the data from the aligned pattern of tape. For magnetic recording the materials commonly used are iron-oxide, cobalt, chromium oxide and pure iron. The main recording media may be a magnetic tape or disk recorders which are used to store and reproduce audio, video signals and computer data. Some other magnetic recording devices are magnetic drum, core and bubble units used for computer storage units.

**B. SPEAKERS** use magnets in their functioning. To produce sound the speaker need to create some vibrations in the air. This can be done with the help of two magnets one permanent magnet of strong magnetization and the other is electromagnet. The permanent magnet is fixed in the centre of cone (diaphragm), which is a conical structure made up of some flexible material to produce vibrations. An electromagnet is attached at the centre of permanent magnet which can move to and fro. When the sound signal in the form of electric current flows through the coil of electromagnet it produces alternating magnetic field which due to interaction with field of permanent magnet vibrates it. As the cone is attached to the electromagnet, with the to and fro motion of electromagnet it vibrates and produces sound. With larger permanent magnet we can produce louder sound. The commonly used material as permanent magnet in speakers is neodymium. The structure of speaker is shown in figure 8.15. Microphones also use magnets in their functioning, but in reverse order. In microphones the cone (diaphragm) vibrates due to sound and hence producing movement in the electromagnet within the magnetic field of permanent magnet. This produces an electric current which acts as the signal for the speaker.

**FIGURE 8.15 ANATOMY OF SPEAKER**



**C. DOOR LOCKS** also use magnets in their working. They have an electromagnet fixed at the door frame and a metal plate fixed with the door, in such a way that when the door is closed the metal plate connects with the electromagnet, as shown in figure 8.16.



## UNIT 8 MAGNETISM

When the current passes through the electromagnet it attracts the metal plate with huge force, so that to open door is difficult. When we have to open the door we disconnect the current flowing through electromagnet which releases the metal plate. As this door requires electricity for its functioning it is mainly used for emergency exits at hotels, offices and residential buildings.

FIGURE 8.16 MAGNETIC DOOR LOCK



### 8.4 TYPES OF MAGNETIC MATERIALS

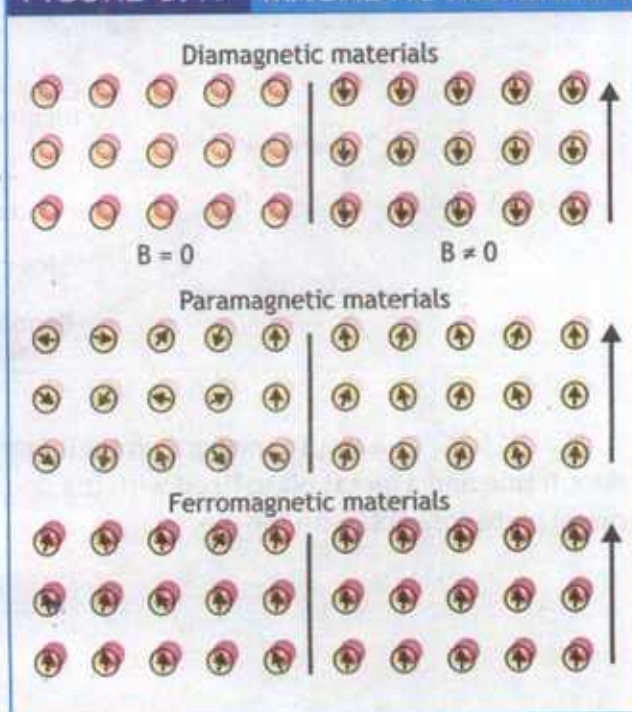
On the base of behavior of materials to the applied external magnetic field, they are classified into three types, i.e. diamagnetic, paramagnetic and ferromagnetic materials.

**A. DIAMAGNETIC MATERIALS:** Materials in which the spin and orbital motions of electrons are so oriented that they cancel each other's effect and the net magnetic field at a single atom level becomes zero, such materials are called diamagnetic materials. They are slightly repelled by a magnetic field and do not retain the magnetic properties when the external field is removed. Their magnetic field intensity is very small and opposite to the external magnetic field, as shown in figure 8.14. Examples of diamagnetic materials are copper, zinc, bismuth, silver, gold, marble, water, glass and wood etc. Such materials which have zero magnetic field ( $B=0$ ) in the absence of external field are called non-magnetic or diamagnetic material.

**B. PARAMAGNETIC MATERIALS:**

Materials which have electrons, whose spin and orbital axis cannot completely cancel each other, in spite of it they add up their magnetic field, are called paramagnetic materials. On the application of external magnetic field they align themselves in the direction of applied field and hence the material is feebly magnetized, as shown in figure 8.17. They experience weak attraction to magnets. Their magnetic field intensity is small and along the direction of external magnetic field. Examples of paramagnetic materials are tungsten, aluminum, lithium and sodium etc. Such materials which have non-zero magnetic field ( $B \neq 0$ ) in the absence of external field are called magnetic material.

FIGURE 8.17 MAGNETIC MATERIALS



**C. FERROMAGNETIC MATERIALS:** Materials which have a net magnetism at the atomic level, even in the absence of external magnetic field, are called ferromagnetic materials. When placed in external field these materials are strongly magnetized in a direction parallel to the applied field and hence they are strongly attracted to a magnet. They retain their magnetization even after removal of applied magnetic field, as shown in figure 8.14. Their magnetic field intensity is very large and along the direction of external magnetic field. Examples of these materials include iron, cobalt, nickel and some metallic alloys.

#### 8.4.1 DIFFERENCE BETWEEN MAGNETIC AND NON-MAGNETIC MATERIALS:

As we studied above that materials are classified as magnetic and non-magnetic on the basis of their response to an applied magnetic field. These differences are summarized in table below.

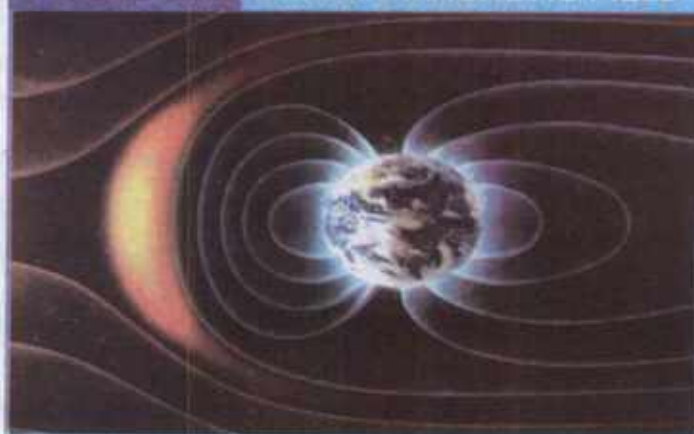
| TABLE 8.1: DIFFERENCE BETWEEN MAGNETIC AND NON-MAGNETIC MATERIALS         |                                                                                   |
|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Magnetic Materials                                                        | Non-magnetic materials                                                            |
| Materials which are attracted to a magnet are known as magnetic materials | Materials which are not attracted to a magnet are known as non-magnetic materials |
| The atomic states of a magnetic material are aligned                      | The atomic states of a non-magnetic material are in random                        |
| They respond to a magnetic field                                          | They do not respond to a magnetic field                                           |
| Magnetic materials have field (magnetic field) around them                | Non-magnetic materials do not have field (magnetic field) around them             |
| Magnetic materials can attract and repel other magnetic materials         | Non-magnetic cannot attract or repel any magnetic material                        |
| Examples of magnetic materials are: Nickel, Cobalt, Steel and Iron.       | Examples of magnetic materials are: Rubber, Plastic, Wood and Copper.             |

## 8.5 EARTH'S MAGNETIC FIELD

Life exists on our Earth, which is due to many factors, among them the magnetic field is the one. Our Earth is a big magnet and has a magnetic field which is essential for survival of life on it. Do you know from where the Earth gets its magnetic property? As we know that the core of Earth is mainly consists of molten iron, electrical currents flowing in the slowly moving molten iron generate the magnetic field of Earth, called "dynamo effect".

Earth's field is also known as geomagnetic field. The presence of a magnetic field acts like a protective shield around the Earth, which saves life on Earth from harmful cosmic rays coming from the outer space and the charge particles and radiations coming from the Sun. The Earth's magnetic field extends millions of kilometers into the space but have very small magnetic field strength.

FIGURE 8.18 EARTH'S MAGNETIC FIELD

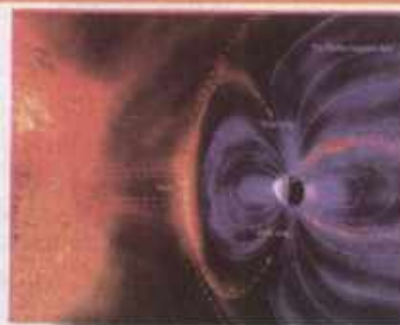


Earth's magnetic field resembles with the field of a bar magnet and is shown in figure 8.18, where from the Sun side the field is pushed a little inside due to continuous striking solar winds consists of radiations and charged particles. The opposite side of the Earth to the Sun, the field is extended several millions of kilometers.



### SCIENCE TIDBITS

Aurora (the dancing lights in the sky) at the northern and southern poles of Earth forms due to the magnetic field pattern of Earth. As shown here the charged particles coming from the Sun hit the Earth at poles due to polar cusps of Earth's magnetic field. When these particles enter the atmosphere they ionize the atoms of air (gases) and hence produce light of different colors depending the nature of gas.



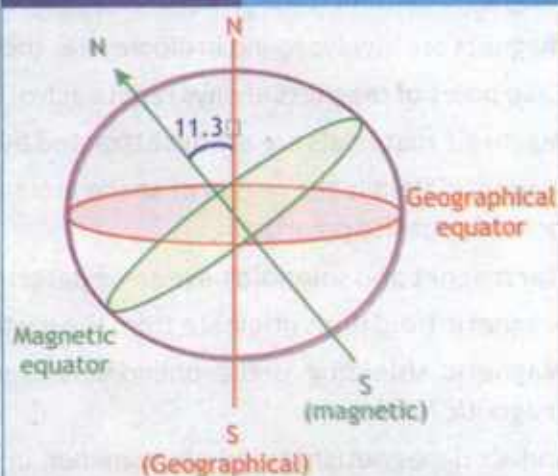


### 8.5.1 GEOGRAPHICAL AND MAGNETIC POLES OF THE EARTH:

If we look at the map of our Earth we see the poles on it, the north-pole is shown at Arctic and the south-pole is at Antarctic. But these poles on map are the geographical poles of the Earth not magnetic poles of Earth. Our Earth spins about its geographical axis (The line joining the geographical poles of the Earth). The magnetic poles of Earth are inclined at an angle of  $11.3^\circ$  to the geographical poles as shown in figure 8.20.

Hence the compass needle does not point towards the north-pole shown on maps instead it points  $11.3^\circ$  away towards the magnetic pole.

FIGURE 8.20 EARTH'S POLES



Earth's magnetic and geographical poles

### 8.5.2 BIO-MAGNETISM:

Magnetism plays a vital role in the survival of life on Earth. It also plays a main role in the behavior of many species living on the planet. Like human's heart and brain produce some magnetic fields for their working, without these fields these organs are of no use. These magnetic fields produced by brain and heart are also used for diagnostic techniques.



#### SCIENCE TIDBITS

In ancient times people use to send messages through pigeons. How they locate their destination to deliver the messages?

Iron crystals are found in the beaks of pigeons. These crystals give the bird a nose for north. Pigeons can sense Earth's magnetic field. With the help of this magnetic navigation pigeons locate their destinations. Similarly some other migrating birds have cryptochrome-4 molecule in their eyes, which is sensitive to the magnetism.



### ASSIGNMENT

Draw by yourself the geographical and magnetic poles of Earth. Also draw magnetic field lines and explain why these lines are different from the field lines of a bar magnet.

Similarly some other species use magnetic fields of Earth for different purposes. Migratory animals, birds, sea turtles and whales use the magnetic field of Earth to navigate. They use to migrate in spring and autumn or some in winter and summer using the polarity of north and south.

**SUMMARY**

**Magnetic domain** is the group of atoms whose N-poles are aligned in the same direction.

**Magnets** are always found in dipole, i.e. they have a N-pole and a S-pole.

**Like poles of magnets** always repel each other, while unlike poles attract each other.

**Magnetic materials** are always attracted by magnets and other magnetic materials.

**Magnetic field** is the region of space around a magnet in which it is attracted by the magnetic pole of opposite polarity.

**Bar magnet and solenoid** have same pattern of magnetic fields.

**Magnetic field lines** originate from the north-pole and end at south-pole.

**Magnetic shielding** is the phenomenon in which some region of space is made free from magnetic field.

**Induced magnetism** is the phenomenon in which a material is magnetized by placing it inside an external magnetic field.

**Temporary magnets** are those magnets which behave like a magnet only in the presence of current.

**Permanent magnets** are those magnets which behave like a magnet even in the absence of current.

**Diamagnetic materials** have zero net magnetic fields per atom.

**Paramagnetic materials** have small net magnetic field per atom.

**Ferromagnetic materials** have large net magnetic field per atom.

**Earth** has a magnetic field which resembles with the field of a bar magnet and shield all the life on it from cosmic rays and radiation from the Sun and outer space.

**Earth's geographical and magnetic poles** are not same but inclined at an angle of  $11.3^\circ$ .

**Migrating birds and animals** use Earth's magnetic field to navigate.

## EXERCISE



### MULTIPLE CHOICE QUESTIONS

**Q1. Choose the best possible option.**

1. If a bar magnet is cut in half it will become
 

|                    |                            |
|--------------------|----------------------------|
| A. a monopole      | B. unmagnetized            |
| C. the same magnet | D. magnet of less strength |
2. Which one is the quickest method to magnetize a material?
 

|                               |                                           |
|-------------------------------|-------------------------------------------|
| A. strike with hammer         | B. moving into magnetic field             |
| C. Stroking the opposite pole | D. putting inside a current carrying coil |
3. Earth's magnetic field intensity is:
 

|                        |                          |
|------------------------|--------------------------|
| A. constant everywhere | B. very high at equator  |
| C. very low at poles   | D. varies place to place |
4. The cause of the Earth's magnetic field is:
 

|                               |                               |
|-------------------------------|-------------------------------|
| A. rotational motion of Earth | B. spinning of Earth          |
| C. Pull of the Sun            | D. motion of ions in the core |
5. Material which is the best one for making a permanent magnet:
 

|              |           |           |          |
|--------------|-----------|-----------|----------|
| A. Soft iron | B. nickel | C. cobalt | D. steel |
|--------------|-----------|-----------|----------|
6. Material which is the best one for making an electromagnet:
 

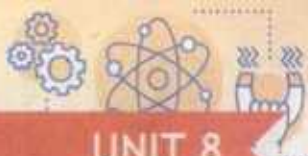
|              |           |           |          |
|--------------|-----------|-----------|----------|
| A. Soft iron | B. nickel | C. cobalt | D. steel |
|--------------|-----------|-----------|----------|
7. A sensitive magnetic material is to shielded by the external magnetic field. It should be kept inside a box of:
 

|         |            |          |              |
|---------|------------|----------|--------------|
| A. wood | B. plastic | C. steel | D. soft iron |
|---------|------------|----------|--------------|
8. Magnetic field lines:
 

|                          |                          |
|--------------------------|--------------------------|
| A. are farthest at poles | B. intersect each other  |
| C. are closed            | D. do not pass in vacuum |
9. When two current carrying wires in the same direction are placed parallel near each other, due to magnetic field produced by each wire they:
 

|                                 |                                         |
|---------------------------------|-----------------------------------------|
| A. repel each other             | B. attract each other                   |
| C. have no effect on each other | D. stop moving the current through them |
10. Which of the following material is ferromagnetic?
 

|           |           |             |           |
|-----------|-----------|-------------|-----------|
| A. silver | B. copper | C. aluminum | D. nickel |
|-----------|-----------|-------------|-----------|



## SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. Can two magnetic field lines intersect each other? Justify your answer.
2. A freely suspended magnet always points along north-south direction. Why?
3. What is the neutral zone or field free region of the magnetic field?
4. Is there any material which does not have any magnetic behavior? Justify your answer.
5. A proton is also a charged particle and spins like an electron. Why its effect is neglected in study of magnetism?
6. What is the geomagnetic reversal phenomenon? Explain.
7. Why the Earth spins about its geographical axis instead of its magnetic axis? Explain.
8. Why the Earth's geographical and magnetic axis are not coincident? Explain.
9. What is the difference between paramagnetic and ferromagnetic materials?
10. At what factors the strength of the magnetic field of an electromagnet depends?
11. Draw magnetic field lines of two solenoids placed near each other i) facing same poles to each other ii) facing opposite poles to each other

## LONG RESPONSE QUESTIONS

QIII. Give a detailed response to the questions given below.

1. Define and explain the magnetism.
2. What is the domain theory of magnetism? Explain.
3. Explain magnetic field strength and magnetic shielding.
4. Explain the magnetic field of a bar magnet and that of a solenoid, also compare them.
5. Define induced magnetism. Also explain some of the methods for induced magnetism.
6. Differentiate between permanent and temporary magnets.
7. Explain some uses of electromagnets and temporary magnets.
8. Explain the three types of magnetic materials.
9. Explain the Earth's magnetic field. Also relate Earth's geographical and magnetic poles.
10. Explain how birds and other migrating animal use Earth's magnetic field to navigate.

## NUMERICAL RESPONSE QUESTIONS

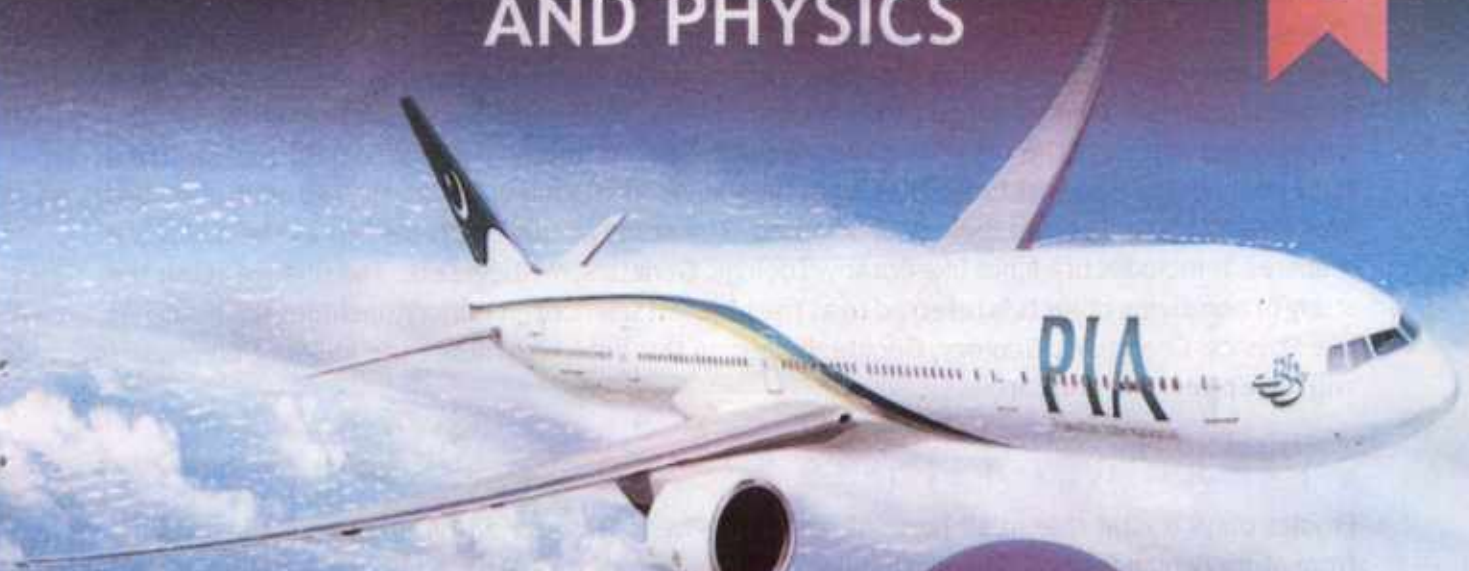
QIV. Solve the following.

1. Find the magnetic field due to a wire at 10 cm, if 1.3 A current is passing through the wire.

(Ans.  $B = 2.6 \times 10^{-5} \text{ T}$ )

# NATURE OF SCIENCE AND PHYSICS

UNIT  
9



How do  
airplanes, flying  
high in the sky find  
their way towards  
the right  
destination?

## Student Learning Outcomes (SLOs)

### The students will

- [SLO: P-09-G-01] Describe physics as the study of matter, energy, space, time and their mutual connections and interactions.
- [SLO: P-09-G-02] Explain with examples that physics has many sub-fields, and in today's world involves interdisciplinary fields.
- [SLO: P-09-G-03] Explain with examples how Physics is a subset of the Physical Sciences and of the natural sciences.
- [SLO: P-09-G-04] State that scientists who specialize in the research of physics are called Physicists.
- [SLO: P-09-G-05] Brief with examples that science is a collaborative field that requires interdisciplinary researchers working together to share knowledge and critique ideas.
- [SLO: P-09-G-06] Understand the terms 'hypothesis', 'theory' and 'law' in the context of research in the physics.
- [SLO: P-10-G-07] Explain, with examples in Physics, falsifiability as the idea that a theory is scientific only if it makes assertions that can be disproven.
- [SLO: P-09-G-08] Differentiate the terms 'science', 'technology' and 'engineering' with suitable examples.



The word “science” has been originated from a Latin word “Scientia” which means “to know”. Therefore, science is to know about everything in nature. Science is the study of physical nature and its aspects. It contains imagination, experimentation and deduction. Humans has been gained knowledge about Science through experiments, observations and trials conducted on the surrounding matters. The organized knowledge collected through several sources has formed a huge pool, which is so vast today that it has been divided into many branches. Two main branches are: Physical Sciences and Biological Sciences. The study of life is referred to as the biological sciences. It includes branches like Botany, Zoology, Genetics, Medicine etc. The science about the study of non-living objects is referred to as the physical sciences. It majorly includes the branches like Physics, Chemistry, Geology, Geography etc. In this book we will see the impact that physics will have on our life and career.

## 9.1 OBJECTIVES OF PHYSICS

Physics plays a vital role in all parts of our lives. Physics discuss everything in our surrounding: from atom (which is small enough that can't be seen even with electron microscope) to galaxies. Everything either natural (such as, the sky, stars, planets, moons, seas and birds etc.) or artificial (such as, submarines, heavy ships, vehicles, satellites, laptops and cellular phones etc.), all involve the laws of physics.

For example, a cell phone, which become the most common component of our life in today's technological world, can be used to facilitate us in many ways (see the figure 9.1). It helps us to locate the position of any person, the car that we have booked or to follow the map by using GPS satellite (see cover picture of this chapter). Aeroplanes and ships also use signal from GPS to follow their path towards the right destination and stay connected with the control office.



FIGURE 9.1 GOOGLE MAP WORKS WITH GPS



Aeroplane runs on the runway to create a pressure difference above and below its wings before it takes off. Similarly, birds use the difference in air pressures above and below their wings to keep themselves high up. Feathers of birds give good thermal insulation especially when fluffed up during winter (see figure 9.2). The sky seems blue when sunlight strikes and scatters off by the gas molecules in our atmosphere. The presence of large water reservoirs such as lakes and seas keep the climates of nearby land moderate due to the large heat capacity of water. Vehicles use the principles of mechanics and thermodynamics to transfer stored chemical energy in fuel to kinetic energy in rotating wheels. Submarines and heavy ships work on the principle of floatation. Cellular phones use electronic

### FIGURE 9.2 PHYSICS AND BIRDS

Birds fluff their feathers during winter to gather more warm air



components and the principles of electromagnetic waves to transfer energy and information from one cellular phone to another. These are just a few examples that involve physics.

### FOR YOUR INFORMATION

Physics is the branch of science that describes the matter, energy, space, time and their mutual connections and interactions throughout the universe.

The objective of physics is to offer an understanding of the physical world by developing theories based on observations and experiments. A scientist who specializes in the field of physics is termed as '*physicist*'. Physicists engage in theoretical and experimental research to explore and explain the fundamental laws of nature. Physicists express everyday happenings in mathematical formulas. These mathematical formulas are then used by all physicists and engineers to guess results of their experiments. For example, Isaac Newton (1642-1727) found the laws behind the motion of bodies, which we now used to design rockets that travel in outer space (to the moon and other planets). Physicists also improve the laws of physics from time to time according to experimental results. For example, Isaac Newton established the laws of motion working at normal speeds, but these laws fail for object's moving with high speed that approaches the speed of light. Albert Einstein (1879-1955) solved this issue by giving the theory of relativity. Theory of relativity gives the same result as Newton's laws of motion at slow speeds, but is more accurate as speeds approaches the speed of light. Hence science is a collaborative field that requires interdisciplinary researchers working together to share knowledge and critique ideas.



## ACTIVITY



- Look around in your class-room and give name of some devices or things which involve physics.
- Discuss the phenomenon of physics that is working there.
- Discuss one natural physics phenomenon that is happening around you.

## 9.2 FIELDS OF PHYSICS

Physics is considered to be the most fundamental of all the sciences. Physics has many sub-fields, and in today's world it involves interdisciplinary fields. In order to study biology, chemistry, or any other natural science, one should have a firm understanding of the principles of physics. For example, biology uses the physics principles of fluid movement to understand how the blood flows through the heart, arteries, and veins. Chemistry relies on the physics of subatomic particles to understand why chemical reactions take place. Geology uses the physics of seismic waves and energy transfer to determine the magnitude and location of earthquakes. Astronomy and cosmology rely on the laws of physics such as theory of relativity to describe the workings of the universe. Some fields of physics are given below.

**BIOPHYSICS:** Biophysics is the study of various characteristics and systems of living body. Fluid dynamics of blood flow and respiration, radiation in diagnostics and treatment etc., are studied in biophysics.

**ASTRONOMY:** Astronomy is the study of everything in the universe beyond Earth's atmosphere. It deals with celestial objects (such as the Sun, the Moon, the planets, and the stars), space and the physical universe as a whole. To study astronomy, astronomers have to stay up late at night to see the celestial objects with the help of a powerful telescope.

**ASTROPHYSICS:** Astrophysics is the study of physical nature of stars and other celestial bodies, and the application of the laws and theories of physics to the interpretation of astronomical observations.

An Astrophysicist investigate the astronomical events such as formation of stars, planets and galaxies, to learn more about the universe.

**COSMOLOGY:** Cosmology is the study of the origin, development, structure, history, and future of the entire universe. cosmology spans the entire universe from birth to death, with a wealth of mysteries at every stage.

**THERMAL PHYSICS:** Thermal physics is the collective study of statistical mechanics, thermodynamics and kinetic theory of gases.

**OPTICS:** Optics is the branch of physics that studies the nature and properties of light, its interactions with matter and the construction of instruments that use or detect it.

**Nuclear Physics:** Nuclear physics is the study of the structure, properties and behaviour of atomic nuclei.



the radiation from unstable nuclei.

**PARTICLE PHYSICS:** Particle physics (or high energy physics) is the study of fundamental particles and forces that create matter and radiation.

**ELECTROMAGNETISM:** Electromagnetism is a branch of physics in which we study the electromagnetic forces between electrically charged particles.

**ACOUSTICS:** Acoustics is the branch of physics that deals with the production, transmission, control, reception, and effects of sound.

**COMPUTATIONAL PHYSICS:** Computational physics is the study and implementation of numerical analysis to solve complex problems in physics.

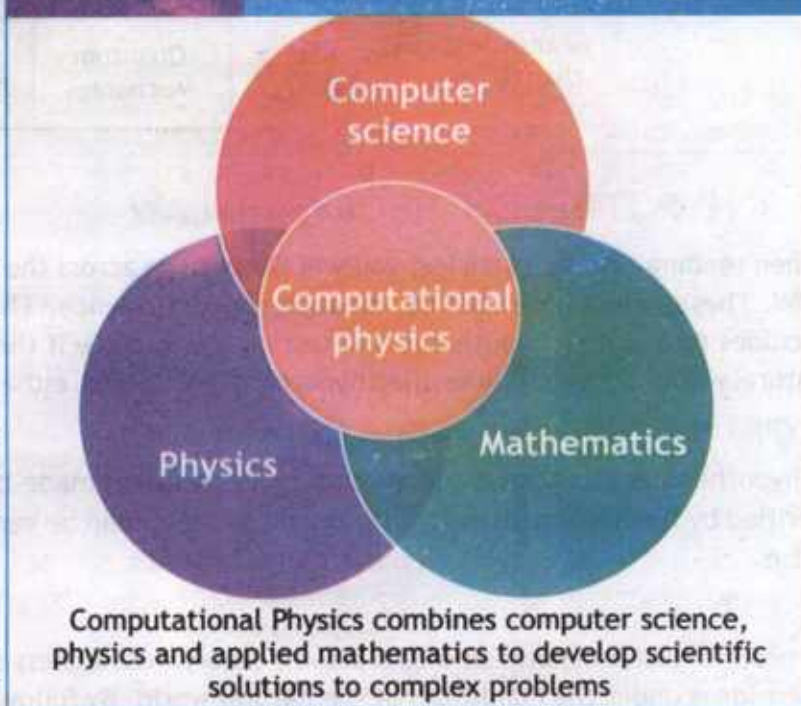
**GEOPHYSICS:** Geophysics is the branch of physics in which we study about the structure of the Earth, physical processes and phenomena occurring especially in the earth and in its vicinity.

**CLIMATE PHYSICS:** Climate Physics is the branch of physics that deals with the study of the Earth's climate.

**CLASSICAL MECHANICS:** Classical mechanics is the branch of physics in which we study the motion of macroscopic objects under the action of forces.

**QUANTUM MECHANICS:** Quantum mechanics is the branch of physics in which we

**FIGURE 9.3 COMPUTATIONAL PHYSICS**



study the mathematical description of motion and behavior of microscopic particles under different situations.

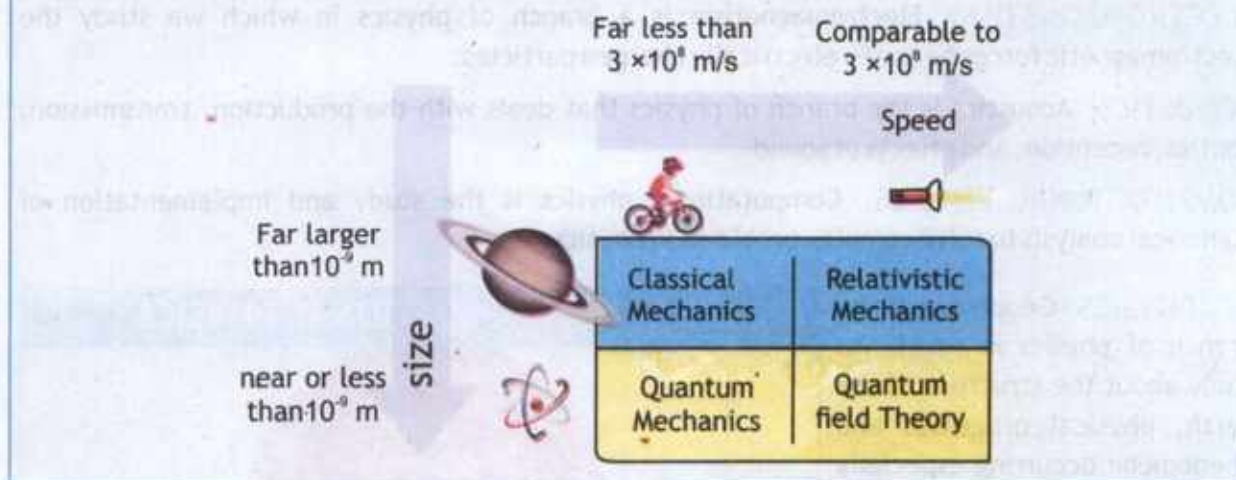
**RELATIVISTIC MECHANICS:** Relativistic mechanics is the branch of physics in which we study the system of bodies whose relative velocities approaches to the speed of light  $c$ , or whose kinetic energies are comparable with the product of their masses ( $m$ ) and the square of the velocity of light ( $c$ ).

A physicist is a scientist who specializes in any field of physics, which covers the interactions of matter and energy at all length and time scales in the physical universe. A Physicists conduct in-depth research on different topics.



## FOR YOUR INFORMATION

Relation between Classical Mechanics, Quantum Mechanics, Relativistic Mechanics and Quantum Field Theory can be easily cleared by the diagram below.



### 9.3 HYPOTHESIS, THEORY AND LAW

When reading research articles, you will likely to go across the terms HYPOTHESIS, THEORY and LAW. These words have specific meanings in the science. The scientific method of research includes formulating hypotheses and testing them to see if they hold up to the realities of the natural world. Successfully verified hypotheses can lead to either theories or laws.

#### HYPOTHESIS

A hypothesis is a tentative assumption or explanation made before any research that can be verified by further investigation. It is made so that it can be verified to see if it might be true or false.

#### THEORY

In order to put a hypothesis into a proven theory, researchers design experiments to challenge their ideas under the conditions of the natural world. By following to the scientific method and working carefully, scientists can finally accumulate enough evidence to prove their hypothesis, thus making it a theory with predictive and extrapolative power. A scientific theory is a description of the nature that scientists have verified through rigorous testing. A theory explains how nature behaves under specific conditions. Theories tend to be as broad as their supporting scientific evidence will permit. A theory is a well-supported explanation of some aspect of the natural world of observations.

Some examples of famous scientific theories that have shaped our understanding of the natural world, are listed below.

- Kinetic Molecular Theory.
- Theory of General Relativity.



## LAW

A law is a statement that summarises an observed regularity or pattern in nature and gives the relationship between variables. Like theories, laws describe phenomena that the scientists have found to be provably true. Laws develop from discoveries and rigorously tested hypotheses, and new theories generally uphold and expand laws.

Examples of some famous laws include:

- Newton's Law of Universal Gravitation.
- Newton's Laws of Motion.
- Boyle's Law.
- Laws of Thermodynamics.

Both scientific laws and theories are considered as fact. However, theories and laws can be disproven when new evidence appears. For example, certain accepted truths of Newtonian physics were partially disproven by Albert Einstein's theory of relativity. The work of Louis Pasteur disproved prior theories of disease in animals. If thorough scientific research upends a previously held belief, scientists must find new hypotheses that better describe how nature works.

## DIFFERENCE BETWEEN THEORY AND LAW

Scientific laws differ from theories in sense that laws tend to describe a narrower set of conditions. A scientific law might explain the relationship between two specific forces or between two changing substances in a chemical reaction. Theories are normally more expansive and they focus on the how and why of natural phenomena.

## 9.4 SCIENCE, TECHNOLOGY AND ENGINEERING

Science and technology are quite different. Science is a system of knowledge that is concerned with establishing accurate conclusions about the behavior of everything in the universe. It is a field in which hypotheses are made, information is gathered, and experiments are performed to determine how something in our natural world works or behaves. Technology, on the other hand, is a field that uses scientific knowledge to develop material products or processes that satisfy human needs and desires.

Science is the pursuit of knowledge and understanding through systematic study, experimentation, and observation. It is the pursuit and application of knowledge and understanding of the natural and social world.

For example in physics, scientists study the principles of motion and energy to understand the behavior of objects. This may include conducting experiments to establish the laws of motion or formulating theories to clarify the forces of gravity.

Technology is the application of scientific knowledge for practical purposes, resulting in the development of tools, machines, and systems. It involves the creation and use of tools, machines, systems, and techniques to solve problems, achieve goals, or perform specific functions.



The development of smartphones for instance is a technological advancement. It involves the application of scientific principles in physics, materials science, and engineering to create a device that combines communication, computation, and various other functions.

Engineering is the practical use of scientific and mathematical principles to create and construct structures, devices, and processes. It requires the application of knowledge to solve real-world problems in a creative and organized manner.

For instance, civil engineering focuses on designing and building infrastructure like bridges, roads, and buildings. Civil engineers utilize scientific principles, such as materials science and structural mechanics, to ensure the development of secure and effective structures.

While these fields are distinct, they are interconnected. Advances in science often lead to technological innovations, and engineers use scientific knowledge to create new technologies that, in turn, drive further scientific exploration.

### SUMMARY

**Physics** is the branch of science that describes the matter, energy and their mutual relationship.

A **hypothesis** is a tentative assumption or explanation made before any research that can be verified by further investigation.

A **theory** explains how nature behaves under specific conditions.

A **law** is a statement that summarises an observed regularity or pattern in nature and gives the relationship between variables.

**Technology** is tools, including methods, that assist people in accomplishing tasks.

**Engineering** is the process of studying and developing technology.

### EXERCISE

#### MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option.

1. What is the best definition of the term "theory," as it is used in science?
  - A. A theory is a guess or hunch about something that has occurred in nature.
  - B. A theory is a comprehensive set of ideas explaining a phenomenon in nature.
  - C. A theory is based on verifiable laws and can be proven true
  - D. A theory is a hypothesis that uses laws and observation to make an assumption.
2. Which statement below correctly identifies the difference between laws and theories?
  - A. Laws describe phenomena, while theories explain why phenomena exist.
  - B. Laws are a statement of fact, while theories are a statement of opinion.
  - C. Laws explain why phenomena exist, while theories explain how.
  - D. Laws are a prediction of phenomena, while theories are an explanation.





3. Why do scientists develop a hypothesis before conducting research?
  - A. It gives them direction on how to interpret the results of their research.
  - B. It helps to predict outcomes and define the parameters of the research.
  - C. Hypotheses give the researcher an outcome to shape their work around
  - D. Hypotheses help a researcher decide which observations to record and which to ignore.
4. The Branch of Physics that is most important when studying how glasses help people see:
  - A. Thermodynamics      B. Electromagnetism      C. Mechanics      D. Optics
5. when studying how air conditioners cool your house, then it is:
  - A. Thermodynamics      B. Electromagnetism      C. Nuclear Physics      D. Optics
6. The branch of Physics that deals with the particles such as neutrons and protons:
  - A. Solid State Physics      B. Plasma Physics      C. Electricity      D. Nuclear Physics
7. Which branch of science plays an important role in engineering?
  - A. Biology      B. Chemistry      C. Physics      D. Genetics
8. Physics is one of the branches of:
  - A. Physical sciences      B. Biological sciences      C. Social science      D. Life sciences

## SHORT RESPONSE QUESTIONS

Give a short response to the following questions

1. Define the following branches of physics:  
Biophysics, Astrophysics, Optics, Relativistic Mechanics, Nuclear Physics, Acoustics, Computational Physics  
Define the terms theory and law. Also give two examples of each.
2. Define Hypothesis?
3. What is the difference between classical mechanics and quantum mechanics?
4. What determines the validity of a theory?
5. Which part of the study is not handled by the classical study of physics?

## LONG RESPONSE QUESTIONS

Give a detailed response to the questions below.

1. Discuss the importance of physics in our daily life.
2. Briefly discuss the importance of physics in other disciplines of science.
3. Differentiate the terms 'science', 'technology' and 'engineering' with suitable examples.
4. Explain the terms, hypothesis, theory and law with examples.

## GLOSSARY

**Acceleration** is the time rate of change of velocity and is a vector quantity.

**Atmospheric Pressure** or barometric pressure is the force exerted by the air (its weight) on unit area.

**Bar magnet and solenoid** have same pattern of magnetic fields.

**Barometer** is a device used to measure atmospheric pressure.

**Centre of gravity** is a single point where the whole weight of an object appears to act.

**Centre of mass** of the body is the point about which mass is equally distributed in all directions.

**Centripetal force** is the force that compels a body to travel a circular path. It may be electric, gravitational, or any other force.

**Density** is mass per unit volume

**Diamagnetic materials** have zero net magnetic fields per atom.

**Displacement** is the shortest distance from the initial and final position of a body.

**Distance** is how much ground an object has covered during its motion.

**Drag Force** is the force applies acting opposite towards the motion of the object which is moving submerge in a certain fluid.

**Dynamics** is the branch of mechanics in which we discuss the motion of bodies along with causes of motion of bodies.

**Earth** has a magnetic field which resembles with the field of a bar magnet and shield all the life on it from cosmic rays and radiation from the Sun and outer space.

**Earth's geographical and magnetic poles** are not same but inclined at an angle of 11.3 degrees.

**Efficiency** is the ratio of useful energy or work output to the total energy or work input.

**Elasticity** is the property of a body, which enables the body to regain its original dimension when the deforming force acting on the body is removed.

**Energy** is the capacity of a body to do work.

**Engineering** is the process of studying and developing technology.

**Error** is the difference between the measured and actual values.

**Ferromagnetic materials** have large net magnetic field per atom.

**Force** is a physical quantity which moves or tends to move a body, stops or tends to stop a moving body or which tends to change the speed and direction of a moving body.

**Frictional force** is the force that resists motion of objects on a surface.

**Graph** is a line straight or curved that shows relation between two quantities out of which one varies as a result of change in other.

**Gravitational Field Strength** is defined as the force per unit mass that earth exerts on a body.

**Gravitational potential energy** is the energy possessed or acquired by an object due to a change in its position when it is present in a gravitational field and is given by  $E = mgh$

**Heat** is the form of energy which is transferred from one body to another body due to the difference in temperature.

**Hooke's law** states that within elastic limits the extension (or compression) is directly proportional to the force applied.

**Hypothesis** is a tentative assumption or explanation made before any research that can be verified by further investigation.

**Impulse** is a certain amount of force you apply for a certain amount of time to cause a change in momentum

**Induced magnetism** is the phenomenon in which a material is magnetized by placing it inside an external magnetic field.

**Inertia** is a property of matter by which it remains at the state of rest or in uniform motion

**Kinetic Energy** is the energy of an object due to its motion and is given by  $E = \frac{1}{2}mv^2$

**Law** is a statement that summarizes an observed regularity or pattern in nature and gives the relationship between variables.

**Law of conservation of energy** states that energy can neither be created nor destroyed. It can be converted from one form to another or transferred from one body to another, but the total amount remains constant.

**Law of Conservation of Momentum** states that if there is no external force applied to a system, the momentum of that system remain constant.

**Like poles of magnets** always repel each other, while unlike poles attract each other.

**Liquid Pressure** is the force exerts by water on the walls of the container from inside

**Magnetic domain** is the group of atoms whose N-poles are aligned in the same direction.

**Magnetic field** is the region of space around a magnet in which it is attracted by the magnetic pole of opposite polarity.

**Magnetic field lines** originate from the north-pole and terminate at south-pole.

**Magnetic materials** are always attracted by magnets and other magnetic materials.

**Magnetic shielding** is the phenomenon in which some region of space is made free from magnetic field.

**Magnets** are always found in dipole, i.e. they have an N-pole and an S-pole.

**Mass** is the quantity of matter in a body.

**Migrating birds** and animals use Earth's magnetic field to navigate.

**Moment of a force or Torque** is the measure of an object tendency to rotate about some point O.  
*Moment of a force = force  $\times$  perpendicular distance of the force to the point.*

**Momentum** is the product of mass and velocity. It is a vector quantity.

**Monometer** is one of the most accurate devices for measuring pressure, including atmospheric pressure in the lower ranges.

**Newton's First Law of Motion** states that everybody continues in its state of rest or uniform

motion in a straight line unless an external net force acts upon it.

**Newton's Second Law of Motion** states that whenever a net force acts on a body, it produces acceleration in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass of the body.

**Newton's Third Law of Motion** states that to every action there is an equal and opposite reaction.

**Orbital velocity** is the speed of an object revolving around another heavy object in an orbit.

**Paramagnetic materials** have small net magnetic field per atom.

**Pascal's Principle** states that if the pressure at one point of a confined fluid is increased by an amount, the pressure increases by the same amount at all other parts throughout the fluid.

**Permanent magnets** are those magnets which behave like a magnet even in the absence of current.

**Physical quantities** are measurable quantities

**Physics** is the branch of science which deals with the study of matter and energy.

**Plasma** is called fourth state of matter which is the ionized state of matter.

**Position** is the distance and direction of a body from a fixed reference point.

**Potential Energy** is the energy of an object due to its position.

**Power** is the rate of doing work or rate of conversion of energy.  $P = W/t$

**Prefix** is a word placed before quantities to modify their meaning.

**Pressure** is force applied per unit area.

**Principle of moments** states that for an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of the anti-clockwise moments taken about the same pivot.

**Renewable & Non-renewable Energy Resources** are such that renewable resources can naturally replenish themselves while non-renewable

resources cannot.

**Scalars** are physical quantities with magnitude only.

**Science** is natural explanations for apparent phenomena.

**Scientific Notation** is an internationally accepted way of writing numbers in which

**Screw Gauge** is a device used to measure a fraction of smallest scale division by

**Seven Base SI Units** are metre (length), kilogram (mass), second (time), ampere (current), candela (luminous intensity), Kelvin (temperature) and mole (amount of substance).

**Significant Figures** are the accurately known digits and first doubtful full digit in any sliding another scale over it.

**Speed** is time rate of change of distance and is a scalar quantity.

**Stability** of an object refers to the ability of the object to return to its original position when the force that changed its orientation is removed.

**States of matter** are four, which are named as Solids, Liquids, Gases and Plasma.

**Stop Watch** is an instrument used for measurement of time interval

**System International (SI)** is the system of units which consists of seven base units and a number of

derived units.

**Technology** is tools, including methods, that assist people in accomplishing tasks.

**Temperature** is the measure of degree of hotness or coldness of a body.

**Temporary magnets** are those magnets which behave like a magnet only in the presence of current.

**Terminal velocity** is the maximum constant velocity that a body can achieve while passing through a resistive (viscous) medium.

**Theory** explains how nature behaves under specific conditions.

**Thermometer** is a device which is used to measure temperature.

**Thermometry** is the branch of physics, which deals with the measurements of temperature.

**Vectors** are physical quantities with magnitude as well as direction.

**Velocity** is the time rate of change of displacement and is a vector quantity.

**Vernier calipers** is a device used to measure a fraction of smallest scale division by

**Weight** is the downward force with which the earth pulls a body towards its center.

**Work** is force multiplied by distance moved in the direction of the force  $W = FS$

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