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# PHYSICS

## 1. MEASUREMENTS

Physics is concerned with the study of objects around us, their nature and motion, and all natural phenomena and attempts to explain them on the basis of fundamental laws. Measurements form the basis for the study of different branches of physics such as astronomy, mechanics, heat, sound, light, electricity, electronics and nuclear physics. Many instruments that we use in our daily life such as computer, car, bus, clock, electrical and electronic instruments, and medical equipments function with several minute parts. We use accurate quantities of medicines for the protection of our health and treatment of the diseases. In sports events the winner is decided by such a short interval of time as one hundredth of a

second. Pollutants present in the order of a few parts in a million spoil the quality of air and water essential for life on earth.

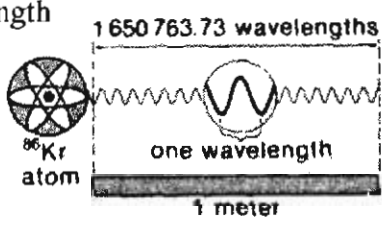
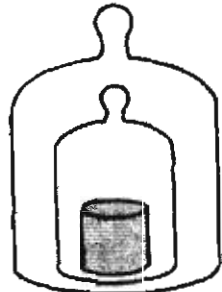
Scientific and technological developments in the fields of communication and transport have shrunk the globe to the size of a small village.

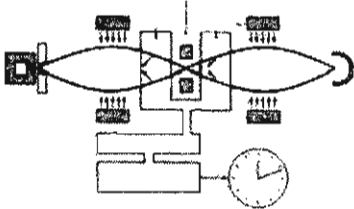
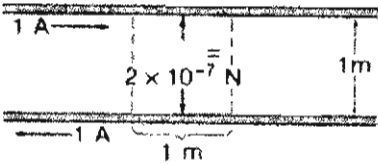
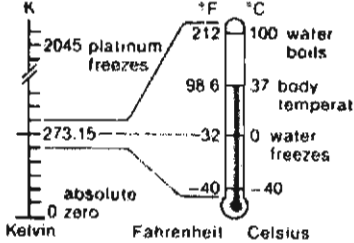

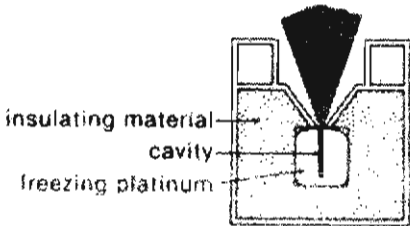
### 1.1 Fundamental units

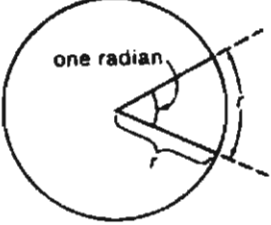
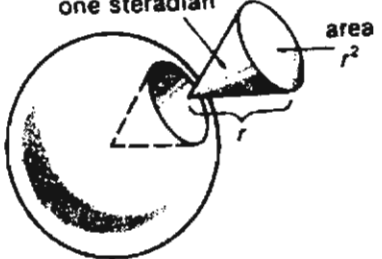
The International System of Units (SI – System International) is the version of the metric system established by an international agreement in 1971.

The SI system consists of seven base units and two supplementary units given in Table 1.1.

Table 1.1 SI units

Quantity	Unit, Symbol	Definition	Year
1. Length 	metre (m)	Distance travelled by light in a vacuum during $\frac{1}{299792458}$ of a second	1983
2. Mass 	kilogram (kg)	The mass of a cylinder of platinum – iridium alloy kept at Bureau of weights and measures at Paris and National Physical Laboratory, New Delhi	1889

Quantity	Unit, Symbol	Definition	Year
3. Time 	second (s)	Duration of 9192631770 cycles of radiation from a hyperfine transition of caesium – 133 atom.	1967
4. Electric current 	ampere (A)	Quantity of current which produce a force of $2 \times 10^{-7}$ N per metre length between two long parallel wires separated by a metre in a vacuum.	1948
5. Temperature 	kelvin (K)	$\frac{1}{273.15}$ of thermodynamic temperature of triple point of water	1967
6. Amount of substance 	mole (mol)	Amount of substance of a system that contains as many atoms, molecules or ions as there are atoms in 0.012 kg of carbon – 12	1971
7. Luminous intensity 	Candela (cd)	The luminous intensity $\frac{1}{600000}$ m <sup>2</sup> of a black body at the temperature of freezing platinum (2045 K).	1979

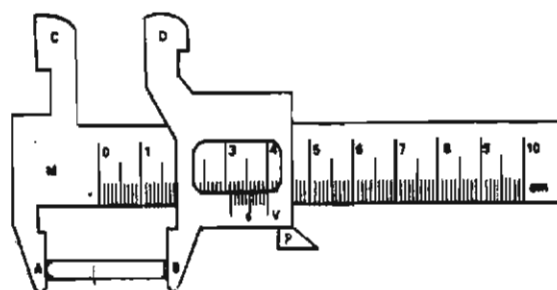
<i>Supplementary units</i>		
<i>Quantity</i>	<i>Unit, Symbol</i>	<i>Definition</i>
1. Plane angle 	Radian (rad)	The plane angle subtended by an arc of length equal to radius at the centre of a circle
2. Solid angle 	Steradian (sr)	The solid angle subtended by an area $r^2$ of a spherical surface at the centre of a sphere of radius $r$ .

## 1.2 Measurement of length

Observe the centimetre, millimetre divisions marked on a metre scale. We can measure the length of objects correct to one millimetre with this scale.

The smallest length that can be measured with a scale is called its least count. So, the least count of the metre scale is one millimetre.

For example, if we measure the length of an object 1 inch long, it lies between 2.5 and 2.6 cm. To measure how long the object extends beyond 2.5 cm mark, we need an auxiliary scale. Pierre Vernier, a French scientist designed the Vernier Callipers to measure lengths accurately using an auxiliary scale.



M = Main scale; V = Vernier scale  
P = Ratchet

*Fig 1.1 Vernier callipers*

### 1. Vernier Callipers

The Vernier Callipers has a fixed main scale with cm, mm divisions marked on it. A small movable scale called vernier scale slides on the main scale. The main scale made up of a steel plate, has two fixed vertical jaws as shows in figure. The vernier scale has a pair of jaws parallel to the fixed jaws.

By pressing a ratchet the vernier scale can be moved and fixed at any point on the main scale. The downward jaws are used to measure the outer dimensions and the upward jaws are used to measure inner dimensions of hollow objects. When the vernier scale moves through a distance a thin steel strip fixed to it extends from the end of the main scale by the same amount. This is used to measure depth of objects. Usually 9 main scale divisions are divided into 10 vernier scale divisions.

$$\text{Length of 1 V.S.D.} = \left(\frac{9}{10}\right) \text{Length of 1 M.S.D.}$$

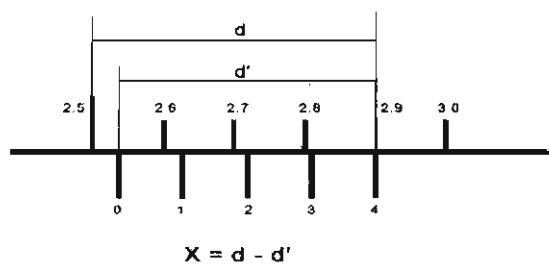
$$= \left(\frac{9}{10}\right) \times 1 \text{ mm}$$

$$= 0.9 \text{ mm}$$

$$\begin{aligned} \text{Least Count of Vernier Callipers} &= 1 \text{ M.S.D.} - 1 \text{ V.S.D.} \\ &= 1 \text{ mm} - 0.9 \text{ mm} \\ &= 0.1 \text{ mm} = 0.01 \text{ cm} \end{aligned}$$

When the two jaws are in contact the zero of the vernier scale coincides with the zero of the main scale.

### Measurement of length using Vernier Callipers



*Fig 1.2 Measuring length*

Gently hold objects such as a cylinder or sphere between the two jaws of the Vernier Callipers. Observe the position of the zero of the vernier scale on the main scale and note it as the main scale reading.

The Vernier Scale division which coincides with any one of the main scale division gives the Vernier scale reading.

$$\text{Length of object} = \text{Main scale reading} + (\text{Vernier scale reading} \times \text{Least Count})$$

If we measure an object of length one inch, its length will be between 2.5 and 2.6 cm. The method of measuring how far the length of the object extends beyond the 2.5 cm mark on the main scale using the vernier scale is explained in Fig.1.2.

As the 4<sup>th</sup> division of the vernier scale coincides with a division in the main scale,

$$\begin{aligned} x &= d - d' \\ &= 4 \text{ main scale divisions} - 4 \text{ vernier scale divisions} \\ &= 4 (1) - 4(0.9) \\ &= 4 - 3.6 \\ &= 0.4 \text{ mm.} = 0.04 \text{ cm.} \end{aligned}$$

$$\begin{aligned} \text{So, the length of the object} &= 2.5 + 0.04 = 2.54 \text{ cm.} \end{aligned}$$

### Problem

A microscope has main scale divisions of 0.5 mm each and 49 main scale divisions divided into 50 vernier scale divisions. Find the least count of the instrument.

$$1 \text{ M.S.D.} = 0.5 \text{ mm}$$

$$1 \text{ V.S.D.} = \frac{49}{50} \text{Length of 1 M.S.D.}$$

$$\text{Least Count} = 1 \text{ M.S.D.} - 1 \text{ V.S.D.}$$

$$= \left(1 - \frac{49}{50}\right) 1 \text{ M.S.D.}$$

$$= \frac{1}{50} \times 1 \text{ M.S.D.}$$

$$= \frac{1}{50} \times 0.5 \text{ mm}$$

$$= 0.01 \text{ mm}$$

$$\text{L.C.} = 0.001 \text{ cm}$$

## 2. Zero error and Zero correction

### 1) Zero error

When the jaws of vernier callipers are in contact, the zero of vernier scale coincides with the zero of the main scale. If the zero of the vernier scale is on the right or left of the zero of the main scale, then it is called **zero error**.

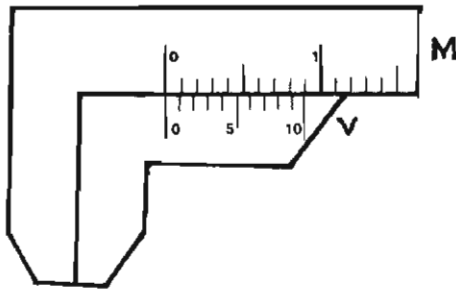


Fig 1.3 Zero error

### 2) Positive error

If the zero of the vernier scale is on the right of the zero of the main scale when the two jaws are in contact, it is called **positive error**.

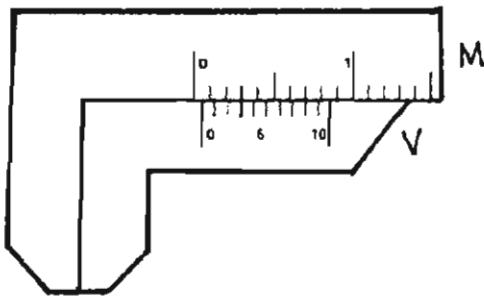


Fig 1.4 Positive error

$$\text{Positive error} = \text{Vernier Scale coincidence} \times \text{Least Count}$$

$$\text{Zero correction} = - \text{Zero error}$$

$$\text{Actual length} = \text{Observed length} + \text{Zero correction}$$

In fig.1.4 the vernier scale coincidence is 3.

$$\text{Positive error} = 3 \times 0.01 = 0.03 \text{ cm}$$

$$\text{Zero correction} = - 0.03 \text{ cm}$$

$$\text{Actual length} = \text{observed length} - 0.03 \text{ cm}$$

### 3) Negative error

If the zero of the vernier scale is on the left of the zero of the main scale when the two jaws are in contact, it is called **negative error**.

In fig.1.5 the vernier scale coincidence is 5

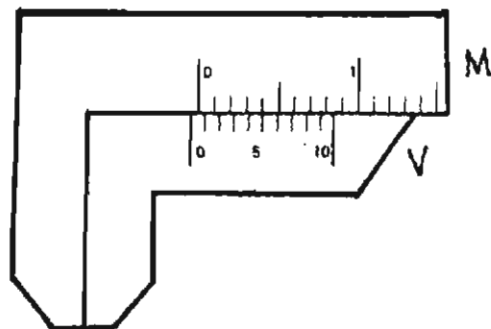


Fig 1.5 Negative error

$$\begin{aligned} \text{Negative error} &= -(10-5) \times 0.01 \\ &= -5 \times 0.01 = -0.05 \text{ cm} \end{aligned}$$

$$\begin{aligned} \text{Zero correction} &= - \text{zero error} \\ &= - (- 0.05 ) \text{ cm} \\ &= + 0.05 \text{ cm} \end{aligned}$$

$$\begin{aligned} \text{Actual length} &= \text{Observed length} \\ &\quad + \text{Zero correction} \end{aligned}$$

Calculate the least count and zero error of the vernier callipers. Gently hold the object whose length is to be determined between the jaws and note down the main scale and vernier scale readings.

$$\begin{aligned} \text{Actual length of the} &= \text{Observed length} \\ \text{object} &\quad + \text{Zero correction} \end{aligned}$$

Make measurements by holding the object in different positions and calculate its average length.

**Activity:** Measure the various dimensions of a metal cylinder, a sphere and a coin. Tabulate the readings and calculate their volumes.

**Table 1.2 Dimensions of a cylinder, a sphere and a coin**

Least count = ..... cm      Zero error = ..... cm      Zero correction = ..... cm

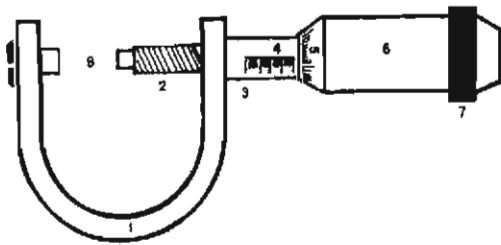
Object	S.No.	Main Scale Reading (cm)	Vernier Coincidence	VSR = (V.C x L.C) (cm)	Observed Length = MSR + VSR (cm)	Actual Length (cm)
Length of cylinder	1					
	2					
	3					
Diameter of cylinder	1					
	2					
	3					
Diameter of sphere	1					
	2					
	3					
Diameter of coin	1					
	2					
	3					
Thickness of coin	1					
	2					
	3					

- (1) Length of cylinder ( $l$ ) = ..... cm = ..... x  $10^{-2}$  m.  
 Diameter of cylinder ( $d$ ) = ..... cm = ..... x  $10^{-2}$  m.  
 Radius of cylinder ( $r$ ) =  $\frac{d}{2}$  = ..... cm = ..... x  $10^{-2}$  m.  
 Volume of cylinder ( $V$ ) =  $\pi r^2 l$  = .....  $\text{cm}^3$  = ..... x  $10^{-6}$   $\text{m}^3$
- (2) Diameter of sphere ( $d$ ) = ..... cm = ..... x  $10^{-2}$  m  
 Radius of sphere ( $r$ ) =  $\frac{d}{2}$  = ..... cm = ..... x  $10^{-2}$  m  
 Volume of sphere ( $V$ ) =  $\frac{4}{3} \pi r^3$  = .....  $\text{cm}^3$  = ..... x  $10^{-6}$   $\text{m}^3$
- (3) Diameter of coin ( $d$ ) = ..... cm = ..... x  $10^{-2}$  m  
 Radius of coin ( $r$ ) =  $\frac{d}{2}$  = ..... cm = ..... x  $10^{-2}$  m  
 Thickness of coin ( $h$ ) = ..... cm = ..... x  $10^{-2}$  m  
 Volume of coin ( $V$ ) =  $\pi r^2 h$  = .....  $\text{cm}^3$  = ..... x  $10^{-6}$   $\text{m}^3$

### 1.3 Screw Gauge

The screw gauge is used to measure lengths, correct to one hundredth of a millimetre. Thicknesses of wire, plate and sheets of paper can be accurately determined using the screw gauge. The lengths are measured by finding the distance advanced by the tip of a fine screw.

**Construction:** The screw gauge consists of a U shaped metal frame. A hollow cylinder with fixed thread cut inside is attached to one end of the metal frame. A fine screw works inside the cylinder. A millimetre scale, marked on the cylinder parallel to the axis of the screw, is called the pitch scale. A sleeve with a bevelled edge is attached to the head of the screw and the edge is



- |                   |                    |
|-------------------|--------------------|
| 1. U-shaped frame | 5. Head scale      |
| 2. Screw          | 6. Hollow cylinder |
| 3. Metal cylinder | 7. Ratchet         |
| 4. Pitch scale    | 8. Plane surface   |

*Fig 1.6 Screw gauge*

divided into 100 equal divisions. This is called the head scale. The tip of the screw has a plane surface. A stud with a plane parallel surface is fixed to the other end of the U shaped frame. A ratchet attached to the head of the screw prevents excessive tightening of the screw.

#### 1. Principle of the screw gauge

The screw gauge works on the principle of a screw. When a screw working

inside a fixed nut is rotated about an axis its tip advances through a distance proportional to the number of rotations of the screw.

**The linear distance through which the tip moves for one rotation is equal to the distance between any two consecutive threads of the screw and is called pitch of the screw.**



*Fig 1.7 Principle of screw*

#### The pitch and least count of a screw gauge

Make the zero of the head scale coincide with any division of the pitch scale and note down the pitch scale reading. Give 10 full rotations to the head scale and note the change in the pitch scale reading.

$$\text{Pitch} = \frac{\text{Distance moved on the pitch scale}}{\text{Number of rotations}}$$

$$\begin{aligned} \text{Distance moved by the screw} \\ \text{for the 10 rotations} &= 10 \text{ mm} \end{aligned}$$

$$\begin{aligned} \text{Distance moved by the} \\ \text{screw for one rotation} &= \frac{10}{10} = 1 \text{ mm} \end{aligned}$$

$$\text{Pitch of the screw} = 1 \text{ mm}$$

When the screw is turned through 1 division of the head scale the distance moved by the tip of the screw is the least count of the screw gauge.

$$\text{Least count} = \frac{\text{Pitch of the screw}}{\text{No. of head scale divisions}}$$

$$\therefore \text{Least count} = \frac{1}{100} = 0.01 \text{ mm}$$

## 2. Zero error and Zero correction

When the plane surface of the screw is in contact with stud, the zero of the head scale coincides with the zero of the pitch scale then there is no zero error in the screw gauge. If the zero of the head scale lies below or above the reference line of the pitch scale, then there is positive or negative error respectively in the screw gauge.

### Positive error

When the tip of the screw is in contact with the stud, let the fifth division of head scale coincide with the pitch scale

Zero error = +5 head scale divisions

When there is no gap between the head of the screw and the stud, the head scale reading is  $5 \times 0.01 = 0.05$  mm.

Therefore, every time, the reading is increased by 0.05 mm.

So, to find the actual length the positive error has to be deducted from the observed length.

Zero correction = - Zero error

Actual length = Observed length + Zero correction

### Negative error

When the tip of the screw is in contact with the stud, if the zero of the head scale lies above the pitch scale, then the

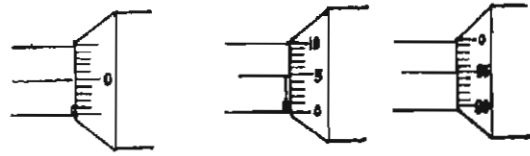


Fig 1.8 Zero error and corrections

error is called negative error. If the 95<sup>th</sup> head scale division coincides with the pitch scale;

$$\begin{aligned} \text{Zero error} &= -(100 - 95) \times 0.01 \text{ mm} \\ &= -5 \times 0.01 = -0.05 \text{ mm} \end{aligned}$$

Zero correction = -Zero error

Actual length = Observed length + Zero correction

So, to find the actual length, the negative error has to be added to observed length.

## 3. Measurement of thickness of a wire using the screw gauge

Find the pitch, least count and zero error of the screw gauge.

Gently grip the given wire between the tip of the screw and the stud by rotating the head of the screw. Note the pitch scale and head scale readings.

Head scale reading = Corrected head scale coincidence  $\times$  Least count

Thickness of the wire = Pitch scale reading + Head scale reading

Table 1.3 Thickness of a wire

Least count = 0.01 mm      Zero error =  $\pm$ ..... mm      Zero correction =  $\mp$  ..... mm

S. No.	Pitch Scale Reading (mm)	Head Scale coincidence	Corrected Head scale coincidence	Thickness = Pitch scale reading + (corrected) head scale coincidence $\times$ least count) mm

Mean thickness of a wire =

Make measurement of the thickness for various positions of the wire and calculate the average value.

**Activity:** Find the thickness of a glass strip, thin wire, plate, sheets of paper and plastic using the screw gauge.

### Problems

1) Find the thickness of the object, if the pitch scale reading is 3 mm and head scale reading is 97 in a screw gauge of least count 0.01 mm.

$$\begin{aligned} \text{Thickness} &= \text{Pitch Scale Reading} \\ &+ (\text{Head Scale} \\ &\text{Coincidence} \times \text{Least} \\ &\text{Count}) \\ &= 3 + (97 \times 0.01) \text{ mm} \\ &= 3.97 \text{ mm} \\ &= 3.97 \times 10^{-3} \text{ m} \end{aligned}$$

2) What is the least count of a screw gauge with a pitch of 1 mm and 50 divisions on the head scale? What is the thickness of the object if the pitch scale reading is 6 mm and head scale reading is 46?

$$\begin{aligned} \text{Least count} &= \frac{\text{Pitch}}{\text{No. of divisions on} \\ &\text{the head scale}} \\ &= \frac{1}{50} = 0.02 \text{ mm} \\ &= 0.02 \times 10^{-3} \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Thickness} &= \text{Pitch Scale Reading} \\ &+ (\text{Head Scale} \\ &\text{Coincidence} \times \text{Least} \\ &\text{Count}) \\ &= 6 + (46 \times 0.02) \text{ mm} \\ &= 6 + 0.92 = 6.92 \text{ mm} \\ &= 6.92 \times 10^{-3} \text{ m.} \end{aligned}$$

**Activity:** Compare the thickness of paper in your Science text book and note book by finding the thickness of (1) 10 sheets and (2) a single sheet of paper.

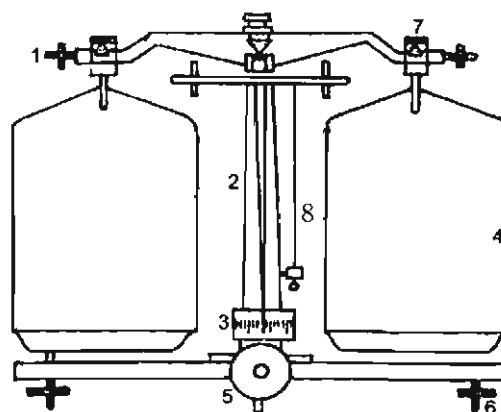
### 1.4 Physical Balance

The physical balance is used to find the mass of an object correct to a milligram.



*Fig 1.9 Beam of balance*

A metal rod moves up and down inside a hollow metal pillar fixed to a wooden base with three levelling screws to keep the balance in a horizontal plane. A metal beam is supported horizontally at its centre by a knife edge resting on the hard surface of the metal rod. At equal distances from the centre and at the edges of the beam two identical scale pans are suspended from two stirrups resting on two upward knife edges made of hard agate stone. A plumb line is suspended from a rigid support at the top of the pillar.



- |                    |                    |
|--------------------|--------------------|
| 1. Adjusting screw | 5. Handle          |
| 2. Pillar          | 6. Levelling screw |
| 3. Ivory scale     | 7. Hanger          |
| 4. Weight pan      | 8. Plumb line      |

*Fig 1.10 Physical balance*

By turning the handle attached to the metal rod, the beam is raised. A long pointer fixed to the centre of the horizontal beam oscillates on an ivory scale fixed at the bottom of the pillar and 0, 10, 20 divisions marked on it.

To make the pointer swing equally on either side of the scale two adjusting screws are provided at the ends of the beam. The balance is kept inside a wooden box with glass doors to protect it from dust and air currents.

### Weight Box

The weight box contains weights in grams and milligrams and a forceps to handle the weights.

Weights in grams: 200, 100, 50, 20, 20, 10, 5, 2, 2, 1.

Weights in milligrams: 500, 200, 200, 100, 50, 20, 20, 10.

### Methods of handling the physical balance

- 1) Adjust the levelling screws to make the balance horizontal so that the plumb line is parallel to the pillar.
- 2) Adjust the screws at the ends of the beam to make the pointer to swing equally on either side of the ivory scale.
- 3) Avoid weighing a body while it is hot.
- 4) The object should be placed on the left pan and the weights on the right pan.
- 5) Avoid adding or removing weights from the pan when the beam is raised.
- 6) The weights should be handled only with forceps.

**Resting point of the balance:** When the beam is raised the pointer swings on the

ivory scale and the extreme points on the left and right are called left and right turning points respectively. The amplitude of the oscillations decrease and finally the pointer comes to rest at a point on a scale. This is known as the resting point.

**Zero resting point:** The resting point of the balance when the scale pans are empty is called the zero resting point.

Raise the beam and adjust the pointer to swing equally on either side. Starting from left, note down 5 consecutive turning points, three on the left and two on the right.

Calculate averages of left turning points and right turning points. Hence calculate the average of the two average turning points. This gives the zero resting point of the balance.

**Example:** Zero Resting point

<i>Turning point</i>	
<i>Left</i>	<i>Right</i>
4	17
5	16
5	
Average $\frac{14}{3} = 4.67$	$\frac{33}{2} = 16.5$

$$\begin{aligned} \text{Zero resting point} &= \frac{4.67 + 16.5}{2} \\ &= \frac{21.17}{2} = 10.58 \end{aligned}$$

### 1. Mass of an object correct to a centigram

Make the balance horizontal. Raise the beam and adjust the pointer to swing equally on either side. Starting from the left note down 5 consecutive turning points and

**Table 1.4 Mass of an object correct to a milligram**

S. No.	Pan		Tuning points		Resting Point	Correct Weight $10^{-3}$ kg
	Left	Right Weight $\times 10^{-3}$ kg	Left	Right		
1	–	–	4 5 5	17 16	10.58 (a)	
2	Object	14.240	5 5 6	17 17	11.17 (b)	
3	Object	14.250	6 6 7	14 14	10.17 (c)	14.246

calculate the zero resting point of the balance. Place the object on the left pan and suitable weights on the right pan. Adjust the weights such that the pointer swings equally on either side on the ivory scale.

Find the resting point for this weight. If this resting point is higher than the zero resting point, add 10 milligram to the weights; if lower than the zero resting point, remove 10 mg from the weights and find the resting point again.

Let **a** be the zero resting point, **b** higher resting point and **c** the lower resting point. The weight corresponding to that resting point which is closer to the zero resting point gives the mass of the object correct to a centigram.

## 2. Mass of an object correct to a milligram

The method of finding the mass of an object correct to a milligram is illustrated in Table 1.4

$$\text{Weight of an object} = W + \left( \frac{10}{(b-c)} \times (b-a) \right) \times 10^{-3} \text{ g}$$

$$= 14.240 + \left( \frac{10}{1} \times 0.59 \right) \times 10^{-3} \text{ g}$$

$$= 14.240 + 0.0059 = 14.2459\text{g}$$

$$W = 14.246 \text{ g}$$

**Activity:** Find the mass, length and diameter of a small metal cylinder with a physical balance, vernier callipers and screw gauge respectively. Calculate from these measurements the density of the material of the cylinder and compare the results with that given in data table.

### Some basic concepts

- \* The SI system of units was established by international agreement in 1971.
- \* SI units consists of seven base units namely metre, kilogram, second, ampere, kelvin, mole, candela and two supplementary units namely, radian and steradian.

- \* The smallest length that can be measured with a measuring instrument is called least count.
- \* Least Count of Vernier Callipers = length of 1 main scale division – length of 1 vernier scale division.
- \* The length of the object using Vernier Callipers = Main Scale reading + (Vernier coincidence x Least Count).
- \* Least Count of screw gauge  

$$= \frac{\text{Pitch of the screw}}{\text{No. of head scale divisions}}$$
- \* The length of the given object using screw gauge = Pitch scale reading + (corrected head scale coincidence x least count)
- \* The physical balance is used to find the mass of an object correct to a milligram.
- \* When the beam is raised the pointer swings. The amplitude of oscillations decrease and finally it comes to rest at a point on the scale, is called the resting point.
- \* The mass of an object correct to a milligram using a physical balance is

$$= W + \left( \frac{10}{(b-c)} \times (b-a) \right) \times 10^{-3} \text{ g}$$

a = Zero resting point

b, c = resting points

### Self - Evaluation

#### Choose the correct answer

1. The unit for quantity of substance is  
 (1) mole            (2) kilogram  
 (3) gram            (4) metre<sup>3</sup>
2. The unit of temperature is  
 (1) Celcius        (2) Farenheit  
 (3) Kelvin          (4) Calorie

3. The unit of electric current  
 (1) candela        (2) ampere  
 (3) volt            (4) mole
4. Least Count of a screw gauge  
 (1) 0.1 mm        (2) 0.01 mm  
 (3) 0.001 mm    (4) 0.01 cm
5. At the end of oscillations the pointer of the physical comes to a rest at  
 (1) turning point    (2) resting point  
 (3) centre of gravity (4) centre
6. The least weight in the weight box  
 (1) 1 g              (2) 10 mg  
 (3) 1 mg            (4) 100 mg

#### Fill in the blanks

7. The distance travelled by light in vacuum in one second is .....
8. The unit for amount of substance is .....
9. .... is used to measure the mass of an object.
10. If the resting point of a physical balance is greater than the zero resting point, 10 mg is ..... to the weight.

#### 11. Match the following

- |                         |                |
|-------------------------|----------------|
| (1) Mass                | (i) Candela    |
| (2) Luminosity          | (ii) Pitch     |
| (3) Solid angle         | (iii) Kilogram |
| (4) Amount of substance | (iv) Steradian |
| (5) Screw gauge         | (v) Mole       |

#### Answer briefly

12. What is the need for measurement ?
13. Define fundamental units.

14. What is the pitch of a screw ?
15. What is zero error of a screw gauge? What is meant by zero correction?
16. What is meant by zero resting point of a physical balance ?
17. What is meant<sup>1</sup> by turning point of a physical balance ?

**Answer in detail**

18. Explain how Vernier Callipers is used to measure the length of an object.
19. Explain the construction and method of measuring the thickness of an object with a screw gauge.
20. Explain the construction of a physical balance.
21. Explain how the weight of an object can be found correct to a centigram using a physical balance.

**Problems**

22. With 50 sheets of paper the screw gauge reads 2 mm on pitch scale and 53 divisions on the head scale. If the pitch is 1 mm, least count 0.01 mm and zero error is 0.03 mm, what is the thickness of a single sheet ? [Ans: 0.05 mm]
23. The pitch of the screw gauges A and B are equal, but have 100 and 50 divisions in their head scales respectively. Which will measure more accurately ?  
[Ans: A]
24. A vernier callipers has mm divisions on the main scale and 19 main scale divisions divided into 20 vernier scale divisions. While measuring the diameter of a cylinder main scale reading is 15 and the vernier coincidence is 5. Find the least count and length of the cylinder.  
[Ans: (i) 0.005 cm (ii) 1.525 cm]

## 2. FORCE AND MOTION

We observe different types of motions in day-to-day life. People walk, birds fly, fishes swim, buses ply, planes fly and ships traverse the oceans. The moons, planets and stars spin on their axes and move around elliptical orbits. We also observe natural phenomena such as water flowing in a river and falling down a waterfall, falling rain drops and flowing wind. We find that motion is common in all these occurrences. The forces acting on a body and the nature of motion produced by them form the subject of this lesson.

### 2.1 Motion

When an object continuously changes its position with respect to time, the object is said to be in motion. **An object which does not change its position with respect to time is said to be at rest.**

Suppose you start from your house at 8.00 a.m. and reach your school at 8.30 a.m. **The change in your position with respect to time is called motion.**

When you travel in a bus you are in motion with respect to your friend standing on the road. But for a person seated next to you in the bus, you are at rest. **So an object is said to be in motion or at rest with reference to changes in its position over time.**

#### Types of motion

Motion can be classified into (1) **random motion** (2) **translational motion** (3) **rotational motion** and (4) **oscillatory motion**.

#### 1. Random motion

The motion of a football, kicked by players with different forces in different directions, movement of incense smoke in air and flight of mosquitoes in front of lamp are all random motions.

#### 2. Translational motion

The motion of an arrow shot from a bow, a bullet fired from a rifle, a fast moving foot ball, speeding train, flight of a bird and an aeroplane are all translatory in nature.

**If the path of an object in translatory motion is in a straight line, it is called rectilinear motion. If the path of the object follows a curved path, it is called curvilinear motion and motion in a circular orbit is called circular motion.**

#### 3. Rotational motion

**If an object rotates about an axis it is called rotational motion.** A spinning top and an electric fan are examples of rotational motion.

A ball rolling down an inclined plane, the moon spinning on its own axis and orbiting the earth, the earth orbiting the sun and the wheel of moving vehicles all possess both rotational and translatory motion.

#### 4. Oscillatory or vibratory motion

**An object moving to and fro about a fixed point is called oscillatory or vibratory motion.**

The motion of the pendulum of a clock, a swing, the needle of sewing machine, a leaf floating on water are examples for oscillatory motion.

**Activity:** Tabulate the different types of motion that you observe in a sewing machine while stitching.

## 5. Scalars and Vectors

**Quantities that require only magnitudes to specify them are called scalar quantities.** Mass, length, time, temperature, angle, area, volume, density and work are scalar quantities.

**Quantities that require both a magnitude and a direction to specify them are called vector quantities.** Displacement, velocity, acceleration, force, momentum and weight are vector quantities.

### 2.2 Distance and speed

Let a car be moving at a speed of  $50 \text{ km h}^{-1}$ . At a constant speed, it travels 25 km in half an hour and 100 km in two hours.

Distance travelled = Speed x time taken

$$\therefore \text{Speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

If a car travels 300 km in 6 hours the average speed of the car =  $300/6 = 50 \text{ km h}^{-1}$  even when its speed is not constant. The speedometer of the car indicates only the speed of the car but does not indicate the direction of travel.

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Time taken}}$$

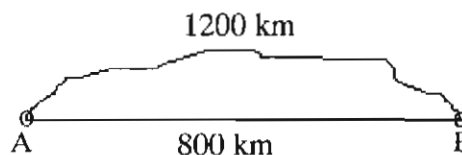
The distance travelled by an object in one second is called **speed**. As speed has only magnitude but no direction, it is a scalar quantity. Its unit is  $\text{ms}^{-1}$ .

The speeds of different motions are given in Table 2.1.

**Table 2.1 Speeds of different motions**

Motion	Speed	
	$\text{ms}^{-1}$	$\text{km h}^{-1}$
1. Rat	0.5	1.8
2. Man	1.0	3.6
3. Bee	5	18
4. P.T.Usha	10	36
5. Cheetah	24	90
6. Speed of sound	340	1224
7. Rotational speed of earth at equator	465	1674
8. Escape velocity at earth's surface	11200	40320
9. Mean velocity of earth round the sun	29780	107208
10. Speed of light	$3 \times 10^8$	$10.8 \times 10^8$

### 2.3 Distance and Displacement



**Fig 2.1 Distance, Displacement**

Let A and B represent two cities at a distance of 800 km through a straight line road and 1200 km through a circuitous road. The distance between the cities vary with reference to the roads. The shortest distance between two points is a straight line directed from one point to the other in a specific direction. But different routes have changing directions and different distances.

The straight line distance between initial and final position of a body in a specific direction is called **displacement**.

As displacement requires both a magnitude and a direction, it is a vector quantity.

The distance between two cities depends on the length of road. As distance is specified only by magnitude, it is a scalar quantity. But the displacement remains the same for the two roads.

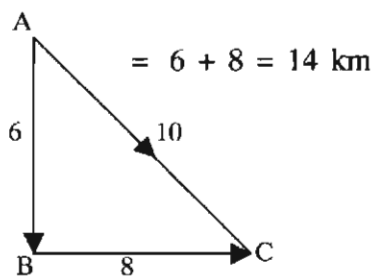
**Table 2.2. Distance and Displacement - Differences**

<i>Distance</i>	<i>Displacement</i>
1. Length of the actual path travelled by a body.	Length of the straight line path between two points
2. It is a scalar	It is a vector
3. Depends on the path.	Does not depend on the path and depends on the initial and final positions of a body
4. $s = v t$	$\vec{s} = \vec{v} t$
5. Distance = speed x time	Displacement = velocity x time

### 1. Resultant displacement

Let a vehicle travel 6 km south from A to B, and travel 8 km east to reach C. What is its resultant displacement ?

Distance travelled = AB + BC



**Fig 2.2 Resultant displacement**

Resultant displacement is the straight line distance between initial and final positions,

$$\vec{AC} = \vec{AB} + \vec{BC}$$

Magnitude of resultant displacement,

$$\begin{aligned} AC &= \sqrt{(AB)^2 + (BC)^2} \\ &= \sqrt{6^2 + 8^2} = \sqrt{100} \\ &= 10 \text{ km.} \end{aligned}$$

The resultant displacement  $\vec{AC}$  is a vector of magnitude 10 km in the south east.

**The resultant displacement of an object is the vector sum of all its displacements.**

### 2. Velocity

The displacement of an object in one second is called **velocity**.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

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

Velocity is a vector quantity. Its unit is  $\text{ms}^{-1}$ .

Let a car in travel through a circuitous road of 1200 km in 20 hours. The displacement of the car towards east is 800 km (Fig 2.1).

$$\begin{aligned} \text{So, average velocity, } \vec{v} &= \frac{800}{20} \\ &= 40 \text{ km.h}^{-1} \text{ (east)} \end{aligned}$$

$$\begin{aligned} \text{Average speed of car} &= \frac{1200}{20} \\ &= 60 \text{ km h}^{-1} \end{aligned}$$

Therefore, the average speed of an object need not be equal to the magnitude of average velocity.

**Table : 2.3 Speed, Velocity – Difference**

<i>Speed</i>	<i>Velocity</i> ..
1. It is the distance travelled by an object in one second.  Speed = $\frac{\text{Distance travelled}}{\text{Time}}$	It is the displacement of an object in one second.  Velocity = $\frac{\text{Displacement}}{\text{Time}}$
2. It is a scalar.	It is a vector.
3. It does not have a direction.	It has the direction of the displacement.

**Problem: 1)** A student takes 10 minutes to go to his school at a distance of 5 km from his house and takes 20 minutes for the return journey. Calculate his average speed and average velocity.

Total distance travelled = 5 + 5 = 10 km

Time taken = 10 + 20  
= 30 minutes  
=  $\frac{1}{2}$  hour

Average speed =  $\frac{\text{Total distance travelled}}{\text{Time taken}}$   
=  $\frac{10}{(\frac{1}{2})} = 20 \text{ km h}^{-1}$

Total displacement = +5 – 5 = 0

∴ Average velocity =  $\frac{\text{Displacement}}{\text{Time}}$   
=  $\frac{0}{(\frac{1}{2})} = 0$

So, if an object comes back to its starting point, its displacement and velocity are zero. But the distance travelled and speed are not equal to zero.

### 3. Instantaneous Velocity

Let an object move from A to B in time  $\Delta t$  and its displacement  $\Delta y$ . Suppose that the velocity of the object increases as it moves from A to B. The velocity of the body at the mid-point C is the average of the velocity of object at A and B. This represents the instantaneous velocity at C.

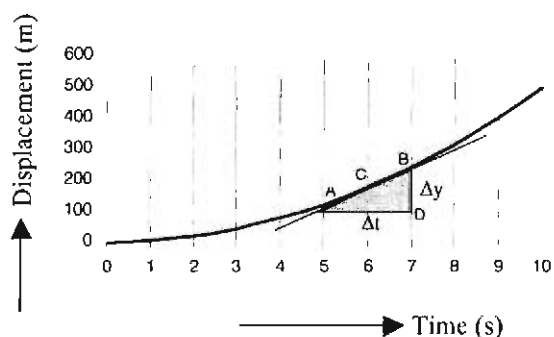
∴ Instantaneous velocity,

$$v = \frac{\text{Displacement}}{\text{Time}} = \frac{\Delta y}{\Delta t}$$

When  $\Delta y$  and  $\Delta t$  are chosen to have smaller values, the instantaneous velocity will be more accurate.

**The velocity of an object in motion at an instant or at a point is called instantaneous velocity.**

The slope of a curve at a point is defined as the slope of the tangent drawn at that point. It is a measure of the inclination of tangent to the x-axis (Fig 2.3).



**Fig 2.3 Instantaneous velocity**

**Table 2.4 Uniform motion**

t (s)	0	1	2	3	4	5	6	7	8	9	10
s <sub>A</sub> (m)	0	20	40	60	80	100	120	140	160	180	200
v <sub>A</sub> (ms <sup>-1</sup> )	0	20	20	20	20	20	20	20	20	20	20
s <sub>B</sub> (m)	0	40	80	120	160	200	240	280	320	360	400
v <sub>B</sub> (ms <sup>-1</sup> )	0	40	40	40	40	40	40	40	40	40	40

The slope of displacement – time curve represents the velocity of the object.

$$\text{Here, slope} = \frac{\text{Displacement}}{\text{time}} = \frac{\Delta y}{\Delta t}$$

$$\text{Instantaneous velocity at C (v)} = \frac{BD}{AD}$$

So the slope of the curve at C represents the instantaneous velocity of the object at C. A positive slope indicates an increasing velocity and a negative slope indicates decreasing velocity of the object.

## 2.4. Uniform and Non-uniform motion

### 1. Uniform motion

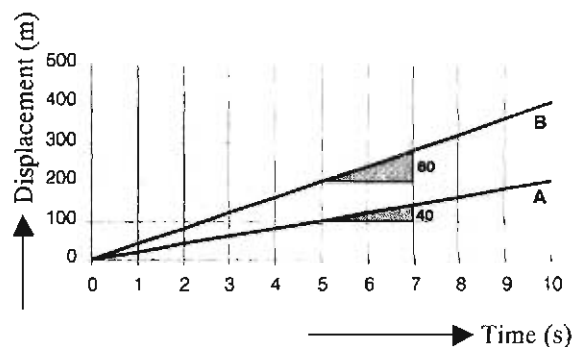
The displacements of two trains moving at a constant speed on straight tracks are given in table 2.4. The graphs, representing the motion of the trains A and B, drawn with time on the x-axis and displacement on the y-axis are shown in fig 2.4. As the displacement time curve is a straight line it has a constant slope.

$$\text{Slope of line A} = \frac{\Delta y}{\Delta t} = \frac{40}{2} = 20 \text{ ms}^{-1}$$

$$\text{Slope of line B} = \frac{80}{2} = 40 \text{ ms}^{-1}$$

So, the trains A and B move with constant velocities.

An object moving with a constant velocity is said to be in **uniform motion**.



**Fig 2.4 Uniform motion, displacement - time graph**

If an object has equal displacements in equal intervals of time it is said to move with uniform velocity.

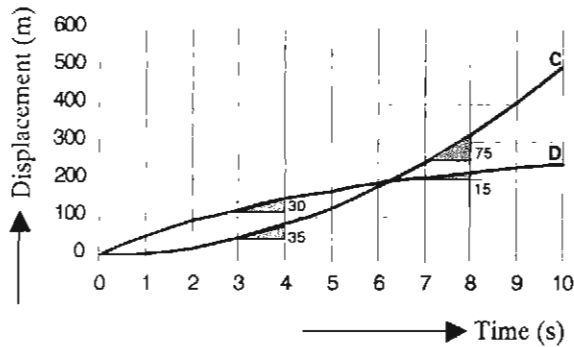
### 2. Non-uniform motion

The time and displacements of two trains moving on straight tracks are given table 2.5. The motion of these two trains are given by the displacement-time curves shown in fig.2.5. The slope of the curve C increases continuously showing that the velocity of the train increases continuously. The velocity of the train increases from 35 ms<sup>-1</sup> at 3.5 second to 75 ms<sup>-1</sup> at 7.5 second. So, the train has a uniform positive acceleration.

As the slope of the curve D decreases continuously showing that the velocity of the train decreases with time. The velocity of the train decreases from 30 ms<sup>-1</sup> at 3.5 second to 15 ms<sup>-1</sup> at 7.5 second. So, the

**Table 2.5 Non-uniform motion**

t (s)	0	1	2	3	4	5	6	7	8	9	10
s <sub>C</sub> (m)	0	5	20	45	80	125	180	245	320	405	500
s <sub>D</sub> (m)	0	50	90	120	150	170	190	205	220	230	240



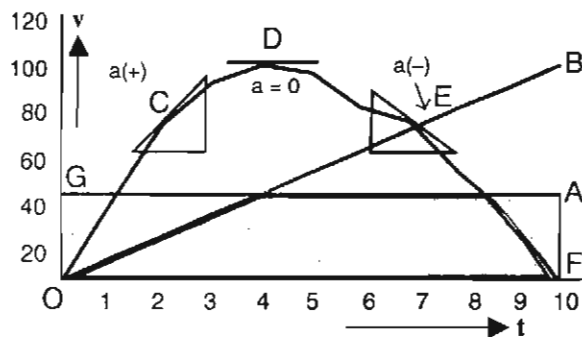
**Fig 2.5 Non-uniform motion, displacement - time graph**

train D has a negative acceleration or retardation.

### 3. Acceleration

Let a train move with a constant velocity on a straight track. As its velocity does not change with time the velocity-time curve (A) shown in fig.2.6.A is a straight line parallel to time axis. Another train, starting from rest, moves with a velocity increasing at the rate 10 ms<sup>-1</sup>. The velocity-time curve (B) is a straight line inclined to the time axis.

If the velocity of an object increases uniformly with time it is said to be uniformly accelerated.



**Fig 2.6 Acceleration**

$$\begin{aligned} \text{Slope of velocity - time curve} &= \frac{\Delta v}{\Delta t} \\ &= \frac{\text{Change in velocity}}{\text{time}} \\ &= \text{acceleration} \end{aligned}$$

**The change in velocity of an object per unit time is called acceleration.** Its unit is ms<sup>-2</sup>. It is a vector quantity.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{time}}$$

The velocity-time graph ODF represents the velocity of a train starting from rest at O which reaches a maximum velocity at D, and then comes to rest at F. The tangent drawn at a point C on the curve ODF has a positive slope. So it represents the positive acceleration of the train. As the slope of the curve at D is zero the acceleration is zero. As the point E has a negative slope it represents negative acceleration or retardation of the object.

**Since velocity x time = displacement, the area under the velocity-time curve represents the displacement of the object (OGAF).**

Observe the motion of the seconds hand of a wall clock. The hand moves uniformly with a constant speed. As its direction changes continuously, its velocity also changes continuously, and therefore it is said to be accelerated.

An object moving with a uniform speed in a circular path has an acceleration

directed towards the centre of the circular path. This is called centripetal acceleration.

## 2.5 Equations of motion for uniformly accelerated bodies

Let the initial velocity of an object be  $u \text{ ms}^{-1}$  and final velocity  $v \text{ ms}^{-1}$  after time  $t$ . Let  $a$  be the uniform acceleration and  $s$ , the displacement of the object.

Acceleration,  $a = \frac{\text{Change in velocity}}{\text{time}}$

$$a = \frac{v - u}{t}$$

$$at = v - u$$

$$v = u + at \quad \dots\dots\dots(1)$$

Average velocity in time ( $t$ ),

$$t = \frac{\text{Distance travelled}}{\text{time}}$$

$$\frac{u + v}{2} = \frac{s}{t}$$

Using equation (1),

$$s = (u + u + at) \frac{t}{2}$$

$$s = (2u + at) \frac{t}{2}$$

$$s = ut + \frac{1}{2} at^2 \quad \dots\dots\dots(2)$$

From equation (1)  $v = u + at$

$$v - u = at$$

$$t = \frac{v - u}{a}$$

But average velocity,

$$\frac{u + v}{2} = \frac{s}{t}$$

$$s = \frac{(u + v)t}{2}$$

Substituting for  $t$ ,

$$s = \frac{(u + v)}{2} \times \frac{(v - u)}{a}$$

$$= \frac{v^2 - u^2}{2a}$$

$$2as = v^2 - u^2$$

$$v^2 = u^2 + 2as \quad \dots\dots\dots(3)$$

These are the equations of motion of uniformly accelerated bodies.

### Problems

2) A car gets accelerated from rest to  $2 \text{ ms}^{-2}$  in 10 sec. Calculate the final velocity and the distance travelled by the car.

Initial velocity of the car,  $u = 0$  (at rest)

Acceleration,  $a = 2 \text{ ms}^{-2}$

Time,  $t = 10\text{s}$

$$v = u + at$$

$$= 0 + 2 \times 10 = 20 \text{ ms}^{-1}$$

$$v = 20 \text{ ms}^{-1}$$

$$\text{Distance travelled, } s = ut + \frac{1}{2} at^2$$

$$= 0 + \frac{1}{2} (2) 10 \times 10 = 100$$

$$s = 100 \text{ m}$$

3) A driver applies brake to stop a train moving at a speed of  $72 \text{ km / hour}$ . The velocity decreases to  $36 \text{ km / hour}$  as the train moves  $200 \text{ m}$ . Find the acceleration of the train.

Initial velocity of the train,  $u = 72 \text{ km h}^{-1}$

$$= \frac{72 \times 1000}{60 \times 60}$$

$$= 20 \text{ ms}^{-1}$$

Final velocity,  $v = 36 \text{ km h}^{-1}$

$$= \frac{36 \times 1000}{60 \times 60} = 10 \text{ ms}^{-1}$$

Distance travelled,  $s = 200 \text{ m}$

Acceleration,  $a = ?$

$$v^2 = u^2 + 2as$$

$$10^2 = 20^2 + 2a(200)$$

$$400a = 10^2 - 20^2$$

$$= 100 - 400 = -300$$

$$a = \frac{-300}{400} = -0.75 \text{ ms}^{-2}$$

4) A train enters a station with a speed of  $50 \text{ ms}^{-1}$ . As the driver applies the brake its slows down at the rate of  $5 \text{ ms}^{-2}$ . If the length of the platform is  $250 \text{ m}$ , will the train stop within the platform?

Initial velocity,  $u = 50 \text{ ms}^{-1}$

Final velocity,  $v = 0$

Acceleration,  $a = -5 \text{ ms}^{-2}$

Distance travelled,  $s = ?$

$$v^2 = u^2 + 2as$$

$$0 = 50^2 + 2(-5)s$$

$$0 = 2500 - 10s$$

$$10s = 2500$$

$$s = \frac{2500}{10} = 250 \text{ m}$$

The distance travelled by the train before it stops equals the length of platform. So, the train will stop within the platform.

## 2.6 Equations of motion for freely falling bodies

All objects are attracted to the centre of the earth with an uniform acceleration due to the earth's gravitational force. This acceleration of an object due to the gravitational force of attraction is called **acceleration due to gravity**. The motion of a freely falling body is an ideal example for uniformly accelerated motion.

The acceleration due to gravity at or near the earth's surface is  $9.81 \text{ ms}^{-2}$ . The acceleration due to gravity on the surface of the moon is  $1.6 \text{ ms}^{-2}$  and near the surface of the sun  $274 \text{ ms}^{-2}$ . For a freely falling body, the initial velocity,  $u = 0$  Let the acceleration  $a = g$  and the distance of free fall  $s = h$

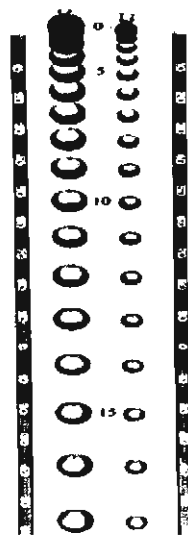


Fig 2.7 Free fall of two bodies

$$v = u + at$$

$$v = 0 + gt$$

$$v = gt \quad \dots(4)$$

$$s = ut + \frac{1}{2}at^2$$

$$h = 0 + \frac{1}{2}gt^2$$

$$h = \frac{1}{2}gt^2 \quad \dots(5)$$

$$v^2 = u^2 + 2as$$

$$v^2 = 0 + 2gh$$

$$v^2 = 2gh \quad \dots(6)$$

The motion of two objects of different sizes and masses are shown in Fig 2.7. From equation (5), it is seen that objects of different masses, released simultaneously from the same height, fall on the ground at the same time with the same velocity. An object thrown vertically upwards, against the force of gravity, have negative acceleration

$$\therefore a = -g$$

## Problems

5) A ball is thrown upward with an initial velocity  $15 \text{ ms}^{-1}$  and is caught by the person who threw it. Calculate the maximum height reached, the velocity at the time of catch and the time of flight of the ball.

(1) with A as origin

$$\begin{aligned} u &= +15 \text{ ms}^{-1} \\ v &= 0 \\ g &= -9.8 \text{ ms}^{-2} \\ h &= ? \\ v^2 &= u^2 + 2as \\ 0 &= 15^2 + 2(-9.8)h \\ h &= \frac{15^2}{2 \times 9.8} = 11.5 \text{ m.} \end{aligned}$$

Maximum height reached by the ball = 11.5 m.

(2) with A as the origin

Initial velocity at A,

$$\begin{aligned} u &= +15 \text{ ms}^{-1} \\ g &= -9.8 \text{ ms}^{-2} \\ h &= 0 \\ v &= ? \\ v^2 &= u^2 + 2as \\ v^2 &= u^2 + 2gh \\ v^2 &= 15^2 + 2(-9.8)0 \\ v &= \sqrt{15^2} = \pm 15 \\ v &= -15 \text{ ms}^{-1} \\ &\text{(downward velocity)} \end{aligned}$$

with B as origin

$$\begin{aligned} u &= 0 \\ s &= 11.5 \text{ m} \\ g &= +9.8 \text{ ms}^{-2} \end{aligned}$$

$$\begin{aligned} v &= ? \\ v^2 &= u^2 + 2as \\ &= 0 + 2(+9.8)11.5 \\ &= 225 \\ v &= \sqrt{225} \\ &= \pm 15 \text{ ms}^{-1} \\ v &= -15 \text{ ms}^{-1} \\ &\text{(downward velocity)} \end{aligned}$$

(3) with A as the origin

Initial velocity,  $u = +15 \text{ ms}^{-1}$

$$\begin{aligned} g &= -9.8 \text{ ms}^{-2} \\ s &= 0 \\ t &= ? \\ s &= ut + \frac{1}{2}at^2 \\ 0 &= 15t + \frac{1}{2}(-9.8)t^2 \\ 0 &= 15t - 4.9t^2 \\ t(4.9t - 15) &= 0 \\ t = 0 \text{ or } 4.9t - 15 &= 0, \\ t &= \frac{15}{4.9} = 3.06 \text{ s} \end{aligned}$$

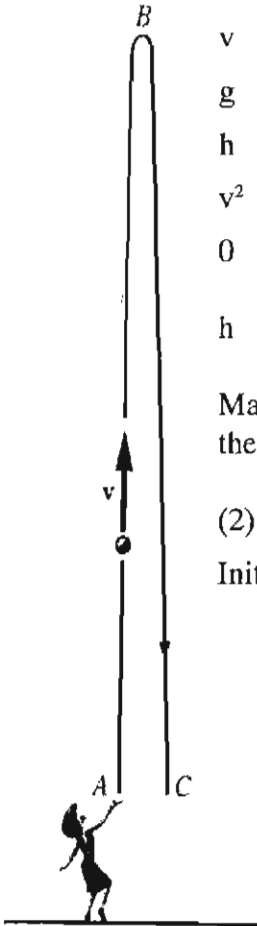
Time of flight,  $t = 3.06 \text{ s}$

(6) Calculate and tabulate the position and velocity of a freely falling body in first four seconds.

with O as the origin

(1) Position

$$\begin{aligned} u &= 0, a = g = -9.8 \text{ ms}^{-2} \\ s &= ut + \frac{1}{2}at^2 \\ h &= \frac{1}{2}(-9.8)t^2 \\ t = 1, \quad h_1 &= \frac{1}{2}(-9.8) \times 1^2 \\ &= -4.9 \text{ m} \end{aligned}$$



$$t = 2, \quad h_2 = \frac{1}{2} (-9.8) \times 2^2$$

$$= -\frac{1}{2} \times 9.8 \times 4$$

$$= -19.6 \text{ m}$$

$$t = 3, \quad h_3 = -\frac{1}{2} (9.8) \times 3^2$$

$$= -\frac{1}{2} \times 9.8 \times 9$$

$$= -44.1 \text{ m}$$

$$t = 4, \quad h_4 = -\frac{1}{2} (9.8) \times 4^2$$

$$= -\frac{1}{2} \times 9.8 \times 16$$

$$= -78.4 \text{ m}$$

$$s_1 : s_2 : s_3 \dots = 1^2 : 2^2 : 3^2 \dots$$

## (2) Velocity

$$a = -g = -9.8 \text{ ms}^{-2}$$

$$u = 0, \quad v = u + at, \quad v = -9.8t$$

$$t = 1, \quad v_1 = (-9.8) \times 1 = -9.8 \text{ ms}^{-1}$$

$$t = 2, \quad v_2 = (-9.8) \times 2 = -19.6 \text{ ms}^{-1}$$

$$t = 3, \quad v_3 = (-9.8) \times 3 = -29.4 \text{ ms}^{-1}$$

$$t = 4, \quad v_4 = (-9.8) \times 4 = -39.2 \text{ ms}^{-1}$$

$$v_1 : v_2 : v_3 \dots = 1 : 2 : 3 \dots$$

	$t$	$y$	$v$	$a$
	(s)	(m)	(m/s)	(m/s <sup>2</sup> )
O	0	0	0	-9.8
	1	-4.9	-9.8	-9.8
	2	-19.6	-19.6	-9.8
	3	-44.1	-29.4	-9.8
	4	-78.4	-39.2	-9.8

## Some basic concepts

- \* When an object continuously changes its position with respect to time the object is said to be in motion.
- \* Motion can be classified into random motion, translational motion, rotational and oscillatory motion.
- \* Quantities specified by magnitudes only are called scalars.
- \* Quantities that require both a magnitude and a direction are called vectors.
- \* The distance travelled by an object in one second is called speed. It is a scalar. Its unit is  $\text{ms}^{-1}$ .
- \* The straight line distance between the initial and final positions of a body in a specified direction is called displacement. It is a vector. Its unit is m.
- \* The resultant displacement of an object is the vector sum of all its displacements.
- \* The displacement of an object in one second is called velocity. It is a vector. Its unit is  $\text{ms}^{-1}$ .
- \* The velocity of an object in motion at an instant or at a point is called instantaneous velocity.
- \* The slope of displacement – time curve represents the velocity of an object.
- \* The slope of the velocity – time curve represents the acceleration of an object.
- \* The acceleration of a body in circular motion towards centre of the circular path is called centripetal acceleration.
- \* All objects are attracted to the centre of the earth with uniform acceleration due to the earth's gravitational force.
- \* The acceleration due to gravity at or near the earth's surface is  $9.81 \text{ ms}^{-2}$ .
- \* Objects of different masses released simultaneously from the same height fall on the ground at the same time with the same velocity.

## Self – Evaluation

### Choose the correct answer

1. The motion of a bullet fired from a rifle is  
 (1) rotational motion (2) circular motion  
 (3) vibrational motion (4) rectilinear motion
2. An example for vector quantity is  
 (1) volume (2) distance  
 (3) momentum (4) temperature
3. The rate of change of velocity is  
 (1) displacement (2) acceleration  
 (3) speed (4) momentum
4. When a body is thrown upwards its velocity  
 (1) increases (2) decreases  
 (3) remains constant (4) attains maximum value
5. The velocity of a vehicle increases from  $20 \text{ ms}^{-1}$  to  $50 \text{ ms}^{-1}$  in 10s. Its acceleration is  
 (1)  $30 \text{ ms}^{-2}$  (2)  $3 \text{ ms}^{-2}$   
 (3)  $15 \text{ ms}^{-2}$  (4)  $0.83 \text{ ms}^{-2}$

### Answer briefly

6. Define – motion.
7. What are the different types of motion ?
8. What is a scalar quantity ? Give examples.
9. What is vector quantity ? Give examples.
10. Distinguish between displacement and distance.
11. Define uniform velocity.
12. Distinguish between speed and velocity.
13. Define acceleration.
14. What is meant by uniform acceleration ?
15. List out the vectors in the equation  $s = ut + \frac{1}{2}at^2$ .
16. What is acceleration due to gravity ? Give its value.

### 17. Match the following

- |                                 |                           |
|---------------------------------|---------------------------|
| (1) Displacement                | (i) negative acceleration |
| (2) Slope of v-t curve          | (ii) scalar quantity      |
| (3) Speed                       | (iii) distance travelled  |
| (4) Area under v-t curve        | (iv) vector quantity      |
| (5) Negative slope of v-t graph | (v) acceleration          |

### Answer in detail

18. Explain the different types of motion of objects.
19. Distinguish between scalars and vectors with examples.
20. Derive the equations of motion.
21. Obtain equations of motions for a freely falling body.
22. Explain with graphs uniform and non-uniform acceleration.
23. Explain instantaneous velocity using a graph.
24. Explain resultant displacement with an example.

### Problems

25. A motor vehicle travels 108 km in three hours. Find its velocity. [Ans:  $10 \text{ ms}^{-1}$ ]
26. An object moves with an initial velocity of  $20 \text{ ms}^{-1}$ , and uniform acceleration  $4 \text{ ms}^{-2}$ . What is its velocity after 10 seconds. [Ans:  $60 \text{ ms}^{-1}$ ]
27. A ball is thrown upwards with the velocity of  $15 \text{ ms}^{-1}$ . Calculate the maximum height and time taken to reach the maximum height. Assume  $g = 10 \text{ ms}^{-2}$  [Ans: 11.25m, 1.5s]
28. A scooter accelerates from rest to  $36 \text{ kmh}^{-1}$  in 10 s. Calculate its acceleration. [Ans:  $1 \text{ ms}^{-2}$ ]
29. A car covers 30 km with a velocity of  $40 \text{ km h}^{-1}$  and the next 30 km with a velocity of  $20 \text{ km h}^{-1}$ . What is the average velocity of the car ? [Ans:  $30 \text{ kmh}^{-1}$ ]
30. A stone is dropped into a well and the sound of its fall on water is heard after 2 sec. What is the depth of water in the well. [Ans: 19.6 m]

## 3. NEWTON'S LAWS OF MOTION

### 3.1 Force



Fig : 3.1  
Sir Isaac Newton

How can a body at rest be made to move? How can the speed of a moving vehicle vary? How can we change the direction of a moving body? These three questions can be combined into a single question. "How can a body be accelerated?"

The straight answer is as follows: A body can be accelerated by applying a force on it.

To pluck a mango from the tree, you pull the mango towards yourself. When you push or pull an object, it is said that a force is exerted by you on the object. You can pull or push an object in different directions. This means that **force has a direction**. Also, you can push or pull an object gently or violently, which means that force has a magnitude too. **Force is a vector quantity.**

To accelerate an object, we need to apply a force on it. So, force can be defined as follows:

**Force is that cause which produces acceleration in the body on which it acts.**

A force acting on a body can cause the following:

**(1) The force can alter the speed of the moving object.**

The force applied can change the speed of the moving body or bring to rest.

Sometimes the force may not succeed in producing any change. For example, if we try to push a strong wall, we will fail to do so.

**Hence force may be defined as a push or a pull, which produces or tends to change the state of rest of a body or of its uniform motion along a straight line.**

If you kick a moving football in the same direction, its speed increases. In other words the ball gets accelerated. If the force is applied in the opposite direction, the speed of the football will decrease, i.e., its motion is retarded or decelerated.

**(2) The force can change the direction of motion of a body.**

When a moving football is kicked in a different direction, it continues its motion in the new direction.

**(3) The force applied can change the shape of an object**

If you pull both the ends of a spring outwards; it is elongated. When you push its ends inwards, it gets compressed. When a balloon or a ball is pressed or a rubber band stretched, its shape gets changed.

### 3.2 Laws of Motion

#### 1. Newton's First Law of Motion

**Every body continues in its state of rest or of uniform motion in a straight line unless it is compelled by an external force to change that state.**

The first law of motion consists of two parts:

The first part of the law, namely every body continues in its state of rest unless it is compelled to change that state by an external force, is a common experience and hence easy to understand. A book placed on the table continues to remain there unless some one moves it i.e., applies a force on it.

The second part of the law, namely, every body continues in its state of uniform motion in a straight line unless it is compelled to change that state by an external force, should be carefully understood. A stone rolled on the ground comes to rest after travelling a short distance. Now roll a smooth ball bearing or a marble on a smooth glass surface with the same force as before. The smooth ball travels a much longer distance before coming to rest.

If the same experiment is repeated in an evacuated chamber on a frictionless smooth surface, we can observe the ball travelling a longer distance. Hence it is clear that when friction or resistance to motion of an object is reduced, it continues in its state of uniform motion. Unless an external force acts on it, both the velocity and direction of the moving body will not change. The closest approximation to this ideal situation is the motion of planets, moons and artificial satellites in free space. Observations show that the planets and satellites continue their uniform motion for centuries together.

### 1) Inertia

The inability of the body to change, by itself, its state of rest or of uniform motion in a straight line is called inertia.

### 2) Inertia of rest

Place a coin on a cardboard placed over a tumbler. Now flip the card quickly with your finger. What happens? The coin will neatly

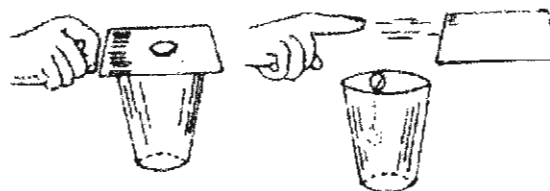


Fig 3.2 Inertia of Rest

drop into the tumbler and the card flies off. The tendency of the coin to remain in its state of rest is called **inertia of rest**.

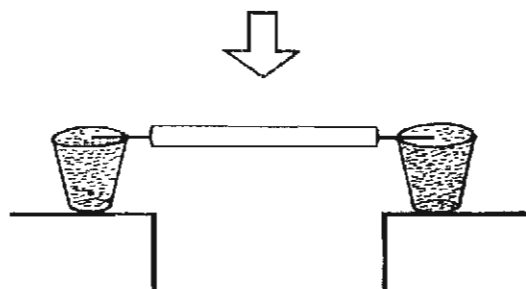


Fig 3.3 Inertia of Rest

**Activity:** A wooden scale is placed horizontally with its two ends resting on two glass tumblers containing water as shown in figure. Strike suddenly the centre of the ruler with a long rod. Observe that neither the glass tumblers break nor the water spill out. But the scale gets broken into two pieces. Why does this happen?

### 3) Inertia of motion

What happens when a moving bus suddenly stops? The passengers are thrown forward and they hit the front seat. In this case, our body has been in motion with the bus and tends to stay in motion even after the

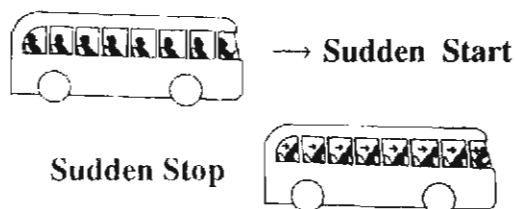


Fig 3.4 Inertia of rest and motion

bus has stopped. This property is called **inertia of motion**. On the other hand, when the bus suddenly starts from rest, we are thrown backwards because, in this case, our body is at rest and tends to stay at rest even after the bus has started moving. This is due to the inertia of rest.

#### 4) Inertia of direction

When a bus takes a turn along a curved track, the passengers experience a force directed away from the center of the curved track. This is due to the tendency of the passenger to continue to move along a straight path. This is called **inertia of direction**.

It follows from Newton's first law of motion that in the absence of any external force a body continues to be in its state of rest or of uniform motion along a straight line. In other words, the body cannot change by itself its position of rest or of uniform motion in a straight line.

**The inability of the body to change by itself its state of rest or of uniform motion in a straight line is called inertia.** Newton's first law of motion is also called the law of inertia.

**Activity :** Place a small card board on the top of a glass of water. Place a match box cover vertically and balance an egg on it as shown in figure . How can you drop the egg into the glass tumbler without touching it?

Pull the cardboard suddenly. Observe that the egg falls into the tumbler and the matchbox cover falls a little farther away. Analyse the reason for this.

The egg possesses more mass and more inertia than the matchbox cover. Therefore, the egg immediately falls into the tumbler, but the matchbox cover, with less mass and less inertia than the egg falls later a little farther away.

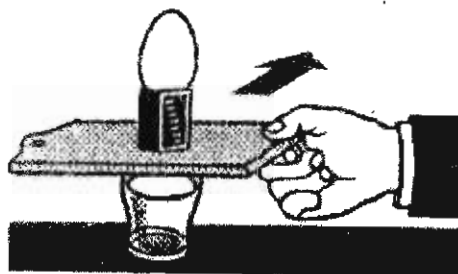


Fig. : 3.5 Inertia and mass

**Activity :** How will you tighten a loose hammer head? When the hammer is brought down and the butt of the handle struck on a hard surface, the hammer head tightens on the handle.

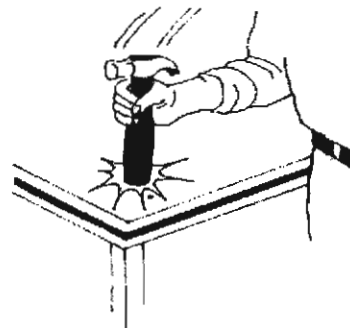


Fig 3.6 Inertia of motion

When the hammer is brought downward, the head and the handle are in motion. When the handle butt strikes the surface, it stops suddenly. Because of inertia, the head continues in motion. This tightens the hammer head on the handle.

#### 5) Momentum

Suppose a rubber ball is rolling along the ground. A force will be required to stop it. If however it is rolling with a larger velocity, a greater force is required to stop it. Again if a rubber ball and an iron ball of the same size are made to roll with equal velocities, much greater force is required to stop the iron ball than rubber ball, because the mass of iron ball is greater than that of rubber ball. Thus the force required to stop a moving body is directly proportional to (1) its mass  $m$  and (2) its linear velocity  $v$ . The product of the mass and velocity of a body is called **momentum**.

Momentum  $p = mv$ . Unit of momentum is  $\text{kg ms}^{-1}$

Momentum is a vector quantity.

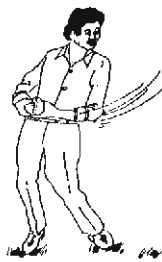
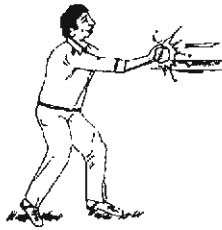


Fig 3.7 Reducing force in Impulse

## 6) Impulse

Observe how a fast moving ball is caught by a cricket player with his hands. When a cricket ball of mass  $m$  and velocity  $v$  is caught by stretching our hands straight, the ball would strike our hands violently with a larger force and cause pain. But, experienced players catch the fast moving ball by moving their hand in the direction of the motion of the ball. Why don't they feel any pain at all? Momentum of the ball moving with velocity  $v$  is  $mv$ . When the ball is stopped,  $v = 0$ ,  $mv = 0$ . Hence the change of momentum =  $mv$ . Now, impulse is defined as the product of the force  $F$  and the time of contact  $\Delta t$ .

$$\therefore mv = F \Delta t$$

If we catch the ball with rigid hands, in a shorter time, the ball will strike our hands with a violent force. But when we move our hands backward while catching the ball, the time of contact is increased and the force is reduced. So, we feel lesser force and pain and also catch the ball without jumping out of our hand.

$$\therefore mv = F \Delta t$$

When we jump from a high place on to a hard surface with stiff legs, you would stop suddenly and the large impulse force might hurt your legs. But if you bend your knees when landing, you increase the contact time and reduce the impulse force and pain.

Explain why in long jump and high jump, the sports persons land on loose sand or rubber foam?

## 2. Newton's Second law of motion

Newton's second law of motion states that the rate of change of momentum of a body is directly proportional to the force and takes place in the direction of the force.

Consider a body of mass  $m$ , whose velocity changes from  $u$  to  $v$  in time  $t$ . Let the magnitude of initial and final momentum of the body be  $p_1$  and  $p_2$ .

$$\text{Hence } p_1 = mu \text{ and } p_2 = mv.$$

The change in momentum is  $(p_2 - p_1)$  in time  $t$ .

Then according to Newton's second law, the magnitude of the force

$$F \propto \frac{p_2 - p_1}{t}$$

Or

$$F = K \frac{p_2 - p_1}{t}$$

where  $K$  is the constant of proportionality.

$$F = K \frac{(mv - mu)}{t}$$

$$F = K \frac{m(v - u)}{t}$$

Here,  $\frac{(v - u)}{t}$  is the magnitude of the rate of change of velocity, which is acceleration  $a$ .

$$\text{Hence we have, } F = k ma$$

The unit of force is chosen in such a manner that  $k=1$ . Substituting this value

$$\therefore F = ma$$

**Unit of force:** If  $m=1$ ,  $a=1$  then  $F=1$ . The force is measured in newton(N). Force is said to be 1 Newton if it produces in a mass of 1 kg an acceleration of  $1\text{ms}^{-2}$ . Another unit of force is kilogram weight (kg-wt). It is the force with which a mass of 1 kg is attracted towards the center of the earth due to gravitational force of attraction.

$$1 \text{ kg-wt} = 9.8 \text{ N}$$

### Problems

1) How long should a force of 100 N act on a body of 20 kg at rest so that it acquires a velocity of  $100 \text{ ms}^{-1}$ ?

Here change in velocity =  $(v-u)$

$$\begin{aligned} &= 100\text{ms}^{-1} \\ m &= 20\text{kg} \\ F &= 100\text{N} \\ t &= ? \\ F &= ma = m \frac{(v-u)}{t} \\ t &= \frac{m(v-u)}{F} \\ &= \frac{20 \times 100}{100} \\ &= 20 \text{ s} \end{aligned}$$

2) A truck starts from rest and rolls down a hill with a constant acceleration . It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it if its mass is 7 metric ton.

Here Initial velocity  $u = 0 \text{ ms}^{-1}$

Distance  $s = 400\text{m}$

Time  $t = 20\text{s}$

Acceleration  $a = ?$

$$\begin{aligned} \text{Using } s &= ut + \frac{1}{2} at^2 \\ 400 &= 0 + \frac{1}{2} \times a \times 20^2 \\ a &= 2 \text{ ms}^{-2} \\ \text{Here mass } m &= 7 \text{ metric ton} \\ &= 7000 \text{ kg} \\ F &= ma \\ &= 7000 \times 2 \\ &= 14,000\text{N} \end{aligned}$$

3) A car of mass 2400 kg moving with a velocity  $20\text{ms}^{-1}$  is stopped in 10s on the application of brakes. Calculate the retardation and the retarding force.

$$\begin{aligned} \text{Initial velocity } u &= 20 \text{ ms}^{-1} \\ \text{Final velocity } v &= 0 \\ \text{time } t &= 10\text{s} \\ \text{Acceleration } a &= ? \\ v &= u + at \\ 0 &= 20 + (a \times 10) \\ 10a &= -20 \\ \text{Acceleration } a &= -2 \text{ ms}^{-2} \\ \text{The negative sign indicates retardation.} \\ \text{Retarding force } F &= 2400 \times (-2) \\ &= -4800 \text{ N} \end{aligned}$$

4) A car of mass 100 kg travelling at 36 km/hr is brought to rest in 5s. Calculate the retarding force.

$$\begin{aligned} m &= 100\text{kg} \\ t &= 5\text{s} \\ u &= 36 \text{ km / hr} \\ &= \frac{36 \times 1000}{60 \times 60} \\ &= 10 \text{ ms}^{-1} \\ \text{Using } v &= u + at \end{aligned}$$

$$0 = 10 + (a \times 5)$$

$$5a = -10$$

$a = -2\text{ms}^{-2}$  which means retardation

Applying  $F = ma,$

Retarding Force  $= 100 \times (-2) = -200\text{N}$

5) What force would be needed to produce an acceleration of  $1\text{ms}^{-2}$  on a ball of mass 1 kg?

Here  $m = 1\text{ kg}$

$a = 1\text{ ms}^{-2}$

$F = ?$

Now  $F = ma = 1 \times 1 = 1\text{N}$

6) Calculate the acceleration produced by a force of 5 N exerted on an object of mass 10 kg?

Here  $F = 5\text{N}$

$m = 10\text{ kg}$

$a = ?$

$F = ma$

$$a = \frac{F}{m} = \frac{5}{10} = 0.5\text{ ms}^{-2}$$

### 1) Mass

The mass of a body is a measure of its inertia. A larger mass possesses a greater inertia and therefore a larger force will be needed to overcome inertia.

### 2) Mass and Weight

Mass is also the measure of the quantity of the matter in a body. The weight of a body is the force acting on the body due to the earth's gravitational force of attraction. The difference between mass and weight of a body are given in Table 3.1.

Weight is maximum on the polar regions and minimum at the equatorial region.

Gravitational force exerted on a body is less on the top of the hill than at the sea level and hence the weight of the body will also be less on the top of the hill

Consider a body of mass  $m$  falling freely with an uniform acceleration  $g$  towards the centre of the earth.

Gravitational force exerted on the body

$$F = mg \quad (\because a = g)$$

According to definition, the force  $F$  is equal to weight of the body.

$$\therefore \text{Weight } W = mg.$$

Since the value of  $g$  differs from place to place, the weight also varies accordingly. At a place having the  $g$  value of  $9.8\text{ ms}^{-2}$ , weight of the body of mass 1 kg,  $W = 1 \times 9.8 = 9.8\text{ N}$

The weight of a body is different on different planets, because of different values of  $g$  on different planets. Therefore, a spring balance would show different readings on different planets. But, when the weight of the body is measured by a beam balance, then the weight measured will be the same everywhere.

To measure the weight of a body, spring balance is used. A beam balance is used to measure the mass of a body.

### 3. Newton's Third law of Motion

To every action, there is always an equal and opposite reaction.

$$\text{Action} = -\text{Reaction}$$

When two bodies A and B act on each other, the force exerted by the body A on B is action and the force exerted by the body B on A is reaction. These forces, according to the third law, are equal in magnitude but opposite in direction.

$$F_{A \text{ on } B} = -F_{B \text{ on } A}$$

**Table 3.1 Difference between Mass and Weight**

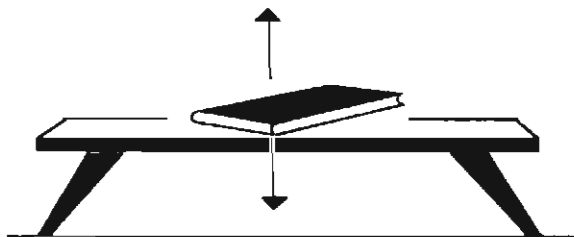
<b>Mass</b>	<b>Weight</b>
1. It is a measure of the quantity of matter in a body.	1. The weight of a body is the gravitational force of attraction on the body.
2. Its unit is kg.	2. Its unit is kgwt or Newton.
3. It is a scalar quantity. $m = \frac{\vec{w}}{\vec{g}}$	3. It is a vector quantity. $\vec{w} = m \vec{g}$
4. Mass is determined by comparing with a standard mass using a beam balance.	4. Weight is determined using a spring balance.
5. Mass of an object remains the same everywhere in the universe. On the earth, mass does not vary with the position or height of an object.	5. Different planets have different gravity. The gravitational force of the earth varies with position and height of the object on earth. So, weight of an object changes from place to place.

Action and reaction act on different bodies. So, they do not cancel one another.

Newton's third law is applicable to bodies both at rest and in motion.

**(1) Action and Reaction - Examples**

**(1) Book - Table**



**Fig 3.8 Book - Table**

A book placed on the table applies a force downward on the table equal to its weight and this is action. An equal and opposite force is exerted by the table upwards on the book and this is reaction.

$$F_{B \text{ on } T} = -F_{T \text{ on } B}$$

**(2) Book - Earth**

Earth's gravitational force acting downward on the book is the action. The book attracts the earth upwards with an equal and opposite force and this is the reaction.

$$F_{E \text{ on } B} = -F_{B \text{ on } E}$$

The upward force exerted by the table on the book should not be considered as reaction for the downward gravitational force on the book (action). Notice that both action and reaction act on the same body in this case.

**(3) Recoil of gun and cannon**

At the time of firing with a rifle, or a cannon the force pushing the bullet forward is the action. At the same time, the bullet



**Fig 3.9 Recoil of a gun**

pushes the rifle or the cannon back with an equal and opposite force and this is the reaction.

(4) A swimmer pushes the water in the backward direction with a certain force. This is the action. The water pushes the swimmer forward with an equal and opposite force and this is the reaction.

(5) The air filled in a balloon is released suddenly keeping the mouth of balloon downward. The air rushing out vertically downwards is the action. The balloon moves upwards in a direction opposite to that of air and this is the reaction.

(6) When a man jumps from a boat floating on water, it is the action. The boat moving away from him is due to reaction.

(7) While walking, we push our foot against the ground and it is the action. The ground in turn exerts an equal and opposite force due to reaction. The vertical component of the reaction balances our weight and the horizontal component pushes us forward.

(8) Rocket Propulsion: The propulsion of a rocket is an example of Newton's third law of motion.

When the fuel of the rocket is ignited, a large amount of gases escape with a very large velocity and momentum. Therefore, force on the burnt out gases is the action.

In turn, the rocket is propelled forward with an equal and opposite force. This is the reaction. The acceleration of the rocket goes on increasing as its mass is constantly reducing.

Observe that action and reaction are acting on two different bodies in all the above events.

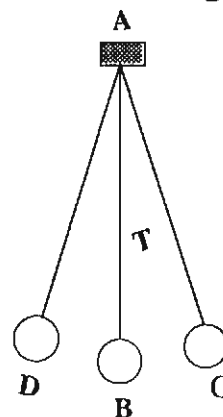
### 3.3 Motion of a Simple Pendulum

In 1583, when Galileo was a medical student at the university of Pisa, he became fascinated by the motion of a huge hanging lamp which had been lighted and left

swinging in a church. Using the beats of his pulse as a timing device, he timed the to-and-fro motion. Based on these studies Galileo formulated the principle of simple pendulum.

Consider the motion of a swing, motion of the hands of a watch and motion of the earth around the sun. All these motions are repeated after a certain intervals of time. Such a motion of an object which repeats itself regularly after a fixed intervals of time is called **periodic motion**. The swing moves to and fro about its mean position. Such a motion is called oscillatory or vibratory. The oscillatory motions have a common feature that they are repetitive and periodic about an equilibrium position.

Motion of the swing and motion of a simple pendulum are examples of a special type of oscillatory or vibratory motion called simple harmonic motion. Simple harmonic motion (SHM) is defined as the oscillatory or vibratory motion in which the restoring force acting on a vibrating body is directly proportional to its displacement from the mean position and directed against it.



*Fig. 3.10 Simple Pendulum*

Simple pendulum consists of a heavy bob, suspended by a light inextensible string from a rigid support. The simple pendulum is shown in diagram. A metallic bob B tied by a thread T is suspended from a rigid support A. The pendulum is made to oscillate between mean position B and extreme positions D and C through a small angle.

The various terms used in simple pendulum are as follows :

- (1) The length of the string from the point of suspension to the centre of the bob is called the length of the pendulum ( $l$ ).
- (2) The time taken by the pendulum to undergo one complete oscillation is called its time period or period ( $T$ ).
- (3) The maximum displacement of the bob from the mean position on either side is called amplitude.

### 1. Laws of simple pendulum

- (1) The time period of a simple pendulum is independent of the material and mass of the bob.
- (2) The time period is independent of the amplitude of oscillation.
- (3) The time period is directly proportional to the square root of the length of the pendulum.

$$T \propto \sqrt{l}$$

- (4) The time period is inversely proportional to the square root of the acceleration due to gravity.

$$T \propto \frac{1}{\sqrt{g}}$$

Combining the laws, we get

$$T = K \sqrt{\frac{l}{g}}$$

where  $K$  is the constant of proportionality. Experimentally  $K$  is found to be equal to  $2\pi$ .

Hence the formula for the time period of a simple pendulum is

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

### 2. To find the acceleration due to gravity using a simple pendulum

The pendulum is set up for a convenient length, say 70cm. Then the pendulum is made to oscillate. The time taken for 20 oscillations is noted with the help of a stop clock. The experiment is repeated for the second time and average is calculated. The time for one oscillation is found. The experiment is repeated for different lengths and the values are tabulated.

By laws of simple pendulum,

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

Squaring both sides,  $T^2 = \frac{4\pi^2 l}{g}$

Acceleration due to gravity,  $g = \frac{4\pi^2 l}{T^2}$

From the table, it is found that  $\frac{l}{T^2}$  is a constant.

### 3. Seconds Pendulum

A pendulum, whose time period is 2 s, takes one second to traverse the arc from one extreme position to the other, and is called a **seconds pendulum**. The length of such a pendulum is approximately 0.995m.

**Table 3.2 Verification of Laws of Simple Pendulum**

S.No.	Length $l$ (m)	Time for 20 oscillations			Period $T$ (s)	$\frac{l}{T^2}$ $ms^{-2}$
		Trial 1	Trial 2	Mean		
1	0.7					
2	0.8					
3	0.9					
4	1.0					
5	1.1					
					mean $\frac{l}{T^2}$	

### 3.4 Parallel forces

When two or more forces act on a body, it is possible to find a single force which would produce the same effect on the body in all cases.

**Resultant is a single force which acting on a body can effectively replace two or more forces acting on it.**

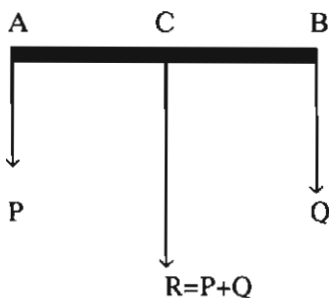
**Equilibrant is that force which acting along with other forces keeps a body in equilibrium. It is equal in magnitude and opposite in direction to the resultant.** Forces whose line of action are parallel are called Parallel forces.

#### 1) Like Parallel forces

If two parallel forces act in the same direction, they are known as like parallel forces.

#### 2) Resultant of like Parallel forces

Let P and Q be two like parallel forces acting at points A and B on a rod AB. The forces P and Q are unequal, but are parallel to each other and act in the same direction.

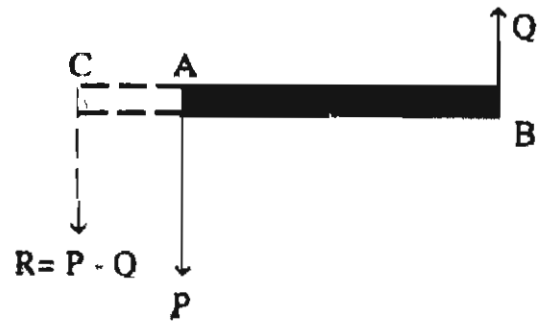


*Fig 3.11 Like parallel forces*

The resultant R of two like parallel forces P and Q acting at points A and B is

- 1) in magnitude, equal to their sum,  $R = (P+Q)$
- 2) in direction, the same as P or Q
- 3) the position of the resultant at a point C between A and B such that  $P \times AC = Q \times BC$

### 3) Unlike Parallel forces



*Fig 3.12 Unlike Parallel forces*

Let P and Q be two unequal, unlike and parallel forces acting at points A and B on a rod AB. The resultant R acts at a point C which is not between P and Q, but outside the base line AB.

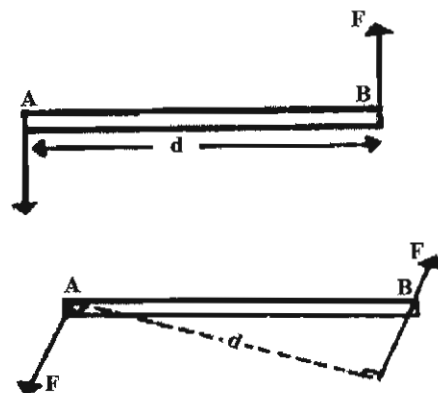
#### 4) Resultant of unlike parallel forces

The resultant is

- 1) in magnitude, equal to their difference;  $R = P - Q$  or  $R = Q - P$
- 2) in the direction of the greater force
- 3) at a point C outside AB on the side of the greater force such that

$$P \times AC = Q \times BC$$

**Two equal and unlike parallel forces not acting at a point constitute a couple.** The effect of the couple will be to turn the body. There can be no resultant to a couple.



*Fig 3.13 Couple*

A body acted on by a couple will rotate until the moment becomes zero, which will happen when the two forces have the same line of action. The forces cannot produce a translatory motion as their resultant is zero. Due to the turning effect in the same direction, they form a couple. **The turning effect of a couple is called its moment.** It is the product of one of the forces and the perpendicular distance between the forces.

Moment of couple

$$= \text{Force} \times \text{perpendicular distance}$$

Its unit is Nm. It is a vector quantity.

### 5) Examples of a couple in action

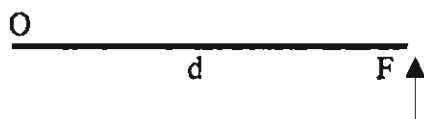
1) Opening a tap. 2) Opening a pen or bottle cap. 3) Steering wheel of a car. 4) Turning a pencil in a sharpener 5) Unscrewing an ear-ring. 6) Turning a screw driver. 7) Winding up the spring of a clock.

### 3.5 Moment of force

**The turning effect of the force acting on a body about an axis is called moment of a force.**

A force acting on a body tends to move the body forward in its direction. This is known as the translatory motion of the body.

In addition to this, a force may produce a *rotatory* motion. It is common experience that in opening or closing a door, the force we apply rotates the door about its hinges. This rotating effect is known as the moment of a force.



**Fig 3.14 Moment of a force**

Consider a rod free to rotate about the point O. Now if a force F is applied on the

body as shown in figure, then this force will not move it in the direction of force. But this applied force will rotate it about the axis passing through O.

**Moment of force is equal to the product of the magnitude of the force and the perpendicular distance of the line of the action of the force from the axis of rotation.**

In figure, moment of the force about the point O = Force  $\times$  Perpendicular distance of the force from the axis =  $F \times d$

Unit of moment of force is newton metre (Nm). It is a vector quantity.

### 1. Principle of Moments

**The principle of moments states that if a body is in equilibrium under the action of a number of parallel forces, the sum of the anti clockwise moments about any point must be equal to the sum of the clockwise moments about the same point.**

According to the principle of moments,

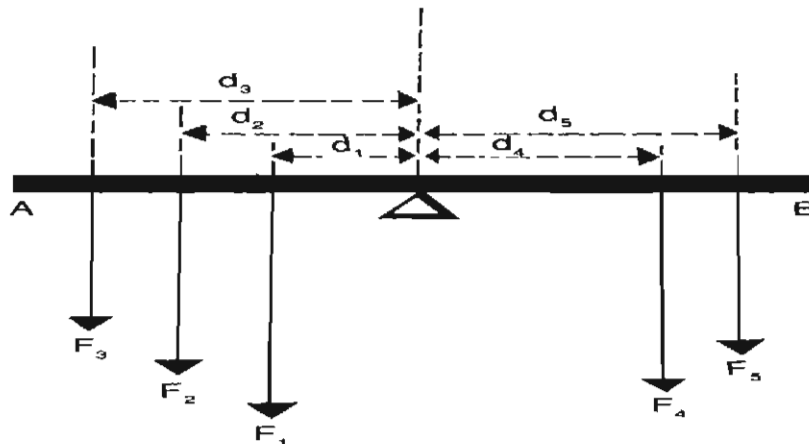
Sum of anticlockwise moments = Sum of clockwise movement

$$F_1d_1 + F_2d_2 + F_3d_3 = F_4d_4 + F_5d_5$$

### 2. Verification of the Principle of Moments

A metre scale is pivoted at its centre of gravity on a stand to rest in equilibrium. Different weights  $m_1$ ,  $m_2$  and  $m_3$  are suspended on the left side of the scale at different distances  $d_1$ ,  $d_2$  and  $d_3$  respectively from the centre.

Weights of values  $m_4$  and  $m_5$  are suspended on the right side of the scale. Their distances are adjusted to make the scale horizontal. Now the distances of  $m_4$  and  $m_5$  are measured as  $d_4$  and  $d_5$  and tabulated. It is understood from the table that the sum of anti clockwise moments is equal to the sum of



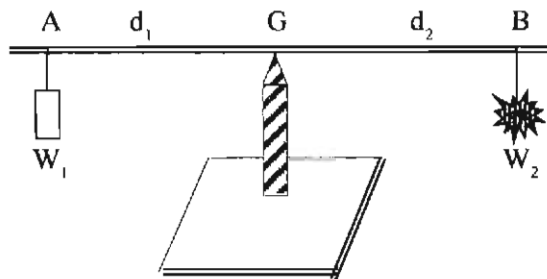
**Fig 3.15 Principle of moments**

clockwise moments. The experiment is repeated by changing the distances of the weights  $m_1$ ,  $m_2$  and  $m_3$ .

distance between the point G and A, the point of suspension of the weight  $W_1$  as  $AG = d_1$ . Similarly measure the distance  $BG = d_2$ .

**3. Determination of weight of a body using Principle of moments**

According to the principle of moments,



**Fig 3.16 Weight of a body**

$$W_2 \times d_2 = W_1 \times d_1$$

$$W_2 = \frac{W_1 \times d_1}{d_2}$$

The experiment can be repeated by changing the value of the known weight and distances  $d_1$  and  $d_2$  and the corresponding readings are tabulated. Hence the average weight of the given body is determined.

Balance a metre scale on a stand such that it remains in equilibrium state. The point at which it is pivoted is the center of gravity G. Suspend a weight  $W_1$  from the scale at A on the left side and suspend the given body at B on the right side of the scale. Let the weight of the body be  $W_2$ . Adjust the positions of  $W_1$  and  $W_2$  until the scale comes to the exact equilibrium position. Now measure the

**Table 3.4 Weight of a body**

S.No.	$W_1$ (Kg)	$d_1$ (m)	$d_2$ (m)	$W_2 = \frac{W_1 \times d_1}{d_2}$ (Kg)
1				
2				
3				

**Table 3.3 Principle of moments**

Sl. No.	Anticlockwise moment (Nm)				Clockwise moment (Nm)		
	$m_1 d_1$	$m_2 d_2$	$m_3 d_3$	Total	$m_3 d_3$	$m_4 d_4$	Total
1							
2							
3							

### Some basic concepts

- \* Force is that cause which produces acceleration in the body on which it acts. Force can alter the speed, direction and shape of the body.
- \* According to Newton's first law of motion, every body continues in its state of rest or of uniform motion in a straight line unless it is compelled by an external force to change that state.
- \* A body has inertia of rest, motion and direction.
- \* Momentum is the product of mass and velocity.
- \* Impulse is the product of applied force and time of contact. It is equal to the change in momentum.
- \* According to Newton's second law of motion,  $F = ma$ .
- \* Mass of a body can be measured by using a beam balance and the weight using a spring balance.
- \* According to Newton's third law of motion, every action has an equal and opposite reaction.
- \* When the restoring force is directly proportional to its displacement from mean position, the vibratory motion is called simple harmonic motion
- \* According to the laws of simple pendulum,  $T = 2\pi \sqrt{\frac{l}{g}}$
- \* Resultant can be found out for both like and unlike parallel forces.
- \* Two equal, opposite and parallel forces acting at different points constitute a couple.
- \* Turning effect of a body is called moment.  $\text{Moment} = F \times d$
- \* According to the principle of moments, sum of anti clockwise moments is equal to the sum of clockwise moments

### Self - Evaluation

#### Choose the Correct Answer

1. Pick out the wrong statement for a body getting accelerated.
  - (1) when its velocity along its straight line remains constant.
  - (2) when its velocity always increases
  - (3) when it falls towards the earth
  - (4) when a force acts on it.
2. When a force of 1N acts on a mass of 1kg the object moves with a
  - (1) speed of  $1 \text{ ms}^{-1}$
  - (2) speed of  $1 \text{ kms}^{-1}$
  - (3) acceleration of  $10 \text{ ms}^{-2}$
  - (4) acceleration of  $1 \text{ ms}^{-2}$ .
3. If A and B are two objects with masses 6 kg and 34 kg respectively, then
  - (1) A has more inertia than B
  - (2) B has more inertia than A
  - (3) A and B have the same inertia.
  - (4) None of the two has inertia.
4. The action and reaction forces referred to in Newton's third law,
  - (1) must act on the same object.
  - (2) Must act on different objects.
  - (3) are different in magnitude but act in the same direction.
  - (4) are different in magnitude and opposite in direction.
5. Inertia depends upon
  - (1) acceleration of the body.
  - (2) velocity of the body.
  - (3) shape of the body.
  - (4) mass of the body.
6. Action and reaction do not balance each other because they
  - (1) act on the same body.
  - (2) act on different bodies.
  - (3) are in the same direction
  - (4) are equal.

7. The net force acting on a body of mass 1 kg moving with a uniform velocity of  $5 \text{ ms}^{-1}$  is
 

(1) 5N	(2) 0.2N
(3) 0N	(4) IN
8. Unit of impulse is
 

(1) $\text{Ns}^{-1}$	(2) Ns
(3) $\text{Ns}^2$	(4) $\text{Ns}^{-2}$
9. The maximum displacement of the simple pendulum bob from the mean position is
 

(1) amplitude	(2) period of oscillation
(3) wavelength	(4) frequency.
10. Period of oscillation of a seconds pendulum is
 

(1) 1s	(2) 2s
(3) 0.995s	(4) 9.95s

**Fill in the blanks**

11. If momentum of a body is changed by  $10 \text{ kgms}^{-1}$  in 5s, then the force acting on the body is ..... N
12. If action is F Newton, the reaction is .....
13. SI unit of weight is .....
14. The definition of force is obtained from Newton's ..... law.
15. When a body of mass 20kg moves with an acceleration of  $2 \text{ ms}^{-2}$ , the rate of change of momentum is .....

**16. Match the following**

- |                               |                           |
|-------------------------------|---------------------------|
| 1) Law of inertia             | (i) Rocket                |
| 2) Newton's third law         | (ii) Measurement of force |
| 3) Weight                     | (iii) Impulse             |
| 4) Rate of change of momentum | (iv) Newton's first law   |
| 5) Newton's second law        | (v) N                     |

**Answer briefly**

17. Why is it dangerous to jump out of a moving bus ?
18. State the law of inertia.
19. Give an example for Newton's first law of motion.
20. State and define the unit of force.
21. Give the relation between force and acceleration.
22. Define momentum of a body.
23. Give the unit of momentum.
24. What is the product of mass of a body and its acceleration equal to ?
25. What is the principle involved in the working of a jet plane ?
26. Give an example for Newton's third law.
27. If a man jumps out of boat, the boat moves backwards. Why ?
28. On what factor does inertia depend?
29. State the laws of simple pendulum.
30. Give two differences between mass and weight.
31. What is a seconds pendulum ?

**Answer in detail**

32. State Newton's first law of motion and explain the two components with an example.
33. What is inertia ? Explain the inertia of rest with an experiment.
34. Explain the inertia of motion and inertia of direction with an example.
35. Explain how impulse is calculated ? Explain it with an example.
36. State Newton's second law and derive the relation  $F = ma$ .
37. Tabulate the differences between mass and weight.

38. State Newton's third law of motion and explain with two examples.
39. How will you determine the acceleration due to gravity ( $g$ ) using a simple pendulum ?
40. Calculate the resultant of two like and unlike parallel forces.
41. How is couple formed? Explain how moment of a couple is calculated with a diagram. Mention two examples to explain the couple.
42. State and verify the principle of moments.
43. How will you measure the weight of a body using the principle of moments ?

#### Problems

44. A motor vehicle of mass 1200 kg is getting accelerated in 5s, with a change of velocity from  $10\text{ms}^{-1}$  to  $15\text{ms}^{-1}$ . Calculate the force acting on the motor vehicle  
[Ans: 1200 N]
45. Calculate the force of impulse when a force of 100 N acts on a body for a time of 0.3s.  
[Ans: 30 N]
46. What is the change in velocity when a force of 20 N acts on a body of 4 kg in 5s?  
[Ans:  $25\text{ms}^{-1}$ ]
47. A force of 20 N acts on a body of mass 5 kg. Calculate its acceleration.  
[Ans:  $4\text{ms}^{-2}$ ]
48. A bullet of mass 25 gm penetrates into a sand bag with a velocity of  $10\text{ms}^{-1}$  and it comes to rest after 0.5s. Calculate the retarding force developed in the sand bag.  
[Ans: 0.5 N]
49. Calculate the period of oscillation of a simple pendulum of length 8m.  
[Ans: 6.28 s]
50. Find the length of the pendulum having the period of oscillation of 1s.  
[Ans : 0.248 m]

## 4. WORK, POWER, ENERGY

### 4.1 Work

Push a book placed on a table and observe that the book moves in the direction of the applied force. The force does work in moving the book.

If a force acts on a body and the point of application of the force moves, then work is said to be done by the force. The work done by a force acting on an object is equal to the product of the force and the displacement of the object in the direction of the force.

When a force  $F$  acts on a body and the body undergoes a displacement  $s$  in the direction of the force, then work done,  $W = Fs$ .

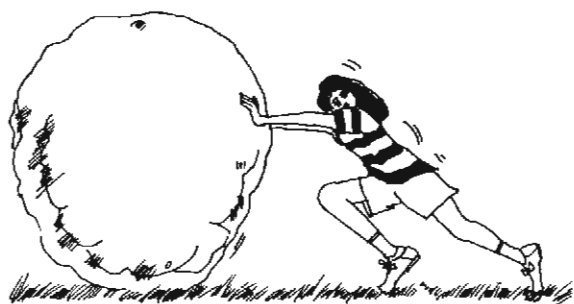


Fig. 4.1 Work

#### 1. Unit of Work

Since the units of force and displacement are Newton and metre respectively, the unit of work is newton-meter, also called Joule (J).

#### 2. Measurement of Work

The direction of the displacement of an object and the direction of the force acting on it can be in different directions. Their directions may be the same, opposite, perpendicular to each other or at an angle.

#### (1) Displacement in the direction of the force

If the displacement of an object is in the direction of the force applied on it, the amount of the work done by the force on the object is obtained by multiplying the force and the displacement.

Work done = Force  $\times$  displacement

$$W = F s$$

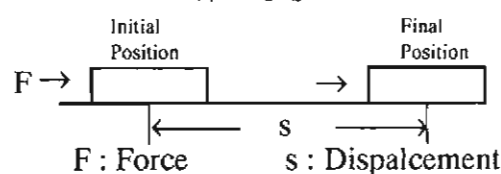


Fig 4.2 Calculation of work done

#### (2) Displacement perpendicular to the direction of the force

If the displacement of an object is perpendicular to the direction of the force acting on it, the work done by the force on the object is zero. Consider, for example, the force of gravity acting on an aeroplane flying in the sky. The force of gravity is in the downward direction, whereas the aeroplane's displacement is in a horizontal direction. So, the force and the displacement are perpendicular to each other. There is no displacement in the direction of the force of gravity, and therefore, the work done by it on the aeroplane is zero.

#### Examples

(1) A person carrying a load on his head and standing at a given place does no work, according to Physics. Since  $s = 0$ , work done  $W = 0$ .

(2) A man carrying a bucket of water and walking on a horizontal road does no work. Since his displacement is perpendicular to the direction of the gravitational force, work done by the gravitational force = 0.

### Work is a Scalar Quantity

Force and displacement are vector quantities. But, work, a product of these quantities is a scalar quantity.

## 4.2 Power

It takes more time to lift a given amount of water from a well using a hand pump. But the same quantity of water can be lifted very quickly using a motor pump. As the work is done in a shorter time, the power of the motor pump is greater than that of the hand pump.

**The rate at which work is done by a force is called the power. In other words, work done per unit time is called power.**

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

$$P = \frac{W}{t}$$

As work  $W$  is measured in Joules and time in seconds, the unit of power is Joule/second. This unit is given the name Watt (1 Watt = 1 Joule/second). The symbol of watt is  $W$ . Another common unit of power is the horsepower (hp). Horsepower is related to watt as **1 horsepower = 746 W**.

Have you heard of the unit kilo watt hour? What does it represent? The unit kilowatt-hour (1 kWh) means one kilowatt of power supplied for one hour. It is, therefore, the unit of energy.

$$\begin{aligned} 1\text{kWh} &= (1000\text{J/s}) \times (60 \times 60) \text{s} \\ &= 3.6 \times 10^6 \text{ J} \end{aligned}$$

Have you noticed the markings 100W and 60W on the electric bulbs? The rated value gives the electric energy consumed by the bulb per unit time and is called power of the bulb. A 100-W bulb consumes 100 J of electric energy per second. A 1mW (milliwatt) laser beam delivers 1mJ of energy every second in the form of light to the surface on which it falls. We say that the power of the laser beam is 1mW. A 100MW (megawatt) power plant produces 100MJ of electric energy per second.

## 4.3 Energy

The energy of a body is said to be the ability to do work. The unit of energy is joule.

There are many forms of energy, such as mechanical energy, heat energy, sound energy, light energy, electrical energy, chemical energy and atomic energy.

Mechanical energy is classified into potential energy and kinetic energy.

### 1. Potential energy

When a spring is pressed or a body is lifted to a height against the gravitational force, the work done is converted into potential energy of the object. Now the amount of work  $W$ , required to lift an object of mass  $m$  through a height  $h$  against the gravitational force is given by

$$\begin{aligned} W &= \text{Force} \times \text{displacement} \\ &= F h = m g h \end{aligned}$$

Hence potential energy of a body is the energy it possesses by virtue of its position or state of strain.

The work done in changing the same of an object is converted into the potential energy of the object. For example, a stretched spring and a rubber band possess potential

energy. The amount of potential energy in the stretched spring or rubber band is the amount of work done to stretch it. During oscillation, a simple pendulum possesses maximum potential energy at its extreme positions. Water stored up in a reservoir, a wound spring and compressed air possess potential energy.

## 2. Kinetic energy

The kinetic energy of a body is the energy possessed by the body by virtue of its motion.

Let a body of mass  $m$  be moving with a velocity  $v$ . Suppose a uniform force  $F$  acts on the body in the opposite direction and brings it to rest in a distance  $s$ . Now the work done by the body against the opposing force will be equal to the kinetic energy of the body.

$$\begin{aligned} \text{Kinetic Energy} &= F \cdot s \\ &= m a \cdot s \end{aligned}$$

$$\text{Initial velocity } u = v$$

$$\text{Final velocity } v = 0$$

Using the equation of the motion,

$$v^2 = u^2 + 2 a s$$

$$0 = v^2 + 2 a s$$

$$a = \frac{-v^2}{2 s}$$

The negative sign indicates negative acceleration of the body.

$$\text{The opposing force} = m a$$

$$m a = \frac{m v^2}{2 s}$$

$$\text{Work done by the force} = F s$$

$$\begin{aligned} &= \frac{m v^2}{2 s} \times s \\ &= \frac{1}{2} m v^2 \end{aligned}$$

Kinetic energy of a body of mass  $m$  moving with a velocity  $v$ ,

$$\text{KE} = \frac{1}{2} m v^2$$

**Activity:** Take a long bamboo stick and make a bow with string tied to its ends. Make an arrow with a light stick. As you stretch the string and release the arrow, it flies off the bow. Observe the changes in the shape of the bow and note transformation and transfer of energy from one body to another. The potential energy stored in the bow due to the change of its shape is converted into the kinetic energy of the arrow.



*Fig. 4.3 Energy transformation in Pole Vault*

**Activity:** In pole vault the sports person runs with a pole in his hands. He rises to a height by supporting him on the pole and jumps over the mark. Notice the energy transformations involved in this event and write a note on it.

## 3. Law of Conservation of energy

Energy can neither be created nor be destroyed. But energy can be converted from one form to another.

This law holds good for all forms of energy. Consider the case of a freely falling body. It possesses a particular amount of potential energy at a given height. When it falls freely, its potential energy goes on decreasing, but its kinetic energy increases exactly by the same amount. At any position during its fall, the loss of potential energy of the body is equal to the gain in kinetic energy. So, the total energy of the body remains a constant.

## Verification of the law of conservation of energy for a freely falling body

For a freely falling body, the sum of potential and kinetic energies remains the same at every instant during the fall.

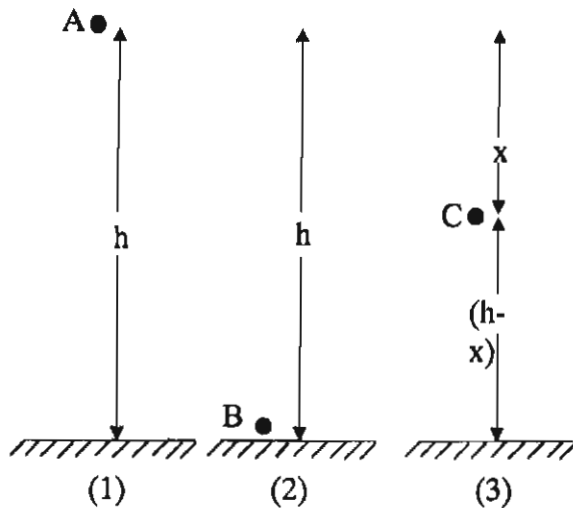


Fig. 4.4 Energy of a freely falling body

Let a body of mass  $m$  be at rest at a point A at a height  $h$  above the ground.

$$\begin{aligned}
 1) \text{ Potential energy at the point A} &= mgh \\
 \text{Kinetic energy} &= 0 \\
 \text{Total energy at A} &= \text{Potential energy} \\
 &\quad + \text{Kinetic energy} \\
 &= mgh + 0 \\
 \text{Total energy at A} &= mgh \quad \dots (1)
 \end{aligned}$$

2) Let the body fall freely from A and strike the ground B with a velocity  $v$ ,

$$\begin{aligned}
 v^2 &= 2gh \\
 \text{Kinetic energy at B} &= mv^2 \\
 &= m \times 2gh \\
 &= mgh \\
 \text{Potential energy at B} &= mg \times 0 = 0 \\
 \text{Total energy} &= \text{Kinetic energy} \\
 &\quad + \text{Potential energy} \\
 &= mgh + 0 \\
 \text{Total energy at B} &= mgh \quad \dots \dots (2)
 \end{aligned}$$

3) Let us calculate the total energy of the body at an intermediate point C between A and B at a depth  $x$  below A. The height of C above the ground is  $(h-x)$ .

$$\text{Potential energy at C} = mg(h-x)$$

If after falling through a distance  $x$ , the velocity is  $v$ , then  $v^2 = 2gx$

$$\begin{aligned}
 \text{The kinetic energy at C} &= \frac{1}{2} mv^2 \\
 &= \frac{1}{2} m \times 2gx = mgx
 \end{aligned}$$

$$\text{Total energy at C} = \text{Potential energy} + \text{Kinetic energy}$$

$$= mg(h-x) + mgx$$

$$\text{Total energy at C} = mgh \quad \dots \dots (3)$$

Comparing the equations (1), (2) and (3) we conclude that the total energy of the freely falling body remains a constant. Thus in the case of a freely falling body, even though there is transformation of energy from the potential to kinetic, there is neither gain nor loss in its total energy. Therefore, the law of conservation of energy holds good.

## 4. Transformation of energy

Energy can be transformed from one form to another. A steam engine changes heat energy into mechanical energy. In a fan, electrical energy is converted into mechanical energy. In an electric heater, the electrical energy is converted into heat energy. A microphone converts sound energy into electrical energy. A loudspeaker, on the other hand, converts electrical energy into sound energy. In an electric bulb, electrical energy is converted into heat and light energy. When you strike a match, the chemical energy of the chemicals on the match is converted into light and heat energy.

## Problems

1) Calculate the amount of work done in drawing a bucket of water weighing 10 kg from a well of depth 20 m.

Mass,  $m = 10 \text{ kg}$

Acceleration due to gravity,  
 $g = 9.8 \text{ ms}^{-2}$

Height,  $h = 20 \text{ m}$

Work,  $w = mgh$   
 $= 10 \times 9.8 \times 20$   
 $= \mathbf{1960 \text{ joule.}}$

2) A box is pushed along a horizontal surface with a constant velocity for a distance of 4 m against a frictional force of 250 N. How much work is done ?

Force required to move the box,

$$F = 250 \text{ N}$$

Displacement  $s = 4 \text{ m}$

Work Done  $W = F \times s$   
 $= 250 \times 4$   
 $= \mathbf{1000 \text{ joule.}}$

3) An electric lift of load 1000 kg takes 20 s to move through a height of 40 m. What is its power ?

Mass,  $m = 1000 \text{ kg}$

Acceleration due to gravity,  
 $g = 9.8 \text{ ms}^{-2}$

Height,  $h = 40 \text{ m}$

Time,  $t = 20 \text{ s}$

Workdone,  $W = mgh$   
 $= (1000 \times 9.8 \times 40) \text{ joule}$

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{1000 \times 9.8 \times 40}{20}$$
$$= \mathbf{19600 \text{ watt}}$$

## 4.4 Sources of energy

Man depends on natural resources such as plants, animals, minerals, fuels, water and soil for his daily needs and comfort. All such resources used by living beings for their energy requirements are called energy resources. As these resources are dependent on nature they are called natural resources.

### 1) Sun is the main source of energy

The sun is the main source of energy for the earth. Green plants use this energy to prepare food by the process of photosynthesis. The green plants convert solar energy into chemical energy and store them in plants. Animals also get their energy from plants. Therefore, all living organisms, directly or indirectly, depend on the sun as the source of energy. The sources of energy can be broadly classified into (1) Renewable sources of energy and (2) Non – renewable sources of energy.

Renewable sources of energy are those which are produced continuously in nature and are inexhaustible. Some examples are (1) Hydro-energy, (2) Solar energy, (3) Geothermal energy, (4) Wind Energy, (5) Tidal Energy, (6) Bio-energy and (7) Nuclear Energy

### 2) Hydro – energy

Have you seen water currents? It carries along with it stones, sand, uprooted trees and animals. This is because water has tremendous energy. Realising this, men started using energy of water to run machines. The hydro-energy can be used for grinding grains, transporting timber from one place to another and for generating electricity.

Generation of electricity is the most important use of hydro-energy. Water is collected at a certain height in huge reservoirs. This water, which has a lot of potential energy,

is then made to fall on turbines connected to huge generators, which generate electricity. Transmission lines are used to distribute this electricity to the consumers. This electricity produced from flowing water is called hydro-electricity. Hydro-electricity has many advantages. The main advantage is that it does not cause pollution. It is also a renewable form of energy as water is a renewable resource. Electricity is produced at a cheaper cost using hydro energy.

### **3) Solar energy**

Almost all the energy resources on the earth derive energy from the sun. Without the energy of the sun, it is impossible for lives to exist or survive. Plants use solar energy for photosynthesis. A part of it is used in heating the air. This in turn causes wind as hot air, being lighter, rises up and the cool air from the surrounding areas rush in to take its place, thereby forming a wind cycle. Using the strong wind, wind mills are operated to produce electricity. Throughout the year the strong wind through the passes in the western ghats, are used to operate wind mills and generate electricity.

Wind mills produce energy in Kayathar of Tirunelveli District and Aralvaimozhi of Kanyakumari District in Tamilnadu. Solar energy is also used in solar heating devices like heater, cooker and solar cells.

Solar energy is an inexhaustible natural source of energy. If we tap and use more solar energy, it can be a better alternative for the present sources of energy, many of which will get exhausted in the near future.

### **4) Geothermal energy**

Geothermal means heat of the earth and therefore energy generated from the heat of the earth is called geothermal energy. Cold water seeps through the fissures of the rocks on the surface of the earth. This water passes down to the lower level where the rocks are

very hot. Thus the cold water first gets converted into hot water and ultimately to steam. Since the pressure is very high, the steam gushes out with a high pressure and this can be harnessed to produce mechanical and electrical energies. This source of power is available only in volcanic regions of the earth.

### **5) Wind Energy**

Moving air is called wind. Windmills are operated using the kinetic energy of the wind. These windmills are used to operate machines and generators to produce electricity.

The wind has kinetic energy. This energy is used to drive sailboats. At present we use more of wind energy as it is a renewable energy and causes no pollution.

#### **Wind resource assessment**

Tamil Nadu Energy Development Agency has taken up Wind Resource Assessment for the identification of high wind prone sites with an annual mean wind speed of 18 km per hour and above. The study has so far been continued mainly to the regions covered by the three passes namely Shenkottab Pass, Aralvoimozhi Pass and Palghat Pass and a few coastal zones. The studies conducted so far have shown that Tamil Nadu is one of the best windy states in the country.

Tamil Nadu is in the forefront in the country in the field of wind power generation. According to a survey, Tamil Nadu can generate 1700 megawatt of electric power from windmills every year. Considering the generating capacity, Tamil Nadu stands next to Maharashtra. So far, windmills capable of producing 800 megawatt of electric power have been installed.

Windmills are used for pumping water for drinking purposes and for minor and small-scale irrigation.

## 6) Tidal Energy

Due to the gravitational pull of the moon tides are formed on the surfaces of the land and oceans of the earth. This rise and fall of sea waves can be harnessed to generate power. India has good potential to build tidal power stations in Gujarat and West Bengal.

## 7) Bio-energy

The energy obtained by the decomposition of organic matter such as animal dung, rotten fruits, vegetables and human excreta is called Bio-energy. When the organic matter is decomposed along with water in the absence of air, it produces gases like methane, carbon dioxide, hydrogen and hydrogen sulphide. Biogas is an excellent fuel which can be used for cooking and lighting purposes. As biogas is made from organic wastes, which are easily available, especially in rural areas, it is being increasingly used.

Biomass consists of waste materials and dead parts of living things. It includes garbage, excretions of animals, sewage, crop residue, wood and industrial waste materials. The biogas is being produced in villages from cow dung and sewage.

Biomass is decomposed in the absence of oxygen and thus methane gas is produced. Methane gas is called biogas. It is used as a fuel for cooking and lighting.

## 8) Nuclear energy

The nuclear energy can be obtained from nuclear fission or nuclear fusion. When a nucleus of heavier elements like Uranium, Thorium or Plutonium is split, two nuclei of lighter elements are formed. This reaction is called nuclear fission. By fusing two nuclei of lighter elements like hydrogen, a heavier nucleus is formed and this process is called nuclear fusion.

In nuclear fission, the heat energy produced can be used for generating electricity. The nucleus of uranium, a radioactive element, on colliding with a neutron splits into two smaller nuclei and a few additional neutrons are released. These additional neutrons further split the other nuclei of Uranium. This process goes on continuously and rapidly multiplying the reactions and therefore this is called a chain reaction.

Nuclear fissions are carried out in the nuclear reactor which controls the chain reaction. The heat produced from the reaction is used to convert water into steam which is then used to drive turbine that generates electricity.

Nuclear power accounts for only 4% of total power generated from all sources of the world. There are about 350 nuclear power stations in the world.

Nuclear power stations in our country are Tarapur Atomic Power Station, Rajasthan Atomic Power Station, Kalpakkam Atomic Power Station in Tamilnadu, Narora Atomic Power Station in Uttar Pradesh, Kakrapar Atomic Power Station in Gujarat and Kaiga Atomic Power Station. Another Atomic Power Station is being constructed at Kudankulam in Tamilnadu..

The energy produced by the sun is due to a nuclear reaction known as thermonuclear fusion. The sun is a huge ball of fire containing 90% of hydrogen. The central core of the sun has millions of atmospheric pressure and a temperature of 14 million degree. In the sun, four nuclei of hydrogen fuse together to form a nucleus of helium.

During fusion, energy is released in the form of heat and light. It is this energy which makes the sun shine. The highly destructive hydrogen bomb is based on the uncontrolled fusion reactions of hydrogen producing a large amount of energy.

## 4.5 Non – renewable sources of energy

Millions of years ago, dead animals and plants got buried, decayed in the absence of air under very high pressure and heat and converted into petroleum and coal. We have been using more and more of the fuels such as petrol, diesel, natural gas and coal which are available only in limited quantities. These fuels are used to operate various machines and vehicles and to generate electricity in a large scale. If we continue to use these fuels at the present rate, we will exhaust them in the next 50 years. It will take millions of years for these resources such as petrol, diesel, natural gas and coal to develop in the earth and hence they are known as non-renewable sources. While using these fuels, burnt out ashes, dust, gases poisonous to living beings, and heat are released and the nature gets largely polluted. Since both coal and petroleum are obtained from fossilized materials, they are also called **fossil fuels**. Fossil fuels consist mainly of hydrocarbons and traces of oxygen and other substances.

**Solid Fuels:** Wood, Coal, Lignite and Agricultural wastes

**Liquid Fuels:** Kerosene, Petrol and Diesel

### 1. The power requirement in India

The demand for electricity is increasing rapidly both in the domestic and industrial fronts. The total power production in 1994 was 78,700 MW and it is estimated that the requirement of power in the year 2007 would be 131,000 MW. The Geological Survey of India estimates that there are 111.88 billion tons of coal in India. We use 56 million tons of coal every year and this figure will rise to 195 million tons by the turn of the century. The energy requirements of India in the years 2004-2005 A.D are given below, giving us an idea of the vast resources needed.

<i>Resources</i>	<i>Requirements</i>	
	<i>1980-1985 (in millions)</i>	<i>2004-2005 (in millions)</i>
Coal	94 ton	450 ton
Oil	32 ton	94 ton
Electricity	221 units	919 units

India is the second most populous country in the world. The need for energy resources is on the increase. Efforts are being made both by governmental and non-governmental organizations for rural electrification and promoting renewable energy technologies.

### 2. Judicious use of energy

Since there is a lack of energy resources, we must use the available energy with utmost care and not waste it. Judicious and economical use of energy can help in overcoming the energy crisis. The wise and economic use of energy resources is called conservation of energy. The following steps can be taken to save and conserve energy:

- 1) Use fans, lights, coolers, room heaters, desert coolers and air conditioners, only when required.
- 2) Encourage the use of solar devices
- 3) Use windmills wherever possible to produce electricity and lift water for agriculture.
- 4) Use Biogas for cooking and other domestic uses.
- 5) Use fuel-efficient vehicles and maintain their engines properly.
- 6) Design and develop automobiles, which can run on electrical energy or solar energy rather than on petrol and diesel.
- 7) Maintain regularly the gas-pipes, oil pipes and water pipes.
- 8) Create awareness among the public about the efficient use of fuel and energy.

### Some basis concepts

- \* Work done by a force is equal to the product of the force and the displacement of the object. Its unit is joule.
- \* Rate at which work done is called Power. Its unit is Watt.
- \* According to the law of conservation of energy, energy can neither be created nor be destroyed. Energy can be converted from one form to another.
- \* The natural resources used for the energy needs of living beings are called energy resources.
- \* Renewable and non-renewable are the two types of energy resources.
- \* Hydro energy, Solar Energy, Geothermal Energy, Wind Energy, Tidal Energy, Bio Energy and Nuclear Energy are renewable sources of energy.
- \* Since Petrol, Diesel, Natural gas and Coal are exhaustible, they are non-renewable sources.
- \* Solid fuels are wood, coal, lignite and agricultural wastes.
- \* Liquid fuels are kerosene, petrol and diesel.
- \* Judicious and economical use of energy is called conservation of energy.

### Self-Evaluation

#### Choose the correct answer

1. When the mass is halved and velocity doubled, the kinetic energy of the object  
(1) remains the same (2) is doubled  
(3) is quadrupled (4) reduced to 1/4
2. Kilowatt hour is the unit of  
(1) energy (2) power  
(3) time (4) force
3. A wound spring possesses  
(1) kinetic energy (2) potential energy  
(3) zero potential energy  
(4) zero energy
4. Which of the following is the unit of energy ?  
(1) watt-hour (2) kilowatt-hour  
(3) joule (4) watt
5. If 20 joule of work is done by an object in 5 seconds, its power is  
(1) 100 W (2) 4 W  
(3) 0.25 W (4) 1000 W
6. The renewable source of energy is  
(1) Lignite (2) Petroleum  
(3) Tidal waves (4) Natural gas
7. Non-conventional source of energy is  
(1) Lignite (2) Geothermal Source  
(3) Petroleum (4) Natural gas
8. The energy produced at a cheaper cost is  
(1) Solar energy (2) Nuclear energy  
(3) Hydro electric energy  
(4) Wind energy
9. Inexhaustible source of energy is  
(1) Petroleum (2) Solar energy  
(3) Natural gas (4) Fossil fuel
10. The device used to control the chain reaction in Nuclear fission is  
(1) Atom bomb (2) Nuclear reactor  
(3) Electric furnace (4) Chemical furnace

#### Fill in the blanks

11. The unit of power is .....
12. When a ball is thrown upwards its ..... goes on increasing.
13. The unit of energy and ..... are the same.
14. The loud speaker converts electrical energy into ..... energy.
15. One horsepower is equals ..... watt.
16. One mw laser beam falls on a surface it delivers ..... energy every second.

17. Green plants use ..... energy for photosynthesis.
18. Electric power is generated using ..... in Kayatharu.
19. In Tamilnadu Atomic Power Station is located in .....
20. Energy is produced in the sun due to .....
21. The temperature of core of the sun is .....
22. **Match the following**

1) Sun	(i) Chain reaction
2) Nuclear fission	(ii) Ocean Tides
3) Geothermal power	(iii) Photosynthesis
4) Moon's gravitational force	(iv) Non-renewable source of energy
5) Lignite	(v) Volcanic region
32. Mention two places in Tamilnadu where windmills are located.
33. How is geothermal energy obtained?
34. How are tidal waves formed in the ocean?
35. What do you mean by bio-energy?
36. How is bio-gas produced?
37. Define nuclear fission.
38. Define nuclear fusion.
39. What is chain reaction?
40. Mention the names of any two of the nuclear power stations in our country.
41. Differentiate nuclear fission and fusion.
42. What is meant by non-renewable sources of energy?
43. What are fossil fuels?
44. What is the use of a nuclear reactor?
45. Explain the nuclear reaction in the sun.

**Answer briefly**

23. Define work. What is its unit ?
24. How is work done by a force calculated?
25. What is the work done by the gravitational force acting downwards on an aeroplane whose displacement is in the horizontal direction ? Give reason.
26. What is power ? Give its unit.
27. Define energy.
28. What is meant by renewable sources of energy?
29. Mention two examples each for renewable and non-renewable sources of energy.
30. State two merits of hydroelectric power generation.
31. Give two applications of solar energy.

**Answer in detail**

46. How will you calculate the work done by a force? Explain the work done when the displacement is in the direction of the force.
47. Calculate the work done when the displacement is perpendicular to the direction of the force. Give two examples.
48. Define potential energy. Derive an expression for it.
49. What is kinetic energy? Derive an expression for it.
50. State and prove the law of conservation of energy for a freely falling body.
51. Hydro-energy is a renewable source - Explain.
52. Write notes on solar energy and geothermal energy.
53. What do you mean by wind energy and tidal energy?

54. How is bio-energy obtained? How can use bio-mass as an energy resource?
55. Explain nuclear fission and fusion. How is electricity generated from a nuclear reactor?

### Problems

56. Calculate the work done in drawing a bucket of water 5 kg from a well of depth 10 m.  
[Ans: 490 J]
57. A box is pushed along a horizontal surface with a constant velocity for a distance of 2 m against a frictional force of 1000 N. Calculate the work done.  
[Ans: 2000 J]
58. An electric lift of total weight 800 kg. takes 10 s to go 10m vertically up. Calculate the power of the lift.  
[Ans 7.84 kW]
59. Calculate the power developed when a work of 50 J is done by a force in 5 s.  
[Ans: 10 W]

60. When a rice bag of mass 200 kg is lifted to a height, the value of potential energy is 9800 J, Calculate the height.

[Ans: 5 m]

61. A boy of mass 50 kg is climbing a hill through a height of 100 m. Calculate the work done by him and the value of potential energy. ( $g = 9.8 \text{ m/s}^2$ ).

[Ans:  $4.9 \times 10^4 \text{ J}$ ]

62. Calculate the kinetic energy of a body of mass 2 kg moving with a velocity of 0.1 m/s.  
[Ans:  $10^{-2} \text{ J}$ ]

### Activity

63. List out the major hydroelectric power stations in India. Find out the rivers across which these power stations are built up.
64. Identify various places, like houses, offices and public places around you, where energy is wasted.
65. Understand how water resource can be increased by the process of rain water harvesting.

## 5. HEAT AND TEMPERATURE

### 5.1 Heat and temperature

Atoms and molecules of a substance are in motion at all temperatures. They do not always move at the same speed. So, different molecules move with different velocities.

When you heat a substance the thermal energy of the molecules increase thereby increasing the temperature of the substance.

**Temperature is the measure of average heat or thermal energy of the particles in a substance. It does not depend on the number of particles or size and shape of the object.**

*Example:* The temperature of a small cup of boiling water is the same as the temperature of the large pot of boiling water.

**Heat and temperature are different concepts, but related to one another. Heat is the total energy of molecular motion of a substance. But temperature is a measure of the average energy of molecular motion in the substance.**

Heat energy depends on the speed of the particles, the number of particles, size and type of particles.

Temperature of a substance does not depend on size or type of particles of the object.

Temperature of a small cup of water may be the same as the temperature of the

large tank of water. The tank of water has more heat because it has more amount of water and thus more thermal energy.

**Heat is the internal energy of a substance. By adding or removing heat, the temperature of a substance can be increased or decreased.**

When you add heat to a substance, its temperature will be increased. As you remove heat from it, the temperature will be lowered.

Higher temperature of a substance means that the molecules in it are moving with higher translational kinetic energy.

When two objects at same temperature are brought into contact, there will be no overall transfer of thermal energy between them. If the objects are at different temperatures, there will be a transfer of heat energy from hotter to the cooler object until both objects reach the same temperature.

**Temperature is not energy, but a measure of it. Heat is energy. The unit of temperature is °C or K. The unit of heat is Joule.**

**Activity:** Take 100 ml of water in a beaker and introduce a thermometer into it. Note the initial temperature of water. Heat it with a spirit lamp, and record the time taken for water to boil and the temperature of boiling water. Repeat the same experiment with 200 ml water and tabulate your observations.

Observe that when the amount of water is doubled, the time taken and hence the amount of heat energy required for boiling is doubled.

**Table: 5.1 Heat and temperature**

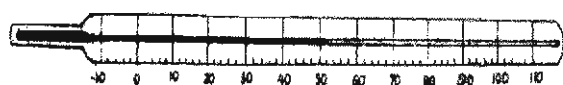
S. No.	Amount of Water (ml)	Initial Temp. (°C)	Boiling Temp. (°C)	Time taken for boiling (Sec)
1.	100			
2.	200			

## 5.2 Thermometer

Thermometer is a device for measuring temperatures of an object. Different kinds of thermometers are designed by measuring the different properties of substances which change uniformly with change of temperature.

For example, thermal expansion of a metal rods, electrical resistance of a metal wire, pressure of a given amount of a gas, expansion of liquids such as alcohol and mercury and luminosity of hot filaments are used in thermometers to measure various temperature ranges.

### (1) Mercury Thermometer



**Fig 5.1 Mercury Thermometer**

The most common temperature – measuring device is the mercury thermometer. It consists of a glass bulb, containing mercury, which is connected to a glass tube with a small capillary bore. An increase in the temperature of the mercury

in the bulb causes it to expand up the bore. The change in the height of the mercury thread in the capillary bore provides a means of measuring a change in temperature.

### (2) Reasons for using mercury as thermometric liquid.

1. Mercury is the only liquid metal. It is opaque and glittering. It can be easily seen through glass.
2. It is a good conductor of heat and attains the temperature of a body quickly.
3. It does not wet to the glass.
4. The expansion of mercury is almost uniform over the ordinary range of temperatures.
5. The expansion is regular even for small rise in temperature.
6. It has a high boiling point (357°C) and a low melting point (-39°C), so that both high and low temperatures can be measured by it.

## 5.3 Temperature scale

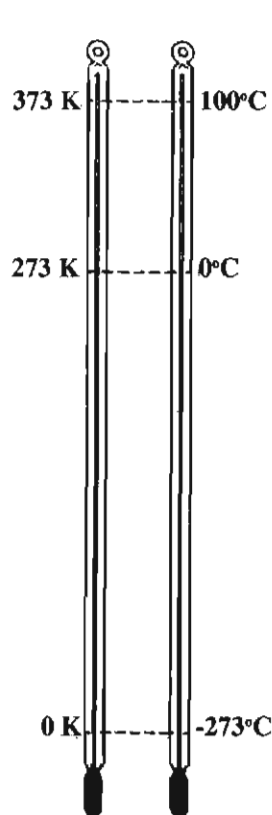
### (1) Celsius Scale

In 1743, Andrews Celsius invented the Celsius scale for measuring the temperature of substances. In this scale, the freezing temperature of pure water is taken as the lower fixed point and the boiling point of water is taken as the upper fixed point, and the interval divided into 100 equal divisions, each division being denoted as one degree Celsius (°C).

As the range of temperature is divided into 100 equal divisions this scale is also called as the centigrade scale.

## (2) Kelvin scale

Kelvin scale is also known as the absolute scale of temperature. The lowest temperature to which a substance can be cooled,  $-273.15^{\circ}\text{C}$ , is taken as the lower fixed point in Kelvin scale.



$$T_K = T_C + 273$$

Fig 5.2 Celsius, Kelvin Scale

denoted by 0K or  $-273.15^{\circ}\text{C}$ .

All objects at all temperatures above absolute zero, emit thermal or heat energy.

As a substance is cooled continuously its temperature decreases. But there is a limit to the lowest temperature to which a substance can be cooled. The lowest possible temperature is taken as zero point of the Kelvin scale. This temperature is called as absolute zero.

At absolute zero, there is no molecular motion and hence no heat energy in a substance. At absolute zero, all atomic and molecular motions stop. So **absolute zero is the lowest temperature possible and**

$$\text{Kelvin Scale (K)} = \text{Celsius Scale } (^{\circ}\text{C}) + 273$$

$$\text{Celsius Scale } (^{\circ}\text{C}) = \text{Kelvin Scale (K)} - 273$$

In Kelvin scale, the freezing point of water is 273 K ( $0^{\circ}\text{C}$ ), the boiling point of water is 373K ( $100^{\circ}\text{C}$ ), and the interval divided into 100 equal divisions.

In Kelvin scale, temperatures are not written with  $^{\circ}$  symbol.

Table 5.2 Freezing and boiling points of water and thermometric liquids.

Liquid	Freezing Point		Boiling Point	
	$^{\circ}\text{C}$	K	$^{\circ}\text{C}$	K
Water	0	273	100	373
Mercury	-39	234	357	630
Alcohol	-117	156	79	352

### Problems

1) Convert the normal temperature of human body  $36.9^{\circ}\text{C}$  into Kelvin scale

$$\begin{aligned} \text{Kelvin} &= \text{Celsius} + 273 \\ &= 36.9 + 273 = 309.9\text{K} \end{aligned}$$

2) What is Celsius temperature equivalent to 380K ?

$$\begin{aligned} \text{K} &= \text{C} + 273 \\ \text{C} &= \text{K} - 273 = 380 - 273 = 107^{\circ}\text{C} \end{aligned}$$

The normal temperature of certain animals are given in Table 5.3

Table 5.3 Normal body Temperatures of various animals

Animal	Dog	Cat	Stallion	Mare	Rabbit	Pig	Sheep	Dairy cow
Normal temp. ( $^{\circ}\text{C}$ )	38.9	38.6	37.6	37.8	39.5	39.2	39.4	38.6

**Activity:** Express the maximum and minimum temperature of cities announced in TV into Kelvin Scale.

### 5.4 Clinical thermometer

Clinical thermometer is similar in construction to a mercury thermometer. It has a short, fine capillary tube with a constriction and a slight bend near the mercury bulb. The radius of the constriction is very small.

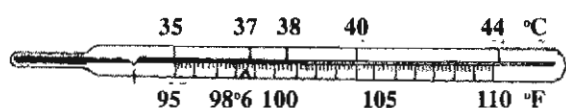


Fig 5.3 Clinical Thermometer

When the mercury bulb is placed below the tongue of the patient the expanding mercury thread forces itself past the constriction and the bend. The length of the capillary tube is suitably calibrated in degrees to read the temperature. When the thermometer is taken out of the mouth of the patient, the mercury level remains the same indicating the temperature of the body. The mercury thread in the bore will not fall back into the bulb because of the constriction in the bore. Then, it can be re-set for later use by shaking down the mercury back into the bulb.

**The normal temperature of human body is 36.9°C.** The clinical thermometer measures temperature in a very short range of 10° from 35° to 44°C. So, it accurately measures even small changes in body temperatures.

### 5.5 Kinetic theory of gases

Celsius, Boltzmann and Maxwell proposed the Kinetic theory of gases. Its postulates are:

1. All gases are made up of large number of tiny particles called molecules.
2. All the molecules of a gas are all identical in mass, volume and other properties.
3. The molecules are all perfectly rigid and elastic spheres.
4. Molecules move along straight lines in random directions, with all possible velocities.
5. Molecules collide with each other and also with the walls of the container.
6. The distance between the two successive collisions of molecules is called a **mean free path**.

### 5.6 Molecular motion and temperature

The average kinetic energy of the molecules of a gas is directly proportional to the temperature of the gas.

As the temperature of a gas increases, the kinetic energy of its molecules also increases. As temperature of gas decreases the kinetic energy of its molecules decreases.

#### Absolute zero

At absolute zero, all atomic and molecular motions stop and it is the lowest temperature to which a substance can be cooled. This is called absolute zero.

Absolute zero is temperature at which all atomic and molecular motions of an ideal gas stop.

### 5.7 Gas laws

Heat is a form of energy. Heat energy produces changes in temperature, volume and pressure of a gas.

## 1. Boyle's law

Robert Boyle deduced the relation between volume and pressure of a gas at a constant temperature. At a constant temperature, the pressure of a given mass of a gas, is inversely proportional to its volume.

Let P be the pressure and V be the volume as a gas at a constant temperature T, then

$$P \propto \frac{1}{V} \quad (\text{at constant temperature})$$

$$\text{i.e., } PV = \text{Constant}$$

### Activity: Pressure and volume of a gas.

Take the cylindrical portion of a large syringe used by a veterinary doctors. Close the narrow end of the barrel tightly and fix it on a wooden frame. Fix a small plate over the piston. Place small weights on the piston and note down the volume of air in the barrel. Increase the weights on the

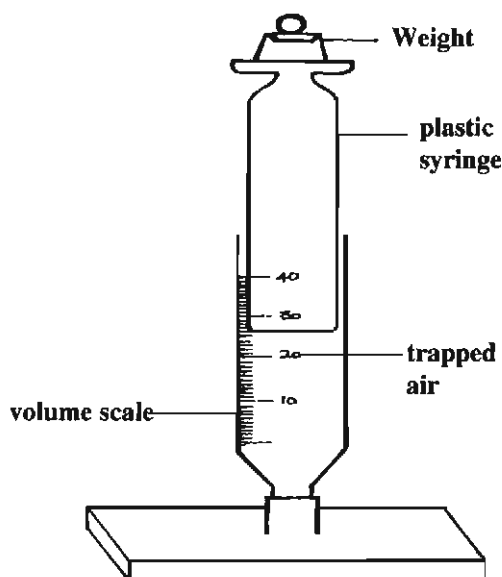


Fig 5.4 Boyle's Law - Activity

piston and note the volume of air in each case and tabulate. Observe that the products of weight (pressure) and volume remains a constant.

Table 5.4 Verification of Boyle's law

S. No.	Weight (g)	Volume of Air (ml)	Weight $\times$ Volume = Constant
1			
2			
3			
4			
5			

## 2. Verification of Boyle's law using Quills tube

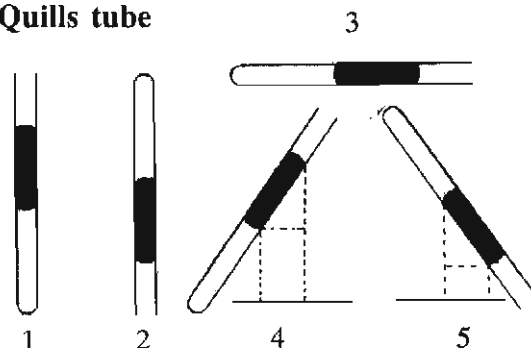


Fig 5.5 Various positions of Quills tube

Quills tube is a capillary glass tube of length 50cm and diameter 2 mm closed at one end with a mercury pellet of length 10 – 15 cm inside it. Air is enclosed between the closed end and mercury pellet. A scale is attached to the Quill tube.

Let H be the atmospheric pressure of air.

1) The quill tube is fixed vertically with its open end up. Let the length as mercury thread be h. Now the pressure of air enclosed in the tube is  $P = H + h$ .

2) The Quill tube is fixed vertically with its open end down. Now, the pressure of air enclosed in the tube is  $P = H - h$ .

The length of the air enclosed in the tube is measured for every position and let it be 'l'.

3) When the Quill tube is fixed horizontally the pressure  $P = H$

4) Repeat the experiment by keeping the tube inclined at some angle to the horizontal

with open end up and down and note down the vertical height of the mercury pellet and the length of the air column in each case.

Tabulate the measurements and observe that the product  $P \times l$  is a constant.

**Table 5.5 Verification of Boyle's law using Quill tube**

S. No.	Position of open end of Quill tube	Vertical Height of Hg thread $h$ ( $10^{-2}m$ )	Pressure of enclosed air $P = (H \pm h) 10^{-2}m$	Length of air Column $l$ ( $10^{-2}m$ )	$p \times l = \text{constant}$
1.	Vertically up				
2.	Vertically down				
3.	Horizontal				
4.	45° upwards				
5.	45° downwards				

### 3. Charles' law – 1

At constant pressure, the volume of a given mass of gas is directly proportional to its kelvin temperature.

At constant pressure  $p, V \propto T$

$$\frac{V}{T} = \text{Constant}$$

### Charles' law – 2

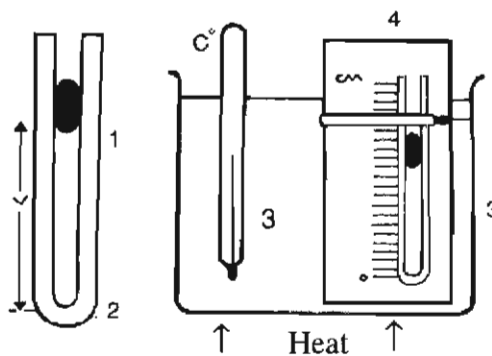
At constant volume, the pressure of a given mass of gas is directly proportional to its kelvin temperature.

At constant volume,  $P \propto T$

$$\frac{P}{T} = \text{Constant}$$

A gas which obeys Boyle's law and Charles' laws is called an **ideal gas**.

**Activity:** This activity explains the relation between volume and temperature of a gas at a constant pressure.



- 1. Trapped air
- 2. Length of air column
- 3. Water
- 4. Scale with tube

**Fig 5.6 Charles Law - Activity**

Dry air is trapped by a mercury thread of length 2mm in a capillary tube closed of one end as shown in the figure. Let Y be the length of the air column. A scale is attached to the tube and kept vertically in a beaker of water. Note the temperature of water in the

beaker. Heat the water in the beaker to 40°C and measure the height of the air column. Repeat the experiment for various temperatures and note down the height of air column in each case.

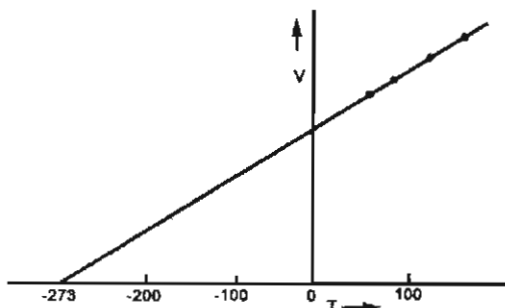


Fig 5.7 Celsius, Kelvin Scale

A graph is drawn with temperature along the X-axis and volume of gas along the Y-axis. By extending the straight line in the graph backwards, to meet the X-axis we find that the volume of a gas becomes zero at -273.15°C. This temperature is called absolute zero (0K).

Table 5.6 Verification of Charles' law

S. No.	Trapped Air		$\frac{V}{T} = \text{Constant}$
	Temperature T°C	Volume V	
1.	40		
2.	50		
3.	60		
4.	70		

## 5.8 Gas equation

The pressure, volume and temperature of a gas are interrelated and change in any one factor affects the other two.

According to Boyle's law,

At constant temperature,  $P \propto \frac{1}{V}$

According to Charles law,

At constant volume,  $P \propto T$

At constant T and V,

$$P \propto \frac{T}{V}$$

$$PV \propto T \text{ (or) } PV = RT$$

where the constant of proportionality R is called the Gas constant

$$\text{So, } \frac{PV}{T} = R = \text{Gas constant}$$

Let  $V_1$  be the volume of the gas at pressure  $P_1$  and temperature  $T_1$ . Let  $V_2$  be the volume of the gas at pressure  $P_2$  and temperature  $T_2$ .

From Boyle's law,

$$P_1 V_1 = P_2 V_2 \text{ (at constant T)}$$

By Charles' law,

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \text{ (at constant P)}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \text{ (at constant V)}$$

Multiplying the above equations,

$$P_1 V_1 \times \frac{V_1}{T_1} \times \frac{P_1}{T_1} = P_2 V_2 \times \frac{V_2}{T_2} \times \frac{P_2}{T_2}$$

$$\frac{P_1^2 V_1^2}{T_1^2} = \frac{P_2^2 V_2^2}{T_2^2}$$

Taking square roots on both sides,

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

This equation is called the Gas equation.

## 5.9 Pressure of a gas on the basis of kinetic theory of gases

The properties of a gas such as pressure and energy are explained by the kinetic theory of gases. The volume of the molecules of a gas is negligibly small compared with the volume of the container. As the distance between molecules of a gas is larger, the force of attraction of between the molecules is negligible.

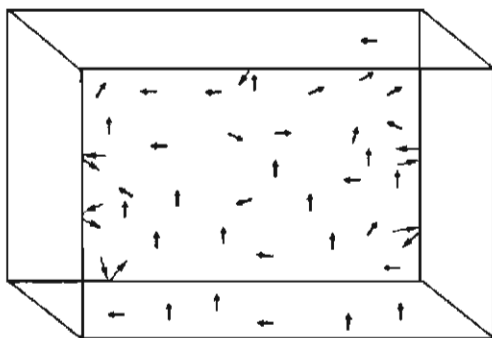


Fig 5.8 Pressure of a gas

Consider a cubic box having thousands of bees. Inside the box the motion of the bees is random and they collide with each other and with the walls of the container exerting an **average pressure** on it. When the kinetic energy of bees increases the pressure on the walls also increases. When volume of the box is reduced, number of collisions and hence pressure increases.

Similarly, the molecules collide with the walls of a container and exert pressure on the walls. Force acting per unit area of walls of container is called pressure. The pressure depends upon the number of collisions on the unit area of the walls. The energy of molecules in the container depends upon the number of molecules per unit volume, velocity of the molecules and mass of the molecules colliding with the walls of the container. The velocities of molecules

of some gases at room temperature are given in Table 5.7.

Table 5.7 Velocity of gas molecules at 300K

S. No.	Gas	Molecular Weight $10^{-3}$ Kg / mole	Velocity $ms^{-1}$
1.	H <sub>2</sub>	2.82	1920
2.	H <sub>2</sub> O (vapour)	18.0	645
3.	N <sub>2</sub>	28.0	517
4.	O <sub>2</sub>	32.0	483
5.	CO <sub>2</sub>	44.0	412
6.	SO <sub>2</sub>	64.1	342

### Problems

3) The volume of a gas at 27°C is 200cm<sup>3</sup>. What will be its temperature when the volume is 250cm<sup>3</sup> provided its pressure remains constant?

$$V_1 = 200 \text{ cm}^3,$$

$$T_1 = 273 + 27 = 300 \text{ K}$$

$$V_2 = 250 \text{ cm}^3 \quad T_2 = ?$$

At constant pressure,  $V \propto T$

$$V_1 \propto T_1$$

$$V_2 \propto T_2$$

$$\therefore \frac{V_2}{V_1} = \frac{T_2}{T_1}$$

$$T_2 = \frac{V_2}{V_1} \times T_1 = \frac{250}{200} \times 300$$

$$T_2 = 375 \text{ K}$$

$$= 102^\circ\text{C}$$

4) Find the volume at STP that would be occupied by 1.9 litre of a gas at a pressure of 81 cm of mercury and temperature 27°C.

At STP,  $P_0 = 76$  cm of mercury.

$$T_0 = 273 \text{ K} \quad V_0 = ?$$

$$P_1 = 81 \text{ cm of mercury}$$

$$V_1 = 1.9 \text{ litre}$$

$$T_1 = 273 + 27 = 300 \text{ K}$$

$$\frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1} ;$$

$$V_0 = \frac{P_1 V_1 T_0}{T_1 P_0}$$

$$V_0 = \frac{81 \times 1.9 \times 273}{300 \times 76} = 1.84 \text{ lit.}$$

5) A 12 litre container contains helium gas at 136 atmospheric pressure. How many balloons with one litre of gas at one atmospheric pressure can be filled with helium gas.

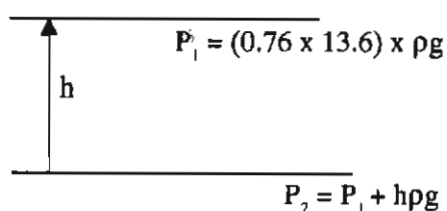
$$P_1 V_1 = n P_2 V_2$$

$$136 \times 12 = n \cdot 1 \cdot 1$$

Number of balloons,

$$n = 136 \times 12 = 1632$$

6) The radius of an air bubble expands from 2mm to 3mm as it rises from the bottom of the sea to the surface. Calculate depth of the sea, assuming that the temperature of the air inside the bubble remains constant.



**At sea level**

$$\text{Pressure of the air bubble} = P_1$$

$$\text{Volume of the air bubble} = V_1$$

$$\text{Radius of the air bubble} = r_1 = 3 \text{ mm}$$

**At the bottom of the sea**

$$\text{Pressure of the air bubble} = P_2$$

$$\text{Volume of the air bubble} = V_2$$

$$\text{Radius of the air bubble} = r_2 = 2 \text{ mm}$$

**According to Boyle's law**

$$P_1 V_1 = P_2 V_2 \text{ (at constant temperature)}$$

$$P_1 \times \frac{4}{3} \pi r_1^3 = (P_1 + h \rho g) \times \frac{4}{3} \pi r_2^3$$

$$P_1 r_1^3 = P_1 r_2^3 + h \rho g r_2^3$$

$$h \rho g = \frac{P_1 (r_1^3 - r_2^3)}{r_2^3}$$

$$h \rho g = \frac{0.76 \times 13.6 \times \rho g (3^3 - 2^3)}{2^3}$$

$$h = \frac{10.33 \times 19}{8} = 24.53 \text{ m.}$$

Depth of the sea,

$$h = 24.53 \text{ m}$$

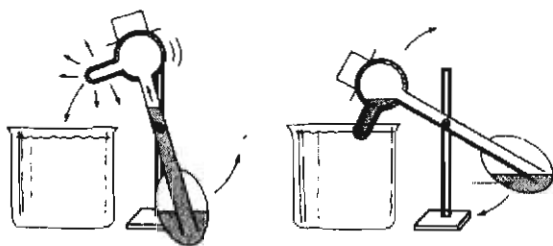
## 5.10 Heat Engines

The engines of automobiles such as motor cycle, car, lorry, bus and train convert the chemical energy of the fuel into kinetic energy of motion.

Gas mixtures, when ignited, attain high temperature and pressure, and possess high internal energy. This energy drives the vehicles with a force. **Heat engines played a vital role in industrial revolution of the world.**

**Activity:** Take a small quantity of water in a test tube and close its mouth tightly with a rubber stopper. Heat the water with a spirit lamp. Observe that the water boils and the pressure of steam pushes out the rubber stopper with a violent force.

Have you seen the toy thirsty bird



*Fig 5.9 Thirsty bird - A cyclic heat engine.*

drinking water continuously. This toy is an example of a cyclic heat engine. The bird's head and belly are made up of two glass bulbs connected by a glass tube which makes the body of the bird. A highly volatile liquid such as ether or freon fills a portion of the belly and the air inside the bulb is removed and sealed. The head and beak of the toy is covered with porous, water absorbent felt. The toy is pivoted near the centre of gravity so that it can swing freely. If you wet the head of the bird with water the liquid raises up the tube. So, the weight of liquid in the head increases and tumbles the head.

The liquid in the head flows back to the belly and the bird straight up and swings. As it oscillates the liquid again raises up the tube, the oscillations slow down and finally the bird tumbles over again. If a beaker of water is placed near the bird so that the beak dips into water when it tumbles over, the bird will continuously drink the water.

As water in the head evaporates it absorbs latent heat from the vapour inside. The vapour cools rapidly and condenses into liquid. This reduces the pressure of vapour in the head. So the liquid from the belly raises up from belly into the head. When the centre of gravity goes above the pivot the bird tumbles again. As the evaporation of ether and condensation occurs continuously the thirsty bird will continually drink water.

1. Observe how the time between two successive dippings of the bird changes with the area of evaporating surface, moisture content of atmosphere and circulation of dry air around the bird.
2. Explain why time between successive dippings decrease if you give ether or alcohol, instead of water, to the bird to drink.
3. When the bird is oscillating cover it with a large glass cages. Will the oscillations of the bird continue or stop? Find out.

The temperature difference between the head and belly of the bird causes a pressure difference. This raises the potential energy of the liquid and gets converted into kinetic energy of the bird and liquid when the bird tumbles over. The entire energy of motion is absorbed from the surroundings.

### **Types of Engines**

The transformation of heat energy into mechanical energy is effected through a device called the heat engine. Heat engines are of two types namely (1) External combustion engine and (2) Internal combustion engine.

### 1) External Combustion Engine – Steam Engine

The steam engine was invented by Thomas New comen in 1705 and perfected by James Watt in 1769.

When we rub our hands together, the mechanical energy gets converted into heat energy. The steam engines are used to convert thermal energy into mechanical energy of motion.

Steam is produced at high pressure and temperature in a boiler using coal as fuel. Steam with high internal energy is admitted into the cylinder C on the right side of the piston through the valve A. The piston is driven to the left. As the piston nears the left end of the cylinder, the sliding valve closes A and opens the valve B. Now the steam rushes into the left side of cylinder pushing the piston to the right.

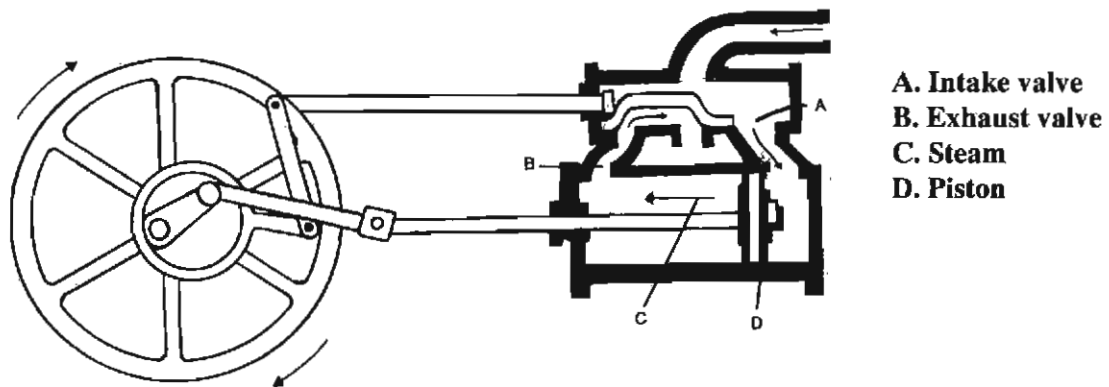


Fig 5.10 Steam engine.

As the piston reaches the right end the value A is again opened, and the whole cycle of operations is repeated. The linear motion of the piston is converted into the rotational motion of the wheel through the connecting rod and the crank.

(1) **Intake Stroke:** As the piston moves down the cylinder the air pressure inside decreases and air-petrol mixture is admitted into the cylinder through the intake valve. This mixture comes from carburetor where petrol is vaporized and mixed with air.

### 2) Internal Combustion Engine

In steam engines combustion of fuel takes place outside and the steam generated drives the engine. But in internal combustion engines combustion of fuels takes place inside engine chamber. Engines used in automobiles such as car, lorry, motor cycle and planes belong to this type.

(2) **Compression stroke:** At the end of the intake stroke, the intake valve, closes and the piston moves up. The fuel air mixture is

### 3) Petrol Engine

The operation of the petrol engine can be explained using the four strokes shown in Fig 5.11.

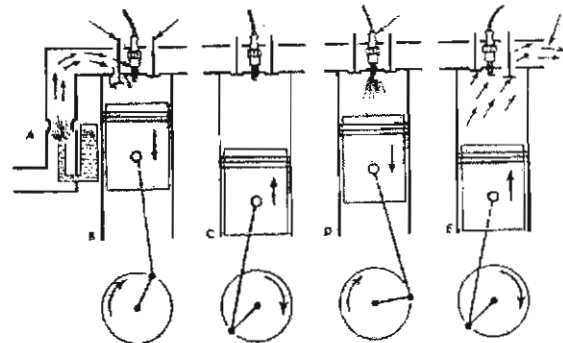


Fig 5.11 Four strokes in a petrol engine

compressed in the cylinder to a small fraction of its original volume and heats up the gas mixture.

In high compression engines, the fuel air mixture is compressed to 1/8 of its volume. As the compression increases efficiency of the engine also increases.

**(3) Power Stroke:** Near the end compression stroke the spark plug is activated. When the fuel ignites its heat of combustion is liberated and fuel-air mixture raised to a high temperature. The pressure of mixture also raises to about 25 atmospheric pressure. This high pressure mixture drives the piston down and does work. The gas mixture expands to a large volume and loses heat.

**(4) Exhaust Stroke:** As the piston moves up, the exhaust valve is opened and allows the spent gases to escape into the air. This cycle of four operations is repeated at a rapid rate. The to and fro motion of the piston is transformed into the rotational motion of the wheel through the piston rod and crank.

#### 4) Diesel Engine

The Diesel engine works in four strokes as the petrol engine. There is no carburetor and spark plug in a diesel engine. In the compression stroke air is compressed to  $\frac{1}{16}$  of its volume so that it becomes hot enough to ignite the fuel without a spark plug. At the end of compression stroke diesel is injected into cylinder and gets ignited by the hot air in the cylinder. The efficiency of diesel engine is 40%.

Gas turbine, jet engine and rocket engine are different types of heat engines.

#### Engine efficiency

The efficiency of an engine } =  $\frac{\text{Work done by heat}}{\text{Amount of heat supplied}}$

For example, 1000 J of heat is supplied to a heat engine and 600 J is exhausted.

work done by heat = 1000 – 600 = 400J.

$$\text{Efficiency} = \frac{400}{1000} \times 100 = 40\%$$

Let the efficiency of an automobile be 15%. So, 85% of the energy is wasted due to friction and insufficient cooling. The efficiency of different types of heat engines are listed in Table 5.8.

**Table 5.8 Efficiencies of Different Engines**

S. No.	Type of Engine	Efficiency (%)
1.	Steam engine	15
2.	Steam turbine	35
3.	High pressure petrol engine	30
4.	Diesel engine	40
5.	Jet engine	15

#### Some basic concepts

- \* Temperature is the measure of average thermal energy of the particles in a substance. It does not depend on the number of particles or size and shape of the object.
- \* Heat is the total energy of molecular motion of a substance.
- \* Heat is the internal energy of a substance.
- \* The unit of temperature is °C or Kelvin. The unit of heat is Joule.

- \* Thermometer is a device for measuring temperature of an object.
- \* The most common temperature measuring device is the mercury thermometer.
- \* Mercury is the only liquid metal.
- \* Boiling point of mercury is 357°C and freezing point of mercury is -39°C.
- \* Absolute zero of temperature is the lowest temperature to which a substance can be cooled (-273.15°C or 0K).
- \* Normal temperature of human body is 36.9°C
- \* The clinical thermometer measures temperatures in very short range of 10° from 35°C to 44°C.
- \* The distance between two successive collisions of molecules is called a mean free path.
- \* Absolute zero is the temperature at which all atomic and molecular motions of an ideal gas stop.
- \* Boyle's law states that, at a constant temperature, the pressure of a given mass of a gas is inversely proportional to its volume.
- \* Charles law states that, at constant pressure, the volume of a given mass of gas is directly proportional to its absolute temperature.
- \* At constant volume, the pressure of a given mass of gas is directly proportional to its absolute temperature.
- \* A gas which obeys Boyle's law and Charles' law is called an ideal gas.
- \* Force acting in unit area of the walls of container is called pressure of a gas.
- \* Heat engine is a device in which heat energy is converted into mechanical energy.

- \* Petrol engine works in four strokes.
  1. Intake stroke, 2. Compression stroke
  3. Power stroke, 4. Exhaust Stroke
- \* Diesel engine consists of four strokes, But it does not have a carburetor and electric spark.
- \* Efficiency of an engine is defined as the ratio between the work done by the heat engine and amount of heat supply to it.
- \* Diesel engine is having more efficiency (40%) than that of other engines.

### Self - Evaluation

#### Choose the correct answer

1. Heat energy is measured in
 

(1) Kelvin	(2) Metre
(3) Celcius	(4) Joule
2. Temperature is measured in
 

(1) Joule	(2) Watt
(3) Kelvin	(4) Metre
3. Absolute Zero is
 

(1) 273K	(2) 100K
(3) 0°C	(4) -273°C
4. Normal temperature of human body is
 

(1) 37°C	(2) 90K
(3) 37K	(3) 100°C
5. If the pressure of a given mass of a gas under constant temperature is doubled, its volume
 

(1) is reduced to $\frac{1}{4}$	(2) is halved
(3) is quadrupled	(4) is doubled
6. The Ideal gas equation is
 

(1) $\frac{P}{T} = \text{Constant}$	(2) $\frac{P}{V} = \text{Constant}$
(3) $PV = \text{Constant}$	(4) $\frac{PV}{T} = \text{Constant}$

7. Temperature of the substance denotes ..... energy of its particles.  
 (1) Total (2) Average kinetic  
 (3) gravitational (4) Potential

**Fill in the blanks**

8. All absolute zero, pressure of a gas is .....
9. The boiling point of water ..... °C
10. .... is the gas equation
11. Kelvin scale is also called ..... scale.
12. If the temperature of a gas is increased at constant volume, its pressure .....
13. All atomic and molecular motion stops at .....
14. In a heat engine, ..... energy is converted into ..... energy.
15. In the compression stroke of a diesel engine air is compressed to ..... its volume to raise its temperature

**16. Match the following**

- |                              |                             |
|------------------------------|-----------------------------|
| 1) Molecular motion stops    | (i) $-117^{\circ}\text{C}$  |
| 2) Absolute Zero             | (ii) Joule                  |
| 3) Unit of heat              | (iii) Absolute zero         |
| 4) Melting point of mercury  | (iv) $-273^{\circ}\text{C}$ |
| 5) Freezing point of alcohol | (v) $-39^{\circ}\text{C}$   |

**Answer briefly**

17. Define: Temperature, heat.
18. Explain why mercury is used as thermometric liquid?

19. What is the normal temperature of the human body?
20. What is the efficiency of a diesel engine?
21. What type of thermometers is used to measure temperature upto  $-100^{\circ}\text{C}$  ?
22. Write the ideal gas equation.
23. State Charle's laws.
24. What is an ideal gas?
25. Define efficiency of a heat engine.

**Answer in detail**

26. Describe the working of a clinical thermometer.
27. Write the postulates of the kinetic theory of gases.
28. Derive the gas equation.
29. Explain how Boyle's law is verified using Quills tube.
30. Describe the working of a 4 stroke petrol engine.
31. Describe the working of a steam engine
32. Tabulate the efficiencies of different types of heat engines.
33. The volume of a gas at  $37^{\circ}\text{C}$  is  $200\text{cm}^3$ . What will be its temperature when its volume becomes  $300\text{cm}^3$ , provided its pressure remains constant. [Ans:  $465\text{ K}$ ]
34. The distance between ice point and steam point on a thermometer is  $20\text{cm}$ . What is the temperature on the Celsius scale when the mercury level is  $12.6\text{cm}$  above the ice point ? [Ans:  $63^{\circ}\text{C}$ ]
35. At constant volume, the pressure of a gas in  $2\text{ pascal}$  at  $127^{\circ}\text{C}$ . Calculate the temperature of the gas when the pressure of increases to  $3\text{ pascal}$ . [Ans:  $327^{\circ}\text{C}$ ]

## 6. WAVE MOTION AND SOUND

Drop a stone into still water. Circular waves spread out from the point of disturbance and travel forward on the surface of water.

During wave motion, an object such as a cork or a leaf floating on the surface of water moves only up and down without moving along the direction of wave. So, waves transfer the energy from one place to another in the medium.

The vibrating particle as such does not have any linear displacement, only the disturbance caused by the vibrating motion of the particle passes from one particle to another in the medium. We call this motion as wave motion.

*Wave motion is the disturbance which travels in the medium due to vibratory motion of the particles of the medium transmitted from one particle to another.*

### 6.1 Types of waves

Waves are classified into **mechanical waves** and **electromagnetic waves**. All waves are produced by the vibratory motion of particles. Some waves require a material medium for their propagation. They travel through solids, liquids and gases. Sound waves, waves on the surface of water and seismic waves are examples of mechanical waves. They obey Newton's laws of motion.

Light waves, radio waves, microwaves infra-red, ultra-violet and X-rays do not require any material medium for their

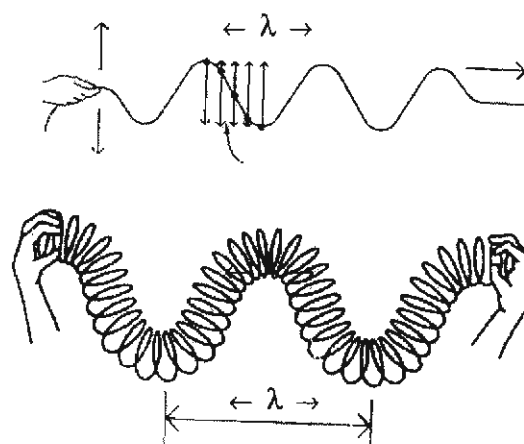
propagation. They travel through vacuum also. They are called electromagnetic waves and they travel in vacuum with a velocity of  $3 \times 10^8 \text{ ms}^{-1}$ . The light emitted by the sun and stars reaches the earth through the vacuum in space.

Mechanical waves are classified according to their mode of propagation as **transverse** and **longitudinal waves**.

**Transverse waves:** A transverse wave is one in which the particles of the medium vibrate in a direction perpendicular to the direction of propagation of the wave.

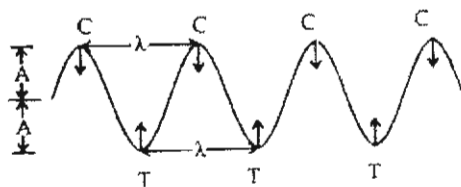
Waves on the surface of water, vibrations of stretched strings in guitar and violin and electromagnetic waves are transverse waves.

**Activity:** Stretch a long rope or a slinky. Fix one of its ends to a wall and hold the other end firmly. Jerk the free end up and



**Fig 6.1** Transverse waves in a string or slinky

down perpendicular to the length of the slinky. You can observe the wave, created by the up and down vibration, moves along the length of the slinky. If you move the free end up and down continuously a wave is formed along the slinky. The particles in the slinky vibrate perpendicular to the direction of wave. This wave is transverse in nature. Any point on the transverse wave which has the maximum displacement in the upward direction is called a **crest**. Any point of a transverse wave which has the maximum displacement in the downward direction is called a **trough**.



**Fig 6.2 Wavelength of a transverse wave**

The distance between any two consecutive crests or troughs of a transverse wave is called **wavelength** ( $\lambda$ ).

**Longitudinal wave:** A longitudinal wave is one in which the particles of the medium vibrate along the direction of the propagation of the wave.

**Sound waves in air or gases travel in the form of longitudinal waves.**

**Activity:** A long spring or slinky is placed horizontally and one of its ends is tied to a wall. The free end of the spring is suddenly

pushed and pulled creating a pulse of compression and rarefaction which move along the spring. If the free end of the spring is pushed or pulled continuously the compressions and rarefactions move along the spring. The particles of the spring vibrate parallel to the direction of the wave and therefore the wave is longitudinal in nature.

In a longitudinal wave, the regions where the coils become closer are called **compressions (C)**. The region where the coils are farther apart are called **rarefactions (R)**.

As sound waves travel in a gas or air, periodic compressions and rarefactions of molecules propagate through the medium.

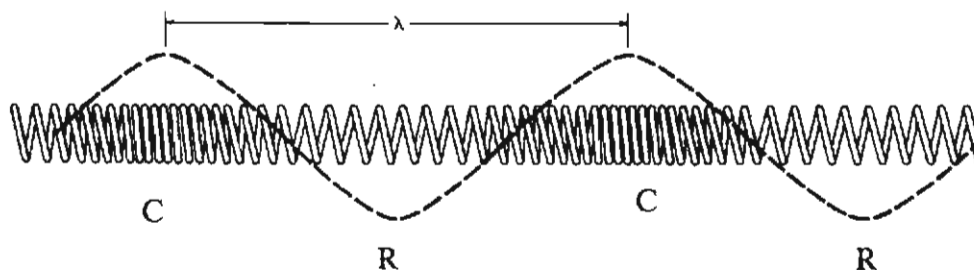
In a longitudinal wave, the distance between any two consecutive compressions or rarefactions is called a **wavelength**.

## 6.2 Wave motion - definitions

1) The **Amplitude (A)** of a wave is the maximum displacement of the vibrating particle about their mean position. Its unit is **metre**.

2) The **Wavelength ( $\lambda$ )** is the distance between two successive particles which are in the same state of vibration. Its unit is **metre**.

The particles of the medium vibrate about their mean position and undergoes a maximum displacement in the upward and downward direction during one complete vibration.



**Fig 6.3 Longitudinal waves**

**Wavelength** is also defined as the distance travelled by the wave during one complete vibration of the particle.

In a transverse wave, the distance between two consecutive crests or troughs is also equal to its **wavelength**. Similarly, the distance between any two consecutive compressions or rarefactions in a longitudinal wave is equal to its **wavelength**.

3) The **Time period** of a wave, is the time taken for one complete vibration of the particle.

It is also defined as the time taken by the wave to travel a distance of one wavelength in the medium. Its unit is **second**.

4) The number of complete vibrations of the particles of the medium in one second is called **frequency** ( $n$ ). Its unit is Hertz.

From the above definitions,

$$n = \frac{1}{T} \quad \text{or} \quad T = \frac{1}{n}$$

### Relation between frequency, wavelength and wave velocity

Wave velocity ( $v$ ) is the distance travelled by the wave in one second. Its unit is  $\text{ms}^{-1}$ .

Wave velocity ( $v$ )

$$= \frac{\text{Distance travelled by the wave}}{\text{Time}}$$

$$v = \frac{\text{Wavelength}}{\text{Time}} = \frac{\lambda}{T}$$

$$v = n\lambda \quad (\text{since } n = \frac{1}{T})$$

$$\text{Wave velocity} = \text{frequency} \times \text{wavelength}$$

$\lambda$  is the distance travelled by the wave during one complete vibration. As the particle makes  $n$  complete vibrations in one second, the distance travelled in one second is  $n\lambda$ . This equals the wave velocity.

The wave velocity depends on the nature of the medium. Waves with different frequencies and wavelengths travel with the same velocity in a medium.

**Table 6.1 Transverse and longitudinal waves - differences**

S. No.	Transverse waves	Longitudinal waves
1.	The particles of the medium vibrate perpendicular to the direction of propagation of wave.	The particles of the medium vibrate along the direction of propagation of wave.
2.	Waves in solids, liquid surfaces are examples of transverse waves.	Longitudinal waves, in general, propagate through solids, liquid and gases.
3.	Transverse waves are propagated in the medium in the form of crest and troughs.	Longitudinal waves are propagated in the medium in the form of compressions and rarefactions.
4.	There is no pressure variation in the medium.	The pressure and density of the medium are maximum at compressions and minimum at rarefactions.

## Nature and propagation of sound

All vibrating bodies produce sound.  
Examples,

1. You can feel the vibrations of vocal chords by touching the vocal chord as you speak. Air passing between the vocal chords make them vibrate and produce sound.

2. Sound is produced due to vibrations in stretched strings in musical instruments such as veena and violin.

3. Vibrations in the air column of the wind instruments and organ pipes such as flute and nathaswaram produce sound.

4. Vibrations of stretched membranes in mirdangam, thabla and drums produce sound on striking the membrane.

**Activity:** Strike a tuning fork gently with a rubber hammer and immediately dip its prongs into water in a beaker. Observe splashing of water droplets caused by the vibrations of the prongs.

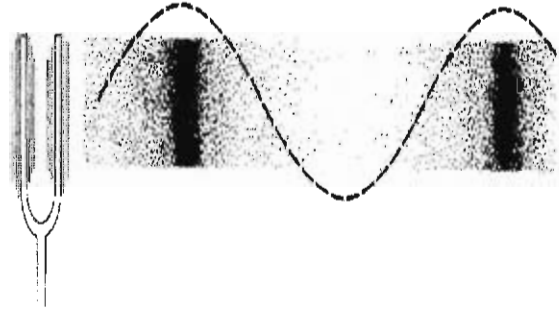
### 1. Propagation of sound in Air

The vibrating prongs of a tuning fork cause the adjacent air molecules to vibrate and produce longitudinal waves.

(1) Consider a tuning fork. The air molecules adjacent to its prongs are at rest.

(2) When the tuning fork is set into vibrations, the prong moves towards the right and compresses the adjacent layer of air. The compressed layer moves forward and compresses the next layer and so on. These compressions pass through the air.

(3) When the prong moves to the left from the mean position, the particles in the



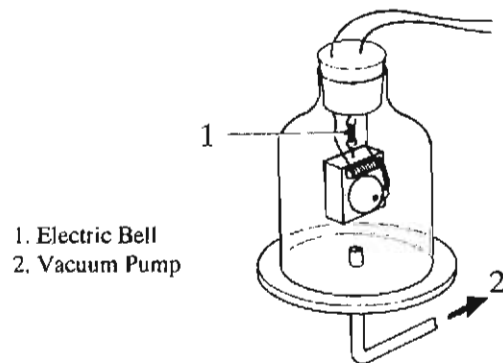
**Fig 6.4 Propagation of sound in air**

region become rarefied due to decrease in pressure of air.

As the tuning fork vibrates continuously, sound waves propagate in air in the form of compressions and rarefactions. Thus sound travels in air or a gas as a longitudinal wave.

### Experiment to show that medium is required for the propagation of sound

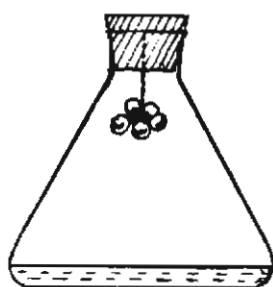
An electric bell is operated inside a bell jar. To reduce the air pressure in the jar, a vacuum pump is connected to it.



**Fig 6.5 Sound requires a medium for propagation**

When the bell is operated with air inside, the sound of the bell is heard loudly. When the air is pumped out, we can observe the motion of the bell, but we do not hear its sound. As there is no medium, sound waves do not travel through it.

**Activity:** Take a small amount of water in a conical flask. Boil the water for a few minutes to drive out the air inside. While water is evaporating, attach a bunch of jingle bells to a string and suspend it inside the flask. Close the flask tightly with a stopper and allow the set-up to cool for sometime. If you shake the flask now, you can see the motion of jingling bells, but sound will be very feeble. The partial vacuum inside the flask reduces the intensity of the sound.



**Fig 6.6** Sound requires a medium for propagation

## 2. Velocity of sound

Sound travels through solids, liquids and gases. The sound travels faster in solids and liquids because the molecules are closer to one another than in the gases. So, the velocity of sound is more in solids and liquids and less in gases. Velocity of sound in air at 0°C is 331 ms<sup>-1</sup>.

## 3. Factors affecting the velocity of sound

(1) **Humidity:** Sound travels faster in humid air than in dry air.

(2) Velocity of sound varies directly as square root of temperature. For every degree rise in temperature the velocity of sound increases by 0.61 ms<sup>-1</sup>.

$$v = (331.45 + 0.61T) \text{ ms}^{-1} \text{ (T in degree Celsius)}$$

(3) **Pressure** has no effect on the speed of sound.

## 6.3 Types of vibration

### 1. Free vibrations

When a body is set into vibrations, and left to itself, it vibrates with a frequency known as its natural frequency. These vibrations are called **free vibrations**.

The natural frequency of a body depends on its mode of vibrations, elasticity and mass of the body.

### Examples

1. Vibrations in a stretched string.
2. Vibrations of a tuning fork.
3. Oscillations of a simple pendulum.

**Table 6.2** Velocity of sound

<i>Solid</i>	<i>Velocity (ms<sup>-1</sup>)</i>	<i>Liquid</i>	<i>Velocity (ms<sup>-1</sup>)</i>	<i>Gas</i>	<i>Velocity (ms<sup>-1</sup>)</i>
Aluminium	5100	Water (0°C)	1402	Air (0°C)	331
Steel	5000	Water (20°C)	1482	Air (20°C)	343
Granite	6000	Sea water	1522	Hydrogen	1284
Glass	5000	Mercury	1452	Helium	965
Wood	3850			Carbondioxide	258

## 2. Forced vibrations

An object can be set into vibrations at a frequency different from the natural frequency by a constant periodic force applied to it. These vibrations are called **forced vibrations**.

**Example:** A swing oscillates with a certain natural frequency. It can be made to oscillate by an external periodic force which provides energy for oscillations.

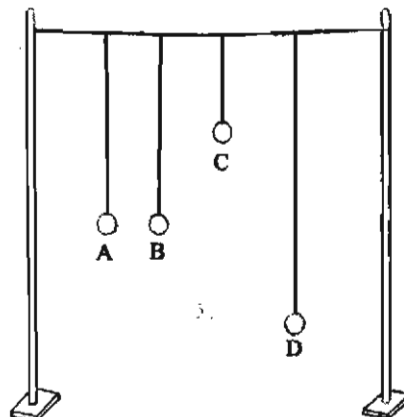
When the string of a guitar or violin is made to vibrate, the sound box of the musical instruments and the air inside are forced to vibrate in response to the vibrations of the string.

If you place the stem of a vibrating tuning fork on the top of a table, the sound becomes louder, because the fork forces the table top to vibrate with its frequency even though these two bodies have different natural frequencies.

## 3. Resonance

When the frequency of forced vibrations of a body equals its natural frequency, the vibrations of the body build up to a very large amplitude. This phenomenon is known as **resonance**.

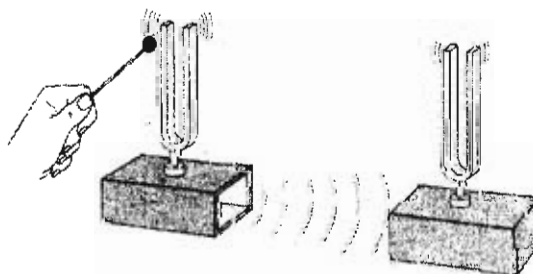
**Activity:** Suspend four pendulums A,B,C,D from a flexible horizontal support, such as a thread. The pendulums A and B are of equal length. Set the pendulum A gently into oscillations. After sometime B starts swinging with gradually increasing amplitude, but pendulums C and D are unaffected. As the amplitude of B increases, the amplitude of A decreases. When B reaches maximum amplitude A will come to a stop. This occurs because A transfers its energy to B continuously. Now the



**Fig 6.7 Using pendulum to demonstrate resonance**

energy is transferred from B to A and A is set into oscillations and B loses its energy and stop. The exchange of energy continues. The natural frequencies of C and D are different from that of A and therefore they are not set into oscillations by A. If two vibrating systems have the same natural frequency, we can achieve energy transfer from one system to another.

**Activity:** Two tuning forks of the same natural frequency are mounted on two similar sound boxes. Place the sound boxes close by and set one tuning fork into oscillations. After sometime if the vibrating tuning fork is stopped by touching it, you continue to hear the sound because of resonance, the energy is transferred from first to the second tuning fork.



**Fig 6.8 Resonance in tuning forks**

Resonance is disastrous at times when soldiers march in step over a bridge, the frequency of forced vibrations may match the natural frequency of the bridge. This resonance will cause the bridge to oscillate with maximum amplitude and destroy the bridge. So, soldiers are not allowed to march on the bridge.

### Determination of velocity of sound in air using a resonance column

Fill a glass jar of length one metre, and 5 cm in diameter, with water and place an open ended glass tube as shown in Fig 6.9. If the vibrating tuning fork of known frequency ( $n_1$ ) is held horizontally near the

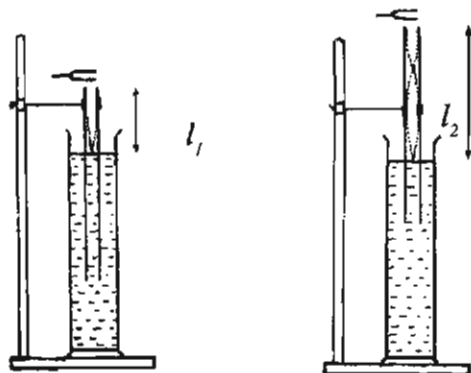


Fig 6.9 Resonance column

upper end, the air inside the glass tube vibrates and a note is heard. The length of air column is adjusted by raising or lowering the glass tube, until resonance occurs and sound of maximum intensity is heard. At this stage, the frequency of the tuning fork and frequency of air column are the same. This is the first resonating length. The length of air column at this position is  $l_1$  and the wavelength of the fundamental mode of vibration,

$$l_1 = \frac{\lambda}{4} \quad \text{or} \quad \lambda = 4 l_1$$

Velocity of sound in air is  $v = n_1 \lambda$

$$\therefore v = n_1 4l$$

The velocity of sound is determined by substituting the values of frequency of the tuning fork ( $n$ ).

If you increase the length of air column, resonance occurs again at  $l_2$

$$\therefore l_2 = \frac{3\lambda}{4} \quad \text{or} \quad \lambda = \frac{4}{3} l_2$$

Velocity of sound in air  $v = n_1 \lambda$

$$\therefore v = n_1 \left( \frac{4}{3} l_2 \right)$$

The experiment is repeated with tuning forks of different frequencies  $n_2$  and  $n_3$  and the mean value of the velocity of sound in air is calculated.

### 6.4 Stationary waves

The stationary waves are formed in an enclosed air column and stretched threads or strings when a progressive wave reflected from a point, gets superimposed on it.

Two waves of same amplitude and frequency travelling in opposite directions superimpose with each other producing stationary waves.

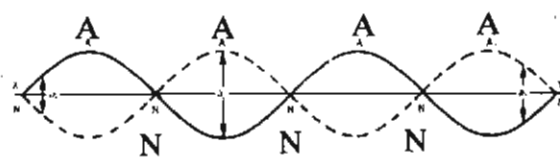


Fig 6.10 Stationary waves

The points at which the amplitude of the wave is minimum are called **nodes** and certain other points where the amplitude of vibrations is maximum are called **antinodes**.

Nodes and antinodes are formed alternatively in a stationary wave.

The distance between two successive nodes or antinodes is  $\frac{\lambda}{2}$ , distance between one node and one antinode is  $\frac{\lambda}{4}$ .

**Example:** Stationary transverse waves are formed in string instruments such as sitar, violin, veena and guitar.

Stationary longitudinal waves are formed in vibrating air columns of musical instruments such as flute, nathaswaram and clarinet.

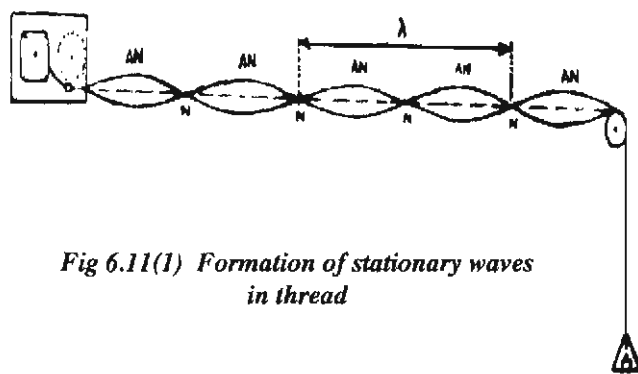


Fig 6.11(1) Formation of stationary waves in thread

**Activity: Formation of stationary waves.** Tie a thin thread to the metal strip of an electrical vibrator. Pass the other end of the thread through a pulley and attach a scale pan with small weights to it. When the vibrator is set into vibrations, the thread vibrates with a few loops between the two ends of the thread with alternating nodes and antinodes.

Observe that the wavelength of stationary waves increase as the load or tension in the string is increased.

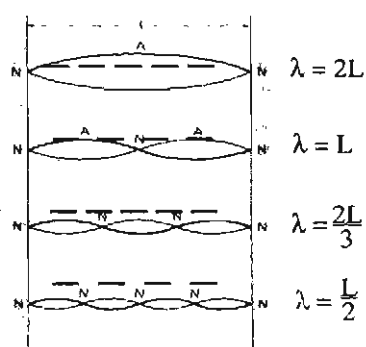


Fig.6.11(2) Wave length of stationary waves in a thread

## 6.5 Vibrations of air column

A vibrating column of air produces sound.

**Activity:** Fill a test tube with a little water. Blow air near its edge and hear the pitch of sound produced by it. Increase the amount of water in the tube and repeat the experiment. Observe that as the length of air column decreases the pitch or frequency of sound increase. Repeat the experiment with a pen cap.

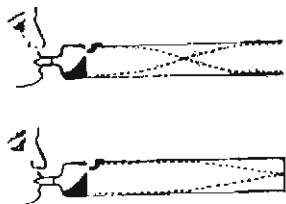


Fig 6.12 Open and one end closed pipe

**Activity:** Take a long organ pipe and blow air into it, so as to produce a sound note.

Close one of its end and observe the pitch of the sound. The pitch or frequency of sound emitted by the closed organ pipe is less than that of open organ pipe.

## 6.5 Vibrations in air column using organ pipe

When you blow air into an organ pipe, the progressive wave superimpose upon the reflected waves and produce standing waves of different frequencies.

### 1. Open organ pipe

When you blow air into an organ pipe open at both ends the air column vibrates with antinodes at the open ends and nodes in between.

(1) **In fundamental mode** or first harmonic two antinodes are formed at the open ends of the pipe of length  $l$  with a node at the mid point (Fig 6.13)

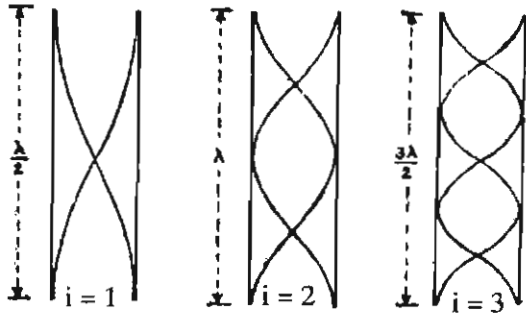


Fig 6.13 Open organ pipe

$$l = \frac{\lambda_1}{2}, \quad \lambda_1 = 2l$$

$$v = n_1 \lambda_1 = n_1 \cdot 2l$$

$$\therefore n_1 = \left( \frac{v}{2l} \right) \quad \dots (1)$$

2) **First overtone:** In the second harmonic three antinodes and two nodes are formed.

$$l = \lambda_2$$

$$v = n_2 \lambda_2 = n_2 l$$

$$n_2 = 2 \left( \frac{v}{2l} \right) = 2n_1$$

$$n_2 = 2n_1 \quad \dots (2)$$

3) **Second overtone:** In the third harmonic, four antinodes and three nodes are formed.

$$l = \frac{3\lambda_3}{2}, \quad \lambda_3 = \frac{2l}{3}$$

$$v = n_3 \lambda_3 = n_3 \frac{2l}{3}$$

$$\therefore n_3 = 3 \left( \frac{v}{2l} \right)$$

$$n_3 = 3n_1 \quad \dots (3)$$

For  $i$  th harmonic

$$n_i = i \left( \frac{v}{2l} \right), \quad \dots (4)$$

(  $i = 1, 2, 3, \dots$  where  $i$  is called the harmonic number)

$$n_1 : n_2 : n_3 = 1 : 2 : 3$$

Therefore in the open organ pipe the harmonics are in the ratio of natural numbers.

## 2. One end closed organ pipe:

When you blow air into an organ pipe of length ( $l$ ) closed at one end, the air column vibrates with a node at the closed end and antinode at the open end.

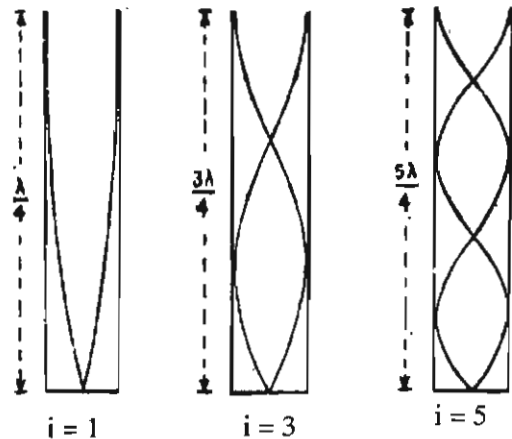


Fig 6.14 Closed organ pipe

1) **Fundamental note:** If  $l$  is the length of the air column, then for the fundamental mode or first harmonic

$$l = \frac{\lambda_1}{4}, \quad \lambda_1 = 4l$$

$$v = n_1 \lambda_1$$

$$v = n_1 \cdot 4l$$

$$\therefore n_1 = \left( \frac{v}{\lambda_1} \right) = \left( \frac{v}{4l} \right) \quad \dots (5)$$

$n_1$  is the fundamental frequency of vibration.

The fundamental frequency in open organ pipe is twice that of closed organ pipe of same length.

2) **First overtone:** When the air column vibrates in the first overtone mode, two nodes and two antinodes are formed.

$$\begin{aligned}
 l &= \frac{3\lambda_3}{4} & \lambda_3 &= \frac{4l}{3} \\
 v &= n_3\lambda_3 = n_3 \frac{4l}{3} \\
 n_3 &= \frac{v}{\lambda_3} = 3 \left( \frac{v}{4l} \right) \\
 \mathbf{n_3} &= \mathbf{3n_1} & \text{.....(6)}
 \end{aligned}$$

The first overtone in the one end closed organ pipe is the third harmonic.

3) **Second overtone:** In this mode nodes and three antinodes are formed.

$$\begin{aligned}
 l &= \frac{5\lambda_5}{4} ; \lambda_5 = \frac{4l}{5} \\
 v &= n_5\lambda_5 = n_5 \frac{4l}{5} \\
 n_5 &= \frac{v}{\lambda_5} = 5 \left( \frac{v}{4l} \right) \\
 \mathbf{n_5} &= \mathbf{5n_1} & \text{.....(7)}
 \end{aligned}$$

This is fifth harmonic.

In closed organ pipe only odd harmonics exist in the pipe and even harmonics cannot be set up in the pipe.

$$\begin{aligned}
 n_1 : n_3 : n_5 &= 1 : 3 : 5 \\
 \text{For a closed organ pipe} \\
 \mathbf{n_i} &= \mathbf{i \left( \frac{v}{4l} \right)} & \text{.....(8)} \\
 & \text{where } i = 1, 3, 5
 \end{aligned}$$

(only odd harmonics exist)

## 6.6 The laws of vibrations of stretched strings

When a stretched string is set into vibrations transverse stationary waves are produced in the string.

(1) When the tension (T) and linear density (m) of the string are kept constant, the frequency of vibration is inversely

proportional to the length of vibrating segment (l)

$$n \propto \frac{1}{l} \quad \text{.....(9)}$$

(2) When the length of the vibrating segment (l) and linear density are kept constant, the frequency of vibration is directly proportional to square root of tension applied to the string.

$$n \propto \sqrt{T} \quad \text{.....(10)}$$

(3) When the length of the vibrating segment and tension are kept constant, the frequency of vibration is inversely proportional to square root of linear density of the material of the wire.

$$n \propto \frac{1}{\sqrt{m}} \quad \text{.....(11)}$$

Combining the above three laws,

$$\begin{aligned}
 n &\propto \frac{1}{l} \sqrt{\frac{T}{m}} \\
 n &= \frac{k}{l} \sqrt{\frac{T}{m}}
 \end{aligned}$$

where k, the proportionately constant =  $\frac{1}{2}$

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}} \quad \text{.....(12)}$$

## 1. Sonometer

The frequency of transverse vibrations of stretched strings depends on vibrating length, tension and linear density. The laws of transverse vibrations of stretched strings can be studied using sonometer.

Sonometer is a hollow wooden sound box. One end of a thin metallic wire is fixed to a peg at the end of the sonometer. The other end of the wire passes through a pulley and a weight hanger is attached to it. The weights in the weight hanger provide tension to the string. To measure the length

of the vibrating segment two movable knife edges are placed under the wire. A metre scale is fixed on the wooden box parallel to the wire to measure the length of the vibrating segment.

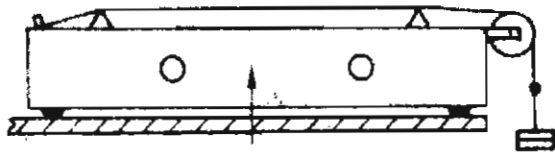


Fig 6.15 Sonometer

When the wire is set into vibrations, transverse stationary waves are produced between the knife edges as shows in Fig 6.16. The length of the vibrating segment for fundamental mode of vibration is  $l = \frac{\lambda}{2} \therefore \lambda = \frac{2l}{i}$ . The wavelength and frequencies of the harmonics  $i = 1, 2, 3$  are given by

$$\lambda_i = \frac{2l}{i}, \quad (i = 1, 2, 3, \dots)$$

$$n_i = \frac{v}{\lambda_i}$$

$$n_i = i \left( \frac{v}{2l} \right) \quad (i = 1, 2, 3, \dots) \dots\dots(13)$$

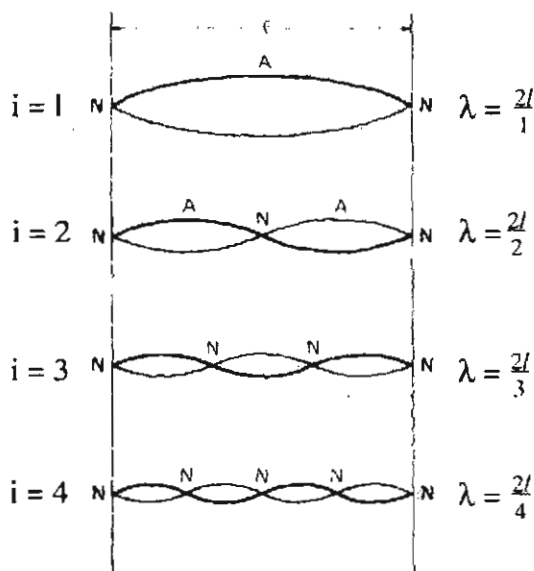


Fig 6.16 Stationary waves in a stretched string

## 2. Verification of laws of stretched strings

**First law:** Place a one kg weight on the weight hanger. Gently strike a tuning fork of known frequency and place its stem on the sonometer box. Adjust the two knife edges for resonance vibration of the wire, so that the paper rider placed on the wire is thrown off. Now measure the distance between two knife edges, as the resonating length  $l$ . Repeat the experiment with tuning forks of different frequencies and measure the corresponding resonating lengths.

Observe that as the frequency increases the resonating length decreases.

$nl$  is a constant when  $T$  and  $m$  are kept constant.

Table 6.3 Verification of First law

S. No.	Frequency (n) Hertz	Resonating length (l) m	$nl = \text{Constant}$
1	256	...	...
2	384	...	...
3	420	...	...
4	512	...	...

**Second law:** Take a tuning fork of known frequency. Increase the weight in the weight hanger and measure the corresponding resonating lengths. From the table observe that  $\frac{\sqrt{T}}{l}$  is a constant, when  $n$  and  $m$  are kept constant.

As the tension increases, the frequency of vibration also increases.

Table 6.4 Verification of Second law

Frequency of tuning fork ... Hertz

S. No.	Weight Kg.	Tension T(N)	Resonating length l(m)	$\frac{\sqrt{T}}{l}$ Constant
1	1	9.8		
2	2	19.6		
3	3	29.4		
4	4	39.2		
5	5	49.0		

**Third law:** With fixed tension and frequency of tuning fork fix wires of different materials and thicknesses and measure the corresponding resonating lengths. Observe that when  $n$  and  $T$  are kept constant,  $l \sqrt{m}$  is a constant where  $m$  is the linear density of the wire.

As the linear density of the wire decreases the resonating length increases.

**Table 6.5 Verification of Third law**

Tension in the string,  $T = \dots N$

Frequency of tuning fork  $n = \dots \text{Hz}$

S. No.	mass per unit length ( $m$ ) $\text{kg m}^{-1}$	Resonating length ( $l$ ) m	$l \sqrt{m}$ Constant
1			
2			
3			
4			

## 6.7 Ultrasonics

Sound is produced by vibrating bodies. We can hear sound of frequencies ranging from 20 Hz to 20,000 Hz. This range of frequencies, sensed by our ear is known as the audible range of sound.

Sound of frequencies above 20,000 Hz are known as ultrasonics. Sound of frequencies below 20 Hz are called infrasonics. We cannot hear ultrasonics and infrasonics.

But certain animals can produce and detect ultrasonics and infrasonics.

**Example:** Bats, while flying produce ultrasonics and detect the reflected waves from the obstacles or prey, thereby estimate

the location, distance and motion of the obstacle or prey. Therefore, bats are able to catch their prey and fly without hitting obstacles even in the dark. Aquatic animals like dolphins use ultrasonics to detect and avoid obstacles in their path. They also use ultrasonics for communication.

**Table 6.6 Audiable range of sound for human and certain animals**

S. No.	Animal	Audible range of Sound Hertz
1.	Human being	20 - 20,000
2.	Elephant	16 - 12,000
3.	Cattle	16 - 40,000
4.	Cat	100 - 32,000
5.	Dog	40 - 46,000
6.	Rodents (Rat, Squirrel, Rabbit)	1000 - 100,000
7.	Bat	1000 - 150,000
8.	Dolphins	70 - 150,000
9.	Wales	
10.	Sea lions	200 - 200,000

Elephants use infrasonics to communicate with other members of the groups in the forest. Some animals sense the infrasonic vibration during earthquake and migrate to safer places.

### 1. Application of ultrasonics

#### 1) SONAR (Sound Navigation And Ranging):

A device used for finding the distance and nature of object under the ocean using ultrasonic waves is called a Sonar.

Sonar devices in a ship produce and send out ultrasonic beams into the sea. By detecting the ultrasonics waves reflected by objects or obstacles, the nature and depth of objects are analysed. We can

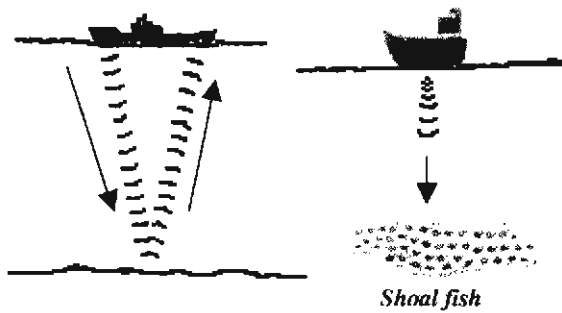


Fig 6.17 Sonar

estimate the location and depth of submarines, shoal of fish, icebergs and the nature of sea bed, minerals using ultrasonics.

### 2) Industrial applications:

1. Ultrasonics are used to detect the cracks inside metal casting of machines without breaking them. They are used to drill holes in glass and steel.
2. Ultrasonic waves produce bubbles in cleaning liquids to remove dirt from minute parts of medical instruments and watches.

### 3) Medical applications:

1. Ultrasonic Echoes are used to view soft tissues and organs which are invisible to X-rays. They are used to monitor the foetus at different stages of its development and to detect defects, if any. X rays are harmful and affect the living cells but ultrasonics are harmless.
2. By using Doppler effect and ultrasonics doctors monitor the function, flow of blood and diseases of brain, heart and kidneys.
3. Ultrasonic waves are used to pulverize and remove kidney stones, cure cancer, joint and muscular pain.

## 6.8 Doppler effect

Listen to the whistle sound of an approaching or receding rail engine. The pitch of the sound increases as the train

approaches you and pitch decreases while receding from you. Such an apparent change in pitch of sound is explained by Doppler effect profounded by Christian Doppler in 1842.

The apparent change in the pitch of sound can also be noticed in the case of approaching or receding aeroplanes and sirens in automobiles.

**The apparent change in pitch or frequency of sound when there is a relative motion between the source and the observer is called Doppler effect.**

### Expression for the apparent frequency of sound.

**Case 1:** Source in motion and observer at rest.

Let the velocity of sound in air be  $v$ , velocity with which the source is approaching the observer  $v_s$  and the actual frequency  $n$ .

Suppose the source S and observer O are at rest. The wavelength of the sound emitted by the source  $\lambda = \frac{v}{n}$ .

Let the source move with the velocity  $v_s$  for one second towards the observer. Then  $SS' = v_s$ . Now the waves produced by the source is crowded within the distance  $OS'$ .

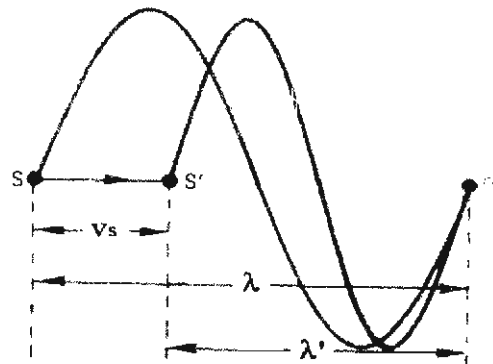


Fig 6.18 Source moving towards observer

$$OS' = v - v_s$$

Therefore the wavelength decreases to

$$\lambda' = \frac{v - v_s}{n}$$

$$\text{Velocity of sound } v = n' \lambda'$$

$$\therefore \text{Apparent frequency } n' = \frac{v}{\lambda'}$$

Substituting for  $\lambda'$

$$\therefore n' = \left( \frac{v}{v - v_s} \right) n \dots(14)$$

$n' > n$ . So, the apparent frequency and the pitch of sound appears to increase.

**Case 2:** If source recedes from the observer the apparent frequency and the pitch of sound decreases

$$\therefore n' = \left( \frac{v}{v + v_s} \right) n \dots(15)$$

$\therefore n' < n$ . So, the apparent frequency of sound decreases

### Uses of Doppler effect in sound

- 1) The principle of Doppler effect is used in RADAR (Radio Detection and Ranging) to determine the velocities and movement of submarines and aeroplanes.
- 2) Traffic control vehicles direct microwaves on speeding vehicles. The waves reflected by the moving vehicles act as a moving source. From the Doppler shift in frequency the speeds of vehicles are detected.
- 3) The Doppler shift of radar waves are used in airports to find the height, speed and distance of approaching planes.
- 4) Bats send out and receive ultrasonic waves reflected by the prey and obstacles with ultrasonics. Bats detect the location, distance and movement of the prey.

### Mach effect – The change in frequency with respect to velocity of moving sources

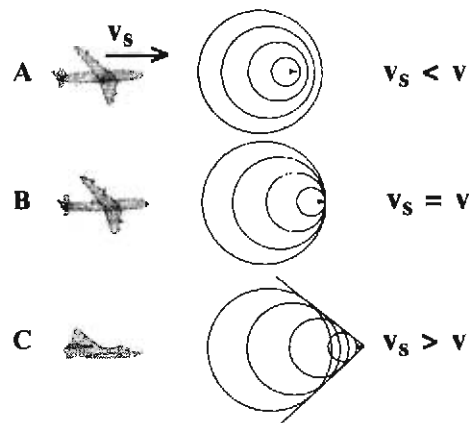
**Case 1: Stationary Source** – Consider a source at rest. Sound waves produced at a constant frequency  $n_0$  move away from the source with a constant velocity  $v$  in the medium. An observer at a distance can hear the same frequency as that of the source.

**Case 2: Source moving with  $v_s < v$  (mach 0.7)** – Let the source be moving to the right with a speed  $v_s = 0.7$  (mach 0.7) and observer at rest. As the source moves with a certain velocity, the waves get compressed on the right and get spread out on the left. The observer in front of the source will hear a higher frequency  $n' > n_0$  and the observer on the left of the source will hear a lower frequency  $n' < n_0$ .

**Case 3: Source moving with velocity of sound  $v_s = v$ .**

The source of sound is moving at a speed  $v_s = v$  or mach 1. The speed of sound in air is  $340 \text{ ms}^{-1}$  (1224 kmph).

Since the source of sound and sound waves are travelling with same speed all waves are bunched at the same point on the right. Therefore, the observer in front of source detect nothing until the source arrives. But when the source of sound passes the observer a thump of sound will be heard.



**Fig 6.19 Mach effect**

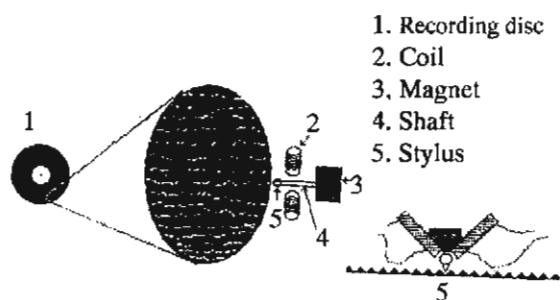
**Case 4: Source moving  $v_s > v$  (Mach 1.4, supersonic)**

(1) Let the source of sound be travelling with 1.4 times the speed of sound (Mach 1.4) and the observer at rest. Since the source is moving faster than sound, the observer in front will hear the sound only after the source of sound has passed away.

(2) **Sonic Boom:** When the source of sound moves with a higher speed, all the waves are bunched together in front in a V-shaped cone of shock waves called mach cone. This sonic boom rattles the window panes and door.

### 6.9 Recording and reproduction of sound

The first attempt to record and reproduce sound was made by Thomas Alva Edison in 1877. The sound is made before a thin diaphragm of a microphone to which a sharp stylus (needle) is attached. The stylus responds to the vibrations on the diaphragm and moves over a rotating cylinder of hard wax. The forward and backward motion of stylus is converted into a wavy form. They wavy line represent the sound waves. This is a mechanical method of recording sound.

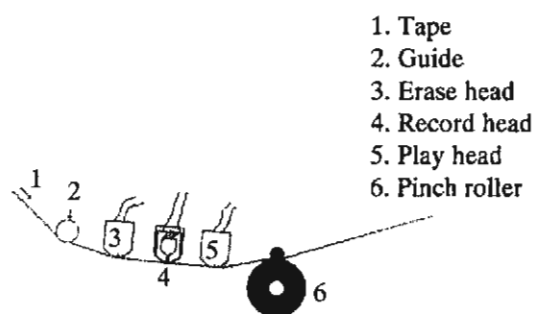


**Fig 6.20 Recording on a disc**

For reproduction, the cylinder is rotated at the same speed at which recording was done. A needle attached to a diaphragm is placed on the groove of the cylinder. The diaphragm of the loudspeaker vibrates reproducing the original sound.

### 1. Recording and reproduction of sound on tape.

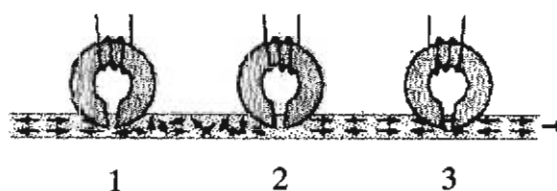
The audio tape is a strip of plastic which is coated with a magnetic material such as iron oxide or chromium dioxide. The tape is held tightly against the capstan by the pinch roller and moved steadily



**Fig 6.21 Recording on tape**

across three magnetic heads namely, erase head, record head and play head. All the magnetic heads are C-shaped metal pieces with a small gap at its end. Coils of wire in the magnetic heads, produce and detect magnetic fields on the tape. The varying current from the microphone produces a varying magnetic field on the recording head and magnetic patterns are recorded on the magnetic tape.

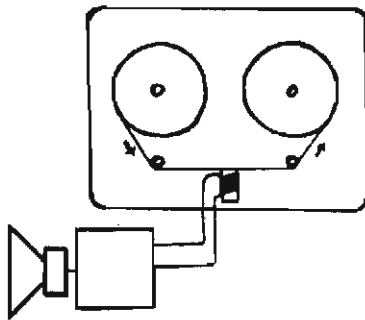
When the tape passes the play head, the varying magnetic field on the tape produces a varying current in the play head coil. The varying current is amplified and passed through a loudspeaker to reproduce the original sound.



**1. Erase head, 2. Record head, 3. Play head**

**Fig 6.22 Recording of sound on tape**

The erase head works just like the record head. The tape passes through the erase head before the record head. An alternating current of high frequency and amplitude passing through the erase head erases all the magnetic patterns already recorded on the tape. The gap in the erase head is wider than that of the record head. So, the tape takes longer time to cross the erase head. Therefore, the magnetic patterns on the tape are completely erased.



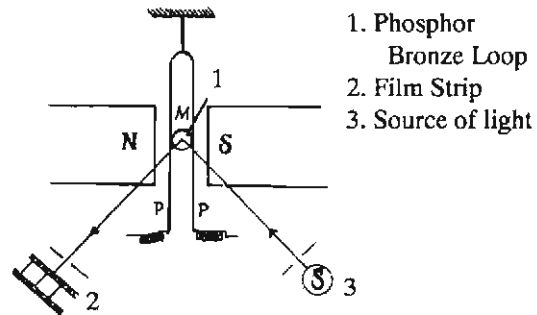
**Fig 6.23 Recording device**

## 2. Sound tracks on the tape

There are four tracks on the tape, of which two are played when the tape moves in one direction and the other two when the tape is reversed. The width of a single track is an important factor in determining the strength of signal that can be recorded. The width of track depends on the width of the tape as well as number of tracks. As many as 24 tracks can be recorded on a tape.

## 3. Recording of sound on films

Sound is recorded on films as a strip of light on one edge of the film. The sound to be recorded is converted into a varying electric current using a microphone. This varying current is passed through a loop of phosphor-bronze wire suspended between the poles of a powerful magnet. A small mirror attached to the loop reflects light from a lamp on to the edge of a moving film.

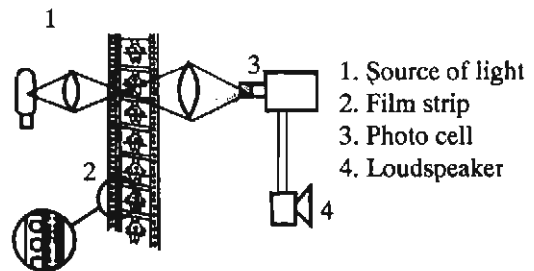


**Fig 6.24 Recording on a film**

The film is moved with a constant speed behind a narrow slit through which the light from the mirror falls on it. This reflected light is recorded as a strip of varying width on the film.

## 4. Reproduction of sound from films

To reproduce the sound from the sound track on the film, light from a powerful lamp is made to fall on the sound track of the film. The light variations are converted into a varying current by a photo cell. These varying current is amplified and fed into a loudspeaker for reproduction of sound.



**Fig 6.25 Reproduction of sound from films**

## Some basic concepts

- \* Wave motion is the disturbance which travel in a medium due to vibratory motion of the particles of the medium transmitted from one particle to another.
- \* Mechanical waves are classified according to their propagation as transverse and longitudinal waves.

- \* A transverse wave is one in which the particles of the medium vibrate in a direction perpendicular to the direction of propagation of wave.
- \* A longitudinal wave is one in which the particles of the medium vibrate along the direction of the propagation of the wave.
- \* In a transverse wave, the distance between any two consecutive crests or troughs is called a wavelength. Similarly, in longitudinal waves the distance between any two consecutive compressions or rarefactions is called a wavelength. Transverse waves propagate through solids and liquid surfaces. Longitudinal waves can propagate through solids, liquids and gases.
- \* The velocity of sound is  $v = n\lambda$ .
- \* Time period is the time taken by the vibrating particle of the medium to complete one oscillation.
- \* The number of waves passing across any point of the medium in one second is called frequency.
- \* All vibrating bodies produce sound.
- \* The velocity of sound in air at  $0^\circ\text{C}$  is  $331 \text{ ms}^{-1}$ .
- \* Vibrations are classified into free vibrations and forced vibrations.
- \* The frequency of forced vibration of a body may agree with natural frequency of vibration of the body. The vibrations of the body build up to a large amplitude and resonance is said to occur.
- \* When two waves of same amplitude and frequency travel in opposite directions stationary waves are formed.
- \* Fundamental frequency in open pipe is twice that of the closed pipe of same length.
- \* The frequency of vibrations of a stretched string depends on length, tension and linear density.
- \* We can hear sound of frequencies ranging from 20 Hz to 20,000 Hz. The range of frequency sensed by human ears is known as audible sound.
- \* Sound of frequencies above 20,000 Hz are known as ultrasonics.
- \* 1 Mach is the velocity of an object travelling with the velocity of sound.
- \* When there is an apparent change in frequency of sound due to relative motion of the source and observer it is called Doppler effect.
- \* Sound is recorded on a tape in the form of varying magnetic fields.

### Solved problems

- 1) The frequency of a tuning fork is 512 Hz. What is the time period?

Frequency of a tuning fork is 512 Hz.

$$n = \frac{1}{T}$$

$$\therefore T = \frac{1}{n} = \frac{1}{512} = 0.00195 \text{ second}$$

- 2) Velocity of sound in air is  $330 \text{ ms}^{-1}$ . What is the range of wavelength of audible sound?

Hearing range of human is  
20 Hz- 20000 Hz.

Velocity of sound in air is  $330 \text{ ms}^{-1}$

$$\therefore \text{wave length } \lambda = \frac{v}{n} \quad (v = n\lambda)$$

$$\lambda = \frac{330}{20} = 16.5 \text{ m.}$$

$$\lambda = \frac{330}{20,000} = 0.0165 \text{ m.}$$

Range of wavelength of audible sound is 16.5m to 0.0165 m.

- 3) A wave pulse on a string moves a distance 10 m in 0.02 sec. Find the velocity of the pulse and wavelength of the wave, if the frequency is 1000 Hz.

Velocity of wave pulse =  $\frac{\text{Distance covered}}{\text{Time taken}}$

$$v = \frac{10}{0.02} = 500 \text{ ms}^{-1}$$

$$\text{wavelength } \lambda = \frac{v}{n} = \frac{500}{1000} = 0.5 \text{ m}$$

- 4) If 512 waves are produced per second. What is the frequency?

Frequency = Number of waves produced per second. If 512 waves are produced in 1 s, the frequency is 512 Hz.

- 5) A body vibrates 3000 times in one minute. If the velocity of sound in air is  $330 \text{ ms}^{-1}$ , find (i) Frequency of vibration (ii) wavelength of wave

$$\text{Frequency } n = \frac{3000}{60} = 50 \text{ Hz.}$$

$$\text{Wavelength } \lambda = \frac{v}{n}$$

$$\lambda = \frac{330}{50} = 6.6 \text{ m.}$$

- 6) A stretched string produces a transverse wave of length 0.2 m, its frequency of vibration is 1700 Hz. Find the velocity of wave.

$$v = n\lambda = 1700 \times 0.2 = 340 \text{ ms}^{-1}.$$

- 7) Find the fundamental mode of vibrations of a pipe closed at one end which respond to a tuning fork of frequency 256 Hz. The velocity of sound in air ( $v = 330 \text{ ms}^{-1}$ )

Fundamental frequency

$$n = \frac{v}{4l}$$

$$l = \frac{v}{4n} = \frac{330}{4 \times 256} = 0.322 \text{ m}$$

- 8) An open organ pipe sounds the fundamental note of frequency 200 Hz. Find the length of the pipe (velocity of sound in air is  $330 \text{ ms}^{-1}$ ).

$$\text{Fundamental frequency } n = \frac{v}{2l}$$

$$l = \frac{v}{2n} = \frac{330}{2 \times 200} \quad l = 0.825 \text{ m.}$$

### Self-Evaluation

Choose the correct answer

- Waves produced on the surface of water  
(1) longitudinal (2) transverse  
(3) electromagnetic wave  
(4) stationary waves
- In longitudinal waves, the particles vibrate in a ..... direction of propagation  
(1) parallel (2) perpendicular  
(3) curved  
(4) parallel as well as perpendicular
- The period of a vibrating body of frequency 100 Hz is  
(1) 10 second (2) 0.01 second  
(3) 0.1 second (4) 100 second
- The time period of a vibrating body is 0.05 second, its frequency is .....  
(1) 25 Hz (2) 50 Hz  
(3) 20 Hz (4) 5 Hz
- Velocity of sound by a tuning fork frequency of 480 Hz is  $340 \text{ ms}^{-1}$ . Its wavelength is .....  
(1) 1.4 m (2) 0.7 m  
(3) 1.63 m (4) 7 m
- The velocity of sound at  $20^\circ\text{C}$  is.....  
(1)  $344 \text{ ms}^{-1}$  (2)  $330 \text{ ms}^{-1}$   
(3)  $440 \text{ ms}^{-1}$  (4)  $120 \text{ ms}^{-1}$
- The velocity of sound is greatest in .....  
(1) solid (2) liquid  
(3) gases (4) vacuum
- The frequency higher than 20,000 Hz is  
(1) ultrasonics (2) infrasonic  
(3) audible (4) sonic
- The Harmonic series in open organ pipe is .....  
(1) 1:3:5... (2) 2:4:6...  
(3) 1:2:3... (4) 1:5:9...
- The vibrations in stretched string does not depend on  
(1) vibrating length (2) tension  
(3) linear density (4) volume

### Fill in the blanks

11. Sound travels in air as ..... waves
12. .... waves cannot pass through gases.
13. Velocity of sound in sea water is .....
14. .... waves are produced by reflected waves.
15. The trumpet is a ..... instrument.
16. Sound travels faster in ..... and slower in .....
17. Depth of ocean is determined by .....
18. .... vibration has maximum amplitude.
19. Vibrations in veena produce ..... waves.
20. The distance between two nodes is .....
21. The fundamental mode of vibration in closed organ pipe is .....
22. The pitch of sound ..... as the length of the wire increases.
23. The frequency of sound emitted by bat is .....
24. .... method is used to record sound in film strips.
25. First overtone in closed organ pipe is .....
26. Audible range of frequency of sound for human .....
27. The pitch of the sound ..... as the source moves towards the observer.
28. The frequency of note emitted by air column in open pipe is ..... that emitted in the closed pipe.
29. In sonometer if the tension is high the pitch of sound is .....
30. .... sound tracks are recorded on tape.
31. One mach is equal to .....

### 32. Match the following

- |  |                        |
|--|------------------------|
| 1) Vibrations due to external periodic force                   | (i) Doppler effect.    |
| 2) Inaudible vibrations  | (ii) Resonance.        |
| 3) Apparent change in pitch                                    | (iii) ultrasonics.     |
| 4) Frequencies of natural and external periodic force are same | (iv) frequency.        |
| 5) Number of waves produced per second                         | (v) infrasonics.       |
| 6) Less than 20 Hz.  | (vi) forced vibration. |

### Answer briefly

33. What is wave motion?
34. Name the types of mechanical waves.
35. What are transverse waves? Give two examples.
36. What are longitudinal waves?
37. What are compressions and rarefactions?
38. What are crests and troughs?
39. Through which media transverse waves propagate?
40. How does sound waves travel in air?
41. What is the velocity of sound at 0°C?
42. What is amplitude of a wave?
43. Define the terms (a) frequency, (b) time period and (c) wavelength. Give their units.
44. What is the relation between frequency, wavelength and velocity?
45. What is wave velocity?
46. What is the velocity of sound in air at 20°C?
47. Name the factors that affect the velocity of sound.
48. How is the velocity of sound affected by (a) pressure (b) temperature ?
49. Name the different types of vibrations.
50. What is free vibration? Give one example.
51. What is forced vibration?
52. Name the condition for forced vibration to occur.
53. What is resonance? Give one example.
54. Why is resonance disastrous?
55. What are stationary waves?
56. What are nodes and antinodes of stationary waves?
57. Give examples for stationary waves in strings.
58. Give examples for stationary waves in air column.
59. Name any two wind instruments.

60. Name any two string instruments.
61. What are harmonics?
62. What are overtones?
63. What is fundamental frequency?
64. What is the ratio of harmonic series in (a) closed organ pipe (b) open organ pipe?
65. What are the laws of sonometer?
66. What is Doppler effect?
67. What are ultrasonics?
68. Mention any two uses of Doppler effect.
69. What is the audible range of sound for a human being?
70. What are infrasonics?
71. How does bats estimate the distance of an object?
72. Mention any two uses of ultrasonics.
73. What is a Sonar? How is it used to find the depth of ocean?
74. What is meant by mach cone?
75. What material is coated on audio tape for recording of sound?
76. What is the method used in recording of sound on films?

#### Answer in detail

77. Distinguish between transverse and longitudinal waves.
78. Derive the relation between frequency, wavelength and velocity.
79. Explain how transverse waves are formed using a spring or slinky.
80. Explain how longitudinal waves are formed in a slinky.
81. Explain how the vibrations of a tuning fork travel in air as a longitudinal wave.
82. How are stationary waves formed? Explain with an experiment.
83. Show that the harmonics in an open organ pipe are in the ratio 1:2:3...
84. Show that the harmonics in closed organ pipe are in the ratio 1:3:5...
85. State the laws of transverse vibrations of a stretched string. Explain how are they verified using the sonometer.
86. Explain how sound is recorded on tapes.
87. Explain how sound is reproduced from the tape.
88. Explain how sound is recorded on films.
89. Explain how sound recorded on the film is reproduced.
90. Explain Doppler effect with an illustration.
91. Explain the uses of ultrasonics in (a) medicine and (b) industry.
92. Explain mach effect.
93. Using sonometer, how will you determine the frequency of a tuning fork?

#### Problems

94. A wave is moving in air with a velocity  $344 \text{ ms}^{-1}$ . Calculate its wavelength if its frequency is 512 Hz. [Ans: 0.67 m]
95. When a stone is dropped in a lake, 5 ripples are formed in one second. If the distance between crest and trough is 5 cm, find the frequency, wavelength and velocity of the ripples. [Ans: 5Hz, 10cm,  $50 \times 10^{-2} \text{ ms}^{-1}$ ]
96. The wavelength of sound wave is 0.64 m and its frequency is 512 Hz. What is the velocity? [Ans:  $327.68 \text{ ms}^{-1}$ ]
97. A source of sound produces 20 crests and 20 troughs in 0.2 second. Find the frequency of wave. [Ans: 100 Hz]
98. What is the frequency of sound of wavelength 2 m and velocity  $340 \text{ ms}^{-1}$ . [Ans: 170 Hz]
99. A sound wave of wavelength 68 m travel 850 m in 2.5 second. Calculate (i) velocity and (ii) frequency of sound. [Ans:  $340 \text{ ms}^{-1}$ , 500 Hz]

## 7. LIGHT

Curved surfaces and mirrors are used in television antenna, headlights and rear view mirrors of automobiles, cosmetic mirrors, ophthalmoscope, torchlight and monitoring mirrors. They reflect light rays just like the plane mirrors and the laws of reflection of light hold good for spherical mirrors. We can think of spherical mirrors as a curved surface with a collection of several small plane mirrors.

**Activity:** Have you looked at your image on the front and backsides of a polished spoon? Observe that the nature and type of images formed by the surfaces are different.

### 7.1 Spherical Mirrors

Spherical mirrors are parts of the hollow spheres of glass with convex and concave reflecting surfaces. The spherical section AOB is formed by cutting the sphere by the plane AB.

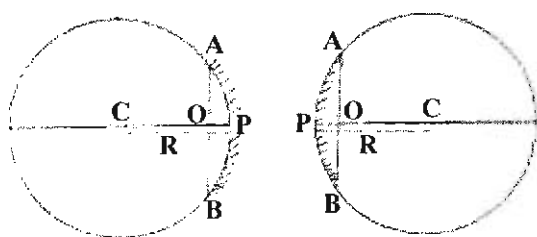


Fig 7.1 Spherical Mirrors

The spherical mirror with a reflecting surface curved like interior of circle called a **concave mirror**.

The spherical mirror with a reflecting surface curved like the outside of circle is called a **convex mirror**.

**Activity:** If you hold a concave mirror near your face, you could observe an erect and enlarged image. As you move the mirror away, the size of the image decreases. At a particular distance the image disappears and an inverted image appears as you move the mirror farther. But in the case of convex mirrors, whatever be the distance, the image is always erect and small in size. This helps us to identify whether the spherical mirror is concave or convex.

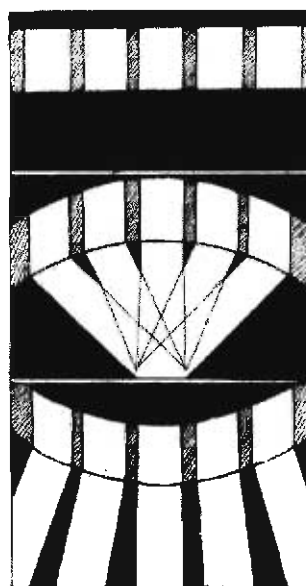
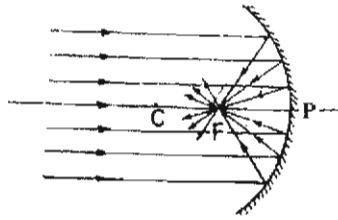


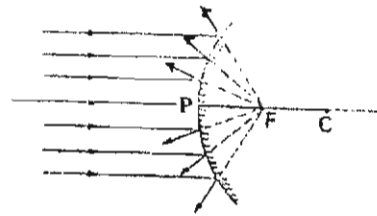
Fig 7.2 Concave and convex mirrors made of plane mirrors

**Activity:** Fix small strips of plane mirrors on a flexible cardboard. Bend the cardboard into concave and convex surfaces. Shine sunlight on the mirrors and observe the images produced on a paper screen.

1. The light beams reflected by the concave mirror are brought to a focus at a point.
2. The light beams reflected by the convex mirror appear to diverge from a point.



(1) Concave mirror



(2) Convex mirror

Fig 7.3 Spherical mirrors

## 1. Spherical mirrors – Definitions

1. The portion APB of the spherical mirror which reflects light is called the **aperture**.
2. The centre of hollow sphere of which the spherical mirror forms a part is called the **centre of curvature (C)**.
3. The geometric centre of spherical mirror is called the **pole (P)** of the mirror.
4. The line joining the pole and the centre of curvature of a spherical mirror is called the **principal axis**.
5. The radius of the sphere of which the spherical mirror forms a part is called the **radius of curvature (R)**. It is the distance between the pole and the centre of curvature of the spherical mirror,  $CP = R$ .
6. The rays of light parallel to the principal axis, after reflection by a concave mirror converge at a point on the principal axis (Fig 7.3). This point is called the **principal focus** of the concave mirror. The rays of light parallel to the principal axis, after reflection by a convex mirror appear to diverge from a point on the principal axis behind the mirror. This point is called the **principal focus** of the convex mirror.
7. The distance between the principal focus and the pole is called the **focal length** of the spherical mirror.

## 2. Real and virtual images in spherical mirrors

### Real images

The image formed by the actual intersection of reflected light rays are called **real images**. Real images can be caught on the screen and they are inverted. For all positions of objects beyond the principal focus the concave mirror produces real images.

### Virtual images

Virtual images cannot be caught on the screen. They are erect. The images seen inside the plane mirrors are virtual images. The images that appear without the actual intersection of reflected rays are called virtual images.

**Example:** Virtual images formed by the plane mirrors are always erect and are of the same size, whatever the position of the object. When objects are placed within the principal focus, the concave mirror produces erect and enlarged virtual images.

All images produced by the convex mirrors are erect, diminished and virtual images.

### 3. Relation between radius of curvature and focal length of a spherical mirror

An incident ray AO parallel to the principal axis PC is reflected through the principal focus (OA'). OC is the bisector of  $\angle AOA'$

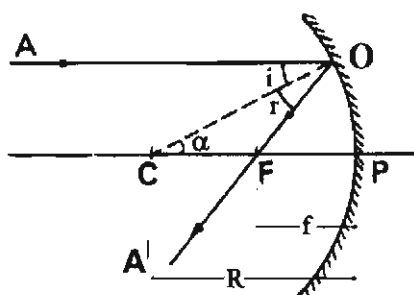


Fig 7.4 Radius of curvature of a spherical mirror

According to laws of reflection,

$$i = r$$

But  $i = \alpha$  (alternate angles)

$$r = \alpha$$

$\Delta FOC$  is an isosceles triangle with

$$\angle COF = \angle OCF$$

$$\therefore OF = FC$$

Since the incident ray AO is close to the principal axis  $PF = FC$  and F is the mid point of PC.

$$PC = PF + FC$$

$$R = f + f = 2f$$

$$\therefore f = \frac{R}{2}$$

The focal length of a spherical mirror is half of its radius of curvature.

**Activity:** Mount a concave mirror on a stand and place an illuminated wire mesh in front of it. Adjust the mirror such that a well defined image is formed by the side by the illuminated wire mesh. The distance between

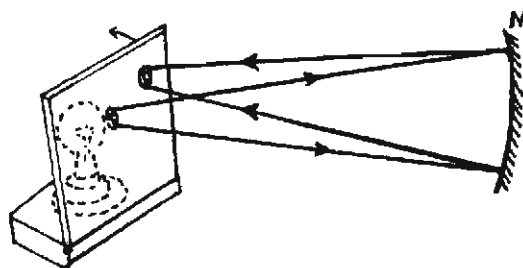


Fig 7.5 Radius of curvature of a concave mirror

the object and the concave mirror gives the radius of curvature of mirror.

### 4. Rules to locate the images formed by spherical mirrors

1. A ray parallel to the principal axis, after reflection from the mirror passes through the principal focus. Fig 7.6(1)
2. A ray passing through the principal focus, F of the concave mirror, after reflection passes parallel to the principal axis Fig 7.6(2)
3. A ray passing through the centre of curvature of a concave mirror is reflected back along the same path. Fig 7.6(3)

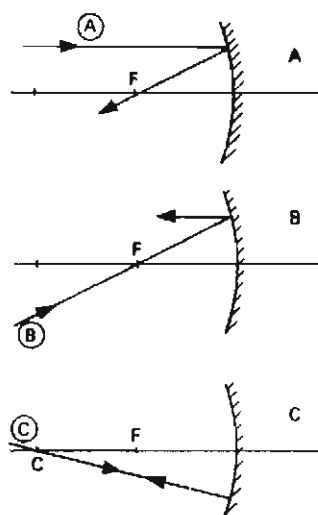


Fig 7.6 (1,2,3) Image formation in a concave mirror

## 7.2 Images formed by a concave mirror

We can locate the images formed by a concave mirror for various positions of an object using the ray diagram and the rules mentioned above.

### 1. Object at infinity

Rays from a distant object are parallel to principal axis and, after reflection by a concave mirror, meet at the principal focus (F) to produce a real image. The image is very small, real and inverted. Fig 7.7(1)

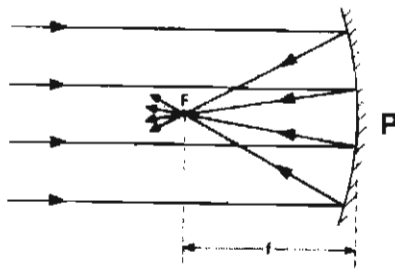


Fig 7.7(1) Object at infinity

### 2. Object beyond C

When the object is placed beyond C, the image is formed between C and F. A ray parallel to the principal axis, after reflection, passes through F. Another ray through C gets reflected back. These two rays meet at I'. The image I' is small, real and inverted. Fig 7.7(2)

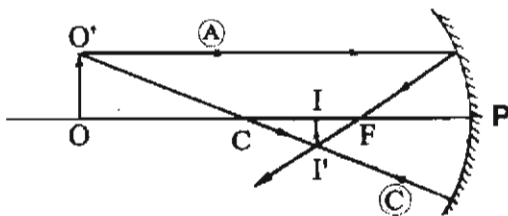


Fig 7.7(2) Object beyond C

### 3. Object at C

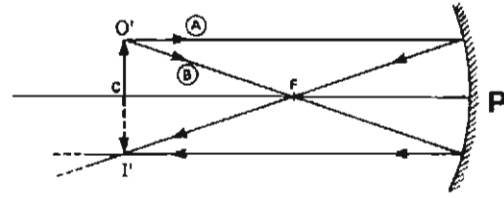


Fig 7.7(3) Object at C

When the object is placed at C, a ray parallel to the principal axis, after reflection passes through F. Another ray through F, after reflection by the concave mirror goes parallel to the principal axis. The reflected rays meet at I' to form a real, inverted image of the same size as the object at C itself. A concave mirror placed behind the projector lamp produces an intense beam of light. Fig 7.7(3)

### 4. Object between F and C

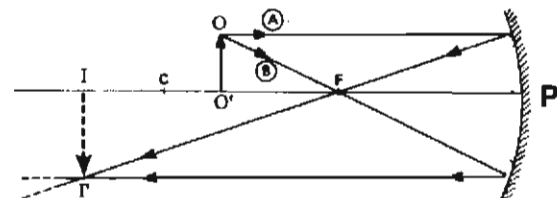


Fig 7.7(4) Object between F and C

When the object is placed between F and C, a ray parallel to the principal axis, gets reflected and passes through F. Another ray through F, after reflection by the concave mirror goes parallel to the principal axis. These two rays meet at I' to produce a real, inverted and magnified image beyond C.

This method is used in the floodlights used in auditorium and playgrounds Fig 7.7(4)

### 5. Object at F

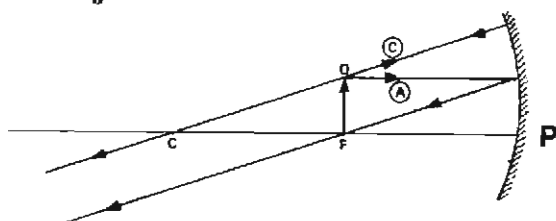


Fig 7.7(5) Object at F

When the object is placed at F a ray parallel to principal axis, after reflection, passes through F. Another ray through C gets reflected back. The reflected rays are parallel and hence meet at infinity. Fig 7.7(5)

This method is used to get parallel beams of light in the torchlight, headlight of automobiles and searchlights.

### 6. Object between F and P

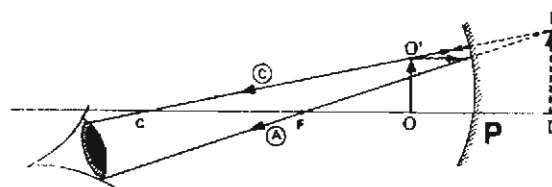


Fig 7.7(6) Object between F and P

When the object is placed between F and P, a ray parallel to the principal axis, after reflection, passes through F. Another ray through C gets reflected back. Extend these reflected rays to locate the image behind the mirror. The image is erect, enlarged and virtual. This method is used in cosmetic mirrors and the mirrors used for close examination by the doctors to produce magnified images. Fig 7.7(6)

Table 7.1 Position, nature and size of images produced by concave mirrors

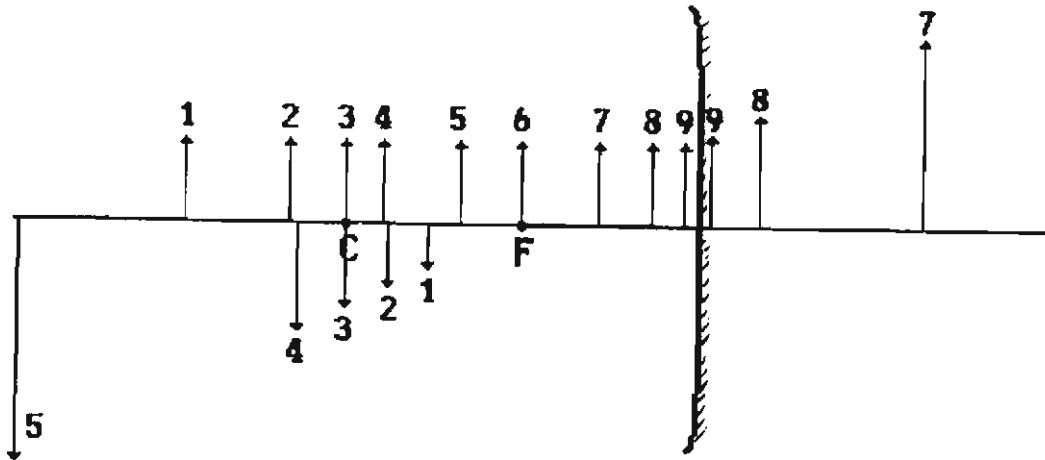
S. No.	Object position	Image	
		Position	Nature, size
1.	At infinity	At principal focus (F)	diminished (point), real and inverted.
2.	Beyond C	Between F and C	Diminished, real and inverted.
3.	At C	At C	same size, real, inverted
4.	Between F and C	Beyond C	enlarged, real and inverted
5.	At F	At infinity	enlarged, real and inverted. No image since the reflected rays are parallel.
6.	Between P and F	Behind the mirror	enlarged, erect and virtual

The position, nature and size of images formed by a concave mirror for various positions of the object are given in Table 7.1.

### 7. Relationship between the object distance and object size and image distance and image size.

As the object distance decreases [Fig 7.7(7)] and the object moves closer to F, the image distance and size increases. When the

object is at the centre of curvature, the image distance and size equals the object distance and size respectively. As the object distance approaches the focal length, the image distance and height approaches infinity. When the object distance equals exactly one focal length, there is no image. As the object distance decreases less than one focal length, the image is virtual and located behind the mirror, the image distance and, its size goes on decreasing. Finally as the object distance



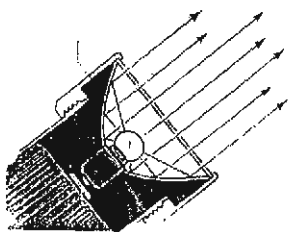
*Fig 7.7(7) The nature of images in a concave mirror*

approaches zero, image distance also becomes zero. The height of image becomes equal to the object height. The position, nature and size of the image for different object locations are marked in the Fig 7.7(7).

**Activity:** Mount a concave mirror on a stand and place a lighted candle such that the flame lies on the principal axis of the mirror. Place a screen in front of the mirror and adjust it to get a well defined real, inverted image on the screen. Observe the location, nature and size of the image for the different object distances and compare your results with those given in the Table 7.1.

### 8. Uses of concave mirror

1) When objects are placed within the principal focus, the concave mirrors produce erect and enlarged virtual images. So it is used as a cosmetic or shaving mirror.

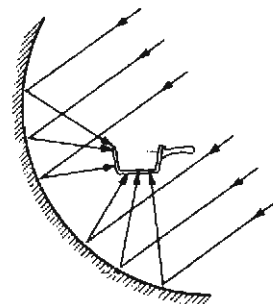


*Fig 7.8 Torchlight*

2) The light from the bulbs of torchlights, projectors and headlamps of automobiles are reflected as a parallel beam by the concave mirrors.

3) Doctors use concave mirrors to reflect light from the headlamp to investigate the ear, throat and nose. Dentist use concave mirrors to magnify and investigate the teeth.

4) Concave mirrors are used in ophthalmoscope and the doctors use it to view the retina of the eye. Light from a lamp is reflected by a concave mirror with a peep hole at its centre to view the retina of the eye.



*Fig 7.9 Solar Cooker*

5. Concave mirrors are used to converges the solar energy and convert it into heat and electrical energy. This heat radiation is used to cook food in a solar cooker.



**Fig 7.10 Dish antenna**

6) Hemispherical dish antennas receive radio waves and microwaves from artificial satellites and help in radio, television and telephone communication.

7) Concave mirrors in reflecting telescopes are used to converge or focus X-rays, light waves and radio waves from distant stars and galaxies.

8) Parabolic reflectors are used in search lights. The lamp at its focus gives a wide beam of light and sends it out as a perfectly parallel beam. It is also used to bring parallel beam from a distant object to a sharp focus.

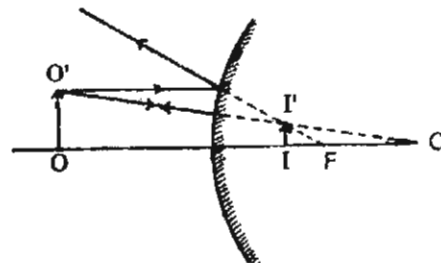


**Fig 7.11 Image in concave and parabolic mirrors**

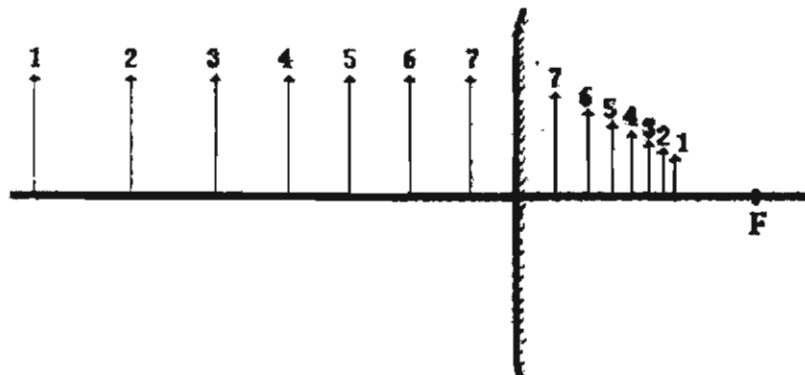
### 7.3 Formation of image by a convex mirror

In case of a convex mirror, the images for all positions of the object lie between P and F. The image is always, virtual, erect and diminished.

As the object distance decreases and moves towards the convex mirror, the image



**Fig 7.12 Image in a convex mirror**

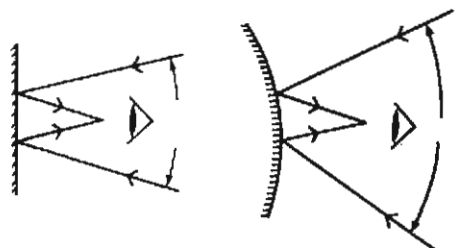


**Fig 7.13 Nature of images in a convex mirror**

distance behind the mirror decreases and the image size increases. As the object approaches the mirror, the virtual and erect image approaches the mirror the image size increases. So, convex mirrors are used as rear view mirrors in automobiles to locate the distance of vehicles coming in the rear.

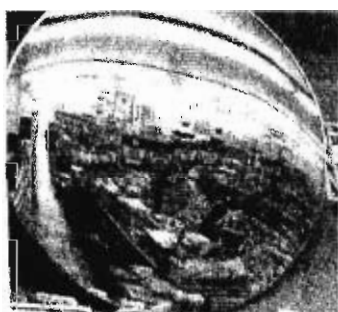
### Uses of convex mirrors

1) A convex mirror is used as rear view mirror in automobiles. It gives a wider field of vision of scenes behind than a plane mirror. It produces an erect virtual image, diminished in size so as to give wider field of view of vehicles in the rear.



*Fig 7.14 Field of view in plane and convex mirrors*

2) Convex mirrors are fixed in super markets to monitor the commodities and the customers in the shop.

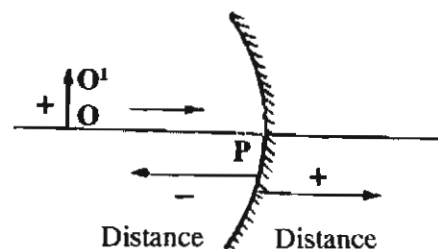


*Fig 7.15 Monitoring convex mirror*

3) Convex mirrors are fixed in blind corners in roads and buildings to view the persons coming in the opposite direction.

## 7.4 Cartesian Sign Conventions

Following sign conventions are used:



*Fig 7.16 Cartesian sign convention*

1. The object is always placed on the left of the spherical mirror so that the incident ray is always from left to right.
2. All distances are measured from the pole of the spherical mirror.
3. Distances measured in the same direction as that of the incident ray are taken as positive.
4. Distances measured in the direction opposite to the incident ray are negative.
5. Heights measured perpendicular to the principal axis, in upward direction are taken as positive.
6. Heights measured perpendicular to the principal axis, in the downward direction are taken as negative.

### Important points

1. Radius of curvature and focal length of a concave mirror are negative because they are measured from the pole of the mirror towards the left.

2. Object distance (-u) and real image distance (-v) are negative. For virtual images on right the image distance is positive (+v).

3. Radius of curvature and focal length of a convex mirror are positive because they are measured from the pole of the mirror towards the right.

### 7.5 Mirror equation

The relation between focal length ( $f$ ), object distance ( $u$ ) and image distance ( $v$ ) of a concave mirror is given by the mirror equation.

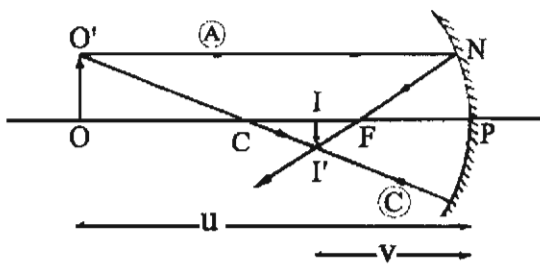


Fig 7.17 Relation between  $u, v, f$  of a concave mirror

#### 1. Concave mirror

Consider an object  $OO'$  beyond  $C$ . The image of this object is formed at  $II'$  as shown in the ray diagram. A ray  $O'N$  parallel to principal axis, after reflection by the mirror, passes through  $F$ . Another ray passing through  $C$ , after reflection from the mirror, retraces its path.  $II'$  is the image formed between  $F$  and  $C$ .

Object distance,  $PO = -u$

image distance,  $PI = -v$

focal length,  $PF = -f$

Radius of curvature,  $PC = -2f$

Since  $N$  is very close to  $P$ ,  $NP$  can be considered as a straight line.

$\triangle OO'C$  and  $II'C$  are similar triangles

$$\therefore \frac{OO'}{II'} = \frac{CO}{IC} \quad \dots(1)$$

$\triangle NPF$  and  $II'F$  are similar triangles

$$\therefore \frac{NP}{II'} = \frac{PF}{FI} \quad \dots(2)$$

$NP$  is parallel to  $OO'$

$$\therefore \frac{CO}{IC} = \frac{PF}{FI} \quad \dots(3)$$

$$\frac{PO - PC}{PC - PI} = \frac{PF}{PI - PF} \quad \dots(4)$$

According to sign convention,

$$\frac{-u - (-2f)}{-2f - (-v)} = \frac{-f}{-v - (-f)} \quad \dots(5)$$

$$uv - 2fv - uf + 2f^2 = 2f^2 - fv$$

$$uv - fv - fu = 0$$

$$\text{or } uv = fv + fu$$

Dividing by  $uvf$ , we get,

$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}} \quad \dots(6)$$

Similarly, we can deduce the mirror equation for virtual images.

#### Magnification

The magnification of a mirror is equal to the ratio of size of the image and size of the object.

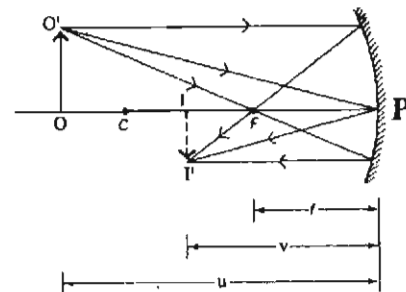


Fig 7.18 Magnification in a concave mirror

$$\text{Magnification} = \frac{\text{image size}}{\text{Object size}} = \frac{II'}{OO'}$$

$$m = -\frac{\text{image distance}}{\text{Object distance}} = -\frac{v}{u}$$

According to sign convention magnification (m) is negative for real image and positive for virtual image.

## 2. Convex mirror

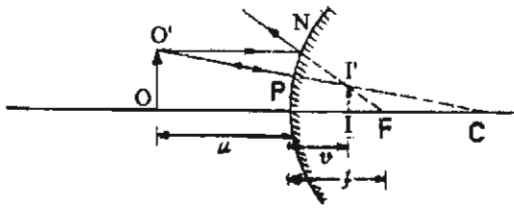


Fig 7.19 Relation between  $u, v, f$  of a convex mirror

Consider an object  $OO'$  placed in front of a convex mirror. The image formed, between  $P$  and  $F$  behind the mirror, is virtual erect and diminished.

According to sign convention

$$PO = -u,$$

$$PF = f$$

$$PI = +v$$

$$PC = R = 2f$$

$\triangle OO'C$  and  $\triangle I'I'C$  are similar triangles

$$\therefore \frac{OO'}{I'I'} = \frac{CO}{CI} \quad \dots(7)$$

As  $N$  is close to  $P$ ,  $NP$  can be considered as a straight line.

$\triangle NPF$  and  $\triangle I'I'F$  are similar triangles

$$\frac{NP}{I'I'} = \frac{PF}{IF} \quad \dots(8)$$

$NP$  and  $OO'$  are parallel to each other. From equation (7) and (8)

$$\frac{CO}{CI} = \frac{PF}{IF} \quad \dots(9)$$

$$\therefore \frac{PC + PO}{PC - PI} = \frac{PF}{PF - PI} \quad \dots(10)$$

Table 7.2 Nature of images formed by plane, concave and convex mirrors.

S. No.	Mirror type	Object Location	Image				Sign				
			Location	Type	Orientation	Size	$f$	$R$	$u$	$v$	$m$
1.	Plane mirror	Anywhere	Behind the mirror, same distance	Virtual image	erect	same	...	$\infty$	-	+	+
2.	Concave mirror	Within $F$	Behind the mirror	Virtual image	erect	enlarged	-	-	-	+	+
		Beyond $F$	Beyond $F$ before the mirror	Real image	inverted	small, same size, enlarged	-	-	-	-	-
3.	Convex mirror	Anywhere	Behind the mirror within $F$	Virtual image	erect	small	+	+	-	+	+

According to sign convention,

$$\frac{2f - u}{2f - v} = \frac{f}{f - v} \quad \dots(11)$$

$$2f^2 - 2fv - uf + uv = 2f^2 - vf$$

$$-fv - uf + uv = 0$$

$$uv = fv + fu$$

Dividing by  $uvf$ , we get,

$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}} \quad \dots(12)$$

## 7.6 Determination of the focal length of a concave mirror

### 1. Distant object method

Mount a concave mirror on a stand facing a distant object. Since the incident light rays are parallel, after reflection by the concave mirror, the rays converge to the principal focus. Place a screen in front of the mirror and adjust it to get a well defined image. A point image is formed on the screen. The distance between the mirror and screen gives the focal length ( $f$ ) of the concave mirror.

### 2. uv method

Mount a concave mirror on a stand and place an illuminated wire mesh in front of it,

such that the object is on the principal axis of the mirror. Place a screen between the mirror and object and adjust its position to get a well defined image.

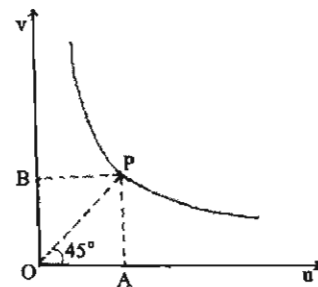
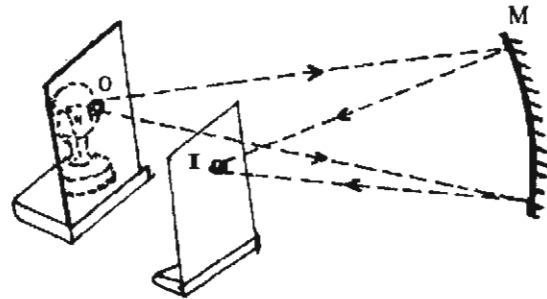


Fig 7.20 Focal length of a concave mirror - uv method

Measure and tabulate object distance ( $u$ ) and image distance ( $v$ ). Repeat the experiment by placing the illuminated object at different distances. Obtain clear images on the screen every time and tabulate the values of  $u$  and  $v$ . Using  $f = \frac{uv}{u+v}$ , calculate the focal length of the mirror and find its mean value.

Table 7.3 uv method to find the focal length of a concave mirror

S. No.	Object distance ( $u$ ) m	Image distance ( $v$ ) m	Focal length $f = \frac{uv}{u+v}$ m
1.			
2.			
3.			
4.			
5.			
mean $f =$			.m

### 3. uv – graphical method

With  $u$  along X axis and  $v$  along Y axis, using same scale, plot a graph to get a parabolic curve. Draw a bisector from the origin at  $45^\circ$  to the x axis to meet the curve at P on the parabolic curve. Draw perpendiculars to X and Y axis from the point P and measure OA and OB.

$\therefore OA = OB = R = 2f$  (Ray diagram in Fig 7.7(3))

$$\therefore f = \frac{OA}{2} = \frac{OB}{2}$$

From this the value of  $f$  can be found.

**Activity:** Graphical construction of the nature of images formed by a concave mirror.

By means of graphical construction, determine the position, size and nature of image of an object 5 cm tall, at a distance of 15 cm from a concave mirror of focal length 10 cm.

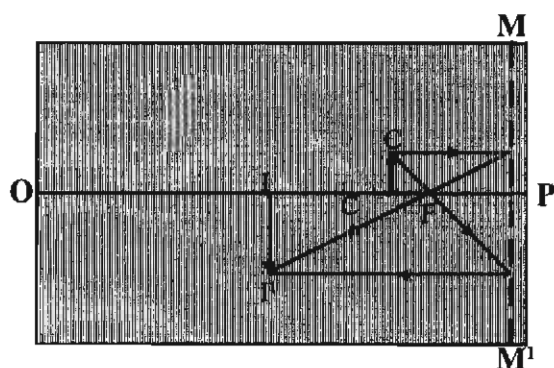


Fig 7.21 Concave mirror graphical method

**Step (1):** Take a graph sheet. Draw a straight line  $mm'$  to represent the concave mirror. Draw principal axis  $OP$ .

**Step (2):** Choose a suitable scale.

Let 1 small square = 1 cm  
 Height of object ( $OO'$ ) = 5 cm (5 small squares)  
 The object distance ( $PO$ ) = 15 cm (15 small squares)  
 Focal length ( $PF$ ) = 10 cm (10 small squares)

Mark the point  $F$  on the principal axis. Consider the object of height 5 cm at a distance 15 cm from the concave mirror.

**Step (3):** Locate the object position and distance.

Draw the ray diagram. As object is between  $F$  and  $C$ , the image is formed beyond  $C$ . The image  $I'$  is real, inverted and enlarged.

**Step (4):** Measure the position, size nature of the image.

Measure from the graph the image distance and its height.

The height of the image is 10 cm, which is twice that of object (5 cm). The image is formed at a distance of 30 cm from the mirror.

**Activity:** With the object of same height placed at a distance of 20 cm in front of the concave mirror, find by graphical method, the position, size and nature of the image.

### Some Basic Concepts

- \* The spherical mirror with a reflecting surface curved like interior of circle is called a concave mirror and if the reflecting surface is curved like the outside of circle it is a convex mirror.
- \* The radius of sphere of which the spherical mirror forms a part is called radius of curvature.
- \* The focal length of a spherical mirror is half of its radius of curvature.
- \* The rays of light parallel to the principal axis, after reflection by a concave mirror, converge at a point on the principal axis. This point is called the principal focus.

- \* The object placed beyond F of a concave mirror produces real inverted images.
- \* All the images formed in a convex mirror are virtual, erect and small.
- \* An object placed at centre of curvature of a concave mirror produce an image of same size as object at C itself.
- \* An object placed within the principal focus of a concave mirror produces a virtual, erect and an enlarged image.
- \* A parabolic reflector, with a bulb at its focus, sends out a perfectly parallel beam.
- \* Convex mirrors are used as rear view mirrors in automobiles.
- \* The relation between u, v, f of a spherical mirror is  $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$
- \* The magnification of a mirror is equal to the ratio of the size of the image and size of the object

$$m = -\frac{v}{u}$$

### Solved problems

1) An object is placed 15 cm in front of a concave mirror of focal length 10 cm. Find the nature, position and magnification of the image.

$$u = -15 \text{ cm} \quad v = ?$$

$$f = -10 \text{ cm}$$

using,

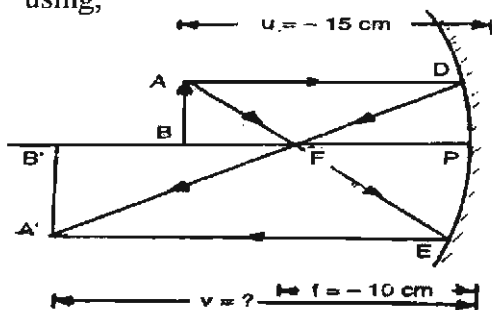


Fig 7.22

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{-15} + \frac{1}{v} = \frac{1}{-10}$$

$$\frac{1}{v} = \frac{1}{-10} + \frac{1}{15} = \frac{1}{30}$$

$$v = -30 \text{ cm}$$

The image is real and inverted in front of the mirror.

$$\text{Magnification} = -\frac{v}{u} = -\left(\frac{-30}{-15}\right)$$

$$m = -2 \text{ (real image)}$$

The size of image is twice the size of the object. The image is formed at 30 cm from the mirror.

2) An object, 5 cm tall, is placed at a distance 10 cm from a convex mirror of radius of curvature 30 cm. Find its nature, position and size of the image.

$$u = -10 \text{ cm}, \quad R = 30 \text{ cm}$$

$$f = \frac{R}{2} = \frac{30}{2} = 15 \text{ cm}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{-10} + \frac{1}{v} = \frac{1}{15}$$

$$\frac{1}{v} = \frac{1}{15} + \frac{1}{10} = \frac{5}{30} = \frac{1}{6}$$

$$v = +6 \text{ cm (image is virtual)}$$

$$m = \frac{-v}{u} = -\left(\frac{6}{-10}\right) = 0.6$$

$$m = \frac{\text{Height of image}}{\text{Height of object}}$$

$$\therefore \text{Height of image} = m \times \text{height of object}$$

$$= 0.6 \times 5 = 3 \text{ cm.}$$

It shows that the image is erect, virtual and diminished.

3) At what locations should an object be placed to get real and virtual images at a distance of 15 cm from a concave mirror of radius of curvature 20 cm.

$$R = 2f = -20 \text{ cm}$$

$$f = -10 \text{ cm}$$

$$v = \pm 15 \text{ cm}$$

**Real image**

$$v = -15 \text{ cm}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{-15} = \frac{1}{-10}$$

$$\begin{aligned} \frac{1}{u} &= \frac{1}{15} - \frac{1}{10} = \frac{2-3}{30} \\ &= \frac{-1}{30} \end{aligned}$$

$$u = -30 \text{ cm}$$

$$\begin{aligned} m &= \frac{-v}{u} = -\left(\frac{-15}{-30}\right) \\ &= -0.5 \end{aligned}$$

If an object is placed at the distance of 30 cm, a real, inverted image of size half is formed in front of the mirror at a distance of 15 cm.

**Virtual image**

$$v = 15 \text{ cm}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{15} = \frac{1}{-10}$$

$$\begin{aligned} \frac{1}{u} &= \frac{-1}{15} - \frac{1}{10} \\ &= \left(\frac{-2-3}{30}\right) = \frac{-5}{30} = \frac{-1}{6} \end{aligned}$$

$$\therefore u = -6 \text{ cm}$$

$$m = \frac{-v}{u} = -\left(\frac{15}{-6}\right) = 2.5$$

If an object is placed at a distance of 6 cm, in front of the image is formed at 15 cm behind the mirror and its size is 2.5 times that of the object.

### Self - Evaluation

**Choose the correct answer**

- Which mirror is used to obtain a parallel beam from a source of light?  
(1) convex (2) concave  
(3) plane (4) glass
  - Which mirror is used to obtain a real image of the same size?  
(1) convex (2) concave  
(3) plane (4) parabolic
  - Where must an object be placed to obtain virtual, magnified image in a concave mirror?  
(1) at C (2) between F and C  
(3) between F and P (4) beyond C
  - The relationship between F and R is  
(1)  $R = \frac{f}{2}$  (2)  $f = \frac{R}{2}$   
(3)  $f = 2R$  (4)  $R = \frac{2}{f}$
  - Principal focus of a spherical mirror is between  
(1) F and C (2) P and C  
(3) beyond C (4) at C
  - Magnification for real image in a concave mirror is  
(1)  $m = \frac{-v}{u}$  (2)  $m = \frac{v}{u}$   
(3)  $m = \frac{-u}{v}$  (4)  $m = \frac{u}{v}$
- State true or false**
- All incident rays passing through the centre of curvature retrace their path.
  - Convex mirror is used to get magnified virtual images.

9. Sizes of image and object are the same for an object placed at C in front of a concave mirror. .
10. For object placed between F and C the image formed by a concave mirror is virtual and enlarged.
11. For object placed between P and F of a concave mirror, the image is virtual inverted and enlarged.
12. Convex mirrors are used as rear view mirrors.
13. Focal length of concave mirror is negative.
14. Virtual image is formed by convex mirror and concave mirror.

#### Fill in the blanks

15. If the inner surface of a spherical mirror is silvered then mirror is .....
16. The image formed by convex mirror is always .....
17. .... is used as headlight mirrors in automobiles.
18. The focal length is the distance from the pole of the spherical mirror ..... of the mirror.
19. The image in convex mirror is always ..... and .....
20. .... mirror has a wide field of view.
21. If the object is at F of a concave mirror, the image is formed at .....
22. The rays parallel to principal axis, after reflection by a spherical mirror pass through .....
23. The ratio of the size of image and size of object is .....
24. Distances measured in the direction of incident ray are .....

#### 25. Match the following

<i>Position of object in concave Mirror</i>	<i>Position of image in concave mirror</i>
1) At infinity	(i) between F and C
2) Beyond C	(ii) at infinity
3) At C	(iii) behind the mirror
4) Between F and C	(iv) at F
5) At F	(v) beyond C
6) Between F and P	(vi) at C

#### Answer briefly

26. You are given convex and concave mirrors. How will you distinguish one from the other?
27. What is the nature of images formed by convex and concave mirrors? Differentiate.
28. Where should an object be placed in front of the concave mirror to get (a) inverted image and (b) erect ?
29. What are spherical mirrors?
30. Mention any two applications of (a) concave and (b) convex mirror.
31. What is principal focus and focal length of a mirror?
32. Define pole, radius of curvature, centre of curvature of a spherical mirror.
33. Where must an object be placed in front of a concave mirror so that it forms a virtual magnified image?
34. Why does a driver prefer a convex mirror for rear view?
35. Distinguish between real and virtual images.
36. What is magnification? Write its formula.
37. Differentiate with a table the nature of images formed by a plane, concave and convex mirrors.
38. Which mirror has wider field of view?

39. What is the difference between plane mirror and convex mirror?
40. Compare and contrast the images formed by concave and plane mirrors.
41. Are all real images larger than the object?
42. A car headlight bulb contains two filaments. Why is this arrangement made? What types of beams of light it produce?
43. Mention the property of parabolic reflectors.
44. Why is the word 'Ambulance' written in the reverse in these vehicles?
45. Why not plane mirrors be used as rear view mirrors instead of convex mirrors?

#### Answer in detail

46. Obtain the relation between focal length and radius of curvature of a concave mirror.
47. Write the sign convention used in spherical mirrors.
48. Obtain the relationship between  $u$ ,  $v$ ,  $f$  for a spherical mirror.
49. Explain how a concave mirror can give real, diminished image and magnified image of an object. Illustrate by ray diagram.
50. Draw a ray diagram and explain how a concave mirror can give virtual, magnified image of an object.
51. Draw a diagram, to show the image formation in a convex mirror. What happens to the image if the object is moved towards the mirror?
52. Draw a ray diagram to produce a parallel beam of light from a point source using a concave mirror.
53. How will you determine, experimentally the focal length of a concave mirror?
54. Write the uses of a concave mirror.
55. Obtain the relationship between  $u$ ,  $v$ ,  $f$  in case of a concave mirror.

#### Problems

56. The radius of curvature of a concave mirror is 20 cm. What is its focal length? [Ans: 10 cm]
57. The focal length of convex mirror is 20 cm. What is the radius of curvature? [Ans: 40 cm]
58. What is the position of the image of an object placed at a distance of 30 cm from a concave mirror of focal length 30 cm? [Ans:  $\infty$ ]
59. If the object size is 1 cm. What is the size of image if magnification is 4. [Ans: 4 cm]
60. An object is placed at 5 cm in front of a convex mirror of focal length 10 cm. Calculate the position, nature and magnification. [Ans: 3.3 cm, 0.67, virtual, erect and small]
61. Find the nature of image formed when the object is placed at a distance of 20 cm from a concave mirror of focal length 10 cm. [Ans: 20 cm, real, inverted, same size]
62. A concave mirror forms a real image four times as tall as object. Object is placed at 10 cm in front of the mirror. Find the position of image and radius of curvature of the mirror. [Ans:  $u = -2.5$  cm,  $f = -2$  cm,  $R = -4$  cm]
63. An object is placed at 8 cm in front of a concave mirror of focal length 12 cm. Find the nature, position and magnification of the image. [Ans:  $v = -24$  cm,  $m = -3$ ]
64. An object is placed in front of a concave mirror so that the inverted image is 4 times compared to object. If the image is formed at 42 cm from the pole, where was the object kept? [Ans:  $u = -11$  cm]
65. An object 3 cm height is placed 8 cm in front of a concave mirror of focal length 6 cm. Find graphically the position, size and nature of image. [Ans:  $v = -24$  cm,  $m = -3$ ,  $H' = -9$  cm]
66. Construct graphically with scale drawing the position, size and nature of the image when the object of 2 cm height is placed at (a) 12 cm from a concave mirror of focal length 8 cm, (b) 10 cm from a concave mirror of focal length 10 cm, (c) 10 cm from a convex mirror of focal length 10 cm.

# CHEMISTRY

## 8. NATURE OF MATTER

### 8.1 States of Matter

Matter is a collection of particles that constitutes a body. It has mass, volume, inertia, weight and density.

Substance exists in three different states of matter known as solid, liquid and gas. The different physical states have certain general characteristics. All the three show an increase in volume when the temperature is increased and decrease in volume when the temperature is decreased. This effect is more in gases than in solids and liquids.

Solids and liquids have surfaces, but gases do not have such a surface.

Water in a glass tumbler has the top surface open. Gases do not have such a surface.

#### 1. Types of Solids

Solids are held together by 'cohesion' which results from the attractive forces between their atoms and molecules.

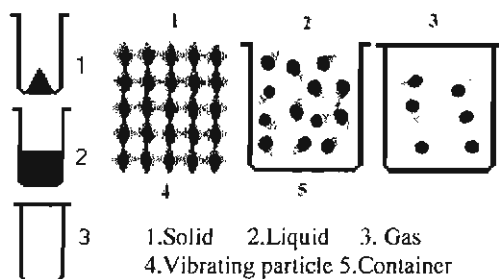


Fig 8.1 Three different states of matter

As a result, solid substances are rigid and hold their shapes unless deformed by

external forces. Two principal types of solids exist: true or crystalline solids and amorphous solids.

Crystalline solids, or crystals, consist of atoms and molecules that are arranged in regular three-dimensional lattices-like the egg in a stack of egg-cartons. The structure is determined by the chemical bonds between the adjacent atoms and molecules. Crystalline solids may form when a solution evaporates. They may also form when a gas or liquid solidifies. Most crystalline solids melt at specific temperatures to become liquids. Examples of crystalline solid include metals, salt and diamond.

Table 8.1 Properties of the three states of matter

Phy. state	Volume	Density	Shape	Fluidity
Solid	Has a fixed volume	high	Has a definite shape	Does not flow
Liquid	Has a fixed volume	Moderate to high	No definite shape, takes the shape of the container	Generally flows easily
Gas	No fixed volume, expands to fill the container	Low	No definite shape, takes the shape of the container	Flows easily

Amorphous solids have neither crystalline structures nor specific melting

points. Glass, carbon black and many resins are examples of amorphous solids.

Liquids and gases are also called fluids (e.g.) hydrogen and water

Hydrogen is the simplest element of all. An atom of its commonest isotope (protium) contains just one proton and one electron. Hydrogen is a diatomic molecule (H<sub>2</sub>) and has the lowest density. It is the commonest element in the universe and is the main element present in the sun. Solar energy powers life on the earth. Heat and light energy from the sun is produced by nuclear fusion reactions in which hydrogen is converted to helium.

### Do You Know?

1. Many companies manufacture mineral water. A few have the following composition.

**Table 8.2 Composition of mineral water**

		mg/l
Calcium	Ca <sup>+2</sup>	55
Magnesium	Mg <sup>+2</sup>	19
Sodium	Na <sup>+</sup>	24
Potassium	K <sup>+</sup>	1
Bicarbonates	HCO <sub>3</sub> <sup>-</sup>	248
Chloride	Cl <sup>-</sup>	42
Sulphates	SO <sub>4</sub> <sup>-2</sup>	23
Nitrates	NO <sub>3</sub> <sup>-3</sup>	<0.1
Iron	Fe <sup>+2</sup>	0
Aluminium	Al <sup>+3</sup>	0
Total dissolved		
Solids at 18°C		280
pH at source		7.4

2. Hydrogen is a gaseous matter. It is the "Fuel of the Future". Hydrogen could be used as a fuel instead of the fossil fuels used at present. In burning hydrogen a lot of energy is released, so hydrogen may be used as a fuel.



## 2. Classification of Matter

Matter can be classified into elements, compounds and mixtures. They are made up of tiny particles such as atoms and molecules.

### Pure substances

A pure substance consists of one substance only. There is nothing else in it. It has no contaminating impurities. A pure substance melts and boils at definite temperatures. **Elements and compounds are pure substances.**

Elements are substances that cannot be chemically broken down into simpler substances. So an element is made up of only one kind of atoms. For example, silver is an element which is made up of only silver atoms. Elements are the **building blocks** of all matter.

For example, the human body contains 65% oxygen, 18% carbon, 10% hydrogen, 3% nitrogen, 2% calcium and 2% other elements.

So far 112 elements have been identified. 21 of these do not occur in nature and have been made artificially. They include elements such as plutonium, curium and unnilpentium. 91 elements occur naturally and range from some very reactive gases such as fluorine and chlorine to noble metals like gold and platinum.

All elements can be classified according to their properties. The major classification is metals, non metals and metalloids. Elements exist as solids (silver, sulphur), liquids (bromine, mercury) and gases (oxygen). The distribution of

elements on earth's crust are given in Table 8.3

**Table 8.3 Distribution of elements on earth's crust**

<i>Element</i>	<i>% by wt</i>	<i>Element</i>	<i>% by wt</i>
Oxygen	49.85	Plutonium	2.33
Silicon	26.03	Magnesium	2.11
Aluminium	7.28	Hydrogen	0.97
Iron	4.12	Titanium	0.41
Calcium	3.18	Chlorine	0.20
Sodium	2.33	Carbon	0.19

**Table 8.4 Names and symbols of some Elements**

<i>English name</i>	<i>Name of the element</i>	<i>Symbol</i>
Hydrogen	hydrogen	H
Helium	helium	He
Lithium	lithium	Li
Beryllium	beryllium	Be
Boron	boron	B
Carbon	carbon	C
Nitrogen	nitrogen	N
Oxygen	oxygen	O
Fluorine	fluorine	F
Neon	neon	Ne
Sodium	natrium	Na
Magnesium	magnesium	Mg
Aluminium	aluminium	Al
Silicon	silicon	Si
Phosphorous	phosphorous	P
Sulphur	sulphur	S
Chlorine	chlorine	Cl
Argon	argon	Ar
Potassium	kalium	K
Calcium	calcium	Ca
Scandium	scandium	Sc
Titanium	titanium	Ti
Vanadium	vanadium	V
Chromium	chromium	Cr
Manganese	manganese	Mn
Iron	ferrum	Fe
Cobalt	Cobalt	Co
Nickel	Nickel	Ni
Copper	cuprum	Cu
Zinc	zinc	Zn

### 3. Atomicity of Elements

The number of atoms present in a molecule of an element is called atomicity.

**Atomicity one:** Atoms of solid element such as silver, potassium, Carbon and inert gases exist as monatomic particles.

**Atomicity two:** Hydrogen, bromine, chlorine, oxygen, nitrogen and fluorine exist as diatomic molecules and they are represented as  $H_2$ ,  $Br_2$ ,  $Cl_2$ ,  $O_2$ ,  $N_2$  and  $F_2$  respectively.

**Polyatomic elements:** Phosphorus molecule contains 4 atoms ( $P_4$ ) and atomicity of sulphur is 8 ( $S_8$ ).

### 4. Compounds

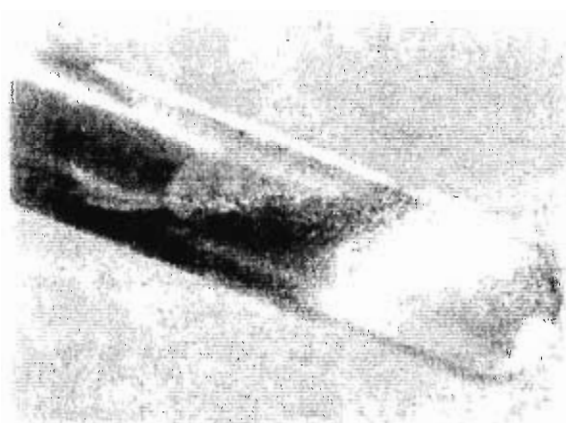
**A Compound is a substance made up of two or more elements chemically combined in a fixed ratio by weight.** They are homogeneous and exhibit definite physical and chemical properties [(e.g) water is a compound. It is made up of two elements hydrogen and oxygen, which combine chemically in a fixed ratio of 1:8 by weight. It possesses properties entirely different from the properties of hydrogen and oxygen. Similarly common salt is a compound of sodium and chlorine]. These elements cannot be obtained back from the compounds by simple physical means. We come across many compounds in our daily life. Some are given in the table.

**Table: 8.5 some common compounds**

<i>Compound</i>	<i>Formula</i>	<i>Importance</i>
Ammonia	$NH_3$	Ammonia is used as a fertilizer.
Calcium carbonate	$CaCO_3$	Calcium carbonate is an ingredient of some tooth pastes and is used for white washing.
Carbondi oxide	$CO_2$	All green plants need carbondioxide to live and grow. Carbon dioxide in the atmosphere helps to regulate the Earth's temperature.

Methane	CH <sub>4</sub>	Methane is the main component in natural gas.
Sodium chloride	NaCl	Sodium chloride or common salt is used in cooking. Human blood contains salts and body cells must have salt to function properly.
Sodium hydroxide	NaOH	Sodium hydroxide (Caustic soda) is used in the manufacture of soap.
Water	H <sub>2</sub> O	Water is the most common substance on Earth. It covers 71 percent of the Earth's surface and fills the oceans. All living things consist mostly of water. 97% of water is in the oceans. The oceans are not simply just pure water. They contain several elements and compounds dissolved in water.

**Activity:** Powdered iron and sulphur are mixed and heated. A black, non magnetic solid Iron (II) sulphide which cannot be changed back into iron and sulphur is formed.



**Fig 8.2** The Synthesis reaction between iron and sulphur

Sugar is a compound containing 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms. Remember that the properties of a compound are different from the properties of the constituent elements. The property of sugar is totally different from the properties of its elements.

## 5. Mixtures

**A mixture is made up of two or more elements or compounds when mixed in any ratio physically.**

All mixtures are heterogeneous except solutions which are homogeneous. (Air, sugar syrup, salt solution, smoke, toothpaste are a few examples of mixtures.

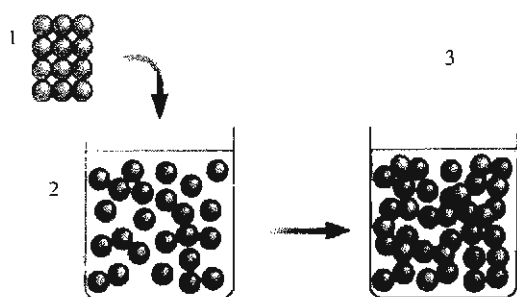
**Table: 8.6** Differences between compounds and mixtures

S. No	Compounds	Mixtures
1.	It is made up of two or more elements that are chemically combined.	It is made up of two or more pure substances that are mixed physically.
2.	A compound has definite melting and boiling points and density.	A mixture has no definite melting or boiling points and density.
3.	The properties of a compound are entirely different from those of its constituents.	A mixture retains the properties of the components.
4.	A compound is always homogeneous.	A mixture is heterogeneous, but some are homogeneous.
5.	The constituents of a compound cannot be separated by physical means.	The components of a mixture can be separated by simple physical means, (dissolving, magnetic separation, heating, and filtration)

## Types of Mixtures

Mixtures are classified as **homogeneous and heterogeneous mixtures**.

A **homogeneous mixture** is one which contains only one phase. A phase is a physically distinct part of a system which is separated by definite boundaries from other parts of the system. Example: Alloys, air, mixture of alcohol and water. Each of them contains only one phase.



*Fig 8.3 When a solute dissolves in a solvent, the solute particles are completely dispersed in the liquid*

1. Solute 2.Solvent 3.Solution

**Heterogeneous mixture** contains more than one phase.

**Example:** 1) Mixture of oil and water  
2) Mixture of Sand and Salt and 3) Mixture of sugar and sand.

## 6. Solutions

If you add salt to a beaker of water and stir, the salt seems to disappear. It forms a **solution**. The solution is clear. Some solutions such as copper sulphate solution are coloured. But they are always clear.

You cannot separate a salt solution by filtering. If you pour it through the filter paper, both the salt and water go through the paper. In a 'solution' the substance which dissolves is called a **solute**. The liquid that dissolves the solute is called the **solvent**. Therefore, a **solution is a homogeneous mixture of solute and solvent**. It generally appears as one phase.

Substances such as salt and copper sulphate, which dissolve in water are said to be **soluble** in water. Substances such as Calcium carbonate are **insoluble** in water.

If you put 100g of water in a beaker and add some NaCl and stir, it dissolves. If you go on adding NaCl, you will eventually get to a point where no more NaCl dissolves. It is called **saturated solution** of NaCl.

A substance's ability to dissolve in another is called its **solubility**.

## 7. Suspensions

If you stir some chalk powder in a beaker of water, you get a milky liquid. The tiny chalk particles float in the water. They may stay there for several hours, but most of them will ultimately fall to the bottom. Some will float. The mixture of chalk particles and water is called a suspension. If you filter the suspension, you can separate the water and chalk particles. The water is filtrate. The chalk particles on the filter paper are the residue.

**Suspension is a mixture in which the particles are suspended in a dispersion medium.** They contain relatively large particles over 1000 nm ( $1\text{nm}=10^{-9}\text{m}$ ) in size. Therefore, a suspension is a heterogeneous mixture. When clay is added to water, a suspension is formed. Suspensions generally do not diffuse through membranes. They are opaque to light.

### *Do you Know?*

Oil and water do not mix. If you add cooking oil into water, the oil floats on water. If you shake the mixture vigorously, a turbid liquid called **emulsion** is formed. Droplets of oil are suspended in the medium.

## 8. Colloids

**Colloids are suspensions that contain extremely small particles.** The particles of colloids are too small to be seen by eye and they scatter light. They do not settle down. Milk, ink, curd, smoke are some examples of colloids. The particles in colloids may be seen only through a microscope. Every colloid has two parts: 1) **The dispersed phase**(Fat in milk or water drops in mist) 2) **Dispersion medium** e.g. water in milk or air in mist.

The dispersed phase and dispersion medium of different types of colloids are given in Table 8.7

**Table 8.7 classification of colloidal solutions**

<i>Dispersed phase</i>	<i>Dispersion medium</i>	<i>Type of colloid</i>	<i>Example</i>
Liquid	Gas	Liquid aerosol	Mist
Solid	Gas	Solid aerosol	Smoke
Gas	liquid	Foam	Soap lather
Liquid	liquid	Emulsion	Milk
Solid	liquid	Sol	Paint
Gas	Solid	Solid foam	Sponge
Liquid	Solid	Gel	Butter

### ***Do you Know ?***

The colloids in which there are strong attractive forces between two phases are called lyophobic colloids (E.g.) gum in water. The colloids in which there are weak forces of attraction between two phases are called lyophilic colloids (E.g.) sulphur in water.

## 9. The Concentration of Solutions

When a chemical substance (solute) is dissolved in a definite volume of solvent, we can measure the quantity of solute in two ways. We can measure either its mass (in grams) or its amount (in moles).

**The amount of solute dissolved in unit volume of solvent is called concentration.**

**Weight percentage concentration of a solution is defined as the weight of a solute in grams present in 100g of solution.**

For example a solution containing 5g of sodium chloride in 45 g of water, the weight percentage =  $\frac{5 \times 100}{(5+45)}$   
= 10% by weight.

### **Self-Evaluation**

### **Answer briefly**

1. What is matter?
2. What are the different types of solids?
3. Why do solids have rigid shapes?
4. Give one important property of a liquid.
5. How much of the earth's surface is covered with water?
6. Mention one element that is extracted from sea water
7. What is a pure substance?
8. What is the nature of the element oxygen?
9. What is caustic soda? Write its use.
10. What are the elements present in sugar?

11. What are the different types of mixtures?
12. Give an example for suspension.
13. What is a colloid?
14. Give one example for solid aerosol.
15. Give an example for a fertilizer.
16. What is an element?

### 17. Match the following

- |                  |                                 |
|------------------|---------------------------------|
| 1) Hydrogen      | - i) calcium                    |
| 2) Gases         | - ii) diatomic molecule         |
| 3) Elements      | - iii) fertilizer               |
| 4) Mineral water | - iv) Fuel of the future        |
| 5) Ammonia       | - v) compressible               |
| 6) Bromine       | - vi) building blocks of matter |
| 7) Sulphur       | - vii) Atomicity-one            |
| 8) Silver        | - viii) Polyatomic element      |

### Fill in the blanks

18. Increasing the \_\_\_\_\_ on the gas reduces the volume of a gas at a fixed temperature.
19. Amorphous solids have neither crystalline structure nor \_\_\_\_\_.
20. An element is made up of only one kind of \_\_\_\_\_.
21. Matter can be classified into elements, compounds and \_\_\_\_\_.
22. The dispersion medium and dispersed phase of soap lather are \_\_\_\_\_ and \_\_\_\_\_ respectively.
23. \_\_\_\_\_ is the example of colloid.

### Answer in detail

24. Differentiate the properties of the three states of matter.

25. Tabulate the common compounds, their formulae and their importance.
26. Give the differences between compounds and mixtures.
27. Tabulate the types of mixtures, their description and examples.

## 8.2 Atoms and Molecules

If elements are simplest form of matter, then, what an element is made of? An attempt to answer this question had been made by several philosophers. But it was John Dalton, a Manchester school teacher, who defined an atom scientifically in the year 1806.

### 1. Dalton's Atomic Theory

According to John Dalton,

- 1) Matter is composed of a large number of extremely small particles called atoms.
- 2) Atoms are indivisible.
- 3) Atoms can neither be created nor destroyed during chemical reactions.
- 4) All atoms of one element are identical in all respects such as size, shape, mass and structure.
- 5) Atoms of different elements are not alike.
- 6) Compounds are formed by the chemical combination of atoms of elements in whole number ratio. For example, two atoms of hydrogen combine with two atoms of chlorine to form two molecules of hydrogen chloride.
- 7) Since an atom is an extremely small particle, its absolute weight cannot be determined. Therefore, Dalton suggested the use of relative weights of atoms. These relative weights are called atomic weights of elements.

**Atomic weight is defined as the ratio of the weight of an atom of an element to that of hydrogen.**

The law of conservation of mass, the law of constant proportions and the law of reciprocal proportions were derived from the above theory. But this theory experienced difficulties in explaining the law of gaseous volumes.

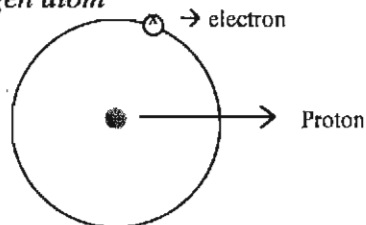
### Limitations of Dalton's theory

Dalton's theory failed in the following aspects:

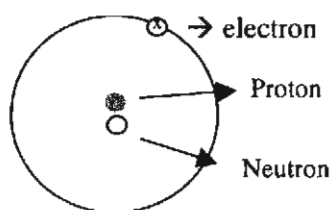
1. After the discovery of radioactivity it was proved that atoms are divisible. We get nuclear energy and radioisotopes by dividing atoms.
2. Atoms are created and destroyed in nuclear reactions i.e. new elements are formed.
3. All atoms of one element need not be identical in all respects (E.g.): Isotopes of hydrogen.

### Isotopes of Hydrogen

*Hydrogen atom*



*Deuterium atom (isotope)*



*Tritium atom (isotope)*

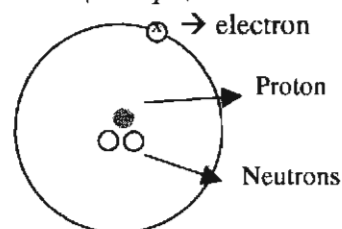


Fig 8.4 Isotopes of Hydrogen

- Isotopes are atoms of the same element with different mass numbers.
- They have the same number of protons and electrons in each atom, but different numbers of neutrons in the nucleus.

### 2. Atomic Mass

An atom is an extremely small particle and its absolute mass cannot be determined. Hence numerical values of the atomic mass scales are used to express the atomic mass of atoms. According to the relative scale of atomic masses, the mass of an atom of an element is expressed as a number, relative to the mass of one atom of hydrogen.

$$\left. \begin{array}{l} \text{Relative atomic} \\ \text{mass of an element} \end{array} \right\} = \frac{\text{Mass of one atom of element}}{\text{Mass of one atom of hydrogen}}$$

For an universally accepted atomic mass unit, carbon-12 isotope was selected as the standard. Its atomic mass is assigned as 12. Atomic mass unit is therefore, 1/12th the mass of a carbon-12 atom. However, the new symbol 'u' is used in the place of amu.

A particular element may consist of several isotopes with different atomic masses. The average relative atomic mass depends upon the isotopic composition of that particular element.

On  ${}_6\text{C}^{12}$  Scale

$$\left. \begin{array}{l} \text{Relative atomic mass} \\ \text{of an element} \end{array} \right\} = \frac{\text{Mass of one atom of element}}{(\text{Mass of one atom of carbon})/12}$$

On the carbon 12 scale, the relative atomic mass of carbon is 12.0000 and the relative atomic mass of hydrogen is 1.00897.

Most of the elements exist as a mixture of several isotopes. These isotopes differ in their mass number. Because of

the existence of isotopes the atom of an element has fractional atomic mass. For example, the isotopes of chlorine,  $\text{Cl}^{35}$  and  $\text{Cl}^{37}$  exist in the ratio 77:23. The average of atomic mass of chlorine is

$$\frac{(35 \times 77) + (37 \times 23)}{100} = 35.46$$

The relative atomic mass of elements is a mere number. If the atomic mass is expressed in grams, **it is known as the gram atomic mass**. Relative atomic masses of elements are referred on the basis of  $\text{C}^{12}$ .

**Table 8.8 Atomic masses of some elements**

Element	symbol	Atomic mass
Hydrogen	H	1
Carbon	C	12
Nitrogen	N	14
Oxygen	O	16
Chlorine	Cl	35.5

### 3. Molecular Mass

The molecular mass of an element or compound is defined as the ratio of the mass of one molecule of it to 1/12 part of the mass of a carbon atom. Carbon with mass number 12 is taken as the standard for the determination of molecular masses of elements or compounds. Molecular mass is a mere number. If the molecular mass is expressed in gram, it is known as gram molecular mass.

**Table 8.9 Molecular masses of some compounds**

Compound	Formula	Molecular Mass
Sulphur dioxide	$\text{SO}_2$	$32 + (2 \times 16) = 64$
Sulphur trioxide	$\text{SO}_3$	$32 + (3 \times 16) = 80$
Hydrogen sulphide	$\text{H}_2\text{S}$	$(2 \times 1) + 32 = 34$
Carbondi sulphide	$\text{CS}_2$	$12 + (32 \times 2) = 76$
Carbon dioxide	$\text{CO}_2$	$12 + (2 \times 16) = 44$

### Points to remember

- 1) The molecular mass is simply a number and not a weight
- 2) It is not absolute but it is only relative to 1/12 the mass of carbon -12.
- 3) If it is expressed in grams, it is known as gram molecular mass. Gram molecular mass of any substance is also known as one mole
- 4) Molecular mass of any substance can be obtained by adding the atomic masses of all atoms of elements present in molecules.

### The Mole Concept

A chemist counts the number of atoms, molecules, ions, electrons etc in terms of moles. So the mole is the chemical counting unit.

#### Definition

The mole is defined as the amount of a substance which contains **Avogadro number** of  $(6.023 \times 10^{23})$  ultimate particles atoms, molecules, ions. Mole is one gram molecular mass of the substance.

Mole is defined as the amount of substance which contains as many elementary units as there are in 12 grams of carbon-12

**Table 8.10 Molar masses of some substances**

Substance	Formula	Relative formula mass ( $M_r$ )	Mass of one mole	The number of molecules in one mole
Carbon	C	12	12g	$6.023 \times 10^{23}$ atoms
Hydrogen	$\text{H}_2$	$2 \times 1 = 2$	2g	$6.023 \times 10^{23}$ molecules
Iron	Fe	56	56g	$6.023 \times 10^{23}$ atoms
Water	$\text{H}_2\text{O}$	$(2 \times 1) + 16 = 18$	18g	$6.023 \times 10^{23}$ molecules
Magnesium oxide	$\text{MgO}$	$24 + 16 = 40$	40g	$6.023 \times 10^{23}$ molecules
Calcium Carbonate	$\text{CaCO}_3$	$40 + 12 + (3 \times 16) = 100$	100g	$6.023 \times 10^{23}$ molecules

## Calculating the mass of one mole of various substances

One mole of each of the different substances contains the same number of atoms, molecules or formula units. The number per mole has been worked out by different experimental methods. It is named after the 19<sup>th</sup> century Italian chemist, Amedeo Avogadro and is  $6.023 \times 10^{23}$  per mole. This is called the **Avogadro Number**. The vast size of this constant show just how small the atoms are.

**Example 1:** Atomic mass of sodium is 23. Hence 23 grams of sodium or 1 mole of sodium contains  $6.023 \times 10^{23}$  sodium atoms

**Example 2:** The molecular mass of sodium chloride (NaCl) is

$$\begin{array}{r} \text{Na- } 23.0 \\ \text{Cl- } 35.5 \\ \hline 58.5 \end{array}$$

58.5 grams of NaCl = 1 mole of NaCl. If 58.5gms of sodium chloride is dissolved in 1 litre of water, a solution of known concentration is obtained. The concentration of this solution is referred to as 1 molar solution. It is written as 1M.

### Calculations on the mole

You can find the molar mass of any substance by following these steps.

1. Write down the formula of the substance. For example ethanol  $C_2H_5OH$ ,
2. Work out its relative formula mass Eg. For ethanol  $M_r = (2 \times 12) + (6 \times 1) + 16 = 46$
3. Express this in grams per mole,

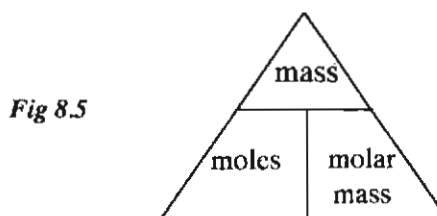
$$\text{Molar mass of ethanol} = 46 \text{ g/mol}$$

In experimental work, chemists work with varying masses. They cannot always use one mole of a substance.

$$\text{Number of moles} = \frac{\text{Mass of substance (g)}}{\text{molar mass (g/mol)}}$$

Using the above equation, it is possible to convert any mass of a particular

substance into moles, or vice versa. The triangle shown below can be a useful aid to memory. Cover the item to be found and you are left with how to work this item out.



We shall look at some examples.

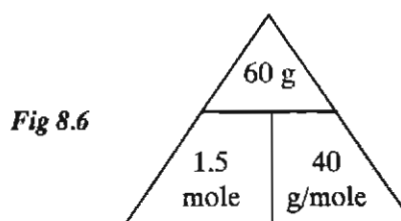
1. How many moles are there in 60g of Sodium hydroxide?

$$M_r(\text{NaOH}) = 23 + 16 + 1 = 40$$

$$\text{Molar mass of NaOH} = 40 \text{ g/mol}$$

$$\text{Number of moles} = \frac{\text{Mass of substances}}{\text{molar mass}}$$

$$\begin{aligned} &= 60/40 \\ &= 1.5 \text{ mol} \end{aligned}$$



- 2) What is the mass of 0.5 mole of Copper(II) sulphate crystals?

We have the relative formula mass of hydrated copper (II) sulphate is

$$M_r(\text{CuSO}_4 \cdot 5\text{H}_2\text{O})$$

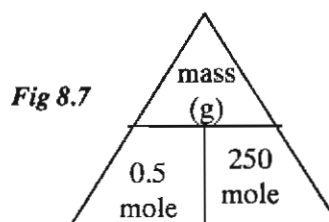
$$= 64 + 32 + (4 \times 16) + (5 \times 18) = 250$$

$$\text{Molar mass of CuSO}_4 \cdot 5\text{H}_2\text{O} = 250 \text{ g/mol}$$

$$\text{Number of mole} = \frac{\text{mass}}{\text{molar mass}}$$

$$\text{Therefore } 0.5 \text{ mole} = \frac{\text{mass}}{250 \text{ g/mol}}$$

$$\text{Mass} = 0.5 \times 250 = 125 \text{ g}$$



3) What is the mass of 0.5 mole of carbondioxide?

**Solution**

$$\begin{aligned} M_r &= \text{CO}_2 \\ \text{Molar mass} &= 12 + (2 \times 16) \\ &= 44 \text{ g/mol} \end{aligned}$$

1 mole weighs 44 g

$$\therefore 0.5 \text{ mole weighs } 44 \times 0.5 = 22\text{g}$$

**Problems**

1) Calculate the mass of 2 moles of carbondioxide.

2) Calculate the mass of four moles of chlorine.

3) Mass of two moles of ammonia is 34 g,

Calculate its molar mass.

4) Calculate the number of molecules in 0.5 mole of water.

### Converting Moles into Masses

**Example:** What is the mass of 0.1 mole of carbon?

**Solution:** Atomic mass of carbon=12  
 Mass of 1 mole of carbon=12g  
 Mass of 0.1 mole of carbon  
 $= 12 \times 0.1 = 1.2\text{g}$

Mass of 0.1 mole of carbon=1.2g

### Converting Mass into Mole

**Example:** How many moles are present in 15g of hydrogen gas?

**Solution:** Mass of 1 mole of hydrogen=2g  
 15g of hydrogen=15/2=7.5moles.

15g of hydrogen is equal to 7.5 moles of hydrogen.

**Problem**

How many moles of sulphurdioxide are present in a container which has 64 g of it?

**Solution**

Atomic mass of sulphur=32  
 Molecular mass of  $\text{SO}_2 = 32 + (16 \times 2) = 64$   
 64g of  $\text{SO}_2$  is 1 mole of sulphurdioxide.

### Conversion of moles into molecules

**Example:** How many molecules of sulphur dioxide is present in 2 moles of sulphurdioxide?

**Solution**

1 mole of  $\text{SO}_2$  contains  $6.023 \times 10^{23}$  molecules

$\therefore$  2 moles of  $\text{SO}_2$  contains  $6.023 \times 10^{23} \times 2$  molecules

$$= 12.046 \times 10^{23} \text{ molecules.}$$

**Problem**

How many molecules of  $\text{CO}_2$  are present in 11 g of  $\text{CO}_2$ ?

**Solution**

11g of  $\text{CO}_2$  contains = 11/44 or 0.25 moles

Number of molecules present in

$$\text{one mole} = 6.023 \times 10^{23}$$

$\therefore$  Number of molecules present in

$$0.25 \text{ mole} = 6.023 \times 10^{23} \times 0.25$$

$$= 1.5056 \times 10^{23} \text{ molecules.}$$

The concept of mole is used to explain the stoichiometry of equations. For example one mole of hydrogen and one mole of bromine combine to give two moles of hydrogen bromide.



2.016g of hydrogen and 159.89g of bromine combine to form 161.9g of hydrogen bromide. Using such balanced chemical equations and mole concept the mass of products formed in a reaction can be calculated.

**Extension**

1) An Aluminium piece has a mass of 270g. How many moles are present in it? Aluminium molecule is mono-atomic.

**Solution**

$$\begin{aligned} \left. \begin{array}{l} \text{Number of moles} \\ \text{of aluminium atoms} \end{array} \right\} &= \frac{\text{Mass in gms}}{\text{gram Atomic mass}} \\ &= 270/27 = 10. \end{aligned}$$

2) A Signature written with carbon pencil weighs 1 mg. Calculate the number of atoms of carbon present in the signature.

**Solution:** We know that 1 mg=0.001g  
 12g of carbon contains  $6.023 \times 10^{23}$  atoms  
 $\therefore$  0.001g of carbon contains ... ..?  
 Number of atoms of carbon =  $\frac{6.023 \times 10^{23} \times 0.001}{12}$   
 $= \frac{6.023 \times 10^{23} \times 10^{-3}}{12} = 5.02 \times 10^{19}$

3) A thermometer contains 0.004 mole of mercury. Calculate the mass of mercury in the thermometer.

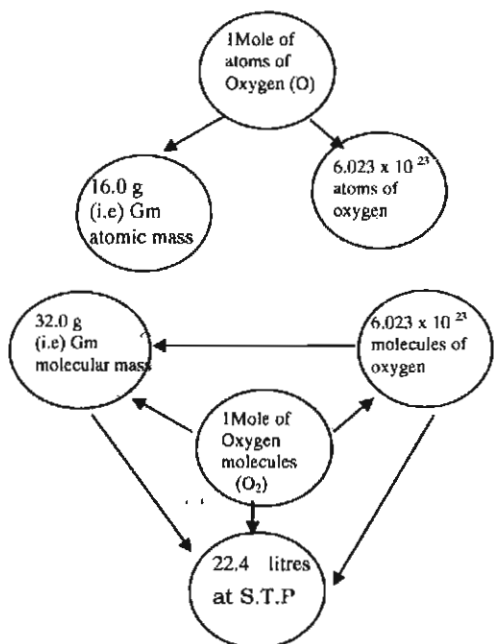


Fig 8.8 Atomic and Molar masses of oxygen

**Solution:** Mercury molecules are monoatomic. One mole of mercury weighs 200.6 g (gram atomic weight)  
 0.004 mole of mercury weigh ... .?

$$\left. \begin{array}{l} \text{Mass of mercury in} \\ \text{the thermometer} \end{array} \right\} \frac{200.6 \times 0.004}{1} = 0.8024 \text{ g}$$

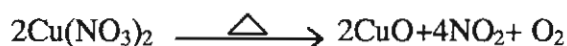
### The Law of Constant Proportions

The same compound however made, contains the same elements combined together in the same fixed proportion by mass (weight) (or) The composition of a

pure chemical compound is independent of the method by which it is prepared.

This law enunciated by Proust in 1700, is known as the Law of Definite proportions or Constant Composition. A chemical compound can be obtained by various methods. For example, a sample of copper(II)oxide may be prepared in the laboratory by the following methods:

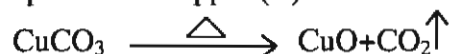
1) Copper(II) nitrate when heated decomposes into copper(II)oxide.



2) Copper (II) hydroxide when heated forms copper (II) oxide.



3) Copper(II) carbonate when heated decomposes into copper (II) oxide

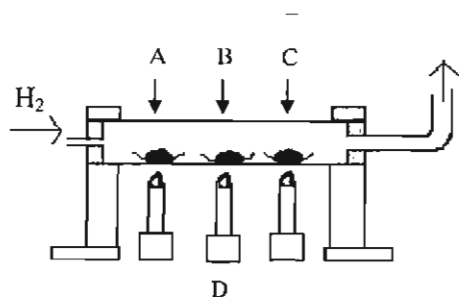


In all the above three experiments copper(II) oxide is a common product. The proportion of copper and oxygen in the above substances will be a constant.

### Experiment

This law can be verified by analyzing the sample of copper (II) oxide prepared in the laboratory by a) heating 5 g of copper (II) nitrate b) heating 5 g of copper (II) hydroxide and c) heating 5 g of copper (II) carbonate, separately in three porcelain boats.

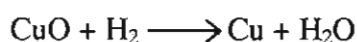
Weighed quantities (5g each) of the three oxide samples A, B and C are taken in another set of porcelain boats and are reduced in a current of dry and pure hydrogen in an ignition tube. The tube is uniformly heated with a set of Bunsen burners for about 25 minutes. After necessary heating, ignition may be stopped and boats may be allowed to cool. They may be kept in a continuous current of hydrogen. In complete reduction of metallic oxide to the corresponding metal, the weight of the copper left behind is determined and the percentage of copper calculated.



A,B,C = COPPER(II) OXIDE, D=BUNSEN BURNERS

Fig 8.9 Law of constant proportions

When copper(II)oxide is heated in a current of hydrogen, the oxygen in it combines with hydrogen and forms water. This goes out as steam and so copper(II)oxide is reduced to copper



There is reduction in weight due to this change. This loss in weight is that of the oxygen in the copper(II)oxide.

#### Calculation

Weight of the empty boat =  $W_1$  g

Weight of the boat+CuO =  $W_2$  g

Weight of oxide =  $(W_2 - W_1)$  g

Weight of boat + copper =  $W_3$  g

Weight of copper =  $(W_3 - W_1)$  g

Weight of oxygen =

weight of CuO-Weight of Cu

$= (W_2 - W_1) - (W_3 - W_1)$  g

$= (W_2 - W_3)$  g

$\therefore$  Copper: Oxygen =  $(W_3 - W_1) : (W_2 - W_3)$

In a similar manner, the ratio between the weights of copper and oxygen in the copper (II) oxide taken in the other two boats (B) and (C) can also be calculated. In each boat the ratio will be 4:1 i.e.

Copper: Oxygen=4:1.

In whatever method we might prepare copper oxide the two elements present in that compound, namely copper and oxygen, always are in the same proportion by weight. The chemical

composition of the compound does not depend on the method of preparation. The ratio of the weights of the elements in a compound is always a constant. This is true for all chemical compounds.

#### Problem

25.00 g of a sample of sodium chloride contained 15.18g of chlorine, while 24.00g of a sample of the same salt contained 14.58 g of chlorine. Show that these figures illustrate the law of constant composition.

#### Solution:

As per the first experiment,

weight of sodium chloride = 25.00 g

Weight of chlorine =15.18 g

Weight of sodium =25.00- 15.18= 9.82 g

Sodium : chlorine = 9.82 : 15.18 = 1:1.545

As per the second experiment,

Weight of sodium chloride = 24.00g

Weight of chlorine =14.58 g

Weight of sodium =24.00 - 14.58 =9.42 g

Sodium : Chlorine = 9.42:14.58 = 1: 1.548

In the two samples of sodium chloride the ratio of the weight of sodium and chlorine is always 1: 1.55.

**Example :** Magnesium oxide always contains 60% magnesium and 40% oxygen by mass and ammonium nitrate always contains 35% nitrogen 60% oxygen and 5% hydrogen by mass.

#### Points to remember

- A particular compound always contains the same elements.
- These elements are always present in the same proportions by mass.
- It does not matter where the compound is found or how it is made.
- These proportions cannot be changed.

**Activity:** The table below shows the masses of magnesium obtained by heating different masses of magnesium oxide.

**Table 8.12**

	Mass in grams of		
	Magnesium	Magnesium Oxide	Oxygen
1	0.06	0.10	0.04
2	0.15	0.25	0.10
3	0.22	0.36	0.14
4	0.24	0.40	
5	0.30	0.50	
6	0.28	0.46	
7	1.10	0.16	
8	0.20	0.32	

1) Write down the correct mass of oxygen that reacts with the magnesium in the last five experiments.

2) Plot a graph of the mass of oxygen reacted against the mass of magnesium used. Draw in the best line for these points.

3) Comment on what this graph shows about the composition of magnesium oxide.

### 1. Percentage Composition

One method of comparing the amounts of elements in a compound is to calculate the percentage by mass of each element in the compound.

So percentage composition is how much of percentage of that element is present in the total mass of the pure substance.

The percentage by mass of a particular element in a compound can be found from calculations of relative formula mass.

The relative formula mass ( $M_r$ ) of a substance is the sum of the relative atomic masses of the elements present in a formula unit.

If the substance is made of simple molecules, this mass may also be called **relative molecular mass ( $M_r$ )**

Calculate the % composition of Nitrogen in Ammonia, Oxygen in water and Oxygen in  $\text{CO}_2$ :

#### Percentage composition of $\text{N}_2$ in $\text{NH}_3$

Molecular formula =  $\text{NH}_3$

Relative Molecular mass =  $14 + (3 \times 1) = 17$

Mass of Nitrogen in the formula = 14

Fractional mass of Nitrogen =  $14/17$

% Composition of Nitrogen =  $(14/17) \times 100 = 82.3$

$\therefore$  % Composition of Hydrogen =  $100 - 82.3$   
= 17.7 %

#### Percentage composition of elements in $\text{H}_2\text{O}$

Molecular formula =  $\text{H}_2\text{O}$

Molecular mass =  $(2 \times 1) + 16 = 18$

Mass of hydrogen in 18 g of water = 2 g.

% composition of hydrogen =  $(2/18) \times 100$   
= 11.1 %

Mass of oxygen in 18 g. of water = 16 g.

% composition of oxygen =  $(16/18) \times 100$   
= 88.8 %

#### Percentage composition of Oxygen in $\text{CO}_2$

Molecular formula =  $\text{CO}_2$

Molecular mass =  $(1 \times 12) + (2 \times 16)$   
= 44

Mass of oxygen in 44 g. of  $\text{CO}_2$  = 32 g.

$\therefore$  % composition of oxygen =  $(32/44) \times 100$   
= 72.7 %

## 2. Empirical Formula

The empirical formula of a compound is the simplest formula deduced from its percentage composition. It indicates the relative number of the different kinds of atoms of which it is composed.

*Eg:* The empirical formula of ethane is  $\text{CH}_3$  and that of benzene is  $\text{CH}$

### Calculation of the empirical formula

The percentage of each element present in a compound is determined first. The empirical formula of a compound is then calculated by the following steps.

1. The percentage of each element is divided by its atomic weight. This gives the relative number of moles of different kinds of atoms in the molecule.

2. The numbers obtained in step (1) are expressed in whole numbers, dividing if necessary each number by the smallest of these numbers.

3. The whole numbers thus obtained give a simple atomic ratio. They indicate the relative number of atoms of each element in a molecule.

4. Finally write down the symbols of various elements side by side and put the above numbers as the subscripts to the lower right hand corner of each symbol. This represents the empirical formula of the compound.

## 3. Molecular Formula

The molecular formula of a compound is defined as the formula which gives the actual number of atoms of various elements present in the molecule of the compound.

Steps for finding the molecular formula:

1. Calculate the empirical formula
2. Find out the empirical formula mass by adding the atomic masses of all the atoms present in the empirical formula of the compound.
3. Divide the molecular mass (determined experimentally by some suitable method) by the empirical formula mass and find out the value 'n'.
4. Multiply the empirical formula of the compound with 'n' so as to find out the 'molecular formula' of the compound.

### Example 1

I. A Compound contains 80% Carbon and 20% Hydrogen. Its molecular mass is 30. Find its empirical formula and molecular formula.

Table 8.13

Element	% composition	% composition / atomic mass	Previous column smaller number
C	80	$80/12=6.7$	$6.7/6.7=1$
H	20	$20/1=20$	$20/6.7 = 2.98 = 3$
Empirical formula			$\text{CH}_3$

empirical formula =  $\text{CH}_3$

Molecular mass = 30

To determine the molecular formula:

Empirical formula mass =  $(12 \times 1) + (1 \times 3) = 15$

$$n = \frac{\text{M.F.mass}}{\text{E.F. mass}}$$

$$= 30/15 = 2$$

Molecular formula = empirical formula  $\times$  2  
=  $\text{CH}_3 \times 2 = \text{C}_2\text{H}_6$

### Example 2

In a compound the percentage of hydrogen and oxygen are 5.8 and 94.2. Its molecular mass is 34. Find its empirical formula and molecular formula.

Table 8.14

Element	% Composition	% Composition	atomic mass	Previous column Smallest number
H	5.8	$5.8/1 = 5.8$		$5.8/5.8 = 1$
O	94.2	$94.2/16 = 5.8$		$5.8/5.8 = 1$
Empirical formula				HO

Molecular formula mass = 34

Empirical formula mass(HO) =  $1+16 = 17$

$$n = \frac{\text{M.F.mass}}{\text{E.F. mass}} = \frac{34}{17} = 2$$

Molecular formula = (EF)<sub>n</sub> = (HO)<sub>2</sub>

Molecular formula = H<sub>2</sub>O<sub>2</sub>

Table 8.15 Differences between empirical formula and molecular formula of a compound

S. No.	Empirical formula	Molecular formula
1	It is the simplest formula	It is the actual formula
2	It corresponds to the percentage composition of a compound.	It corresponds to the molecular mass of a compound.
3	It represents the relative number of atoms of each element in one molecule of a compound.	It shows the actual number of each atom of the element in one molecule of a compound.

Understand the law of constant proportions from the tables

Table 8.16

	Mg	O
Mass combined	0.24 g	0.16 g
Molar mass	24 g/mol	16 g/mol
No of moles	0.01 mol	0.01 mol
Simplest ratio	1	1
Formula	MgO	

Table 8.17

	Si	O
Percentage by mass	47 %	$100-47=53\%$
Mass in 100g	47 g	53 g
Molar mass	28 g/mol	16 g/mol
No of moles	1.68 mol	3.31 mol
Simplest ratio	1	2
Formula	SiO <sub>2</sub>	

Table: 8.18

	P	O
Percentage by mass	44 %	$100-44=56\%$
Mass in 100g	44 g	56 g
Molar mass	31 g/mol	16 g/mol
No of moles	1.4 mol	3.5 mol
Simplest ratio	$\frac{1}{2}$	$\frac{2.5}{5}$
Formula	P <sub>2</sub> O <sub>5</sub>	

### Self-Evaluation

#### Fill in the blanks

- Empirical formula indicates \_\_\_\_\_ number of different kinds of atoms of which it is composed.
- Molecular mass may be obtained by adding the \_\_\_\_\_ masses of all the atoms present in the molecule.
- A \_\_\_\_\_ molecule of glucose contains \_\_\_\_\_ atoms of carbon, \_\_\_\_\_ atoms of Hydrogen and \_\_\_\_\_ atoms of oxygen.

#### 4. Match the following

- |                            |  |
|----------------------------|--|
| 1) Deuterium               | i) The simplest formula of a substance |
| 2) Atomic mass of hydrogen | ii) Isotope                            |
| 3) Empirical formula       | iii) one                               |
| 4) Hydrogen                | iv) Molecular mass-44                  |
| 5) Carbon-di-oxide         | v) The lightest element                |

#### Answer briefly

- What is the average atomic-mass of chlorine?
- Molecular mass of nitric acid is 63. How?
- Atomic mass of sodium is 23. How many sodium atoms will be present in 1 mole of sodium?
- Give the molecular formula of ethane
- 1 mole of  $\text{SO}_2$  contains  $6.023 \times 10^{23}$  molecules. How many molecules will be present in 2 moles of  $\text{SO}_2$ ?
- What are the isotopes of hydrogen?
- Which formula is required for writing molecular-formula?
- What is the value of a.m.u of carbon-12?
- Define relative atomic mass of the element on the basis of hydrogen.
- What is the average atomic mass of an element?
- What is the molecular mass of oxygen?
- What is the value of Avogadro number?
- What is percentage composition?
- What is empirical formula?

#### Answer in detail

- What are the steps followed in calculating empirical and molecular formulae?
- Define:
  - The law of constant proportions.
  - Percentage composition
  - The mole
  - Molecular mass

#### Problems

- Determine the mass of each of the following:
  - One mole of magnesium
  - 3.5 moles of carbondioxide
- Calculate the formula mass of the following:
  - KBr
  - $\text{Ca}(\text{OH})_2$
- What is the mass of one mole of Calcium Hydroxide?
- If you have a flask containing 9.0 g of water, how many moles of water are in the flask?
- How many molecules of chlorine gas will there be in a tank containing 7.10 g of chlorine.
- Calculate the number of atoms in each of the following:
  - 0.5 mole of nitrogen atoms
  - 0.2 mole of nitrogen molecules
- Express the masses of the following substances in terms of 'moles'.
  - 2 g of hydrogen
  - 7 g of nitrogen
  - 73 g of hydrogen chloride
- Complete the following statements:
  - a mole of hydrogen atoms contains \_\_\_\_\_ atoms
  - a mole of oxygen molecules contains \_\_\_\_\_ atoms
  - a mole of chlorine atoms weighs \_\_\_\_\_ g
  - a mole of water molecules weighs \_\_\_\_\_ g
- What is the simplest formula of a compound, which has the following composition: Carbon 80%, hydrogen 20%. If the molecular mass is 30 calculate its molecular formula.

30. 1) Calculate the empirical formula of a compound that contains 27.3% carbon and 72.7% oxygen by mass.
- 2) A compound is found to contain 40% carbon, 6.76 % hydrogen and 53.34 % oxygen. Find the empirical formula.
31. Dichloroethane has a molecular mass of 99 g. Analysis of a sample shows that it contains 24.3% carbon, 4.1% hydrogen and 71.6% chlorine. What is the molecular formula?
32. Calculate the number of molecules in the following.
- a) 4g of oxygen  
b) 11 g of carbondioxide
33. Calculate the molecular mass of the following:
- a)  $\text{PCl}_5$     b)  $\text{NH}_3$   
c)  $\text{HCl}$     d)  $\text{H}_2\text{O}_2$
34. Convert into mole
- a) 12g of oxygen  
b) 20g of water  
c) 22g of carbondioxide.
35. A compound 'x' after analysis gave 85.72% of carbon and 14.28% of hydrogen. If the molecular mass of the compound is 28, find out the molecular formula.
36. 1.375g of cupric oxide was reduced by heating in a current of hydrogen and the mass of copper that remained was 1.098g. In another experiment 1.175g of copper was dissolved in the nitric acid and the resulting copper nitrate converted into cupric oxide by ignition. The mass of cupric oxide formed was 1.476g. Show that these results illustrate the law of definite proportion.
-

## 9. STRUCTURE OF ATOM

Matter is made up of atoms. How do atoms join together to form molecules? Why do certain atoms react vigorously? Why do hydrogen atoms pair up and helium atoms remain single?

To answer these questions, we should consider the structure of atoms. Atoms are made up of various sub-atomic particles, protons, neutrons and electrons. The atom is the smallest particle that possesses the characteristics of a particular element.

### 9.1 Constituents of an Atom

#### Sub atomic particles

**Evidence for the structure of atom came from studies of** (1) The nature of rays produced in discharge tubes. (for example Cathode ray tubes) (2) The radiations given out by excited gases. and (3) The nature of radioactivity.

**J.J.Thomson** (in 1897) found that cathode ray tubes produced beams of small particles that could be deflected by an electric field. He found that these rays were beams of negatively charged particles and named them **electrons**. Using a different type of discharge tubes filled with a small amount of hydrogen, **Goldstein** discovered the positively charged **protons**.

Then, in 1932, **Chadwick** discovered a neutral particle, **neutrons**, by bombarding metal targets with radiation from radioactive materials.

#### Discovery of electrons - cathode rays

Much of the information about electrons is obtained from the study of cathode rays, during the experiments with gas discharge tubes. A discharge tube is a long glass tube containing a gas at a low pressure.

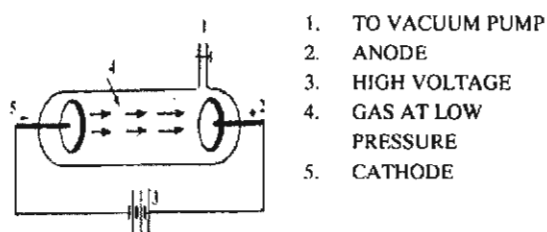


Fig. 9.1 Cathode rays

This tube is fitted with metal electrodes on either ends across which high voltage can be applied. The tube is also connected to a vacuum pump for controlling the pressure of gas inside the discharge tube. On applying high voltage, cathode rays are generated from the cathode and they glow on the spot where they fall upon.

#### 1. Properties of Cathode Rays

1) Cathode rays travel in straight lines: An object placed in the path of cathode rays casts a sharp shadow. (figure 9.2) It shows that the cathode rays travel in straight lines.

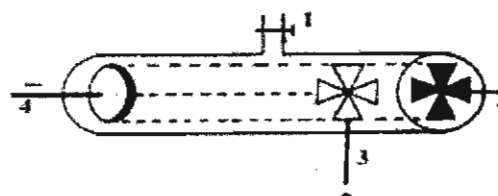


Fig 9.2 AN OBJECT PLACED IN PATH OF CATHODE RAYS CASTS A SHARP SHADOW

1. TO VACUUM PUMP  
2. SHADOW  
3. ANODE  
4. CATHODE

2) Heating effect: When cathode rays are focussed on a thin metal foil, it gets heated to incandescence.

3) Cathode rays consist of material particles: This is indicated by the fact that a light paddle wheel placed in the path of the cathode rays starts rotating.

4) Effect of electrical field : When electric field is applied to a stream of cathode rays, they get deflected towards positive plate. It showed that the cathode rays are negatively charged.

5) Effect of magnetic field: when magnetic field is applied, the cathode rays get deflected. The direction of deflection again indicates that the cathode rays are negatively charged.

6) On striking against the walls of the discharge tube cathode rays produce faint greenish fluorescence.

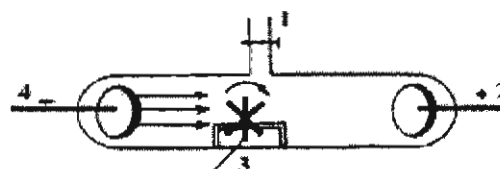
7) Cathode rays ionize the gas through which they pass.

8) Cathode rays produce x-rays when they are made to fall on metals such as tungsten, copper etc.

9) They can penetrate through thin metal foils.

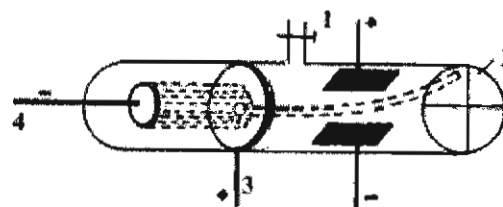
10) The charge to mass ratio ( $e/m$ ) for the particles in the cathode is independent of the nature of the gas taken in the discharge tube or the nature of the cathode.

The above mentioned properties of cathode rays indicated that they consist of a fast-moving stream of negatively charged material particles. These particles were named as electrons.



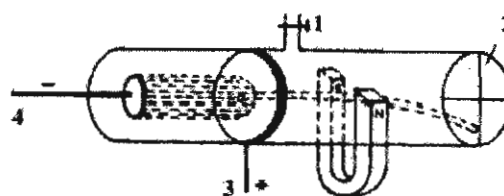
**MOVEMENT OF LIGHT PADDLE WHEEL**

1. TO VACUUM PUMP    2. ANODE  
3. LIGHT PADDLE WHEEL 4. CATHODE



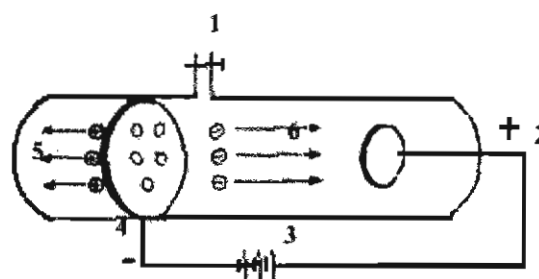
**EFFECT OF ELECTRIC FIELD ON CATHODE RAYS**

1. TO VACUUM PUMP    3. ANODE  
2. FLOURESCENT SCREEN 4. CATHODE



**EFFECT OF MAGNETIC FIELD ON CATHODE RAYS**

1. TO VACUUM PUMP    3. ANODE  
2. FLOURESCENT SCREEN 4. CATHODE



**Fig 9.3 CANAL RAYS**

1. TO VACUUM PUMP    2. ANODE  
3. HIGH VOLTAGE SOURCE 4. CATHODE  
5. ANODE RAYS        6. CATHODE RAYS

## 2. Electron

Electrons are the constituent of all atoms. Whatever the source, electrons always have the same mass and the same charge, mass of electron =  $9.08 \times 10^{-31}$  kg. This is about 1/1840 of the mass of hydrogen atom. Charge of an electron is

$1.602 \times 10^{-19}$  coulomb. Charge of an electron is taken as unit negative charge.

### 3. Anode Rays or Canal Rays

Goldstein, in 1886 discovered the existence of a new type of rays in the discharge tube. He used a perforated cathode in the discharge tube. On passing the electric discharge at low pressure he observed a new type of rays streaming behind the cathode. These rays were named anode rays or canal rays. These rays consist of positively charged particles.

**The properties of anode rays are:**

- 1) Anode rays travel in straight lines.
- 2) Anode rays consist of material particles.
- 3) Anode rays are deflected by electric field towards negatively charged plate. This indicates that they are positively charged.
- 4) Anode rays are deflected by magnetic field. The direction of deflection indicates that they are positively charged.
- 5) Charge to mass ratio of the particles in the anode rays depends upon nature of the gas taken in the discharge tube. (e/m) ratio is much less than that for an electron.

### 4. Discovery of Protons

A proton is a fundamental particle and a constituent of all atoms. It is the lightest positively charged particle identified by Goldstein.

The mass of a proton is equal to  $1.673 \times 10^{-27}$  kg or 1.0073 a.m.u. Its charge is the same in magnitude, as the charge of an electron but of opposite sign. So a proton is a particle of unit mass and unit positive charge. It is identical with hydrogen ion  $H^+$ . A proton is produced

from a hydrogen atom by knocking out an electron.

Charge to mass ratio for protons was found to be  $9.58 \times 10^7$  coulombs/kg. Charge on proton is opposite but equal in magnitude to the charge on the electron, i.e.  $1.602 \times 10^{-19}$  coulomb. From these two observations mass of a proton works out to be  $1.673 \times 10^{-27}$  kg. It is practically the same as the mass of a hydrogen atom and is about 1840 times the mass of an electron.

### 5. Discovery of Neutron

In 1920, Rutherford predicted the existence of neutral particles, called neutrons. The neutrons were discovered by James Chadwick in 1932. It is the third fundamental particle.

Chadwick bombarded lighter elements like beryllium and lithium nuclei with  $\alpha$  particles. As a result, neutrons were emitted from the metal.



Beryllium + Helium  $\rightarrow$  Carbon + neutron

### 6. Properties of Neutrons

The mass of a neutron is  $1.675 \times 10^{-27}$  kg. It is nearly equal to the mass of a proton. Neutrons are electrically neutral. They are not deflected by electric and magnetic fields.

**A neutron is a sub-atomic particle carrying no charge and having mass  $1.675 \times 10^{-27}$  kg which is almost equal to that of a hydrogen atom.**

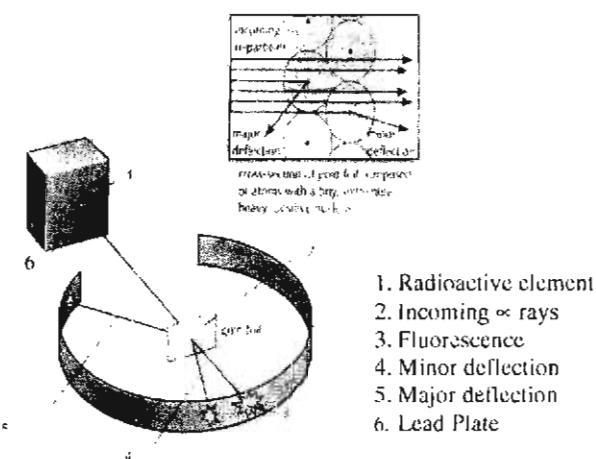
Therefore the mass of the atom is largely due to protons and neutrons in the nucleus of the atom.

**Table 9.1 Properties of subatomic particles**

Name of the Particle	Electrical Charge	Relative mass (amu)	Actual mass in kg	Location in atom
Electron	-1	$\frac{1}{1840}$	$9.108 \times 10^{-31}$	Outside the nucleus
Proton	+1	1	$1.672 \times 10^{-27}$	In the nucleus
Neutron	0	1	$1.675 \times 10^{-27}$	In the nucleus

### 7. Rutherford's Scattering Experiment

Rutherford in 1911 performed an experiment which led to the downfall of Thomson's model. The experiment involved the bombardment of a thin sheet of gold (thickness of  $4 \times 10^{-5}$  cm) by  $\alpha$  particles. These particles were obtained in the form of a narrow beam by passing through a slit in the lead plate.



**Fig 9.4 Alpha scattering experiment**

A circular screen coated with zinc sulphide (ZnS) was placed around the foil to detect the deflection suffered by  $\alpha$  particles as shown in the Figure.

- 1) Most of the  $\alpha$  particles (nearly 99%) passed through the gold foil undeflected.
- 2) Some of the  $\alpha$  particles were deflected by small angles.
- 3) A few particles (1 in about  $10^6$ ) were either deflected by a very large angle or

were actually reflected back along their path.

### Explanation for the Observations

Since most of the  $\alpha$  particles pass through the foil undeflected, it indicates that the most of the space in an atom is empty.

$\alpha$  particles being positively charged and having considerable mass could be deflected only by some heavy, positively charged centre. The small angle of deflections of  $\alpha$  particles indicated the presence of a heavy positive centre in the atom. This positive centre is nucleus.

$\alpha$  particles which make head-on collision with heavy positive centre are deflected through large angles. Since the number of such  $\alpha$  particles is very small, the space occupied by the heavy positive centre must be very small.

### 8. Rutherford's Nuclear Model of Atom

(1) An atom consists of two parts, a nucleus and a region of space outside the nucleus.

(2) Most of the mass and all the positive charge of an atom are concentrated in a very small region called nucleus.

(3) The nucleus contains protons. (Neutrons were not known at that time)

(4) The magnitude of the charge on the nucleus is different for atoms of different elements.

(5) The nucleus is surrounded by electrons, which are revolving around it at very high speed. The electrostatic force of attraction between electrons and the nucleus is balanced by the centrifugal force acting on the revolving electrons.

(6) Total negative charge on the electrons is equal to the total positive

charge on the nucleus so that atom on the whole is electrically neutral.

(7) Most of the space inside an atom is empty.

(8) The volume of the nucleus is minute compared to the volume of the atom.

*Do you Know?*

### Failure of Rutherford's model

1) Rutherford's model fails to indicate anything about the electronic structure of atom.

2) Neutrons are also present in the nucleus. As neutrons were not discovered at that time, this model did not include these particles.

3) Rutherford's atom model could not exist and failed in view of electromagnetic theory.

### Explanation

According to this model, electrons revolve around the nucleus. Since electrons are charged particles, electron revolving in orbits should continuously emit energy. As a result of this, it would slow down and would not withstand the attractive forces of the nucleus. Hence, it would move closer and closer to the nucleus and finally fall into the nucleus by following a spiral path (Figure 9.5). This means that atom should collapse. But we know that atom is stable. Thus, Rutherford's model failed to explain the stability of atoms.

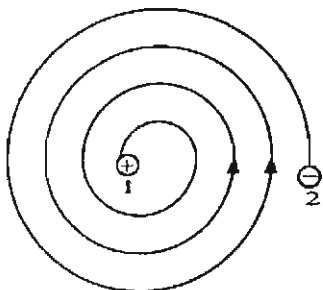


Fig : 9.5 Gradual decrease in the radius of orbit.  
1. Nucleus 2. Electron

## 9.2. Atomic Number and Mass Number

### 1. Atomic Number

Moseley devised an experiment to find out positive charge on the nucleus of an atom. He calculated the charge on the nucleus.

Since positive charge on the nucleus is due to the presence of protons and each proton carries one unit positive charge. **The atomic number of an element is equal to the number of protons in the nucleus of its atom.**

Further in an atom, the number of protons is equal to the number of electrons. Hence **atomic number is also equal to the number of electrons in an atom of the element.**

Atomic Number ( $Z$ ) = Number of protons  
or Number of electrons.

### 2. Mass Number

The mass of an atom is mainly concentrated in the nucleus. In the nucleus there are protons and neutrons. So the mass of an atom is mainly due to protons and neutrons. Protons and neutrons are collectively called as nucleons. Total number of protons and neutrons in the nucleus is called mass number of the atom. It is generally represented by the letter  $A$ .

Mass Number  $A$  = number of protons +  
number of neutrons

### Isotopes

While working with neon gas, J.J.Thomson observed two kinds of neon atoms. They were exactly alike chemically but different in mass. Atoms of the same element that differ in mass number are called isotopes. Isotopes have the same

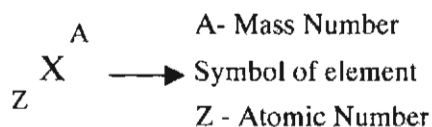
number of protons but a different number of neutrons. For example, the isotopes of neon are neon-20, which has 10 neutrons, neon-21, which has 11 neutrons, and neon-22, which has 12 neutrons.

Because an atom is electrically neutral, the number of electrons must be equal to the number of protons. The mass difference of isotopes must then be due to the different numbers of neutrons in the nucleus. Thus, the number of protons determines the identity of the element and the number of neutrons determines the particular isotope of the element.

**Thus isotopes of an element are the atoms of the element with same atomic number but different mass-numbers.**

### Isotopes of Hydrogen

Hydrogen has three isotopes, Protium(H), Deuterium(D) and Tritium(T). All the three isotopes have atomic number 1, however the mass numbers are 1, 2, and 3 respectively. The isotopes of other elements do not have special names; they are indicated by giving mass-number value on the symbol.



Three isotopes of hydrogen can be represented as  ${}_1\text{H}^1$ ,  ${}_1\text{H}^2$ ,  ${}_1\text{H}^3$ .

**Table 9.2 Isotopes of Hydrogen**

Nuclide	Protons	Neutrons	Mass Number
Protium	1	0	1
Deuterium	1	1	2
Tritium	1	2	3

**Table : 9.3 Properties of some elements**


me	Mass Number(A)	Atomic Number (Z)	No of Protons (Z)	No of Neutrons(A-Z)	No of Electrons (Z)
Hydrogen (H)	1	1	1	0	1
Helium (He)	4	2	2	2	2
Lithium (Li)	7	3	3	4	3
Beryllium(Be)	9	4	4	5	4
Boron (B)	11	5	5	6	5
Carbon(C)	12	6	6	6	6
Nitrogen (N)	14	7	7	7	7
Oxygen (O)	16	8	8	8	8
Fluorine (F)	19	9	9	10	9
Neon(Ne)	20	10	10	10	10
Sodium(Na)	23	11	11	12	11
Magnesium(Mg)	24	12	12	12	12
Aluminium(Al)	27	13	13	14	13
Silicon(Si)	28	14	14	14	14
Phosphorus (P)	31	15	15	16	15
Sulphur (S)	32	16	16	16	16
Chlorine (Cl)	35	17	17	18	17
Argon(Ar)	40	18	18	22	18
Potassium(K)	39	19	19	20	19
Calcium(Ca)	40	20	20	20	20

**Table: 9.4 Isotopes of Oxygen ,Carbon and Chlorine**

Oxygen	Oxygen-16	Oxygen-17	Oxygen-18
	${}_8\text{O}^{16}$	${}_8\text{O}^{17}$	${}_8\text{O}^{18}$
	8 protons 8 electrons 8 neutrons	8 protons 8 electrons 9 neutrons	8 protons 8 electrons 10 neutrons
Carbon	Carbon-12	Carbon-13	Carbon-14
	${}_6\text{C}^{12}$	${}_6\text{C}^{13}$	${}_6\text{C}^{14}$
	6 protons 6 electrons 6 neutrons	6 protons 6 electrons 7 neutrons	6 protons 6 electrons 8 neutrons
Chlorine	Chlorine-35	Chlorine-37	
	${}_{17}\text{Cl}^{35}$	${}_{17}\text{Cl}^{37}$	
	17 protons 17 electrons 18 neutrons	17 protons 17 electrons 20 neutrons	

### 9.3 Bohr's Model of Atom

Bohr proposed a modification to Rutherford's model. He gave up the classical theories of electromagnetic radiation and applied Planck's quantum theory.



Neils Bohr (1885-1962) was a Danish physicist. He is regarded as the founder of the modern atomic theory. In 1913 Bohr devised an atomic model, and showed that it could explain the spectra of elements and their position in the periodic table.

In 1916 he became professor of physics at Copenhagen. He was awarded the Nobel prize for physics in 1922. For his work on the peaceful use to atomic energy, he received the first **Atoms for Peace Award** in 1957.

#### 1. Postulates of Bohr's Theory

- 1) The electrons revolve round the nucleus in fixed closed orbits, known as **stationary states**, but no radiation emitted. (Non-radiating orbits). Here electrons do not lose energy. The angular momentum of electrons in such orbits is given by  $n(h/2\pi)$  where  $n$  is an integer.
- 2) The electron orbits are grouped together in shells. A shell is a group of orbits with similar energy. (energy shells or energy levels)

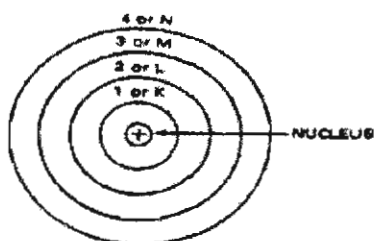


Fig. 9.6 Bohr's Orbits

- 3) Each orbit is at different distance from the nucleus.
- 4) The shells at a distance have higher energy than those close to the nucleus.  
(i.e) The orbit closest to the nucleus has the least energy.
- 5) Electrons fill the shells starting with the first shell, which is closest to the nucleus.
- 6) Each shell can only hold a certain number of electrons (this maximum number is  $2n^2$ , where 'n' is the number of the shell from the nucleus)

If  $n = 1$  number of orbit = 1 and the number of electrons that may be accommodated = 2. The name of the orbit or shell is K. ( $2 \times 1^2 = 2$ )

7) The first shell can only contain up to 2 electrons. The second shell can contain a maximum of 8 electrons. The third shell can contain up to 18 electrons; but for small atoms (those with up to 20 electrons altogether) the third shell will not hold more than 8.

8) The outer electrons of some atoms can be removed fairly easily to form ions.

9) Chemical bonding between atoms to form molecules involves the electrons in the outer shell only.

10) An atom radiates energy when an electron falls from a higher to lower orbit. It absorbs energy in changing from a lower to a higher energy level. If  $E$  is the energy associated with the electron in an outer orbit and  $E_1$  is associated with the electron in the next inner orbit then  $E_2 - E_1 = h\nu$  or  $\Delta E = h\nu$ , where  $\Delta E$  is the difference in energy and 'h' is the Planck's constant, 'v' is the frequency of radiation emitted.

11) The electron in motion in an orbit is subjected to two forces. (a) The electrostatic force of attraction between nucleus and electron (b) The centripetal force of the electron to go away from the orbit. They are equal in magnitude but

opposite in direction. So the electrons have stability.

12) The angular momentum of an electron revolving in an orbit should become integral multiples of  $h/2\pi$  ( $h$  = Planck's constant).

$$\text{Angular momentum} = mvr = nh/2\pi$$

Here,  $n$  = Orbit number,  $r$  = radius of orbit,  $m$  = mass of electron,  $v$  = velocity of electron. So, the angular momentum of electrons in atoms is quantized.

13) The energy of an electron in an orbit was calculated by Bohr.

14) Atoms can emit or absorb energy only in specific amounts (quanta). The quanta involved depend on the orbit to which electron is entering and leaving.

**Table : 9.5 Electronic configuration**

Atom	Symbol	Number of Electrons	Electron Distribution in Shells	Valency
Hydrogen	H	1	1	1
Helium	He	2	2	0
Lithium	Li	3	2,1	1
Beryllium	Be	4	2,2	2
Boron	B	5	2,3	3
Carbon	C	6	2,4	4
Nitrogen	N	7	2,5	3
Oxygen	O	8	2,6	2
Fluorine	F	9	2,7	1
Neon	Ne	10	2,8	0
Sodium	Na	11	2,8,1	1
Magnesium	Mg	12	2,8,2	2
Aluminium	Al	13	2,8,3	3
Silicon	Si	14	2,8,4	4
Phosphorus	P	15	2,8,5	3,5
Sulphur	S	16	2,8,6	2
Chlorine	Cl	17	2,8,7	1
Argon	Ar	18	2,8,8	0
Potassium	K	19	2,8,8,1	1
Calcium	Ca	20	2,8,8,2	2

## 2. Superiority of Bohr's Model over Rutherford's Model

1) Bohr's model could explain the stability of an atom.

An electron revolving in a particular orbit cannot lose energy. The electron can lose energy only if it jumps to some lower energy level. If no lower energy level is vacant then electron will keep on revolving in the same orbit without losing energy. Hence there is stability.

In the case of Rutherford's model, when the electron loses energy, it has to confine to spiral path. So there could not be stability.

2) Bohr's theory helped in calculating energy of an electron in a particular orbit of hydrogen.

It is possible to derive a mathematical relation for energy of an electron in the  $n^{\text{th}}$  orbit of hydrogen

3) Bohr's model could explain the atomic spectrum, of hydrogen.

## 3. Electronic configuration of elements

The electronic configuration of elements means the distribution of electrons in the orbital of their atoms. The number of electrons in an atom is equal to atomic number of the element. These electrons are distributed in various orbitals in the increasing order of energy. These orbitals are called s,p,d,f.

**Table 9.6 Distribution of electrons in sub shells**

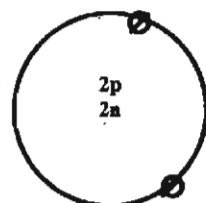
Energy level	No of $e^-$ s	Sub levels	Electronic configuration
$n=1$	2	s	$1s^2$
$n=2$	8	s,p	$2s^2 2p^6$
$n=3$	18	s,p,d	$3s^2 3p^6 3d^{10}$
$n=4$	32	s,p,d,f	$4s^2 4p^6 4d^{10} 4f^{14}$

The simplest element is hydrogen. Its atomic number is 1. The single electron of hydrogen atom occupies the 1s orbital. The electronic configuration of hydrogen atom is written as  $1s^1$ .

**Example**

**1. Helium**

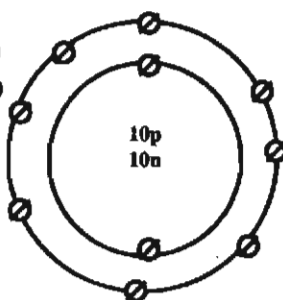
Number of protons = 2  
 Number of electrons = 2  
 Number of neutrons = 2



Electronic configuration [2] or  $1s^2$

**2. Neon**

Number of protons = 10  
 Number of electrons = 10  
 Number of neutrons = 10



Electronic configuration [2,8] or  $1s^2 2s^2 2p^6$

**Table : 9.7 Electronic configuration of first 10 elements**

At. No.	Elements	Electronic Configuration
1	Hydrogen	$1s^1$
2	Helium	$1s^2$
3	Lithium	$1s^2 2s^1$
4	Beryllium	$1s^2 2s^2$
5	Boron	$1s^2 2s^2 2p^1$
6	Carbon	$1s^2 2s^2 2p^2$
7	Nitrogen	$1s^2 2s^2 2p^3$
8	Oxygen	$1s^2 2s^2 2p^4$
9	Fluorine	$1s^2 2s^2 2p^5$
10	Neon	$1s^2 2s^2 2p^6$

**Table : 9.8 Difference between Orbit and Orbital**

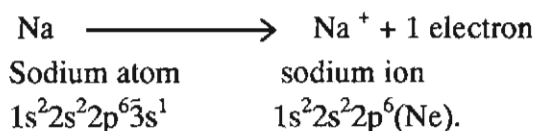
Orbit	Orbital
1) It is a circular path around the nucleus in which the electron revolves.	It is a region in space around the nucleus in which the probability of finding the electron is maximum.
2) It represents the movement of electron in one plane.	It represents the three-dimensional space around the nucleus.

3) Its shape is circular.	Its shape may be spherical (s) dumb-bell (p) or other spheres (d,f)
4) The position and velocity of electron at any instant can be found precisely.	It is impossible to find the position and velocity of electron at some instant with certainty.

**Electronic configuration of sodium atom**

Atomic Number of sodium = 11  
 (Na)  $1s^2 2s^2 2p^6 3s^1$

First two shells are completely filled up. Third shell carries only one electron. Sodium loses one electron to attain the Neon structure.



Now sodium ion with a single positive charge is formed.

**4. Valence Electrons and Valency**

**Valence electrons**

The outermost shell of an atom is called valence shell. The electrons present in the valence shell are called valence electrons.

**Valency**

Valency is defined as the combining capacity of an element and it is measured by the number of atoms of hydrogen or any univalent element with which one atom of the element combines. It is a whole number.

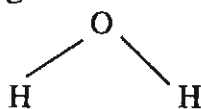
The modern definition of valency is the number of electrons gained or lost by an atom of an element during a chemical reaction.

**Examples**

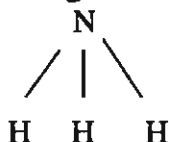
1) One atom of chlorine combines with one hydrogen atom to form a molecule of hydrogen chloride. So valency of chlorine is one.



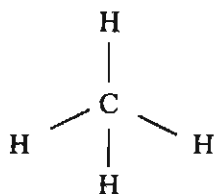
2) One oxygen atom combines with 2 hydrogen atoms to form water. So the valency of oxygen is two.



3) One atom of nitrogen combines with 3 atoms of hydrogen to form ammonia. So the valency of nitrogen is 3.



4) In methane, one carbon atom combines with 4 hydrogen atoms. So its valency is 4.



5) Sometimes valency of an atom can be obtained by indirect method. Consider in the case of  $\text{Al}_2\text{O}_3$ . 2 aluminium atoms combine with 3 oxygen atoms. But each oxygen atom can combine with 2 hydrogen atoms.

$\therefore$  2 aluminium atoms can combine with either 3 oxygen atoms or 6 hydrogen atoms.



$\therefore$  Each aluminium atom can combine with 3 hydrogen atoms.

$\therefore$  the valency of aluminium is 3.

### Variable Valency

Some elements like copper, iron, gold and mercury exhibit more than one valency. **Variable valency is the characteristic property of transition elements.** Variable valency depends on its state of combinations with other elements.

### Example

Cuprous Oxide	$\text{Cu}_2\text{O}$	Valency of Copper 1
Cupric Oxide	$\text{CuO}$	Valency of Copper 2
Ferrous Chloride	$\text{FeCl}_2$	Valency of Iron 2
Ferric Chloride	$\text{FeCl}_3$	Valency of Iron 3

### Self Evaluation

#### Choose the correct answer

1. The negatively charged particle, electron was discovered by

- 1) Crooke
- 2) John Dalton
- 3) J.J. Thomson
- 4) Bohr

2. Which one of the following is not true about cathode rays.

- 1) Positively charged particles
- 2) They travel in straight line
- 3) They are made up of particles
- 4) Negatively charged particles

3. Isotopes of a given element contain,

- 1) the same number of protons and neutrons.
- 2) the same number of protons but different numbers of neutrons.
- 3) different numbers of both protons and neutrons
- 4) different numbers of protons but the same number of neutrons.

4. The mass number of an element is A. Its atomic number is Z. The number of neutrons in that element is

- 1)  $A+Z$
- 2) A
- 3)  $A-Z$
- 4) Z

5. Atomic weight of Bromine is 79.9. Its atomic number is 35. The numbers of protons, electrons and neutrons in this element are respectively.

- 1) 35,35 and 45
- 2) 35,45 and 35

- 3) 45,35 and 35    4) 35,35 and 35.
6. Proton is a ....
- 1) sub-atomic particle having a unit negative charge and unit mass
  - 2) sub-atomic particle having a unit positive charge and no mass.
  - 3) sub-atomic particle having no charge but unit mass.
  - 4) sub-atomic particle having a unit positive charge and unit mass.
7. Neutron is a .....
- 1) sub-atomic particle having a unit-mass but no electrical charge
  - 2) sub-atomic particle having no mass but unit electrical charge.
  - 3) sub-atomic particle having no mass and no electrical charge
  - 4) sub-atomic particle having a unit mass and unit electrical charge.
8. Emission of radiant energy in an excited atom is caused by the movement of an electron from one stationary state to another of
- 1) higher energy    2) lower energy
  - 3) equal energy    4) no energy

#### Fill in the blanks

9. The atomic number of an element is equal to the number of \_\_\_\_\_ in its nucleus.
10. The mass of an electron is \_\_\_\_\_.
11. Atoms having the same number of protons but different number of neutrons are called \_\_\_\_\_.
12. The particles that make-up the atomic-nucleus are called \_\_\_\_\_.
13. The relative atomic mass of chlorine is \_\_\_\_\_.

#### State true or false

14. The mass number of an element is the total number of sub-atomic particles in its nucleus contributing to its mass.
15. The nucleus of an oxygen atom has the same number of protons, as does the nucleus of a fluorine atom.

16. As per Bohr's theory electrons in atoms can rotate only in certain selected orbits.
17. The electronic configuration of carbon is  $1s^2 2s^2 2p^2$ .
18. The electrons in an atom are not distributed in various orbitals in the increasing order of energy.
19. The lowest possible energy level, of an electron is called ground state.
20. The atomic number of the element is the number of protons in the nucleus of an atom of an element.
21. Copper and Iron have the valency 1.
22. Valency is the number of electrons gained only by an atom of an element during chemical reaction.

#### 23. Match the following

- |                          |                     |
|--------------------------|---------------------|
| 1) Chadwick              | i) no charge        |
| 2) Neutrons              | ii) positive charge |
| 3) Scattering experiment | iii) ionize gases   |
| 4) Cathode rays          | iv) neutrons        |
| 5) Canal rays            | v) ZnS screen       |

#### Answer in detail

24. Explain Rutherford's experiment, which proved the existence of atomic nuclei. What were his observations?
25. What are the properties of cathode-rays?
26. What are the properties of Anode or canal rays?
27. Explain the discovery of neutrons and properties of neutrons.
28. Tabulate a few elements showing the composition of atoms.
29. Explain in detail on the postulates of Neils Bohr's theory.
30. Tabulate the electron arrangement of the first 10 elements.
31. What is the superiority of Bohr's model over Rutherford's model?
32. Explain valency and variable valency of elements.