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ISBN 978-93-528-6679-3

eISBN 978-93-530-6114-2

First Impression

Published by Pearson India Education Services Pvt. Ltd, CIN: U72200TN2005PTC057128.

Head Office: 15th Floor, Tower-B, World Trade Tower, Plot No. 1, Block-C, Sector-16, Noida 201 301, Uttar Pradesh, India.

Registered Office: 4th Floor, Software Block, Elnet Software City, TS-140, Block 2 & 9, Rajiv Gandhi Salai, Taramani, Chennai 600 113, Tamil Nadu, India.

Fax: 080-30461003, Phone: 080-30461060

Website: in.pearson.com, Email: companysecretary.india@pearson.com

Compositor: Saksham Printographics, Delhi
Printer in India at

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Preface

Pearson IIT Foundation Series has evolved into a trusted resource for students who aspire to be a part of the elite undergraduate institutions of India. As a result, it has become one of the best-selling series, providing authentic and class-tested content for effective preparation—strong foundation, and better scoring.

The structure of the content is not only student-friendly but also designed in such a manner that it motivates students to go beyond the usual school curriculum, and acts as a source of higher learning to strengthen the fundamental concepts of Physics, Chemistry, and Mathematics.

The core objective of the series is to be a one-stop solution for students preparing for various competitive examinations. Irrespective of the field of study that the student may choose to take up later, it is important to understand that Mathematics and Science form the basis for most modern-day activities. Hence, utmost effort has been made to develop student interest in these basic blocks through real-life examples and application-based problems. Ultimately, the aim is to ingrain the art of problem-solving in the mind of the reader.

To ensure high level of accuracy and practicality, this series has been authored by a team of highly qualified teachers with a rich experience, and are actively involved in grooming young minds. That said, we believe that there is always scope for doing things better and hence invite you to provide us with your feedback and suggestions on how this series can be improved further.

Chapter Insights

REMEMBER

Before beginning this chapter you should be able to:

- Define the measuring quantities like length, width, height, volume, density, etc
- Use the decimal system
- Know the different unit systems and conversion of higher value to lower value

Remember section will help them to memories and review the previous learning on a particular topics

Key points will help the students to identify the essential points in a chapter

KEY IDEAS

After completing this chapter you should be able to:

- Know the types of physical quantities, different systems of units and their importance
- Use the measuring devices in practical examples
- Understand the method of determination of error in the measurements

SCALARS AND VECTORS

Physical quantities that can be defined using magnitude only are known as scalar quantities.

Examples: Distance, speed, mass, density, temperature.

Physical quantities that can be defined only if both its magnitude and direction are specified are called vector quantities.

Examples: Velocity, acceleration, force, torque.

Distance is the length of the path from the initial position to the final position, traced by the particle while in motion. It is a scalar quantity, and is path-dependent.

Text: concepts are explained in a well structured and lucid manner

Note boxes are some add-on information of related topics

Note

1. Average velocity of a moving body may be equal to zero but average speed cannot be equal to zero. For example, the average velocity of an athlete completing one round while running along a circular track is zero, though his average speed is not zero.

EXAMPLE

A constant force acts on a body of mass 10 kg and produces in it an acceleration of 0.2 m s^{-2} . Calculate the magnitude of force acting on the body.

SOLUTION

Given

$$\begin{aligned} \text{Mass} &= 10 \text{ kg} \\ a &= 0.2 \text{ m s}^{-2} \end{aligned}$$

$$\therefore \text{Force} = \text{mass} \times \text{acceleration} (F = ma)$$

$$\therefore F = (10 \text{ kg}) \times (0.2 \text{ m s}^{-2}) = 2 \text{ N}$$

Thus, the magnitude of force acting on the body is 2 N.

Examples given topic-wise to apply the concepts learned in a particular chapter

Illustrative examples solved in a logical and step-wise manner

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. State the law of conservation of momentum.
2. Give two examples of renewable sources of energy.
3. If no external _____ acts, the total momentum of the colliding bodies is conserved.
4. What is normal reaction or normal force?
5. Give two examples of non-renewable sources of energy.
6. A person getting down from a fast moving bus falls on the ground. This can be explained by _____.
7. Define force field.
8. Define viscous force.
17. Friction always acts _____ to the surfaces in contact.
18. What is meant by an unbalanced force?
19. When is the work done maximum with a given force and displacement?
20. The impulse of a body is equal to _____.
21. (i) Define inertia of motion.
(ii) Define inertia of direction.
22. 1 kg_{wt} is equal to _____ N.
23. Define the S.I. unit of force.
24. What is the relation between momentum and kinetic energy?

Different levels of questions have been included in the *Test Your Concept* as well as on *Concept Application* which will help students to develop the problem-solving skill

'Test Your Concepts' at the end of the chapter for classroom preparations

'Concept Application' section with problems divided as per complexity: Level 1; Level 2; and Level 3

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

1. Stretched spring has the energy in the form of potential energy.
2. Work and energy have the same S.I. units.
3. Friction depends on the area of contact between two surfaces.
4. Friction can be reduced by polishing surfaces.
11. The total momentum of two bodies before collision is equal to their _____ after collision.
12. To do the same work in less time, the power should be _____.
13. When a body is dropped from a height, its _____ energy changes to its _____ energy.
14. _____ force opposes the relative motion between the two bodies.

54. When two bodies are in relative motion, kinetic frictional force acts between the bodies.
When a log of wood is dragged up an inclined plane, kinetic frictional force acts in between the log and the plane. This frictional force is directly proportional to the weight of the block and the cosine of the angle between the inclined plane and the horizontal.
If the angle (θ) of inclination of the plane increases, the $\cos(\theta)$ value decreases, and hence, the force of friction also decreases.

55. Initial State: P.E. = mgh , K.E. = $\frac{1}{2}mu^2$
Final State: P.E. = mgh , K.E. = 0

According to Law of conservation of energy,
(P.E. + K.E.)_{initial} = (P.E. + K.E.)_{final}

$$\text{Ans: } \sqrt{2g(H-h)}$$

56. Use
 $F = ma = \frac{m(v-u)}{t}$

$$\text{Ans: } -90\text{N}$$

57. The acceleration in the ball is due to force exerted by spring on the balls.

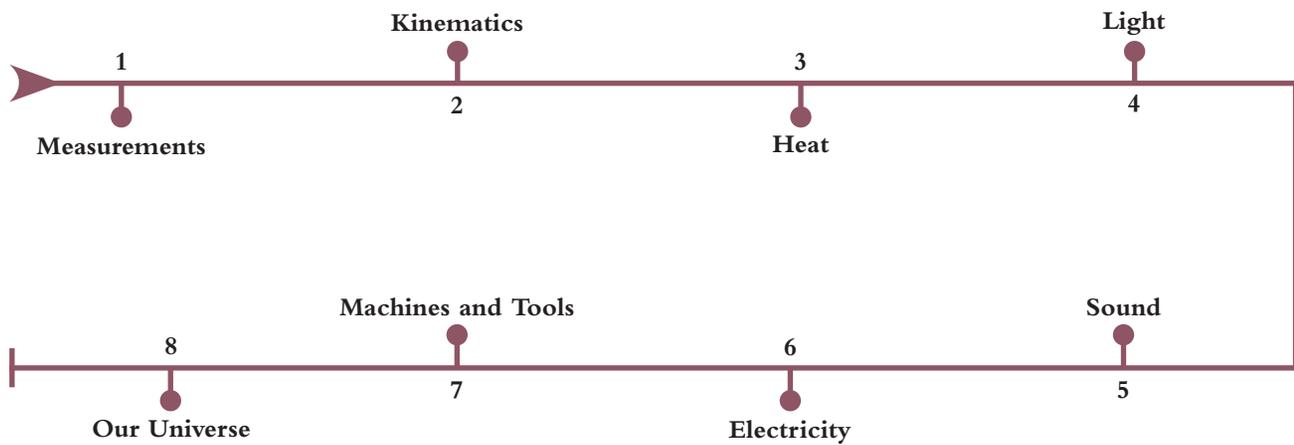
The potential energy of the compressed spring is converted into kinetic energy of the balls.

$$\text{Ans: } 20 \text{ m s}^{-2}$$

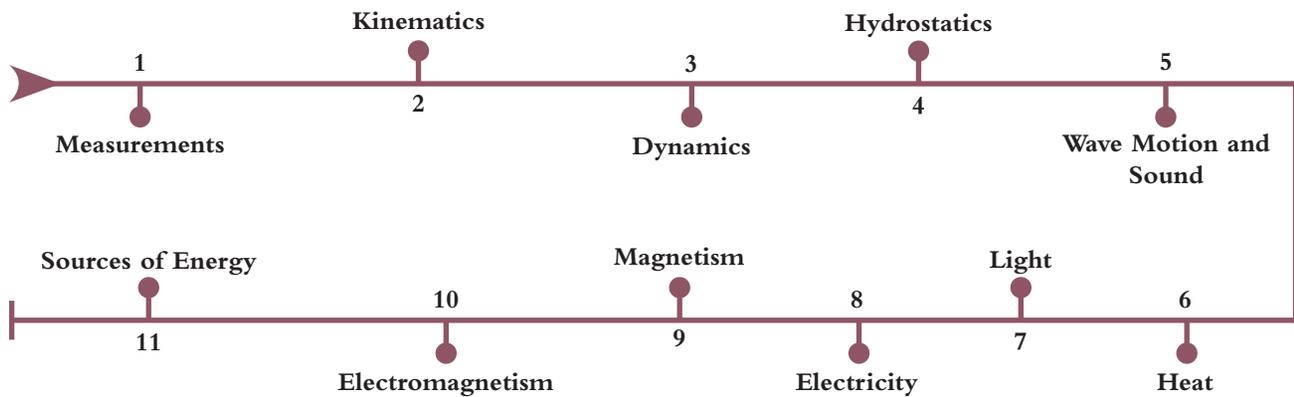
Hints and Explanation for key questions along with highlights on the common mistakes that students usually make in the examinations

Series Chapter Flow

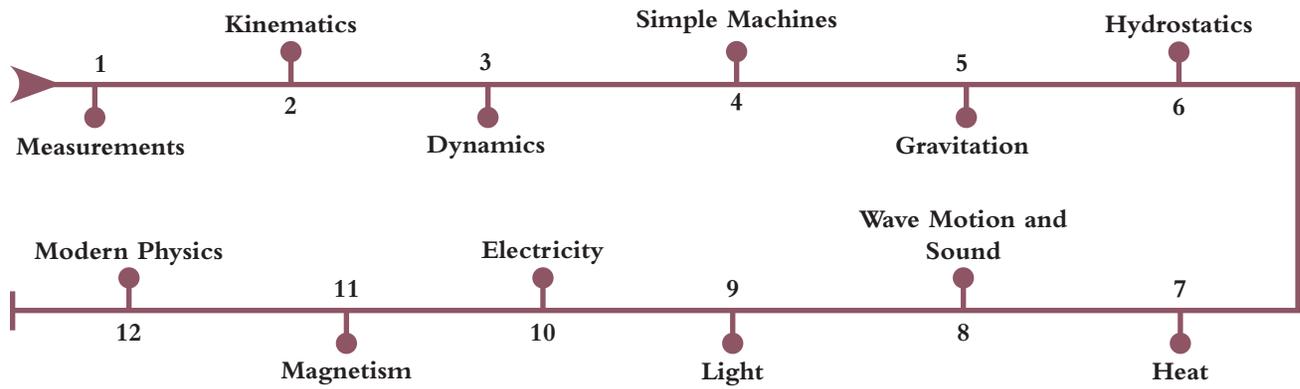
Class 7



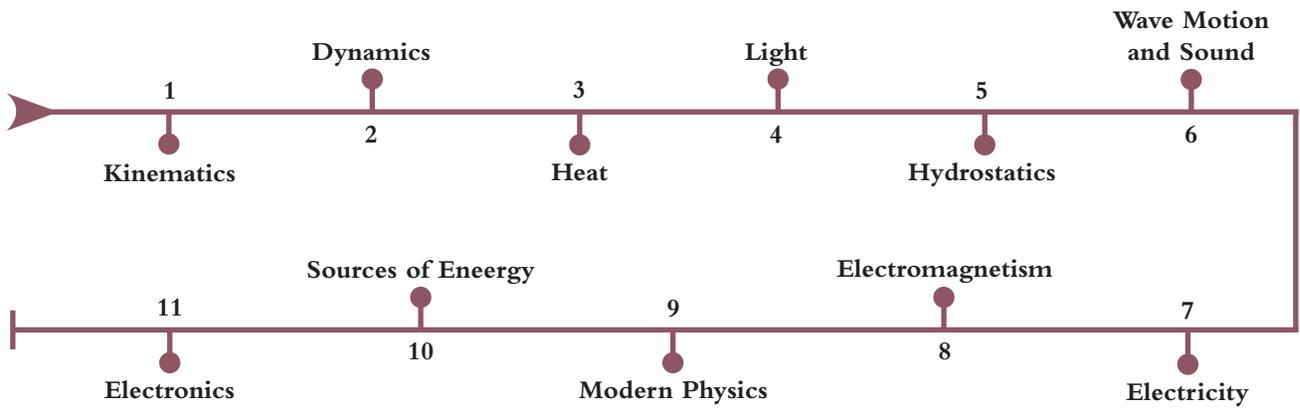
Class 8



Class 9



Class 10



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Chapter 1

Measurements



REMEMBER

Before beginning this chapter you should be able to:

- Define the measuring quantities like length, width, height, volume, density, etc
- Use the decimal system
- Know the different unit systems and conversion of higher value to lower value

KEY IDEAS

After completing this chapter you should be able to:

- Know the types of physical quantities, different systems of units and their importance
- Use the measuring devices in practical examples
- Understand the method of determination of error in the measurements
- Recognize the importance of accuracy and also the working principle of different instruments used for taking measurements accurately

INTRODUCTION

Physics is a branch of science in which we study the laws of nature. In this branch, the nature and its laws are described quantitatively and qualitatively. The quantitative study of nature involves the estimation and measurement of various physical quantities like distance, weight, temperature, etc.

In our daily life, measurement of various quantities has become an inevitable part. To understand its importance, let us take few examples. Motion of a body can be changed by applying force. The acceleration produced can be known only if the applied force and the mass of the body are measured. Alternatively, the change in velocity in a given interval of time should be measured, from which the acceleration can be determined.

PHYSICAL QUANTITY

The quantities which can be defined and measured are called physical quantities.

Example: Force, distance, time, current, etc.

The laws of physics can be described in terms of these physical quantities.

Measurement of Physical Quantities and Their Units

Measurement is a method of comparison of an unknown quantity with a standard quantity. This fixed or definite quantity which we take as a standard and by the help of which we can measure other quantities of the same kind is defined as the unit.

The measure of a physical quantity is expressed in two parts, namely the magnitude and the unit. For example, when we say force is 12 newton. In fact, we can now measure speed of light also. 12 is the magnitude and newton is the unit of force.

Scalar Quantity

The physical quantities which can be described completely by their magnitude only are called scalar quantities. There is no need to know or specify their directions.

Example: Distance, mass, time, speed, density, etc.

These quantities can be added according to ordinary algebraic rules.

Vector Quantity

The physical quantities which can be described completely giving/stating by both their magnitude and direction are called vectors. If we state only magnitude or only direction, then their significance is not clear.

Example: Force, velocity, acceleration, etc.

Addition of these quantities can be done by special methods of addition—Law of polygon or law of vector.

Types of Physical Quantity and Its Unit

The physical quantities are classified into two categories—fundamental quantities and derived quantities.

Fundamental Quantities

The physical quantities that do not depend on any other physical quantity for their measurement are called fundamental quantities. Mass, length, time, electric current, temperature, luminous intensity and amount of substance are the fundamental quantities.

Derived Quantities

The physical quantities that are derived from the fundamental quantities are called derived quantities. Area, volume, density, force, velocity, etc., are some examples of derived quantities.

Rules—Writing Units

1. The symbol for a unit, which is named after a scientist, should start with an upper case letter.

Example: Newton-N, Joule-J, Pascal-Pa, Kelvin-K, etc.

2. The symbol for a unit, which is not named after a person, is written in lower case.

Example: Metre-m, mole-mol, second-s

3. In their full form, the units should start with a lower case letter.

Example: Newton, metre, joule, second, hertz, etc.

4. Symbol of a unit should not be in plural form.

Example: 500 metres should be written as 500 m and not 500 ms.

Wrong notation	Correct notation
Ns	N
Ks	K
mols	mol

5. A compound unit (obtained from units of two or more physical quantities) is written either by putting a dot or leaving a space between symbols of two units.

Example: Unit of torque—N m (or) N.m

Unit of impulse—N s (or) N.s

Pole strength of magnet—A m (or) A.m

Unit of electric charge—As or A.s

6. The denominators in a compound unit should be written with negative powers.

Example: Unit of density is kg m^{-3} , not kg/m^3

Unit of acceleration is m s^{-2} not m/s^2

Systems of Units

The following systems of units are in common use

1. **F.P.S. system:** In this system, the units of mass, length and time are pound, foot and second, respectively.
2. **C.G.S. system:** In this system, the units of mass, length and time are gram, centimetre and second, respectively.

3. **M.K.S. system:** In this system, the units of mass, length and time are kilogram, metre and second, respectively.
4. **S.I.-(Systeme International d' unites):** This system is an improved and extended version of M.K.S system. This system defines seven fundamental quantities and two supplementary quantities.

Quantity	S.I. Units	Symbol
1. Length	metre	m
2. Mass	kilogram	kg
3. Time	second	s
4. Electric current	ampere	A
5. Temperature	kelvin	K
6. Luminous intensity	candela	cd
7. Amount of substance	mole	mol
8. Angle	radian	rad
9. Solid angle	steradian	sr

Some derived quantities	S.I. units	Symbol
1. Force	newton	N
2. Work	joule	J
3. Frequency	hertz	Hz
4. Charge	coulomb	C

Definitions of Units

1. **Metre:** One metre is 1,650,763.73 times the wavelength of orange light emitted by a krypton atom at normal pressure.
2. **Kilogram:** One kilogram is the mass of a certain cylinder made from an alloy of platinum-iridium, maintained at 0°C, in the International Bureau of Weights and Measures at Paris, France.
3. **Second:** One second is the time taken by a cesium atom (Cs^{133}) to complete 9,192,631,770 vibrations.
4. **Ampere:** One ampere is that current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce a force equal to 2×10^{-7} newton per metre of length between them.
5. **Kelvin:** Kelvin is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.
6. **Mole:** Mole is the amount of substance of a system, which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12.
7. **Candela:** Candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $1/683$ watt per steradian.

Dimensions of Physical Quantities

The nature of any physical quantity can be described by mentioning the powers to which the fundamental units are raised to give the unit of the given quantity.

The quantities of the three fundamental quantities mass, length and time are denoted by M, L and T, respectively.

Definition: The powers to which the units of fundamental quantities mass, length and time are raised to obtain the unit of a physical quantity is known as dimensions of the given quantity.

Example: unit of density of a body = $\frac{\text{unit of mass}}{\text{unit of volume}} = \text{kg m}^{-3}$

Here, mass appears once in the numerator and length appears thrice in the denominator. Thus, the dimensional formula of density is $[M^1 L^{-3} T^0]$. Since the physical quantity time is not involved in the density, its exponent is shown as zero.

Thus, in density the dimension of mass = 1, the dimension of length = -3 and the dimension of time = 0.

EXAMPLE

Write the dimensional formula of speed.

SOLUTION

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{length}}{\text{time}}$$

In the unit of speed the unit of mass does not appear, thus, its dimension is zero.

$$\therefore [\text{Speed}] = [M^0 L^1 T^{-1}]$$

EXAMPLE

What is the dimensional formula of force?

SOLUTION

Force = mass \times acceleration

Unit of force = unit of mass \times unit of acceleration = unit of mass $\times \frac{\text{unit of length}}{(\text{unit of time})^2}$

Dimensional formula = $[M L T^{-2}]$

MEASURING DEVICES

Many devices and instruments are used to measure various physical quantities. For example the length of an object can be measured by using scale, measuring tape, vernier callipers, etc., and the mass of an object can be measured by using a common balance, spring balance, etc. Every measuring device has its own accuracy, it can be represented in terms of least count.

Least Count

The **least count** of an instrument is the smallest measurement that can be made accurately with that instrument. For example the least count of a metre scale is 0.1 cm and the least count of a table clock is 1 second.

Metre Scale

It is graduated in cm. Therefore, each centimetres (cm) is further divided in ten equal parts, called division. So, 1 division is 1/10th of a cm, i.e., 1 mm. Its least count is 1 mm. While measuring the length of any object using a scale, the observation should be made without any *parallax error*.

The length of a rod can be measured by keeping the scale in contact with the object as shown in the Fig. 1.1.

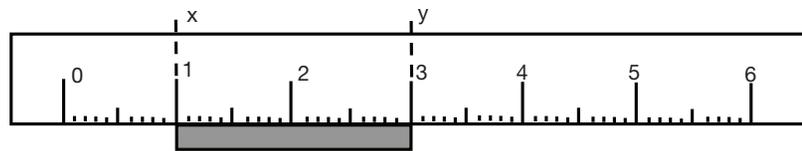


FIGURE 1.1

x and y are the readings corresponding to the edges of the object.

$$\text{Length of object} = y - x = 3.0 \text{ cm} - 1.0 \text{ cm} = 2.0 \text{ cm}$$

Using a scale the length of a rod having uneven ends or the diameter of a sphere can be measured with the help of two wooden blocks *A* and *B* as shown in the Fig. 1.2.

The length of a rod (ℓ) or the diameter of a sphere (d) is equal to the difference between the readings y and x corresponding to the positions of the two edges of the objects.

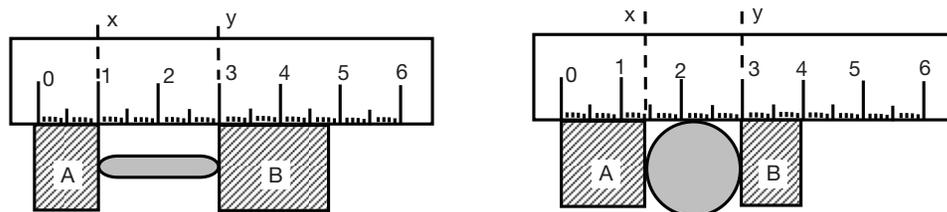


FIGURE 1.2

$$\text{Length of the rod, } \ell = y - x = 3.0 - 1.0 = 2.0 \text{ cm}$$

$$\text{Diameter of the sphere, } d = y - x = 3 - 1.4 = 1.6 \text{ cm}$$

In Fig. 1.3, the edge B of object is not exactly coinciding with any division of scale.

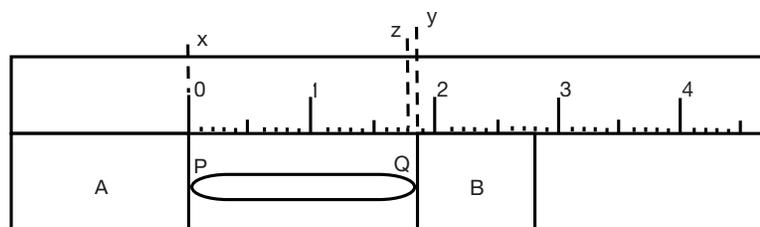


FIGURE 1.3

In the above case, to measure the length of the rod AB, more accurately, the distance between the 18th division of the scale and the edge Q should be measured.

$$\text{Length of the rod } PQ = y - x = (z - x) + (y - z)$$

The difference between the readings y and z can be measured by engraving a graduated scale on the wooden block B. The metre scale used is referred to as the main scale and the scale drawn on the block B is called vernier scale.

Vernier Callipers

It is an instrument which uses a combination of two scales (main scale and vernier scale) sliding over each other such that the least count of the instrument is less than the least count of the main scale.

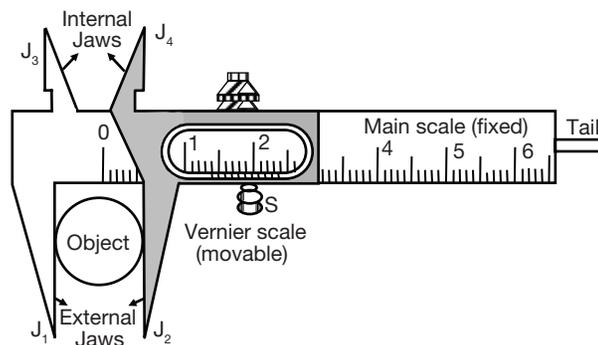


FIGURE 1.4

Principle of vernier: The principle of a vernier is to make ' N ' vernier scale divisions equal to $(N - 1)$ main scale divisions.

Generally the standard vernier scale is provided with 10 graduations to coincide with 9 main scale divisions, i.e., the 10 divisions of the vernier scale measure 9 mm.

Procedure for Taking a Measurement Using Vernier Callipers

1. Determine the least count of the Vernier Callipers:

$$\text{Least count (L.C.)} = 1 \text{ M.S.D.} - 1 \text{ V.S.D.} = 1 \text{ mm} - 0.9 \text{ mm} = 0.1 \text{ mm} = 0.01 \text{ cm}$$

or

$$\text{Least count (L.C.)} = \frac{1 \text{ M.S.D.}}{\text{No of V.S.D.'s}} = \frac{1 \text{ mm}}{10} = 0.1 \text{ mm} = 0.01 \text{ cm}$$

2. To measure the external dimensions of an object, it should be held tightly between the external jaws J₁ and J₂ and to measure the inner dimensions, it should be held with internal jaws J₃ and J₄.
3. Note the main scale reading (M.S.R.). The main scale reading is always the smaller of the two values, between which the zero of the vernier scale lies.
4. Note the vernier scale division (V.S.D.) which coincides with any main scale division.

5.

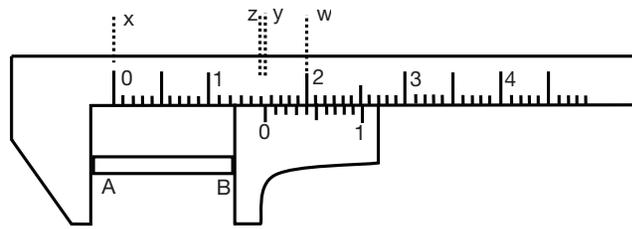


FIGURE 1.5

$$\begin{aligned} \text{The length of rod } AB &= y = (z) + (y - z) = (z) + (w - z) - (w - y) \\ &= \text{M.S.R.} + \text{V.S.D.} \times \text{M.S.D.} - \text{V.S.D.} \times \text{V.S.D.} = \text{M.S.R.} + \text{V.S.D.} (\text{M.S.D.} - \text{V.S.D.}) \end{aligned}$$

$$\therefore \text{Total reading} = \text{M.S.R.} + (\text{V.S.D.} \times \text{L.C.})$$

EXAMPLE

While measuring the diameter of a sphere with a vernier callipers, M.S.R. and V.S.D. are 35 mm and 5, respectively. If the vernier scale coinciding with 19 divisions of main scale, what is the diameter of the sphere?

SOLUTION

$$\text{M.S.R.} = 35 \text{ mm}$$

$$\text{V.C.D.} = 5$$

$$\text{Diameter of the sphere} = \text{M.S.R.} + \text{V.C.D.} \times \text{L.C.}$$

Given that 20 divisions of the vernier scale is equal to 19 division of the main scale,

$$\text{L.C.} = 1 \text{ M.S.D./no. of divisions on V.S.} = 1 \text{ mm}/20 = 0.05 \text{ mm}$$

$$\text{Total reading} = \text{M.S.R.} + n \times \text{L.C.} = 35 \text{ mm} + 5 \times 0.05 \text{ mm} = 35.25 \text{ mm}$$

Zero Error

When the fixed and the movable jaws of a vernier callipers are made to come in contact, if the zeroes of both the main scale and the vernier scale are not coinciding with each other, the instrument is said to have a **zero error**.

Positive Zero Error

If the zeroth division of the Vernier scale is to the 'right' of the zeroth division of the main scale when the two jaws are brought in contact with each other, the error is said to be positive and the correction is negative. If the n th division of the vernier scale coincides with some division on the main scale, then the zero error is $(+n \times \text{Least count})$ and the correction is $(-n \times \text{Least Count})$ cm.

Negative Zero Error

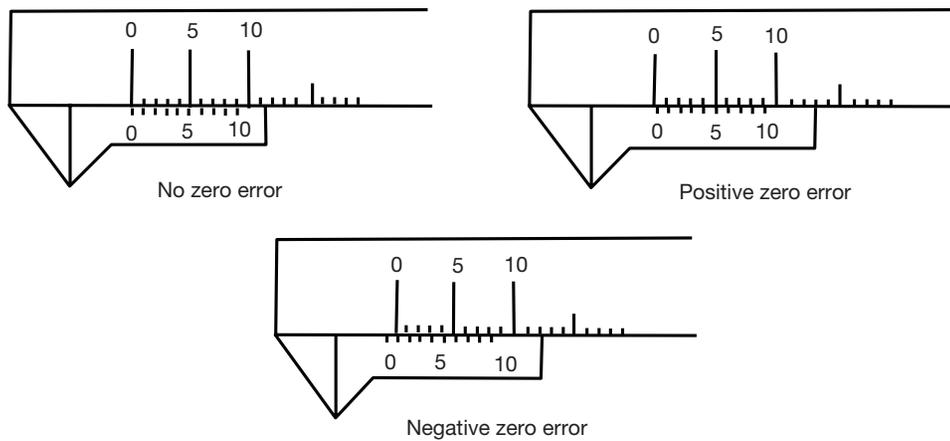


FIGURE 1.6

If the zeroth division of the vernier scale is to the 'left' of the zeroth division of the main scale, the error is said to be negative and the correction is positive. If the n th division of the vernier scale coincides with some division on the main scale, then the zero error = $-(N - n) \times \text{Least Count}$ and the correction = $+(N - n) \times \text{Least Count cm}$, where N is the number of divisions on the vernier scale.

In case of any zero error in the instrument, the corresponding correction is to be added to the measurement calculated in step 5, on page 1.7.

EXAMPLE

When the jaws of a vernier callipers are closed, the 0th division of its vernier scale is to the right of the zero of the main scale and the V.C.D. is 6. Find the correction to be made to the observed measurement (take its least count as 0.1 mm)

SOLUTION

The vernier coincidence, $n = 6$

Zero error = V.C.D. \times L.C.

= $6 \times 0.1 \text{ mm} = 0.6 \text{ mm}$ and the error is positive. Thus, the correction = -0.6 mm

Screw Gauge

It is an instrument used for measuring the dimensions of a very small magnitude, like the diameter of thin wires or thickness of thin laminations, etc., which require accuracy up to 0.001 cm.

Principle of a Screw Gauge

The screw gauge works on the principle of a screw in a nut. When the head of a screw rotates once completely, the tip of the screw moves by a distance equal to the distance between the threads on it. This distance is called pitch of the screw.

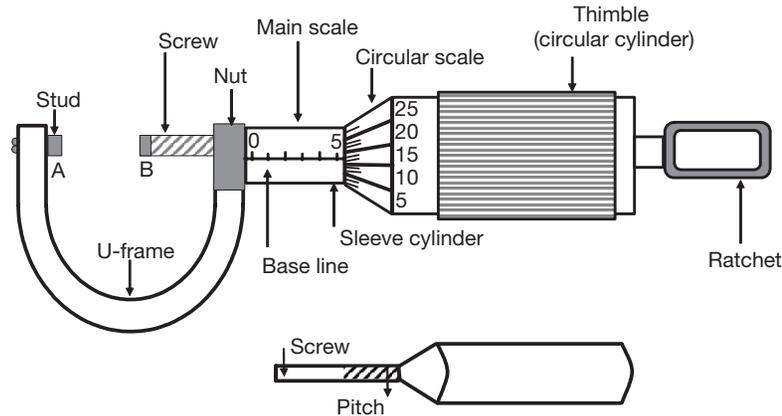


FIGURE 1.7

Description of a Screw Gauge

A typical screw gauge consists of a jaw (U-shaped frame) with a fixed stud at one end and a nut (a hollow cylinder with internal threading) incorporated on the other end.

Graduations (divisions of 1mm or 0.5 mm) are provided on an index line on the outer surface of the cylinder. This forms the **pitch scale (or main scale)**.

A long screw, with threading identical to that in the hollow cylinder, runs through the cylinder. At the other end of the screw a barrel with a milled head is attached. The end of the barrel opposite to the milled head is tapered with equal divisions (0–50 or 0–100) marked on it. This forms the **head scale (circular scale)**.

When the flat end of the screw comes in contact with the fixed stud of the jaw, the tapered edge of the barrel coincides with the zero on the index line and the zero of the circular scale coincides with the index line of the main scale.

Pitch of a Screw Gauge

It is defined as the distance between the two consecutive threads of the screw, measured along the axis of the screw, i.e., it is the distance travelled by the tip of the screw for one complete rotation of the head of the screw.

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

Generally, it is 1 mm.

Least Count of a Screw Gauge

It is the smallest distance moved by the tip when the screw turns through the one division marked on it.

$$\text{Least count} = \frac{\text{Pitch}}{\text{Number of Circular Scale Divisions}}$$

Observed measurement = Main scale reading + Circular Scale Reading \times L.C.

Procedure for Taking a Measurement Using a Screw Gauge

1. Determine the least count (L.C.) of the screw gauge.
2. Hold the object, whose measurement is to be made, tightly between the stud and tip of the screw.
3. The value of the main scale division just preceding the edge of the circular scale is noted as M.S.R.
4. The value of the circular scale division coinciding with the reference line of the main scale is noted as C.S.R.
5. The measurement of the object = M.S.R. + (C.S.R. \times L.C.)
6. In case any zero error is present in the instrument, the corresponding correction is to be added to the observed measurement calculated in step 5.

When the stud and the tip of the screw of a screw gauge are made to come in contact, if the zeroes of both the main scale and the circular scale are not coinciding with each other, the instrument is said to have a **zero error**.

Positive Zero Error

When the stud and the tip of the screw of a screw gauge are made to come in contact, if the zeroth division of the circular scale is 'below' the reference or base line of the main scale, the error is said to be positive and the correction is negative. If n is the circular scale division coinciding with the index line of the main scale, then

$$\text{Zero error} = +n \times \text{least count and Correction} = -n \times \text{least count}$$

Negative Zero Error

When the stud and the tip of the screw of a screw gauge are made to come in contact, if the zeroth division of the circular scale is 'above' the reference line of the main scale, the error is said to be negative and the correction is positive. If n is the circular scale division coinciding with the index line of the main scale, then

$$\text{Zero error} = -(N - n) \times \text{least count and the Correction} = +(N - n) \times \text{least count}$$

where N is the total number of divisions on the *circular scale*.

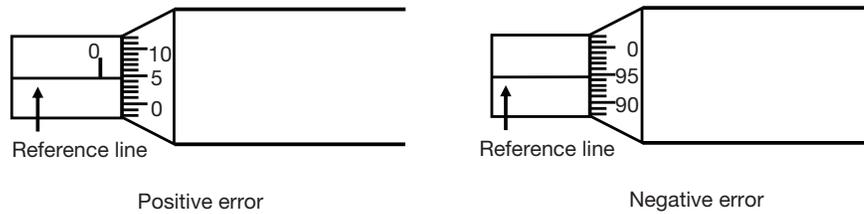


FIGURE 1.8

True measurement = Observed measurement + Correction for zero error

Observed measurement = (M.S.R.) + (C.S.R. \times L.C.)

MEASUREMENT OF MASS

Physical Balance

Physical balance is an instrument, working on the principle of moments, and is used in laboratories to determine the mass of substances/bodies more accurately than a common balance. The smallest mass that can be determined using a physical balance is 1 mg.

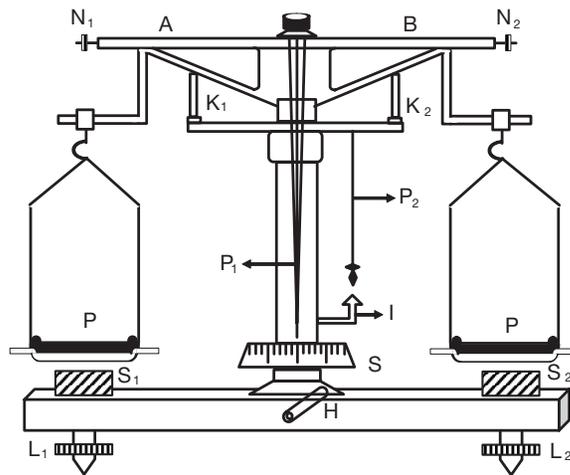


FIGURE 1.9 Physical Balance

P – Pans

P_1 – Pointer

P_2 – Plumb line

K_1, K_2 – Supports

N_1, N_2 – Balancing screws

L_1, L_2 – Levelling screws, I -index

H – Handle

Description of a Physical Balance

A physical balance consists of a balancing beam AB, balanced on a knife-edge in the middle, the knife-edge is mounted on a pillar fixed to a wooden base. Two stirrups for the pans are supported on two knife-edges on either side of the beam, equidistant from the centre. The pans are hung from the stirrups. A long metallic pointer p is attached perpendicular to the beam at the centre. The free end (pointed tip) of the pointer moves over a scales with graduations to indicate the equilibrium of the beam. The beam is allowed to rest on two metal supports fixed to the central pillar, when not in use.

By turning the handle (H), provided at the bottom of the pillar, the beam may be raised from the supports or rested on them. Two screws N_1 , N_2 with nuts are provided on either end of the beam to balance the beam when raised on 'no-load'. The entire arrangement is enclosed in a glass box with a wooden frame. A plumb line is suspended from the central metal support and by adjusting the levelling screws L_1 , L_2 provided at the bottom of the enclosure, the base of the instrument may be made perfectly horizontal the central pillar being vertical.

Precautions to be Observed Before Using the Balance

1. Raising and lowering of the beam must be done gently by turning the handle without any jerks.
2. Arrest the beam when not in use.
3. Handle the weights using the forceps only and do not touch them with hands.
4. Keep the doors of the balance box closed during weighing so that air current does not disturb balance.
5. While weighing chemicals which may damage the pans, appropriate containers or vessels must be used. If necessary, they should be placed in air-tight vessels.
6. Very hot or very cold substances should be avoided as they would affect the weighing due to the air currents that they would cause.

Determination of Mass of a Body Using Physical Balance

1. When handle ' H ' is turned gently, oscillations of the pointer on either side of the extreme points known as turning points are observed.
2. The point on the scale at which the pointer comes to rest is known as the resting point (RP).
3. If the resting point with equal empty pans is observed, that point is known as the zero, resting point (ZRP).
4. To find the ZRP, release the beam using the handle with equal empty pans. As the pointer starts oscillating note the successive turning points, three on the left and two on the right of the pointer after 2 or 3 swings.
5. Find the average of the left and right turning points separately and then find the average of these values, to arrive at the ZRP.
6. Place the substance of unknown mass in the left pan and place the standard weights in the right pan, in descending order, till it counter balances.
7. On releasing the beam, the pointer swings to an extent of zero point. Note the weight and find the RP.

8. If $RP > ZRP$, it is called HRP.

9. If $RP < ZRP$, it is called LRP.

If HRP is obtained, add 10 mg (lowest mass) to get LRP and when LRP is obtained remove 10 mg to get HRP.

10. Mass of the body = Mass at HRP or LRP \pm P g

$$\text{If HRP is obtained, } P = \frac{\text{HRP}-\text{ZRP}}{\text{HRP}-\text{LRP}} \times 0.01 \text{ g}$$

$$\text{If LRP is obtained, } P = \frac{\text{LRP}-\text{ZRP}}{\text{LRP}-\text{HRP}} \times 0.01 \text{ g}$$

NOTE

If $RP = ZRP$, then mass at $RP =$ correct mass.

Measurement of Mass by a Common Balance

Level the balance by adjusting the levelling screws L_1 , L_2 , the plumb-line P_2 is made to coincide with the line of the index I . Adjust the balancing screws N_1 , N_2 on either side of the central beam such that the pointer swings equally on either side of the zero mark.

Arrest the beam gently by lowering the central rod (turning the central handle) and then gently place the article, to be weighed, on the left pan.

Place the standard weights, in the descending order of magnitude, check for the oscillation of the pointer equally on either side of the central zero mark. This checking is done by raising the central rod.

The mass of the article is given by the total of the weights placed on the right pan.

Spring Balance

The spring balance works on the principle of Hooke's law—'the elongation in a spring is directly proportional to the force applied to it within its elastic limit'.

Description

A spring balance consists of a spring enclosed in a metallic case. One end of the spring is attached to the metal casing and the other end is free with a hook attached to it. A pointer is fixed on to the spring to indicate the elongation.

This pointer can slide along a scale attached to the metallic case. Generally each division of scale represent 1 g_f (or) 100 g_f .

This scale is graduated from top to bottom. When no load is suspended from the hook, the pointer coincides with the zero on the scale and when some load is suspended the pointer slides down along the scale and gives the measure of the mass of load.

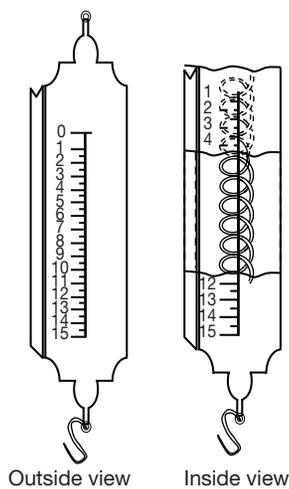


FIGURE 1.10

MEASUREMENT OF TIME

Time

It is defined as the interval between two events. It is a fundamental quantity. The unit of time in S.I. system is second.

Solar Day

The time taken by the Earth to complete one rotation about its own axis, is called 'Solar Day'.

Mean Solar Day

The average of all the solar days that occur during one full revolution of the Earth around the sun, is called 'Mean Solar Day'.

1 mean solar day = 24 hours

1 hour = 1/24th part of the mean solar day

1 minute = 1/1440th part of the mean solar day

1 second = 1/86400 of the mean solar day

1 year is the time in which the Earth completes one complete revolution around the sun. It can be measured with the help of a stop clocks or a stop watch explained below.

Simple Pendulum

It consists of a heavy sphere, called bob, suspended freely from a fixed point by a light, inextensible string enabling it to oscillate freely about the mean position.

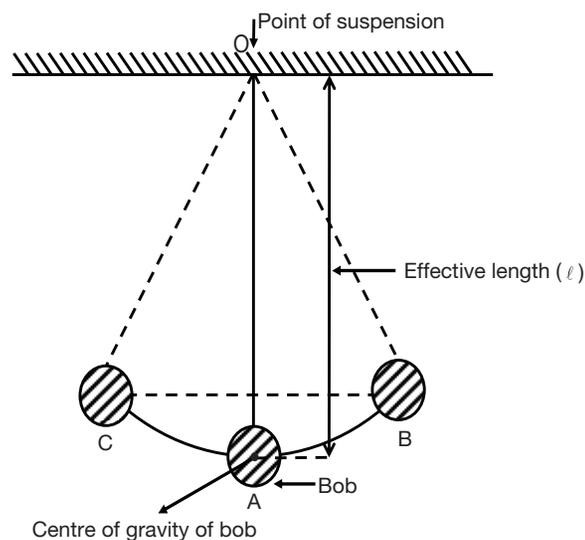


FIGURE 1.11 A simple pendulum

The pendulum with a time period of 2 seconds is called seconds pendulum'.

Pendulum Clock

Some wall clocks work on the principle of seconds pendulum. These clocks contain a seconds pendulum made up of invar steel rod and have a metal bob at its end.

Stop Watch

We use a stop watch and a stop clock to measure short intervals of time of the order of a few seconds. A stop watch consists of two dials one is divided in seconds and provided with a seconds needle and the other (smaller one) divided in minutes; it is also provided with a minutes hand. For each complete rotation of the seconds hand, the minute hand moves through 1 minute division. The seconds divisions on a big dial are further divided to measure $1/2$ a second or $1/5$ th of a second. Every stop watch is provided with a dual purpose knob, which is used to start and stop the watch.

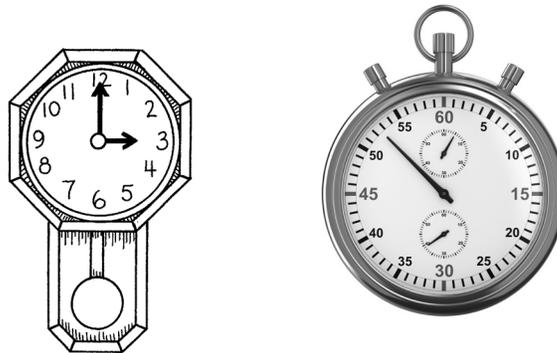


FIGURE 1.12

MEASUREMENT OF VOLUME

The space occupied by an object is called its volume.

Units: S.I. unit: m^3

C.G.S. unit: cm^3

Other units are ml, litre, etc.

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

$$1 \text{ ml} = 10^{-6} \text{ m}^3$$

$$1 \text{ l} = 1000 \text{ cm}^3 = 1000 \text{ ml}$$

$$1 \text{ l} = 10^{-3} \text{ m}^3$$

Volume of a regular shaped body can be calculated using a standard formulae, after measuring the required dimensions.

Example:

$$\text{Volume of a cube} = (\text{side})^3$$

$$\text{Volume of a cuboid} = l \times b \times h$$

$$\text{Volume of a sphere} = \frac{4}{3} \pi (\text{radius})^3$$

$$\text{Volume of a cylinder} = \pi r^2 h$$

Volume of Liquids

Volume of liquids can be measured using some measuring devices described below:

- 1. Measuring jar:** It is a cylindrical jar graduated in ml from the bottom to the top. It is available with various capacities. It is used to measure the desired amount of a liquid.
- 2. Measuring flask:** It is a round bottomed flask with a long neck. It has only one mark etched on the neck. The liquid taken up to this mark will have a volume equal to that mentioned on its body.
- 3. Pipette:** It is a long narrow glass tube with a spherical or cylindrical bulb in the middle. It can be filled by sucking up the liquid into it. A mark is etched on it. When the pipette is filled up to this mark, the liquid will have a volume shown on its surface. It is used to take a constant amount of liquid.
- 4. Burette:** Burette is similar to a measuring jar but it is provided with a pitch cock at the bottom and by using which the desired amount of liquid can be taken.

Instruments for Measuring the Volume of Liquids

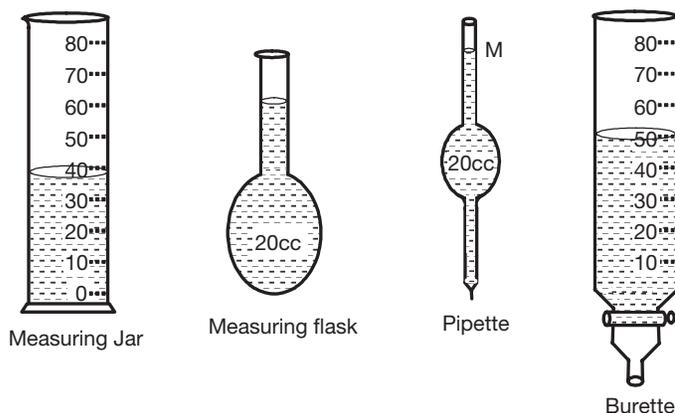


FIGURE 1.13

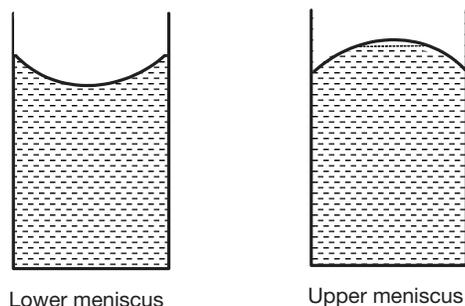


FIGURE 1.14

Normally, the surface of a liquid is slightly curved near the walls of the container due to a phenomenon known as **surface tension**. This is particularly prominent in narrow tubes like the burette and pipette. This curved surface of the liquid is known as **meniscus**.

For liquids like water and alcohol the curvature is concave, whereas for liquids like mercury the curvature is convex.

While reading the liquid level in a burette, pipette, etc., the lower meniscus is taken into consideration for liquids like water and the upper meniscus for liquids like mercury.

Determine the Volume of Irregular Solids

Solids Heavier than Water and Insoluble in Water

- Take some water in a measuring jar and note the level of water, $V_1 \text{ cm}^3$.
- Immerse a solid by suspending from a string. Note the new level of water, $V_2 \text{ cm}^3$.
- Volume of the solid = $(V_2 - V_1) \text{ cm}^3$.

Solids Lighter than Water and Insoluble in Water

- Immerse a sinker (a heavy solid, like a stone) in a measuring jar containing some water and note the level of water, $V_1 \text{ cm}^3$.
- Tie the light solid, whose volume is to be determined, to the sinker and lower the combination into the water.
- Note the new level of water, $V_2 \text{ cm}^3$.
- Volume of the solid = $(V_2 - V_1) \text{ cm}^3$.

Determine the Average Volume of Lead Shots

- Take some water in a measuring jar and note the level of water $V_1 \text{ cm}^3$.
- Drop n lead shots gently into the water.
- Note the new level of water $V_2 \text{ cm}^3$.
- Average volume of a lead shot = $\frac{V_2 - V_1}{n} \text{ cm}^3$

Determine the Volume of a Solid by Using the Overflow Jar

- Fill the overflow jar with water till the water just starts overflowing through the spout.
- Keep a graduated measuring jar under the spout.
- Lower gently the solid whose volume is to be determined.
- Note the volume, $V \text{ cm}^3$ of the water that overflows into the measuring jar.
- The volume of the solid = volume of the water displaced = $V \text{ cm}^3$.

Determine the Volume of a Single Drop of Water

- Fix a clean burette upright to a stand.
- Fill it with water.
- Remove any air bubbles by opening the tap for some time.
- Note the level, V_1 , of water in the burette, say $V_1 = 60 \text{ cm}^3$.
- Allow the water to trickle slowly, drop by drop, counting the number of drops (n) at the same time.

- Close the tap when water level touches $V_2 = 40 \text{ cm}^3$ mark.
- It means $V_1 - V_2 = 60 - 40 = 20 \text{ cm}^3$ of water has drained out.
- The average volume of a drop of water = $20/n \text{ cm}^3$.

MEASUREMENT OF DENSITY

Density of a substance is mass per unit volume. It is a derived quantity. The unit of density in S.I. System is kilogram per metre³ (kg m^{-3}) and in CGs system, it is gcm^{-3}

e.g., density of water = $1 \times 10^3 \text{ kgm}^{-3}$

e.g., density of steal = $7.8 \times 10^3 \text{ kgm}^{-3}$

e.g., density of air = $1.3 \times 10^{-3} \text{ kgm}^{-3}$

Relative Density (or specific gravity) of a substance is the ratio of density of the substance to the density of water. Since this is a ratio of densities, it is a mere number without any units. It gives us an idea as to how dense or heavy the substance is, in comparison with water. R.D. of steal is 7.8 means steal is 7.8 dencer than water.

Determination of the Density of Solids

The mass of the given body is determined using a physical balance and it's volume is determined by displacement method. (Point 4 on pg 1.17)

The density of the solid is calculated using the expression

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Example: Suppose mass is 80g and volume is 10 cm^3 .

Then Density, $\rho = \frac{M}{V} = \frac{80 \times 10^{-3} \text{ kg}}{10 \times 10^{-6} \text{ m}^3} = 8 \times 10^3 \text{ kgm}^{-3}$.

Determination of the Density of Liquids Using a Specific Gravity Bottle

Density bottle or specific gravity bottle is a glass bottle with a long narrow neck and a glass stopper with a hole fitted in to the neck, designed to hold a specific volume of liquid indicated on the bottle.

The specific gravity bottle is washed and dried. The mass of the empty bottle (m_1) is determined using a physical balance. The bottle is filled with water and the stopper is replaced. The bottle is wiped dry from outside and the mass (m_2) is determined. Now the bottle is emptied, dried and again filled with the given liquid. The bottle is again wiped dry from outside and the mass (m_3) is determined.

Taking the density of water as 1 g cm^{-3} , the volume of the bottle = mass of the water filled in it = $(m_2 - m_1) \text{ cm}^3$.

Density of the liquid is calculated from the expression,

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{m_3 - m_1}{m_2 - m_1} \text{ g cm}^{-3}$$

Determination of the Density of Air

A round bottom flask, fitted with a rubber bung at its neck, is taken. A glass tube is passed through the bung and a rubber tube with clamp is fitted to the glass tube. The air from the flask is removed by connecting it to a vacuum pump and the clamp on the tube is closed. The mass of the flask (m_1) along with the bung, etc., is then determined. Maintaining the temperature of the flask constant (room temperature) throughout, the clamp is opened and the flask is once again filled with dry air (by allowing it to pass through calcium chloride). The mass of the flask (m_2) is determined. The volume of air ($V =$ volume of the flask) is determined by filling it with water and measuring the volume of water by pouring it into a measuring jar.

The density of air is calculated from the expression,

$$\text{Density of air} = \frac{m_2 - m_1}{V} \text{ g cm}^{-3}$$

Care should be taken that the atmospheric pressure and the temperature are maintained constant throughout the experiment. The density of air at S.T.P. is about $0.00129 \text{ g cm}^{-3}$ (1.29 kg m^{-3})

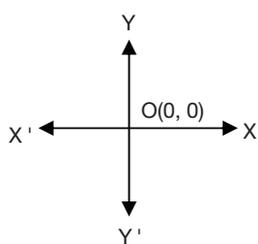


FIGURE 1.15

GRAPH

Graph is a pictorial presentation of the variation of one quantity with respect to another quantity.

Generally a graph sheet is divided into four quadrants by using two mutually perpendicular lines, X^1X and Y^1Y named as X -axis and Y -axis, respectively. The X -axis moves from left to right and the Y -axis from bottom to top. The point of intersection O is the origin and is always assigned with co-ordinates $(0, 0)$.

Two axes are labelled with two quantities. Generally X -axis is assigned with an independent quantity and Y -axis with a dependent quantity. Scale should be selected such that the maximum portion of the graph sheet (more than half) can be used. Scale should be such that the graph sheet can be further divided easily for subdivisions.

Example: 2, 5, 10, 20 are preferable to 3, 6, etc.

In the case of very large or small values, some multiplying factor can be used. Before plotting a graph the measurements made in an experiment are recorded in a tabular form. For example, let us take the plotting of $s - t$ (distance-time) graph for a body moving with uniform velocity.

The displacement of the body at the end of equal time intervals are recorded as shown in the table. Since distance depends on time, distance is dependent variable. So, we will take it on Y-axis. Now, we select a convenient scale for each axis. On X-axis, it is 2 cm = 1 s and on Y-axis, it is 2 cm = 5 cm.

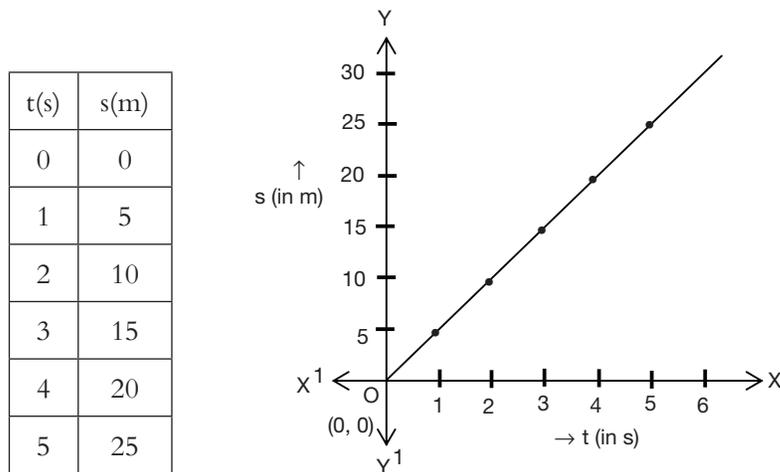


FIGURE 1.16

Then, we have to mark each data on the graph with a sharp marker. This is called ‘Plotting’. Maximum number of marks (points) should be joined such that a smooth curve, called best fit curve or smooth line, called best fit line is obtained.

Uses of Straight Line Graph

1. The slope of a straight line graph gives us the variation of the quantity taken on the Y-axis with respect to the quantity taken on the X-axis.

Example: Slope of $s - t$ graph gives the velocity of the body.

Slope of the straight line can be determined by taking two reference points $A(x_1, y_1)$, $B(x_2, y_2)$.

$$\text{Slope} = \frac{y_2 - y_1}{x_2 - x_1} \text{ unit}$$

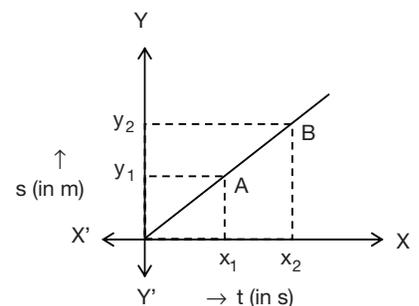


FIGURE 1.17

2. From a graph it is also possible to determine the value of one quantity for a given value of another quantity.

From the above graph, the displacement of the body at the end of 10 s can be determined.

3. A straight line graph gives us the information about the proportionality between the two plotted quantities.

From the above graph, it can be understood that $s \propto t$.

4. A graph drawn between the velocity of a uniformly accelerating body starting with a non-zero velocity makes an intercept on Y-axis. This intercept gives us the initial velocity of body.

Scientific Notation

Bigger objects like the Earth, the sun and the universe constitute the macrocosm, whereas smaller objects like the atoms, cells and bacteria constitute the microcosm.

The magnitude of any quantity can be written as a product of a number between 1 and 10 and a number which is a power of 10 (exponential part).

Example:

$$13540 = 1.354 \times 10^4$$

$$0.000125 = 1.25 \times 10^{-4}$$

The exponential part in such a representation is known as the order of magnitude.

Standard Prefixes Used with the S.I. System of Units

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci-	D
10^{21}	zetta	Z	10^{-2}	centi-	c
10^{18}	exa	E	10^{-3}	milli-	M
10^{15}	peta	P	10^{-6}	micro-	μ
10^{12}	tera	T	10^{-9}	nano	n
10^9	giga	G	10^{-12}	pico	p
10^6	mega-	M	10^{-15}	femto	F
10^3	kilo-	k	10^{-18}	atto	a
10^2	hecta-	h	10^{-21}	zepto	z

Errors and Accuracy

Degree of accuracy is the extent to which one can measure a quantity without any error.

There are two types of errors, considered, in general. They are:

1. Absolute error = Measured value – True value
2. Relative error = $\frac{\text{Absolute Error}}{\text{Actual Value}}$. If the relative error is expressed in percentage, it is called percentage error.

Percentage errors: The percentage error is defined as

$$\text{Percentage error} = \frac{\text{Absolute Error}}{\text{Actual Value}} \times 100$$

Effect of Combining Errors

It is not possible to produce greater accuracy by mathematical manipulations, like addition, subtraction, multiplication, division, etc.

When a number of values are added or subtracted, the result cannot be more accurate than the least accurate value.

When a number of values are multiplied or divided, percentage error in the result is the sum of the percentage errors of separate values used.

Significant Figures

The digits, whose values are accurately known in a particular measurement, are called its significant figures. The digit on the extreme right known as the doubtful digit. It is also called least significant digit. The digit on the extreme left is called most significant digit.

Rules for Determining Significant Figures

All non-zero digits are significant figures.

Example: 1234 m has 4 significant figures, 1, 2, 3 and 4.

All zeroes occurring between non-zero digits are significant figures.

Example: 10234 kg has 5 significant figures, 1, 0, 2, 3 and 4.

All zeroes to the right of the last non-zero digit are not significant.

Example: 1230 has only 3 significant figures, 1, 2 and 3. Zero is not significant

All zeroes to the right of the decimal point and to the left of a non-zero digit are not significant.

Example: 0.00123 m has only 3 significant figures, 1, 2 and 3.

All zeroes to the right of a decimal point and to the right of a non-zero digit are significant.

Example: 0.2300 has 4 significant figures, 2, 3, 0 and 0. Zero to the left of decimal point is not significant.

Rounding off the Digits

If the digit next to the one to be rounded off is greater than 5, the digit to be rounded off is increased by 1.

Example: $12.47 = 12.5$

If the digit next to the one to be rounded off is less than 5, the digit to be rounded off is left unchanged.

Example: $12.43 = 12.4$

If the digit next to the one to be rounded off is equal to 5, the digit is increased by one if it is odd, e.g., $12.\underline{3}5 = 12.4$ and it is left unchanged if the digit is even, e.g., $12.\underline{8}5 = 12.8$.

While **adding** or **subtracting** the measured numbers, write the numbers one below the other with all the decimal points in one line. After adding (or subtracting as the case may be) locate the first column from the left, that has a doubtful digit. All the digits to the right of this column are dropped after rounding off that digit.

Example:

$$32.76 + 0.0811 + 282.5 = ?$$

32.76

0.0811

282.5

315.3411 \Rightarrow 315.3

While **multiplying** or **dividing**, the number of the significant digits in the answer is equal to the least number of significant figures in the numbers multiplied (or divided as the case may be).

The insignificant digits are dropped from the result, after rounding off, if they appear after the decimal point. The insignificant digits are replaced by a zero if they appear before the decimal point.

Example:

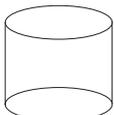
$$\frac{2014 \times 31.5}{11.9} = 5331.1764\dots = 5330,$$

since 11.9 and 31.5 have only three significant digits each.

\therefore Result should also have these significant figures.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

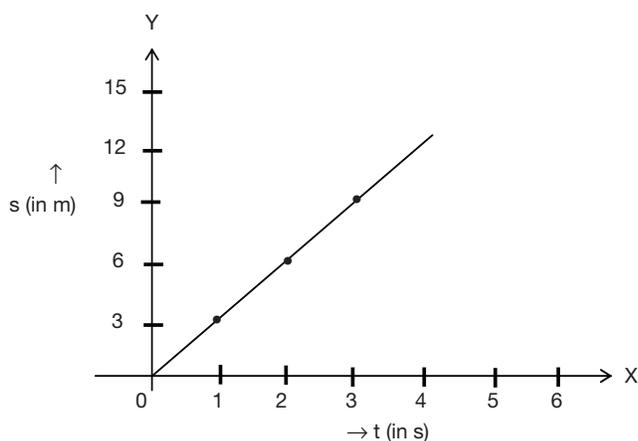
- Define relative density.
- The value of $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ and $g = 9.8 \text{ m s}^{-2}$. The unit of g/G in C.G.S system is _____.
- The number of significant figures in 10.02 is _____.
- What is the principle of working of a physical balance?
- What are the C.G.S. and S.I. units of area? Give the relationship between them.
- The smallest measurement that can be made accurately by an instrument is called _____.
- A rectangular metal sheet of area 2 m^2 is rolled to a cylinder of volume $(4/p) \text{ m}^3$. The radius of the cylinder, thus, formed is _____ m. 
- What is the least count of a standard screw gauge?
- Define significant figures.
- In a standard vernier callipers, 'N' vernier scale divisions are equal to _____ main scale divisions.
- Name the different parts of a screw gauge.
- If the energy of a photon is given by, $E = \frac{hc}{\lambda}$, where h is the Planck's constant, c is the velocity of light and λ is the wavelength of the radiation, then the unit of Planck's constant is _____.
- The distance between the two consecutive threads of a screw is known as the _____ of the screw.
- What is the principle of a screw gauge?
- Define light year.
- The time taken by a seconds pendulum to go from one extreme end to the other is _____.
- Define the pitch of a screw.
- Area and volume are not _____ quantities.
- If the length of a vernier scale having 25 divisions correspond to 23 main scale divisions, and given that 1 M.S.D. = 1 mm, the least count of the vernier callipers is _____.
- The diameter of a wire was measured as 1.65 mm with a certain faulty screw gauge, when the correct diameter was 1.60 mm. What type of error does the faulty screw gauge have?
- Define the least count of a vernier callipers.
- If surface tension is defined as force per unit length, then the dimensional formula of surface tension is _____.
- Define density.
- Define resting point and zero-resting point.
- The time periods of two simple pendula, having different lengths, is the same on two different planets. If the lengths of the two pendula are in ratio of 1 : 9, then the ratio of the accelerations due to gravity on the two planets is _____.
- What is the principle of vernier callipers?
- The diameter of a rod as measured by a screw gauge of pitch 0.5 mm is 8.3 mm. The pitch scale reading is _____.
- Define
 - Solar day.
 - Mean solar day.
- If the length of a seconds pendulum on a planet is 2 m, then the acceleration due to gravity on the surface of that planet is _____ (Take the acceleration due to gravity on the surface of the Earth = 9.8 m s^{-2})
- What is meant by degree of accuracy?

Short Answer Type Questions

- State the rules used for significant figures while rounding off the digits.
- What are the precautions that should be taken while using a physical balance?
- Discuss the zero error of a vernier callipers and state how it can be corrected.
- Describe a method to find the density of an object that is lighter than water.



35. A vernier calliper has 20 divisions on vernier scale and its M.S.D. is 0.5 mm. When a hollow cylinder is held by its internal jaws the M.S.R. and V.C.D. of callipers are 1.2 cm and 10, respectively. Find the radius of cross section of the cylinder.
36. If the callipers used in the above problem is faulty and the positive zero error coinciding division is 2, then find out the actual radius of the cylinder.
37. Define least count. Describe the method to find the least count of a screw gauge.



38. A displacement-time graph of a body moving with uniform velocity is shown in the figure. Find out its velocity and its displacement at the end of 5 seconds.
39. Write the expressions for pitch and least count of a screw gauge.
40. Discuss the types of zero errors in vernier callipers and state how they are corrected?
41. The head scale of a screw gauge has 200 divisions. Its head advances by 1 mm for 2 complete rotations of its head. Find its pitch and least count.
42. Describe briefly the method to determine the density of an irregular body.
43. A screw gauge has a positive error of 4 divisions. When this screw gauge holds a sphere, the main scale reading is 4 mm and the head scale coinciding division is 24. If its least count is 0.01 mm, find out the volume of the sphere.
44. Draw a neat sketch of a screw gauge. Discuss the positive and negative zero errors in a screw gauge and their corrections.
45. What is the effect of combining errors?

Essay Type Questions

46. Explain the principle of a screw gauge and explain the method of determining the diameter of a wire.
47. State the rules for determining the number of significant digits for addition and multiplication. Give examples?
48. Describe an experiment to find the volume of a sphere using vernier callipers.
49. Describe a method to determine the mass of a body using a physical balance.
50. Draw a neat sketch of a physical balance and name the various parts.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- A simple pendulum can be used to determine acceleration due to gravity at a given place.
- If the zeroth division on the vernier scale and the main scale do not coincide, when the jaws are in contact, then there exists an error.
- If p is the pitch of a screw, then the distance by which the screw advances, when given n rotations, is $\frac{p}{n}$.
- If the percentage errors in the measurement of length and breadth of a rectangle are 2% and 3%, respectively, then the percentage error in the determination of the area is 5%.



5. Velocity gradient is defined as 'change in velocity per unit distance'. Then its unit in F.P.S. system is s^{-1} .
6. $10^6 \mu\text{m}$ are equal to one metre.
7. The least count (the minimum weight that can be weighed) of a physical balance is one gram.

Direction for questions 8 to 14

Fill in the blanks.

8. In a spring balance, the extent of a pull of spring is _____ to the magnitude of the weight (force) applied on it.
9. If N divisions on the vernier scale are equal to $(N - 2)$ divisions on the main scale, then the least count is _____.
10. The order of magnitude of $0.00045726 \text{ m s}^{-1}$ is _____.
11. When the jaws of a standard vernier calipers are closed, if the n th division of the vernier scale coincides with the n th M.S.D., the zero error is _____.
12. The least count of a Screw gauge having 1 mm pitch and 100 circular scale divisions is _____ μm .
13. The least count of a vernier calipers having 20 vernier divisions when 1 M.S.D. = 0.1 cm is _____ cm.
14. Given the specific gravity of gold as '19', the mass of 100 cm volume of gold is _____ kg.

Direction for question 15

Match the entries given in Column A with appropriate ones from Column B.

15. Match items in Column A with these in Column B.

Column A	Column B
A. Positive zero error ()	a. Ratio
B. Density ()	b. Significant figures = 2
C. Least count of vernier calipers ()	c. Pitch per C.S.D.
D. Density ()	d. (V.C.D.) x (L. C.)
E. 2.200 ()	e. Zero of the circular scale above the index line
F. Momentum ()	f. 1 M.S.D. per vernier division
G. Relative Density ()	g. Significant figures = 4

H. Negative zero error ()	h. Kg m^{-3}
I. 2200 ()	i. $[\text{M}^1\text{L}^{-3}\text{T}^0]$
J. Least count of a screw gauge ()	j. $[\text{M}^1\text{L}^1\text{T}^{-1}]$

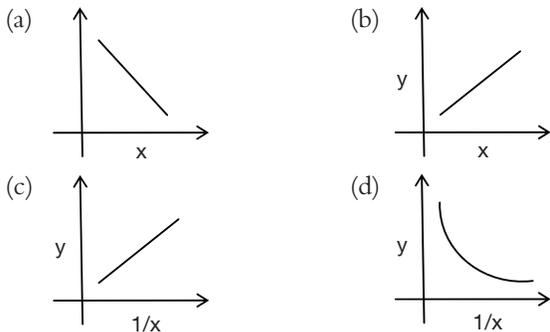
Direction for questions 16 to 45

For each of the questions, four choices have been provided. Select the correct alternative.

16. If the conductance of a conductor (G) is $\frac{I^2 t}{W}$, where I is current, t is time and W is work done, then the unit of conductance expressed in terms of fundamental units is _____.
 - (a) $\frac{A^2 s^3}{\text{kg}^2 \text{m}}$
 - (b) $\frac{A^2 s^3}{\text{kg}^2 \text{m}}$
 - (c) $\frac{A^2 s^3}{\text{kgm}^2}$
 - (d) $\frac{A^2 s^3}{\text{kg}^2 \text{m}^{-2}}$
17. The length of one main scale division of a given vernier calipers is 1 cm. When the jaws are in contact, the last division of the vernier scale coincides with 99th mark of the main scale. Then the least count of the calipers is _____.
 - (a) 0.01 mm
 - (b) 0.01 cm
 - (c) 0.1 cm
 - (d) 0.1 mm
18. The sensitivity of a physical balance is increased by the use of _____.
 - (a) knife edges
 - (b) leveling screws
 - (c) plumb line
 - (d) light pans
19. In a simple pendulum experiment, the percentage errors in the measurement of g and l are $\alpha\%$ and $\beta\%$, respectively, then the maximum error in measuring T will be _____.
 - (a) $\frac{1}{2}(\alpha + \beta)\%$
 - (b) $\frac{1}{2}(\alpha - \beta)\%$
 - (c) $\frac{1}{2}(\beta - \alpha)\%$
 - (d) $2(\beta - \alpha)\%$
20. The least count of a vernier calipers is 0.025 mm. If the 12th division of the vernier scale coincides with a main scale division and the zero of the vernier scale is to the right of the zero of the main scale, then the zero error is _____.
 - (a) +0.3 cm
 - (b) +0.03 mm
 - (c) +0.12 mm
 - (d) None of the above



21. Two variables x and y vary such that $xy = \text{constant}$. Which of the following graphs represent the above relationship?



22. The difference between ZRP and HRP of a physical balance when 47.86 g of a substance is placed in its pans is 3. When 10 mg is added in its pans, the difference between HRP and LRP is obtained as 5. The most accurate mass of the body is _____ g.

- (a) 47.875 (b) 47.845
(c) 47.866 (d) 47.854

23. If 17 divisions of the circular scale of a screw gauge are below the index line of the pitch scale, then the zero error is _____ circular divisions.

- (a) +17 (b) -17
(c) 83 (d) 34

24. Which of the following measurements is most precise?

- (a) 5 cm (b) 5.00 cm
(c) 5.000 cm (d) 5.00000 cm

25. The length and breadth of a rectangle were measured using an instrument and the area was determined as 28.83 cm². The instrument used could be _____.

- (a) a vernier caliper whose least count is 0.1 mm
(b) a metre scale
(c) a vernier caliper whose least count is 0.3 mm
(d) None of the above

26. The time period of two pendulums of same length oscillating on different planets A and B is 2 s and 3 s, respectively. The ratio of acceleration due to gravity on the two planets is _____.

- (a) 9 : 4 (b) 3 : 2
(c) 2 : 3 (d) 4 : 9

27. If the zero error correction of a screw gauge with least count 0.01 mm is +0.05 mm,

- (a) the number of C.S.D. is 100, and the zero of the circular scale is 5 divisions above the index line.

(b) the number of C.S.D. is 100, and the zero of the circular scale is 5 divisions below the index line.

(c) the number of C.S.D. is 50, and the zero of the circular scale is 5 divisions above the index line.

(d) Both (1) and (3)

28. If a graph is plotted between the length of a pendulum (l) and its time period (T), then the two quantities are plotted as _____.

- (a) l along X-axis
(b) T along Y-axis

- (a) Only (a) is true
(b) Only (b) is true
(c) Both (a) and (b) are true
(d) Both (a) and (b) are false

29. To construct a seconds pendulum having a length of 100 cm, the value of g should be?

- (a) $\pi \text{ m s}^{-2}$ (b) $100 \pi \text{ m s}^{-2}$
(c) $\frac{1}{\pi^2} \text{ m s}^{-2}$ (d) $\pi^2 \text{ ms}^{-2}$

30. When the jaws of a vernier calipers are in contact, the eight division of the vernier scale coincides with the seventh division of the main scale. If N is the number of divisions on the vernier scale and the least count is x , then the zero error correction is

- (a) $-8x$ (b) $(N - 8)$
(c) $-(N - 8)x$ (d) $+8x$

31. The percentage errors in the measurement of the length (L) and breadth (B) of a rectangle are $l\%$ and $b\%$, respectively. Then the percentage error in the calculation of the area will be _____.

- (a) $(lb)\%$ (b) $(l + b)\%$
(c) $(L + l)(B + b)$ (d) $Lb + BL$

32. The least count of a vernier calipers is 0.01 cm and if the zero mark of the vernier scale is to the right of zero of the main scale and the vernier coincidence is 7 when the jaws are in contact, then the zero error is _____ cm.

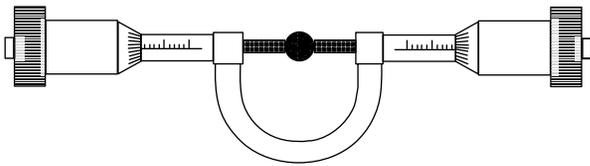
- (a) $+6 \times 0.01$ (b) $+7 \times 0.01$
(c) -7×0.01 (d) -6×0.01

33. The thimble of a screw gauge has 50 divisions. The spindle advances 1 mm when the screw is turned through two revolutions. Then the pitch of the screw is _____.

- (a) 0.5 mm (b) 0.15 mm
(c) 0.5 mm (d) 0.01 mm



34. The ZRP of a physical balance is 10.5 while finding mass of a substance. For a weight 34.23 g the resting point was found to be 8.5. when 10 mg was removed the resting point was 11.0. The most accurate mass of the substance is _____ g.
- (a) 34.15 (b) 34.31
(c) 34.238 (d) 34.222
35. The smallest weight that can be measured accurately using a physical balance is _____ g (grams).
- (a) 10 (b) 0.001
(c) 0.1 (d) 0.01
36. A vernier calipers and a screw gauge have the same least count and zero error with the difference that the vernier calipers has positive zero error and the screw gauge has negative zero error. The number of circular scale divisions on the screw gauge is twice the number of vernier scale divisions on the vernier calipers, and the pitch of the screw gauge is 1 mm.
- If the vernier coinciding division and the circular scale reading for the zero error on the instruments are 3 and 97, respectively, then find the number of vernier scale divisions on the vernier calipers.
- (a) 10 (b) 200
(c) 50 (d) 100
37. A screw gauge has as many circular scale divisions as there are threads in 5 cm length of the screw. If the pitch of the screw is 0.5 mm, then what is its least count?
- (a) 0.001 mm (b) 0.001 cm
(c) 0.0005 mm (d) 0.0005 cm
38. A combined double screw gauge as shown in the figure is used as



If the readings on the two scales with the tips of the screws touching each other are 2.97 mm and 6.04 mm, when a rod is held between the screws readings are 12.55 mm and 5.96 mm, what is the diameter of the rod?

- (a) 9.5 mm
(b) 9.6 mm
(c) 9.58 mm
(d) Not possible to determine
39. The least counts of a vernier calipers and a screw gauge are in the ratio of 5 : 1. The main scales of

both the instruments are marked in mm. The zero error on the vernier calipers is +0.15 mm where as that on screw gauge is -0.06 mm. If the diameter of a rod lies between 0.9 cm and 1.0 cm, and x and y are the VCD and CSR on the two instruments, relation between x and y given that the number of C.S.D. = 100, is

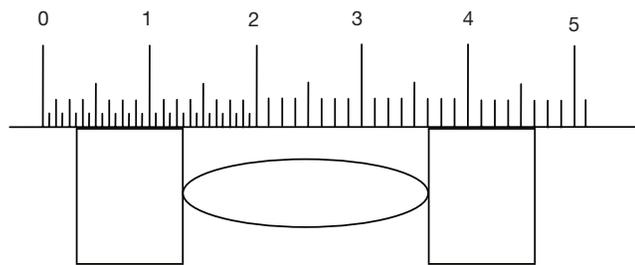
- (a) $x - 5y = 9$ (b) $5x - y = 9$
(c) $x - 5y = 21$ (d) $5x - y = 21$
40. The mass of a certain amount of salt determined by two different persons was found to differ by 200 mg, one using the left pan for the weights and the other using the right pan. Which of the following statement is false?
- (a) There is a zero error in the balance.
(b) The true mass of salt is the mean of the two weighings.
(c) The true mass is 100 mg less than the higher value.
(d) The true mass is 200 mg more than the lower value.
41. The lengths of two simple pendula are in the ratio of 2 : 3 and the ratio of the acceleration due to gravity at the two places where they are set up is 3 : 2. The ratio of their frequencies is
- (a) 3 : 2 (b) 4 : 9
(c) 9 : 4 (d) 2 : 3
42. Pendulum A is x cm shorter than a seconds pendulum and pendulum B is x cm longer than the seconds pendulum. The ratio of their time periods is 3 : 4. The length of the pendulum with higher frequency is
- (a) 86 cm. (b) 114 cm
(c) 128 cm. (d) 72 cm.
43. If surface tension is defined as force per unit length, which of the following quantities will have the same units as surface tension?
- (a) work \times volume \times speed
(b) $\frac{\text{work} \times \text{velocity}}{\text{volume}}$
(c) $\frac{\text{work} \times \text{velocity}}{\text{rate of change of volume}}$
(d) $\frac{\text{work}}{\text{time}} \times \frac{\text{volume}}{\text{velocity}}$
44. If the each of the units of force, velocity and frequency are doubled, how many times has the unit of mass become?
- (a) doubled (b) four times
(c) halved (d) one-fourth



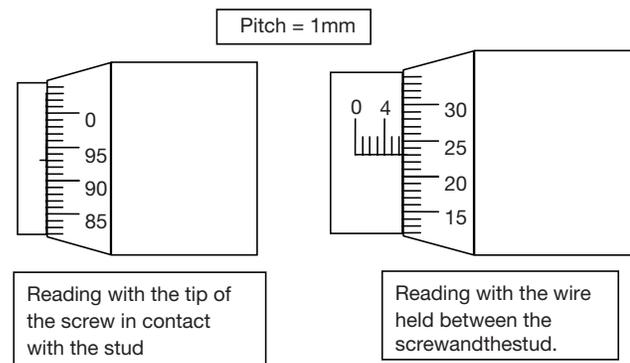
Level 2

45. The dimensional formula of a physical quantity is known to be $[M^1L^2T^{-3}]$. Write down the units of this quantity in C.G.S. and S.I. units and calculate the multiplication factor for conversion from S.I. to C.G.S. units.
46. The pitch of a screw gauge is 0.5 mm and the number of divisions on the circular scale is 100. When a glass plate is held between the studs of the screw gauge, the main scale reads 1.5 mm and the 69th division of the circular scale coincides with the index line of the main scale. What is the thickness of the glass plate?
47. A specific gravity bottle weight 10 g when it is empty. It weighs 100 g and 110 g when filled with an oil and water, respectively. What is the relative density of oil?
48. A vernier scale has 10 divisions. It slides over a main scale whose least count is 1.0 mm. If the number of divisions on the main scale, to the left-hand side of zero of the vernier scale is 4 and the 8th vernier scale division coincides with the main scale, find the measurement.
49. The fundamental frequency of a stationary wave formed in a stretched wire is $n = \frac{1}{2l} \sqrt{\frac{T}{m}}$ where 'l' is length of the vibrating wire, 'T' is the tension in the wire and 'm' is its mass per unit length. If the percentage error in measurement of l , T and m are $a\%$, $b\%$ and $c\%$, respectively, then find the maximum error in measuring n .
50. A vernier scale with 10 divisions slides over a main scale whose pitch is 0.5 mm (pitch = 1 M.S.D.). If a bob of diameter 9.75 mm is held between the jaws, determine the MSR and V.C.D. if
(a) there is no zero error
(b) the zero error = 0.35 mm
51. When the tip of the screw of a screw gauge is in contact with the stud, the zero of the circular scale is 3 divisions below the index line. To hold a wire the thimble is given a little over 3 rotations in the anti-clockwise direction and with wire held tightly the 32nd division of the circular scale is now in line with the base line. The pitch of the screw is 0.5 mm and the number of divisions on the circular scale are 100. Find the correct diameter of the wire.

52. A simple pendulum designed on the moon as a seconds pendulum is taken to a planet where the acceleration due to gravity on the surface is twice that on the Earth. If $g_{\text{earth}} : g_{\text{moon}} = 6 : 1$, find the period of oscillation of the pendulum on the planet mentioned above.
53. In the figure given above, the main scale is marked in inches. Determine the length of the object held between the two blocks. If 1 inch = 2.54 cm, find the length in cm.

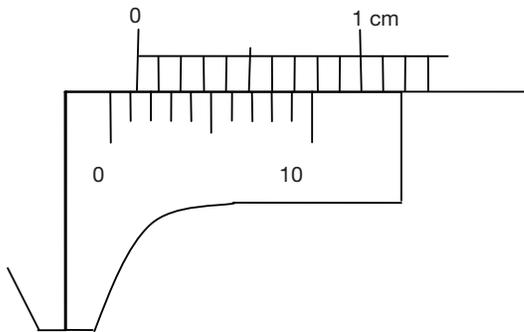


54. Find the ratio of the relative densities of two substances if their masses are equal when the volume of one is $1\frac{1}{2}$ times that of the other.
55. Find the area of cross-section of a rod, the diameter of which is measured with a screw gauge with readings as shown in the figure.



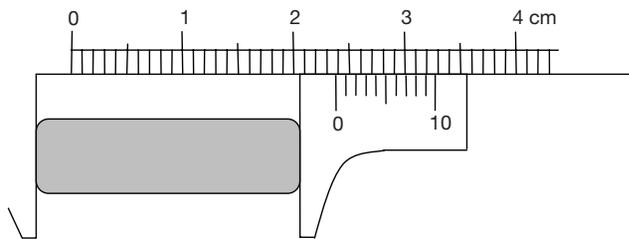
56. The working of a common balance or a physical balance is based on the 'Principle of moments'. A metre scale of uniform density is balanced at the centre. If a mass of 2 kg is suspended at an edge of the scale, then what mass should be suspended on other side at $1/4$ th length of the scale to maintain the horizontal position of the scale?
57. Determine the least count and the zero error of the vernier calipers shown in the figure below. What is the corresponding zero correction?





58. A pendulum clock in a museum was found to lose 1 minute in every 24 hours. What corrective measure should the curator of the museum undertake?
59. The corrected length of a rod when measured with the help of a vernier calipers is 25.4 mm.

(Refer the figure below)



Determine the zero error.

60. The following are the values known in a particular measurement, 30.56, 12.6, 21.09. What is the sum of the values when rounded off to one decimal point?
61. What is the dimensional formula of (a) volume (b) density and (c) universal gravitational constant 'G'. The gravitational force of attraction between two

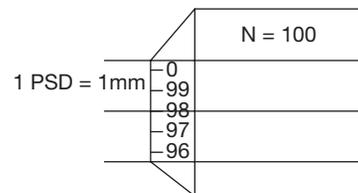
objects of masses m and m separated by a distance d is given by, $F = \frac{G m_1 m_2}{d^2}$

Where G is the universal gravitational constant.

62. The distance travelled by a body in different time intervals is tabulated as follows. Draw the distance time graph.

Time (s)	0	10	20	30	40
Distance (m)	0	40	80	120	160

63. 1 yotta meter is how many kilometer?
64. When the studs of a screw gauge are in contact the position of the head of the screw is as shown below, Determine the zero error.



65. Name the part of the physical balance which is used to increase its sensitivity.
66. The ZRP of a physical balance is 10.5 while finding mass of a substance. For a weight 34.23 g the resting point was found to be 8.5. When 10 mg was removed the resting point was 11.0, find the most accurate mass of the substance.
67. If the units of mass, length and time are doubled, then what happens to the unit of 'relative density'? Discuss.
68. An irregular solid, when immersed in water, displaces 374th litre of water. When immersed in a given liquid, it displaces 600 g of the liquid. What is the density of the liquid?

Level 3

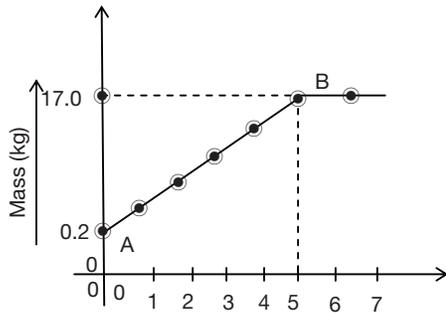
69. The dimensional formula of a physical quantity x is $[M^1L^2T^{-2}]$ and that of another quantity y is $[M^1L^1T^{-1}]$. If a third quantity z is directly proportional to the square of y and inversely proportional to x , then find the dimensional formula of z .
70. A simple pendulum is completely submerged under water. Discuss the variation in its time period.
71. The purpose of plumb line in a physical balance and in the hands of a mason is same. If so, what is that purpose? If it is absent in a physical balance, what

happens to the mass of a body measured in the balance?

72. A liquid flows into a vessel initially empty at a steady rate of $70 \text{ cm}^3 \text{ s}^{-1}$. The pictorial representation (graph) of the increase in the mass of the vessel with time is given below.
- (i) What does the point A represent?
- (ii) What does the horizontal line beyond B indicate?



- (iii) Find the capacity of the vessel.
 (iv) Find the density of the liquid.



73. The distance between two consecutive threads on the screw of a screw gauge is 0.5 mm. The number of divisions on the circular scale is 100. A wire is placed between the studs of the screw gauge. Find the diameter of the wire if the pitch scale shows 14th division and 40th circular division coincides with the base line. The given apparatus was detected to have negative zero error. The 90th division on the circular scale coincides with reference line, when the studs are in contact.
74. The divisions on the main scale of a screw gauge are 1 mm apart and the screw of the spindle advances by 5 main scale divisions when the spindle is given 5 complete rotations. How many divisions are to be provided on the circular scale for the least count of the instrument is to be $1\ \mu\text{m}$? What changes are required of the number of divisions can be only 500 for the same least count?
75. A vernier scale with 10 divisions slides over a main scale whose pitch is 0.5 mm (pitch = 1 MSD). If a bob of diameter 9.75 mm is held between the jaws, determine the M.S.R and V.C.D if
 (a) there is no zero error.
 (b) the zero error = 0.35 mm.
76. Using a screw gauge without any zero error, the diameter of a wire was determined as 2.74 mm. If the screw advances 5 mm when the thimble is given 10 complete rotations, what are the possible values of the pitch scale reading, circular scale reading and the least count if N is the number of head scale divisions?
77. In a physical balance when the beam is released with empty pans, the successive left and right turning points are obtained as 5, 6, 6 and 18, 18, respectively. After placing the substance whose mass is to be determined and when the beam is released, the resting point obtained is 13. When 10 mg is added to the pan, the resting point is obtained as 11. If the mass at LRP is 60 g, find the correct mass of the body corrected to a milligram.
78. To determine the weight of a solid body lighter than water, a sinker is used. The solid body of density $0.5\ \text{g cm}^{-3}$ is tied to the sinker of volume $50\ \text{cm}^3$ and the combination is immersed into water. If the volume of water displaced is $80\ \text{cm}^3$, find the weight of the body.



CONCEPT APPLICATION

Level 1

True or false

1. True 2. True 3. False 4. True 5. True 6. True 7. False

Fill in the blanks

8. proportional 9. $\frac{1\text{M.S.D.}}{2}$ 10. -4 11. $+n \times \text{L.C.}$ 12. $10 \mu\text{m}$ 13. 0.005 cm 14. 1.9

Match the following

15. A : d B : h C : f D : i E : g F : j G : a H : e I : b J : c

Multiple Choices

16. (c) 17. (b) 18. (a) 19. (a) 20. (d) 21. (c) 22. (c) 23. (a) 24. (d) 25. (b)
 26. (a) 27. (d) 28. (c) 29. (d) 30. (b) 31. (b) 32. (b) 33. (b) 34. (c) 35. (d)
 36. (b) 38. (d) 39. (a) 40. (d) 41. (d) 42. (a) 43. (d) 44. (c)

Explanation for questions 31 to 45:

31. Errors are additive, hence, percentage error in area = $(a\% + b\%)$

32. The error is positive.

$$\therefore \text{Positive zero error} = +n \times \text{L.C.} = +7 \times 0.01.$$

33. Pitch of the screw = $\frac{\text{Distance moved by spindle}}{\text{Number of rotations}}$
 $= \frac{1 \text{ mm}}{2} = 0.5 \text{ mm}$

34. Correction = $-\left(\frac{\text{ZRP} - \text{LRP}}{\text{HRP} - \text{LRP}}\right) \times 10 \text{ mg}$
 $= -\left(\frac{10.5 - 8.5}{11.0 - 8.5}\right) \times 10 \text{ mg} = \frac{-2}{2.5} \times (10 \text{ mg})$
 $= -8 \text{ mg} = -0.008 \text{ g}$

$$\text{Correct mass} = 34.23 \text{ g} - 0.008 \text{ g} = 34.222 \text{ g}$$

35. zero error of vernier calipers = zero error of screw gauge

$$x \text{ L.C.} = (N^1 - y) \text{ L.C.}$$

$$x = N^1 - y$$

$$x + y = N^1$$

$$N^1 = 3 + 97 = 100$$

$$N = \frac{1}{2} N^1 = 50$$

36. The smallest weight that can be measured accurately using a physical balance is 1 mg i.e., 0.001 g.

37. Let the n rotations advance the screw by 5 cm

$$\therefore \text{Pitch} = \frac{5}{n} \text{ cm}$$

But pitch = 0.5 mm = 0.05 cm

$$\therefore \frac{5}{n} = 0.05$$

$$n = 10$$

Thus, there are 100 threads in 5 cm of the screw, i.e., 100 circular scale divisions.

$$\therefore \text{L.C.} = \frac{0.05}{100} = 0.0005 \text{ cm}$$

38.

	Scale 1	Scale 2	Total
With rod	12.55	5.96	18.51
Without rod	2.97	6.04	9.01
Movement of screw	9.58	- 0.08	= 9.5 mm

\therefore Diameter of the rod = 9.5 mm

39. Least count of screw gauge = $\frac{1}{100} = 0.01 \text{ mm}$
 Least count of vernier calipers

$$= 5 \times 0.01 = 0.05 \text{ mm}$$

Let d be the diameter of the rod

$$9 \text{ mm} < d < 10 \text{ mm}$$

$$d = 9 + x \times 0.05 - 0.15 \text{ by vernier caliper}$$

$$d = 9 + y \times 0.01 + 0.06 \text{ by screw gauge}$$

$$5x - 15 = y + 6$$

$$5x - y = 21$$



40. $l_1 : l_2 = 2 : 3$

$g_1 : g_2 = 3 : 2$

$$\frac{T_1}{T_2} = \frac{\sqrt{l_1/g_1}}{\sqrt{l_2/g_2}} = \sqrt{\frac{4}{9}}$$

$$\frac{T_1}{T_2} = \sqrt{\frac{4}{9}} = \frac{2}{3} \therefore \frac{f_1}{f_2} = 3 : 2$$

41. $l_A = l - x$

$l_B = l + x$

Where $l = 100$ cm

$l_A < l_B$

$T_A < T_B$

$$\frac{T_B}{T_A} = \frac{4}{3}$$

$$\therefore \sqrt{\frac{l_B}{l_A}} = \frac{T_B}{T_A}$$

$$\frac{l+x}{l-x} = \frac{16}{9}, \frac{l}{x} = \frac{25}{7}$$

$$x = \frac{7}{25} \times 100 = 28 \text{ cm}$$

Higher frequency \Rightarrow lower time period Regular shorter pendulum = pendulum A

\therefore length of pendulum A = $100 - 28 = 72$ cm

42. Units of Surface Tension = N m^{-1}

$$\text{work} \times \text{volume} \times \text{speed} = (\text{N m}) \times (\text{m}^3) \times \text{m s}^{-1} = \text{N m}^5 \text{ s}^{-1}$$

$$\frac{\text{work} \times \text{velocity}}{\text{volume}} = \frac{(\text{N m}) \times (\text{m s}^{-1})}{\text{m}^3} = \text{N m}^{-1} \text{ s}^{-1}$$

$$\frac{\text{work} \times \text{velocity}}{\text{rate of change of volume}} = \frac{(\text{N m}) \times (\text{m s}^{-1})}{(\text{m}^3 \text{ s}^{-1})}$$

$$\frac{\text{work}}{\text{time}} \times \frac{\text{volume}}{\text{velocity}} = \frac{\text{N m}}{\text{s}^{-1}} \times \frac{\text{m}^3}{\text{m s}^{-1}} = \text{N m}^3 \text{ s}^2$$

43. $2 \text{ N} = 1 \text{ N}_1 = 1 \text{ kg}_1 \text{ m}_1 \text{ s}_1^{-2}$

$2 (\text{m s}^{-1}) = \text{m}_1 \text{ s}_1^{-1}$

$2 \text{ s}^{-1} = \text{s}_1^{-1}$

$\therefore 1 \text{ m} = 1 \text{ m}_1$

$2 \text{ kg m s}^{-2} = 1 \text{ kg}_1 \text{ m}_1 \text{ s}_1^{-2}$

$$1 \text{ kg}_1 = 2 \text{ kg} \frac{1 \text{ m } 1 \text{ s}^{-2}}{1 \text{ m}_1 1 \text{ s}_1^{-2}}$$

$$1 \text{ kg}_1 = 2 \text{ kg} \left(\frac{1 \text{ m}}{1 \text{ m}} \right) \left(\frac{1 \text{ s}^{-1}}{1 \text{ s}_1^{-1}} \right)^{+2}$$

$$= 2 \text{ kg } 1 \times \left(\frac{1}{2} \right)^2 = \frac{2}{4} \text{ kg} = \frac{1}{2} \text{ kg}$$

Level 2

44. (i) M, L and T in the dimensional formula are replaced by the units of mass, length and time, respectively, in the corresponding system

(ii) $1 \text{ kg m}^2 \text{ s}^{-3} = 10^7 \text{ g cm}^2 \text{ s}^{-3}$

45. (i) Find the thickness of the glass plate using the formula $\text{TR} = \text{PSR} + (\text{C.S.D.} \times \text{L.C.})$

(ii) $\text{L.C.} = \frac{\text{Pitch}}{\text{N}}$

(iii) Thickness = 1.845 mm

46. (i) The mass of the empty specific gravity bottle = m_1

(ii) The mass of empty specific gravity (SG) bottle + oil = m_2

(iii) The mass of empty specific gravity bottle + water = m_3

(iv) The mass of oil = $m_2 - m_1$

(v) The mass of water = $m_3 - m_1$

(vii) The relative density of oil =

$$\frac{(m_2 - m_1)/v}{(m_3 - m_1)/v} = \frac{m_2 - m_1}{m_3 - m_1}$$

(viii) Relative density of the oil = 0.9

47. (i) Least count = $\frac{1 \text{ M.S.D.}}{\text{N}}$

(ii) Measurement = M.S.R. + (V.C.D. \times L.C.)

(iii) Measurement = 4.8 mm

48. (i) $n = \frac{1}{2l} \sqrt{\frac{T}{m}}$

(ii) $a\% = \frac{\text{change in length}}{\text{length}} \times 100$



$$b\% = \frac{\text{change in time period}}{\text{time period}}$$

$$c\% = \frac{\text{change in mass}}{\text{mass}}$$

$$(iii) \text{ Error in } n = \left(\frac{b+c+2a}{2} \right)\%$$

49. (i) Diameter = $x + ly$

Here x is the M.S.R. in mm, l is the least count in mm and y is the vernier coinciding division. Substitute the given values and estimate x and y

In case of zero error,

Diameter = $x + l(y - z)$, where z is the V.S.D. for positive zero error. (correction is negative)

- (ii) (a) 19, 5 (b) 20, 2

50. (i) Positive zero error = zero below the index line

Observed reading = P.S.R. + (C.C.D. \times L.C.)

P.S.R. = 3

$$\text{Least count} = \frac{\text{pitch}}{\text{No. of C.C.D.'s}}$$

Correct diameter = observed reading + correction

- (ii) 3.645 mm

51. (i) $T \propto \frac{1}{\sqrt{g}}$

$$\frac{T_p}{T_m} = \sqrt{\frac{g_m}{g_p}}$$

Given, $T_m = 2$ s, $g_m = 6g_e$ and $g_p = 2g_e$

Here the suffixes p , m and e represent planet, moon and earth, respectively.

- (ii) 3.45 s

52. (i) Express 1 M.S.D. in the different portions of the scale as a fraction of an inch and convert into cm. Count the total number of divisions and convert into cm to arrive at the length of object in cm. Alternately, find the length in inches and convert into cm.

- (ii) Count the number of M.S.D.'s from left block to 2, say x

$$1 \text{ M.S.D.} = \frac{1}{16} \text{ inch}$$

Count the number of M.S.D.'s from 2 to right

block, say y

$$\text{Here, } 1 \text{ M.S.D.} = \frac{1}{8} \text{ inch}$$

$$\text{Length of the object} = \left(x \times \frac{1}{16} + y \times \frac{1}{8} \right) \text{ inch} = \left(\frac{x+2y}{16} \right) \text{ inch}$$

Convert this value to cm

- (iii) 5.87 cm

53. (i) $\frac{(\text{relative density})_A}{(\text{relative density})_B} = \frac{M_A / V_A}{M_B / V_B}$

- (ii) 2 : 3

54. (i) Least count = $\frac{\text{pitch}}$

Correct reading = observed reading + correction for zero error

Correction is positive if the error is negative

- (ii) 31.19 mm²

55. (i) $d_1 = \frac{1}{2}$ of a metre = distance of 2 kg from the support

- (ii) $d_2 = \frac{1}{4}$ of a metre

- (iii) Find W_2 using the theorem of moments, i.e., $w_1 d_1 = w_2 d_2$

- (iv) Mass = 4 kg

56. (i) Least count = $\frac{1 \text{ M.S.D.}}{N}$

Zero correction = - zero error

= - [(Main scale coinciding division) - (V.S. coinciding division)]

- (ii) + 1.2 mm

57. (i) Time period of a pendulum is proportional to the square root of its length.

- (ii) If the clock loses 1 minute in every 24 hours does it mean that the time period is greater than the required one, then should the length of the pendulum be increased or decreased?

58. (i) Correct length = (observed reading) - (zero error)

Zero error is positive if observed reading is greater than the correct length, and negative if the observed reading is less than the correct reading

- (ii) -1.6 mm



59. 30.56

12.6

21.09

64.25

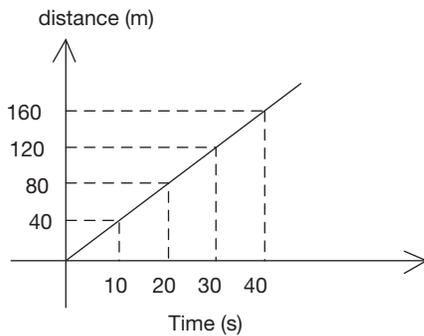
When rounded off to one decimal point, the value is 64.2.

60. (a) Volume = length³ = [M⁰L³T⁰]

(b) Density = $\frac{\text{mass}}{\text{volume}} = \frac{\text{mass}}{\text{length}^3} = [M^1L^{-3}T^0]$

(c) $F = \frac{Gm_1m_2}{d^2} \Rightarrow G = \frac{Fd^2}{m_1m_2}$
 $\Rightarrow \frac{M^1L^1T^{-2} \times L^2}{M^2} = [M^{-1}L^3T^{-2}]$

61.



62. 1 yotta metre = 10²² metre = 10¹⁹ km

63. Error = -2 div = -2 × $\frac{1}{100}$ mm = -0.02 mm

64. The knife-edges in a physical balance increase its sensitivity.

65. Correction = $-\left(\frac{\text{ZRP} - \text{LRP}}{\text{HRP} - \text{LRP}}\right) \times 10 \text{ mg}$
 $= -\left(\frac{10.5 - 8.5}{11.0 - 8.5}\right) \times 10 \text{ mg} = \frac{-2}{2.5} \times (10 \text{ mg})$
 $= -8 \text{ mg} = -0.008 \text{ g}$
 Correct mass = 34.23 g - 0.008 g = 34.222 g

66. The relative density of a body is ratio of the density of the body to the density of water. R.D. has no units. It is a ratio of same physical quantity.

If the units of mass, length and time are doubled, there will be the same change in the densities of both the body and the water. So, the ratio of the density of body and density of water do not change. Hence, the relative density is a ratio which is a constant for a particular substance.

67. An irregular solid when immersed in water displaces $\frac{3}{4}$ th litre of water. The volume of the solid = 750 cm³.

(ℓ 1 litre = 1000 cm³)

The mass of the displaced water = 750 g.

When immersed in a given liquid, it displaces = 600 g.

The relative density of the liquid

$$= \frac{\text{density of the liquid}}{\text{density of water}}$$

$$= \frac{\text{mass of liquid of volume (V)}}{\text{mass of water of same volume (V)}} = \frac{600 \text{ g}}{750 \text{ g}}$$

Relative density = 0.8

∴ Density of the liquid is 0.8 g cm⁻³

= 0.8 × 10³ kg m⁻³. = 800 kg m

Level 3

68. (i) $z \approx \frac{\text{pitch}}{\text{No. of C.C.D.'s}}$
 Dimensional formula of z
 $= \frac{(\text{dimensional formula of } y)^2}{\text{dimensional formula of } x}$

(ii) [M¹ L⁰ T⁰]

69. (i) $T = 2\pi\sqrt{\frac{\ell}{g}}$

Multiplying and dividing by \sqrt{m} (m = mass of the bob), on the right-hand side,

$$T = 2\pi\sqrt{\frac{\ell m}{mg}}$$

mg = weight of the body

The downward force acting on the bob.

What is the net downward force when the bob is immersed in water?

70. (i) Mass measured is accurate if the beam is horizontal.

(ii) If the beam is not horizontal, does it affect the turning points observed?



71. (i) Slope of the graph = mass flow rate
 $T = 0$ represents initial condition

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{\text{mass flow rate}}{\text{volumetric flow rate}}$$

- (ii) At $t = 0$ the vessel is empty, and for $t > 5$ min, there is no increase in mass of the vessel. What could be the reasons for the mass of the vessel to remain constant?

What does the inclined line AB indicate?

- (iii) 16.8 kg
 (iv) 21 litres
 (v) 800 kg m^{-3}
72. (i) Calculate L.C.

$$= \frac{\text{pitch}}{\text{number of division on circular scale}}$$

- (ii) P.S.R. = nth division \times pitch
 (iii) Observed reading = P.S.R. + (H.S.R. \times L.C.)
 (iv) Zero error = - [H.S.R. + (N - n) \times L.C.]
 (v) Correction is positive if error is negative.
 (vi) Correct measurement = observed reading + correction.
 (vii) Correct measurement = 7.25 mm

73. 1 MSD = 1 mm

$$\text{Pitch} = \frac{5 \text{ MSD}}{5} = 1 \text{ MSD} = 1 \text{ mm}$$

$$\text{Least count} = \frac{P}{N}$$

$$N = \frac{1 \text{ mm}}{1 \mu\text{m}} = 100$$

$$N = 500; P = (N) \times (\text{L.C.}) = 500 \times 1 \mu\text{m} = 0.5 \text{ mm}$$

$$\text{Pitch} = 0.5 \text{ mm}$$

74. (a) Least count = $\frac{1 \text{ MSD}}{N}$
- $$= \frac{0.5 \text{ mm}}{10} = 0.05 \text{ mm}$$
- Diameter = $x + ly$
- $$9.75 \text{ mm} = (x + 0.05y) \text{ mm}$$
- $$= x + 0.05y$$

Since $y < 10$ and $0.05y < 0.5$, 9.75 can be written as $9.5 + 0.25$

$$(9.5 \text{ mm}) + (0.25 \text{ mm}) = (x \text{ mm}) + (0.05y \text{ mm})$$

$$x = 9.5 = (\text{MSR}) \times (\text{L.C.})$$

Since 1 MSD = 0.5 mm

$$\text{The MSR} = \frac{9.5}{0.5} = 19 \text{ and } 0.05y = 0.25$$

$$y = 5$$

$$\text{MSR} = 19, \text{VCD} = 5$$

(b) $9.75 = (x + ly) - 0.35$

$$(x + ly) = 9.75 + 0.35$$

$$= 10.10$$

$$= 10 + 0.1$$

$$x = 10 = \text{MSR} = \frac{10}{0.5} = 20$$

$$0.05y = 0.1$$

$$y = \frac{0.1}{0.05} = 2 (= \text{VCD})$$

$$\text{MSR} = 20, \text{VCD} = 2$$

75. Pitch = $\frac{5 \text{ mm}}{10} = 0.5 \text{ mm}$, least count

$$= \frac{0.5}{N} = \frac{1}{2N}$$

$$\text{Diameter} = \text{P.S.R.} + \text{C.S.C.D} \propto \text{L.C.}$$

$$= xp + y \frac{P}{N} = p \left(x + \frac{y}{N} \right)$$

$$x + \frac{y}{N} = 5.48$$

$$\text{Since } \frac{y}{N} < \text{pitch}, x + \frac{y}{N} = 5 + 0.48$$

$$x = 5$$

$$\frac{y}{N} = 0.48 \Rightarrow y = 0.48N$$

Thus, the C.S.C.D depends on the number of divisions on the circular scale for example, if the number of circular scale divisions is 100, the C.S.D is 48.

$$\text{P.S.R.} = 5$$

$$\text{L.C.} = \frac{1}{2N}$$

$$\text{C.S.C.D} = 0.48N$$

76. Average of left turning points = $\frac{5+6+6}{3} = \frac{17}{3}$

$$= 5.\bar{6} \approx 5.7$$

$$\text{Average of right turning points} = \frac{18+18}{2} = 18$$



$$\begin{aligned}\text{Mean of left and right turning points} &= \frac{5.7 + 18}{2} \\ &= \frac{23.7}{2} = 11.85 \approx 11.8\end{aligned}$$

(Zero-resting point (ZRP) = 11.8

After placing the substance, the resting point (RP) = 13.

This RP is greater than ZRP, hence, it is higher-resting point (HRP) = 13.

When 10 mg is added, RP obtained = 11.

This RP is less than ZRP, hence, it is lower-resting point (LRP) = 11.

Given, mass at LRP = 60 g.

Mass at HRP = 59.990

Mass of the body, $M = \text{Mass at HRP} + P \text{ g}$

$$\begin{aligned}\text{Where } p &= \frac{(\text{H.R.P} - \text{Z.R.P}) \times 0.01}{\text{H.R.P} - \text{L.R.P}} \\ &= 59.990 + \frac{1.2}{2} \times 0.01 \\ &= 59.990 + 0.6 \times 0.01 = 59.996 \text{ g}\end{aligned}$$

77. Volume of the liquid displaced = 80 cm^3 = volume of sinker + volume of solid body.

Volume of sinker = 50 cm^3 .

$\therefore (80 \text{ cm}^3) = (50 \text{ cm}^3) + \text{volume of solid body}$.

$\therefore \text{Volume of the solid body} = 80 - 50 = 30 \text{ cm}^3$.

Mass of the body = $d \times v = 0.5 \times 30 = 15 \text{ g}$.

Weight of the body = 15 gwt.



Chapter 2

Kinematics



REMEMBER

Before beginning this chapter you should be able to:

- Define terms such as rest and motion, scalar and vector, distance and displacement, speed and velocity, acceleration and retardation
- Recall the concept of motion and its applications

KEY IDEAS

After completing this chapter you should be able to:

- Understand the term kinematics
- Know the types of motion: projectile and uniform circular motion
- Define the scalar and vector quantities
- Understand the basic terms and to determine the equations of motions relating to these terms
- Derive the equations of motion for the objects projected upwards and falling freely under gravity
- Discuss the motion of an object on a plane
- Explain the motion of objects by graphical representation

INTRODUCTION

In the present chapter, the focus is on the study of equations which describe the motion of a body and discuss the properties of freely falling bodies, vertically projected bodies and bodies undergoing projectile motion. At first, let us review some important terms and concepts.

Kinematics is the branch of mechanics dealing with the study of the motion of particles, without taking into account the forces and energies involved.

A **particle** (point object) is an object without extent. A particle is said to be at rest if its position, relative to the surroundings, does not change with respect to time. A particle is said to be in **motion** if its position, relative to the surroundings, changes with respect to time. Motion and rest refer to the state of bodies described in relation to its surroundings.

Example: Consider any building on the Earth. It is at rest with respect to the Earth. Since the Earth revolves a round the sun as well as it rotates on its own axis, all the objects on the Earth are in motion. Hence, there is no absolute rest. It means the building is at rest with respect to its surroundings but in motion with respect to sun.

Types of Motion

In day to day life, we come across various types of motion, like the motion of the planet, the motion of wind, etc.

Motion can be classified into:

1. Random motion
2. Translational motion
3. Rotational motion
4. Oscillatory or vibratory motion

Random Motion

In this type of motion, the particles move randomly, i.e., they do not move along a definite path.

Example: The motion of dust particles in wind or in air.

Translational Motion

In this type of motion, every particle of the body has the same displacement. Translational motion can be along a straight line or along a curved path. The motion along a straight line is called rectilinear motion and the motion along a curved path is called curvilinear motion.

Example: Rectilinear motion: Train speeding along a straight track. It is also referred to as one dimensional motion.

Example: Curvilinear motion: The path of a ball hit by a batsman for a sixer. This type of motion is also referred to as a two or three dimensional motion.

Rotational Motion

If the particles of the body revolve in a circle about the same axis, then the motion is said to be rotational.

Examples:

1. Rotation of Earth on its axis
2. Pulley used in drawing water
3. Merry Go round
4. A great wheel
5. Motion of a fan.

Oscillatory or Vibratory Motion

A to and fro motion about a fixed point is called oscillatory or vibratory motion.

Examples:

1. When the string of a guitar is plucked, it performs an oscillatory motion.
2. The motion of the pendulum of a clock.

SCALARS AND VECTORS

Physical quantities that can be defined using magnitude only are known as scalar quantities.

Examples: Distance, speed, mass, density, temperature.

Physical quantities that can be defined only if both its magnitude and direction are specified are called vector quantities.

Examples: Velocity, acceleration, force, torque.

Distance is the length of the path from the initial position to the final position, traced by the particle while in motion. It is a scalar quantity, and is path-dependent.

Example: Consider two places A and B . One can reach B from A by three different ways:

1. Along $ACDB$
2. Along AOB
3. Along the straight line AB

The length of the path varies. Hence, the distance travelled is not the same in the three cases though the initial and final positions are the same.

S.I. unit of distance is metre (m).

C.G.S. unit of distance is centimetre (cm).

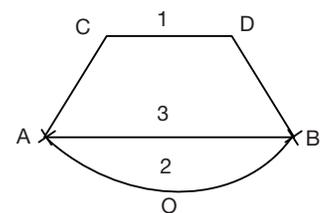


FIGURE 2.1

DISPLACEMENT

It is the length of the directed straight line connecting the initial and the final positions of a body in motion in a given time interval. It refers to the change of position with reference to direction. Displacement is a vector quantity, and is independent of the path.

The magnitude of a displacement is the length of the shortest path from the initial to final position, i.e., it is the length of the line segment joining the initial position and final position. The displacement vector is directed away from the initial position and towards the final position.

The unit of distance as well as that of the displacement is centimetre in C.G.S. system and metre in S.I. system.

Example: Let us consider the example given earlier for distance. The displacement is always the length of the straight line AB , (the shortest distance) and is directed from A to B (irrespective of the path traversed)

$$\text{Displacement} = \overrightarrow{AB}$$

Note

$$\overrightarrow{AB} \neq \overrightarrow{BA}$$

But,

$$|\overrightarrow{AB}| = |\overrightarrow{BA}|$$

Vectors are represented by directed line segments. The arrow of the directed line segment indicates the direction of the vector. The length of the directed line segment drawn to scale represents the magnitude of the vector.

Example: If a person moves along a straight path in the east direction for a distance of 3 km (P to Q) and then turns towards right and moves straight and covers a distance of 4 km (towards south and reaches a point R), the total displacement of the person is obtained by drawing a straight line from P to R , as shown in the Fig. 2.2.

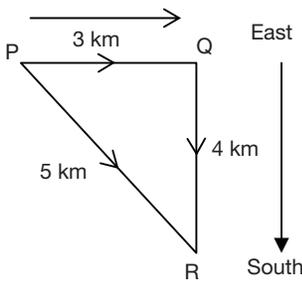


FIGURE 2.2

If the length of the line segment PQ is 3 cm, the scale taken is 1 cm = 1 km, then the length of the line segment QR would be 4 cm and accordingly we get the length of the line segment PR as 5 cm. As the scale taken is 1 cm for 1 km, the magnitude of the total displacement is 5 km and the direction is nearly along south-east.

$$\therefore \overrightarrow{PR} = \overrightarrow{PQ} + \overrightarrow{QR}$$

Now, the total displacement (\overrightarrow{PR}) = 5 km along approximate south-east is obtained as the sum of the displacements 3 km along east (\overrightarrow{PQ}) and 4 km along south (\overrightarrow{QR}). Thus, the two individual displacements \overrightarrow{PQ} and \overrightarrow{QR} are considered as the “component” of the displacement \overrightarrow{PR} . Thus, the vector \overrightarrow{PR} is said to be resolved into \overrightarrow{PQ} and \overrightarrow{QR} , the individual components that are perpendicular to each other. This representation of one vector as a sum of two component vectors is called resolution of a vector.

SPEED

Speed is the rate of distance travelled. It is the ratio of the distance travelled to the time taken to cover that distance.

$$\text{Speed} = \frac{\text{distance}}{\text{Time}}$$

It is a scalar quantity. The unit of speed is cm s^{-1} in C.G.S. system and m s^{-1} in S.I. system.

Instantaneous speed is the speed of a particle at a given instant. It is defined as the ratio of the distance travelled in an extremely small interval of time tending to zero.

Average Speed

It is the ratio of the total distance to the total time taken.

$$\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}} = \frac{s}{t}$$

If x_1, x_2, x_3, x_4 are the distances travelled in the time intervals t_1, t_2, t_3 and t_4 , respectively, then

$$\text{Average speed} = \frac{x_1 + x_2 + x_3 + x_4}{t_1 + t_2 + t_3 + t_4}$$

Average speed is the average of initial and final speed if the particle is in motion such that its speed changes (either increases or decreases) at a constant rate.

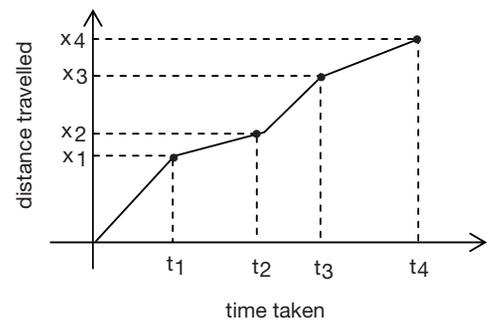


FIGURE 2.3

Uniform Speed

A body is said to be moving with uniform speed if equal distances are covered in equal intervals of time.

Example: A bike is moving on the road at 40 kmph speed that means for every one hour it is covering 40 km.

Variable Speed

A body has a variable speed if it does not cover equal distances in equal intervals of time.

Example: A train while departing from railway station increases its speed gradually that means it is moving with variable speed.

VELOCITY

Velocity is the ratio of displacement to the time interval during which the displacement has occurred.

$$\text{Velocity } (v) = \frac{\text{Displacement}}{\text{Time}} = \frac{s}{t}$$

It is a vector quantity. The magnitude of velocity is expressed in cm s^{-1} in C.G.S. system and in m s^{-1} in S.I. system. The direction of velocity is along the direction of displacement.

Uniform Velocity

A body is said to have uniform velocity if it undergoes equal displacements in equal intervals of time. Since displacement is a vector, equal displacements implies the body is moving along a straight line path. Thus, a body moving with uniform velocity is in motion along a straight line path with a constant speed.

Uniform motion and non-uniform motion

In uniform motion, the distance moved by the particle in equal intervals of time is the same whether the duration of time is small or large. In non-uniform motion, the distance moved by the particle in equal intervals of time is not the same.

Variable Velocity

If a body undergoes unequal displacements in equal intervals of time, then the body is said to possess variable velocity. Velocity is said to be variable if there is a change either in its magnitude or in its direction or both.

Instantaneous Velocity

It is the velocity of the particle at a given instant. The direction of instantaneous velocity is along the tangent drawn to the curve describing the path at that instant if the body undergoes curvilinear motion.

Instantaneous velocity,
$$\vec{v} = \frac{\overline{\Delta s}}{\Delta t}$$

$\overline{\Delta s}$ is the change in the displacement in a small interval of time Δt .

In Fig. 2.4, instantaneous velocity,
$$\vec{v} = \frac{\overline{\Delta s}}{\Delta t} = \frac{CB}{AC}$$

In the case of a body moving with variable velocity (non-uniform motion), the instantaneous velocity at any instant is given by the slope of the tangent drawn at a point in to the displacement time curve in Fig. 2.5.

$$\vec{V} = \frac{CB}{AC}$$

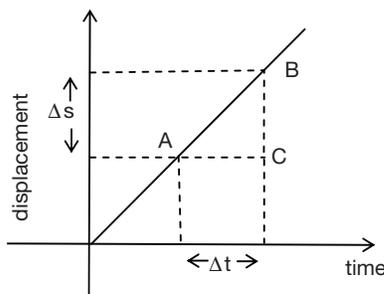


FIGURE 2.4 Uniform motion

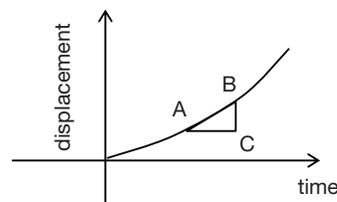


FIGURE 2.5 Non-uniform motion

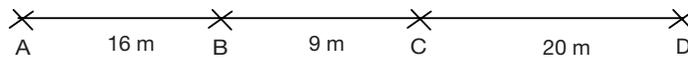
Average Velocity

It is the ratio of total displacement to the total time taken.

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

Average velocity is a vector quantity.

Example:



Consider a body moving along a straight line AD, travelling 16 m in the 1st second, 9 m in the next second and 20 m in the 3rd second.

Total displacement = 45 m along AD

Total time = 3 s

$$\text{Average velocity} = \frac{45 \text{ m}}{3 \text{ s}} = 15 \text{ m s}^{-1} \text{ along } \overline{AD}$$

Note

1. Average velocity of a moving body may be equal to zero but average speed cannot be equal to zero. For example, the average velocity of an athlete completing one round while running along a circular track is zero, though his average speed is not zero.
2. Average velocity = $\frac{\vec{v} + \vec{u}}{2}$ in case the body is moving with uniform rate of change of velocity.

Here, \vec{v} is the final velocity and \vec{u} is the initial velocity

ACCELERATION

Acceleration is defined as the rate of change of velocity. It is a vector quantity. The unit of acceleration is cm s^{-2} in C.G.S. system and m s^{-2} in S.I. system.

$$\text{By definition, acceleration, } \vec{a} = \frac{\text{Change in velocity}}{\text{Time}} = \frac{\vec{v} - \vec{u}}{t}$$

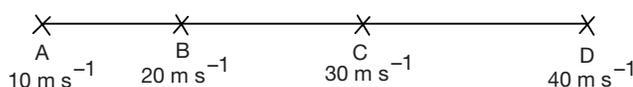
The direction of acceleration is along the direction of change in velocity of the body.

Example: A overtaking bus increases its velocity that means it is accelerating.

Uniform Acceleration

If the change in velocity of the body is equal in an equal intervals of time, then the body is said to move with uniform acceleration.

Example:



Consider a body moving along a straight line passing through the points A, B, C, D, such that it covers the distances AB, BC and CD in equal intervals of time of one second. Let the velocity of the body at A, B, C and D be 10 m s^{-1} , 20 m s^{-1} , 30 m s^{-1} and 40 m s^{-1} , respectively.

Position	Time 't' (s)	Δt (s)	Velocity v (m s^{-1})	Change in velocity Δv (m s^{-1})	Rate of change of velocity $\Delta v/\Delta t$ (m s^{-2})
A	0	1	10	10	10
B	1		20		
C	2	1	30	10	10
D	3	1	40	10	10

We find that during the motion of the body, the velocity is not constant, but the rate of change (increase) of the velocity is constant, i.e., the body is moving with uniform acceleration.

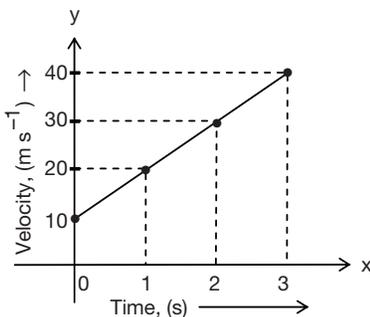


FIGURE 2.6

Plotting a graph of velocity (along y -axis) and time (along x -axis), we get a straight line as shown in Fig. 2.6. The slope of the graph is positive, and hence, the acceleration here is considered positive.

However, if the velocity of the body referred to in the above example at A, B, C and D is 40 m s^{-1} , 30 m s^{-1} , 20 m s^{-1} and 10 m s^{-1} , respectively, the graph would once again be a straight line but sloping downwards. The slope of the line here is said to be negative, and hence, the acceleration in such cases where the velocity decreases as time progresses is referred to as negative acceleration or retardation or deceleration.

Whenever the magnitude of velocity decreases, the rate of change of velocity is referred to as retardation or deceleration. It is not necessary that the rate of change of velocity, i.e., the acceleration is always constant. In situations where the rate of change of velocity of a body in motion is not constant, the body is said to be moving with non-uniform acceleration or variable acceleration.

Equations of uniformly accelerated rectilinear motion

These equations give the relation between velocity, distance, time and uniform acceleration of a body moving along a straight line.

- To deduce,

$$v = u + at$$

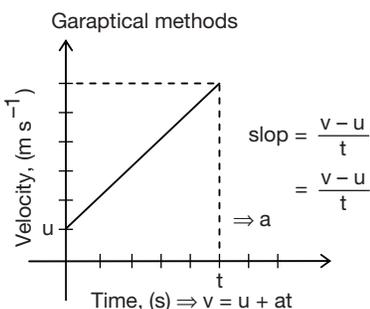
Consider a body having initial velocity u and velocity after time t seconds is v .

$$\text{Rate of change of velocity} = \frac{v - u}{t}$$

i.e.,

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

$$v = u + at$$



2. To derive,

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

$$\text{Average velocity} = \frac{v+u}{2} \quad (2.1)$$

(since acceleration is constant)

But average velocity is the ratio of the total displacement to the total time.

$$\therefore \text{Average velocity} = \frac{s}{t} \quad (2.2)$$

Comparing (2.1) and (2.2)

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

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

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

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

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

3. To derive,

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

$$\text{Average velocity} = \frac{s}{t} \quad (2.3)$$

$$\text{Average velocity} = \frac{v+u}{2} \quad (2.4)$$

From (2.3) and (2.4)

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

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

$$\left[\text{but } v = u + at; \frac{v-u}{a} = t \right]$$

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

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

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

Or

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

4. To deduce the equation for the displacement of a body in the n th second:



Let AB be the distance travelled by a body in n seconds, and AC be the distance travelled by a body in $(n - 1)$ seconds.

Thus, the distance travelled in the n th second is $CB = S_n$.

$$S_n = AB - AC \quad (2.5)$$

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

$$AB = un + \frac{1}{2} an^2 \quad (2.6)$$

$$AC = u(n - 1) + \frac{1}{2} a(n - 1)^2 \quad (2.7)$$

Substituting (2.6) and (2.7) in (2.5), we get

$$S_n = un + \frac{1}{2} an^2 - [u(n - 1) + \frac{1}{2} a(n - 1)^2]$$

$$S_n = un + \frac{1}{2} an^2 - [un - u + \frac{1}{2} an^2 - an + \frac{1}{2} a]$$

$$S_n = un + \frac{1}{2} an^2 - un + u - \frac{1}{2} an^2 + an - \frac{1}{2} a$$

$$S_n = u + an - \frac{1}{2} a$$

$$S_n = u + a \left(n - \frac{1}{2} \right)$$

Or

$$S_n = u + \frac{1}{2} a [2n - 1]$$

Problem Solving Tactics

In deriving the equations, we have assumed that all the vector quantities are in the same direction. However, all vectors need not be in the same direction. Giving due consideration to this, '+' and '-' signs should be assigned to the quantities.

Convention I: In this convention, the direction of displacement is taken as positive.

Convention II: In this convention, a convenient cartesian co-ordinate system is taken with the origin at the initial position of the body, and '+' and '-' signs are accordingly assigned.

EXAMPLE

A car initially at rest moves with a constant acceleration along a straight road. After its speed increases to 40 km h^{-1} , it moves with a constant speed and finally retards uniformly. The time intervals for the three parts of the journey are in the ratio $1 : 3 : 1$. Find the average velocity

SOLUTION

Maximum velocity = 40 km h^{-1}

Let the time taken for the first part of the journey, i.e., during acceleration be t .

From definition of average velocity we have,

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

Here v is the final velocity = 40 km h^{-1} ,

u is the initial velocity = 0

and s is the displacement = s_1 (say)

$$\therefore s_1 = \left(\frac{40 + 0}{2} \right) t$$

$$\therefore s_1 = 20 \times t = 20t \text{ km} \quad (1)$$

Since the time intervals are in the ratio of $1 : 3 : 1$, if t is the time for the first part, the time taken for second and third parts are $3t$ and t , respectively.

Thus, if s_2 is the distance travelled with constant speed,

$$s_2 = v \times t_2 = 40 \times 3t = 120t \text{ km} \quad (2)$$

Similarly, if s_3 is the distance travelled with uniform retardation in the last part of the journey,

$$s_3 = \left(\frac{v + u}{2} \right) t_3.$$

Here $v = 0$, $u = 40 \text{ km h}^{-1}$, $t_3 = t$

$$\therefore s_3 = \frac{(0 + 40)}{2} t = 20t.$$

Total distance travelled = $s_1 + s_2 + s_3 = s$

$$s = 20t + 120t + 20t$$

$$s = 160t$$

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

$$= \frac{160t}{5t} = 32 \text{ km h}^{-1}$$

Since the car is moving along a straight line, therefore, average velocity = 32 km h^{-1}

EXAMPLE

A car moves with a constant velocity of 10 m s^{-1} for 10 s along a straight track, then it moves with uniform acceleration of 2 m s^{-2} for 5 seconds . Find the total displacement and velocity at the end of the 5th second of acceleration.

SOLUTION

Let v_1 and t_1 be the initial velocity and the time for the first part where the car is moving with a constant velocity.

$$t_1 = 10 \text{ s}; v_1 = 10 \text{ m s}^{-1}$$

\therefore Distance travelled $s_1 = v_1 t_1$

$$\text{i.e., } s_1 = 10 \times 10 = 100 \text{ m}$$

For the second part, i.e., when the car accelerates,

$$a = 2 \text{ m s}^{-2}, v = ?$$

$$t = 5 \text{ seconds } s_2 = ?$$

$$u = 10 \text{ m s}^{-1}$$

$$v = u + at$$

$$v = 10 + 2 \times 5$$

$$v = 10 + 10$$

$$v = 20 \text{ m s}^{-1}$$

$$s_2 = ut + \frac{1}{2} at^2$$

$$s_2 = 10 \times 5 + \frac{1}{2} \times 2 \times 5^2$$

$$= 50 + 1 \times 25 = 50 + 25 = 75 \text{ m}$$

Total displacement $s = s_1 + s_2$

$$\therefore s = 100 + 75 = 175 \text{ m.}$$

EXAMPLE

A bike moving along a straight road covers 35 m in the 4th second and 40 m in the 5th second. What is its initial velocity and acceleration (if the acceleration is assumed to be uniform)?

SOLUTION

Let s_4 and s_5 be the distances travelled in the 4th second and the 5th second, respectively.

$$s_4 = 35 \text{ m}, s_5 = 40 \text{ m}$$

From the equations of motion, the distance travelled by a body in the n th second is given by,

$$s_n = u + a \left(n - \frac{1}{2} \right)$$

$$\therefore 35 = u + a \left(4 - \frac{1}{2} \right)$$

$$40 = u + a \left(5 - \frac{1}{2} \right)$$

$$\text{i.e., } 35 = u + \frac{7}{2}a$$

$$40 = u + \frac{9}{2}a$$

$$70 = 2u + 7a \quad (1)$$

$$80 = 2u + 9a \quad (2)$$

Solving equations (1) and (2), we get

$$a = \frac{10}{2} = 5 \text{ m s}^{-2}; \quad u = \frac{35}{2} = 17.5 \text{ m s}^{-1}$$

Acceleration Due to Gravity

Objects thrown vertically upwards move up to a certain distance and then fall back to the ground. This is due to earth's gravitational force.

Due to gravitational force, all objects are accelerated towards the Earth. This uniform acceleration towards the Earth, irrespective of the mass is known as acceleration due to gravity and is denoted by 'g'.

Equations of Motion of Objects under the Influence of Gravity (Neglecting air Resistance)

Here, since acceleration of a body moving vertically, either upward or downward, is due to gravity, 'a' is substituted by 'g' and the displacement 's' is substituted by 'h'. Thus, we have

$$v = u + gt$$

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

$$v^2 = u^2 + 2gh$$

Where,

v is the final velocity,

u is initial velocity,

g is acceleration due to gravity and

t is time taken.

'g' is chosen to be positive if the body is moving towards the Earth, i.e., downward and g is negative if the body is moving in upwards direction.

NOTE

It is purely a matter of choice and convenience that we choose a particular direction as positive. In the above case, for example, the final result will remain the same even if we choose the upward direction as positive and downward as negative or vice-versa.

Equations of Motion of a Body Dropped from a Certain Height

A freely falling body is one which moves only under the influence of gravity (i.e., no other force acts on it) like air friction.

Let us consider the special case of a freely falling body which is dropped or released from rest for which the initial velocity, $u = 0$, and acceleration, $a = +g$.

Taking $u = 0$, $s = h$ and $a = +g$, we can write the equations of motion for a freely falling body, as

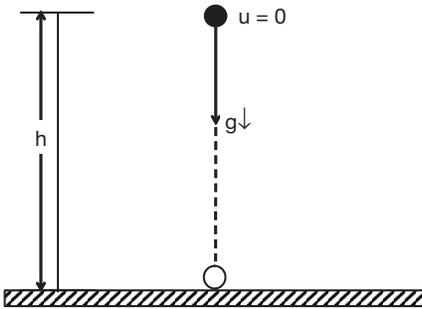


FIGURE 2.7

1. $v = u + at$

$$v = gt$$

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

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

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

$$v^2 = 2gh$$

From $h = \frac{1}{2}gt^2$;

$$t = \sqrt{\frac{2h}{g}}, \text{ where 't' is the time of descent.}$$

Equations of Motion for a Body Projected Vertically Upwards

Consider a body projected vertically upwards with an initial velocity, u . As the body moves up, its velocity decreases, since the Earth pulls the body downwards with an acceleration of 'g'. The body moves until its velocity becomes zero (at maximum height). Such bodies are called **vertically projected bodies**. As the direction of motion is against the direction of acceleration due to gravity (g), the sign of 'g' is taken to be negative.

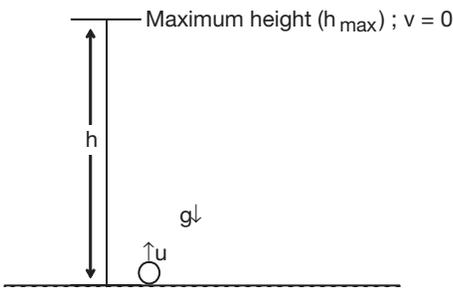


FIGURE 2.8

Taking $s = h$ and $a = -g$, we can write the equations of motion for such a body as follows:

1. $v = u + at$

$$v = u - gt$$

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

$$h = ut - \frac{1}{2}gt^2$$

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

$$v^2 - u^2 = -2gh$$

$$v \text{ at maximum height} = 0; a = -g; s = h$$

$$\therefore h_{\max} = \frac{u^2}{2g} \quad (\text{from } v^2 = u^2 - 2gh)$$

For a body projected vertically upward, the time of ascent (t_a) is the time taken by it to reach the maximum height.

$$t_a = \frac{u}{g} \quad (\text{from } v = u - gt)$$

Time of Descent

As derived earlier, for a body dropped from a height 'h', the time of descent is given by,

$$t_d = \sqrt{\frac{2h}{g}}$$

A vertically projected body after reaching its maximum height (h_{\max}) starts falling and behaves as a body dropped from maximum height. The time that it takes to reach the ground from the maximum height, can be given by,

$$t_d = \sqrt{\frac{2h_{\max}}{g}}, \quad t_d = \sqrt{\frac{2u^2 / 2g}{g}} = \frac{u}{g}$$

$$\therefore t_d = \frac{u}{g}$$

This proves that the time of ascent is equal to the time of descent for bodies projected vertically up, and the body returns to the same level from where it is projected.

Time of Flight (t_f)

It is the total time during which a body moving under gravity remains in air above the plane of projection.

$$t_f = t_a + t_d = \frac{u}{g} + \frac{u}{g} = \frac{2u}{g}$$

i.e.,

$$t_r = \frac{2u}{g}$$

EXAMPLE

A ball is thrown vertically upwards with a velocity of 20 m s^{-1} . Find the time of flight, neglecting the air resistance ($g = 10 \text{ m s}^{-2}$)

SOLUTION

When the body comes back to the initial position, the displacement $\vec{s} = 0$.

$$\text{From } s = ut - \frac{1}{2}gt^2$$

$$0 = ut - \frac{1}{2}gt^2$$

$$ut = \frac{u^2}{2g}$$

$$t = \frac{2u}{g}. \text{ Here 't' is the time of flight, i.e., } t_a + t_d.$$

$$\therefore \text{ Time of flight, } t = \frac{2 \times 20}{10} = 4 \text{ s}$$

Velocity on Reaching the Ground

When a body is dropped from a height 'h', its initial velocity is zero and it attains a velocity 'v' on reaching the ground.

$$\text{As } v^2 - u^2 = 2gh \text{ and } u = 0, v = \sqrt{2gh} \quad (2.8)$$

$$\text{We also know that for a body thrown upwards with an initial velocity } u; u = \sqrt{2gh_{\max}} \quad (2.9)$$

Comparing equations (2.8) and (2.9), we can say that the velocity of the body falling from a certain height h , on reaching the ground is equal to the velocity with which it has to be projected vertically upwards to reach the same height h .

This shows that, the upward speed at any point in the flight of a body is same as its downward speed at that point. But note that directions of their velocities are opposite, and hence, the velocities are different though their speeds are the same.

EXAMPLE

A body falls from a height of 45 m from the ground. Find the time taken by the body to reach the ground. (Take $g = 10 \text{ m s}^{-2}$)

SOLUTION

Given, the initial velocity of the body $u = 0$ and $g = 10 \text{ m s}^{-2}$

Distance travelled by the body, $s = 45 \text{ m}$

Using the equation, $s = ut + \frac{1}{2}gt^2$ we get

$$45 = 0 + \frac{1}{2} \times 10 t^2$$

$$\therefore t^2 = \frac{90}{10} = 9 \Rightarrow t = 3 \text{ s}$$

PROJECTILE

When a body moves under the influence of gravity, it moves along a vertical straight line, only if there is no horizontal component for the initial velocity (neglecting wind velocity and air resistance)

Examples:

1. A mango falling from a tree.
2. A ball projected vertically downwards.

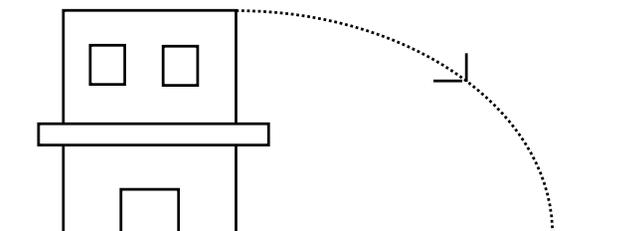


FIGURE 2.9

If the initial velocity has both horizontal and vertical components, the path of the body will not be a straight line, but will be a parabola, called trajectory.

Examples:

1. A ball kicked horizontally from the top of a building.
2. A missile fired from a cannon.

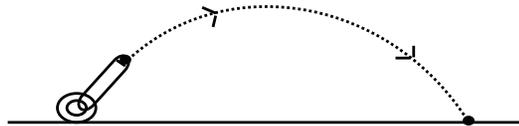


FIGURE 2.10

A billiard ball struck on a billiard table would move horizontally along the surface of the table. Here, changes in the position and the velocity and the corresponding acceleration (deceleration) would be only in the horizontal direction, i.e., either forward (+ve) or in the reverse direction (-ve). The influence of gravity on the motion of the ball is absent.

However, when we consider the motion of shot-put or a long jumper, they move under the influence of gravity. Such objects which are given horizontal velocity and are allowed to travel under influence of gravity are called projectiles.

Any projectile has two dimensional motion, i.e., combination of motion in two different directions. They are as follows:

1. Uniform velocity along the horizontal direction, since no force acts on the projectile along the horizontal. Thus, the acceleration is zero along the horizontal direction.
2. Uniform accelerated motion along the vertical since it is acted upon by gravity.

The motion of the projectile can be represented graphically by plotting horizontal displacement along X-axis and vertical displacement along the Y-axis.

The motion of projectile is considered in the absence of air resistance.

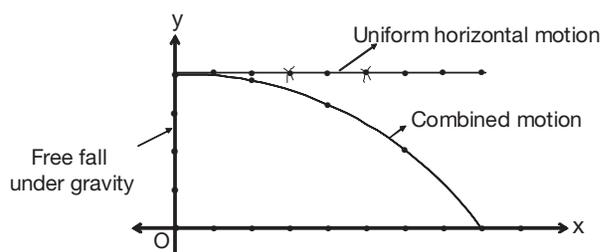


FIGURE 2.11

Similarly the path of a ball hit high by a batsman would be as shown below.

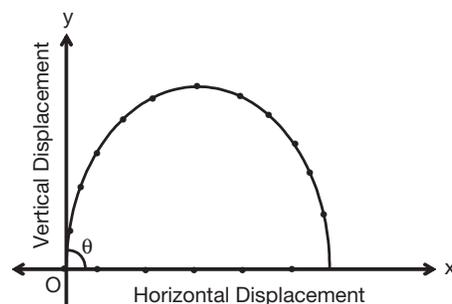


FIGURE 2.12

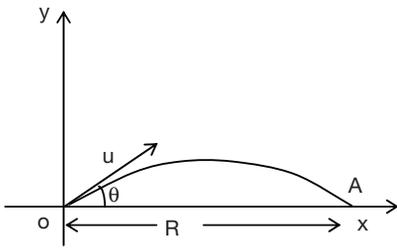


FIGURE 2.13

Example: Consider a shot-put given an initial velocity making an angle θ with the horizontal. Plot the displacement along the X-axis (horizontal) and the Y-axis (vertical) on graph for every 1 second.

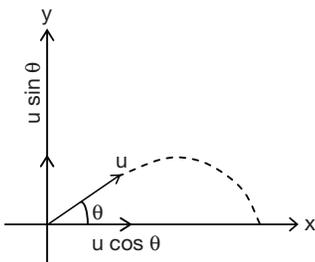
The graph obtained is as shown in Fig. 2.13. This curve is called parabola. Hence, the trajectory of a projectile is a parabola.

RANGE (R)

It is the maximum distance covered by a projectile along the horizontal.

1. Range is OA as shown in the Fig. 2.13.
2. Range depends on the angle of projection (θ).
3. Time taken by the projectile to reach the highest point from the point of projection = time taken by the projectile to reach the ground from the highest point.

The four equations of motion discussed earlier, namely, $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$ and $S_n = u + a\left(n - \frac{1}{2}\right)$ are applicable to bodies that move along a straight path with uniform acceleration.



However, in the case of projectiles, their motion is not along a straight line path. Thus, the four equations of motion mentioned cannot be directly applied to projectiles. To know the position of a projectile after certain interval of time, we need to know its horizontal and vertical displacements from the point of projection in the given time, that is, we need to know the velocity and acceleration of the projectile in both the horizontal and the vertical directions. Thus, it is necessary to resolve or split the vector (initial velocity of projection of the projectile) into horizontal and vertical directions and take the corresponding component of the velocity.

If θ is the angle of projection of a projectile with velocity ' u ', the horizontal component of velocity is ' $u \cos \theta$ ' and the vertical component of velocity is ' $u \sin \theta$ '. There exists no change in the horizontal component of velocity of the projectile as gravitational pull does not affect its horizontal motion. Thus, the horizontal component remains ' $u \cos \theta$ ' throughout the motion of the projectile. However, the vertical component of velocity, i.e., ' $u \sin \theta$ ' changes as the projectile is under gravitational pull in the vertical direction.

Thus, the vertical component of velocity decreases in the upward direction, till it becomes zero at the highest point and then the projectile falls down under gravity.

The motion of the projectile is a result of both the vertical and horizontal components and it follows a parabolic path.

The equations of motion can be applied independently for acquiring the horizontal and the vertical displacements or velocity of the projectile. For example, the horizontal and the vertical displacement can be obtained by using equation $s = ut + \frac{1}{2}at^2$ in both the directions.

If 'x' and 'y' are the horizontal and vertical displacements, respectively, at the end of 't' seconds, they are given by, $x = (u \cos\theta)t$ and $y = (u \sin\theta)t - \frac{1}{2}gt^2$.

UNIFORM CIRCULAR MOTION

In the previous topics, we studied about the change in the magnitude of velocity when a body undergoes rectilinear motion. Now we will consider the situation where a body can be accelerated without changing the magnitude of velocity.

Consider a person seated in a merry-go-round which is in motion. The person undergoes circular motion as shown. Examine the direction of motion of the person at every point.

We observe that any body moving along a circular path changes its direction continuously, even though the speed is constant. Thus, the body is continuously accelerated. This acceleration acts towards the centre of the circular path and is called **centripetal acceleration**.

If a body moves along a circular path with constant speed such that its acceleration is uniform, then the body is said to be in uniform circular motion.

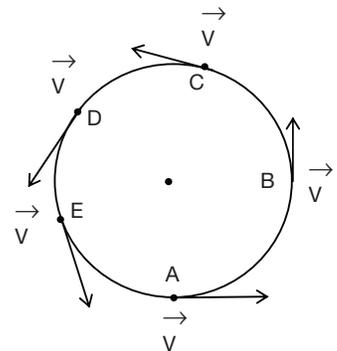


FIGURE 2.14

GRAPHICAL REPRESENTATION OF MOTION ALONG A STRAIGHT LINE

The motion of a particle (or body) can be analysed by plotting different types of graphs. These graphs are useful to study the rectilinear motion of a body. There are three types of graphs in kinematics, namely, displacement–time graph, velocity–time graph and acceleration–time graph. In plotting these graphs, time is taken along the X-axis as an independent quantity. The dependent quantity, i.e., quantity that changes with time, namely, displacement, velocity or acceleration is taken along the Y-axis.

Displacement–Time Graphs

1. The $s - t$ graph is along the X-axis. The displacement is zero for any amount of time. Thus, this type of graph indicates that the body is at rest, with no displacement.

Example: A bus stopped at bus stop.

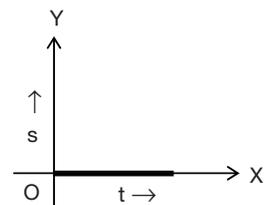


FIGURE 2.15

2. The $s - t$ graph is parallel to X-axis. The displacement is constant and does not change with respect to time. Thus, the body has some initial displacement and is at rest.

Example: A bus stopped at bus stop 2 metres away from the railway station.

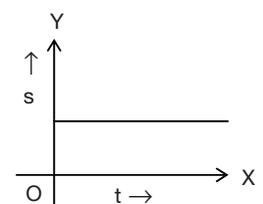


FIGURE 2.16

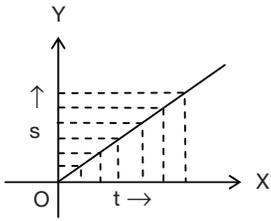


FIGURE 2.17

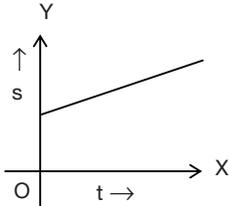


FIGURE 2.18

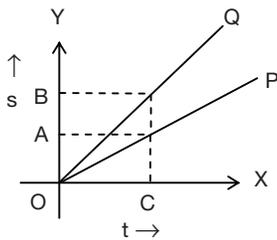


FIGURE 2.19

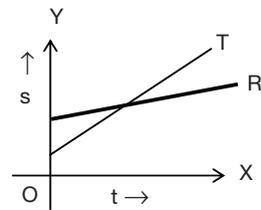


FIGURE 2.20

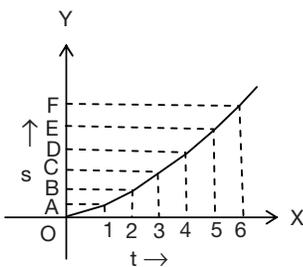


FIGURE 2.21

3. The $s - t$ graph is a straight passing through origin and making an angle with the X -axis. The body has equal displacements in equal intervals of time. Thus, the body is moving with uniform velocity. The initial displacement of the body is zero.

Example: A person riding a bike at the speed of 50 kmph on a straight road from rest.

4. The $s - t$ graph is a straight line making a positive angle with the horizontal and has a positive intercept on the Y -axis. Thus, the body has uniform velocity with some initial displacement.

Example: A bus start 2 m away from TIME's building and moving at a speed of 60 kmph.

5. The $s - t$ graph of two bodies P and Q are shown in Fig. 2.19 by lines OP and OQ , respectively. Since they are straight lines making positive angle with X -axis and passing through the origin, their initial displacement is zero and they have uniform velocity. But from the Fig. 2.19, it is clear that the displacement of Q is more than that of P in a given time. Thus, the velocity of Q is more than that of P . The magnitude of uniform velocity can be obtained by measuring the slantness (slope) of the lines from the horizontal. Displacement of P and Q are given by, OA and OB , respectively. Thus, magnitude of the velocity of P is given by, $v_p = OA/OC$. This is the slope of OP . Similarly, magnitude of the velocity of Q is given by, $v_Q = OB/OC$. This is the slope of OQ . As $OB > OA$, $v_Q > v_p$, the time considered (OC) being constant.

6. In Fig. 2.20, the $s - t$ graphs of two bodies R and T are shown by thick and thin lines, respectively. It is clear from the Fig. 2.20 that the bodies are moving with uniform velocity. Even though the initial displacement of T is less than that of R , (As the length of intercept on Y -axis for T is less than that of R), the slope of T is greater than that of R . Thus, the magnitude of uniform velocity of T is greater than that of R .

7. The $s - t$ graph of a body is as shown in Fig. 2.21. It is not a straight line, but is a curve. It is obvious from the Fig. 2.21 that the displacement of the body is not equal in equal intervals of time. Thus, the body has variable velocity.

From the Fig. 2.21, it is clear that $OA < AB < BC < CD < DE < EF$, which are the successive displacements of the body in successive intervals of time. Thus, the displacement per unit time, i.e., velocity of the body increases with time. Hence, the body is moving with acceleration.

Example: A train while departing from the station.

The velocity of the body at any instant of time can be obtained by drawing a line that touches the curve at the given point (also called tangent) and measuring the slope of the tangent as shown in the Fig. 2.22.

Example: Speed of a train at 8:00 a.m. is 40 kmph and at 3:30 a.m. is 60 kmph.

The displacement of the body at an instant of time t_1 is s_1 . Point P on the graph indicates this position. If the velocity of the body at the instant t_1 , is to be calculated, a tangent AC is drawn at the point P , and the slope of the tangent AC that gives the instantaneous velocity can be calculated by using the expression. $\frac{AB}{BC}$ where BC gives the time interval considered and AB gives the displacement of the body in the time interval.

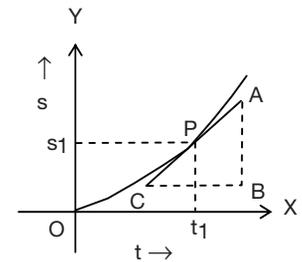


FIGURE 2.22

8. The $s - t$ graph of a body is as shown in Fig. 2.23. The graph is a curve. This indicates that the velocity of the body is not uniform. The tangents at the points P and Q on the curve give the velocity of the body v_1 and v_2 at the instants t_1 and t_2 , respectively. It is clear from the Fig. 2.23 that the slope of the tangent at P is greater than the slope of the tangent at Q . Thus, $v_2 < v_1$. This implies that the velocity of the body is decreasing with time, i.e., the body moves with retardation in the positive direction (direction of displacement) as the displacement of the body increases with time.

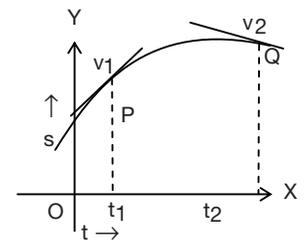


FIGURE 2.23

Example: A train arrived to the railway station.

9. The $s - t$ graph of a body is as shown in Fig. 2.24. The graph is a straight line making an obtuse angle with the positive X-axis. The body has some initial displacement and this displacement decreases with time. The decrease in displacement is equal in equal intervals of time. Thus, the body moves in opposite direction to the direction of displacement with uniform velocity.

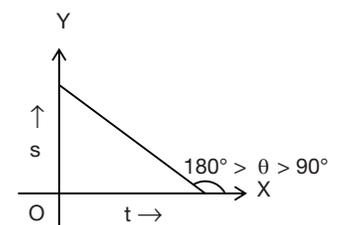


FIGURE 2.24

Example: A bus which is already travelled certain distance on a straight road returning back with the same constant speed.

10. The $s - t$ graph of a body is as shown in Fig. 2.25. It is a curve, and thus, the velocity of the body is non-uniform. The velocity of the body at two different instants of time t_1 and t_2 is given by the slope of the tangents at the points P and Q as v_1 and v_2 , respectively, as shown in the Fig. 2.25. It is obvious from the figure that the slope at Q is more than that at P indicating that $v_2 > v_1$. Also, as time increases, displacement of the body decreases as evident from the Fig. 2.25. Thus, the body is moving in opposite direction to the direction of displacement with acceleration.

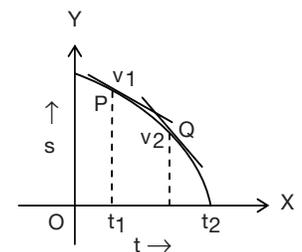


FIGURE 2.25

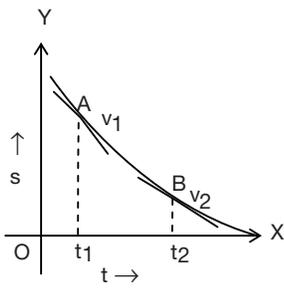


FIGURE 2.26

11. The $s - t$ graph of a body as shown in the Fig. 2.26 is a curve. The body has initial displacement and as time increases, the displacement decreases. Thus, the body is moving in opposite direction to the direction of displacement with non-uniform velocity. The velocity of the body at two instants of time ' t_1 ' and ' t_2 ' is given by the slopes of the tangents drawn to the curve at points A and B as v_1 and v_2 , respectively. It is obvious from the Fig. 2.26 that the slope of the tangent at A is greater than the slope of the tangent at B . Thus, $v_1 > v_2$. This implies that the body is moving with retardation in the opposite direction to the direction of displacement.

Uses of Displacement–time Graph

1. The position of the body at any intermediate time can be found out.
2. Slope of the tangent to the curve gives instantaneous velocity at that moment.
3. Average velocity is the slope of the line passing through the initial and final position on the curve.
4. Nature of motion can be determined.
5. The nature of curve describes the type of motion it was.

Velocity–Time Graph

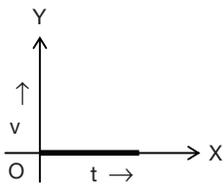


FIGURE 2.27

Similar to the displacement–time graph, the velocity–time graphs can be any one or the combination of more than one of the following types.

1. The graph is a straight line along the X -axis. This implies the body is at rest.

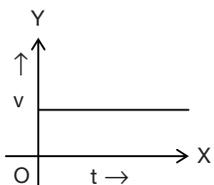


FIGURE 2.28

2. The graph is a straight line parallel to the X -axis. This implies that the velocity does not change with respect to time. Thus, the graph indicates the uniform velocity.

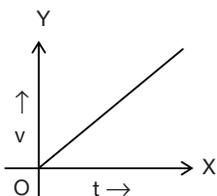
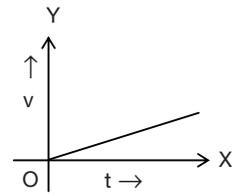


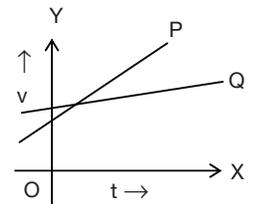
FIGURE 2.29

3. The graph is a straight line making an acute angle with the positive X -axis and passing through the origin. Thus, the initial velocity of the body is zero and has equal increase in velocity in equal intervals of time. Thus, the body moves with uniform acceleration. The magnitude of the acceleration is given by the slope of the line (**NOTE:** slope of $s-t$ graph gives the velocity).

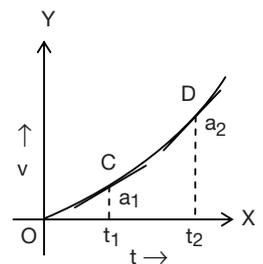
4. The $v - t$ graph of a body is as shown in Fig. 2.30. The graph is a straight line making an acute angle with the positive X -axis and having an intercept on the positive Y -axis. Thus, the body has some initial velocity u and moves with uniform acceleration.

**FIGURE 2.30**

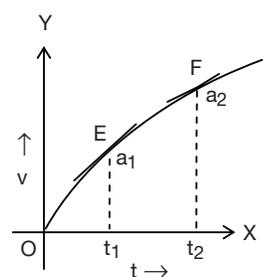
5. The $v - t$ graphs of two bodies P and Q are as shown in Fig. 2.31. The graphs are straight lines making acute angle with the positive X -axis and having intercepts on the positive Y -axis. Thus, both the bodies have initial velocities and move with uniform acceleration. The Y -intercept of P is less than that of Q . This indicates that the initial velocity of P is less than that of Q . But the slope of P is greater than that of Q . This indicates that the magnitude of uniform acceleration of P is greater than that of Q .

**FIGURE 2.31**

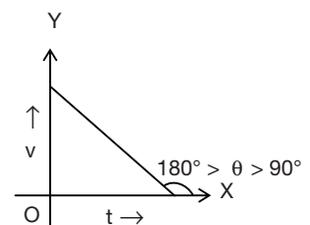
6. The $v - t$ graph of a body is as shown in Fig. 2.32. As the curve begins at the origin, the initial velocity of the body is zero and moves with non-uniform or variable velocity. The acceleration of the body at instants t_1 and t_2 is given by the slopes of the tangents drawn to the curve at the points C and D as a_1 and a_2 , respectively. From the Fig. 2.32, it is obvious that $a_2 > a_1$. Thus, the body moves with increasing acceleration.

**FIGURE 2.32**

7. The $v - t$ graph of a body is as shown in the Fig. 2.33. The graph is a curve which implies that the body is moving with variable velocity. The acceleration of the body at instants t_1 and t_2 is given by the slopes of the tangents drawn to the curve at points E and F as a_1 and a_2 , respectively. From the Fig. 2.33, it is obvious that $a_1 > a_2$. Thus, the body moves with decreasing acceleration. But it is not retardation as the velocity of the body is not decreasing with time. As the curve begins at the origin, the initial velocity of the body is zero.

**FIGURE 2.33**

8. The $v - t$ graph of a body is as shown in Fig. 2.34. It is a straight line making an obtuse angle with the positive X -axis. There is some initial u velocity of the body and has an equal decrease in velocity in equal intervals of time. Thus, the body moves with uniform retardation, the magnitude of which is given by the slope of the line.

**FIGURE 2.34**

SOLUTION

$$\text{Deceleration} = \text{slope of } BC = \frac{(10 - 5) \text{ m s}^{-1}}{(4 - 3) \text{ s}} = 5 \text{ m s}^{-2}$$

Total distance travelled = Area of the triangle ABC + Area of rectangle $OADE$

$$= \frac{1}{2} AC \times BC + AD \times DE$$

$$S = \left(\frac{1}{2} \times 4 \times 5 \right) + (5 \times 5) = 35 \text{ m}$$

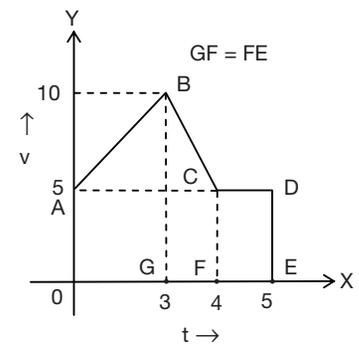


FIGURE 2.38

Acceleration–Time Graph

In this type of graph as shown in Fig. 2.39 acceleration is plotted along Y-axis and time along X-axis.

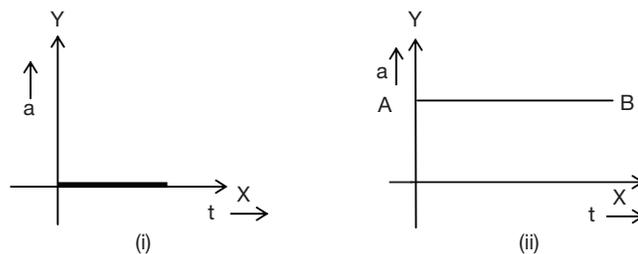


FIGURE 2.39

1. $a = 0$, body moving with constant velocity.
2. ' a ' is constant, body moving with uniform acceleration.

Uses of Acceleration–time Graph

1. Acceleration at any intermediate time can be determined.
2. Area under the curve gives the change in magnitude of velocity that is $(v - u)$.

EXAMPLE

In the Fig. 2.40, find the change in velocity at $t = 5$ seconds. Given a is in m s^{-2} and t is in s .

SOLUTION

Here, we find that the acceleration is not constant, and we cannot use the equation $v = u + at$.

\therefore Change in velocity = area under the $a - t$ curve.

$$= \frac{1}{2} \times 5 \times 10 = 25 \text{ m s}^{-1}.$$

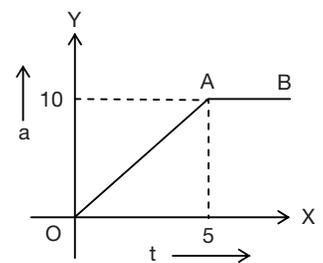


FIGURE 2.40

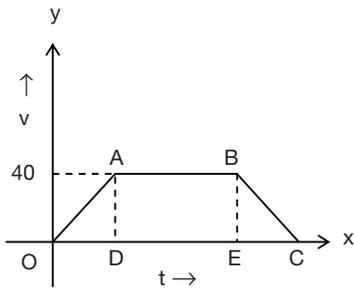


FIGURE 2.41

Graphical Method—Solutions

Let us consider a body starts from rest and increases its velocity upto 40 ms^{-1} for some time. Further it travelled some distance with 40 ms^{-1} velocity and comes to rest after certain time.

Let the time intervals given for acceleration, uniform velocity and retardation be x , $3x$ and x ; represented by OD , DE and EC , respectively. Area under the graph gives the total displacement.

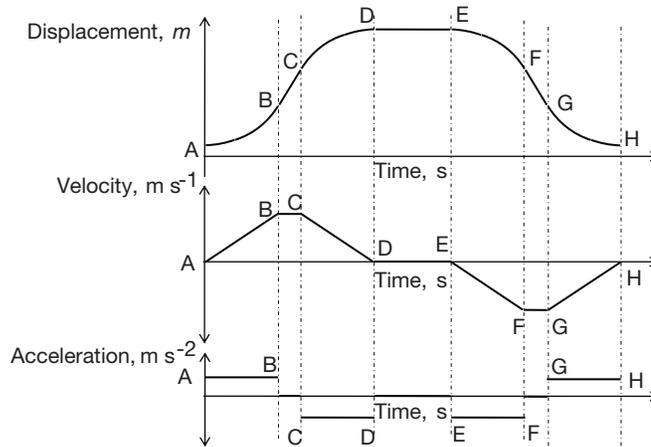


FIGURE 2.42

$$\therefore S = \text{Area } (OAD + ABED + BEC)$$

$$= \frac{1}{2} (OD) (AD) + (DE) (AD) + \frac{1}{2} (EC) (BE) = \frac{1}{2} x (40) + (3x) (40) + \frac{1}{2} x (40) = 160x \text{ km.}$$

$$\text{Total time} \quad t = x + 3x + x = 5x \text{ h.}$$

$$\therefore \text{Average velocity} = \frac{s}{t} = \frac{160x}{5x} \text{ km h}^{-1} = 32 \text{ km h}^{-1}.$$

Given above are graphs that describe the motion of a person on his motorcycle. From the graphs, these are the points that can be concluded about his motion in different intervals of time.

A - Person starts the motorcycle, $u = 0$.

AB - He moves towards right at a constant acceleration, $v = at$.

BC - Uniform motion; he is going at constant speed, $a = 0$.

CD - He applies brakes and starts to slow down; acceleration is negative (deceleration).

D - He stops completely.

DE - He takes rest.

E - Starts his motorcycle again.

EF - He moves toward left at constant acceleration (increasing speed). Velocity and acceleration negative due to the motion in opposite direction

FG - Moves in opposite direction (to left) at constant speed.

GA - Applies brakes and starts to slow down (deceleration).

H - He stops completely. (velocity = 0)

NOTE

In plotting the graphs, all vectors in the forward direction are taken as positive and in the opposite direction are taken as negative.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

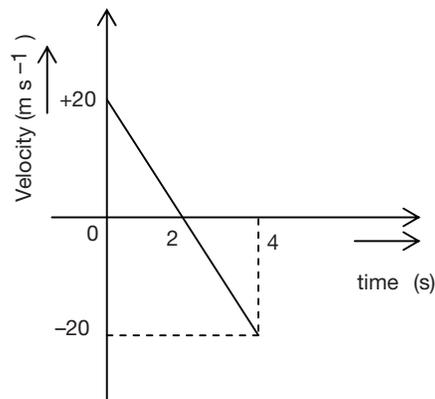
1. Give the three equations of motion for a particle moving in one dimension.
2. A stone is dropped from the top of a tower and allowed to travel freely under gravity. What is the initial velocity of the stone?
3. If the ratio of the final velocities of two bodies falling freely is 4 : 3, then the ratio of the heights from which they fall is _____.
4. Give two examples of projectile motion.
5. What is meant by the range of a projectile?
6. Explain the motion of a body undergoing circular motion with an example.
7. A particle in uniform circular motion has uniform speed but non-uniform _____.
8. Define time of ascent and time of descent.
9. (i) When is a body said to be at rest?
(ii) When is it said to be in motion?
10. A body projected with when is it said to be in motion a certain velocity making an angle, other than 90° , to horizontal is known as _____.
11. What are scalar and vector quantities? Give some examples.
12. Does the velocity remain the same in case of uniform circular motion?
13. What are the C.G.S. and M.K.S. units of distance and displacement?
14. A particle in one dimensional motion, moving with constant velocity must have _____ acceleration.
15. What is meant by time of flight?
16. Why is distance called scalar quantity and displacement a vector quantity?
17. If a body does not change its position with respect to its surroundings, the body is said to be _____.
18. What is uniform circular motion?
19. Give the C.G.S. and M.K.S. units of velocity and speed.
20. Retardation is a _____ quantity (scalar/vector).
21. Which physical quantity is plotted on X-axis for all types of graphs representing motion of a body?
22. What is meant by acceleration and retardation?
23. A freely falling body travels with _____.
24. When is a body said to have zero acceleration?
25. One body is dropped from the top of a tower and the other is projected vertically upwards. Can the acceleration due to gravity be the same?
26. A particle moves from P to Q with a uniform velocity V_1 and Q to P with a velocity V_2 . Its average velocity is _____.
27. Give examples of bodies moving under the influence of gravity.
28. A body moving along a straight line between two places moves with a velocity v_1 for first half of time to travel between the places and with a velocity v_2 for the remaining half time. Then its average velocity is _____.
29. What is the acceleration of a body when the velocity remains constant?
30. What is a trajectory?

Short Answer Type Questions

31. Derive an expression for maximum height reached when a body is projected vertically upwards.
32. A water tank is placed on the top of a building of height 19 m. Water overflowing from the tank was found to reach the ground in 2 seconds. Find the height of the tank. (Take $g = 10 \text{ m s}^{-2}$)
33. What are the different types of motion? Give an example for each.
34. Derive an expression for the time taken by a body which is thrown vertically upwards to reach maximum height.
35. If a runner with a certain initial velocity moves with uniformly acceleration in such away that he covers 200 cm in the 2nd second and 220 cm in the 4th second, then find his initial velocity and the acceleration.



36. Show that the time of ascent and the time of descent are equal for a body in vertical motion.
- OR
- Show that the time of flight is equal to $(2u)/g$.
37. Derive $v = u + at$.
38. The driver of a TGV travelling at a speed of 90 m s^{-1} sights a truck on the rail track at a distance of 1 km ahead. Then he applies the brakes to decelerate the train at the rate of 5 m s^{-2} . What is the distance travelled by the train before coming to rest? Will the train collide with the truck?
39. Derive an expression for time of descent.
40. A body dropped from the top of a cliff reaches the ground in 5 s . Find the height of the cliff.
41. Give the equations of motion of a body projected vertically upwards.
42. A train travels from one station to another station at an average speed of 40 km h^{-1} and returns back to the first station at an average speed of 60 km h^{-1} . Find the average speed and average velocity of the train? Ignore the stoppage time at the second station.
43. From the velocity-time graph given below, for a body projected vertically upwards,
- find the velocity of projection
 - maximum height attained by the body



44. Determine 'a' of the object which
- moves in a straight line with a constant speed of 20 m s^{-1} for 12 seconds .
 - changes its velocity from 0 m h^{-1} to 360 m min^{-1} in 4.2 s .
45. Give the equations of motion of a body falling under gravity, being dropped from a certain height.

Essay Type Questions

46. Explain the characteristics of the following graphs.
- Displacement-time
 - Velocity-time
 - Acceleration-time
47. Derive $S_n = u + \frac{a}{2}(2n - 1)$.
48. Derive $s = ut + \frac{1}{2}at^2$.
49. Obtain $s = ut + \frac{1}{2}at^2$ by graphical method.
50. Derive $v^2 - u^2 = 2as$.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- A body moves with retardation when it is projected vertically upwards.
- A body is projected vertically up. On reaching maximum height, its velocity becomes zero.
- Velocity-time graph can be used to find the displacement.
- If a body moves with constant velocity, its displacement depends on the square of time taken.
- When two balls of different masses are thrown vertically upwards with the same initial speed, the heavier body rises to greater height than the lighter body.
- Equations of motion are applicable only when a body moves with uniform velocity.
- The distance travelled by a freely falling body in every successive second is the same.



Direction for questions 8 to 13

Fill in the blanks.

8. The ratio of velocities acquired by a freely falling body starting from rest at the end of 1 second and 2 seconds is _____.
9. If a stone is thrown vertically up and it is caught after time 't' seconds, then the maximum height reached by it is _____.
10. Area under the velocity–time graph gives _____.
11. The ratio of magnitude of average velocity to average speed is _____.
12. The directions of both displacement and average velocity are _____.
13. _____ is produced in a body whenever there is a change in its velocity.

Direction for question 14

Match the entries in Column A with the appropriate ones in Column B.

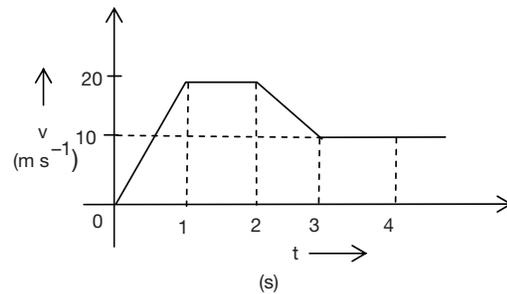
14.

Column A	Column B
A. Uniform Velocity ()	a. 
B. Uniform acceleration with initial velocity ()	b. 
C. Uniform acceleration ()	c. 
D. Increasing acceleration ()	d. 
E. Uniform retardation ()	e. 
F. Decreasing acceleration at steady rate ()	f. 
G. Uniform acceleration with initial displacement ()	g. 
H. Body at rest with initial displacement ()	h. 

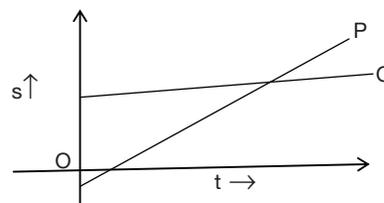
Direction for questions 15 to 42

For each of the questions, four choices have been provided. Select the correct option.

15. The ratio of magnitude of displacement to distance is always
 - (a) less than 1
 - (b) greater than 1
 - (c) equal to 1
 - (d) less than or equal to 1
16. The ratio of the heights from which two bodies are dropped is 3 : 5, respectively. The ratio of their final velocities is
 - (a) $\sqrt{5} : \sqrt{3}$
 - (b) $\sqrt{3} : \sqrt{5}$
 - (c) 9 : 25
 - (d) 5 : 3
17. The variation of the velocity of a particle moving along a straight line is illustrated in the graph given below. The distance covered by the particle in 4 seconds is _____ m.

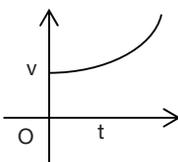
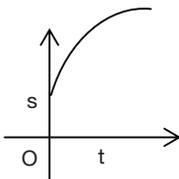
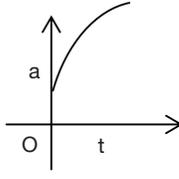
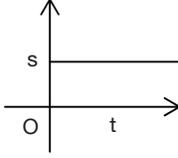


- (a) 20
 - (b) 40
 - (c) 35
 - (d) 55
18. An ant moves from one corner of a hall to the diagonally opposite corner. If the dimensions of the floor of hall are 8 m × 6 m, the displacement of the ant is _____ m.
 - (a) 14
 - (b) 10
 - (c) 28
 - (d) 2
19. The figure given below shows the displacement–time graph of the two particles P and Q. Which of the following statements is correct?



- (a) Both P and Q move with uniform equal speed.
 - (b) P is accelerated and Q is retarded.



- (c) Both P and Q move with uniform speed, but the speed of P is more than the speed of Q .
- (d) Both P and Q move with uniform speeds but the speed of Q is more than the speed of P .
20. When brakes are applied, the velocity of a car changes from 40 m s^{-1} to 10 m s^{-1} in 10 s. The acceleration produced in it is _____ m s^{-2} .
- (a) -3 (b) 3
(c) -5 (d) 5
21. If a body starts from rest and moves with uniform acceleration, then
- (a) $v \propto t$ (b) $s \propto t$
(c) $v \propto s$ (d) $s \propto \sqrt{t}$
22. If a body is projected vertically upwards, then on reaching maximum height, its
- (a) velocity is zero and the acceleration is not zero.
(b) velocity is not zero and the acceleration is zero.
(c) both velocity and acceleration are not zero.
(d) both velocity and acceleration are zero.
23. The ratio of the times taken by a body moving with uniform acceleration in reaching two points P and Q along a straight line path is $1 : 2$. If the body starts from rest, then the ratio of the distances of P and Q from the starting point is
- (a) $4 : 1$ (b) $1 : 4$
(c) $2 : 3$ (d) $3 : 1$
24. A body with an initial velocity of 3 m s^{-1} moves with an acceleration of 2 m s^{-2} . Then the distance travelled in the 4th second is _____ m.
- (a) 10 (b) 6
(c) 7 (d) 28
25. A bus travels the first one-third distance at a speed of 10 km h^{-1} , the next one-third distance at a speed of 20 km h^{-1} and the next one-third distance at a speed of 30 km h^{-1} . The average speed of the bus is
- (a) 20 m s^{-1} (b) $\frac{50}{11} \text{ m s}^{-1}$
(c) $\frac{180}{11} \text{ m s}^{-1}$ (d) 30 m s^{-1}
26. Which of the following graphs indicates that a body is undergoing retardation?
- (a)  (b) 
- (c)  (d) 
27. The velocity of a body is given by the equation $v = 6 - 0.02t$, where t is the time taken. The body is undergoing
- (a) uniform retardation.
(b) uniform acceleration.
(c) non-uniform acceleration.
(d) zero-acceleration.
28. A body starts from rest and moves with uniform acceleration for 2 s. It then decelerates uniformly for 3 s and stops. If deceleration is 4 m s^{-2} , the acceleration of the body is _____ m s^{-2} .
- (a) 10 (b) 8.7
(c) 4 (d) 6
29. Density is a _____ quantity.
- (a) scalar (b) derived
(c) neither (1) nor (2) (d) Both (1) and (2)
30. A particle moves from P to Q with a uniform velocity v_1 and Q to P with a velocity v_2 . If it moves along a straight line between P and Q , then its average velocity will be _____.
- (a) $\frac{2v_1v_2}{v_1 + v_2}$ (b) $\frac{v_1v_2}{2}$
(c) $\frac{v_1 + v_2}{2}$ (d) zero
31. If a body is projected vertically up from a point and it returns to the same point, its
- (a) average speed is zero, but not average velocity.
(b) Both average speed and average velocity are zero.
(c) average velocity is zero but not average speed.
(d) Both average speed and velocity depend upon the path.
32. If a ball thrown vertically up attains a maximum height of 80 m, then its velocity of projection is (Take $g = 10 \text{ m s}^{-2}$)
- (a) 40 m s^{-1} (b) 20 m s^{-1}
(c) 50 m s^{-1} (d) 10 m s^{-1}
33. A vertically projected down body travels with
- (a) uniform velocity.
(b) uniform speed.



- (c) uniform acceleration.
(d) uniform retardation.

34. A particle revolves along a circle with a uniform speed. The motion of the particle is _____.
(a) one dimensional (b) two dimensional
(c) translatory (d) oscillatory

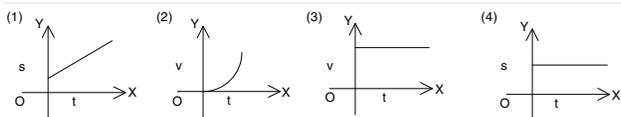
35. If u is the initial velocity, of a body projected with an angle θ with the horizontal, then the maximum height reached

- (a) $\frac{u^2}{g}$ (b) $\frac{u^2 \sin \theta}{2g}$
(c) $\frac{u \sin \theta}{2g}$ (d) $\frac{u^2 \sin^2 \theta}{2g}$

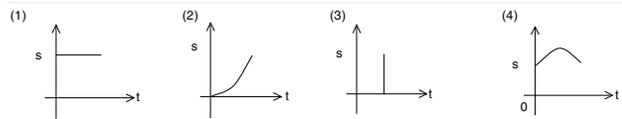
36. If the body is projected up into air with certain angle, then the path followed by it is

- (a) Linear path (b) Elliptical path
(c) Parabolic path (d) Spherical path

37. Which one of the following graph indicates that the body is at rest?



38. Which of the following graphs given below is impossible?



39. If a body travels with an acceleration a_1 for time t_1 and acceleration a_2 for time t_2 , t_1 and t_2 being successive time intervals, then the average acceleration of the body is

- (a) $\frac{a_1 t_1 + a_2 t_2}{2(t_1 + t_2)}$ (b) $\frac{a_1 t_1 + a_2 t_2}{(t_1 + t_2)}$
(c) $\frac{(a_1 + a_2)}{t_1 + t_2}$ (d) $\frac{a_1 t_1 - a_2 t_2}{(t_1 + t_2)}$

40. If a body covers 26 m and 30 m in the 6th and 7th seconds of its travel, then the initial velocity and acceleration of the body are

- (a) 4 m s^{-1} , 4 m s^{-2} (b) 6 m s^{-1} , 4 m s^{-2}
(c) 10 m s^{-1} , 8 m s^{-2} (d) 0 , 4 m s^{-2}

41. The ratio of maximum heights reached by two bodies projected vertically up is $a : b$, then the ratio of their initial velocities of is

- (a) $a : b$ (b) $a^2 : \sqrt{b}$
(c) $\sqrt{b} : \sqrt{a}$ (d) $\sqrt{a} : \sqrt{b}$

42. A particle moves along a circular track of 6 m radius such that the arc of the circular track covered subtends an angle of 30° at the centre. The distance covered by the body is

- (a) $\pi \text{ m}$ (b) $13\pi \text{ m}$
(c) $4\pi \text{ m}$ (d) $6\pi \text{ m}$

Level 2

43. Show that for a body projected vertically up from the ground, the distance travelled by it in the last second of its upward motion is a constant independent of its initial velocity.

44. A ball is dropped from the top of a tower of height 80 m. At the same time, another ball is projected horizontally from the tower. Find the time taken by both the balls to reach the ground.

(Take $g = 10 \text{ m s}^{-2}$)

45. A person travels the total distance in two parts in the ratio 2 : 1 with a constant speed of 30 km h^{-1} in the first part and 40 km h^{-1} in the second part. What is the average speed of the journey?

46. A balloon starts rising from the ground, vertically upwards, uniformly at the rate of 1 m s^{-1} . At the

end of 4 seconds, a body is released from the balloon. Calculate the time taken by the released body to reach the ground.

(Take $g = 10 \text{ m s}^{-2}$)

47. A pendulum of length 28 cm oscillates such that its string makes an angle of 30° from the vertical when it is at one of the extreme positions. Find the ratio of the distance to displacement of the bob of the pendulum when it moves from one extreme position to the other.

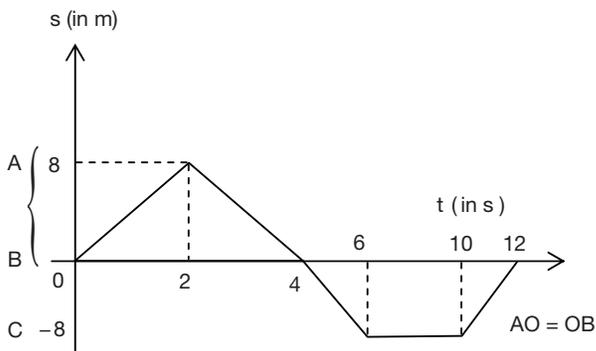
48. A cannon fires a shell with a speed of 84 m s^{-1} . When the cannon is inclined at 45° , the horizontal distance covered is observed as 630 m. What is the percentage decrease in the horizontal distance observed due to air resistance?



49. A stone is dropped from a certain height on earth and it takes 12 seconds to reach the ground. If the same stone is dropped from the same height on moon, find the time that it will take to reach the surface of the moon. Ignore the air resistance.

$$\text{(Given } g_{\text{moon}} = \frac{1}{6} g_{\text{earth}})$$

50. The distance travelled by a body in the n th second is given by the expression $(2 + 3n)$. Find the initial velocity and acceleration. Also, find its velocity at the end of 2 seconds.
51. For a body that is dropped from a height, find the ratio of the velocities acquired at the end of 1 second, 2 seconds and 3 seconds, respectively.
52. The ratio of distance described by a body falling freely from rest in the last second of its motion to that in last but one second of its motion is $5 : 4$. Find the total time taken by the body to reach the ground.
53. A ball is thrown vertically upwards with an initial velocity such that it can reach a maximum height of 15 m. If, at the same instance, a stone is dropped from a height of 15 m, find the ratio of distances travelled by them when they cross each other.
54. A body projected vertically up crosses points A and B separated by 28 m with velocities one-third and one-fourth of the initial velocity, respectively. What is the maximum height reached by it above the ground?
55. A body is dropped from a certain height. Plot a displacement–time, velocity–time and acceleration–time graphs of the body.
56. Given below is the displacement–time graph of a body moving in a straight line. Find the distance covered in 4 seconds. Also find the displacement of the body at the end of 12 seconds.



57. A car moves linearly with uniform retardation. If the car covers 40 m in the last 2 seconds of its motion,

what is the velocity of the car at the beginning of the last second?

58. The horizontal component of vector \vec{a} is equal to the vertical component of vector \vec{b} . If 30° is the angle made by \vec{a} with its vertical axis and that made by \vec{b} with its horizontal axis, then calculate the value of \vec{b} in terms of \vec{a} .
59. In the given figure, determine the force acting along x -axis if the angle between the force and x -axis is $\theta = 30^\circ$ or 60° .



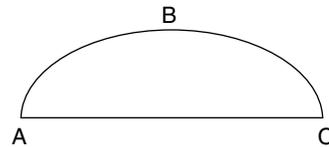
60. A person travels 6 m towards east, 8 m towards north and 16 m towards south. What is the displacement of the person?
61. The velocity of a retarding body changes from 90 km h^{-1} to 36 km h^{-1} . Find the change in its velocity in m s^{-1} .
62. A person is running along a circular track of area $625 \pi \text{ m}^2$ with a constant speed. Find the distance travelled and displacement in 30 s and 15 s., if he has to complete the race in 30 s.
63. In each of the questions given below, a statement is provided. State whether the given statement is true or false. Substantiate your answer by giving the reasons.
- (1) It is not possible for an accelerating body to have zero velocity.
 - (2) It is possible for a body undergoing linear motion to have displacement and velocity in opposite directions.
 - (3) It is not possible for a body undergoing linear motion to have velocity and acceleration in opposite directions.
 - (4) It is possible for a body to have uniform speed, when it is moving with an acceleration.
64. An object travels for 10 s with uniform acceleration along a straight line path. During this period if the velocity of the object is increased from 5 m s^{-1} to 25 m s^{-1} , then find the distance travelled by the body.
65. A body is projected vertically upward. If its velocity after 2 s is 25 m s^{-1} , find the velocity of projection.
(Take $g = 10 \text{ m s}^{-2}$)



66. A stone is projected vertically upward with a velocity of 25 m s^{-1} . Find its time of descent. (Take $g = 10 \text{ m s}^{-2}$)
67. A body is dropped from a certain height ' h ' metres. Assuming that the gravitational field is nullified, after the body has travelled $h/2$ metres such that $g = 0$, discuss the motion of the body. Find an expression for the time taken by the body to reach the ground.
68. Calculate the time of flight of a body which is thrown upto a height of 5 m from the ground.
69. An object projected vertically up from the top of a tower took 5 s to reach the ground. If the average velocity of the object is 5 m s^{-1} , find its average speed. (Given, $g = 10 \text{ m s}^{-2}$).
70. In case of an oblique projectile or horizontal projectile, why the horizontal component of velocity remains constant, but the vertical component of velocity changes continuously?
71. A body is dropped from a certain height and another body is projected horizontally. Which one will reach the ground first?
72. If the initial velocity of an oblique projectile is 20 m s^{-1} and it makes an angle 60° with the horizontal, what are the components of velocity in the horizontal and vertical direction?
73. Two particles of masses ' m ' and $4 'm$ ' are moving along the circular paths of radii r and $2r$, respectively

with equal velocity. What is the ratio of centripetal force acting on them?

74. A body is projected from the ground with a velocity of 10 m s^{-1} such that it makes an angle 30° with the horizontal. What is the horizontal velocity at the maximum height?
75. A body is projected horizontally with a velocity 23 m s^{-1} from a height of 5 m. What is the velocity of the body on reaching the ground?
76. A body travels in a semi-circular path of radius 7 m as shown. If the time taken to travel from A to C is 11 s, find
- (1) the distance covered.
 - (2) the displacement.
 - (3) the speed.
 - (4) velocity.
 - (5) What is the displacement if it completes the circle?



77. A person travels a total distance in three parts in the ratio $4 : 3 : 1$ with a constant speed of 90 km h^{-1} , 20 m^{-1} and 10 m s^{-1} , respectively. What is the average speed of the person while journey?

Level 3

78. Are all physical quantities that have magnitude and direction vectors? Give example to support your answer. When is a physical quantity called vector?
79. A body is dropped from a certain height above the ground. Its time of descent is 5 s. But at $t = 3 \text{ s}$, the body is stopped and then released. What is the remaining time the body should travel to reach the ground?
80. A body is dropped from a height of 2 m. It penetrates into the sand on the ground through a distance of 10 cm before coming to rest. What is the retardation of the body in the sand?
81. A car starts from rest and moves with uniform acceleration of $\alpha \text{ m s}^{-2}$ along a straight line. It then retards uniformly at a rate $\beta \text{ m s}^{-2}$ and stops. If ' t ' is the time elapsed, they find the average speed of the car.
82. A ball thrown vertically upwards with a speed ' u ' from the top of a tower reaches the ground in

9 seconds. Another ball thrown vertically downwards from the same position with the same speed ' u ', takes 4 seconds to reach ground. Calculate the value of ' u '. (Take $g = 10 \text{ m s}^{-2}$)

83. A train leaves station 'A' for station 'B'. The train travels along a straight line without any halts between the stations. During the first and last 200 m of its journey, the train has uniform acceleration and retardation both equal to 1 m s^{-2} , respectively. For the rest of the journey, the train maintains uniform speed. Calculate the average speed of the train, given the distance between the two stations is 4 km.
84. A ball thrown vertically up from the top of a tower reaches the ground in 12 s. Another ball thrown vertically downwards from the same position with the same speed takes 4 s to reach the ground. Find the height of the tower. (Take $g = 10 \text{ m s}^{-2}$)

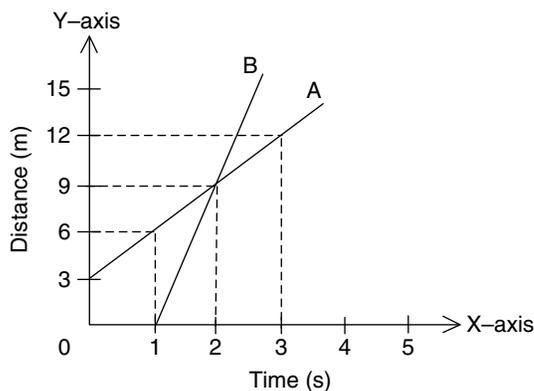


85. Two stones A and B are dropped from the top of two different towers such that they travel 44.1 m and 63.7 m in the last second of their motion, respectively. Find the ratio of the heights of the two towers from where the stones were dropped.
86. A missile is launched from the ground making an angle of 45° with the horizontal. If it is required to hit the target on the ground at 1600 km, with what velocity should it be launched? (Take $g = 10 \text{ m s}^{-2}$). Assume the acceleration due to gravity to be uniform throughout the motion of the missile.
87. If a football kicked from the ground moves with a velocity of 20 m s^{-1} making 30° with the horizontal, find its vertical displacement and horizontal displacement after 1 second. (Take $g = 10 \text{ m s}^{-2}$)
88. From the following data, calculate the acceleration in each time interval of two seconds and plot acceleration-time graph.

Velocity (m s^{-1})	0	2.5	5	7.5	10	12.5
Time (s)	0	2	4	6	8	10

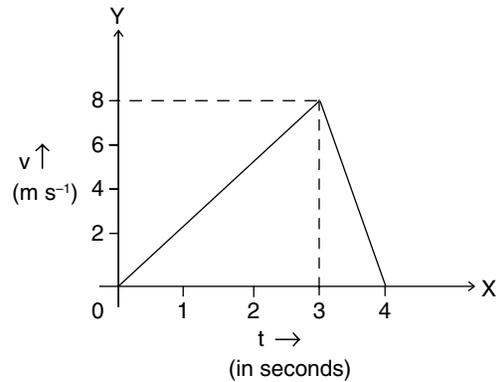
Does the body have uniform velocity or uniform acceleration?

89. The below figure shows the distance-time graph of two bodies A and B. Analyse the graph and answer the given questions.
- Which body is travelling faster?
 - What is the distance travelled by them at the end of 2 s?

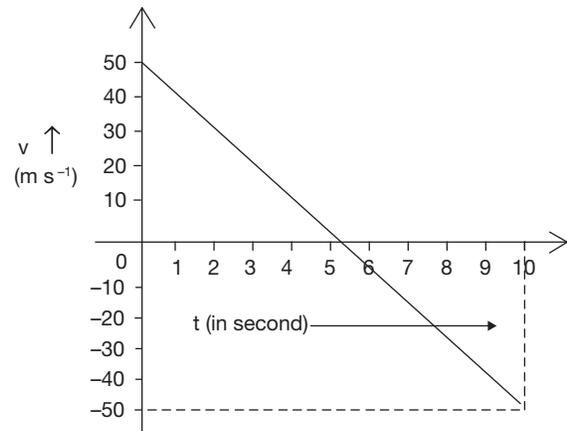


90. From the below figure, find the
- acceleration of the body during the first three seconds of its motion.

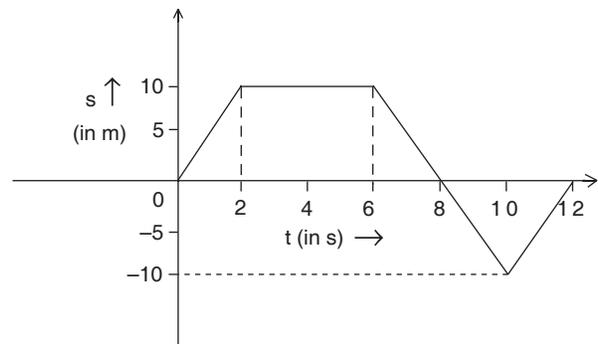
- deceleration of the body during the last second of its motion.
- displacement of the body at the end of 4 s.



91. From the below figure, find the displacement at the end of 10 s and also find at what rate the velocity of the body decreases.



92. From the adjacent figure a displacement-time graph of a body moving in a straight line. Find the distance covered and the displacement of the body at the end of 12 seconds.



CONCEPT APPLICATION

Level 1

True or false

1. True 2. True 3. True 4. False 5. False 6. False 7. False

Fill in the blanks

8. 1 : 2 9. $g \frac{t^2}{8}$ 10. displacement 11. less than or equal to 1 12. same 13. Acceleration

Match the following

- 14 A : c B : d C : f and d D : g E : b F : h G : a H : e

Multiple choice questions

15. (d) 16. (b) 17. (d) 18. (b) 19. (c) 20. (a) 21. (a)
 22. (a) 23. (b) 24. (a) 25. (b) 26. (b) 27. (a) 28. (d)
 29. (d) 30. (d) 31. (c) 32. (a) 33. (c) 34. (b) 35. (d)
 36. (c) 37. (d) 38. (c) 39. (b) 40. (a) 41. (d) 42. (a)

Explanations for questions 30 to 42:

30. When a body moves from P to Q and travels back to P the total displacement of the body is zero. Average velocity is also zero.

31. When a body is projected up and it returns to the point of projection, the average velocity is zero but not the average speed.

$$32. H_{\max} = 80 \text{ m} = \frac{u^2}{2g}$$

$$u^2 = 80 \times 2 \times 10$$

$$u = \sqrt{4 \times 2 \times 10 \times 2 \times 10} = 40 \text{ m s}^{-1}$$

33. A vertically projected down body travels with uniform acceleration.

34. The motion of a body along a circle with a uniform speed can be described as two – dimensional motion.

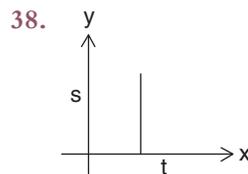
$$35. v_1^2 - u_1^2 = 2gh$$

$$v_1 = 0, u_1 = u \sin \theta$$

$$\therefore h_{\max} = \frac{u^2 \sin^2 \theta}{2g} = \frac{u^2 \sin^2 \theta}{2g}$$

36. Parabolic path.

37. In choice (d), the displacement of the body is constant as time passes.



In this graph, time remains constant which is impossible.

39. Average acceleration = $\frac{\text{change in velocity}}{\text{time taken}}$

Change in Velocity for time $t_1 = a_1 t_1$

Change in Velocity for $t_2 = a_2 t_2$

$$\therefore \text{Average acceleration} = \frac{a_1 t_1 + a_2 t_2}{(t_1 + t_2)}$$

$$40. S_n = u + \frac{a}{2}(2n - 1)$$

$$n = 6$$

$$S_6 = 26 = u + \frac{a}{2}(2 \times 6 - 1)$$



$$\begin{aligned} 2 \times 26 &= 2u + a(12-1) \\ 52 &= 2u + 11a \end{aligned} \quad (1)$$

$$n = 7$$

$$S_7 = 30 = u + \frac{a}{2}(2 \times 7 - 1) \quad (2)$$

$$60 = 2u + 13a$$

Subtract (1) from (2)

$$\begin{aligned} 60 &= 2u + 13a \\ 52 &= 2u + 11a \\ \hline 8 &= 2a \end{aligned}$$

$$8 = 2a$$

$$a = 4 \text{ m s}^{-2}$$

$$52 = 2u + 11(4)$$

$$2u = 52 - 44$$

$$2u = 8$$

$$u = 4 \text{ m s}^{-1}$$

$$41. \frac{h_1}{h_2} = \frac{a}{b}$$

$$\text{But } h = \frac{u^2}{2g}$$

Hence, $h \propto u^2$

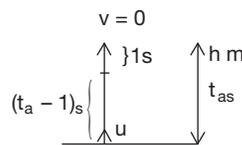
$$\therefore \frac{h_1}{h_2} = \frac{u_1^2}{u_2^2}$$

$$\frac{u_1}{u_2} = \sqrt{\frac{a}{b}} \Rightarrow u_1 : u_2 = \sqrt{a} : \sqrt{b}$$

$$\begin{aligned} 42. \theta &= 30^\circ \\ \text{distance covered } (l) &= r\theta \\ &= 30^\circ \times 6 = \frac{\pi}{6} \times 6 \text{ m} \\ \text{distance} &= \pi \text{ m} \end{aligned}$$

Level 2

$$43. (i) \quad h \text{ or } s = ut_a - \frac{1}{2}gt_a^2$$



$$\begin{aligned} (ii) \quad S_{n^{\text{th}}} &= h - s_{(t_a-1)} \\ &= \left(ut_a - \frac{1}{2}gt_a^2 \right) - \left[u(t_{a-1}) - \frac{1}{2}g(t_{a-1})^2 \right] \\ &= ut_a - \frac{1}{2}gt_a^2 - ut_a + u + \frac{g}{2}t_a^2 - 2\left(\frac{g}{2}\right)t_a + \frac{g}{2} \\ \text{distance covered in} \\ \text{last one second} &= u - u + \frac{g}{2} = \frac{g}{2} \end{aligned}$$

$$44. (i) \quad t = \sqrt{\frac{2h}{g}}$$

$$(ii) \quad \text{From the value of } h, \text{ find } t \text{ using } t = \sqrt{\frac{2h}{g}} \quad (1)$$

(iii) The initial velocity of the dropped ball and the initial vertical component of velocity of a horizontally projected ball is zero.

$$\therefore t_1 = t_2$$

(iv) Find time taken by the two balls using 1.

$$45. (i) \quad \text{Average speed} = \frac{\text{total distance}}{\text{total time taken}}$$

$$(ii) \quad 32.73 \text{ km h}^{-1}$$

$$46. (i) \quad s = ut + \frac{1}{2}at^2$$

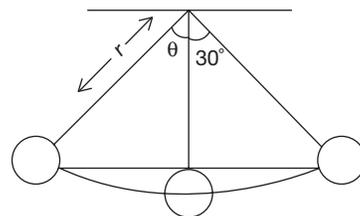
(ii) Distance traveled by the balloon in 1 second is 1 m.

(iii) Calculate the distance traveled at the end of 4 seconds = height at which the body is released.

(iv) Body will have initial velocity in the upward direction = velocity of the balloon.

(v) Substitute the value of g , u and s in equation $S = ut + \frac{1}{2}gt^2$ and find t .

(vi) 1 s



$$47. (i) \quad \text{Displacement} = 2r \sin \theta$$

$$\text{Distance} = \text{Length of the arc} = r\theta$$



- (ii) The angle made by the pendulum with the vertical is $= \frac{1}{2}$ the angle made by the arc described by the pendulum.
- (iii) The length of the arc = radius of the arc \times angular displacement.
- (iv) Does the length of the arc give the distance traveled by the pendulum?
- (v) Find the initial and final positions of the pendulum between its extreme positions.
- (vi) Is the shortest length between the extreme positions of the pendulum equal to its length?
- (vii) The length of the pendulum gives the value of displacement.
- (viii) 22 : 21

48. 12.5%

49. (i) Time of descent $= \sqrt{\frac{2h}{g}}$
- (ii) Calculate the height on earth using equation $h = \frac{1}{2}gt^2$ by substituting the values of g and t .
- (iii) g on moon = $-g$ on earth.

(iv) Find the time taken on moon by using the equation $h = \frac{1}{2}gt^2$, by substituting the values of h and g of moon.

(v) $12\sqrt{6}$ s

50. (i) Formula of S_n

$$(ii) S_n = u + \frac{a}{2}(2n - 1)$$

$$S_n = (v - \frac{a}{2})$$

(iii) 9.5 m s^{-1}

51. (i) $v = u + gt$

- (ii) When the body is dropped, initial velocity = 0.
- (iii) Substitute values of t in equation $v = u + gt$ and find the values of v_1 , v_2 and v_3 , for each value of ' t '.

(iv) Find their ratio.

(v) 1 : 2 : 3

52. (i) $S_n = u + \frac{g}{2}(2n - 1)$

(ii) Using formula of S_n relate S_n to S_{n-1} for the ratio given

(iii) Find n , i.e., total time taken

(iv) 5.5 s

53. (i) Time of motion of $A =$ Time of motion of $B = \frac{1}{2}$ Time of descent of B

(ii) Let x be the distance traveled by the ball.

(iii) Let y be the distance traveled by the stone.

$$(iv) \text{ Time of flight} = \sqrt{\frac{2h}{g}} \quad h = x + y$$

$$(v) \text{ Time of descent of the stone} = \sqrt{\frac{2y}{g}}$$

(vi) Equate 3 and 4 and obtain the relation between x and y .

(vii) Find the ratio of x and y .

(viii) 3 : 1

54. (i) $H = \frac{u^2}{2g}$

$$s = ut - \frac{1}{2}gt^2$$

(ii) 576 m

55. Relate equations

56. (i) Definition of distance and displacement.

(ii) Distance = total path covered

Displacement = shortest path covered between initial and final points.

(iii) 16 m, 0

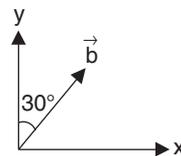
57. (i) $S_n = u + \frac{a}{2}(2n - 1)$

$$v = u + at$$

(ii) Find v after n seconds and relate it to the sum of the distance covered in n th and $(n - 1)$ th second.

(iii) 40 m s^{-1}

58.



horizontal, component of \vec{a} , $\Rightarrow a_x = a \cos \theta$ and given



$$\theta = 30^\circ \Rightarrow a_x = a \frac{\sqrt{3}}{2} \text{ and vertical component of } \vec{b}$$

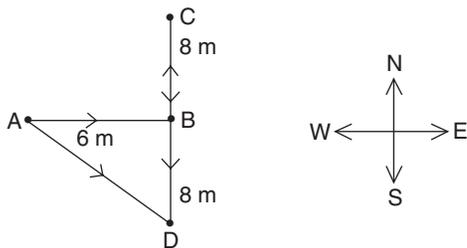
$$\Rightarrow b_y = b \sin \theta \text{ and given } \theta = 60^\circ$$

$$\Rightarrow b \sin 30 \Rightarrow \frac{b}{2}$$

$$\text{Given } a_x = b_y \Rightarrow \frac{a\sqrt{3}}{2} = \frac{b}{2} \Rightarrow b = a\sqrt{3} \text{ units.}$$

59. $F_x = F \cos \theta = 15 \times \cos \theta = 15 \cos \theta$

60. AB = 6 m, BD = 8 m



Then the displacement is AD

$$= \sqrt{(AB)^2 + (BD)^2} = \sqrt{6^2 + 8^2}$$

$$= \sqrt{36 + 64} = \sqrt{100} = 10 \text{ m}$$

61. Change in velocity in $\text{km h}^{-1} = 36 - 90 = -54 \text{ km h}^{-1}$
 $-54 \text{ km h}^{-1} = -54 \times 5/18 \text{ m s}^{-1} = -15 \text{ m s}^{-1}$

62. Given ground is in circular shape of radius “ r ” and Area = 625π sqm

$$A = \pi r^2 = 625\pi \Rightarrow r^2 = 625 \Rightarrow r = \sqrt{625} = 25 \text{ m}$$

In 30 s, the distance travelled by him = circumference of the circle = $2\pi r = 2\pi(25) \text{ m} = 50\pi \text{ m} = 157.14 \text{ m}$.

The displacement = 0, because the starting and ending points are same.

\Rightarrow Now, the distance in 15

$$s = \frac{\text{distance in 30 s}}{2}$$

$$= \frac{157.14}{2} = 78.57 \text{ m}$$

The displacement in 15

$$s = \text{diameter of circular ground}$$

$$= 2r = 2 \times 25 = 50 \text{ m.}$$

63. (1) The statement is false. When a body is projected vertically upwards, its velocity decreases as it moves up. This is due to the retardation of

the body caused by the gravitational pull of the Earth on the body. When the body reaches its maximum height, its velocity is zero, but it is still under acceleration due to gravity. Hence, it is possible for an accelerating body to have zero velocity.

(2) The statement is false. Velocity is defined as displacement per unit time. Thus, velocity is also displacement, but for a unit time. Hence, the direction of displacement and velocity are one and the same. Thus, it is not possible for a body undergoing linear motion to have displacement and velocity in opposite directions.

(3) The given statement is false. It is possible for a body undergoing linear motion to have velocity and acceleration in opposite directions. For example, if a body is thrown in upward direction, its velocity is in the upward direction, whereas its acceleration which is due to gravity is in the downward direction.

(4) The given statement is true. It is possible for a body to have uniform speed, when it is moving with an acceleration. For example, if a body is moving with uniform speed along a circular path, the direction of velocity of the body changes continuously, and thus, it has an acceleration directed towards the centre of the circular path.

64. $t = 10 \text{ s}$

$$u = 5 \text{ m s}^{-1}$$

$$v = 25 \text{ m s}^{-1}$$

$$s = ?$$

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

$$s = \frac{u+v}{2} \times t = \frac{25+5}{2} \times 10 = 150 \text{ m}$$

65. $u = ?$

$$v = 25 \text{ m s}^{-1}$$

$$g = 10 \text{ m s}^{-2}$$

$$t = 2 \text{ s}$$

$$v = u - gt$$

$$25 = u - 10(2) \Rightarrow u = 25 + 20 = 45 \text{ m s}^{-1}$$

66. In case of vertical projectile, time of ascent = time of descent = u/g .

$$\therefore \text{Time of descent} = 25/10 = 2.5 \text{ s.}$$

67. From height h to $h/2$ from ground the body travels



with an acceleration equal to 'g'.

Thereafter, in the absence of gravity the body moves with uniform velocity.

Velocity at A, $u = 0$

Time taken by body to travel from A to B

$$t_1 = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \cdot \frac{h}{2}}{g}} = \sqrt{\frac{h}{g}}$$

Velocity of body at B, $v = u + at$

$$0 + g \times \sqrt{\frac{h}{g}} = \sqrt{hg}$$

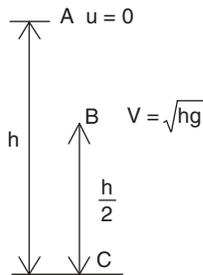
Time taken by body to travel from B to C with uniform

Velocity $v = \sqrt{hg}$ is $t_2 = \frac{s}{v}$

$$= \frac{h}{2\sqrt{hg}} = \frac{1}{2}\sqrt{\frac{h}{g}}$$

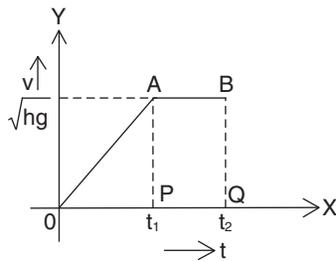
Net time taken by body to reach ground $t = t_1 + t_2$

$$= \sqrt{\frac{h}{g}} + \frac{1}{2}\sqrt{\frac{h}{g}} = \frac{3}{2}\sqrt{\frac{h}{g}}$$



Alternate method:

Drawing the $v-t$ graph, we get



Velocity at A $= \sqrt{hg}$ and $t_1 = \sqrt{\frac{h}{g}}$

$$\text{Area of } \Delta OAP = \frac{h}{2}$$

Thus, area of ABPQ should be equal to $h/2$.

$$\therefore t_2 - t_1 = \frac{1}{2}\sqrt{\frac{h}{g}}$$

$$\therefore t_2 = t_1 + \frac{1}{2}\sqrt{\frac{h}{g}} = \frac{3}{2}\sqrt{\frac{h}{g}}$$

68. Time of flight = Time of ascent + Time of descent

$$T_f = \frac{2u}{g}$$

$$\therefore h = \frac{u^2}{2g} \Rightarrow 2gh \Rightarrow u = \sqrt{2gh}$$

$$g = 9.8 \text{ mg}^{-2}$$

$$\therefore u = \sqrt{2 \times 9.8 \times 5} = \sqrt{98}$$

$$= 9.89 \text{ m s}^{-1} \approx 9.9 \text{ m s}^{-1}$$

$$T_f = \frac{2(9.9)}{9.8} \approx 2 \text{ s}$$

69. Let the height of the tower be 'h'

average velocity = 5 m s^{-1}

time = 5 s

total displacement = height of the tower

= average velocity \times time

$$= 5 \times 5$$

$$\therefore H = 25 \text{ m}$$

On applying equations of motion,

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

$$-H = ut - \frac{1}{2} gt^2$$

$$-25 = u \times 5 - \frac{1}{2} \times 10 \times 5 \times 5$$

$$u = 20 \text{ m s}^{-1}$$

Total distance travelled by the body is

$$= \frac{u^2}{2g} + \frac{u^2}{2g} + h = \frac{u^2}{g} + 25$$

$$= \frac{20 \times 20}{10} + 25 = 65 \text{ m}$$

$$\text{Average speed} = \frac{65}{5} = 13 \text{ ms}^{-1}$$

70. In case of an oblique projectile or horizontal projectile, the horizontal component of velocity remains constant because there is no effect of acceleration due to gravity in the horizontal direction. But the vertical component of velocity changes because the acceleration due to gravity is always acting vertically. So, when a body is moving downwards its vertical component of velocity increases, when a body is moving upwards its vertical component of velocity decreases. 29. Both the bodies will reach simultaneously as they have the same initial velocity and displacement



71. Both the bodies will reach simultaneously as they have the same initial velocity and displacement

72. The initial velocity; $u = 20 \text{ m s}^{-1}$.

Horizontal component of velocity is u_x .

$$\cos \theta = \frac{u_x}{u} \Rightarrow u_x = u \cos \theta$$

$$\therefore u_x = 20 \times \cos 60^\circ = 20 \times 1/2 = 10 \text{ m s}^{-1}$$

Vertical component of velocity is u_y .

$$\sin \theta = \frac{u_y}{u} \Rightarrow u_y = u \sin \theta$$

$$\therefore u_y = 20 \times \sin 60^\circ = 20 \times \frac{\sqrt{3}}{2} = 10\sqrt{3} \text{ m s}^{-1}$$

73. Centripetal force $F = \frac{mv^2}{R}$

$$\frac{F_1}{F_2} = \frac{mv^2}{r} \times \frac{2r}{4mv^2} = \frac{1}{2}$$

74. Horizontal velocity remains unchanged, and hence, it is equal to

$$u \cos \theta = 10 \cos 30^\circ = 10 \frac{\sqrt{3}}{2} = 5\sqrt{3} \text{ m s}^{-1}$$

75. To find vertical velocity, we can use

$$v_y = \sqrt{2gh}$$

Substitute $g = 9.8 \text{ m s}^{-2}$, $h = 5 \text{ m}$

$$v_y = \sqrt{2 \times 9.8 \times 5} = \sqrt{98} = 7\sqrt{2} = 9.9 \text{ m s}^{-1}$$

Velocity on reaching the ground is

$$v = \sqrt{v_x^2 + v_y^2}$$

Substitute $v_x = \sqrt{23} \text{ m s}^{-1}$, $v_y = \sqrt{98} \text{ m s}^{-1}$

$$\begin{aligned} v &= \sqrt{(\sqrt{23})^2 + (\sqrt{98})^2} = \sqrt{23 + 98} \\ &= \sqrt{121} = 11 \text{ m s}^{-1} \end{aligned}$$

76. Radius, $r = 7 \text{ m}$

Time, $t = 11 \text{ s}$

$$(a) \text{ Distance covered} = \pi r = \frac{22}{7} \times 7 = 22 \text{ m}$$

$$(b) \text{ Distance covered} = 7 + 7 = 14 \text{ m}$$

$$(c) \text{ Speed} = \frac{\text{distance covered}}{\text{time}} = \frac{22}{11} = 2 \text{ m s}^{-1}$$

$$(d) \text{ Velocity} = \frac{\text{displacement}}{\text{time}} = \frac{14}{11} = 1.27 \text{ m s}^{-1}$$

(e) When the body completes full circle, its displacement is zero.

77. Given the ratio of distance = 4 : 3 : 1 with constant speeds of 90 km h^{-1} , 20 m s^{-1} and 10 m s^{-1} . Let 'd' be the total distance covered and velocity = 90 km h^{-1}

$$= 90 \times \frac{5}{8} = 25 \text{ m s}^{-1}$$

Let the time taken to cover the first part t_1

$$= \frac{d_1}{v_1} \text{ and } d_1 = \frac{4d}{8 \times 25} \text{ then } t_1 = \frac{4d}{8 \times 25} = \frac{d}{50}$$

Similarly, then

$$t_2 = \frac{3d}{8 \times 20} = \frac{3d}{160}$$

and the distance travelled in

$$\text{Second part} = \frac{3d}{8} = d_2 \text{ and}$$

$$t_3 = \frac{d}{8 \times 10} = \frac{d}{80}$$

and the distance travelled in third part = $\frac{d}{8}$.

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}}$$

$$= \frac{d}{\frac{d}{50} + \frac{3d}{160} + \frac{d}{80}} = d \left(\frac{400}{41d} \right) = \frac{400}{41}$$

$$\text{Average speed} = 68.9 \text{ m s}^{-1}$$

Level 3

78. (i) Consider electric current and discuss.
 (ii) In a circuit the electric current flowing towards junction is + 5A and away from junction are -3A and -2A
 (iii) Net current = +5 - 3 - 2 = 0

- (iv) From the above example, find whether the net current has magnitude and direction.
 (v) The 2 hint gives the information whether current is a vector or a scalar.
 (vi) Does the magnitude of electric current change with direction?



79. (i) $h = \frac{1}{2} g t^2$
 (ii) Using the given conditions, find the height for the time of descent of 5 seconds. Then find the distance travelled in the first 3 seconds and find time needed to travel the remaining distance.
 (iii) 4 s

80. (i) $v = \sqrt{2gh}$
 (ii) $a = \frac{v^2 - u^2}{2s}$
 (iii) Find the velocity of the body on reaching the ground. This becomes the initial velocity for the retardation of the body in sand. Using that data find the retardation.
 (iv) -196 m s^{-2}

81. (i) Average speed =

$$\frac{\text{Total distance}}{\text{time}} = \frac{\text{Area under } v-t \text{ graph}}{\text{time}}$$
 (ii) Plot a $v-t$ graph for acceleration and retardation.
 (iii) Take velocity along Y-axis and time along X-axis.
 (iv) Find the area under the curve.
 (v) Area under the curve gives net displacement.
 (vi) Calculate average speed using the formula

$$\text{average speed} = \frac{\text{net displacement}}{\text{total time}}$$

$$\text{Total time} = t_1 + t_2 = t$$

- (vii) Find the velocity using $v = u + at$ for both acceleration and retardation.
 (viii) Equate the two equations.
 (ix) Write t_2 in terms of t and t_1 in the equation obtained from 7.
 (x) Obtain an expression for t_1 from equation obtained from 8.
 (xi) Substitute the value of t_1 obtained from 9 in equation of average speed obtained from 5.
 (xii) $\frac{\alpha\beta}{2(\alpha + \beta)}$

82. (i) Displacement of the two balls is the same.
 (ii) Displacement for the body dropped = displacement of the body which is projected upwards from the top of the tower.
 (iii) Let t_1 and t_2 be the time taken for the body dropped and projected.

- (iv) Find S_1 and S_2 for both bodies using equation $S = ut + \frac{1}{2}gt^2$.
 (v) Equate S_1 and S_2 and solve u .
 (vi) 25 ms^{-2}

83. Let t_1 be the time taken for the first part, t_2 for second part and t_3 , deceleration part. Then,

$$s = 1/2at^2$$

$$200 = \frac{1}{2} \times 1 \times t_1^2 \Rightarrow t_1 = 20 \text{ s} \quad (1)$$

$$\text{Similarly, } t_3 = 20 \text{ s} \quad (2)$$

the velocity after t_1 second is

$$v = at_1$$

$$v = 1 \times 20$$

$$v = 20 \text{ m s}^{-1}$$

Distance to be covered with uniform speed of 20 m s^{-1} is $4000 - 400 = 3600 \text{ m}$

$$t_2 = \frac{\text{distance}}{\text{speed}} = \frac{3600}{20} = 180 \text{ s}$$

Total time = $180 + 40 = 220 \text{ s}$

Average speed = $\frac{\text{total distance}}{\text{total time}}$

$$= \frac{4000}{220} = \frac{200}{11} \text{ m s}^{-1} = 18\frac{2}{11} \text{ m s}^{-1}$$

84. **Ball 1**

u (upwards)

$T_1 = 12 \text{ s}$,

Ball 2

u (downwards)

$T_2 = 4 \text{ s}$

For both the bodies, displacement and final velocity are equal and their initial velocities are equal but opposite in direction.

Use $s = ut + \frac{1}{2}gt^2$ and substitute $u = v - gt$,

$$\text{gives } s = (v - gt)t + \frac{1}{2}gt^2 \Rightarrow s = vt - \frac{1}{2}gt^2$$

$$\Rightarrow h = vt - \frac{1}{2}gt^2$$

$$1/2 gt^2 - vt + h = 0$$

This is a quadratic equation in t .

Similar to $ax^2 + bx + c = 0$

If α, β are two roots then

$$\alpha + \beta = -b/a$$

$$\alpha\beta = c/a$$

$$\text{Sum of roots} = t_1 = t_2 = \frac{v}{g/2}$$

$$16 = \frac{v}{g/2}$$



$$v = 16 \times 5 = 80 \text{ m s}^{-1}$$

$$\text{Product of roots} = t_1 t_2 = \frac{h}{g/2}$$

$$12 \times 4 \times 5 = h$$

$$h = 240 \text{ m}$$

85. Stone A

$$S_n = \frac{g}{2}(2n-1)$$

$$\frac{44.1}{4.9} = 2n-1$$

$$2n-1 = 9$$

$$n = 5 \text{ s}$$

$n =$ time of descent (as n is last second)

$$h \propto n^2 \quad [h = 1/2 gt^2]$$

$$\frac{h_A}{h_B} = \frac{5^2}{7^2} = 25 : 49$$

- 86.** Let the missile hit the target in time ' t ' and let ' u ' be its launching velocity. Then, horizontal distance = horizontal velocity \times time

Substituting

$$1600 \times 10^3 = u \cos \theta \times t$$

$$16 \times 10^5 = u \times \cos 45^\circ \times t$$

$$16 \times 10^5 = \frac{u}{\sqrt{2}} \times t \quad (1)$$

When the missile hits the target, its vertical displacement is zero. For vertical motion of missile,

$$y = (u \sin \theta) t - 1/2 gt^2$$

Substituting $y = 0$

$$0 = t (u \sin \theta - 1/2 gt)$$

$$t = \frac{2u \sin \theta}{g} = \frac{2 \times u}{\sqrt{2} \times 10}, \text{ substituting in (1),}$$

$$16 \times 10^5 = \frac{u}{\sqrt{2}} \times \frac{2u}{\sqrt{2} \times 10}$$

$$u = \sqrt{16 \times 10^6} = 4 \text{ km s}^{-1}$$

- 87.** To find vertical displacement use the formula

$$y = u \sin \theta \cdot t - 1/2 gt^2$$

Substituting $u = 20 \text{ m s}^{-1}$, $\theta = 30^\circ$, $t = 1 \text{ s}$,

$$g = 10 \text{ m s}^{-2}$$

$$y = 20 \times \sin 30 \times 1 - 1/2 \times 10 \times 1^2$$

$$= 20 \times 1/2 - 5$$

$$= 10 - 5 = 5 \text{ m}$$

Vertical component of displacement = 5 m.

Horizontal distance = $u \cos \theta \cdot t$

Substituting $u = 20 \text{ m s}^{-1}$,

$$\cos 30^\circ = \frac{\sqrt{3}}{2}$$

$$t = 1 \text{ s}$$

Horizontal component of displacement

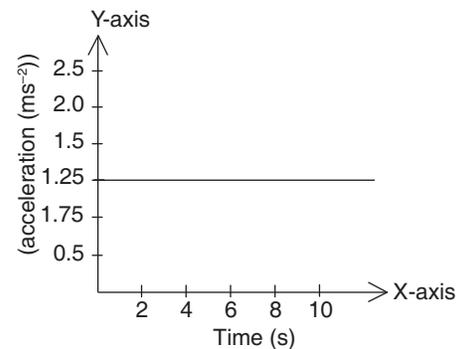
$$= 20 \times \frac{\sqrt{3}}{2} \times 1 = 10\sqrt{3} \text{ m}$$

88. Acceleration

(m s ⁻²)	1.25	1.25	1.25	1.25	1.25	1.25
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Time (s)	0	2	4	6	8	10
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The body has non-uniform velocity and uniform acceleration.



- 89.** (a) Speed is given by the slope of the distance – time graph. The slope of line B is more than that of A. Hence, speed of B is more than that of A.

(b) Distance covered by A = 9 – 3 = 6 m ;

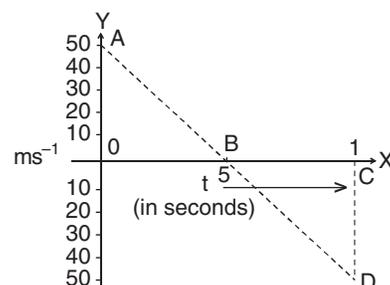
Distance covered by B = 9 m.

- 90.** (a) Acceleration of body = slope of v - t graph

$$= \frac{8-0}{3-0} = \frac{8}{3} \text{ m s}^{-2}.$$

(b) Acceleration of body = negative slope of velocity – time graph = $\frac{0-8}{4-3} = -8 \text{ m s}^{-2}$.

(c) Displacement of the body is the area under velocity – time graph = $1/2 \times 8 \times 3 + 1/2 \times 8 \times 1 = 12 + 4 = 16 \text{ m}$.



Displacement covered = Area under graph
 = Area of (Δ OAB + Δ BCD)

$$= \frac{1}{2}(50 \times 5) + \frac{1}{2}(-50) \times 5$$

$$= \frac{1}{2}(250) - \frac{1}{2}(250) = 0 \text{ m}$$

Rate of change in velocity = Acceleration

$$= \text{Slope of graph} = \frac{-50 - (+50)}{10} = -10 \text{ m s}^{-2}.$$

91. From the graph, it is clear that at the end of 12 seconds, the displacement is zero. The displacement of the body in the first two seconds of motion is 10 m in the forward direction. This distance in the first two

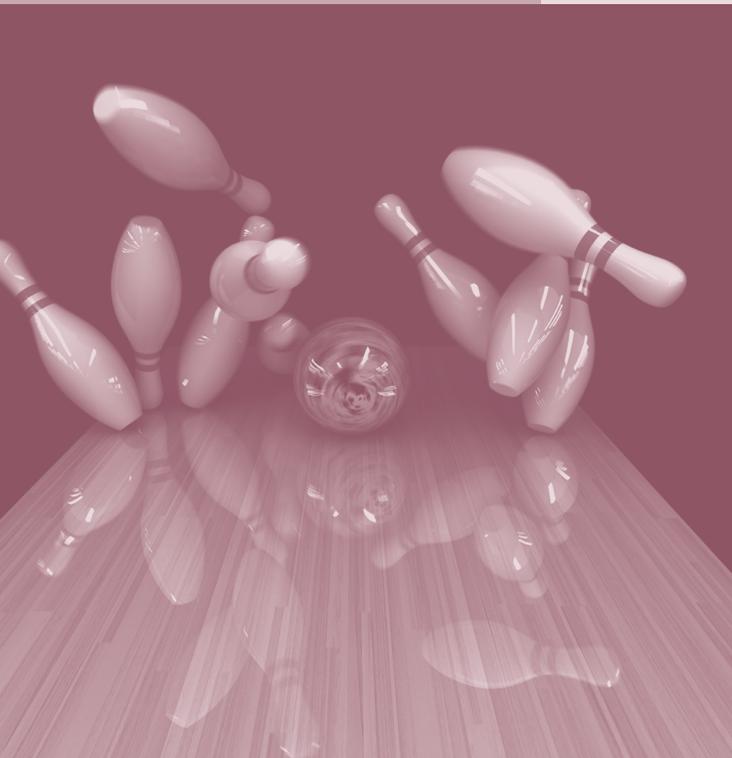
seconds (s_1) is 10 m. Then for the next 4 seconds, i.e., till $t = 6$ s, the body is at rest (as the graph is a straight line parallel to the time axis). In the next two seconds, i.e., by the time $t = 8$ s, the body retraces its path and the displacement is zero. This implies that the distance travelled (s_2) in this duration, i.e., $t = 6$ s to $t = 8$ s is 10 m. Similarly, in the next four seconds, i.e., from $t = 8$ s to $t = 12$ s, the body has moved in backward direction by 10 m and then retraces its path to come to the initial position. Thus, in the last four seconds, i.e., $t = 8$ s to $t = 12$ s, the body travels a distance of $s_3 = 20$ m.

\therefore The total distance travelled by the body at the end of 12 s is $s = s_1 + s_2 + s_3 = 10 + 10 + 20 = 40$ m



Chapter 3

Dynamics



REMEMBER

Before beginning this chapter you should be able to:

- Review the types of force and define friction
- State Newton's laws of motion and law of conservation
- Define Potential and kinetic energies and their derivations, centre of gravity, transformation of energy and law of conservation of energy, stability of bodies
- Understand equilibrium of bodies, levers, pulley, and inclined plane

KEY IDEAS

After completing this chapter you should be able to:

- Explain Newton's laws of motion
- Understand the different factors that affect friction and study the advantages and disadvantages of friction
- Derive the expressions for different forms of energy
- Understand the principle of conservation of energy
- Learn the terms associated with a simple pendulum and to verify the laws of simple pendulum

INTRODUCTION

Dynamics is the study of motion of bodies while taking into account the cause of their motion (force).

FORCE IN NATURE

We observe various kinds of forces being applied in our daily activities. We press the tube to squeeze out the tooth paste or the cream. We pull or push the door in order to open or close it. This pull or push or press is referred to as force.

Effects of Forces

1. Force can move or tend to move an object, at rest for example, when a football is kicked, it moves with a certain speed.
2. Force is used to bring an object to rest.

Example: a ball rolling on a rough surface stops after some time, due to the frictional force between the ball and the surface.

3. Force can increase or decrease the speed of a body.

Example: An iron piece kept near a magnet is accelerated towards the magnet.

4. Force can be employed to change the shape or the dimensions of a body.

Example: When we sit on a cushioned seat, the cushion gets compressed. When a rubber band is pulled, it gets elongated.

5. Force is used to change the direction of motion.

Example: A car changes its direction when it takes a turn along a curve. An electron revolving round the nucleus changes its direction continuously due to the electrostatic force between the nucleus and the electron.

Thus, force can be defined as an agent, which can produce acceleration in a body on which it acts, or produce a change in its size or shape, or both.

Contact Force

Some forces act only if they have physical contact with the body. Such forces are called 'contact forces'.

Example: Mechanical force like a push or a pull is a contact force. A spring can be stretched or compressed by applying a force to it.

Non-contact Force

Forces caused by bodies which do not make contact with each other and act through intermediate space are called non-contact forces.

Gravitational Force

When a ball is thrown up into the air, it is pulled back towards the Earth due to earth's gravitational force.

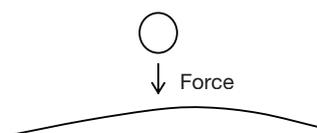


FIGURE 3.1

Electrostatic Force

When an electric charge is placed near another electric charge, it experiences a force of attraction or repulsion, depending on whether the two are unlike charges or like charges, respectively.

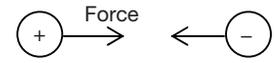


FIGURE 3.2

Force Field

Region or space in which a non-contact force such as magnetic force, gravitational force acts is called force field. The region surrounding a magnet, where a magnetic substance experiences a force is called magnetic field of the magnet.

The region surrounding an electric charge, where another electric charge, positive or negative, experiences a force is called electric field. Thus, a field is a sphere of influence of a non-contact force. It often extends over large distances.

Centripetal Force

When a body is moving uniformly along a circular path, the magnitude of its velocity remains constant, but its direction changes continuously. According to Newton's first law of motion, a body in motion cannot change its direction on its own. So, a body moving along a circular path is under the influence of an external force. Force which can make a body move along a circular path is the force acting perpendicular to the direction of velocity and always directed towards a fixed point. This force is called 'centripetal' force. Its value depends on the mass of the body, magnitude of its velocity and the radius of the circular path described.

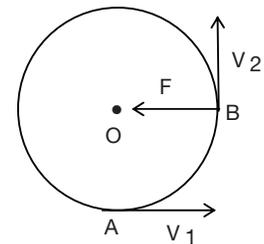


FIGURE 3.3

$$\text{Centripetal force} = \frac{mv^2}{r}$$

Here, m is the mass of a body, v is the magnitude of the velocity or speed of the body and r is the radius of the circular path.

Example: One end of a string is tied to a stone and the other end of the string is tied to a finger and is whirled in a vertical plane.

Centripetal force is exerted by the finger on the stone, and appears as a tension in the string.

Centrifugal Force

It is the force which acts away from the centre of a circular path. This force is equal and opposite in direction to the centripetal force. Centrifugal force is a pseudo force and not a reaction force.

Example: Passengers seated in a car experience an outward push, when the car moves along a circular path or turns around a curve. This outward push is a centrifugal force. Passengers are not physically pushed by an external agent, but experience the pseudo force as they are in an accelerating car.

Rigid Body

A body which is not deformed under the action of a force or a number of forces is known as a rigid body.

MOMENTUM (p)

It is easier to stop a tennis ball than a foot ball, when both are moving with the same velocity. This is because the foot ball has a larger mass than does the tennis ball. A bullet fired from a gun can easily get embedded in a wooden block. If the same bullet is thrown by hand, it cannot penetrate the wooden block. Here, the bullet fired from the gun has greater velocity.

Thus, mass and velocity of a body increase the impact or the effect of the force. The product of mass and velocity of a body defines a physical quantity called momentum. Thus, momentum is a quantity referring to the motion of a body.

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

$$\vec{p} = m \times \vec{v}$$

All moving bodies possess momentum. Momentum is a vector quantity. The direction of momentum is the same as that of velocity since mass is always a positive scalar quantity.

Units of Momentum

By definition, momentum = mass \times velocity

\therefore S.I. unit of momentum is kg m s^{-1}

C.G.S. unit of momentum is g cm s^{-1}

Dimensional formula of momentum:

$$\begin{aligned} \text{Momentum} &= \text{Mass} \times \text{Velocity} \\ &= M^1 L^1 T^{-1} \end{aligned}$$

EXAMPLE

Find the magnitude of momentum of a body of mass 10 kg moving with a velocity of 5 m s^{-1} .

SOLUTION

Given:

$$\text{mass} = 10 \text{ kg}; \quad \text{velocity} = 5 \text{ m s}^{-1}$$

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

$$\therefore p = mv = 10 \text{ kg} \times 5 \text{ m s}^{-1} = 50 \text{ kg m s}^{-1}$$

EXAMPLE

A body of mass 5 kg at rest is acted upon by a force. Its velocity changes to 5 m s^{-1} . Find its initial and final momentum.

SOLUTION

Given

$$\text{Mass, } m = 5 \text{ kg}$$

$$\text{Initial velocity, } u = 0 \text{ m s}^{-1}$$

$$\text{Final velocity, } v = 5 \text{ m s}^{-1}$$

$$\text{Initial momentum (} p_1 \text{)}$$

Since the body is at rest, its initial momentum is zero.

$$(\because p = \text{mass} \times \text{velocity})$$

$$p_1 = 0$$

\therefore Final momentum, (p_2)

$$p_2 = mv$$

$$p_2 = (5 \text{ kg}) \times (5 \text{ m s}^{-1}) = 25 \text{ kg m s}^{-1}$$

Unbalanced External Force

The forces acting on a book at rest on a table are

1. force due to gravity acting vertically downwards, and
2. force exerted by the table on the book acting vertically upwards.

These two forces are equal in magnitude and opposite in direction. Hence, the resultant of these two forces acting on the book is zero. Such forces are called balanced forces.

Hold one end of a string and from the free end suspend a pan with some weights. Forces acting on the string are

3. force due to gravity W , acting downwards, and
4. force exerted by the hand T , acting upwards through the string.

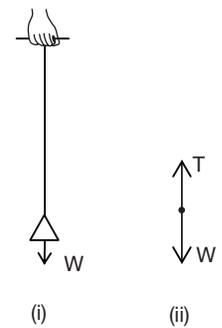


FIGURE 3.4

Add weights continuously to the pan until the string gets cut. It is seen that when the downward force is greater than the upward force, the string gets cut and the pan along with the weights falls down.

Thus, the body moves if the resultant external force acting on the body is not equal to zero. If two or more external forces acting on a body cause the body to move, they are referred to as unbalanced forces.

NEWTON'S LAWS OF MOTION—OBSERVATIONS OF GALILEO

It was Galileo, who demonstrated the relationship between motion and force. He used two inclined smooth planes on which he rolled a ball to study the cause of motion.

1. The velocity of the body increases when it rolls down an inclined plane and it decreases, when the body rolls up the plane.
2. If the ball rolls between two planes, inclined equally, it will attain the same height on both the sides.
3. If the inclination of the second plane is gradually decreased, the ball rolls over a larger distance in order to reach the same height.
4. When the second plane is horizontal, the ball continues to move indefinitely. But in practice the ball comes to rest due to friction.
5. When the surface of the second plane is rough, the ball would cover less distance.

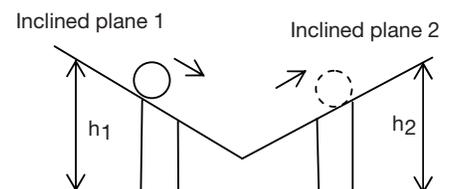


FIGURE 3.5

Based on the above facts, Galileo concluded that

‘The natural state of a body is not the state of rest. It is the tendency of the body to oppose change in its state of motion or rest.’

Newton formulated laws of motion, based on Galileo’s experiment.

NEWTON’S FIRST LAW OF MOTION

‘Every body remains in a state of rest or of uniform motion along a straight line unless and until it is compelled by an external force.’

Newton’s first law of motion helps us to understand that

1. an external agent or an unbalanced external force is required to accelerate a body and
2. a body cannot change its state of rest or of uniform motion along a straight line on its own.

First law gives the precise definition of inertia.

Inertia

The tendency of a body to remain in its state of rest or of uniform motion along a straight line is called inertia. It is due to inertia that an external, unbalanced force must be exerted on the body to change its state of rest or of uniform motion.

Inertia of Rest

It is the reluctance of a body to change its state of rest.

Example: When a bus starts suddenly, the passengers are thrown backwards. This happens because the body tends to stay at rest even after the vehicle has started moving.

Inertia of Motion

It is a tendency of a body to continue its motion along a straight line.

Example: Your bicycle continues to move forward for some time even after you stop pedalling. This is due to the inertia of motion of the bicycle.

Inertia of Direction

It is the inability of a body to change its direction of motion along a straight line.

Example: A person, sitting in a moving car will be pushed towards the left, when the car turns suddenly to the right. When the car takes the sharp turn to the right, it changes its direction of motion but the person tends to move in the original direction due to inertia and is pushed towards the left.

Mass and Inertia

A larger force is required to move a loaded truck from rest than an unloaded truck. The force depends on the inertia of the body, thus, inertia depends on the mass of the body. A body of greater mass has larger inertia. Therefore, mass is a measure of inertia.

Thus, all bodies do not offer same resistance to change their state of rest or of uniform motion.

NEWTON'S SECOND LAW OF MOTION

When a force acts on a body, the momentum of the body changes. Larger the force, greater will be the change in momentum. This is summarized in Newton's second law of motion.

'The rate of change of momentum of a body is directly proportional to the net force acting on it and takes place in the direction of the net force.'

i.e.,
$$F \propto \frac{\Delta p}{\Delta t}$$

Derivation of $F = ma$

Consider a body having an initial momentum \vec{p}_1 . Let its momentum change to \vec{p}_2 when a net force \vec{F} acts on it during a time interval Δt

$$\text{Change in time } \Delta t \text{ in momentum} = \vec{p}_2 - \vec{p}_1$$

$$\therefore \text{Change in momentum in unit time} = \frac{\vec{p}_2 - \vec{p}_1}{\Delta t}$$

i.e.,
$$\text{Rate of change of momentum} = \frac{\vec{p}_2 - \vec{p}_1}{\Delta t}$$

But $\vec{p}_2 = m\vec{v}$ (\vec{v} is the final velocity) and $\vec{p}_1 = m\vec{u}$ (\vec{u} is the initial velocity)

$$\therefore \text{Rate of change of momentum} = \frac{m\vec{v} - m\vec{u}}{\Delta t} = m \left(\frac{\vec{v} - \vec{u}}{\Delta t} \right) = m \frac{\Delta \vec{v}}{\Delta t}$$

Here, $\Delta \vec{v}$ is the change in velocity.

$$\text{From Newton's second law of motion, } F \propto \frac{m\Delta \vec{v}}{\Delta t}$$

$$\Rightarrow F \propto ma \quad \left(\because \vec{a} = \frac{\Delta \vec{v}}{\Delta t} \text{ is the acceleration of the body} \right)$$

$$F = k ma$$

Unit of force is chosen in such a way that it produces unit acceleration in a body of unit mass. Then the constant of proportionality, $k = 1$

$$\therefore F = ma$$

Thus, Newton's second law of motion establishes that an unbalanced external force is required to accelerate a body. Force is a vector quantity.

Units of Force

Force has two types of units, namely, absolute unit and gravitational unit.

Absolute unit of force in S.I. system is called newton (N).

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m s}^{-2}$$

1 newton is that force which acts on a mass of 1 kg and produces an acceleration of 1 m s^{-2} . Absolute unit of force in C.G.S. system is called dyne.

$$1 \text{ dyne} = 1 \text{ g} \times 1 \text{ cm s}^{-2}$$

\therefore 1 dyne is that force which produces an acceleration of 1 cm s^{-2} in a body of mass 1g.

Relation between Newton and Dyne

$$\begin{aligned} 1 \text{ N} &= 1 \text{ kg} \times 1 \text{ m s}^{-2} = (1000 \text{ g}) \times (100 \text{ cm s}^{-2}) \\ &= 10^3 \text{ g} \times 10^2 \text{ cm s}^{-2} = 10^5 \text{ g cm s}^{-2} = 10^5 \text{ dynes.} \end{aligned}$$

Gravitational unit of force in S.I. system is called define Kilogram weight (kg_{wt}) or kilogram force (kg_f).

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

Gravitational unit of force in C.G.S. system is called Gram weight (g_{wt}) or gram force (g_f)

$$1 \text{ g}_{\text{wt}} = 980 \text{ dynes}$$

Dimensional Formula of Force

$$\begin{aligned} F &= \text{mass} \times \text{acceleration} \\ &= \text{M}^1 \times \text{L}^1 \text{T}^{-2} \end{aligned}$$

\therefore Dimensional formula of force = $[\text{M}^1 \text{L}^1 \text{T}^{-2}]$

IMPULSIVE FORCE AND IMPULSE

When a sharp knock is given to a door, the moving finger has momentum. Once the door is struck, the momentum of the finger is reduced to zero in a very short interval of time. As a result the force imparted on the door is very large in a short interval of time, finger get hurted.

This large force acting for a short interval of time is called impulsive force. The product of force and time during which the force acts is called impulse.

$$\text{Impulse} = \text{force} \times \text{time}$$

\therefore Impulse = mass \times acceleration \times time = $m a \times t$

$$= \frac{m(v-u)}{t} \times t = mv - mu$$

Thus, impulse can be defined as change in momentum. Like momentum, impulse is a vector quantity.

Unit of Impulse

$$\text{Impulse} = \text{force} \times \text{time}$$

\therefore unit of impulse in S.I. system is N s or kg m s^{-1} and in C.G.S. system, it is dyne second or g cm s^{-1} .

Dimensional Formula of Impulse

$$\text{Impulse} = F \times t = M^1 L^1 T^{-2} \times T^1 = M^1 L^1 T^{-1}$$

Examples: A cricket fielder lowers his hands while catching a ball. If the ball is caught without lowering the hands, the fielder will hurt his hands due to a large force. When the ball is caught by moving the hand in the direction of motion of the ball, the duration of the impact increases. As a result, the rate of change of momentum decreases, and thus, the force exerted by the ball on the hand is reduced.

An athlete taking a long jump or a high jump bends his knees before landing. By doing so, he increases the time of fall. This decreases the rate of change of momentum and this greatly reduces the impact of fall.

A blacksmith holds the rod in an anvil while striking it with a hammer thereby decreasing the time of contact, and increasing the impulsive force.

Thus, from the above facts, it is understood that the rate of change of momentum can be increased or decreased, respectively, by decreasing or increasing the time of contact.

EXAMPLE

A constant force acts on a body of mass 10 kg and produces in it an acceleration of 0.2 m s^{-2} . Calculate the magnitude of force acting on the body.

SOLUTION

Given

$$\begin{aligned} \text{Mass} &= 10 \text{ kg} \\ a &= 0.2 \text{ m s}^{-2} \end{aligned}$$

$$\therefore \text{Force} = \text{mass} \times \text{acceleration} (F = ma)$$

$$\therefore F = (10 \text{ kg}) \times (0.2 \text{ m s}^{-2}) = 2 \text{ N}$$

Thus, the magnitude of force acting on the body is 2 N.

EXAMPLE

A cricket ball of mass 100 g is moving with a velocity of 10 m s^{-1} and is hit by a bat so that it turns back and moves with a velocity of 20 m s^{-1} . Find the impulse and the force if the force acts for 0.01 s.

SOLUTION

Given,

$$M = 100 \text{ g} = 0.1 \text{ kg}$$

Let the direction of the final velocity after being struck by the bat be positive and the initial velocity before being struck by the bat be negative.

$$\begin{aligned}
 \therefore \text{Initial velocity } u &= -10 \text{ m s}^{-1} \\
 \text{final velocity } v &= +20 \text{ m s}^{-1} \\
 \text{time } t &= 0.01 \text{ s} \\
 \text{Impulse} &= \text{change in momentum} \\
 \text{Impulse} &= m(v - u) \\
 &= 0.1[20 - (-10)] \\
 &= 0.1[20 + 10] \\
 &= 0.1 \times 30 \text{ kg m s}^{-1} = 3 \text{ kg m s}^{-1} \\
 F &= ma \\
 \text{Force} &= \frac{\text{Change in momentum}}{\text{time}} \\
 &= \frac{\text{Impulse}}{\text{time}} = \frac{3 \text{ kg ms}^{-1}}{0.01\text{s}} \\
 \therefore \text{Force} &= \frac{0.1(20 + 10)}{0.01} = \frac{3}{0.01} = 300 \text{ N}
 \end{aligned}$$

EXAMPLE

A car moving at a speed of 36 km h^{-1} is brought to rest while covering a distance of 100 m . If the mass of the car is 400 kg , find the retarding force on the car and the time taken by the car to stop.

SOLUTION

Since the car is brought to rest, its final velocity, $v = 0$

Initial velocity of the car, $u = 36 \text{ km h}^{-1} = 36 \times \frac{5}{18} = 10 \text{ m s}^{-1}$.

Distance traveled by the car, $s = 100 \text{ m}$

Mass of the car, $m = 400 \text{ kg}$

Force = mass \times acceleration (from Newton's second law)

To find the acceleration, we use equation of motion $v^2 = u^2 + 2as$

$$\begin{aligned}
 0 &= 100 + 200a \\
 a &= \frac{-100}{200} = -0.5 \text{ m s}^{-2}
 \end{aligned}$$

Acceleration is negative because the final velocity ($= 0$) is less than the initial velocity ($= 36 \text{ km h}^{-1}$)

$$\begin{aligned}
 \therefore F &= m \times a \\
 &= 400 \times -0.5 = -200 \text{ N}
 \end{aligned}$$

Here, the negative sign represents a retarding force

MASS AND WEIGHT

Mass

Mass is the amount of matter contained in a body. Mass of a body is the measure of inertia. Mass is a scalar quantity. Its unit is kg in SI system and gram in C.G.S. system. Mass of a body does not vary with position and remains the same everywhere. It is measured by a beam balance.

Weight

It is the force acting on a body due to gravity.

Weight = mass \times acceleration due to gravity

$$W = mg$$

Weight is a vector quantity. S.I. unit of weight is newton or kg_{wt} . Weight varies from place to place. Weight of a body is maximum at the poles and minimum at the equator ($\because g$ is minimum at equator and maximum at the poles).

Since gravitational force decreases with height, the weight of a body is less on the top of a mountain compared to that at the sea level. Weight of a body is measured by a spring balance.

The dimensional formula of weight = $[M^1L^1T^{-2}]$

EXAMPLE

A coconut of mass 1 kg falls from a tree. Find its weight (Take acceleration due to gravity = 9.8 m s^{-2})

SOLUTION

Mass = 1 kg

\therefore Weight = $1 \text{ kg} \times 9.8 \text{ m s}^{-2} = 9.8 \text{ N}$

NEWTON'S THIRD LAW OF MOTION

Statement

For every action, there is an equal and opposite reaction.

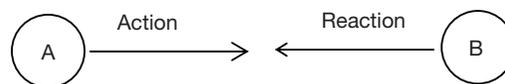


FIGURE 3.6

Consider two bodies A and B colliding. A exerts a force on B and this is called action. According to Newton's third law, B exerts an equal force on A but in the opposite direction. This is known as reaction.

Every action is accompanied by a reaction. Thus, we find that forces always exist in pairs. In other words, a single isolated force cannot exist. Action and reaction do not act on the same body. They involve two bodies. Hence, they do not cancel each other. It is not required that the two bodies should have physical contact to exert force on each other.

Examples:

1. Gravitational force between the sun and the planets.
2. The force exerted between two magnets which are kept apart.

Applications of Newton’s Third Law of Motion

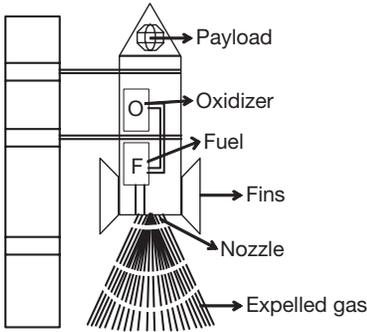


FIGURE 3.7 Rocket – different parts

1. In order to bowl a bouncer, a fast bowler has to pitch the ball very hard on the ground. The ground exerts an equal and opposite force on the ball (reaction) and this bounces the ball at a desired height.
2. When the fuel of a rocket is ignited, huge amounts of gases escape with high velocity through the opening N at the rear end. The force on the gases forms action. The burnt gases in turn exert a force, equal in magnitude but opposite in direction, on the rocket. This is the reaction force (Acceleration of the rocket keeps on increasing as the mass is constantly reduced due to the burning of the fuel).

Law of Conservation of Momentum

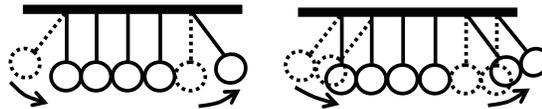


FIGURE 3.8

Newton demonstrated using the equipment shown in the Fig. 3.8, that, if an external force acting on a system is zero, the total momentum of the system remains constant. The total momentum of the system of balls is the same before and after collision.

Verification of Law of Conservation of Momentum

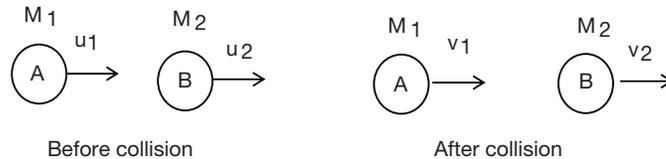


FIGURE 3.9

Consider two bodies A and B of masses M_1 and M_2 and let u_1 and u_2 be their initial velocities, respectively. Let the two bodies collide with the collision lasting for t seconds, during the time of which their velocities change.

Let v_1 and v_2 be their velocities after collision. From the second law of motion, we have.

$$\text{Rate of change of momentum of } A, \vec{F}_A = \frac{\Delta \vec{p}_1}{t}$$

$$\text{Rate of change of momentum of } B, \vec{F}_B = \frac{\Delta \vec{p}_2}{t}$$

From Newton's third law,

$$\vec{F}_B = -\vec{F}_A$$

The force exerted by A on B is equal and opposite to the force exerted by B on A .

$$\frac{\Delta\vec{p}_2}{t} = -\frac{\Delta\vec{p}_1}{t}$$

$$\Delta\vec{p}_2 = M_1v_1 - M_1u_1$$

$$\text{Similarly, } \Delta\vec{p}_1 = M_2v_2 - M_2u_2$$

$$M_2v_2 - M_2u_2 = -(M_1v_1 - M_1u_1)$$

$$(M_1u_1 + M_2u_2) = (M_1v_1 + M_2v_2)$$

\therefore Total momentum before collision = total momentum after collision.

EXAMPLE

A bomb of mass 6 kg initially at rest explodes into two fragments of masses of 4 kg and 2 kg, respectively. If the greater mass moves with a velocity of 5 m s^{-1} , find the velocity of the 2 kg mass.

SOLUTION

Given,

$$M_1 = 4 \text{ kg}$$

$$M_2 = 2 \text{ kg}$$

Since the bomb is initially at rest, $U = 0$.

$$\therefore \text{ Its initial momentum} = MU = 6 \times 0 = 0$$

$$v_1 = 5 \text{ m s}^{-1} \quad v_2 = ?$$

Using the law of conservation of momentum

$$MU = m_1v_1 + m_2v_2$$

$$0 = 4 \times 5 + 2 \times v_2$$

i.e.,

$$0 = 20 + 2 \times v_2$$

$\therefore v_2 = \frac{-20}{2} = -10 \text{ m s}^{-1}$, $-ve$ sign of v_2 implies that 2 kg mass moves in the direction opposite to 4 kg mass.

Normal Force

Consider a block of wood of mass ' m ' at rest on the surface of a table.

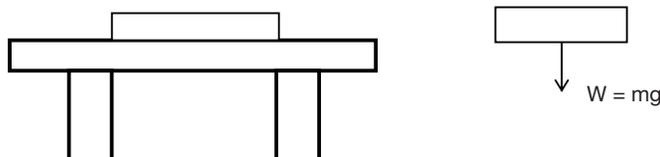


FIGURE 3.10

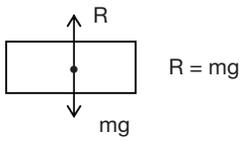


FIGURE 3.11

The force acting on the block is the force due to gravity = weight of the block = mg

This force is acting vertically downwards. Since the block is at rest, the net force acting on the block must be zero, i.e., there should be a force acting vertically upwards and should be equal to mg . This is the force exerted by the table (on the block) acting perpendicular to the surface of the table, and is called normal (reaction) force.

Thus, normal force can be defined as the force experienced by a body in a direction perpendicular to the surface, when it is pressed against that surface.

The units of normal force is newton in S.I. system and dynes in C.G.S. system. This normal force, in this case is the reaction force exerted by the table on the body. The normal reaction force, however, is not always equal to the weight of the body mg . It depends on various factors.

Normal Reaction on a Body Placed on an Inclined Surface

When a block of wood is placed on smooth inclined plane, inclined at an angle θ , to the horizontal, the force acting on the block is the force due to gravity acting vertically downwards. This force has two components:

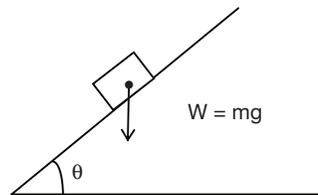


FIGURE 3.12

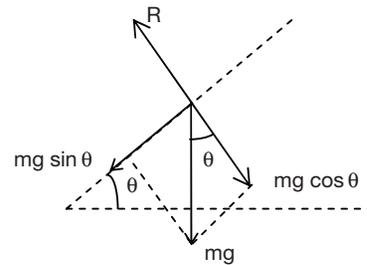


FIGURE 3.13

1. one along the plane = $mg \sin \theta$
2. one perpendicular to the plane = $mg \cos \theta$

Since the block is sliding down the plane and has no motion along the direction perpendicular to the plane, net force along the perpendicular direction is zero

i.e., $R - mg \cos \theta = 0$
 $\therefore R = mg \cos \theta$

Thus, the normal reaction in this case is not ' mg ' but ' $mg \cos \theta$ '

Normal Reaction Under the Action of an Applied Force

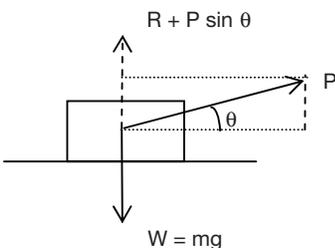


FIGURE 3.14

Case (1)

Consider a block of wood placed on a horizontal surface. Let the block be pulled by a force ' P ' as shown.

1. Perpendicular component of P , i.e., $P \sin \theta$ acts vertically upwards.
2. The weight of the block is balanced by $R + P \sin \theta$, where R is the normal reaction.

$$\therefore \quad R + P \sin \theta = mg$$

$$R = mg - P \sin \theta$$

Thus, the normal reaction decreases when we pull an object.

Case (2)

If the block of wood is pushed by a force ' P ' which makes an angle θ with the horizontal, then the perpendicular component of P , i.e., $(P \sin \theta)$, acts vertically downwards

Thus, the weight of the block is balanced by $R - P \sin \theta$, where R is the normal reaction.

$$R - P \sin \theta = mg$$

$$R = mg + P \sin \theta$$

Thus, the normal reaction increases when we push an object.

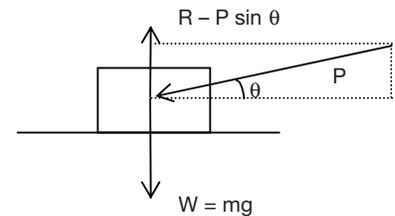


FIGURE 3.15

FRICTION

When a ball rolls over a surface, it slows down and comes to rest after travelling for a certain distance. According to Newton's first law, the ball cannot come to rest on its own.

Thus, there should be some force which opposes the motion of the ball over the surface in contact. This force should act in a direction opposite to the direction of the motion of the ball to cause a deceleration. This force is known as frictional force or friction. Thus, friction is the force which opposes relative motion of one body over the other.

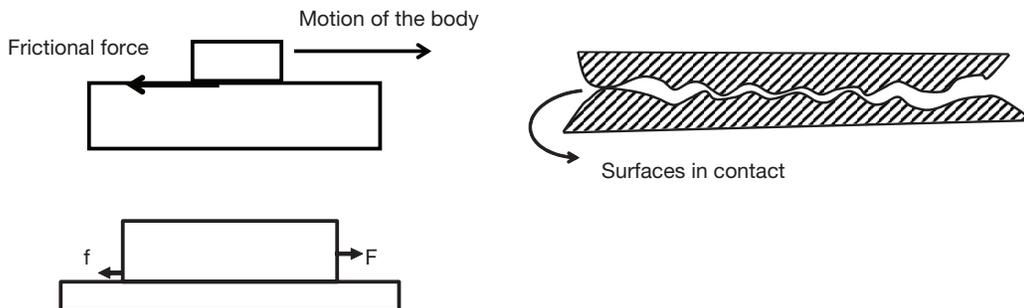


FIGURE 3.16

When we observe the contact surfaces of the bodies under the microscope, the surfaces have many ridges and depressions causing unevenness, though they appear to be smooth. When the surfaces of the two different bodies are brought in contact with one another, their irregularities interlock and this opposes relative motion of one body over the other. In order to overcome this, a force has to be applied.

Types of Friction

There are three types of friction, namely,

1. Static friction
2. Kinetic or dynamic friction
3. Rolling friction

Static Friction

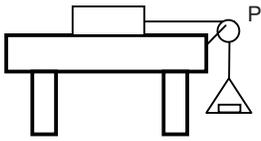


FIGURE 3.17

Place a wooden block on a table. Fasten a string to the block, and to the free end of the string, attach a scale pan. The string is passed over a pulley (P). Add a small weight to the scale pan which would tend to move the block but not set it in motion, i.e., the block is still at rest. This is due to frictional force, which does not allow one body to slide over another and this is called static friction.

Thus, static friction comes into play whenever the two surfaces are stationary, relative to each other, in spite of an external force being applied to the body in the direction of the plane of surfaces in contact. Here the friction balances the applied force.

Increase the weight in the pan gradually so that the block just begins to move. This weight corresponds to the maximum value of static friction which comes into play, and just allows the body to slide on another body. This maximum static friction is called limiting friction.

Frictional force always acts in a direction opposite to that of the motion of the body.

Laws of Limiting Friction

1. Limiting friction depends on the nature of the surfaces in contact, provided normal reaction remains the same.

Example: When a ball is given the same initial velocity on two different surfaces, it covers different distances.

2. The force of limiting friction varies directly as the normal reaction

$$F_s \propto N$$

$$F_s = \mu_s N$$

Here, F_s is the limiting friction, N is the normal reaction and μ_s is the co-efficient of static friction.

3. The force of limiting friction is independent of the area of contact provided normal reaction and nature of the surface remains constant.

Experimental Verification of Laws of Limiting Friction

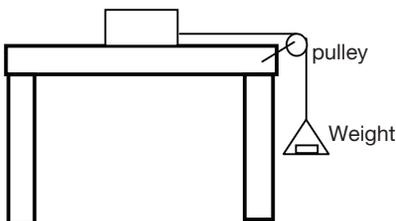


FIGURE 3.18

1. Take a plastic box and a wooden box of the same weight. Place each one of them on the table and apply force by adding weights to the scale pan (as shown). Note down the limiting frictional force in each case, that would be required to make the box to start sliding over the table. This shows that the limiting friction depends on the nature of surfaces, since different bodies were used in the two cases.

2. Place a book on the table and slide it on the table by adding the weights to the pan. Note down the maximum force required to just slide the book. Now place two books one above the other and again determine the limiting friction (maximum force required just to slide the books). The weight of the books gives the normal reaction. Repeat the experiment by increasing the number of books (weight increases).

Find the ratio of limiting friction and the normal reaction.

It is found that the ratio is constant, i.e., $\frac{\text{limiting friction}}{\text{Normal reaction}} = \text{constant} = \mu_s$ (coefficient of friction)

Thus, limiting friction is directly proportional to the normal reaction. This implies that greater the normal reaction, greater is the friction.

Sliding or Dynamic or Kinetic Friction

When a body slides over a surface, the friction developed between the sliding body and the surface on which it is sliding is known as kinetic or dynamic or sliding friction (f_k). The kinetic friction of a body is directly proportional to the normal reaction and does not depend on the velocity with which it is moving.

Mathematically,

$$f_k \propto R$$

or

$$f_k = \mu_k R$$

where ' μ_k ' is a constant of proportionality called coefficient of kinetic friction. ' μ_k ' depends on the nature of the materials of which the bodies are made, nature of the surfaces in contact, but not on the velocity with which the body is moving.

Dynamic friction is less than the static limiting friction.

Rolling Friction

It is the frictional force which comes into play when a body rolls over the other. It is always easier to roll a body over a surface than to drag it. Thus, rolling friction is less than Kinetic friction, which in term, is less than static friction.

1. All vehicles are provided with wheels.
2. Ball bearings are used in cycles, and machine parts, etc., to minimize friction.

Rolling friction of a body is directly proportional to the normal reaction acting on the body.

$$f_r \propto R$$

$$\Rightarrow \mu_r = \frac{f_r}{R}$$

Here, μ_r is the proportionality constant and is called coefficient of rolling friction.

μ_r depends on the nature of the surfaces in contact

$$\mu_r = \frac{f_r}{R}$$

Thus, coefficient of rolling friction is the ratio of rolling friction on a body to its normal reaction.

NOTE

1. $f_s > f_k > f_r \therefore \mu_s > \mu_k > \mu_r$
2. Rolling friction increases with increase in area of contact.

Friction in Fluids

Fluids also exert friction on the bodies moving through them. But the friction of the fluids is less compared to that between the solid surfaces. If the velocity of a fluid increases, frictional force also increases.

Example: Shooting stars or meteors enter the Earth's atmosphere from space. As they enter, they glow due to the large amount of heat produced. The heat is generated due to friction of air.

Viscous Force

Adjacent layers of a fluid oppose the relative motion between them. Thus, there exists a frictional force between the fluid layers. This frictional force is known as viscous force. Ghee is more viscous than water.

In order to minimize frictional force, racing cars, aeroplanes, space ships, boats, ships, etc., are specially designed (stream-lined). Fishes and birds have stream-lined bodies. Friction due to air is smaller than that due to water. Hovercraft which moves a little above the surface of water moves faster than ships and boats.

Advantages of Friction

1. Without friction, it is not possible for us to walk on the floor. If the surface on which we walk is perfectly smooth, we tend to skid and we are unable to walk.
2. The friction between the lateral surface of a match box and the head of the match stick enables us to light the match stick. When we rub the head of the match stick on the rough surface of the match box, due to the friction between the two, heat is developed and the developed heat is enough to ignite the fuel present in the head of the match stick. We cannot light the match stick on rubbing it against a smooth plane glass surface.
3. It is friction which makes it possible to hold an object in our hand.
4. It is the friction between the brake liners and the brake drum of a vehicle which helps in stopping a moving vehicle when brakes are applied.
5. Fixing nails to walls and screws to boards is possible only due to friction.
6. Friction between the chain and the wheels helps us to transfer motion from one part of a machine to another.
7. Writing with chalk on a board is possible only due to friction between the surface of the board and the chalk.
8. The friction between meteors and the atmosphere produces heat to such an extent that the meteors are burnt out in the atmosphere itself before they strike the Earth's surface and this averts disasters.
9. It is possible to place dishes or any object on the ground or a table due to frictional force.

Disadvantages of Friction

1. Friction causes the wear and tear of machine parts and this leads to the damage of machinery.
2. Friction produces heat and more energy is required to overcome it.
3. Friction causes loss of energy during transformation of energy from one form to another. This should be minimized.
4. Friction generates heat, and this increases energy consumption. Moreover the heat produced damages the machine parts. In some machines, the heat generated due to friction is removed by circulating water.

Methods to Reduce Friction

1. Friction can be reduced by using lubricants (materials that are used to make motion smoother).

Lubricants can be a solid, liquid or in the gaseous form.

Solid lubricant – boric powder, talcum powder, etc.

Liquid lubricant – oil, ghee, etc.

Gaseous lubricant – air, oxygen, etc.

Example: Boric powder is sprayed on carrom boards, which reduces friction between the board and the striker, caroms, etc.

Lubricant changes the nature of the surfaces in contact. This reduces ' μ '.

2. Friction can be reduced by polishing the surfaces in contact. But over polishing increases friction.
3. Sliding friction can be converted to rolling friction by pulling modifications in arrangement. This reduces friction.

Example:

- A suitcase with wheels and without wheels.
 - Ball bearings are used in automobiles and machines.
4. Automobiles, aeroplanes and ships are specially designed to reduce friction. This is known as stream-lining. Fishes and birds also have stream-lined bodies.

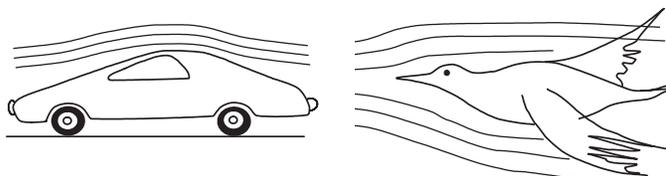


FIGURE 3.19

WORK

When we push or pull a body at rest, it may or may not be set into motion. When the body is set into motion, we say that some work is done. We may apply a large amount of force on a wall and try to displace it. Since the wall does not move or get displaced, we say work is not done. From these examples, it is clear that whenever force is applied on a body and the body gets displaced, work is said to be done. Sometimes, instead of the total force applied on a body, only a part of it may be responsible to bring the body into motion from rest. In such a situation also, work is said to be done.

‘Work is said to be done when a net force acting on the body, displaces the body in the direction of the force.’

The work done on a body is proportional to the net force acting on the body and the displacement produced by the force on the body.

Mathematically,

$$W \propto F \text{ and } W \propto s$$

‘ W ’, ‘ F ’ and ‘ s ’ are work done, applied force and displacement of the body in the direction of force, respectively.

From the above, we get

$$W = kFs$$

Unit of force is defined in such a way that $k = 1$

$$W \propto Fs$$

$W = kFs$, where ‘ k ’ is a proportionality constant and the unit of force work is defined in such a way that $K = 1$.

Hence,

$$W = Fs$$

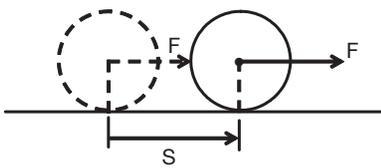


FIGURE 3.20

Thus, when one unit force applied on a body produces a displacement of one unit in the direction of force, one unit of work is said to be done.

Consider a lawn roller being pulled as shown in Fig. 3.20. The direction of applied force is in the direction of displacement. Hence, the total force applied is utilized and is responsible for the displacement of the roller. Thus, we can write work done, $W = Fs$.

But when the direction of applied force makes an angle ‘ θ ’ with the direction of displacement as shown in Fig. 3.21, the total force applied is not responsible for the movement of the roller.

Only a part or a component of force which is equal to ‘ $F \cos\theta$ ’ is responsible for the displacement of the roller. Hence, in this case, work done is given as,

$$W = (F \cos\theta) s \text{ or } W = Fs \cos\theta$$

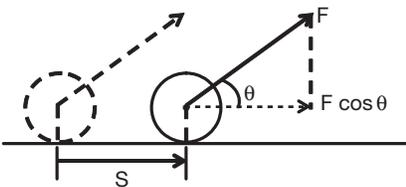


FIGURE 3.21

So, in general we can express the work done as the ‘product of displacement of a body and the component of force responsible for the displacement of the body’. The component of force responsible for the displacement will be in the direction of displacement and generally it is ‘ $F \cos\theta$ ’ where θ is the angle between the directions of force and displacement. Hence, the general way of expressing work is $W = Fs \cos\theta$.

Case (i) If $\theta < 90^\circ$

$W = Fs \cos\theta \Rightarrow$ work done is positive as $\cos\theta > 0$ when $0^\circ < \theta < 90^\circ$

Case (ii) If $\theta > 90^\circ \Rightarrow$ work done is negative as $\cos\theta < 0$ when $90^\circ < \theta < 180^\circ$

Case (iii) If $\theta = 90^\circ \Rightarrow$ work done is equal to zero as $\cos 90^\circ = 0$

Example: In uniform circular motion, work done by a centripetal force is equal to zero since centripetal force and displacement of the body are perpendicular to each other.

NOTE

1. If the net force is perpendicular to the displacement, the work done is always equal to zero.
 2. Work done is equal to zero, if $s = 0$ or $F = 0$
- In the case of pulling or pushing a lawn roller, work is done on the lawn roller.

In the case of pulling or pushing a lawn roller, work is done on the lawn roller.

When we use a pressure cooker, the steam produced in the cooker due to pressure pushes up the weight kept on the lid where work is done by steam. Work is a scalar quantity.

Units of Work

The C.G.S. unit of work is 'erg' (which is derived from the Greek word 'Energia' meaning 'in work') and the S.I. unit of work is joule(J) (in honour of the English scientist James Prescott Joule).

$$1 \text{ erg} = 1 \text{ dyne} \times 1 \text{ cm.}$$

Hence, one erg is defined as 'the work done when a net force of one dyne displaces a body through one centimetre in its direction'.

Similarly, 1 joule = 1 newton \times 1 metre.

Hence, one joule is defined as 'the work done when a net force of one newton displaces it through one metre in its direction'.

Dimensional Formula of Work

Work = (Force) (displacement)

$$W = Fs$$

$$[W] = [M^1L^1T^{-2}] \cdot [L^1] = M^1L^2 T^{-2}$$

\therefore Dimensional formula of work is $[M^1L^2T^{-2}]$

POWER

Consider a man lifting a load through a certain height in 10 seconds. The same load can be lifted by a boy through the same height in 15 seconds of time. Then we say the man is more powerful as he has done the same work faster; and the boy is less powerful as he has done the same work taking more time. Hence, when we talk about power, the time taken to do the work is also considered; and not the amount of work alone.

Thus, power is defined as the rate at which the work is done

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

i.e.,
$$P = \frac{W}{t}$$

Since both work done and time, are scalars, power is also a scalar quantity.

If a force (F) acting on a body makes the body undergo uniform motion such that the body covers a displacement (s) in time (t), then power

$$P = \frac{W}{t} = \frac{Fs}{t} = F \left(\frac{s}{t} \right) = Fv$$

where, ' v ' is the velocity of the body.

So, power can also be expressed as $P = Fv$

Unit of Power

Unit of power is watt (W)

$$\begin{aligned} \text{Power} &= \frac{\text{work}}{\text{time}} \\ \Rightarrow 1 W &= 1 \text{ Js}^{-1} \\ 1 \text{ watt} &= \frac{1 \text{ joule}}{1 \text{ second}} \end{aligned}$$

Thus, power is said to be 1 watt when 1 joule of work in 1 second. Other commonly used units of power are kilowatt and horsepower.

1. Kilowatt (kW):

$$1 \text{ kW} = 1000 \text{ watts}$$

2. Horsepower (hp):

$$1 \text{ hp} = 746 \text{ watts} = 0.746 \text{ kW}$$

or

$$1 \text{ kW} = \frac{1}{0.746} \text{ hp} = 1.34 \text{ hp}$$

Dimensional Formula of Power

$$\begin{aligned} \text{Power} &= \frac{\text{work}}{\text{time}} = \text{Force} \times \frac{\text{displacement}}{\text{time}} \\ &= M^1 L^1 T^{-2} \times L^1 / T^1 \\ &= M^1 L^{1+1} T^{-2-1} = M^1 L^2 T^{-3} \end{aligned}$$

ENERGY

When we do not eat food, we feel weak and cannot do any work. When we consume food, we get the capacity or ability to do work.

This 'capacity to do work is known as energy'. The word 'energy' is derived from the Greek word 'energia', which means 'in work'. Hence, the units of work and energy are same.

Examples of Energy

1. Sound energy is produced when an object vibrates. The sound vibrations cause waves of pressure that travel through a medium, such as air, water, wood or metal. Sound energy is a form of mechanical energy. Hence, sound is a form of energy.
2. Heat produced in a pressure cooker due to the building up of pressure can lift the weight placed on the lid upwards. So, heat is a form of energy.
3. At the microscopic and atomic level, the light incident on certain metallic surfaces can cause emission of electrons from the surface. So, light is capable of doing work and is also a form of energy.
4. A magnet placed near a toy car made of some magnetic material like iron can attract it and make it move. Hence, work can be done by magnetism; this form of energy is called magnetic energy.
5. Electricity flowing through conductors can make the machines move and this is electrical energy.
6. The energy possessed by bodies on account of their position or motion or arrangement is called mechanical energy. The water stored in the dam or the flowing water is capable of doing work and that is an example of mechanical energy.
7. The energy possessed by atoms of elements or molecules of compounds, such that it is released and capable of doing some work when a chemical reaction takes place is known as chemical energy.
8. The energy released during nuclear reactions is known as nuclear energy.

Units of Energy

Energy is measured in terms of the work done by a body. Therefore, the unit of energy is same as that of work.

C.G.S. unit of energy is erg.

S.I. unit of energy is joule (J).

Some other common units of energy used are

1. watt hour
2. kilowatt hour
3. electron volt
4. calorie

Kilowatt Hour

It is a widely used commercial measure of the electrical energy consumed. It is defined as the 'electrical energy consumed when an electric power of one kilowatt is used for one hour of time'.

$$\begin{aligned}
 1 \text{ kW h} &= 1 \text{ kW} \times 1 \text{ hour} \\
 &= 1000 \text{ watts} \times 3600 \text{ second} \\
 &= 36 \times 10^5 \text{ watt second} \\
 &= 3.6 \times 10^6 \text{ joule}
 \end{aligned}$$

Electron Volt

It is defined as electric work done when an electron moves between two points in an electric field maintained at a potential difference of one volt.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

Calorie

Calorie is defined as the amount of heat energy required to raise the temperature of one gram of pure water from 14.5°C to 15.5°C.

MECHANICAL ENERGY

Mechanical energy is the energy possessed by a body on account of its position, or motion configuration. Mechanical energy can be further classified into potential and kinetic energy.

POTENTIAL ENERGY

It is defined as the energy possessed by a body by virtue of its position or state.

Examples of Potential Energy

We have to wind the spring of a toy, in order that it may work. This work is stored in the wound spring in the form of potential energy. As the spring unwinds, it uses the potential energy to set the toy in motion.

Water stored at a height possesses potential energy due to its position. When water falls from a height, it rotates the blades of a turbine, which in turn generates electrical energy.

In mechanics, we deal with two types of potential energy. They are gravitational potential energy and elastic potential energy.

Gravitational Potential Energy

A body dropped from a height falls to the ground. This is due to the work done by the gravitational force acting on the body. Gravitational force of attraction acts on the body in the downward direction (towards the Earth's surface) and displaces it through a certain height (from which it is dropped). Hence, work is done by the gravitational force.

On the other hand, if we want to lift a body in the upward direction, we must apply force on the body in the upward direction and displace it through a certain height. Hence, we do some work on the body against the gravitational pull. So, in giving a position to a body at a certain height from the ground, we do work on it and this work is possessed by the body as the energy which is known as 'gravitational potential energy'.

So, gravitational potential energy is defined as 'the energy possessed by a body by virtue of its position' (with respect to the surface of the Earth).

Derivation of an Expression for Gravitational Potential Energy

Consider a body of mass ' m ' resting on the ground. Its weight ' mg ' acts vertically downwards towards the centre of the Earth. In order to lift the body through a certain height ' h ', we apply a force ' F ' equivalent to its weight in the upward direction.

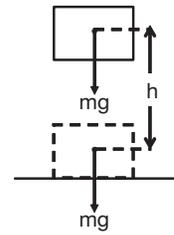


FIGURE 3.22

∴ work done on the body, W

$$= \text{force } (F) \times \text{displacement } (h)$$

$$= (mg) \times (h) = mgh$$

This work done on the body is stored in it in the form of gravitational potential energy. Therefore, gravitational potential (P.E.) = mgh .

Elastic Potential Energy

A spring which is compressed can do some work. If a small ball is kept on the compressed spring and then it is released, the ball is pushed away. So, work is done by the spring. So, a compressed spring has the energy stored in it by its state of compression. Similarly a stretched or extended spring too has energy stored in it by its state of extension. Such stored energy is known as 'elastic potential energy'. So, elastic potential energy is defined as the 'the energy possessed by an elastic body by virtue of its state of compression or extension'.

HOOKE'S LAW

Consider a wire of length ' ℓ ' and area of cross-section ' A ' fixed to a rigid support as shown, in Fig. 3.23.

To the free end of the wire, a scale pan is attached.

Increase the weights in the scale pan in steps of 50g and note down the change in the length of the wire ($\Delta \ell$).

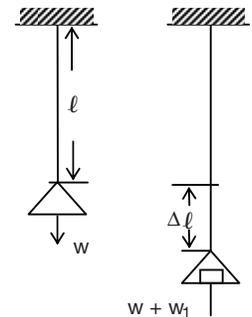


FIGURE 3.23

S.No	Weight	Extension ($\Delta \ell$)	$\Delta \ell / \ell$	$(F/A) / (\Delta \ell / \ell)$
1	W			
2	$W + 50 \text{ g}$			
3	$W + 100 \text{ g}$			
4	$W + 150 \text{ g}$			

The ratio of change in length to the original length of the wire is called strain.

$$\text{Strain} = \frac{\Delta \ell}{\ell}$$

Force acting per unit area is called stress.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

Find out the ratio of stress to strain. It is found that this ratio is a constant up to a certain limit called elastic limit. Thus, Hooke's law states that 'within the elastic limit, the ratio of stress to strain is constant.'

$$\therefore \text{stress} \propto \text{strain} \Rightarrow \text{Stress} = E \times \text{Strain}$$

$$\text{or} \quad \frac{\text{stress}}{\text{strain}} = E$$

where E is a constant called 'Young modulus' (in honour of Thomas Young).

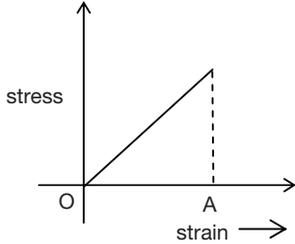


FIGURE 3.24

When you elongate or extend or stretch a spring, the force developed in it is found to be directly proportional to the magnitude of extension. Mathematically, $F \propto x$, where F and x are force applied to the spring and the extension of the spring, respectively. Then $F = kx$, where ' k ' is the constant of proportionality called 'elastic constant' or 'spring constant' or 'force constant'.

The graph of stress versus strain of an elastic body is as shown in the Fig. 3.24 and A is the strain corresponding to the elastic limit of the body.

Derivation of Expression of Elastic Potential Energy

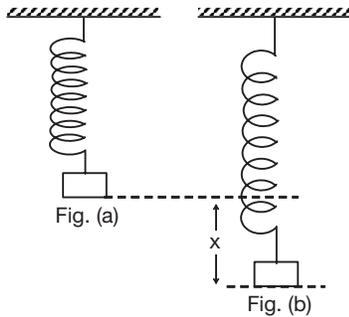


FIGURE 3.25

Consider a spring of a certain length suspended from a rigid support and a block of some mass attached to it Fig. 3.25(a). We do some work on it when we apply a force and give it an extension Fig. 3.25(b).

Work is done on the spring from a state of zero extension to a state of extension = ' x '.

When the extension is zero, the force applied on the spring $F_1 = k(0) = 0$.

When the extension is ' x ', the force applied on the spring $F_2 = k(x) = kx$

$$\therefore \text{Average force } F = \frac{F_1 + F_2}{2} = \frac{0 + kx}{2} = \frac{kx}{2}$$

\therefore work done on the spring, $W = (\text{Average force}) \times (\text{Total extension})$

$$\Rightarrow W = \frac{kx}{2} \times x$$

$$\Rightarrow W = \frac{1}{2} kx^2$$

This work done on the spring is stored in it in the form of elastic potential energy. Hence, elastic potential energy (E.P.E.) = $\frac{1}{2} kx^2$

KINETIC ENERGY

It is defined as the energy possessed by a body by virtue of its motion. To set a body, which is at rest, into motion, we apply force on it and set it into motion. Thus, the force we apply displaces the body and work is done. This work done on the body is stored in it in the form of kinetic energy. The body which is set in motion can put another body, which is at rest, into motion, just as a moving billiard ball hits a stationary ball and makes it move. Thus, the moving body is capable of doing work by virtue of its motion.

Example: A bullet moving with a high velocity possesses kinetic energy. Due to this, the bullet can penetrate the object it strikes.

Derivation of Expression for Kinetic Energy

Consider a body of mass ' m ', which is at rest'. Let a constant force ' F ' act on it and displace it through a distance ' S ' in time ' t '.



FIGURE 3.26

Let ' v ' be the velocity of the body at the end of time ' t '.

The acceleration produced in the body $a = \frac{\text{change in velocity}}{\text{time interval}}$

$$\Rightarrow a = \frac{v - u}{t} \quad (\text{since } u = 0)$$

$$a = \frac{v}{t} \quad (3.1)$$

\therefore Force acting on the body is given by,

$$F = ma = m \frac{v}{t} \quad (3.2) \text{ (from equation (3.1))}$$

The displacement of the body is given by,

$$s = \text{average velocity} \times \text{time}$$

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

$$\therefore s = \left(\frac{v + 0}{2} \right) t = \frac{vt}{2} \quad (\because u = 0) \quad (3.3)$$

Work done by the force is given by,

$$W = \vec{F} \cdot \vec{S} \quad (3.4)$$

$$= \frac{mv}{t} \cdot \frac{vt}{2} \quad (\text{from (3.2) and 3.3})$$

$$W = \frac{mv^2}{2}$$

Kinetic energy can be expressed as the amount of work done by the body before coming to rest.

$$\therefore \text{kinetic energy} = \frac{1}{2} mv^2$$

$$\text{K.E.} = \frac{1}{2} mv^2$$

WORK ENERGY THEOREM

Statement

Work done on a body by a resultant force acting on it is equal to the change in the kinetic energy of the body

$$\therefore \text{work done, } W = \Delta KE$$

where, ΔKE is the change in kinetic energy.

Relation between Kinetic Energy and Momentum

The momentum of a body is given by $p = mv$, where ' m ' and ' v ' are mass and velocity of the body, respectively.

$$\text{Kinetic energy of the body is given by K.E.} = \frac{1}{2} mv^2$$

$$\begin{aligned} \therefore \text{K.E.} &= \frac{1}{2} (mv) v = \frac{1}{2} pv \\ &= \frac{1}{2} p \left(\frac{p}{m} \right) = \frac{p^2}{2m} \end{aligned}$$

LAW OF CONSERVATION OF ENERGY

Statement

Energy can neither be created nor destroyed, but it can be converted from one form to another. The law of conservation of energy is one of the fundamental laws of nature.

Verification of the law of conservation of energy in the case of a freely falling body

Consider a body of mass ' m ' at rest at a certain height ' h ' above the ground as shown in the Fig. 3.27. The total energy of the body at position ' A ' is equal to its potential energy as its velocity at the point is zero and so its kinetic energy is zero.

$$\therefore \text{potential energy at } A, P.E._A = mgh.$$

$$\text{Kinetic energy at } A, K.E._A = \frac{1}{2} m(0)^2 = 0$$

$$\therefore \text{Total energy at } A, T.E._A = P.E._A + K.E._A = mgh + 0 = mgh \quad (3.5)$$

When the body is dropped, it falls down towards the Earth due to gravitational force. Hence, gradually its potential energy decreases and kinetic energy increases. Consider a point ' B ' in its path where it has both potential and kinetic energy.

If ' x ' is the height of position ' B ' from the ground, displacement of the body = $h - x$.

If ' v ' is the velocity of the body at ' B ', then $v^2 = u^2 + 2gs = 0^2 + 2g(h - x) = 2g(h - x)$

Now potential energy at B , $P.E._B = mgx$

$$\text{Kinetic energy at } B, K.E._B = \frac{1}{2} mv^2 = \frac{1}{2} m 2g(h - x) = mg(h - x) = mgh - mgx$$

$$\therefore \text{total energy at } B, T.E._B = P.E._B + K.E._B$$

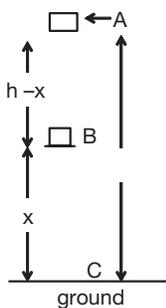


FIGURE 3.27

$$\begin{aligned} T.E._B &= (mgx) + (mgh - mgx) \\ &= mgh \end{aligned} \quad (3.6)$$

Finally at the ground, i.e., at position 'C', the height of the body is zero.

$$\therefore \text{Potential energy at C, } P.E._C = mg(0) = 0$$

If 'v' is the velocity of the body on reaching the ground, then, $v^2 = 2gh$

$$\therefore \text{Kinetic energy at C, } K.E._C = \frac{1}{2} mv^2 = \frac{1}{2} m(2gh) = mgh$$

Thus, the total energy at C, $T.E._C = P.E._C + K.E._C$

$$T.E._C = 0 + mgh = mgh \quad (3.7)$$

From equation (3.5), (3.6) and (3.7), it is clear that at any position in the path of a freely falling body, its total energy is constant. Thus, the law of conservation of energy is verified in the case of a freely falling body. Similarly, the law of conservation of energy can be verified in the case of a body projected vertically up.

Law of Conservation of Energy in the Case of a Simple Pendulum

The law of conservation of energy can be verified in the case of a simple pendulum too. Consider a simple pendulum, suspended from a rigid support as shown in the Fig. 3.28.

Position 'A' is the mean position of the pendulum bob. If the bob is displaced towards the right (position B) or left (position C), it has only potential energy as the velocity of the bob at these extreme positions is zero. As the pendulum bob moves towards the mean position 'A', all of its potential energy is converted into kinetic energy. Hence, when the pendulum moves from one extreme position (say C) to the mean position (A), total energy is converted from the potential to the kinetic energy and when it crosses the mean position and moves to the other extreme position (say B), its total energy is converted from kinetic to potential energy again.

In between the mean position and the extreme positions, the energy of the bob is partly kinetic and partly potential.

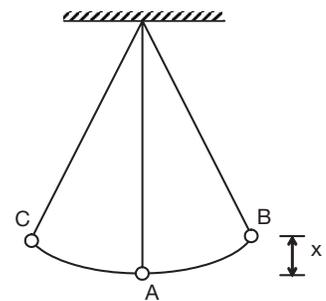


FIGURE 3.28

Transformation of Energy

According to the law of conservation of energy, energy can neither be created nor destroyed; but can be converted from one form to another. Following are some examples of conversion of energy from one form to another.

1. When we rub hands, the mechanical energy due to friction between the hands is converted into heat energy.
2. When a knife is rubbed against a grinding stone, the mechanical energy changes into heat, light and sound energy.
3. When brakes are applied to a vehicle, at the point where the brakes rub against the wheel, the mechanical energy changes to heat energy.
4. When a clock having a main spring is wound, the mechanical energy is converted into potential energy of the spring. This potential energy of the main spring of the clock changes into kinetic energy of the hands of the clock.

5. When a bow with an arrow is stretched, work done in stretching is stored as potential energy of the bow and this potential energy of the bow is transformed into kinetic energy of the arrow when the arrow is released.
6. Water stored in a dam has potential energy and this is converted into the kinetic energy of water when released. This kinetic energy of water can be converted into mechanical energy by making it fall on the blades of a turbine and can rotate them. The mechanical energy of the turbine can be converted into electrical energy, which can be transmitted to distant places and transformed into various other forms.
7. When a torch is switched on, the chemical energy of the cells is converted into electrical energy and that in turn is converted into light energy by the bulb.
8. An electric motor of a mixer cum grinder transforms electrical energy into kinetic energy, of its blades.
9. A microphone converts sound energy into electrical energy and a speaker converts electrical energy back into sound energy.
10. In an electric heater, oven or a geyser, etc., electric energy is converted into heat energy.
11. In a steam engine, the heat energy of the steam is converted into mechanical energy, of the engine.
12. In an electric generator, the mechanical energy changes into electrical energy.
13. When a fuel is burnt, the chemical energy of the fuel is converted into heat energy, of the engine.
14. During the charging of a battery, the electrical energy is changed into chemical energy.

EXAMPLE

What is the work done in bringing a moving body to rest in a distance of 2 m, by applying a force of 4 N?

SOLUTION

Work done = Force \times displacement

Since the body is brought to rest, the force applied is a retarding force (F)

$$F = 4 \text{ N}$$

$$S = 2 \text{ m}$$

$$\therefore \text{Work} = \text{force} \times \text{displacement} = 4 \times 2 = 8 \text{ J}$$

EXAMPLE

A labourer climbs up a staircase carrying a load of 10 kg on his head. The staircase has 20 steps and each step is 0.2 m high. Find the work done by the labourer in carrying the load. ($g = 10 \text{ m s}^{-2}$)

SOLUTION

Load is lifted against gravity, hence, work is done against the gravitational force.

$$\therefore \text{work done} = mgh = \text{potential energy}$$

$$\text{Height of one step} = 0.2 \text{ m}$$

Height of 20 steps = Total height = $h = 20 \times 0.2 = 4 \text{ m}$

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

$$\begin{aligned} \therefore \text{work done} &= mgh \\ &= 10 \times 10 \times 4 = 400 \text{ J} \end{aligned}$$

EXAMPLE

A body of mass 2 kg is accelerated from rest to a velocity 20 m s^{-1} in 5 s. What is the work done and power consumed?

SOLUTION

From the work-energy theorem we have,

work done = change in kinetic energy

$$\text{Work done} = \frac{1}{2} \times m [v^2 - u^2]$$

$$m = 2 \text{ kg}$$

$$u = 0$$

$$v = 20 \text{ m s}^{-1}$$

$$\text{Work done} = \frac{1}{2} \times 2 \times [20^2 - 0] = 400 \text{ J}$$

$$\text{power} = \frac{\text{work}}{\text{time}}$$

$$\text{work} = 400 \text{ J}$$

$$\text{time} = 5 \text{ s}$$

$$\therefore P = \frac{400 \text{ J}}{5 \text{ s}} = 80 \text{ W}$$

EXAMPLE

The cable of an electric motor exerts a force of 30 N on a body and pulls it through a distance of 20 m in one minute. What is the power of the motor?

SOLUTION

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

Given

$$F = 30 \text{ N}$$

$$s = 20 \text{ m}$$

$$t = 1 \text{ minute} = 60 \text{ s}$$

Work = force \times displacement

$$\therefore \text{Work} = 30 \times 20 = 600 \text{ J}$$

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{600 \text{ J}}{60 \text{ s}} = 10 \text{ W}$$

EXAMPLE

A 2 kg block is dropped from a height of 5 m. What is the potential energy and kinetic energy of the block at a height 2 m from the ground? What is kinetic energy of the block on reaching the ground?

SOLUTION

$$m = 2 \text{ kg}$$

$$h = 5 \text{ m}, h_1 = 2 \text{ m}$$

$$\begin{aligned} \text{At 'A' total energy is entirely potential energy} &= mgh \\ &= 2 \times 10 \times 5 \\ &= 100 \text{ J} \end{aligned}$$

As it falls, its kinetic energy increases

\therefore At 'B', its total energy

= potential energy + kinetic energy

Total energy at B = Total energy at A

(from law of conservation of energy)

$$\begin{aligned} \text{Total energy at B} &= \text{Potential energy} + \text{Kinetic energy} \\ &= mgh_1 + \text{kinetic energy} \end{aligned}$$

$$100 = 2 \times 10 \times 2 + \text{kinetic energy}$$

$$100 = 40 + \text{kinetic energy}$$

$$\therefore \text{kinetic energy at B} = 100 - 40 = 60 \text{ J}$$

Kinetic energy at the ground = potential energy at height h (from the law of conservation of energy)

$$\therefore \text{Kinetic energy at the ground} = 100 \text{ J}$$

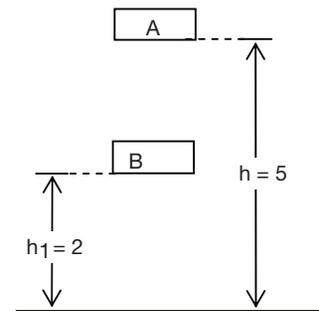


FIGURE 3.29

Sources of Energy

The materials from which we derive energy are known as sources of energy. Sun is the main source of all energy. Solar energy is the direct or indirect source of all energy. Energy sources can be classified into renewable and non-renewable sources.

Renewable Sources of Energy

Certain sources of energy like solar energy, wind energy, tidal energy are available in abundance in nature and which would never be exhausted are known as 'renewable sources of energy'. The sources get replenished continuously.

Non-renewable Sources of Energy

Sources of energy like coal, petroleum products, wood, etc., get consumed and cannot be replenished easily. These are called non-renewable sources of energy.

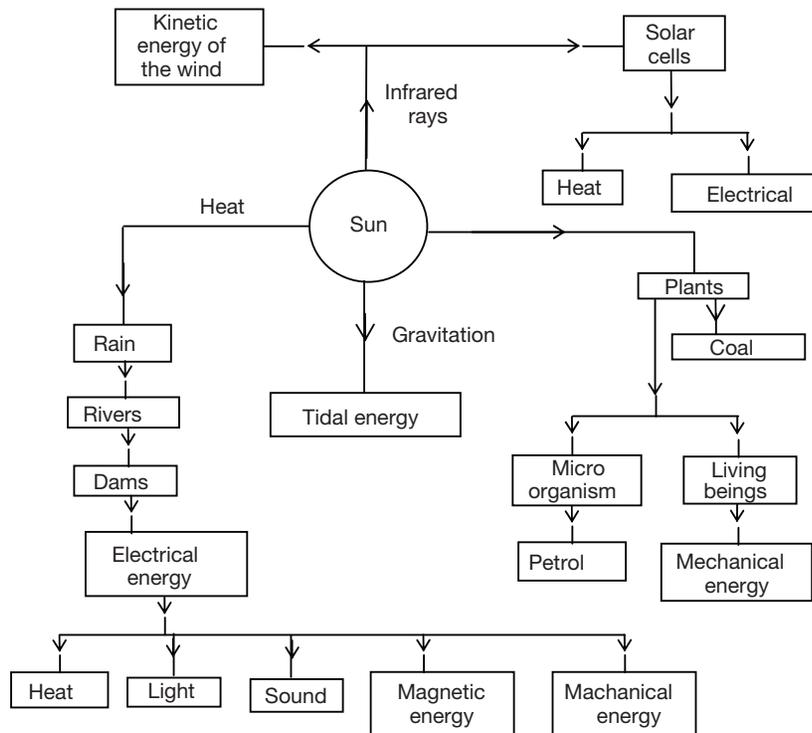


FIGURE 3.30 Sources of Energy

Fossil Fuels

Some sources of energy are obtained from fossilized substances, and hence, they are called fossil fuels. Hydrocarbons are the main constituents of fossil fuels.

Example: Coal, petrol and natural gas.

Coal

Dead animals and plants were buried for millions of years under the sediments of the Earth. In the absence of air and under high pressure and heat due to the Earth's crust, they got converted into coal. The main element of coal is carbon. Based on the carbon content, coal is classified as peat lignite, bituminous and anthracite. The other constituents of coal are hydrogen, oxygen and sulphur. Coke is obtained by the destructive distillation of coal.

Different forms of coal	Carbon %
(1) Peat	about 27%
(2) Lignite	28% to 30%
(3) Bituminous	78% to 87%
(4) Anthracite	94% to 98%

Petroleum

Petroleum is oil from rocks and is another type of fossil fuel. There are different products which can be derived from petroleum through a process called fractional distillation. The primary products that are derived are petroleum gas, which contains mainly ethane, propane, butane, etc., petrol which is a widely used fuel for automobiles; kerosene which is mainly used for domestic purposes; diesel which is used for automobiles and locomotives; fuel oil which is mainly used in industrial boilers; and paraffin wax is used in making candles, etc. Petroleum when refined gives lubricants, diesel, gasoline, etc.

Natural Gas

It is a mixture of gases and contains mainly methane and is also a rich source of hydrogen gas. Natural gas can be supplied through pipes or in cylinders.

Tidal Energy

Tidal energy is due to the gravitational pull of moon. The rise and fall of the tides can be used to generate electrical energy.

Geo-thermal Energy

‘Geo’ means related to the Earth and ‘thermal’ means related to the heat. It is due to the Earth’s heat. The interior part of the Earth is very hot. Thus, the water which seeps deep down into the Earth, gets heated and gets converted into steam. This steam comes out with a very high pressure and can be used to do mechanical work or generate electricity.

Ocean Thermal Energy

Upper layers of the ocean gets heated due to the absorption of sun’s heat. This results in temperature difference between the upper surface and the lower surface. This difference in temperature can be used to generate electrical power.

Hydro Energy

Water falling from a great height is made to fall on a turbine and the turbine rotates generating electrical power. This flowing water can be used for transporting timber.

Wind Energy

Movement of air is called wind. Difference in temperature and pressure are the cause of wind. Wind possesses kinetic energy. This kinetic energy is used to operate windmills. Windmills are installed in places having fairly strong and constant winds. The site of the a windmill should have a minimum wind speed of about 15 km h^{-1} .

Windmills are used to generate electrical power as well as for pumping water. Windmills, that can generate electrical energy in large scale called wind generators, are being developed by researchers.

Biogas

It is a renewable source of energy. Biogas is produced by the decomposition of organic waste like dung, vegetable waste, human excreta, etc. Biogas is a mixture of gases like methane, carbon dioxide, hydrogen and hydrogen sulphide. Biogas can be supplied through pipes for cooking and lighting and it can be used for generating electrical power.

Nuclear Energy

Nuclear energy can be either obtained by nuclear fusion or nuclear fission reactions.

Nuclear Fission

When a uranium nucleus is bombarded with a neutron, it splits into two fragments with the release of energy. This phenomenon is known as fission. During this reaction, two or three neutrons are also released. These neutrons can carry out further fission by bombarding the remaining uranium nuclei. Thus, fission is a sustained chain reaction.

Controlled chain reaction takes place in a vessel, which is called nuclear reactor. The heat developed during fission is used to convert water into steam and this steam is used to generate electrical power.

Atom bomb is based on the principle of uncontrolled chain reaction. The nuclear waste obtained during fission is harmful.

Nuclear Fusion

Sun and stars generate energy by fusion reactions. Fusion is the process of combining lighter nuclei to form a heavy nucleus with the release of energy. Fusion takes place at very high temperature, hence, fusion is referred to as a thermo-nuclear reaction.

In sun and stars, hydrogen atoms combine to form helium nuclei. In a hydrogen bomb, uncontrolled fusion reactions take place. The technology for controlling fusion reaction has not yet been developed.

Energy Crisis

Energy resources like coal, petrol, etc., could get, therefore depleted and in future. These sources of energy could become scarce. These energy resources should not be wasted, and should be economically and judiciously used.

In order to avoid energy crisis, alternative energy resources which are renewable should be used.

1. Automobiles which run on electrical and solar devices should be used in place of those which run on petrol or diesel.
2. Solar cookers and biogas should be used for cooking.
3. Whenever possible, windmills should be used to generate electricity.
4. The regular maintenance of oil and gas pipes also helps combat energy crisis.

Periodic Motion

A motion which repeats itself after equal intervals of time is known as periodic motion. For example, the revolution of the Earth around the sun, the oscillations of a mass suspended from a spring.

Oscillatory Motion (Vibratory Motion)

It is a periodic motion in which the body moves to and fro repeatedly about its mean position. For example, the vibrations of a tuning fork.

Simple Harmonic Motion (SHM)

It is an oscillatory motion in which the restoring force acting on a body is directly proportional to its displacement from the mean position.

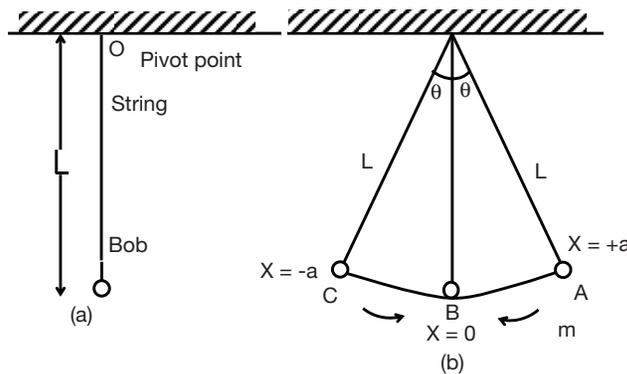


FIGURE 3.31

Simple Pendulum

Simple pendulum consists of a bob suspended by a light inextensible string from a rigid support.

When the bob is pulled to one side and released, the pendulum starts oscillating.

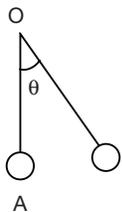


FIGURE 3.32

Angular Displacement (θ)

Angle which the bob makes with the vertical is called angular displacement. If A is the mean position, OA is the vertical line and θ is called angular displacement.

Length of the Pendulum

It is the distance, where the point of support to the centre of the mass, of the bob.

Oscillation

The motion of the bob from one extreme position to the other and back to the starting position is called one oscillation.

B and C are the extreme positions of the pendulum bob. The motion of the bob from B to C and from C to B is called one oscillation.

Amplitude: It is the maximum displacement of the bob from its mean position.

Period (T): It is the time taken by the pendulum to complete one oscillation.

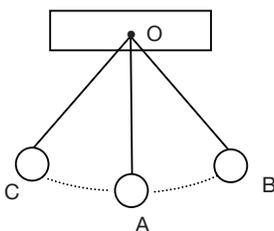


FIGURE 3.33

Frequency (f): It is the number of oscillations made by the oscillating body in one second.

$$\text{Frequency} = \frac{1}{\text{period}}$$

$$f = \frac{1}{T}$$

The unit of frequency is cycles per second or hertz (Hz).

Laws of Simple Pendulum

The laws governing the working of a simple pendulum are as follows:

1. The time period of oscillation of a simple pendulum is independent of the material, mass, shape and size of the bob.
2. The time period of oscillation of a simple pendulum does not depend upon the amplitude of oscillation, provided the angular amplitude is less than 4° .
3. The period of oscillation of the pendulum varies directly as the square root of the length of the pendulum.

$$T \propto \sqrt{L} \quad (3.8)$$

4. The period of oscillation of the pendulum varies inversely as the square root of acceleration due to gravity.

$$T \propto \frac{1}{\sqrt{g}} \quad (3.9)$$

Combining (3.8) and (3.9), we have

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

$$\therefore T = k\sqrt{\frac{L}{g}}$$

k is the proportionality constant and is equal to 2π

$$\therefore T = 2\pi\sqrt{\frac{L}{g}}$$

$$\therefore g = 4\pi^2 \frac{L}{T^2}$$

Experiment to Find Acceleration Due to Gravity Using a Simple Pendulum

1. Adjust the length of the pendulum to a suitable length (say 80 cm) and note down the length.
2. Set the bob to oscillate and find the time taken for 10 oscillations (t_{10}).

3. Calculate the time taken for one oscillation (period of oscillation) using

$$T = \frac{t_{10}}{10} \text{ s}$$

4. Calculate $\frac{L}{T^2}$

5. Repeat the experiment for different lengths, say from 80 cm to 120 cm.

It is noted that $\frac{L}{T^2}$ is always constant.

6. Calculate 'g' using the formula $g = 4\pi^2 \frac{L}{T^2}$

S.No.	L (in m)	t_{10} (s)	$T = \frac{t_{10}}{10}$ (s)	$\frac{L}{T^2}$ (ms ⁻²)	$g = 4\pi^2 \frac{L}{T^2}$ (ms ⁻²)

NOTE

The pendulum whose time period is 2 seconds is called seconds pendulum.

EXAMPLE

A certain simple pendulum has a period of 2 s. What will its period be when the length of the pendulum is doubled?

SOLUTION

The period of the simple pendulum is given by, $T = 2\pi\sqrt{\frac{L}{g}}$

Let 'L' be the original length, (L_1)

Time period, $T_1 = 2$ s.

When the length is doubled, $L_2 = 2L$

Time period, $T_2 = ?$

$$T_1 = 2\pi\sqrt{\frac{L_1}{g}} \tag{1}$$

$$T_2 = 2\pi\sqrt{\frac{L_2}{g}} \tag{2}$$

dividing (2) by (1)

$$\frac{T_2}{T_1} = \sqrt{\frac{L_2}{L_1}}$$

$$\frac{T_2}{2} = \sqrt{\frac{2L}{L}}$$

$$\frac{T_2}{2} = \sqrt{2}$$

$$T_2 = 2\sqrt{2} = 2 \times 1.41$$

$$\therefore T_2 = 2.82 \text{ seconds}$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

- State the law of conservation of momentum.
- Give two examples of renewable sources of energy.
- If no external _____ acts, the total momentum of the colliding bodies is conserved.
- What is normal reaction or normal force?
- Give two examples of non-renewable sources of energy.
- A person getting down from a fast moving bus falls on the ground. This can be explained by _____.
- Define force field.
- Define viscous force.
- State Hooke's Law.
- Name the force which is responsible for circular motion.
- Define the S.I. unit of work.
- A change in the state of rest or of uniform motion is produced by _____.
- What are lubricants?
- 1 newton = _____ dyne.
- Can all bodies have equal momentum?
- What type of energy does a flying bird possess?
- Friction always acts _____ to the surfaces in contact.
- What is meant by an unbalanced force?
- When is the work done maximum with a given force and displacement?
- The impulse of a body is equal to _____.
- (i) Define inertia of motion.
(ii) Define inertia of direction.
- 1 kg_{wt} is equal to _____ N.
- Define the S.I. unit of force.
- What is the relation between momentum and kinetic energy?
- The time period of a seconds pendulum is _____ seconds.
- (i) Give the dimensional formula of force
(ii) Give the dimensional formula of momentum
(iii) Write the dimensional formula of impulse
- A body 'A' of mass m_1 on collision exerts a force on another body B of mass m_2 . If the acceleration produced in B is a_2 , then the acceleration (in magnitude) of A is _____.
- State work energy theorem.
- Define impulse.

Short Answer Type Questions

- Distinguish between renewable and non-renewable sources of energy.
- Explain the cause of friction between two bodies in contact.
- A foot ball of mass 0.5 kg moving with a velocity of 10 m s^{-1} hits a pole and, the ball turns back and moves with a velocity of 20 m s^{-1} . Find the impulse and the force exerted on the ball if the force acts for 0.02 s.
- Distinguish between nuclear fission and fusion reactions.
- Explain Newton's third law of motion with an example.
- A body of mass 5 kg moving with a velocity 3 m s^{-1} collides with another body of mass 3 kg at rest. After collision, both move with the same velocity. Find their common velocity.
- What is meant by energy crisis?
- Derive the relation between newton and dyne.
- A cart of mass 20 kg at rest is to be dragged at a speed of 18 km h^{-1} . If the co-efficient of friction between the cart and the ground is 0.1, what is the minimum force required to drag the cart to a distance of 10 m? (Take $g = 10 \text{ m s}^{-2}$)
- (i) Define periodic motion.
(ii) Define oscillatory motion.



40. Discuss with an example to show that inertia depends on mass.
41. What will the work done be when a bullet of mass 10 g at rest is accelerated to a velocity of 20 m s^{-1} in 10 s? Calculate the power developed by the bullet during 10 s.
42. Define simple harmonic motion.
43. State Newton's Laws of motion.
44. A body of mass 5 kg is dropped from a height of 20 m.
- (i) What are the potential and kinetic energy of a body, when it falls through a distance of 15 m?
- (ii) Find the kinetic energy of the body at the ground level. Take $g = 10 \text{ m s}^{-2}$

Essay Type Questions

45. Describe an experiment to find 'g' using a simple pendulum.
46. State and verify the law of conservation of momentum.
47. Define and derive an expression for gravitational potential energy.
48. State the law of conservation of energy and verify it in the case of a freely falling body.
49. Derive $F = ma$ from Newton's second law of motion.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

1. Stretched spring has the energy in the form of potential energy.
2. Work and energy have the same S.I. units.
3. Friction depends on the area of contact between two surfaces.
4. Friction can be reduced by polishing surfaces.
5. All forces exist in pairs.
6. Impulse and momentum have similar units.
7. Mass of a body is a measure of its inertia.

Direction for questions 8 to 14

Fill in the blanks.

8. A cricket ball, during its flight after being hit, possesses _____ energy and _____ energy.
9. The change in momentum of a body has the same _____ as that of force applied on it.
10. A car at rest can be moved or a moving car can be stopped by applying _____.

11. The total momentum of two bodies before collision is equal to their _____ after collision.
12. To do the same work in less time, the power should be _____.
13. When a body is dropped from a height, its _____ energy changes to its _____ energy.
14. _____ force opposes the relative motion between the two bodies.

Direction for question 15

Match the entries given in Column A with appropriate ones from Column B.

15.

Column A	Column B
A. Inertia	a. variable velocity.
B. Action and Reaction	b. time period changes with change in length
C. Unit of friction	c. dimensionless and unitless quantity.
D. Lubricants	d. stretched rubber band



Column A		Column B	
E.	Unbalanced force	e.	to reduce force of friction.
F.	Friction	f.	inability to change the state of rest on its own.
G.	Simple pendulum	g.	change in kinetic energy
H.	Elastic potential energy	h.	opposition to the relative motion
I.	Coefficient of friction	i.	acts on two different bodies.
J.	Work	j.	newton

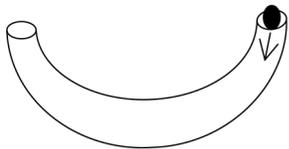
Direction for questions 16 to 45

For each of the questions, four choices have been provided. Select the correct alternative.

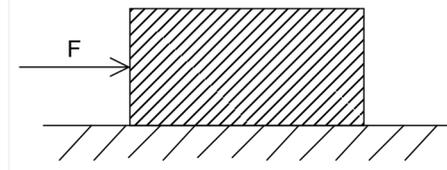
16. The statement 'friction is a self adjusting force' is _____.
 (a) a false statement
 (b) true in the case of static friction
 (c) true in the case of rolling friction
 (d) true in the case of sliding friction
17. The time period of a simple pendulum is independent of
 (a) the shape of its bob.
 (b) the material of the bob.
 (c) the mass of the bob.
 (d) All the above
18. Two bodies of masses m and $4m$ are moving with equal kinetic energy. The ratio of the velocities with which they are travelling is _____.
 (a) 1 : 2
 (b) 2 : 1
 (c) 3 : 4
 (d) 4 : 5
19. The weight of a body is 20 kg. This weight is equal to _____.
 (a) 1960 N
 (b) 196 J
 (c) 196×10^5 dyne
 (d) 19.6 N
20. When a spring having spring constant 2 N m^{-1} is stretched by 5 cm, the energy stored in it is
 (a) 0.025 J
 (b) 0.0025 J
 (c) 0.25 J
 (d) 2.5 J
21. The momentum ' P ' and kinetic energy ' E ' of a body of mass ' m ' are related as
 (a) $P = \sqrt{2mE}$
 (b) $P = \frac{1}{2} mE$
 (c) $P = \frac{2m}{E}$
 (d) $P = 2mE$
22. The force acting on a body when its momentum changes by 10 kg m s^{-1} , in 5 seconds is _____ N.
 (a) 15
 (b) 2
 (c) 5
 (d) 10
23. Two electric motors of power 1.75 hp and 3.5 hp pump water simultaneously. The ratio of amount of water pumped by them, in a given time, is
 (a) 1 : 2
 (b) 2 : 1
 (c) 1 : 4
 (d) 4 : 1
24. The change in momentum of a body
 (a) is equal to the force applied on it.
 (b) is equal to the product of force applied on it and the time of application of the force.
 (c) Both (a) and (b) are true
 (d) Both (a) and (b) are false
25. A fast moving car, whose engine is switched off, comes to rest, on a rough road. This is due to _____.
 (a) static friction
 (b) rolling friction
 (c) sliding friction
 (d) coefficient of rolling friction being greater than the coefficient of static friction
26. The rate of change in momentum of a body is
 (a) equal to the force applied on it.
 (b) proportional to the force applied on it.
 (c) in the direction of applied force.
 (d) All the above are true
27. Action and reaction
 (a) always exist in pairs.
 (b) are equal in magnitude.
 (c) always act in opposite directions.
 (d) All the above are true
28. Identify the false statement
 (a) It is difficult to run on sand as the force of friction is small.
 (b) Friction is necessary in everyday life.



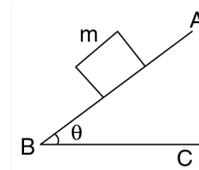
- (c) Friction causes wear and tear of the moving machinery parts.
- (d) The coefficient static friction increases on increasing the area of contact.
29. When the branch of a tree is shaken, the ripe fruits get detached from the branch. This is an example of
- Newton's first law of motion.
 - Newton's second law of motion.
 - Newton's third law of motion.
 - All the above
30. A stone, tied to the string is whirled in a vertical circle. Then _____.
- the potential energy of the stone is maximum at the top most position
 - the kinetic energy of the stone is maximum at the lowest position
 - the potential energy is maximum at the bottom most position
 - Both (a) and (b)
31. A body having a mass 100 gram is allowed to fall freely from a height 1000 m under the action of gravity. Its kinetic energy after 10 seconds is (take $g = 1000 \text{ cm} / \text{sec}^2$)
- 5 joules
 - 50 joules
 - 500 joules
 - 5000 joules
32. A marble is dropped into a friction less U-tube as shown in the figure. If the tube is semicircular with mean radius 5 cm and the mass of the ball is 2 gram, find its velocity at the bottom of the tube. (Take $g = 10 \text{ ms}^{-2}$).



- 1 m s^{-1}
 - 1 cm s^{-1}
 - zero
 - 0.1 m s^{-1}
33. A block of mass 2 kg is placed on the floor. The coefficient of static friction between the two surfaces is 0.4. A force of 2.5 newton is applied on the block as shown. The force of friction between the block and the floor is



- 7.84 N
 - 2.50 N
 - 6.45 N
 - 13.34 N
34. Two bodies A and B, moving in the same direction collide and after collision, move with the common velocity in the direction of A.
- The magnitude of force exerted by A on B is greater than the magnitude of force exerted by B on A.
 - Both of them exert an equal but opposite force on each other.
 - The change in momentum of A and B are equal but opposite in direction.
 - Both (b) and (c).
35. When a person is walking on ground
- he applies a force on the ground.
 - the ground exerts a force on him.
 - No force is applied by the person.
 - Both (a) and (b)
36. Identify the vector physical quantity from the given following
- impulsive force.
 - weight.
 - momentum.
 - All the above
37. A block of mass ' m ' placed on an inclined plane slides with uniform acceleration. Then



- the sum of the forces acting downwards along the plane are equal to the sum of the forces acting upwards along the plane.
- the weight of the body acts perpendicular to the inclined plane AB .
- the normal reaction of the block is acting perpendicular to the horizontal plane (BC) .
- the component of weight $mg \cos\theta$ acts perpendicular to the inclined plane.



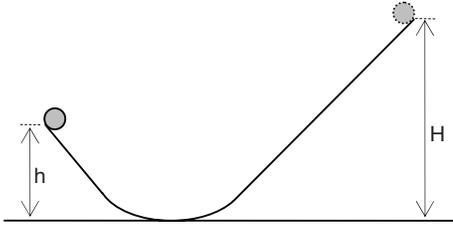
38. A body 'A' of mass 4 on collision exerts a force on another body B of mass 10. If the acceleration produced in B is 10 ms^{-2} , then the acceleration (in magnitude) of A is _____.
- (a) 25 ms^{-2} (b) 10 ms^{-2}
(c) 52 ms^{-2} (d) 5 ms^{-2}
39. If the momentum of a moving bus with constant mass is doubled, then its kinetic energy becomes _____.
- (a) double (b) triple
(c) quadruple (d) remains constant
40. The bodies of equal masses have kinetic energy in the ratio of 4 : 9. The ratio of their velocity is
- (a) 3 : 2 (b) 4 : 9
(c) 2 : 3 (d) 9 : 4
41. An engine develops 10 kW power. How much time will it take to lift a mass of 200 kg to a height of 40 m? (take $g = 10 \text{ m s}^{-2}$)
- (a) 10 s (b) 20 s
(c) 7 s (d) 8 s
42. The time period of a seconds pendulum _____.
- (a) changes with change in place on earth
(b) remains constant
- (c) is independent of mass of the bob
(d) Both (a) and (c)
43. Which among the following is a thermo nuclear reaction?
- (a) controlled fission reaction.
(b) uncontrolled fission reaction.
(c) exothermic chemical reaction.
(d) fusion reaction.
44. The displacement of the bob of a simple pendulum from its mean position (linear displacement) depends upon
- (a) angular displacement.
(b) maximum kinetic energy
(c) maximum potential energy
(d) All the above
45. A steam engine uses coal to produce steam. Then, ultimately, chemical energy of the coal is converted into
- (a) mechanical energy.
(b) heat energy.
(c) control energy.
(d) sound energy.

Level 2

46. A bullet of mass 50 g moving horizontally with velocity 100 m s^{-1} , hits and get embedded in a wooden block of mass 450 g placed on a vertical wall of height 19.6 m. If the bullet gets embedded in the block, then find how far from the wall, does the block fall on the ground? (Take $g = \text{m/s}^2$)
47. A porter carries 50 kg weight over his head. Discuss the work done in each of the following cases.
- Moving on horizontal road, with uniform velocity.
 - Moving on a slope with uniform velocity.
 - Moving on horizontal road, with acceleration.
 - Lifting the luggage to keep it on his head.
 - Lowering the luggage from his head, to the ground.
48. A lorry and a car are brought to rest by the same breaking force. What is the difference in the distance covered by them before they come to stop if their kinetic energies are equal?
49. Explain why a car does not move when the force is applied on it by a person present inside the car?
50. A heavy weight can be lifted by using simple machines such as pulley system by applying a small force. Does this mean that less work is done by using a simple machine than if the weight had been lifted directly? Explain.
51. Discuss the conditions under which no work is done on a body.
52. A compressed spring is clamped in its compressed position and is then dissolved in an acid. Discuss what happens to its potential energy.
53. A wooden block is placed on an inclined plane. Explain how friction between the block and the inclined plane varies with the variation in the angle of inclination of the inclined plane.
54. A log of wood is dragged up an inclined plane. Explain how the friction varies as the inclination of the plane is varied.



55. A ball is pushed from the top of an inclined plane of height ' h ' so that it reaches the top of the other inclined plane, upto a height H , as shown in the figure below.

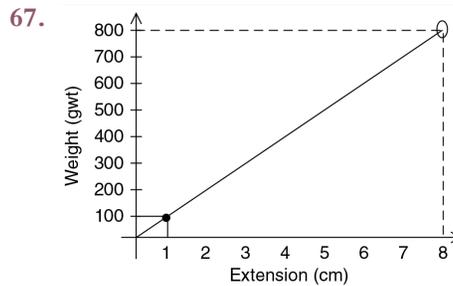


If the inclined planes are smooth and $h < H$, find the velocity with which the ball should be pushed from the first inclined plane.

56. A tennis player returns, with his racket, a tennis ball of mass 100 g coming towards him with a speed of 162 km h^{-1} . If the ball returns with the same speed and it remains in contact with racket for 0.1 s, find the force exerted by him on the ball.
57. Two identical balls of mass 2 kg each are kept in contact with a compressed spring, on either side of it. When the spring is released, the balls move with a velocity 10 m s^{-1} . Find the acceleration produced in each ball if the spring constant is 4 N m^{-1} .
58. Consider a big cylindrical roller. Is it easy to pull it or push it? Explain.
59. Explain how the energy is conserved in the case of a body executing circular motion in a vertical plane. If the speed of the body at the highest point is 3 m s^{-1} , find its speed at the lowest point when the radius of the circular path is 1 m. (Take $g = 10 \text{ m s}^{-2}$)
60. A person jumps onto a cement floor from a height of 1 m and comes to rest in 0.1 second. The same person on jumping from a height of 9 m into a sand pit, comes to rest in 1 second. Compare the forces exerted on him by cement floor and sand pit.
61. Raju was selected for long jump in athletics in his school. He could do 'long jump' well on sand bed, but when he demonstrated this on the road, he felt pain in the joints. Explain.
62. A lorry moving with 54 km h^{-1} speed hits a rock and comes to halt within 0.1 s. If the mass of the lorry is twenty metric tonne, then find the force exerted by the rock on the lorry.
63. Identify all forces that are acting on the objects described below.
- A block placed on a rough inclined surface.
 - A person standing on a horizontal surface.
- (c) The bob of a simple pendulum when it is at one extreme end while oscillating about its mean position.
64. A Pakistani player Shoab Akhtar bowls a cricket ball of mass 250 g with a speed of 120 km h^{-1} towards the batsman Dhoni. (Assume that the ball strikes the bat with the same speed). The time of impact of the bat with the ball is 0.1 s. After striking, if the ball bounces back with half its speed before striking, find the force which Dhoni exerts on the ball.
65. Two groups of students A and B , with two students in each group, challenge to accelerate two bodies P and Q , respectively, placed on a frictionless surface as shown in the figure. Which group is successful in imparting more acceleration? Justify. Find the acceleration of both the bodies.



66. Laxman found in a Bengali movie that rickshaw pullers are pulling the rickshaws by running on their feet. He got the doubt why they are pulling instead of pushing. Clarify his doubt.



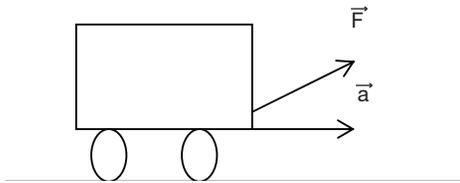
A spring balance is used to measure the weight of a body. The measured weight and the respective extension is shown in the graph. Find the spring constant of the spring balance.

68. Rahul goes to school daily on his cycle. It is his daily observation that he needs to apply more force to initiate the cycle to move, as compared to when the cycle is in motion. Explain.
69. Find the momentum of a bullet of mass 0.05 kg which does a work of 1000 J on a wooden block when it hits the wooden block.
70. An empty bus and a loaded bus cover a distance of 100 km each within the same time interval. Then explain which bus has to spend more energy.

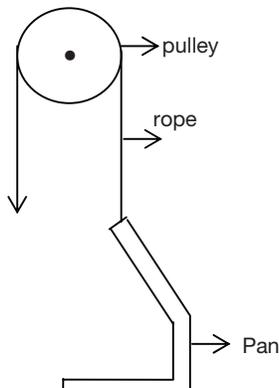


Level 3

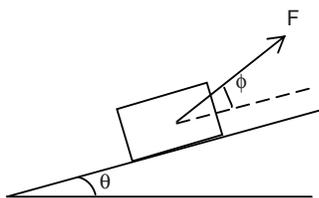
71. Are the direction of acceleration on a body and the direction of external force acting on the body always the same? If not, give an example. If the given statement is true, how do you account for it in the following situation? A toy car is tied to a string and is being pulled in a direction making an angle with the horizontal, whereas the toy car accelerates in a horizontal direction as shown in the figure.



72. Consider the following figure. A man sits in a pan and tries to raise himself by pulling the rope downwards. Will he be able to raise himself up? Explain.



73. A wooden block of mass ' m ' is pulled up an inclined plane having an inclination ' θ ' with the horizontal, with a force that makes an angle ϕ with the plane as shown in the figure. If the coefficient of kinetic friction between the plane and the block is μ_k , derive an expression for the acceleration of the block.



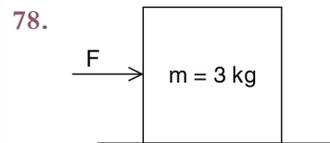
74. Nine identical books each of mass 500 g are placed one above the other. Find the maximum force required to take out the fifth book if the coefficient

of friction between contact surfaces of the books is 0.2, is the same force required to pull any one of the books? Explain.

75. A ball of mass m is dropped from a height h_1 , and after striking the ground the ball bounces back to a height h_2 ($h_2 < h_1$). If the ratio of the kinetic energy while passing a point at height h ($= \frac{h_2}{2}$) in the two directions is 2 : 1, what is the ratio of h_1 to h_2 ?

76. During the sports day celebrations of a school, a game of shooting is held. The students have to target the inflated balloons fixed at a certain distance. It is observed that each student when fires a bullet from the gun it is pushed back due to some force. Explain the reason for this observation. Also find out the magnitude of the force on the gun if the masses of the bullet and the gun are 50 g and 2 kg, respectively, and the bullet is fired with a velocity of 100 m s^{-1} . The bullet takes 5 ms to move through the barrel of the gun.

77. A lorry is moving on a narrow one way road. By mistake, a car enters into the same road in the opposite direction. The drivers of the vehicles by looking at this, apply same uniform breaking force to bring them to rest. They stop with a gap of a few meters. What is the difference in the distance covered by them before they come to stop if their initial kinetic energies are equal?



A blocks of mass 3 kg is placed on a rough surface as shown in the figure. Coefficient of maximum static friction between the surface and the block is 0.2 then find the minimum force ' F ' required to move the block.

- 79.
-



A block of 2 kg mass dropped from a height of 2.1 m, falls on a spring of length 10 cm placed vertically on the ground as shown in the figure. Find the maximum compression in the spring if the spring constant, k , of the spring is $3.28 \times 10^4 \text{ N m}^{-1}$. (take $g = 10 \text{ m s}^{-2}$).

80. In a game of shooting, a wooden block of mass 950 g is placed on the top of a vertical pole 19.6 m high. When the students standing on the top of a build-

ing fire bullets from the gun, they move horizontally. The bullet strikes the block, gets embedded in it and dislodges the block from the pole. The winner is declared based on how far from the pole, the wooden block would fall. A student who fires the bullet of mass 50 g with a velocity of 100 m s^{-1} is declared as the winner. Find how far from the pole would the wooden block fall. (Take $g = 9.8 \text{ m s}^{-2}$)

CONCEPT APPLICATION

Level-1

True or false

1. True 2. True 3. False 4. True 5. True 6. True 7. True

Fill in the blanks

8. potential, kinetic 9. direction 10. external force 11. total momentum 12. increased/greater
13. potential, kinetic 14. friction

Match the following

15. A : f B : i C : j D : e E : a F : h G : b H : d I : c J : g

Multiple choices

16. (b) 17. (d) 18. (b) 19. (c) 20. (b) 21. (a) 22. (b)
23. (a) 24. (b) 25. (b) 26. (d) 27. (d) 28. (d) 29. (a)
30. (d) 31. (c) 32. (a) 33. (b) 34. (d) 35. (d) 36. (d)
37. (d) 38. (a) 39. (c) 40. (c) 41. (d) 42. (d) 43. (d)
44. (d) 45. (a)

Solutions for questions 31 to 45:

31. $\text{K.E} = \frac{1}{2} mV^2$

For a freely falling body

$$V = gt \therefore V = 1000 \times 10 = 10^4 \text{ cm / sec}$$

$$\text{K.E} = \frac{1}{2} \times 100 \times 10^4 \times 10^4 = 5 \times 10^9 \text{ ergs} = 500 \text{ joules.}$$

32. $\frac{1}{2} v^2 = gh \Rightarrow v^2 = 2gh$

$$v = \sqrt{2 \times 10 \times 0.05} = 1 \text{ m s}^{-1}$$

33. Maximum possible frictional force $f_{\text{max}} = \mu_s R = \mu_s mg = 0.4 \times 2 \times 9.8 = 7.84 \text{ N}$ Since the applied force is 2.5 N (which is less than 7.84 N), therefore, the frictional force will be 2.5 N.

34. By Newton's third law of motion, if A exerts certain force on B , B also exerts an equal force on A . Therefore, both exert equal but opposite force on each other. By the law of conservation of momentum, it follows that change in momentum of A and B are equal and opposite.

35. A person walking on the ground applies a force on the ground and the ground exerts a force on the person.

36. We know,

$$f \times t = mv - mu$$

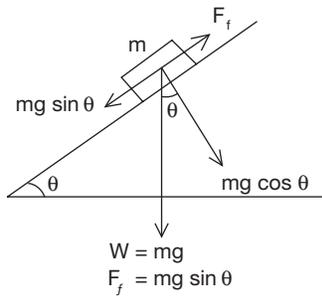
$$= m(v - u) = \Delta p$$

$$F \times t = \text{change in momentum}$$

Therefore, impulsive force and momentum and weight are vector quantities.



37.



38. According to Newton's third law of motion, action = - (reaction)

$$\therefore F_1 = -F_2$$

$$m_1 a_1 = -m_2 a_2$$

$$a_1 = -\frac{m_2}{m_1} a_2$$

$$\text{magnitude of acceleration} = \frac{m_2}{m_1} a_2 = \frac{10 \times 10}{4} 25 \text{ m s}^{-2}$$

39. $KE = \frac{P^2}{2m} \Rightarrow KE \propto P^2$

If momentum doubles, kinetic energy quadruples.

40. If mass remains constant, $KE \propto v^2$

$$\Rightarrow \frac{KE_1}{KE_2} = \left(\frac{v_1}{v_2}\right)^2 \Rightarrow \frac{4}{9} = \left(\frac{v_1}{v_2}\right)^2$$

taking square root on both the sides, $\frac{2}{3} = \frac{v_1}{v_2}$

41. Power, $p = w/t$

$$10 \times 10^3 W = \frac{mgh}{t} = \frac{200 \times 10 \times 40}{t}$$

$$t = \frac{200 \times 10 \times 40}{10^4} = 8 \text{ s}$$

42. The time period of seconds pendulum will change as

$$T \propto \frac{1}{\sqrt{g}} \text{ and } g \text{ varies on the surface of the Earth.}$$

Also, T is independent of mass of bob.

43. In nuclear fusion reaction takes places at very high temperature, hence, fusion reactions are referred to as thermo nuclear reaction.

44. The displacement of the bob depends up on the maximum potential energy, maximum kinetic energy and the angular displacement.

45. In steam engine, coal is burnt to derive heat energy and this heat energy is converted in to mechanical energy.

Level 2

46. Use

$$m_1 u_1 + m_2 u_2 = v(m_1 + m_2)$$

where v is the common velocity.

To find distance from wall at which the block falls,

$$\text{use } R = v \times \sqrt{\frac{2h}{g}}$$

where v is the horizontal velocity of the block, and h is the height of the wall.

Ans: 20 m

47. (1) $W = F_s \cos \theta$. Hence, work is maximum when θ is zero and it is zero when θ is 90° .

(2) While walking work is done against friction between the feet and the ground.

(3) For lifting, lowering or holding the luggage the applied force acts in the vertical direction

48. Kinetic energies of the car and the lorry are equal, before coming to rest and after coming to rest.

Applying work energy theorem, work done in each case may be determined.

Use work = force \times displacement, to find the linear distance covered by both.

49. (1) The force applied by a person from inside a vehicle constitutes internal force.

(2) Newton's first law: A body remains in a state of rest unless acted upon by a net external force.

50. Input energy = work done by effort

Output energy = work done by load.

51. Work = $F_s \cos \theta$, where F is the applied force, s the displacement and θ the angle between the two vectors.

Ans: 9 N

52. When a spring is compressed, its potential energy increases.



Can this potential energy be changed into other forms of energy?

What form of energy is released due to chemical reaction in an acid, when a metal dissolves in it?

53. (1) Friction is proportional to the net normal reaction force.
 (2) $R = mg \cos \theta$
 (3) $f \propto \cos \theta$
 (4) $\cos 0^\circ = 1, \cos 90^\circ = 0$

54. When two bodies are in relative motion, kinetic frictional force acts between the bodies.

When a log of wood is dragged up an inclined plane, kinetic frictional force acts in between the log and the plane. This frictional force is directly proportional to the weight of the block and the cosine of the angle between the inclined plane and the horizontal.

If the angle (θ) of inclination of the plane increases, the $\cos(\theta)$ value decreases, and hence, the force of friction also decreases.

55. Initial State: P.E. = mgh , K.E. = $\frac{1}{2}mu^2$
 Final State: P.E. = mgH , K.E. = 0

According to Law of conservation of energy, (P.E. + K.E.)_{initial} = (P.E. + K.E.)_{final}

Ans: $\sqrt{2g(H-h)}$

56. Use
 $F = ma = \frac{m(v-u)}{t}$

Ans: -90N

57. The acceleration in the ball is due to force exerted by spring on the balls.

The potential energy of the compressed spring is converted into kinetic energy of the balls.

Ans: 20 m s^{-2}

58. In case of pulling the cylindrical roller with a force ' F ' (say)

Find whether the component of this force increases or decreases the normal reaction on the cylindrical roller.

In case of pushing the cylindrical roller with a force (F^1) find whether the component of this force (F^1) increases or decreases the normal reaction on the cylindrical roller.

As the normal reaction increases, how does it affect the friction?

59. A body executing circular motion in a vertical plane will have both kinetic and potential energies.

The sum of K.E. and P.E. at a position in the circular motion is always constant for a body executing uniform circular motion.

At the highest point, potential energy will be maximum.

At the lowest point, kinetic energy will be maximum

By law of conservation of energy, the total energy of the body at the lowest point is equal to that at the highest point.

Find the value of speed of the body at the lowest point.

Ans: 7 ms^{-1}

60. Use,

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

And find v by using

$$v = \sqrt{2gh}$$

Ans: $\frac{10\sqrt{5}}{3\sqrt{5}}$

61. We know, $F \times t = m(v-u)$

The change in the momentum is constant when he jumps either on the road or on the sands bed because the initial and final velocities are same

Then, $F \times t = \text{constant}$

If the impulsive time is increased, then the impact of impulse force decrease and vice versa. When Raju jumped on the road, the impulsive time is less and impulsive force is more and this is the reason for the pain in the joint.

62. The mass of the body $m_L = 20,000\text{kg}$

The initial velocity of the lorry $u = 54 \text{ km h}^{-1}$

$$= 54 \times \frac{5}{18} = 15 \text{ m s}^{-1},$$

the final velocity of lorry = 0

The time of impact, $t = 0.1\text{s}$

The force exerted by the rock on the lorry is equal to the rate of change of momentum in the lorry

$$\therefore F = ma = m\left(\frac{v-u}{t}\right)$$

$$F = m_L a_L = 20,000 \times \left(\frac{0-15}{0.1}\right)$$

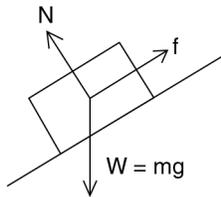
$$= -30,00,000 \text{ N} = -3 \times 10^6 \text{ N}$$

\therefore The force exerted by lorry on the rock = $-3 \times 10^6 \text{ N}$

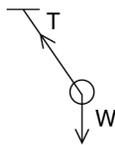
\therefore Force exerted by the rock on the lorry = $3 \times 10^6 \text{ N}$



63. (a) Three forces act on a body placed on a rough inclined plane.
- Weight in the downward direction.
 - Normal force which is perpendicular to the surface on which it is placed.
 - frictional force as shown in the figure.



- (b) (i) weight of the person is in the downward direction.
 (ii) Normal reaction force in the upward direction.
 (iii) Frictional force in a direction opposite to his motion.
- (c) Two forces act on the bob. One is weight of the bob acting downward and the other is tension along the string.



64. Mass of the ball, $m = 250\text{g} = \frac{1}{4}\text{ kg}$

Velocity of ball just before striking the bat,
 $u = -120\text{ km h}^{-1}$

Velocity of the ball just after striking the bat

$$v = \frac{1}{2}(u) = \frac{1}{2}(120) = 60\text{ km h}^{-1}$$

Time of impact, $t = 0.1\text{ s}$

$$\text{Force on the ball, } F = ma = \frac{m(v-u)}{t}$$

$$= \frac{1}{4} \left(\frac{60 - (-120)}{0.1} \right) \times \frac{5}{18} = 125\text{ N}$$

Thus, the force exerted by Dhoni is 125N

65. Forces acting on 10 kg mass are both in the same direction.

Hence, the net force = sum of two forces

$$\Rightarrow F_1 = 10 + 15 = 25\text{ N}$$

$$m_1 = 10\text{ kg}$$

$$a_1 = \frac{F_1}{m_1} = \frac{25}{10} = 2.5\text{ m s}^{-2}$$

Forces acting on 5 kg mass are in opposite directions.

$$\therefore \text{Net force} = F_2 = 15 - 10 = 5\text{ N, } m_2 = 5\text{ kg}$$

$$a_2 = \frac{F_2}{m_2} = \frac{5}{5} = 1\text{ m s}^{-2}, \text{ in the direction of greater force.}$$

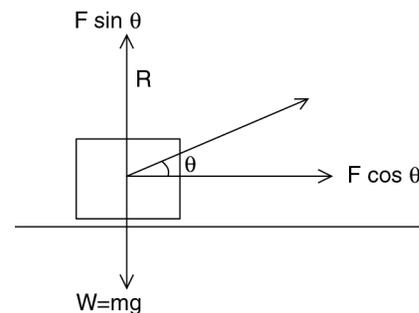
Thus, the students of group A is successful in importing greater acceleration.

Acceleration of a body depends on net force acting on the body and mass of the body.

The net force on the first body is 25 N and on the second body is 5 N.

Even though the mass of the first body is double the mass of the second body, the net force acting on the first body is five times more than the net force acting on the second body. As such the acceleration of the first body is more than the acceleration of the second body.

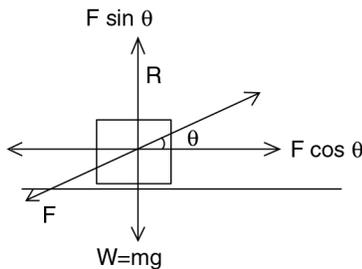
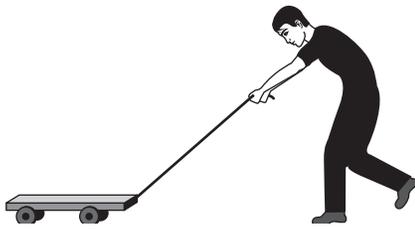
66. Case I:



While pulling, the rickshaw puller applies a force 'F'. Then the vertical component of the force 'F', i.e., $F \sin\theta$ acts vertically upwards and acts opposite to the direction of weight (mg) this decrease the value of normal reaction

$$R = (mg - F \sin\theta) \text{ and also frictional force } F_f = \mu R = \mu (mg - F \sin\theta)$$





While pushing, the rickshaw puller applies a force ' F ' then vertical component of force (F), i.e., $F \sin \theta$ acts in a perpendicular downward direction in the direction of the weight.

This increases the value of normal reaction (R) and also frictional force (F_f)

$$R = (mg + F \sin \theta)$$

$$F_f = \mu R = \mu(mg + F \sin \theta)$$

Since in case (2), the frictional force is more than that in the case (1), it becomes difficult to push and comparatively easy to pull.

Level 3

71. According to Newton's second law of motion, $F = ma$. What are the vectors in the above equation?

Does the equation mean that the acceleration of a body is in the direction of the applied force?

In the given situation, does the total applied force on the body act in the direction of its displacement?

If force has a component along the horizontal, why does the acceleration not have its component along the horizontal?

72. Consider the force to be applied on the free end of the rope when the pan is stationary. How does this force vary when the person pulls himself and the pan upwards?

67. We know $F = kx$

$$K = F/x$$

$$\Delta F = F_1 - F_2 = 800 - 100 = 700 \text{ g}_{\text{wt}}$$

The extension $\Delta x = x_1 - x_2$

$$= 8 - 1 = 7 \text{ cm}$$

$$\Rightarrow K = \frac{\Delta F}{\Delta x} = \frac{700}{7} = 100 \text{ g}_{\text{wt}} \text{ cm}^{-1}$$

68. We know, that dynamic friction is less than static limiting friction. So, frictional (static limiting friction) force is more just before the cycle starts moving compared to the frictional force (kinetic friction) that exists when the cycle is in motion. Hence, it requires more force to initiate the motion in the cycle than the force required to keep the cycle moving.

69. Mass of bullet, $m = 0.05 \text{ kg}$

K E of the bullet K E = 1000 J

$$\text{We know, K E} = \frac{P^2}{2m}$$

Where P = momentum of the bullet

$$P^2 = (2m) (\text{KE}) = 2 \times 0.05 \times 1000$$

$$= 0.1 \times 1000 = 100$$

$$P = \sqrt{100} = 10 \text{ kg ms}^{-1}$$

70. The mass (m) of the empty bus is less than the mass (m) of loaded bus and both the buses take the same time to cover 100 km each, therefore, their average velocities are same.

We know that kinetic energy K.E. = $1/2(\text{mass})(\text{velocity})^2$. From this, we know that the K.E of the heavy bus is more than that of the empty bus.

73. When the wooden block moves up, find the direction of the kinetic frictional force.

For force ' F ', two components acting along inclined plane and another in upward direction is given by?

Find the net force acting along the inclined plane.

Find the net force acting perpendicular to the inclined plane.

Substitute the value for normal reaction

Find the net acceleration acting along the inclined plane by dividing the net force by the mass of the body.

$$\text{Ans: } a = \frac{F_{\text{net}}}{m}$$

$$= \frac{1}{m} [F \cos \phi - \mu_k (mg \cos \phi - F \sin \phi) - mg \sin \theta]$$



74. Use $F = \mu mg$

The force of friction F_1 on the upper surface, is given by,

$$F_1 = 4\mu mg$$

where ' m ' is the mass of each book.

The force of friction on the lower surface

$$F_2 = 5\mu mg$$

Ans: 9 N

75. **Case A:**

What is the 'law of conservation of energy'?

What is the total energy of the ball at a height of h_1 .

Then, potential energy of the ball at a height of h_1 is mgh_1 (1)

Are both the energies equal?

When the ball is dropped from a height of h_1 , what is the potential energy of the ball at $\left(\frac{h_2}{2}\right)$?

Take the velocity of the ball at a height of $\left(\frac{h_2}{2}\right)$ as ' V_1 '.

Then find the kinetic energy of the ball at $\left(\frac{h_2}{2}\right)$.

Is the total energy at height $\frac{h_2}{2}$ the sum of K.E. and P.E.? (2)

Then find the kinetic energy in terms of the potential energy (3)

Case B:

After striking the ground, the ball rises to a height of ' h_2 '.

Then the potential energy of the ball at a height of ' h_2 ' is mgh_2 (4)

Find the total energy of the ball at a height of ' h_2 '?

Take velocity of the ball at a height of $\left(\frac{h_2}{2}\right)$ after bouncing from ground as ' V_2 '.

Find the kinetic energy of the ball at the height $\frac{h_2}{2}$. (5)

Find the potential energy of the ball at the same height $\frac{h_2}{2}$. (6)

Find the total energy of the ball at this position. (7)

Now, find the kinetic energy of the ball in terms of its potential energy. (8)

By solving, (3) and (8) find the ratio of h_1 to h_2

$$\text{Ans: } \frac{h_1}{h_2} = \frac{3}{2}$$

76. By law of conservation of momentum,

$$(50 \times 10^{-3}) \times 100 = 2 \times v$$

$$\therefore v = 2.5 \text{ m s}^{-1}$$

Time taken by the bullet to move through barrel of the gun, $\Delta t = 5 \times 10^{-3} \text{ s}$

According to Newton's second law motion,

$$F = m \frac{\Delta v}{\Delta t}$$

$$\text{Force acting on the bullet} = m \left(\frac{v-u}{\Delta t} \right)$$

$$= 50 \times 10^{-3} \left(\frac{100-0}{5 \times 10^{-3}} \right) = 1000 \text{ N}$$

According to Newton's third law of motion, action = reaction

Thus, force acting on the gun = 1000 N

77. Work done by the force in bringing the lorry and the car to rest is the same. Work done by the force is equal to the change in kinetic energy in the lorry and in the car. As the kinetic energies are equal $W = F \cdot s$ = change in kinetic energy. Since the force is also the same, the distance traveled by the lorry and the car will be the same.

$$\text{Proof: } \frac{W_1}{W_2} = \frac{F_1}{F_2} \times \frac{S_1}{S_2}$$

$$\Rightarrow \frac{S_1}{S_2} = \frac{W}{W} \times \frac{F}{F} = \frac{10}{1}$$

difference between distances covered by lorry and card is zero.

78. Maximum force required to just move the block = Limiting friction

Frictional force between horizontal surface and the block is $f_1 = \mu_s N = 0.2 \times 3 \times 9.8 = 5.88 \text{ N}$

79. The loss of potential energy of the Earth-block system is equal to the gain of potential energy in spring-block system.

Let the spring be compressed by ' x '.

The loss of potential energy of earth-block system = $mg(h - \ell + x)$

The gain of potential energy of spring block system = $\frac{1}{2} kx^2$



$$\begin{aligned}
 &= \frac{1}{2} kx^2 \\
 &= 2 \times 10(2.1 - 0.1 + x) = \frac{1}{2} \times 3.28 \times 10^4 \times x^2 \\
 &= 40(2 + x) = 3.28 \times 10^4 x^2 \\
 &\Rightarrow 820x^2 - x - 2 = 0 \\
 &\Rightarrow 820x^2 - 41x + 40x - 2 = 0 \\
 &\Rightarrow 41x(20x - 1) + 2(20x - 1) = 0 \\
 &\Rightarrow (20x - 1)(41x + 2) = 0
 \end{aligned}$$

$$\begin{aligned}
 x &= \frac{1}{20} \text{ or } -\frac{2}{41} \\
 x &= \frac{1}{20} \text{ m or } 5 \text{ cm}
 \end{aligned}$$

80. Mass of bullet, $m = 50 \text{ g} = 50 \times 10^{-3} \text{ kg}$
 Mass of block, $M = 950 \text{ g} = 950 \times 10^{-3} \text{ kg}$
 Initial velocity of bullet = 100 m s^{-1}

Let 'u' be the velocity of bullet and block system after collision. Then, according to the law of conservation of momentum

$$\begin{aligned}
 50 \times 10^{-3} \times 100 + 950 \times 10^{-3} \times 0 \\
 = (50 + 950) \times 10^{-3} \times u
 \end{aligned}$$

$$u = \frac{5 + 0}{100 \times 10^{-3}} = 5 \text{ ms}^{-1}$$

Thus, the block is dislodged from the pole with a horizontal velocity (u) of 5 m s^{-1} .

The height of pole $h = 19.6 \text{ m}$.

$$\text{Time of descent } t_d = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 19.6}{9.8}}$$

$$= \sqrt{2 \times 2} = 2 \text{ s}$$

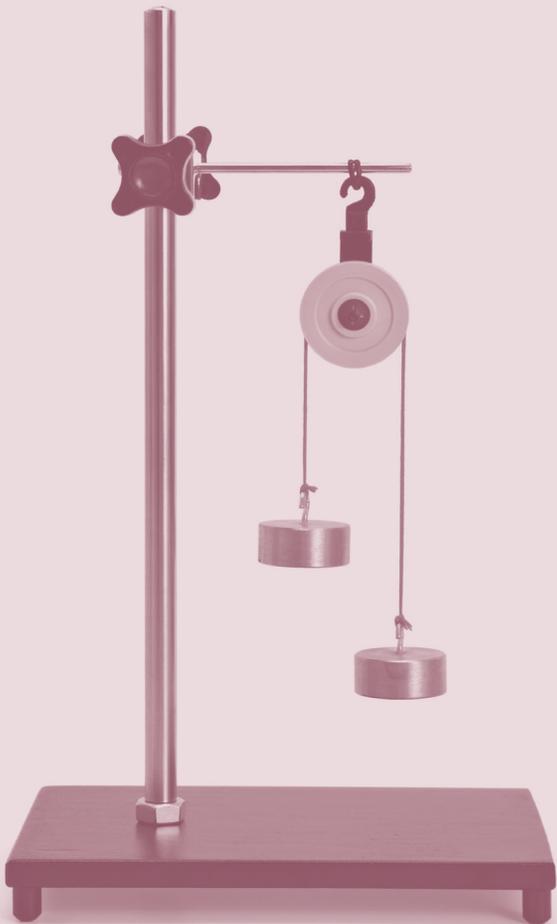
The distance at which the block strikes the ground from the bottom of the pole = $ut = 5 \text{ m s}^{-1} \times 2 \text{ s} = 10 \text{ m}$.



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Chapter 4

Simple Machines



REMEMBER

Before beginning this chapter you should be able to:

- Recall the construction, working and maintenance of different types of tools
- Define force and its types

KEY IDEAS

After completing this chapter you should be able to:

- Learn how simple machines are classified into different types of levers
- Understand how an inclined plane is used as a simple machine
- Explain the different factors affecting the turning effect of a body
- Study about the functioning of gears, wheel and axle and their applications

INTRODUCTION

Human beings are the most developed and the most intelligent of all the species on the Earth. Yet the humans are not perfect. We have quite a number of shortcomings. We do not possess the strength of an elephant or the agility of a cheetah. What do we do when we face a challenging task? We take the help of a number of tools and devices. These tools and devices that help us are called simple machines. For example, in order to screw or unscrew a nut, we use a spanner or a screw driver. A spanner is a type of simple machine. In this chapter, we will learn more about different types of simple machines, the principles on which they work and their applications.

In order to understand the mechanical operations of simple machines and their applications, it is necessary to have a knowledge of parallel forces and their effects.

PARALLEL FORCES



FIGURE 4.1

The forces whose lines of action are parallel are called parallel forces. Consider two forces A and B acting along the directions as indicated in the Fig. 4.1. Since the lines of action of these two are parallel, they are parallel forces. Parallel forces acting in the same directions are called like parallel forces. Their magnitudes may or may not be equal.

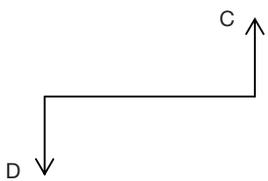


FIGURE 4.2

Now, consider the two forces, C and D acting at two different points as shown in the Fig. 4.2. The lines of action of C and D are parallel. Thus, they are parallel forces. But they act in opposite directions. Parallel forces acting in opposite directions are called unlike parallel forces. Their magnitudes may or may not be equal. When a single force has the same effect as when a number of forces act simultaneously on a body, that force is called 'resultant' of all the forces.

A force which brings a body, which is not in equilibrium due to number of unbalanced forces acting on it, into an equilibrium state is called equilibrant.

Resultant of Parallel Forces

Consider two like parallel forces A and B acting on a horizontal rod MN at the points M and N , respectively, as shown in the Fig. 4.3. The resultant of the parallel forces is R and acts at O on the rod.

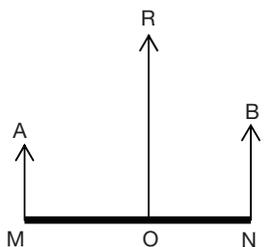


FIGURE 4.3

The following can be said about R .

- 1. Magnitude of R :** It is equal to the sum of the magnitudes of A and B .

$$R = A + B$$

- 2. Direction of R :** It is the same as that of A and B .

- 3. Position of O :** It is a point on the rod between M and N , such that

$$A \times MO = B \times NO.$$

Resultant of Unlike Parallel Forces

Two unlike parallel forces A & B acting on a horizontal rod are shown in the Fig. 4.4. The resultant of these forces acts at point 'O' which lies outside the rod.

- Magnitude of R:** It is equal to the difference in the magnitude of the greater and the smaller forces.

$$R = (A - B) \text{ or } (B - A)$$

- Direction of R:** Same as that of greater force (here in the direction of B).

- Position of O:** Outside MN on the side of the greater force such that $A \times MO = B \times NO$.

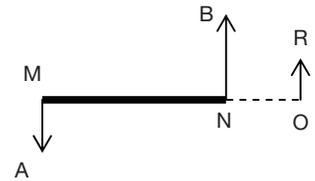


FIGURE 4.4

EXAMPLE

Two like parallel forces acting on a rod, 15 N and 5 N are separated by a distance of 4 m. What is the magnitude, direction and point of application of the resultant?

SOLUTION

Let A and B be the two parallel forces acting at points M and N , respectively.

The magnitude of the resultant force is given by,

$$\begin{aligned} R &= A + B \\ &= 15 \text{ N} + 5 \text{ N} = 20 \text{ N} \end{aligned}$$

The direction of the resultant is same as that of the two forces.

Let the position of the resultant R be at O , at a distance x from M .

We have

$$\begin{aligned} A \times MO &= B \times NO \\ 15 \times x &= 5 \times (4 - x) \\ 15x &= 20 - 5x \\ 20x &= 20 \\ \therefore x &= 1 \text{ m} \end{aligned}$$

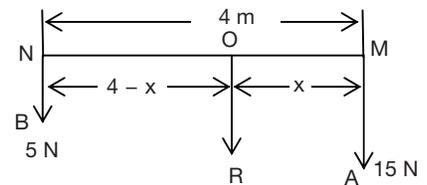


FIGURE 4.5

EXAMPLE

Find the magnitude, direction and position of the resultant, if the forces in the above problem are unlike?

SOLUTION

The magnitude of the resultant is

$$\begin{aligned} R &= A - B \text{ (greater force - smaller force)} \\ &= 15 \text{ N} - 5 \text{ N} = 10 \text{ N} \\ R &= 10 \text{ N} \end{aligned}$$

Its direction is same as that of the greater force, i.e., A .

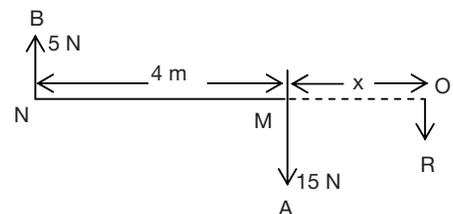


FIGURE 4.6

Its position is outside MN on the side of A at point 'O' at a distance 'x' from A , such that

$$\begin{aligned} A \times MO &= B \times NO \\ 15 \times x &= 5 \times (4 + x) \\ 15x &= 20 + 5x \\ \therefore x &= 2 \text{ m} \end{aligned}$$

SIMPLE MACHINES

A device which allows us to apply force at a convenient point so as to overcome a force at some other point is called simple machine. Although, they are called simple machines, they can help us in a number of ways. Their functions are:

1. As a force multiplier, i.e., to lift a heavy load with less effort.
Example: Screw jack to lift a car or truck.
2. To change the point of application of force.
Example: Instead of applying force directly to the wheels of a bicycle, it is easier and more convenient to apply it to the pedals.
3. To change the direction of application of effort according to our convenience.
Example: It is difficult to lift a bucket full of water from a well but the task becomes easier if the force is applied in downward direction with the help of a pulley.
4. As a speed multiplier.
Example: In vehicles, gears, help in changing speed.

A machine cannot do any work on its own. We have to apply a force at a convenient point on the machine which gets transferred to some other point where the required work is done more effectively.

The force applied to a machine is called effort. The force overcome by a machine in response to the effort is called load. The ratio of load to effort is called 'mechanical advantage' of a machine.

$$\begin{aligned} \text{Mechanical advantage (M.A.)} &= \frac{\text{Load (L)}}{\text{Effort (E)}} \\ \Rightarrow \text{M.A.} &= \frac{L}{E} \end{aligned}$$

Simple machines are tools which involve the usage of either levers or inclined planes or a combination of both.

EXAMPLE

Consider a machine whose mechanical advantage is 5. It raises a load of 25 N. Calculate the minimum effort that has to be applied to it.

SOLUTION

Load raised by the machine, $(L) = 25 \text{ N}$

Given, the mechanical advantage of the machine, $\text{M.A.} = 5$.

Effort, (E) = ?

$$\text{M.A.} = \frac{25}{E} = 5$$

\therefore Effort = 5 N

LEVERS

Lever is a straight or a bent rod, capable of rotating about a fixed point. The fixed point about which a lever rotates is called fulcrum. The distance between effort and fulcrum is called 'effort arm'. The distance between load and fulcrum is called 'load arm'.

Types of Levers

Since levers are used for our convenience, the positions of load, effort and fulcrum are changed relative to each other so that the task at hand can be handled more effectively.

Accordingly, levers are classified into three types or classes.

- Class I Lever or Levers of First Order:** When the fulcrum is between the effort and the load, the lever is classified as first order lever.

Examples: Scissors, see-saw, crowbar, etc.

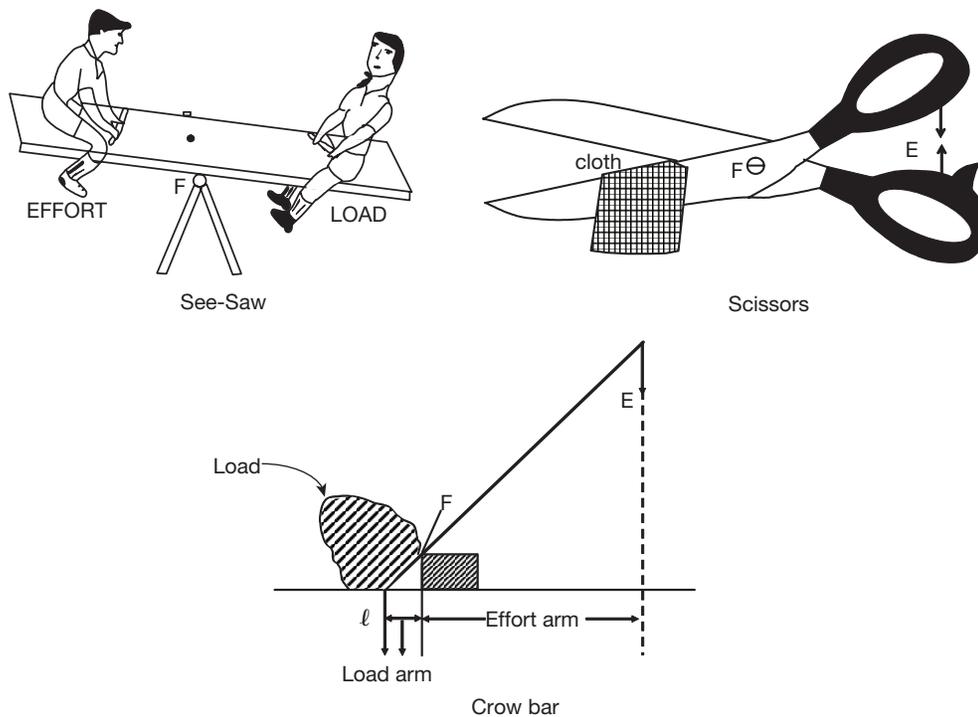


FIGURE 4.7 Examples of Class I Lever

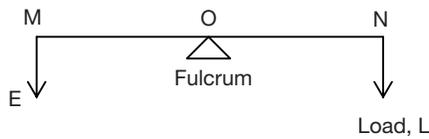


FIGURE 4.8

Mechanical Advantage (M.A.) of Class I Lever

The Fig. 4.8 shows a class I lever under equilibrium. The fulcrum is at point 'O' such that

$$\text{load} \times \text{load arm} = \text{effort} \times \text{effort arm.}$$

$$\Rightarrow L \times NO = E \times MO$$

$$\therefore \frac{L}{E} = \frac{MO}{NO}$$

Thus, the mechanical advantage of a lever of first order is,

$$\text{M.A.} = \frac{MO}{NO} = \frac{\text{effort arm}}{\text{load arm}}$$

Thus, the mechanical advantage of a lever depends on the ratio of the lengths of the effort arm to the load arm.

- 2. Class II Lever or Levers of Second-order:** In this class of levers, the load lies between the effort and the fulcrum.

Example: A nut cracker, wheel barrow, oar of a boat, bottle opener, etc.

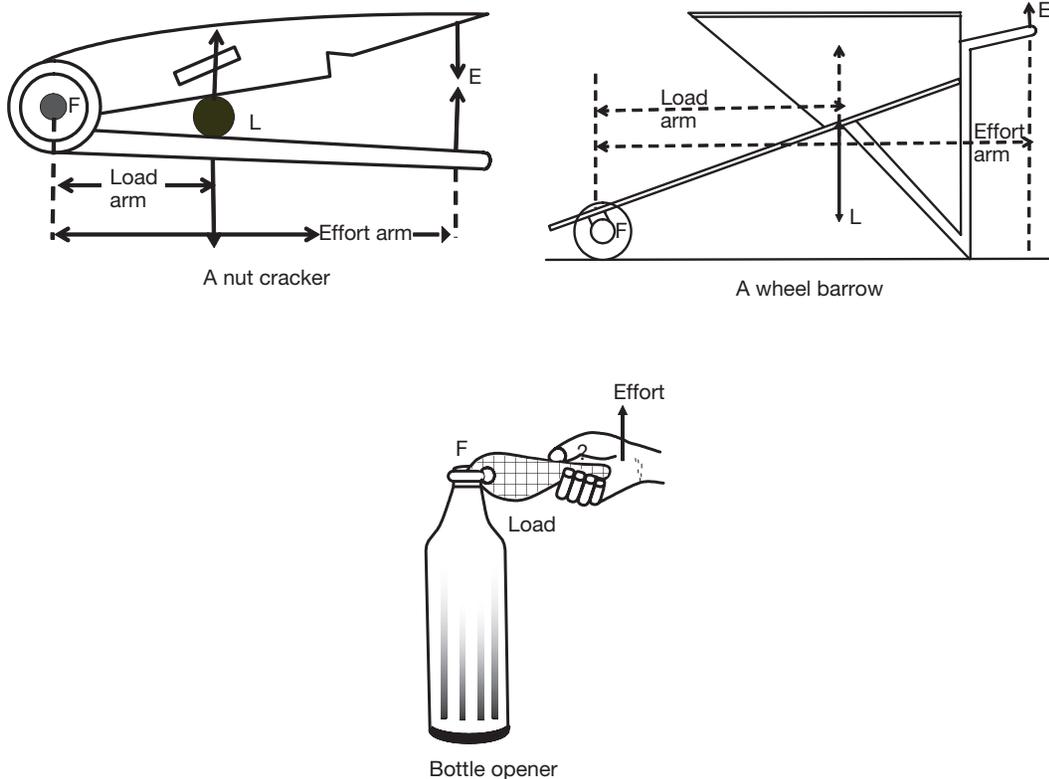


FIGURE 4.9 Examples of Class II Lever

Mechanical Advantage of Class II Lever

The Fig. 4.10 shows a class II lever under equilibrium. When the lever is in equilibrium,

$$\begin{aligned} \text{load} \times \text{load arm} &= \text{effort} \times \text{effort arm} \\ L \times NO &= E \times MO \end{aligned}$$

The mechanical advantage of the lever,

$$\text{M.A.} = \frac{L}{E} = \frac{MO}{NO} = \frac{\text{effort arm}}{\text{load arm}}$$

In class II levers, the effort arm is always greater than the load arm. Therefore, the M.A. is always greater than 1. Thus, by using a class II lever, a greater load can be lifted with a lesser effort, i.e., class II levers are used as force multipliers.

- 3. Class III Lever or Lever of Third Order:** The levers in which effort lies between load and fulcrum are called class III lever.

Example: Fire tongs, bread knife, etc.

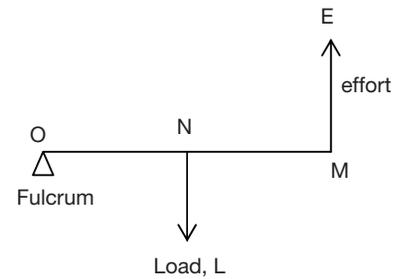


FIGURE 4.10

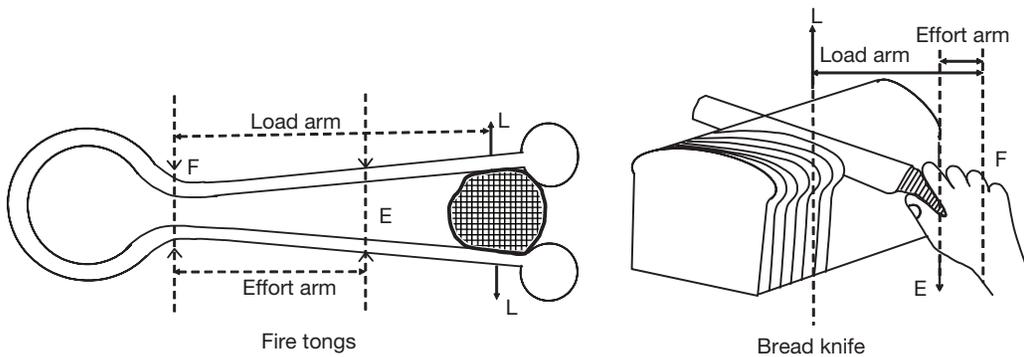


FIGURE 4.11 Examples of Class III Lever

Mechanical Advantage for Class III Levers

Consider a class III lever under equilibrium as shown in the Fig. 4.12.. When the lever is in equilibrium,

$$\begin{aligned} \text{load} \times \text{load arm} &= \text{effort} \times \text{effort arm} \\ L \times NO &= E \times MO \end{aligned}$$

Thus, the mechanical advantage of the lever,

$$\begin{aligned} \text{M.A.} &= \frac{L}{E} = \frac{MO}{NO} \\ \therefore \text{M.A.} &= \frac{MO}{NO} = \frac{\text{effort arm}}{\text{load arm}} \end{aligned}$$

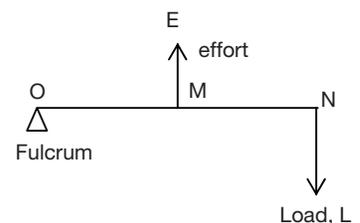


FIGURE 4.12

In Class III levers, the length of the load arm is always greater than that of the effort arm. Therefore, its M.A. is always less than 1.

Hence, it cannot be used as a force multiplier. Instead, class III Levers are used as speed multipliers.

EXAMPLE

The load arm and effort arm of a lever are 10 cm and 50 cm, respectively. The load and effort are applied on the opposite sides of the fulcrum. Identify the class of the lever. Find its mechanical advantage. If the effort applied is 10 N, how much load can be raised by it?

SOLUTION

Since the fulcrum lies in between the load and effort, it is class I lever.

Mechanical advantage (M.A.) of levers is given by,

$$M.A. = \frac{\text{effort arm}}{\text{load arm}} = \frac{50 \text{ cm}}{10 \text{ cm}}$$

Thus, mechanical advantage, M.A. = 5.

Given, Effort (E) = 10 N, Load (L) = ?

$$\begin{aligned} \therefore L &= E \times M.A. \\ &= 10 \times 5 = 50 \text{ N} \end{aligned}$$

EXAMPLE

To lift a piece of burning coal of mass 200 g, a cook uses a fire tong of length 30 cm. He applies the effort at a distance of 10 cm from its fulcrum. Find the effort applied by the cook. ($g = 10 \text{ m s}^{-2}$)

SOLUTION

Given:

Mass of the coal = 200 g.

Thus, Load = 0.2 kg

$L = 0.2 \times 10 = 2 \text{ N}$. Length of the load arm
= 30 cm and the length of the effort arm = 10 cm

load \times load arm = effort \times effort arm

$$\therefore \text{effort} = \text{load} \times \frac{\text{load arm}}{\text{effort arm}} = 2 \times \frac{30}{10} = 6 \text{ N}$$

EXAMPLE

Length of a nut cracker is 25 cm. A nut is kept 8 cm away from the fulcrum and an effort of 32 N is applied at the other end of the nut cracker. Calculate the resistance offered by the nut?

SOLUTION

A nut cracker is class II lever, i.e., load lies between effort and the fulcrum.

Given : load arm = 8 cm,

Effort arm = length of nut cracker = 25 cm,

Effort = 32 N

Resistance offered by the nut is the load for the nut cracker.

load \times load arm = effort \times effort arm

$$L \times 8 \text{ cm} = 32 \text{ N} \times 25 \text{ cm}$$

$$\therefore L = \frac{32 \text{ N} \times 25 \text{ cm}}{8 \text{ cm}} = 100 \text{ N.}$$

INCLINED PLANE

It is difficult to lift a heavy load vertically up. Hence, while loading a goods truck, a plank is kept between the truck and the ground at a certain angle to the ground and the load is pushed or pulled over the slope provided by the plank. Such an arrangement is called an inclined plane. Inclined plane is a smooth rigid flat surface, that is at an angle to the horizontal plane.

Mechanical Advantage of an Inclined Plane

Consider a plane AB inclined at an angle θ to the horizontal.

Let l be the length of the plane. The end B of the plane is at a height ' h ' from the ground.

When the load ' L ' is moved from A to B by applying an effort E , it is displaced by length ' l '.

$$\text{Work done by the effort} = \text{effort} \times \text{displacement}$$

$$\Rightarrow E \times AB = E \cdot l$$

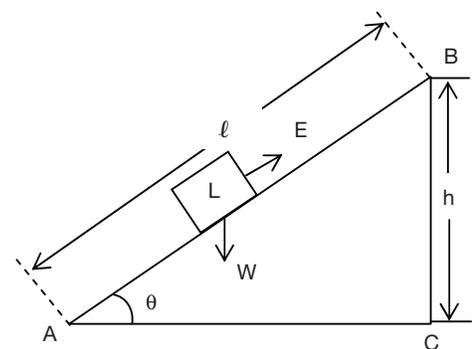
Now consider the same load to be lifted vertically up from C to B by applying a force equal to the weight W of the load.

$$\text{Work done on the load} = \text{load} \times \text{displacement}$$

$$\Rightarrow L \times BC = L \cdot h$$

Since the load is raised to the same height ' h ' in both cases, work done is the same.

$$\therefore L \times h = E \times l \Rightarrow \frac{L}{E} = \frac{l}{h}$$

**FIGURE 4.13**

The ratio of load to effort is the mechanical advantage (M.A.) of the plane.

$$\therefore \text{M.A.} = \frac{\ell}{h} = \frac{\text{length of the inclined plane}}{\text{height of the inclined plane}}$$

$$\text{M.A.} = \frac{1}{\sin \theta} \left[\because \sin \theta = \frac{h}{\ell} \right]$$

$$\text{As } 0^\circ < \theta < 90^\circ, \sin \theta < 1 \Rightarrow \text{M.A.} > 1$$

Thus, the M.A. of on inclined plane increases with the decrease in the angle θ .

EXAMPLE

A plank of length 4 m is inclined to the ground such that its one end is resting on the ground and the other end is 1m above ground level. Calculate the effort that has to be applied to push a load of 48 N up the plank.

SOLUTION

Length of the plank $l = 4$ m.

Height of the inclined plane, $h = 1$ m.

Mechanical advantage of the inclined plane is

$$\text{M.A.} = \frac{\ell}{h} = \frac{4 \text{ m}}{1 \text{ m}}$$

$$\text{M.A.} = 4$$

By definition, M.A. is equal to $= \frac{\text{load (L)}}{\text{effort (E)}}$

$$\Rightarrow 4 = \frac{48 \text{ N}}{E}$$

$$\therefore E = \frac{48 \text{ N}}{4}$$

$$E = 12 \text{ N}$$

MOMENT OF FORCE

According to Newton's laws of motion, when a force is applied on a rigid body, it can make the body undergo linear motion. This is true when a body is free to execute linear motion. Consider the case of a body which is not free to move (travel) but can rotate about a point or a line. Now, by applying force, the body can be made to rotate about the fixed point. For example a door is pivoted at one of its ends at the hinges and by applying force to the door, we can produce a turning effect. The line passing through the door hinges is called axis of rotation. In general, a line passing through the point of rotation, such that a body rotates about this line is called axis of rotation. The turning effect of the force on the body about the point or axis of rotation is called moment of force or torque.

Turning a page, rotating a steering wheel, opening a door are the examples in daily life which show that a turning effect can be produced on the application of force. As discussed, this turning effect of force acting on a body about an axis is called torque or moment of force.

Applications of Turning Effect of Force

1. Opening and closing a door: The door rotates about the axis of rotation passing through its hinges. If a force is applied at the hinges, the door cannot be opened or closed. When the force is applied at a point which is very close to the hinges, a large amount of force is required to open the door, whereas, when the force is applied at a point which is comparatively at a greater distance from the hinges, it becomes easier to open or close the door, as the magnitude of force required is less.
2. To tighten or loosen a nut, the force is applied at the end of the long handle of a spanner so that the nut can be turned easily by applying less force. The longer the handle, the lesser will be the force required.

Factors Affecting the Turning of a Body

From the above discussion it can be seen that the magnitude of the torque depends on:

1. The magnitude of the force applied.
2. The perpendicular distance of the line of action of the force from the axis of rotation (also called radius vector).

Moment of force or torque of a body can be defined as ‘the product of the magnitude of the force and the perpendicular distance of the line of action of force from the axis of rotation’.

Moment of force, $\tau = \text{Force} \times \text{Perpendicular distance}$. Moment of force is a vector quantity.

Units of Moment of Force

S.I.: N m

C.G.S.: dyne cm

Dimensional formula of moment of force: $[ML^2T^{-2}]$

Clockwise and Anti-clockwise Moments

If a body is turned anti-clockwise on the application of force, the moment of force is said to be anti-clockwise moment and is taken as a positive moment. The moment of force is taken as a negative moment when the body is turned clockwise.

EXAMPLE

A force of 8 N is applied to a body at a distance of 20 cm from the point at which it is pivoted. Calculate the torque or moment of force about the pivot.

SOLUTION

Given, applied force, $F = 8 \text{ N}$.

Distance of the point of application of force from the axis of rotation, $r = 20 \text{ cm} = \frac{20}{100} \text{ m}$

$$\begin{aligned}
 \text{Hence, Torque } (\tau) &= F \times r \\
 &= 8 \text{ N} \times \frac{20}{100} \text{ m} \\
 &= 1.6 \text{ N m}
 \end{aligned}$$

EXAMPLE

When a force of 10 N is applied about the axis of rotation of a body, it produces a torque of 5 N m. Find the distance of the point of application of the force from the axis of rotation.

SOLUTION

Given

$$\text{Torque } (\tau) = 5 \text{ N m}$$

$$\text{Force } (F) = 10 \text{ N}$$

$$\text{Distance } (r) = ?$$

$$\tau = F \times r$$

$$\therefore r = \frac{\tau}{F} = \frac{5 \text{ N m}}{10 \text{ N}} = 0.5 \text{ m}$$

EXAMPLE

A mechanic unscrews a nut by applying a force of 120 N on a spanner of length 40 cm. What should be the required length of the spanner in order to apply only 40 N force?

SOLUTION

In the 1st case, the force applied,

$F = 120 \text{ N}$ and the magnitude of the perpendicular distance (called radius vector),

$$r = 40 \text{ cm} = \frac{40}{100} \text{ m}$$

$$\text{Torque } (\tau) = 120 \text{ N} \times \frac{40}{100} = 48 \text{ N m.}$$

In the 2nd case, applied force $F = 40 \text{ N}$ and the length of the radius vector is to be found.

$$r = ?$$

$$\tau = F \times r \text{ is the same in both the cases.}$$

Hence,

$$48 = 40 \times r$$

$\therefore r = 1.2 \text{ m}$. Hence, to apply a force of 40 N for the same torque, the mechanic should use a spanner of length 1.2 m.

EQUILIBRIUM

A body can be said to be in equilibrium if a number of forces acting on the body do not produce a change in the state of rest or of uniform motion of the body.

The essential conditions to say that a body is in equilibrium are,

1. the resultant of all forces on the body is zero such that its state of rest or of uniform motion do not change and
2. the resultant of all the torques acting on the body is zero so that it does not rotate.

Principle of Moments

For a rigid body, which is in equilibrium under the action of a number of forces in a plane, the sum of clockwise moments is equal to the sum of anti-clockwise moments.

(or)

The algebraic sum of moments of all the forces about the axis of rotation is zero for a body in equilibrium.

Verification of Principle of Moments

1. Suspend a metre scale horizontally from a fixed support.
2. Take different hanger weights W_1, W_2, W_3, W_4, W_5 and W_6 and suspend W_1, W_2 and W_3 weights on the left side and W_4, W_5 and W_6 on the right side of the metre scale.
3. Adjust the relative distances of the weights on either sides, such that the beam remains horizontal.
4. Note the corresponding distance of each weight from the point of suspension. Let them be l_1, l_2, l_3, l_4, l_5 and l_6 , respectively.
5. Total anti-clockwise moments = $W_1 l_1 + W_2 l_2 + W_3 l_3$ and the total clockwise moments = $W_4 l_4 + W_5 l_5 + W_6 l_6$
6. Since scale is in sum of ACW moments = Sum of CW moments

i.e.,
$$W_1 l_1 + W_2 l_2 + W_3 l_3 = W_4 l_4 + W_5 l_5 + W_6 l_6$$

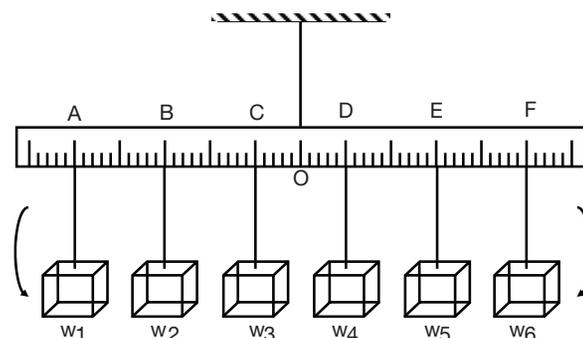


FIGURE 4.14

A physical balance works on the principle of moments and is used to find the mass of a body, which in turn helps us to find the weight of the body ($W = mg$)

COUPLE

A pair of equal, coplanar and unlike parallel forces acting on a rigid body whose lines of action are not the same and produces a turning effect on the body is called couple.

Example: Opening a tap, turning a key, turning a steering wheel of a vehicle are examples of couple.

Moment of a Couple

It is defined as the product of any one of the forces constituting a couple and the perpendicular distance between the lines of action of the two forces.

Moment of a couple = Force \times arm of the couple

$$C = F \times d$$

Couple is a vector quantity.

Units of Couple

S.I.: N m

C.G.S.: dyne cm

Dimensional formula of couple: $[ML^2T^{-2}]$

Properties of Moment of a Couple

1. Moment of couple always leads to pure rotation.
2. A couple can never be replaced by a single force. It can be replaced only by another couple.
3. The resultant couple acting on a body is equal to the vector sum of the moments of individual couples acting on it.

EXAMPLE

A heavy metallic scale of length 1 m has its centre of gravity at 50 cm division. It is suspended at a 30 cm mark. A load of 60 g_{wt} has to be tied at its zero cm mark to keep it in equilibrium. Calculate the weight of the scale.

SOLUTION

The scale is in equilibrium. Thus, according to the principle of moments, the sum of clockwise moments ($W_1 \ell_1$) is equal to the sum of anti-clockwise moments ($W_2 \ell_2$).

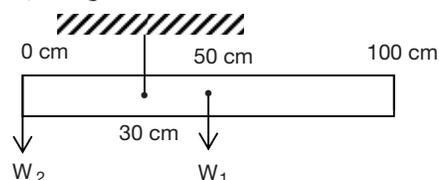


FIGURE 4.15

$$\therefore W_1 \ell_1 = W_2 \ell_2$$

W_1 = weight of the scale.

ℓ_1 = distance of centre of gravity of the scale from the point of suspension

$$= 50 - 30 = 20 \text{ cm}$$

W_2 = load = 60 g_{wt}

$\ell_2 = 30 \text{ cm}$ = distance of load from the point of suspension

$$\therefore W_1 \times 20 \text{ cm} = 60 \text{ g}_{\text{wt}} \times 30 \text{ cm}$$

$$\therefore W_1 = \frac{60 \text{ g}_{\text{wt}} \times 30 \text{ cm}}{20 \text{ cm}} = 90 \text{ g}_{\text{wt}}$$

EXAMPLE

A uniform metre scale 1 m long is suspended at 50 cm division. A known weight of 160 g_{wt} is tied at 80 cm division and the scale is balanced by a weight of 240 g_{wt} tied to the scale at a certain distance from the point of suspension on the opposite side. Calculate this distance.

SOLUTION

As the scale is in equilibrium.

Applying principle of moments, we get

$$W_1 \ell_1 = W_2 \ell_2, \text{ where } W_1 = 160 \text{ g}_{\text{wt}}, W_2 = 240 \text{ g}_{\text{wt}} \text{ and } \ell_1 = 80 \text{ cm} - 50 \text{ cm}$$

$$\text{i.e., } 160 \text{ g}_{\text{wt}} \times (80 - 50) \text{ cm} = 240 \text{ g}_{\text{wt}} \times \ell_2$$

$$\begin{aligned} \therefore \ell_2 &= \frac{160 \times 30}{240} \\ &= 20 \text{ cm} \end{aligned}$$

EXAMPLE

A car has a steering wheel of diameter 30 cm. It is turned with anti-parallel forces of a magnitude of 4 N each. Calculate the moment of couple.

SOLUTION

Diameter of the steering wheel of the car = perpendicular distance between the pair of forces = 30 cm

$$= 0.3 \text{ m}$$

Applied force = 4 N

\therefore Moment of the couple = Force \times perpendicular distance

$$= 4 \times 0.3$$

$$= 1.2 \text{ N m.}$$

ROMAN STEELYARD

A roman steelyard is based on the principle of moments. It is a balance with unequal arms and a fixed fulcrum. It consists of a horizontal beam (AB) and a movable rider (R) which can be moved along the length of the beam. The beam is suspended by a hook (H) and the position of the rider is adjusted in a way that the beam stays horizontal. This position of rider is called zero-load position 'O'.

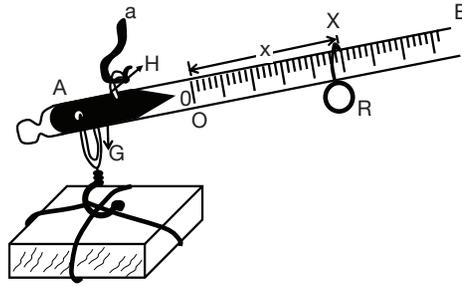


FIGURE 4.16 Roman steelyard

If G is the centre of gravity of the beam and W is its weight, then

$$W \times HG = R \times HO \quad (4.1)$$

If a load L is attached to the hook provided at A and the rider is moved to a point X such that the beam is horizontal, then

$$L \times HA + W \times HG = R \times HX \quad (4.2)$$

On subtracting equation (4.1) from equation (4.2), we get

$$L \times HA = R \times OX$$

$$\Rightarrow L = \frac{R \times OX}{HA}$$

Since R and HA are constant for a given steelyard, $L \propto OX$.

The beam is calibrated in terms of weight such that the position of the rider gives the unknown weight directly.

EXAMPLE

In a Roman steelyard, the weight of the rider is 25 dyne. When an unknown load is attached 5 cm from the point of suspension, the rider had to be moved by 35 cm. Calculate the unknown load

SOLUTION

For Roman steelyard

$$L = \frac{R \times OX}{HA}$$

Where L = unknown load

OX = distance moved by rider.

$HA =$ distance of the load from point of suspension

$$\therefore L = \frac{25 \text{ dyne} \times 35 \text{ cm}}{5 \text{ cm}} = 175 \text{ dyne}$$

WHEEL AND AXLE

It consists of a strong cylindrical rod pivoted at its ends. This cylindrical rod is called axle. A wheel is attached to the axle such that they have a common axis of rotation.

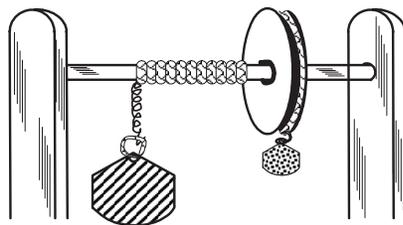


FIGURE 4.17 Wheel and axle

A load which is to be lifted is attached to the rope wound around the axle. The effort needed to lift the load is applied to the rope wound in around the wheel in the opposite direction.

Let R and r are the radii and the axle of the wheel, respectively.

The effort is applied along AE and the load is moved along LB . For one complete rotation of the wheel, the axle too completes one rotation. Then, the work done by the effort = $E \times 2\pi R$

Similarly, the work done on the load = $L \times 2\pi r$

As the work done by the effort is equal to the work done on the load, we get

$$E \times 2\pi R = L \times 2\pi r$$

$$\Rightarrow E \times R = L \times r \text{ or}$$

$$\frac{L}{E} = \frac{R}{r}$$

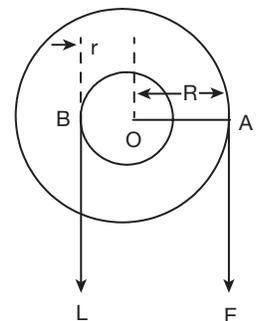


FIGURE 4.18

$$\begin{aligned} \text{Mechanical advantage of wheel and axle} &= \frac{L}{E} = \frac{\text{Load}(L)}{\text{Effort}(E)} \\ &= \frac{\text{Radius of the wheel}}{\text{Radius of the axle}} = \frac{R}{r} \end{aligned}$$

EXAMPLE

In a wheel and axle, for one complete rotation the magnitude of displacement of effort is 5 times that of the load. What load can be lifted by applying an effort of 10 N? If the radius of the wheel is 35 cm, what is the radius of the axle?

SOLUTION

In one rotation,

$$\text{displacement of effort} = 2\pi R$$

$$\text{displacement of load} = 2\pi r$$

$$\text{given } 2\pi R = 5(2\pi r)$$

$$\begin{aligned} \text{M.A.} &= \frac{2\pi R}{2\pi r} \\ &= \frac{5(2\pi r)}{2\pi r} \end{aligned}$$

$$\therefore \text{M.A.} = 5$$

$$\text{Also, M.A.} = \frac{L}{E}$$

$$5 = \frac{L}{10 \text{ N}}$$

$$\therefore L = 50 \text{ N}$$

$$R = 35 \text{ cm}; r = ?$$

$$5 = \frac{2\pi(35)}{2\pi r}$$

$$\therefore r = \frac{35}{5} = 7 \text{ cm.}$$

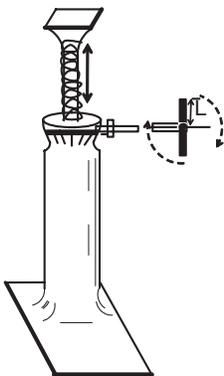
SCREW JACK

FIGURE 4.19

A screw jack is a combination of a screw and a lever. The screw is turned by a horizontal bar connected to the lever. The screw moves linearly up or down with every rotation by a distance equal to the distance between its adjacent threads. This distance is called pitch of the screw.

A car or any other load which is to be raised is placed on the top of the screw. The effort needed to lift it is applied at the end of the lever. As the lever completes one revolution, the screw rotates once and moves up by the distance equal to its pitch, thereby lifting the load up by the distance equal to its pitch.

$$\text{Work done by the effort} = E \times 2\pi \ell$$

Where ℓ = length of the lever and E = effort.

$$\text{Work done in lifting the car} = L \times P$$

Where L = load (weight of the car) and

P = pitch of the screw.

As work done by the effort is equal to the work done on the load, we have $L \times P = E \times 2\pi\ell$

$$\frac{L}{E} = \frac{2\pi\ell}{P}$$

But the ratio of load to effort is the mechanical advantage, M.A. of the screw jack.

$$\therefore \text{M.A} = \frac{2\pi\ell}{P}$$

As the length of the lever is increased, the M.A. of the screw jack increases. Screw jack is also used in microscopes, and in workshops where book binding is done.

EXAMPLE

The pitch of a screw jack A is half that of another screw jack B. For 10 complete rotations of the lever, which one of the jacks will lift a car higher? Which one will need more effort to do an equal work if both the jacks have levers of equal length?

SOLUTION

For one rotation of the lever, the screw moves up by a distance equal to its pitch.

\therefore greater the pitch, higher the car gets lifted.

\Rightarrow Jack B lifts the load higher

In the case of a screw jack,

$$\frac{W}{E} = \frac{2\pi L}{P}$$

$$\therefore E = \frac{W \times P}{2\pi L}$$

As the work done by the two jacks is equal, and the length of their levers is equal, the effort is directly proportional to the pitch, i.e., as the pitch increases, the effort to be applied also increases. Hence, jack B needs more effort.

GEARS

Gear is a circular wheel with teeth around its rim. The teeth of one gear get successively engaged with the teeth of another gear, and as the first gear rotates in one direction, it makes the second gear rotate in the opposite direction. In this way, motion, torque and speed can be transferred from one gear to another. The gear which is made to rotate by another gear is called driven gear. The gear which rotates another gear is called driving gear. The number of teeth in the driving and the driven gears decide whether speed is transferred or torque.

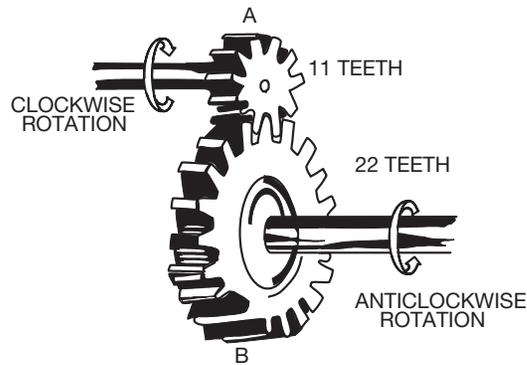


FIGURE 4.20 Two gear system in external contact

When the number of teeth in a driving gear is less than those present in a driven gear, torque is transferred. For example to drive uphill, either first or second driving gear of an automobile is engaged with the driven gear. These gears have less number of teeth than the driven gear.

$$\text{Gain in torque} = \frac{\text{No. of teeth in the driven gear } (N_2)}{\text{No. of teeth in the driving gear } (N_1)}$$

Similarly on a smooth horizontal road, top gear of automobile is engaged with the driven gear. The top gear has more number of teeth than the driven gear. So, when it completes one rotation, the driven gear completes many more rotations. Thus, speed is transferred.

A set of two or more gears is called train of gears.

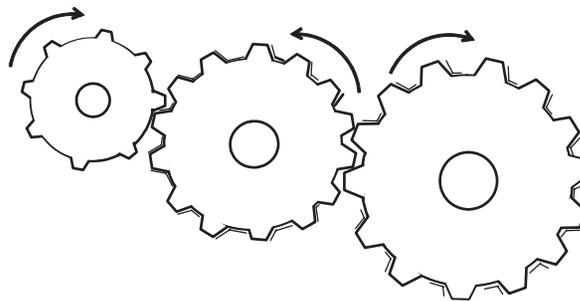


FIGURE 4.21

Functions of Gears

1. Used to increase or decrease the speed of rotation.
2. Used to transmit motion and power.
3. Used to produce a change in direction of the applied force.

Types of Gears

- 1. Chain drive:** For hoisting, conveying and transmitting power, a chain drive is used.
Example: cycle chains.
- 2. Belt drive:** For long distance power transmission, belt drives are used.
Example: Sewing machines, rice mills, flours mills, etc.
- 3. Gear box:** For linking wheels to the engine, gears can be used.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. State the principle of moments.
2. Give one example of each the three types of levers.
3. What is the reason for providing a handle to a hand flour grinder at its rim?
4. Define a lever.
5. What are the factors that help in determining the weight of an object, when measured using a Roman steelyard?
6. A nut cracker is a _____ order lever.
7. What is the M.A. of an inclined plane equal to?
8. Define a simple machine.
9. Define fulcrum, load arm and effort arm of a lever.
10. What is the principle used in wheel and axle? Mention its applications.
11. What are the types of simple machines?
12. Torque is a _____ quantity.
13. What is the principle used in a physical balance and a Roman steelyard?
14. Define parallel forces.
15. Mention the three types of levers.
16. In a screw jack, the work done by an effort is always _____ that done on its load.
17. Define like parallel forces and unlike parallel forces.
18. What is the principle used in the working of a screw jack?
19. The efficiency of a machine is 50%. If 300 J of energy is given to the machine, its output is _____.
20. What is a torque? Mention its C.G.S and S.I. unit.
21. What are the M.A. of the three types of levers?
22. How can the mechanical advantage of a screw jack be increased?
23. Explain why a door cannot be opened when force is applied at the hinges.
24. What is the need of a long handle for a spanner?
25. Define couple and mention its C.G.S and S.I. units.
26. _____ can transmit motion and power.
27. When is a body said to be in equilibrium?
28. What is an inclined plane?
29. What are gears and where are they used?
30. When can a beam balance have static equilibrium?

Short Answer Type Questions

31. What are the conditions or factors needed for producing a turning effect on a body?
32. Theoretically derive an expression for the mechanical advantage of a wheel and axle.
33. Give the properties of moment of a couple.
34. Why do we use simple machines?
35. Explain how a couple can produce only rotation.
36. For one complete rotation of a wheel, the effort is displaced by 44 cm and load by half the distance. What are the radii of the wheel and the axle?
37. In what way, can we use simple machines?
38. A sloping plank is used to push goods onto a truck. Its length is 3 m and the end which touches the truck is at a height of 1.5 m. Calculate its M.A. If the effort applied is 25 N, what load can be pushed into the truck?
39. Derive the mechanical advantage of a screw jack.
40. Compare like and unlike parallel forces.
41. Explain with the help of an example, how speed of rotation can be increased using gears.
42. Length of a crowbar is 150 cm. Its fulcrum is at a distance of 30 cm from the load. What is its mechanical advantage?
43. Explain the basis on which levers are classified.
44. Give the advantages of gears.
45. Obtain an expression for M.A. of all the three types of levers.



Essay Type Questions

46. What are like and unlike parallel forces? State their characteristics.
47. Explain the construction and working of a Roman steelyard.
48. Describe an inclined plane and obtain an expression for its mechanical advantage.
49. Explain the construction and working of a wheel and axle.
50. Explain any one method to verify the principle of moments.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- Gears are used in vehicles to transmit motion and power.
- An increase in the pitch of the screw increases the mechanical advantage of a screw jack
- A wheel and axle can be treated as a modified form of a first order lever.
- Moment of force is the product of the force applied on a body and the perpendicular distance between parallel forces, producing pure rotation.
- The pair of forces in a couple need not always be equal in magnitude.
- The mechanical advantage of an inclined plane increases with its slope.
- The length of the effort arm is greater than that of the load arm in a second-order lever.

Direction for questions 8 to 14

Fill in the blanks.

- Roman steelyard works on the principle of _____.
- A pair of scissors is an example of _____ order lever.
- _____ is the modified form of an inclined plane.
- A set of gears is called _____ of gears.
- To balance a uniform metre scale suspended at 50 cm mark, with 200 g weight suspended from it at 20 cm mark, a weight of _____ g must be suspended at 90 cm mark.
- A road on a hill is an example of _____.
- The resultant of two like parallel forces 5 N and 10 N is _____ N.

Direction for question 15:

Match the entries in Column A with appropriate ones from Column B.

15.

Column A	Column B
A. S.I. unit of a pair of equal, unlike, parallel, coplanar forces	() a. load \div effort
B. Pliers	() b. third-class lever
C. Opening screw type lid of a bottle	() c. measuring mass
D. Resultant of two like parallel forces	() d. N m
E. Mechanical advantage	() e. second-order lever
F. Wheel barrow	() f. principle of moments
G. Efficiency	() g. ratio of radii of wheel to that of axle
H. C.G.S unit of torque	() h. acts in the same direction as that of the constituent forces
I. Algebraic sum of moments is zero, in equilibrium	() i. gears
J. Fire tongs	() j. first order lever
K. Replacing type of a truck	() k. output / input
L. Power transmission in vehicles	() l. pulley
M. M.A. of a wheel and axle	() m. dyne -cm
N. $L = E$ but makes the effort convenient to apply	() n. screw jack
O. Roman steel yard	() o. couple



Direction for questions 16 to 30

For each of the questions, four choices have been provided. Select the correct alternative.

16. A gear may be used to
 (a) increase the speed of rotation.
 (b) increase the torque
 (c) Both (a) and (b)
 (d) Neither (a) nor (b)
17. If the number of teeth in the driven gear of a vehicle is less than that in its driving gear, the vehicle gains _____.
 (a) speed
 (b) momentum
 (c) Both (a) and (b)
 (d) None of the above
18. A simple machine
 (a) acts as a force multiplier
 (b) acts as a speed multiplier
 (c) helps to change the direction of application of effort
 (d) All the above
19. The efficiency of a rough inclined plane is 90%. The energy spent in raising a load of 225 N through 2 m is
 (a) 750 N (b) 500 J
 (c) 850 J (d) 900 J
20. In a Roman steel yard, the distance of the rider from its zero mark is proportional to the
 (a) weight of the load.
 (b) distance of the position of centre of gravity of the steel rod from the fulcrum.
 (c) distance of point of suspension of the load from the fulcrum.
 (d) All the above
21. The work done in sliding a wooden box of mass 5 kg along a friction less inclined plane of inclination 30° and length 10 m is _____ J. ($g = 10 \text{ m s}^{-2}$)
 (a) 500 (b) 250
 (c) 125 (d) 1500
22. A rod is free to rotate about its mid point. If the clockwise moments of 17 N m and 25 N m, respectively, are acting at the two ends of the rod, then the net moment acting on the rod is
 (a) 42 N m, anti-clockwise
 (b) 42 N m, clockwise
 (c) 8 N m, anti-clockwise
 (d) 8 N m, clockwise
23. Pulley is the most commonly used simple machine to draw water from a well since
 (A) its mechanical advantage is greater than one
 (B) it changes the direction of application of effort and makes it convenient to draw water
 (a) Only A is true
 (b) Only B is true
 (c) Both A and B are true
 (d) Both A and B are false
24. The ratio of load to displacement of the rider from its zero mark in a Roman steel yard is 20 gf:1 cm. If the rider is displaced by 20 cm from its zero mark, the load attached to the steel yard is _____.
 (a) 40 gf (b) 4 kg
 (c) 400 gf (d) 0.04 kgf
25. When the handle of a screwjack is rotated 8 times, the load is raised by 10 cm. If the length of the handle is 0.5 m, the M.A is
 (a) 40π (b) 20π
 (c) 120π (d) 80π
26. M.A. is always greater than 1 in
 (a) I class levers
 (b) II class levers
 (c) III class levers
 (d) All the above
27. The length of an inclined plane is halved and the angle of inclination is changed from 30° to 60° . If the work done in pulling a load up the first inclined plane is 'w', then the work done in pulling the same load up the second inclined plane is
 (a) $2w$ (b) $\frac{\sqrt{3}w}{2}$
 (c) $\frac{w}{2}$ (d) $\frac{2w}{\sqrt{3}}$
28. The radii of the axle and the wheel are increased by 3 times and 5 times, respectively. The new M.A. advantage of the wheel and axle is
 (a) $\frac{5}{3}$ times the initial M.A.
 (b) $\frac{3}{2}$ times the initial M.A.



(c) $\frac{25}{9}$ times the initial MA

(d) $\frac{9}{4}$ times the initial M.A.

29. Two unlike parallel forces 2 N and 16 N act at the ends of a uniform rod of 21 cm length. The point where the resultant of these two act is at a distance of _____ cm from the greater force.

(a) 1 (b) 2

(c) 3 (d) 4

30. A wheel and axle with radii 20 cm and 5 cm, respectively, can be considered as

(a) a second-order lever with its M.A. > 1

(b) a third-order lever with its M.A. < 1

(c) a first-order lever with its M.A. > 1

(d) a first-order lever with its M.A. < 1

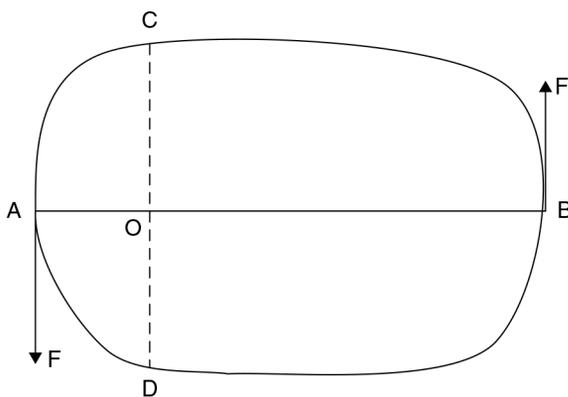
Directions for questions 31 to 33

These questions are based on the diagram shown below.

Two equal forces, $F = 30$ N act opposite to each other, at points A and B . The distances between various points is as follows.

$AO = 20$ cm, $OB = 50$ cm and $OC = OD = 25$ cm

The body is free to rotate about 'O', in the plane of the paper.



31. The moment of couple and the moment of the force about 'O' in N m are

(a) 21 and 21 (b) 21 and 9

(c) 31 and 4 (d) None of these

32. If the direction of the force at A is reversed, keeping the direction of the force at B unchanged, the moment of the force about 'O' in N m is

(a) 15 (b) 6

(c) 21 (d) 9

33. If the two forces instead of acting at A and B , act at 'C' and 'D' along OC and OD in the opposite directions, then the moment of the force about 'O' in N m is

(a) 21 (b) 0

(c) 9 (d) 6

Directions for questions 34 to 46:

Select the correct alternative from the given choices.

34. Which of the following physical quantities would complete the analogy given below. linear motion: force: rotational motion: _____

(a) work

(b) momentum

(c) torque

(d) angular acceleration

35. An effort of 35 N is applied on a machine having mechanical advantage 6. The load that is lifted using the effort is _____ N.

(a) 210 (b) 41

(c) 6 (d) 29

36. In a simple machine, the load is displaced by 3 cm corresponding to a displacement of the effort by 300 mm. The velocity ratio of the machine is _____.

(a) 10 (b) 270

(c) 330 (d) 900

37. The efficiency of a machine is 50%. If 300 J of energy is given to the machine, its output is _____.

(a) 150 erg (b) 350 J

(c) 250 J (d) 150 J

38. Which of the following is not true about simple machines? They

(a) save energy.

(b) can change the direction of the effort.

(c) can be used to overcome large force.

(d) gain velocity.

39. The resultant of two like parallel forces 5 N and 10 N is _____ N.

(a) 10 (b) 5

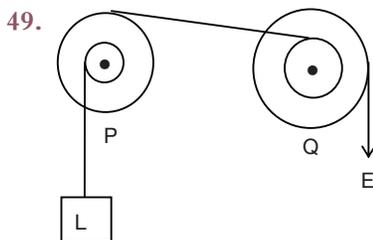
(c) 15 (d) 50



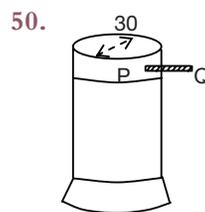
40. In a second-order lever, if the length of the load arm is 5 cm, the length of its effort arm cannot be _____.
- (a) 4 cm (b) 6 cm
(c) 10 cm (d) 20 cm
41. The beam of a Roman steelyard remains horizontal when
- (a) no load is placed on the hook.
(b) the rider is at the zero of the scale.
(c) Both (a) and (b)
(d) The beam of a Roman steelyard can never be horizontal.
42. If the radius of a steering wheel is increased to four times its original value, then the moment of couple acting on the steering wheel for the given forces
- (a) increases four times.
(b) decreases two times.
(c) increases eight times.
(d) increases sixteen times.
43. By increasing the angle of inclination, the M.A. of an inclined plane
- (a) decreases.
(b) increases.
(c) remains the same.
(d) depends on the load to be raised.
44. The ratio of load to displacement of the rider from its zero mark in a Roman steel yard is $20 \text{ g}_f : 1 \text{ cm}$. If the rider is displaced by 20 cm from its zero mark, the load attached to the steel yard is _____.
- (a) 40 g_f (b) 4 kg_f
(c) 400 g_f (d) 0.04 kg_f
45. If the angle of inclination of an inclined plane is 30° , its mechanical advantage is _____
- (a) 30 (b) $1/2$
(c) 2 (d) None of the three
46. An effort of 350 N is applied on an inclined plane having mechanical advantage 6. The load that is lifted using the effort is _____ N.
- (a) 2100 (b) 410
(c) 600 (d) 329

Level 2

47. A uniform metre scale of weight 20 g_f is supported on a wedge placed at 60 cm mark. If a weight of 30 g_f is suspended at 15 cm mark, where should a weight 200 g_f be suspended in order to balance the metre scale?
48. The efficiency of a simple machine having mechanical advantage 5 is 80%. If the displacement of the effort in lifting a load by using the machine is 20 cm, find the displacement of the load.

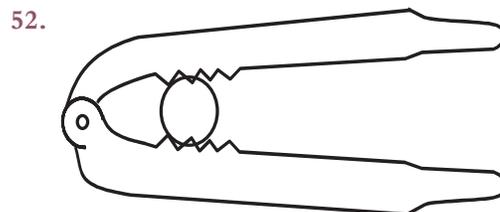


Two wheel and axle systems P and Q are connected as shown in the figure. The radii of wheels and axles of P and Q are 20 cm, 27 cm, 3 cm and 5 cm, respectively. If $L = 540 \text{ kg}_{wt}$, find E .



The pitch of the screw in a screw jack shown in the figure is 5 cm and the diameter of the head of its vertical shaft is 30 cm. If the length of the rod PQ fixed to the shaft is 55 cm, find the effort required to raise a load of 10.56 quintal using the jack. (Take $1 \text{ quintal} = 100 \text{ kg}_{wt}$)

51. On what principle does a bicycle work? What is the mechanical advantage of a bicycle? Determine the velocity ratio of a bicycle in which the ratio of teeth on the rear sprocket wheel to that on the front wheel is $1 : 3$.



The maximum force than can be borne by the nut placed in a cracker (shown in the figure) is 200 N. The length of the cracker is 20 cm and the nut is placed at a distance of 15 cm from the free end of the cracker. If a boy can apply a maximum force of 25 N, find whether he can crack the nut. If not, find the length of the extension rod that should be attached to the cracker handle so that the boy can crack the nut.

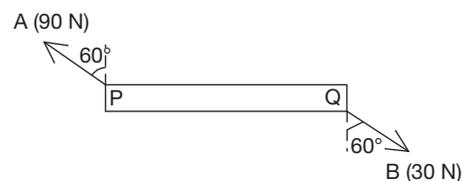
53. An inclined plane of length 2 m is used to load Maruti cars into a carrier truck. If the body of the truck is at a height of 1 m from the ground, find the effort required to load a car using the inclined plane. The unladen weight of a Maruti car is 600 kg_{w.t.} (Take $g = 10 \text{ m s}^{-2}$)
54. Why do we use the first gear to start a car or scooter at rest? What would happen if we started a car/scooter in a higher gear?
55. To push open a door, a person applies a force of 75 N on the handle of the door, at an angle of 60° from the normal to its plane. If the handle is located at a distance of 80 cm from its hinge, find the torque applied by him.
56. The number of teeth in the crank wheel and free wheel of a bicycle, connected by a chain are 48 and 24, respectively. Their diameters are 20 cm and 10 cm, respectively. The radius of the rear wheel to which the free wheel is fixed coaxially is 10 times that of the free wheel. If a cyclist pedals the bicycle at two rotations per second, find the speed of the cyclist.
57. Can a body rotate even if net force acting on it is zero? Can a single force stop a body from rotation, if the body is rotating under the action of a 'couple'? Explain.
58. Find the ratio of the effort required to raise a given load to a certain height, when the angle of inclination of a plank is changed from 60° to 45° . Also find the lengths of the plank in the two cases given the load has to be raised to a height of 5 m.
59. How can we obtain the resting point—indicating equilibrium, even with unequal masses in the two pans of a physical balance?
60. Each of the two guns, mounted on a rotating platform with their lengths parallel to each other, fires

20 bullets per second at a speed of 50 m s^{-1} . If the perpendicular distance between the two guns is 1.2 m and the mass of each bullet is 25 g, find the couple acting on the platform.

61. The effort measured in S.I. system in lifting a load through a simple machine is numerically equal to its mechanical advantage. If the mechanical advantage of the machine is increased by 20%, the same effort can lift a load of 12 kg_{w.t.}. Find the magnitudes of the effort and the original load. (Take $g = 10 \text{ m s}^{-2}$)
62. What is the reason for providing a handle to a hand flour grinder at its rim?
63. To produce a couple of 20 N m on a disc of radius 10 cm, what is the force to be applied.
64. A ladder is at rest with its upper end against a wall and the lower end on a floor. Is it more likely to slip when a man stands on its lower rungs or its upper rungs. Explain?
65. A uniform metallic rod PQ of length 2 m is acted upon by two forces A and B along the directions as shown in the figure. Find the magnitude and position of the resultant normal force that acts on the rod.



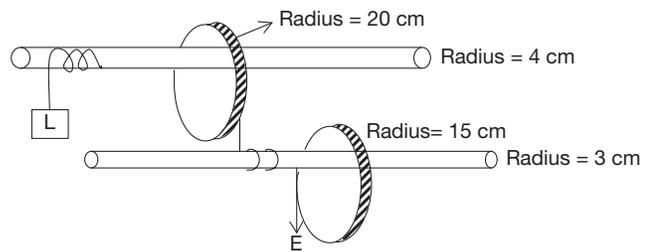
66. A uniform metallic rod AB of length 1.4 m is lifted by two forces P and Q acting along the directions as shown in the figure. If the magnitudes of P and Q are 20 N and 50 N, respectively, find the magnitude and the position of the resultant normal force that acts on the rod.



67. The effort measured in S.I. system in lifting a load through a simple machine is numerically equal to its mechanical advantage. If the mechanical advantage of the machine is increased by 20%, the same effort can lift a load of 12 kg_{w.t.}. Find the magnitudes of the effort and the original load. (Take $g = 10 \text{ m s}^{-2}$)



68. Find the ratio of efforts required to raise a given load, when the angle of inclination of a given plank is changed from 60° to 30° . Also find the percentage change in the mechanical advantage.
69. A man uses a rough inclined plane of length 3 m to raise a load of $100 \text{ kg}_{\text{wt}}$. If he does 2400 J of work and the inclined plane offers 300 N resistance, find the mechanical advantage (Take $g = 10 \text{ m s}^{-2}$).
70. In an arrangement of two wheel and axle systems, the radii of wheels are 20 cm and 15 cm and the radii of axle are 4 cm and 3 cm. Calculate E if $L = 540 \text{ kg}$.



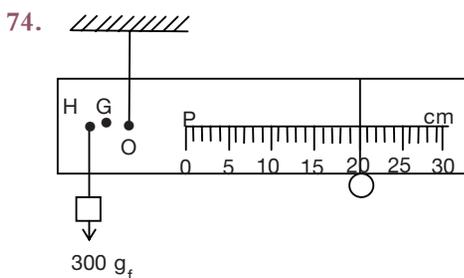
71. The pitch of a screw in a screw jack A is half that of another screw jack B. for 5 complete rotations of the lever, which one of the jack will lift a car more higher? which one need more effort to do an equal work if both the jacks have levers of equal length.

Level 3

72. A scooter or a motor-cycle is a compound machine made up of several simple machines. Study the following parts of a scooter/motor cycle and identify the simple machines involved in them.
- (i) Clutch levers
 - (ii) Throttle
 - (iii) Front brake lever
 - (iv) Rear brake pedal
 - (v) Stand
 - (vi) Rear view mirror
 - (vii) Wheels
 - (viii) Chain drive

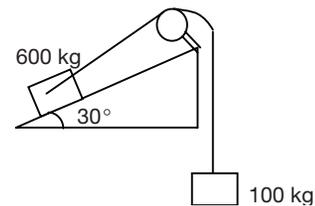
A person weighing 50 kg, moves on a scooter of 100 kg at a speed of 36 km h^{-1} and applies brakes to stop within a distance of 10 m. If the mechanical advantage of the brake system (comprising brake drum, lever, etc.) is 10^3 , find the force with which the person should press the foot pedal to stop the vehicle.

73. How can a spring balance and a rigid rod be used to weigh objects beyond the maximum reading of the balance? Explain



A balance similar to Roman steelyard is shown in the figure. G is the position of centre of gravity of the beam. Given $OG = 3 \text{ cm}$, $OH = 4 \text{ cm}$ and $OP = 5 \text{ cm}$. If the weight of the rider is 60 g_f find the weight of the beam, least count of the balance and the maximum load that can be measured using the balance.

75. A load of $600 \text{ kg}_{\text{wt}}$ is raised over an inclined plane as shown in the following figure.

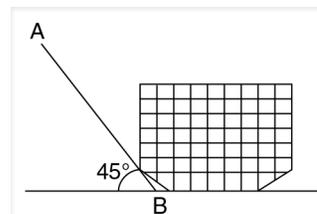


How much force forming a couple should act on the pulley so that the load is just raised?

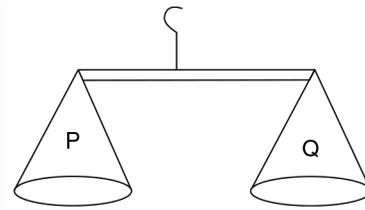


A solid roller having a diameter of 0.82 m is to be raised on to a step of height 32 cm (shown in the figure). If the roller weighs $50 \text{ kg}_{\text{wt}}$, find the minimum force that can be applied on the roller for the purpose. (Take $g = 10 \text{ m s}^{-2}$)

77. A wooden crate with a heavy machine weighing 3000 N slides on the ground when pushed by a lever AB of length 100 cm as shown in the figure. The force required to slide the crate acts at a distance of 10 cm from the fulcrum. If the coefficient of friction between the crate and the ground is $\sqrt{2}$, find the effort required to move the crate. (Take the value of $\sqrt{2} = 1.4$)

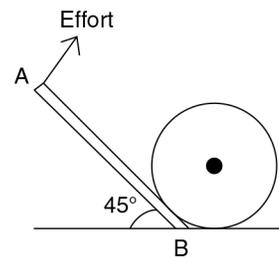


78. A balance similar to a Roman steel yard is constructed such that the length of the scale on the beam of the balance is 50 cm and the least count on the scale is 1 mm. The zero mark of the scale is at a distance of 15 cm from the point of suspension of the balance. The hook that is used to attach the loads and the centre of gravity of the beam are at distances 8 cm and 5 cm, respectively, from its fulcrum. If the weight of the rider of the balance is 50_{gf} , find the weight of the beam, the maximum load that can be measured using the balance and its least count.
79. Can a body rotate even if the net force acting on it is zero? Can a single force stop a body from rotation if the body is rotating under the action of a 'couple'? Explain.
80. The length of the beam of a common balance shown in the figure is 100 cm. The pans (P and Q) and the strings used to suspend them to the beam in its edges are identical. The hook (H) that is used to lift the balance is arranged at 50.5 cm from the end of the beam where the pan Q is suspended.



The pan P is used for placing the standard weights. If a customer buys 9 kg of a material using the pan, find the percentage loss in the mass.

81. A road roller of 200 kg wt slides on ground when pushed by a lever AB of length 1 m, as shown in the figure. The force required to slide the roller acts at a distance of 5 cm from the fulcrum. If the coefficient of friction between the roller and the ground is $\sqrt{2}$, find the effort required to move the roller. (Take $g = 10 \text{ m s}^{-2}$)



CONCEPT APPLICATION

Level-1

True and false

1. True 2. False 3. True 4. False 5. False 6. False 7. True

Fill in the blanks

8. Principle of moments 9. first class/first order 10. Screw 11. train
12. 150 13. inclined plane 14. 15

Match the following

- 15 A : d B : j C : o D : h E : a F : e G : k H : m
 I : f J : b K : n L : i M : g N : l O : c

Multiple choice questions

16. (c) 17. (c) 18. (d) 19. (b) 20. (a) 21. (b) 22. (b)
23. (b) 24. (c) 25. (d) 26. (b) 27. (b) 28. (b) 29. (c)
30. (c) 31. (a) 32. (d) 33. (b) 34. (c) 35. (a) 36. (a)
37. (d) 38. (a) 39. (c) 40. (a) 41. (c) 42. (c) 43. (a)
44. (c) 45. (c) 46. (a)

Explanations for questions 30 to 33:

31. The moment of couple is $F \times AB$

$$= 30 \times \frac{70}{100} = 21 \text{ Nm}$$

The moment of the force, at point B = $F \times OB$

$$= 30 \times \frac{50}{100} = 15 \text{ Nm}$$

The moment of the force, at point A = $F \times AO$

$$= 30 \times \frac{20}{100} = 6 \text{ Nm}$$

The total moment of the force, about 'O' is

$$= F \times OB - F \times OA \\ = 15 + 6 = 21 \text{ N m}$$

The body will rotate in an anti-clockwise direction.

32. The moment of the force about B

$$= F \times OB = 30 \times \frac{50}{100} = 15 \text{ Nm} \quad (1)$$

The moment of the force about A = OA

$$= 30 \times \frac{20}{100} = 6 \text{ Nm} \quad (2)$$

The total or resultant moment of the force about 'O'.

$$= F \times OB - F \times OA$$

From (1) and (2)

$$= 15 - 6 = 9 \text{ N m}$$

The body will continue to rotate in the direction of greater moment of force, i.e., anti-clockwise direction.

33. The moment of the force at C about O is zero because the perpendicular distance of the force from the fulcrum is zero.

For similar reasons, the moment of the force at D about O is zero.

Explanations for questions 34 to 46:

34. Force causes linear motion and linear acceleration and a torque causes rotational motion and angular acceleration.

35. Load = (effort) \times (mechanical advantage)
= (35 N) \times (6) = 210 N

36. Velocity ratio $\frac{\text{displacement of effort}}{\text{displacement of load}}$
= $\frac{300 \text{ m}}{3 \text{ cm}} = \frac{30 \text{ cm}}{3 \text{ cm}} = 10$



$$37. \eta = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\eta \times \text{input}}$$

$$= \frac{50}{100} \times 300\text{J} = 150\text{J}$$

38. Energy is conserved.

39. The magnitude of the resultant of two like parallel forces is given by the sum of their magnitudes. Thus, the answer is 15 N.

40. The mechanical advantage of a second-order lever is always greater than one. The length of its effort arm should be greater than the length of its load arm. Given the length of the load arm = 5 cm. Thus, the length of the effort arm cannot be 4 cm.

41. When no load is placed on the hook, the Roman steel yard can be made horizontal only by placing rider at the zero of the scale.

$$42. C = F \times d$$

$$C_1 = F \times (2r_1)$$

$$C_2 = F \times (2r_2)$$

$$= F \times 2(4r_1) = 4C_1$$

43. $MA = \frac{1}{\sin \theta}$. Therefore, MA decreases when angle of inclination is increased.

44. For a load of 20 g, the rider is moved by 1 cm. Thus, for a distance of 20 cm, the load = (20) (20) = 400_{gf}

45. Mechanical advantage of an inclined plane is $\frac{1}{\sin \theta}$

$$46. \text{Load} = (\text{effort}) \times (\text{mechanical advantage})$$

$$= (350 \text{ N}) \times (6) = 2100 \text{ N}$$

Level 2

47. (i) Apply the law of moments.

(ii) Let the weight of 200 g_f be suspended at distance 'x'.

(iii) moment of force = force \times perpendicular distance of force from the wedge.

(iv) Find anti-clockwise and clockwise moments.

(v) Principle of moments : sum of anti-clockwise moments = sum of clockwise moments.

(vi) 67.75 cm mark on scale.

48. (i) Relation between mechanical advantage, velocity ratio and efficiency

(ii) Relation between mechanical, advantage, velocity ratio and efficiency.

(iii) Definition of velocity ratio.

(iv) Displacement of the load = 3.2 cm

49. (i) Mechanical advantage of a wheel and axle

(ii) Relate the load of Q to the effort of P.

(iii) Mechanical advantage of a wheel and axle is equal to the ratio of the radius of the wheel to that of its axle.

(vi) $E = 15 \text{ kg}_f$

50. (i) Expression for M.A. of a screw jack

(ii) Find the effective length of the rod (lever) using the information.

(iii) Find the distance covered by the effort for one complete rotation of the shaft.

(iv) Find the mechanical advantage of the screw jack.

(v) Relate M.A. with L and E.

(vi) $E = 120 \text{ kg}_f$

51. (i) Consider how the effort applied is transmitted.

(ii) Bicycle uses more than one simple machine.

(iii) Let L = length of pedal

E = effort applied on pedal

W = load to be overcome

R = radius of rear wheel

(iii) Find the M.A. of cycle using principle of lever: effort \times displacement of effort = load \times displacement of load

$$\text{M.A.} = \frac{W}{E}$$

(iv) Velocity ratio = ratio of number of teeth on front wheel to that on rear sprocket wheel

52. (i) Nut cracker is a second-order lever.

(ii) Find the load from the given information.

(iii) Find the lengths of the effort arm and the load arm from the given information.

(iv) Relate mechanical advantage, load and effort.

(v) Find the required effort and compare it with the force that can be exerted by the boy.

(vi) Consider the force that can be exerted by the



boy as effort and find the length of the effort arm.

- (vii) Compare the length of the effort arm obtained and its given length.
- (viii) Boy cannot crack the nut Extension = 20 cm

53. (i) Relation between length, height of the inclined plane and load, effort

(ii) Effort = 3000 N

54. (i) Consider the forces required to move a vehicle (i) at rest (ii) moving at uniform velocity.

(ii) In the 1st gear of the vehicle, the driven gear has more number of turns than the driving gear.

(iii) Gain in torque

$$= \frac{\text{number of turns in driven gear}}{\text{number of turns in driving gear}}$$

(iv) The car at rest has to overcome inertia and static friction which requires a large torque.

55. (i) $\tau = r F \sin\theta$

(ii) Torque = 30 N m

56. (i) Relation between length, height of the inclined plane and load, effort

(ii) Velocity of the cyclist = 12.56 m s⁻¹ or 45 m h⁻¹

57. (i) Consider the various types of forces acting on a body which cause rotation.

(ii) A body rotates when couple acts on it.

(iii) Couple consists of equal and opposite forces acting at two different points.

(iv) Couple can be balanced only with equal and opposite couple.

58. (i) Relation between mechanical advantage (M.A.) and angle of inclination (θ)

(ii) Load is constant and also height is constant

(iii) Relate mechanical advantage to the corresponding trigonometric ratio of the angle of inclination.

(vi) Also relate mechanical advantage to load and effort.

(v) From the above two find a relation between load, effort and trigonometric ratio of the angle of inclination.

(vi) Observe that the load is constant, and find the effort in the two cases.

(vii) Relate mechanical advantage to the length of the plane and the height of the plane.

(viii) Ratio of the efforts = $\sqrt{6} : 2$

Length of the plank in the first case = 5.773 m

Length of the plank in the second case = 7.07 m

59. (i) Consider the adjustments made to a physical balance while determining the zero resting point.

(ii) By adjusting screws.

60. (i) Force = Impulse \div Time

(ii) Force on the gun = force on the bullets = $m \left(\frac{v-u}{t} \right)$, where v and u are final and initial velocities of bullets, respectively, and m = mass of each bullet.

(iii) Couple = force \times perpendicular distance between the forces.

(iv) 30 N m

61. (i) Definition of mechanical advantage.

(ii) Relate mechanical advantage and effort in the two cases.

(iii) Convert the load given into S.I. units and use the definition of mechanical advantage.

(iv) Effort = 10 N ; Load = 100 N

62. The handle provided to apply the effort and to increase mechanical advantage.

63. Radius = 10 cm \Rightarrow diameter = 20 cm = 0.2 m

Given $\tau = 20 \text{ N m} \Rightarrow \tau = F \times r$

$F = \tau \div r \Rightarrow F = 20 \div 0.2 = 100 \text{ N}$

64. When a man stands at the upper end, the moment of his weight about the lower end of the ladder is greater compared to that when he is at the bottom of the ladder. Therefore, the ladder is more likely to slip when he stands at the top.

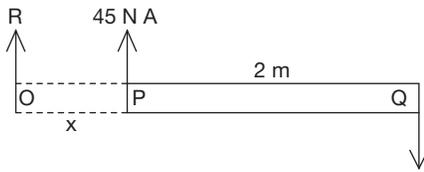
65. The forces that act normally to the rod are

$$A \cos 60^\circ = 90 \times \frac{1}{2} = 45 \text{ N}$$

$$B \cos 60^\circ = 30 \times \frac{1}{2} = 15 \text{ N.}$$

As the two forces are unlike parallel forces, the resultant of these two forces is outside the rod at a point 'O' and in the direction of greater force, i.e., A.





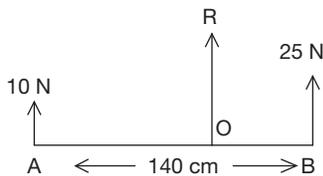
Magnitude of $R = 45 - 15 = 30 \text{ N}$

Position of R : Let ' R ' is at ' O ' and at a distance of x m from ' P '. Then

$$\begin{aligned} 45 \times x &= 15 \times (2 + x) \\ 3x &= 2 + x \\ 2x &= 2 \\ x &= 1 \text{ m} \end{aligned}$$

66. The component of P along normal to AB at $A = 20 \cos 60^\circ = 10 \text{ N}$

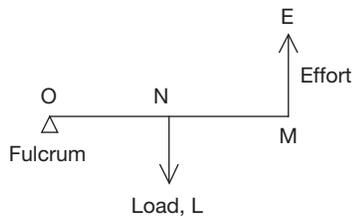
The component of Q normal to AB at $B = 50 \cos 60^\circ = 25 \text{ N}$. Thus, the given situation is similar to that shown in the figure.



Now applying the principle of moments, we get $10 (AO) = 25 (BO)$

$$10 (AO) = 25 (140 - AO)$$

$$\Rightarrow AO = 100 \text{ cm and magnitude of } R = 10 \text{ N} + 25 \text{ N} = 35 \text{ N}$$



67. I case: $MA_1 = E = \frac{L}{E} \Rightarrow L = E^2$

$$\begin{aligned} \text{II case} &= MA_2 \\ &= MA_1 + 20\% \text{ of } MA_1 \\ &= 1.2 MA_1 \\ &= 1.2 E \end{aligned}$$

$$\text{But } MA_2 = \frac{L^1}{E}$$

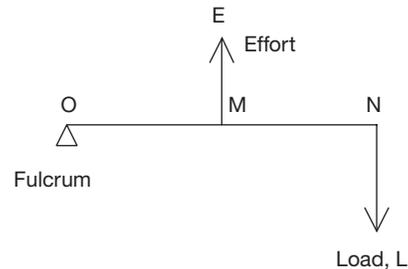
$$\begin{aligned} \text{Given } L^1 &= 12 \text{ kg}_{wt} \\ &= 120 \text{ N} \end{aligned}$$

$$\text{Hence, } MA_2 = \frac{120}{E} = 1.2E.$$

Or

$$E^2 = 100 \Rightarrow E = 10 \text{ N}$$

Hence, the original load $= E^2 = 100 \text{ N}$



68. The ratio of efforts $\left(\frac{E_1}{E_2}\right)$ is

$$\frac{E_1}{E_2} = \frac{mg \sin \theta_1}{mg \sin \theta_2} \Rightarrow \frac{E_1}{E_2} = \frac{\sin \theta_1}{\sin \theta_2}$$

Substituting $\sin 60^\circ = \frac{\sqrt{3}}{2}$ and $\sin 30^\circ = 1/2$,

we get

$$\frac{E_1}{E_2} = \frac{\sqrt{3}}{2} \times 2 = \sqrt{3}$$

$$\therefore E_1 : E_2 = \sqrt{3} : 1$$

$$\text{Change in M.A.} = \frac{1}{\sin 30^\circ} - \frac{1}{\sin 60^\circ} = 2 - \frac{2}{\sqrt{3}}$$

$$= 2 \left(1 - \frac{1}{\sqrt{3}}\right) = 2 \left(\frac{\sqrt{3}-1}{\sqrt{3}}\right)$$

$$\% \text{ Change in MA} = \frac{\text{Change in MA}}{\text{initial MA}} \times 100$$

$$= \frac{2(\sqrt{3}-1)}{\sqrt{3} \times \frac{2}{3}} \times 100 = (\sqrt{3}-1) \times 100$$

$$= 0.732 \times 100 = 73.2\%$$

69. Work done to raise the load
 = Work done against gravity + work done against friction,

$$w = mg \sin \theta \times l + f \times l$$

$$\text{Substituting } W = 2400 \text{ J, } mg = 1000 \text{ N,}$$

$$l = 3 \text{ m, } f = 300 \text{ N, we get}$$

$$2400 \text{ J} = (1000 \times \sin \theta + 300) \times 3$$



$$1000 \sin\theta + 300 = 800$$

$$1000 \sin\theta = 500$$

$$\sin\theta = \frac{500}{1000}$$

$$\sin\theta = \frac{1}{2}$$

$$M.A. = \frac{\text{load}}{\text{effort}} = \frac{mg}{mg \sin\theta + f_s}$$

$$\text{substitute } mg = 1000 \text{ N } \sin\theta = \frac{1}{2}$$

$$f_s = 300 \text{ N}$$

$$MA = \frac{1000}{1000 \times \frac{1}{2} + 300} = \frac{1000}{800} = \frac{5}{4} = 1.25$$

Alternative method:

Length of the given inclined plane $l = 3 \text{ m}$ (given).

Work done by the effort, $W_e = 2400 \text{ J}$ (given)

Let 'E' be the effort.

$$\therefore W_e = El \Rightarrow 2400 = E(3) \Rightarrow E = 800 \text{ N}$$

Mass of the load = 100 kgwt

$$\therefore \text{Load } L = (100)(10)$$

$$[\because g = 10 \text{ m s}^{-2}]$$

$$= 1000 \text{ N}$$

\therefore Mechanical advantage (M.A.)

$$= \frac{L}{E} = \frac{1000}{800} = 1.25$$

70. Let MA_1 and MA_2 be the mechanical advantages of the upper and lower wheel and axles, respectively

$$MA_1 = \frac{L_1}{E_1} = \frac{R_1}{r_1} \quad (1)$$

Where $L_1 = 540 \text{ kg wt}$, $R_1 = 20 \text{ cm}$, $r_1 = 4 \text{ cm}$

$$MA_2 = \frac{C_2}{E_2} = \frac{R_2}{r_2}$$

$$= \frac{E_1}{E_2} = \frac{R_2}{r_2} \quad (2)$$

From (1) $\frac{540}{E_1} = \frac{20}{4}$

$$E_1 = \frac{540}{5} = 108 \text{ kg wt}$$

\therefore From (2) $\frac{108}{E_2} = \frac{15}{3} \Rightarrow \frac{108}{E_2} = 5$

$$E_2 = \frac{108}{5} = 21.6 \text{ kg}$$

$$\text{wt} = 21.6 \times 9.8 = 211.68 \text{ N}$$

71. Since the height of lifting the car by a Jack depends on the pitch of the screw, and for one rotation of the lever, the screw moves up by a distance equal to its pitch.

Therefore, greater the pitch, higher the car gets lifted, same is the Jack's that it will raise the car high, and same is case of screw jack.

$$\frac{w}{E} = \frac{2\pi L}{P}$$

$$\therefore E = \frac{W \times P}{2\pi L}$$

The work done by The two jacks is equal and the length of their levers is equal, $E \propto$ pitch. If pitch increases, effort increases.

Level 3

72. (i) Equations of motion, Newton's second law of motion and principle of moments.

(ii) Calculate retardation using $a = \frac{V^2 - u^2}{2S}$.

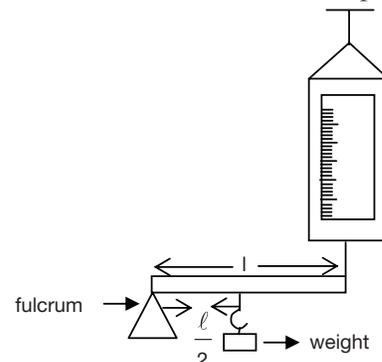
(iii) Calculate the braking (retarding) force using $F = M.A.$, where 'm' is the combined mass of the scooter and the person.

(iv) Calculate effort using:

$$\text{effort} = \text{load}/M.A. = F/M.A.$$

(v) 1.5 N

73. (i) Consider the lever as a force multiplier.



- (ii) The spring balance and the rigid rod are arranged as shown in the figure.
- (iii) The weight (W) is suspended from the rod and reading of the spring balance (R) is noted.
- (iv) Applying principle of moments, we get
weight \times distance of weight from the fulcrum
 $=$ reading \times distance of spring balance from the fulcrum.

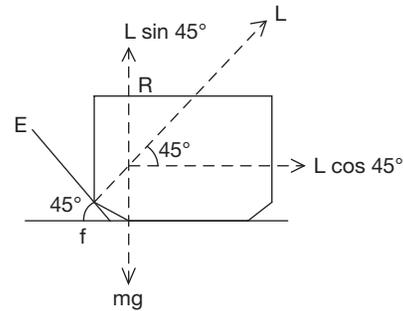
74. (i) Principle of moments
(ii) Working of Roman steel yard
(iii) Weight of the beam acts at its position of centre of gravity.
(iv) Rider at zero mark on the scale balances the weight of the beam.
(v) Distance of the rider from its zero mark on the scale is directly proportional to the load attached.
(vi) Weight of the beam = 100 g_f
Least count of the balance = 15 g_f
Maximum load that can be attached = 450 g_f

75. (i) Use the definition of mechanical advantage and principle of moments.
(ii) Calculate the effort (E) required to pull the load, using $E = mg \sin \theta$.
(iii) Part of the total force required to pull the load is provided by 100 kg_{wt}.
(iv) Calculate the remaining force by $E - (100 \times 10)$ N = F_1 .
(v) $F_1 \times R$ forms anti-clockwise moment on the pulley, where $R =$ radius of the pulley.
(vi) Let F_2 be the force forming a couple so that the load is just raised.
(vii) Calculate F_2 using: $F_1 \times R = F_2 \times 2R$.
(viii) 1000 N.

76. (i) Analyse the forces that act on the roller and the point of application of force for the torque.
(ii) $\tau = rF$ and τ is constant
(iii) Weight of the roller acts at its geometric centre (downwards).
(iv) Find the effective ' r ' to calculate the torque using the Pythagoras theorem and then find the torque.
(v) For a given torque, ' F ' is minimum where ' r ' is maximum.

- (vi) Maximum ' r ' is the diameter of the roller.
- (vii) $E = 110$ N

77. Different forces that act on the crate are shown in the figure



From the figure it is clear that

$$R + L \sin 45 = mg$$

$R = \left[mg - \frac{L}{\sqrt{2}} \right]$ and the force that is responsible for the motion of the roller is $L \cos 45^\circ$.

$$\text{Thus, } L \cos 45^\circ = f = \mu R \Rightarrow \frac{L}{\sqrt{2}} = \mu \left(mg - \frac{L}{\sqrt{2}} \right)$$

$$\frac{L}{\sqrt{2}} = \mu mg - \frac{\mu L}{\sqrt{2}} \Rightarrow \frac{L}{\sqrt{2}} (\mu + 1) = \mu mg$$

Or
$$L = \frac{\sqrt{2} \mu mg}{\mu + 1}$$

Now, (effort) (effort arm) = (load)(load arm)

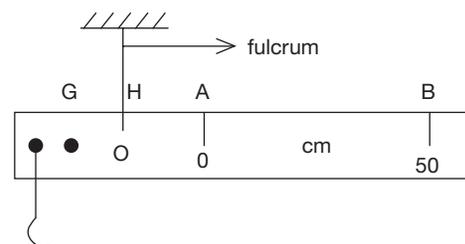
$$\text{Effort} = \frac{L \times \ell}{e} = \frac{\ell \left(\frac{\sqrt{2} \mu mg}{\mu + 1} \right)}{e}$$

Given $\ell = 10$ cm, $e = 100$ cm,

$$mg = 3000\text{N and } \mu = \sqrt{2}$$

$$= \left(\frac{10}{100} \right) \left(\frac{\sqrt{2} \times \sqrt{2} \times 3000}{\sqrt{2} + 1} \right) = 250 \text{ N}$$

78. The information given in the question can be depicted as shown in the figure.



G is the position of centre of gravity. H is the position of the hook, O is the fulcrum, A and B are zero cm mark and 50 cm mark of the scale on the beam



Given $OG = 5$ cm, $OH = 8$ cm and

$$OA = 15$$
 cm

Mass of the rider $R = 50$ gf.

Let x g be the mass of the beam

Then $x(OG) = R(OA)$

$$X = \frac{R(OA)}{OG} = \frac{50 \times 15}{5} = 150 \text{ g}$$

Thus, the weight of the beam is 150 gf

Let L be the maximum load that is attached to the balance. Then

$$L(OH) + x(OG) = R(OB)$$

$$L = \frac{R(OB) - x(OG)}{OH} = \frac{50(65) - 150(5)}{8} = 312.5 \text{ g}$$

The distance moved by the rider on the scale from its zero mark is directly proportional to the load attached. Thus, 50 cm (=500 mm) corresponds to 312.5 g. Thus, the least count of the balance = 0.625 g

79. A couple acting on a body rotates it, if the body is free to rotate. A couple is formed by two equal forces acting in opposite directions, though their lines of action are not same. The net force acting on a body under the action of a couple is zero, though the body rotates. When a body rotates under the action of a couple, it cannot be stopped from rotating by applying a single force. To stop it from rotating, a couple of equal magnitude but in opposite sense of applied couple is required.

80. The information given in the question is shown in the diagram

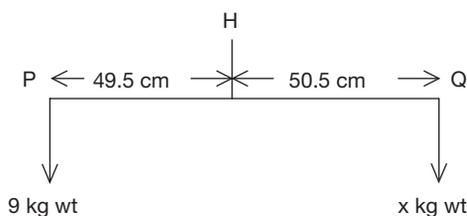
Applying the principle of moments,

$$\text{we get } (9 \text{ kg}_{\text{wt}} \times 49.5 \text{ cm}) = (x \text{ kg}_{\text{wt}} \times 50.5 \text{ cm})$$

$$X = 8.8 \text{ kg}_{\text{wt}}$$

Hence, the loss = $9 \text{ kg}_{\text{wt}} - 8.8 \text{ kg}_{\text{wt}} = 0.2 \text{ kg}_{\text{wt}}$

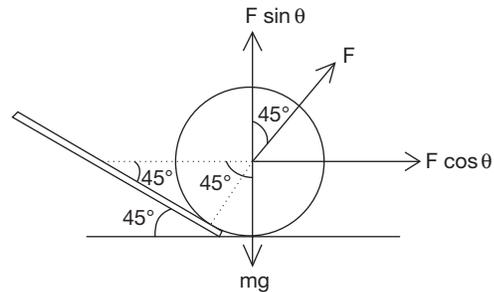
$$\Rightarrow \text{percentage loss} = \frac{0.2 \text{ kg}_{\text{wt}}}{9 \text{ kg}_{\text{wt}}} \times 100 = 2.2\%$$



81. The various forces acting on the road roller are shown below in figure.

Let the force required to slide the roller be F . The component of the force F , to overcome the force of friction f_s is

$$F \cos \theta = F \cos 45^\circ = \frac{F}{\sqrt{2}} \quad (1)$$



The force of friction $f_s = \mu N$ where $N = mg - F \sin \theta$ substituting $mg = 200 \times 10 = 2000$ N

$$\sin \theta = \sin 45^\circ$$

$$N = 2000 - \frac{F}{\sqrt{2}}$$

The frictional force f_s

$$f_s = \mu N = \sqrt{2} \times \left(2000 - \frac{F}{\sqrt{2}} \right)$$

$$f_s = 2000\sqrt{2} - F \quad (2)$$

Equationg (1) and (2)

$$\frac{F}{\sqrt{2}} = 2000\sqrt{2} - F$$

$$F = 4000 - \sqrt{2}F$$

$$F = \frac{4000}{\sqrt{2} + 1} = \frac{4000}{\sqrt{2} + 1} \times \frac{\sqrt{2} - 1}{\sqrt{2} - 1} = 4 \times 414 = 1656 \text{ N}$$

Applying the law of moments to the lever,

$$E \times \text{effort arm} = \text{load} \times \text{load arm}$$

$$E \times 1 = 1656 \times 0.05$$

$$E = 82.8 \text{ N} \approx 83 \text{ N (approximately)}$$



Chapter 5

Gravitation

REMEMBER

Before beginning this chapter you should be able to:

- Remember the universal law of gravitation
- Recall the applications of law of gravitation in scientific development

KEY IDEAS

After completing this chapter you should be able to:

- Understand the fact that every body in the universe is attracted by the universal gravitational force
- Deduce an expression of universal gravitational force
- Explain mass and weight, center of mass, center of gravity and related terms
- Discuss the factors affecting the stability of a body and thereby to understand how these are important in different applications



INTRODUCTION

The study of the Earth and the universe has fascinated many scientists since ages. The knowledge of the universe, like a water drop in an ocean, is the result of the work of scientists and philosophers since ages. The galaxies, the solar system and the motion of planets and other celestial bodies in the solar system had puzzled many in the past. The brilliant thoughts of certain people clubbed with their incessant efforts to understand the nature produced some theories and concepts that enable us to comprehend nature better. The question of how the motion of celestial bodies in the universe are governed, was debated on till around the 2nd century. This was when Ptolemy, a Greek scientist, put forward his theory regarding the motion of planets and the sun.

The force that keeps the celestial bodies intact in the universe was called ‘gravitational force’ or the ‘force of gravitation’. According to the theory put forward by Ptolemy, all the planets in the solar system and the sun revolve around the Earth in concentric circular orbits with the Earth as the centre. This theory is called ‘Ptolemaic theory’ or ‘geocentric theory’. The suffix ‘geo’ refers to the Earth and so the theory is named ‘geocentric theory’. This geocentric theory was accepted as established for centuries till a Polish monk, Copernicus, proposed a theory in around 16th century AD. According to the theory proposed by Copernicus, it is not the Earth but the sun which is the centre of the universe and all other planets including the Earth revolve around the sun in circular orbits. Since ‘helios’ refers to the sun in Greek, this theory is called ‘heliocentric theory’. The quest to understand the universe continued and many observations were made regarding planetary motions by Tycho Brahe. His assistant, Johannes Kepler analysed the observations of his master and proposed three laws for planetary motion. These laws proposed by Kepler are called Kepler’s laws of planetary motion and are discussed below.

KEPLER’S LAWS OF PLANETARY MOTION

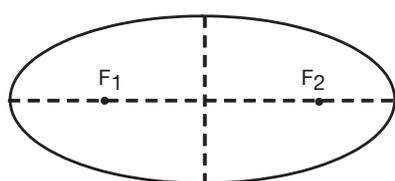


FIGURE 5.1 An ellipse

1. The shape of the orbits of the planets revolving around the sun was originally considered to be circular. Kepler’s analysis of planetary motion revealed that the shape of the orbits of the planets was not circular, but was elliptical in shape. Ellipse is a plane figure similar to an elongated circle as shown in Fig. 5.1.

It has two axes mutually perpendicular to each other. The longer axis is called major axis and the shorter one is called minor axis. The point of intersection of these two axes is the centre of the ellipse. There are two fixed points on the major axis of the ellipse and these are called foci (shown as F_1 and F_2 in Fig. 5.1. According to Kepler’s first law of planetary motion, all the planets revolve round the sun in different elliptical orbits and the sun is located at one of the foci of the orbits. This law is also known as the ‘**law of orbits**’.

2. While a planet revolves round the sun in its elliptical orbit, the length of the shortest line joining the planet and the sun is not constant throughout the elliptical path.

According to Kepler’s second law of planetary motion, a planet revolves round the sun in such a way that the line joining the sun and a planet covers equal areas in equal intervals of time.

Consider a planet revolving around the sun in its elliptical orbit. Consider the positions of the planet at equal intervals of time (say one month) as shown in the Fig. 5.2 as A, B, C and D. The lines joining the sun and the planet at these positions are SA, SB, SC and SD, respectively. According to Kepler's second law of planetary motion, the area of the sectors SAB; SBC and SCD are equal. This law is also called '**law of areas**'.

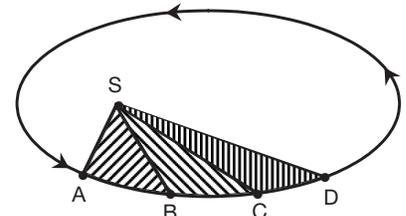


FIGURE 5.2

3. Different planets have different elliptical orbits. Also the length of the line joining a planet and the sun is not constant for each and every position of the planet. If the shape of the orbit of a planet is circular, then the length of the line joining the sun and the planet will be constant and is the radius of the orbit. Since the orbits of the planets are elliptical and the distances of the planets from the sun are not constant throughout, we consider the average of the distances called average radius of the orbit. Now, according to Kepler's third law of planetary motion, the square of the period of revolution of a planet around the sun (T^2) is directly proportional to the cube of the average radius of the planet's orbit (R^3).

$$T^2 \propto R^3$$

If the period of revolution of two planets are T_1 and T_2 , and the average radii of their orbits are R_1 and R_2 , respectively, then $\frac{T_1^2}{R_1^3} = \frac{T_2^2}{R_2^3} = \text{Constant}$.

This law is also referred to as the **law of periods**.

NEWTON'S LAW OF GRAVITATION

When you throw a ball up, it goes a certain distance upwards and falls down again. According to Newton's first law of motion, a body at rest moves only when a net non-zero external force acts on it. When the ball went up, you had applied force on it, then why did it fall back? Which force is responsible for it?

These questions troubled Sir Isaac Newton when he observed an apple falling from a tree. He concluded that the Earth must be exerting a force of attraction on the apple, and hence, it gets accelerated towards it. He proved that this force of attraction is not confined between the Earth and other bodies on the Earth, but this force exists between any two bodies anywhere in the universe which he called force of gravitation.

Sir Issac Newton studied the gravitational force between different bodies and proposed a law to account for the magnitude and the direction of gravitational force between any two bodies in the universe. This law is known as the law of gravitation and is applicable to any two bodies in the universe. According to Newton's law of gravitation, 'the gravitational force of attraction between any two bodies in the universe is directly proportional to the product of their masses and is inversely proportional to the square of the distance between them'. Expressing the statement in a mathematical form, we have

$$F \propto m_1 m_2 \quad (5.1)$$

and
$$F \propto \frac{1}{r^2} \quad (5.2)$$

Where ' m_1 ' and ' m_2 ' are the masses of the two bodies and ' r ' is the distance between them. The second part of the statement, i.e., $F \propto \frac{1}{r^2}$ is called inverse square law.

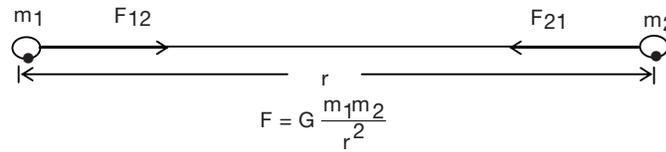


FIGURE 5.3 Force of gravitation between two particles. The force due to m_1 on m_2 is denoted by F_{12} and that due to m_2 on m_1 is F_{21}

Combining equations (5.1) and (5.2), we get $F \propto \frac{m_1 m_2}{r^2}$

$$\Rightarrow F = G \left(\frac{m_1 m_2}{r^2} \right) \quad (5.3)$$

where ' G ' is the constant of proportionality, called 'universal gravitational constant'.

Equation (5.3) gives the magnitude of the gravitational force between two bodies of masses ' m_1 ' and ' m_2 ', separated by distance ' r '. The direction of this gravitational force is along the line joining the centers of the two bodies, and acting towards each other.

If the masses of the two bodies considered above are equal to unity, i.e., $m_1 = m_2 = 1$ kg and the masses are separated by a unit distance, i.e., $r = 1$ m, then equation (5.3) becomes,

$$F = G \left(\frac{1 \text{ kg} \times 1 \text{ kg}}{(1 \text{ m})^2} \right)$$

$$\Rightarrow F = G \text{ newton.}$$

Thus, the constant ' G ' can be defined as 'the gravitational force of attraction between two bodies each of unit mass and separated by a unit distance'.

Rewriting the equation (5.3), we get $G = \frac{F r^2}{m_1 m_2}$.

Thus, the S.I. unit of ' G ' = $\frac{(\text{unit of force}) \times (\text{unit of distance})^2}{(\text{unit of mass})^2} = \text{N m}^2 \text{ kg}^{-2}$.

Similarly C.G.S. unit = dyne $\text{cm}^2 \text{ g}^{-2}$

Let $m_1 = m_2 = 1$ unit

$r = 1$ unit

Then the equation (5.1) becomes

$$F = \frac{G(1)(1)}{(1)^2}$$

$$F = G$$

Thus, G is the force of gravitation between two bodies of unit mass separated by unit distance. Newton himself couldn't find the value of G . Its value was found about 100 years later by a British scientist Henry Cavendish. Today the accepted value of G is $6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$.

G is a scalar quantity and its dimensional formula is $[M^{-1}L^3T^{-2}]$

INVERSE SQUARE LAW—ITS DEDUCTION

While arriving at the inverse square law for forces under gravitation, Newton made some assumptions in the planetary motion. Considering the orbits of planets to be circular, Newton accounted the gravitational force between the sun and the planet for the centripetal force of the planet revolving in its orbit. The magnitude of the centripetal force of a planet in its orbit is given by, $F = mv^2/r$ where ' m ' is the mass of the planet, ' v ' is the velocity of the planet in its orbit called orbital velocity and ' r ' is the radius of the orbit. The magnitude of the orbital velocity of the planet is given by, $v = \frac{2\pi r}{T}$, where ' T ' is its period of revolution and ' $2\pi r$ ' is the circumference of the orbit.

Thus, the centripetal force is expressed as,

$$F = \frac{m \left(\frac{2\pi r}{T} \right)^2}{r} = \frac{m \times 4\pi^2 r^2}{T^2 r} = \frac{4\pi^2 m r^3}{T^2 r^2}.$$

Now, from Kepler's third law of planetary motion, $\frac{r^3}{T^2} = \text{constant}$. Mass of the planet being constant, we get

$$F = (4\pi^2 m) \left(\frac{r^3}{T^2} \right) \times \frac{1}{r^2} = \text{Constant} \times \frac{1}{r^2}.$$

$\Rightarrow F \propto \frac{1}{r^2}$, which is the inverse square law.

EXAMPLE

Calculate the gravitational force of attraction between a car of mass 600 kg and a bike of mass 100 kg separated by a distance of 20 m.

SOLUTION

Given:

Mass of the car (m_1) = 600 kg

Mass of the bike (m_2) = 100 kg

Distance between them, $r = 20$ m

Gravitational constant $G = 6.67 \times 10^{-11} \text{ N m}^{-2} \text{ kg}^{-2}$

\therefore gravitational force of attraction,

$$F = \frac{G m_1 m_2}{r^2} = \frac{6.67 \times 10^{-11} \times 600 \times 100}{(20)^2} = 1.0005 \times 10^{-8} \text{ N}.$$

\therefore The gravitational force of attraction between the car and the bike is 1.0005×10^{-8} N. This force is too small to be felt. Similarly, the gravitational forces of attraction between the bodies in our surroundings on the Earth is very minute and cannot be perceived in comparison with the gravitational force due to earth.

MASS AND WEIGHT

Mass of a body is the measure of the amount of matter present in the body. The C.G.S. unit of mass is 'gram (g)' and its S.I. unit is 'kilogram (kg.)'.

Consider a spherical body of mass ' m ' close to the surface of the Earth. Let the mass of the Earth be ' M '. Then there exists a gravitational force of attraction between the two bodies, i.e., the sphere and the Earth, and this force acts along the line joining their centres. Since the mass of the sphere is negligible compared to the mass of the Earth, as discussed earlier, the sphere is pulled towards the centre of the Earth. This gravitational pull experienced by the body is termed as its 'weight' and is denoted by ' W '.

So, a body dropped from a certain height from a surface on the Earth falls to the ground due to the gravitational pull of the Earth or we say that the weight of a body is directed towards the centre of the Earth. According to Newton's second law of motion $F = ma$, where ' a ' is the acceleration of a body, ' m ' its mass and ' F ' is the force acting on the body. Here, when a body is dropped, there is an acceleration in the body due to the gravitational pull of the Earth and the weight of the body is the force acting on it. Thus, we write $W = mg$, where ' g ' is the acceleration due to gravity. The magnitude of ' g ' varies from place to place, and so the weight of the body is not constant throughout in the universe, whereas the mass of the body is the same everywhere.

Unit of weight is dyne in the C.G.S. system and newton (N) in the S.I. system. Also another unit called gravitational unit is used to measure weight. The gravitational units of weight are gram weight (g_{wt}) or kilogram weight (kg_{wt}).

Let us now differentiate between 'mass' and 'weight' of a body.

Mass	Weight
It is the amount of matter contained in a body.	It is the gravitational pull of the Earth on a body.
It is a scalar quantity.	It is a vector quantity.
It is constant anywhere in the universe.	It varies according to variation in the acceleration due to gravity.
It is measured in gram (C.G.S. unit) or kilogram (S.I. unit).	It is measured in dyne (C.G.S. unit) or newton (S.I. unit). It is also measured in gram-weight (g_{wt}) or kilogram-weight (kg_{wt}).
It is measured using a common balance.	It is measured using a spring balance.

Centre of Mass

From the universal law of gravitation, we understand that the force of gravitation acts along the line joining the two particles. An extended body is a collection of a number of such

particles. To identify the line of action of the gravitational force in such cases, we define a point called centre of mass. Centre of mass is a point within or outside a body where its whole mass can be assumed to be concentrated. For example, for spherical bodies like the Earth, the centre of mass is at the centre of sphere. For extended bodies, we say that the force of gravitation acts along the line joining their centres of mass.

Hence, considering the Earth as a sphere, the force of gravity acts towards the centre of the Earth. The distance between the Earth and a body is equal to the distance between the centre of earth and the centre of mass of that body.

The Fig. 5.4 represents the gravitational force between two spherical bodies like the Earth and the moon.

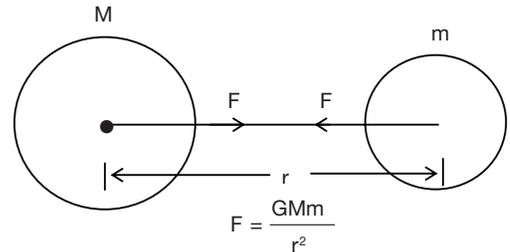


FIGURE 5.4

G and g—The Relation between Them

If ' M ' is the mass of the Earth and ' r ' is the distance between the body and the Earth as shown in Fig. 5.5, then the gravitational force of attraction between them as given by Newton's law of gravitation is $F = \frac{GMm}{r^2}$.

If the height of the body from the ground is negligible compared to the radius of the Earth (R), then the distance of the body from the centre of the Earth (r), can be approximated to be equal to the radius of the Earth (R). Thus, $F = \frac{GMm}{R^2}$.

As discussed earlier, weight (mg) of a body is the gravitational pull of the body towards the centre of the Earth.

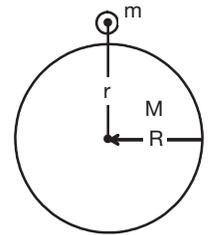


FIGURE 5.5

$$\therefore F = \frac{GMm}{R^2} \Rightarrow g = \frac{GM}{R^2}$$

This is the relation between the acceleration due to gravity (g) on the surface of the Earth and the universal gravitational constant (G). If the values of the radius and mass of the Earth are known, the value of acceleration due to gravity on the Earth's surface can be calculated.

Acceleration Due to Gravity on other Celestial Bodies

Celestial body	Mass (kg)	Radius (m)	Acceleration due to gravity ($m\ s^{-2}$)
Sun	2×10^{30}	7×10^8	273
Earth	6×10^{24}	6.4×10^6	9.77
Moon	7.3×10^{22}	1.74×10^6	1.67
Mars	6×10^{20}	43×10^6	2.16
Jupiter	2×10^{27}	7×10^7	27.22
Saturn	6×10^{26}	6×10^7	11.12

EXAMPLE

The mass of the Earth is 6×10^{24} kg and its radius is 6400 km. Find the acceleration due to gravity on the surface of the Earth.

SOLUTION

Given

Mass of the Earth, $M = 6 \times 10^{24}$ kg

Radius of the Earth, $R = 6400$ km = 64×10^5 m

Universal gravitational constant, $G = 6.67 \times 10^{-11}$ N m² kg⁻²

Acceleration due to gravity on the surface of the Earth, $g = \frac{GM}{R^2}$

$$g = \frac{GM}{R^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(64 \times 10^5)^2} = 9.77 \text{ m s}^{-2}$$

EXAMPLE

The mass and radius of the planet Jupiter are 2×10^{27} kg and 7×10^7 m, respectively. Calculate the acceleration due to gravity on the surface of Jupiter.

SOLUTION

Given

Mass of Jupiter, $M = 2 \times 10^{27}$ kg

Radius of Jupiter, $R = 7 \times 10^7$ m

Universal gravitation constant, $G = 6.67 \times 10^{-11}$ N m² kg⁻²

Acceleration due to gravity on the surface of Jupiter,

$$g = \frac{GM}{R^2} = \frac{6.67 \times 10^{-11} \times 2 \times 10^{27}}{(7 \times 10^7)^2} = 27.22 \text{ m s}^{-2}$$

Acceleration Due to Gravity—Factors Affecting It

Unlike universal gravitational constant, the value of acceleration due to gravity is not constant on the surface of the Earth. It varies from place to place, and thus, the weight of a body changes from place to place. The value of acceleration due to gravity on the surface of the Earth at its equator is taken as standard and is equal to 9.82 m s^{-2} . Some of the factors that affect acceleration due to gravity are discussed below.

- Altitude:** Let ' g_0 ' represent the acceleration due to gravity on the surface of the Earth and ' g ', the same at a height ' h ' from the Earth's surface, respectively. Then the relation between them is given by,

$$g = \frac{g_0}{\left(1 + \frac{h}{R}\right)^2}$$

When $h \ll R$, the relation is approximated and is given by,

$$g = g_0 \left(1 - \frac{2h}{R} \right).$$

The following table gives an idea about the variation of 'g' with altitude.

Altitude (km)	Acceleration due to gravity (m s^{-2})
0	9.82
500	8.28
1000	7.34
5000	3.08
6371	2.46
10000	1.49
20000	0.573
30000	0.301

EXAMPLE

Calculate the acceleration due to gravity at a height of 1600 km from the surface of the Earth. (Given acceleration due to gravity on the surface of the Earth $g_0 = 9.8 \text{ ms}^{-2}$ and radius of earth, $R = 6400 \text{ km}$).

SOLUTION

Given

Height from the surface of the Earth, $h = 1600 \text{ km}$.

Radius of the Earth, $R = 6400 \text{ km}$.

Acceleration due to gravity on the surface of the Earth, $g_0 = 9.8 \text{ m s}^{-2}$

\therefore acceleration due to gravity at the given height,

$$g = \frac{g_0}{\left(1 + \frac{h}{R} \right)^2} = \frac{9.8}{\left(1 + \frac{1600}{6400} \right)^2} = \frac{9.8 \times 16}{25} = 6.272 \text{ ms}^{-2}$$

EXAMPLE

Given that the radius of the Earth and acceleration due to gravity on the surface of the Earth as 6400 km and 9.8 m s^{-2} , respectively, find the acceleration due to gravity at a height of 5 km from the surface of the Earth.

SOLUTION

Given acceleration due to gravity on the surface of the Earth, $g_0 = 9.8 \text{ m s}^{-2}$ radius of the Earth, $R = 6400 \text{ km}$.

Height, $h = 5 \text{ km}$

Here $h \ll R$, \therefore acceleration due to gravity at a height from the surface of the Earth

$$g = g_0 \left(1 - \frac{2h}{R} \right) = 9.8 \left(1 - \frac{2 \times 5}{6400} \right) = 9.8 \left(\frac{639}{640} \right) = 9.785 \text{ m s}^{-2}$$

2. **Depth:** As we go deep into the Earth below its surface, the acceleration due to gravity decreases. The relation between, the acceleration due to gravity (g_d) at a depth ' d ' and at the surface of the Earth (g_o) is approximately given by the expression

$$g_d = g_o \left(1 - \frac{d}{R} \right).$$

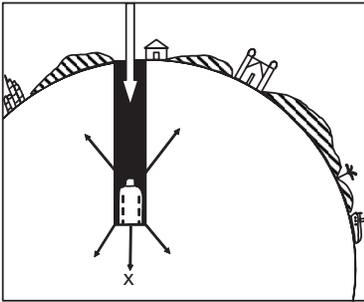


FIGURE 5.6

If $d = R$, i.e., at the centre of the Earth, there is no acceleration due to gravity.

When a body is inside the Earth, it is acted upon by forces of attraction from different sides. This decreases the value of ' g '. At the centre (i.e., the centre of mass) of the Earth the net force of attraction acting on the body is zero, therefore, ' g ' is also zero.

At every other point inside the Earth, the effective gravitational force on a body will be less than that on the surface of the Earth. Thus, the acceleration due to gravity inside the Earth is less than that on the surface of the Earth.

EXAMPLE

Given radius of the Earth and acceleration due to gravity on the surface of the Earth as 6400 km and 9.8 m s^{-2} , respectively. Find the acceleration due to gravity at a depth of 1600 km from the surface of the Earth.

SOLUTION

Given acceleration due to gravity on the surface of the Earth, $g_0 = 9.8 \text{ m s}^{-2}$

Radius of the Earth, $R = 6400 \text{ km}$

Depth, $d = 1600 \text{ km}$.

\therefore acceleration due to gravity at the given depth,

$$\begin{aligned} g &= g_0 \left(1 - \frac{d}{R} \right) \\ &= 9.8 \times \left(1 - \frac{1600}{6400} \right) = 9.8 \times \frac{3}{4} = 7.35 \text{ m s}^{-2} \end{aligned}$$

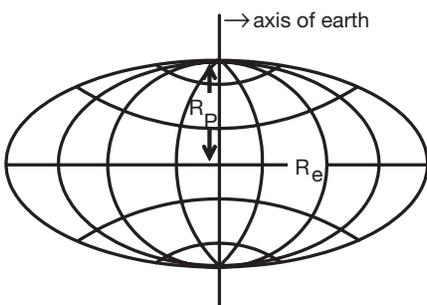


FIGURE 5.7

3. **Latitude:** The shape of the Earth is not spherical; but it is ellipsoidal. This implies that it is bulged at the equator and flattened at the poles as shown in the Fig. 5.7.

Thus, the radius of the Earth measured along its equator, also called equatorial radius (R_E); is greater than its radius measured along the poles, also called polar radius (R_P). Since $g = \frac{GM}{R^2}$, we can write accelerations due to gravity at the equator and the poles of the Earth, represented by g_E and g_P , respectively, as $g_E = \frac{GM}{R_E^2}$ and $g_P = \frac{GM}{R_P^2}$.

As $R_E > R_p$, we get $g_E < g_p$. At the equator of the Earth, latitude is zero and at the poles whether north or south, its value is 90° . Thus, acceleration due to gravity increases as the latitude increases.

FREE FALL

Let a bucket tied to a rope passing over a pulley fall in a well. What forces act on it?

The forces acting on it are gravity and the force of friction between the rope and pulley which oppose the fall of the bucket. If you drop a stone from a cliff, in addition to gravity, air resistance acts on it. Hence, not all bodies fall down freely. A body is said to be falling freely or in a state of free fall when it is under the influence of gravity alone and no other force acts on it.

When bodies are in free fall, the acceleration due to gravity acting on them is the same and is independent of their masses.

Consider a small iron ball of a certain mass and a feather of the same mass being dropped from a height. Since both move with the same 'g', we would expect them both to reach the ground simultaneously. But this is not the case and the feather takes more time to reach the ground. It experiences more air resistance, which slows down its fall.

In the light of this, now consider an iron ball and a wooden ball of the same size dropped simultaneously from the same height. Since they experience the same air resistance, the effect of air resistance can be neglected and the two balls can be considered to be in free fall. Hence, they will reach the ground simultaneously.

This famous experiment was conducted by Galileo from the top of the leaning tower of Pisa. The mass of the iron ball is greater than the mass of the wooden ball of the same size. Yet, they fall simultaneously. This disproved the theory put forward by Aristotle according to which a heavier body falls faster than a lighter body.

The mass does not affect the acceleration due to gravity during freefall was further proved by Sir Isaac Newton. He made a coin and a feather fall simultaneously in an evacuated tube, 6 m long. Since there is no air resistance, both reached the bottom of the tube simultaneously.

WEIGHTLESSNESS

Attach a load to a spring balance and note the reading. When the spring balance along with the load is allowed to fall freely, it shows zero reading as if no weight acts on it. When you jump from a height, you would feel as if you have no weight. This phenomenon is called 'weightlessness'. When a lift starts descending, momentarily you would feel a decrease in your weight. A body experiences weight because of the force of gravity acting on it. When the body is in free fall, this force is used to accelerate it towards the centre of the Earth and there is no reaction force acting on it. Hence, it experiences weightlessness.

Astronauts in space ships orbiting the Earth are within its gravitation field, yet they experience weightlessness. The force of gravity acts as centripetal force to keep them in orbit.

In the reference frame of the space ship, every part of the space ship is subject to the same force and this is equivalent to a free fall. Thus, the astronauts feel weightless.

CENTRE OF GRAVITY

Weight is the force of gravity acting on a body. An extended rigid body is made up of number of particles. Let w be the weight of each particle acting towards the centre of earth. Thus, an extended body is acted upon, by a large number of parallel forces each equal to w .

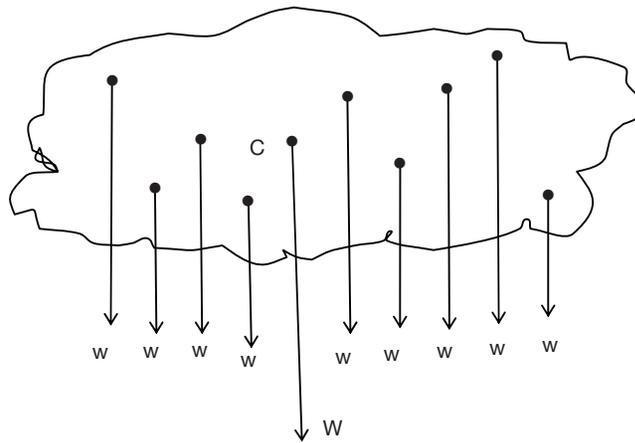


FIGURE 5.8

Let ' n ' such forces be acting on the body such that the sum of all ' n ' forces is equal to the resultant W as shown in the Fig. 5.8.

$$W = w + w + w + \dots w \text{ (} n \text{ times)}$$

$$W = nw$$

The point inside (or outside) the body where this resultant weight acts is called centre of gravity (C.G.) of the body. For a body having a regular shape and uniform density, C.G. lies at its centre. The whole body can be balanced by suspending or pivoting it at its centre of gravity.

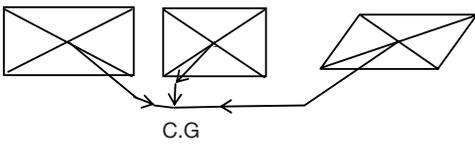
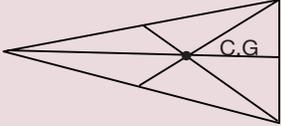
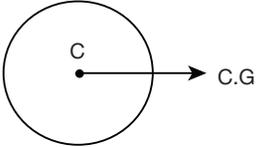
We have already seen that the centre of gravity is a point inside a body where the entire weight of the body is assumed to act.

How do we locate this point? The location of this C.G. (centre of gravity) depends on whether the body is regular or irregular in shape.

Centre of Gravity of Regular Bodies

The C.G. of a body having a definite geometrical shape and uniform density is located at its geometric centre.

The following table gives the locations of C.G. of some common regular bodies

Body (lamina)	Location of C.G.	Diagram
Rectangle, square or parallelogram	Point of intersection of diagonals	
Triangle	Point of intersection of medians	
Sphere	Geometric centre	

Centre of Gravity of Irregular Bodies

Take a piece of cardboard having irregular shape. Make three holes near any three of its sharp corners far apart and label them as 1, 2, 3.

From a nail fixed to a wall, suspend this cardboard from hole 1 such that it can oscillate about that nail. Now suspend a plumb line from the nail over the cardboard. When the cardboard is stationary, draw a straight line on the cardboard along the thread of the plumb line. Repeat the procedure for the remaining holes and draw lines. The point where all these lines meet on the cardboard is the C.G. of the irregular shaped cardboard. Normally the centre of gravity lies within the body. In case of L-shaped bodies, it lies outside the body rings.

Example:

Boomerang, cycle tube

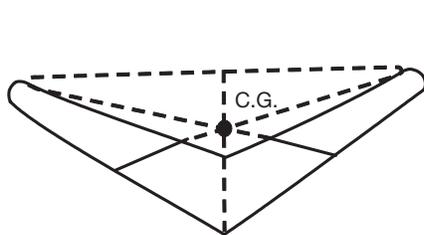


FIGURE 5.9 Boomerang

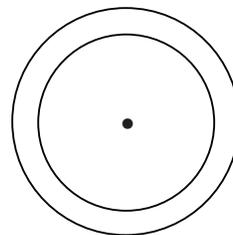


FIGURE 5.10 Cycle tube

EQUILIBRIUM

When an external force is applied to a body, its state of rest or uniform motion may change. If the state of rest or uniform motion of a body does not change even on application of one or more external forces, the body is said to be in equilibrium. For a body to be in equilibrium, the following two conditions should be satisfied.

1. All forces acting on the body must lie in the same plane, i.e., they must be coplanar forces.

- The resultant of all torques acting on the body should be zero so that the body does not rotate on the application of a force.

While studying the equilibrium of bodies, we often use the term ‘position of body’. In physics, it has specific meaning and is associated with the C.G. of the body. By position of a body, we refer to the position of its C.G. with respect to the base on which the body is placed. This means the position of a body refers to the height of C.G. above its base.

On the application of an external force, the location of the body may change but its position would remain unchanged as shown in the Fig. 5.11.

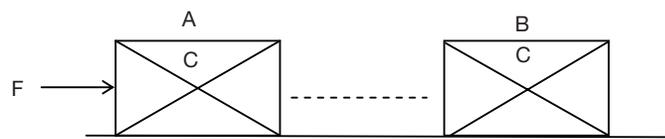


FIGURE 5.11

The body has been displaced from A to B but the height of C.G. above its base has remained the same. So, its position has not changed.

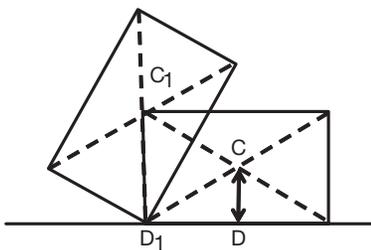


FIGURE 5.12

In the Fig. 5.12, the position of the body has changed. The position of a body or the change in the position of the body on the application of force decides the type of equilibrium the body is in.

There are three types of equilibria. They are:

- Stable equilibrium
- Unstable equilibrium
- Neutral equilibrium

Let us discuss each of them briefly.

Stable Equilibrium

A body is said to be in stable equilibrium when its position changes on the application of external force, but once the external force is removed, it regains its original position. For example, a cone resting on its base is in stable equilibrium.

A body can be in stable equilibrium if it satisfies the following conditions:

- The straight line joining its centre of gravity and the centre of the Earth (C.E.) should always pass through its base on the application of external force.
- The body should have a broad base.
- The base of the body should be heavy lowering its C.G., i.e., the centre of gravity should be as low as possible.

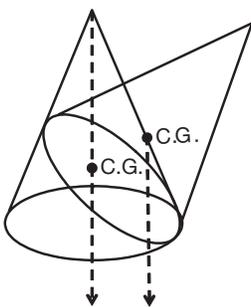


FIGURE 5.13

Example: A giraffe while drinking water from a pond spreads its rear legs wide apart, giving it more stability.

Example: A book laying flat on a table, a brick with its broader face on the ground, a cone resting on its base.

Unstable Equilibrium

If the position of a body changes on the application of an external force such that it does not regain its original position, on removing the force, the body is said to be in unstable equilibrium.

Example:

- A person standing on one leg, a cone resting on its apex, a brick standing on its edge, etc.
- A body is in unstable equilibrium under the following conditions.
 1. On application of an external force, the line joining the C.G. and the centre of the Earth falls outside its base.
 2. The base of the body is narrow.
 3. The top of the body is heavy. This raises its C.G.

Neutral Equilibrium

If a body is displaced on the application of an external force, but at each new place, its position is similar to the original one, the body is said to be in neutral equilibrium.

Example: A rolling ball, a cone resting on its sides, a rolling cylinder, etc.

The conditions required for neutral equilibrium are given below.

1. On the application of an external force, the position of the C.G. is same, i.e., it is neither lowered nor raised.
2. The line joining the C.G. and the C.E. falls within the base of the body on application of forces.

The equilibrium of bodies plays an important role in our daily life. Some practical examples of equilibrium are given below.

1. Passengers are asked to occupy the lower deck first in a double-decker bus. Only after the lower deck is full, they are allowed to occupy seats in the upper deck. In any case, passengers are not allowed to stand in the upper deck. The C.G. of the system may rise to such an extent that the line joining the C.G. of bus and C.E. may fall outside the base of the bus when it is taking a sharp turn and the bus may topple.
2. Passengers are not allowed to stand when a boat is midstream. If passengers stand, the C.G. of system is raised and the boat may topple.

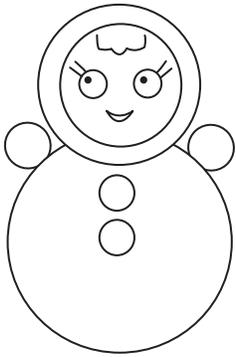


FIGURE 5.14 Rolly-Polly doll

3. Self erecting doll: These dolls always stand erect no matter how much they are tilted to one side on application of force. They have a heavy base which is curved. The C.G. lies below the centre of curvature of the base. The line joining the C.G. of the doll and the C.E. always passes through the base even if it is tilted by 90° .

As soon as the external force is removed, the doll comes to its original stable position. Such dolls are also called Tanjore dolls or roly-polly dolls.

4. When a ship is being loaded with cargo, heavy objects are loaded in the lowest deck. This lowers the C.G. of the ship so that it maintains its equilibrium even in rough waters.

GRAVITATION—APPLICATIONS

Science and technology being at its pinnacle, today it is possible for us to measure the mass of the Earth, radius of the Earth the value of acceleration due to gravity with the greatest precision. Newton's law of gravitation helps us to even estimate the masses of other planets and stars accurately. If two stars are close to each other, they revolve around their centre of mass. Such a system of two stars orbiting around their centre of mass is called double star or a binary star. Newton's law of gravitation helps in determining the mass of each star of a double star.

If the motion of a star has small irregularities, those irregularities can be detected using the latest technology. One of the irregularities in the motion of stars is called 'wobble'. This wobble may indicate the possibility of a planet moving around the star. In such cases, the mass of the planet can be estimated using the law of gravitation.

Just like animals and human beings, plants are also affected by gravity. To understand the effect of gravity on plants, let us do an activity. Take some bean seeds that are broad and flat. Soak them in water overnight. Take the soaked seeds and fix them to a wooden stick wrapped with a wet cloth with the help of pins.

Fix the seeds to the wooden stick such that different seeds have different orientation. Now keep the wooden stick in a glass jar Fig. 5.15. Keep the cloth, wrapped to the wooden stick, damp by sprinkling water on it regularly.

Observe the seeds in the jar regularly for a week and you will find that whatever may be the orientation of the seed, on germination the roots always grow downwards and the shoots upwards, as shown in the Fig. 5.16. This phenomenon is called geotropism, which establishes the effect of gravity on plants.

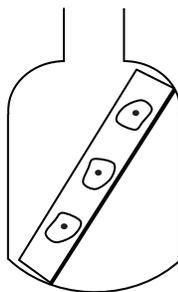


FIGURE 5.15

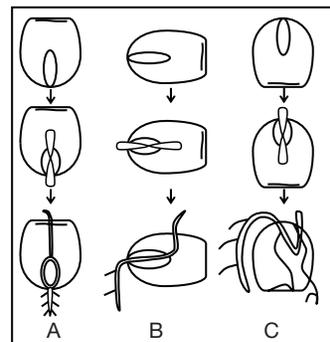


FIGURE 5.16

Geotropism shows that on the Earth, plants recognize gravity and the roots grow downward to access the nutrients in the soil. Simultaneously, the shoots grow upwards, against gravity, seeking air and sunlight.

In spaceships gravity is absent. It has been found that in the absence of gravity, plants grow randomly. In such a case, growth of plants is affected as they get deprived of vital nutrients. It is necessary for us to develop a way to make plants grow properly in space ships as they are necessary for purifying water, making the atmosphere suitable for living, for producing food and recycling the nutrients. Hence, new ways of growing plants in negligible gravity are being tested. Many new experiments are being conducted. It has been found that the supply of oxygen during space flights helps the roots of plants to grow in the direction in which nutrients are available.

ARTIFICIAL SATELLITES

The moon is a natural satellite of the Earth. A man-made object which orbits around the Earth is called an artificial satellite. They have many uses like collecting and relaying information, weather forecasting, conducting scientific experiments, etc.

The fixed path which a satellite revolves round the Earth is called an orbit. The velocity of a satellite in an orbit is called orbital velocity. Depending on the orbit, a satellite can be classified as polar satellite or geostationary satellite.

The distance of the orbit of satellite from the centre of the Earth and the orbital velocity play a main role in the stability of a satellite. The force of gravity serves as a centripetal force and keeps the satellite in its orbit. To place a satellite in a desired orbit, they are launched from the Earth using rockets. In order to remain in an orbit, a satellite should have a specific orbital velocity. In an orbit 200 km away from the centre of the Earth a satellite should have a velocity of 7.78 km s^{-1}

If an object is launched from the Earth's surface with a velocity of 11.2 km s^{-1} , it will escape from the Earth's gravitational field and will not return to earth. Spacecrafts like Voyager, Cassini, etc., are launched to escape from the Earth's gravitational field and are used to explore deeper space. The minimum velocity at which an object can escape the Earth's gravity is called escape velocity. The escape velocity for an object to be launched from the moon is 2.38 km s^{-1} .

Time period of a satellite is the time taken by it to complete one revolution around the Earth. If the time period of a satellite is 24 hrs, it is synchronous with the Earth's rotation about its own axis. Such a satellite always stays at the same point when seen from the Earth and is called geo-stationary satellite. Such satellites orbit around the Earth at a distance of about 36000 km from the surface of the Earth.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

- Define free fall.
- Define an artificial satellite.
- When does a body experience a free fall?
- The leaning tower of PISA does not collapse inspite of being in a slanting position. Then the building is said to be in _____ equilibrium.
- What is a geostationary satellite and what is its time period?
- State Newton's universal law of gravitation
- What is the effect of mass of the body on acceleration due to gravity (g)?
- On Mount Everest, the value of the acceleration due to gravity is _____ than its value in Kashmir valley.
- State Newton's inverse square law.
- Where does the C.G. of regular shaped bodies lie?
- State S.I. and C.G.S. units of 'G' and mention its value in both the systems.
- State Kepler's 1st law of planetary motion.
- A spring balance measures the _____ of a body.
- Time period of revolution of a planet is 1000 days. If the distance between the sun and planet is altered such that 8000 days on it will make one year, then this altered distance is _____ the original distance.
- State Kepler's 2nd law of planetary motion.
- What do you understand by the position of a body?
- Define escape velocity of an object.
- State Kepler's 3rd law of planetary motion.
- Irregularity in the motion of a star is known as a _____.
- If the ratio of the weights of a body of mass 'm' measured on two different planets 'A' and 'B' is 1 : 2 and the ratio of radii of two planets 'A' and 'B' is 2 : 4, respectively, then the ratio of the masses of two planets is, respectively _____.
- Define mass, weight and centre of gravity.
- Define the following.
 - stable equilibrium
 - unstable equilibrium
 - neutral equilibrium
- Define geotropism.
- What is acceleration due to gravity?
- Define the time period of a satellite
- How does altitude affect ' g '?
- The time period of a geostationary satellite is equal to _____ hours.
- Geotropism is the phenomenon which shows the effect of _____ on plants.
- What is the effect of latitude on ' g '?
- What is wobble?

Short Answer Type Questions

- How is gravitation used to detect the presence of a binary star or a planet which is bound to a star?
- Calculate the acceleration due to gravity on a planet of mass 2×10^{27} kg and radius 14×10^7 m.
- Explain how the apparent weight of a person, taking a ride in a roller-coaster varies.
- If the mass of the Earth is decreased by 10% keeping its size constant, how is the weight of a body on the Earth affected?
- Compare mass and weight.
- Weights of two bodies are 20 N and 30 N. If they are separated by a distance of 2 m, what is the force of gravitation acting between them?
(Take $g = 10 \text{ m s}^{-2}$)
- How does the centre of mass of bodies affect the force of gravitation between them?
- A bowl with a semi spherical base is designed such that its centre of gravity is located at the centre of curvature of the spherical part. Explain giving reasons, to which state of equilibrium the bowl belongs. If the bowl is filled with water upto the centre of



gravity, explain how the equilibrium state would be affected/unaffected.

39. What is equilibrium? State the conditions required to keep a body in equilibrium
40. Mass of moon is 7.3×10^{22} kg and its radius is 1.74×10^6 m. Find the value of the acceleration due to gravity on the moon.
41. If the distance between the Earth and the sun shrinks to half the present distance, then find the new duration of the year.
42. The mean distance of two planets A and B from the sun is 2 and 4 times the distance of the Earth from the sun, respectively. Find the ratio of the time taken by the two planets to make one revolution around the sun.
43. State the conditions for stable, unstable and neutral equilibria.
44. A body weighs 98 N on the Earth. How much does it weigh on the moon? (Take $g_E = 9.8 \text{ m s}^{-2}$, $g_m = 1.61 \text{ m s}^{-2}$)
45. Give two practical examples of the equilibrium of bodies in our daily life.

Essay Type Questions

46. Explain how you would find the C.G. of regular and irregular bodies.
47. Write a note on geotropism.
48. State Kepler's laws of planetary motion.
49. Write a note on artificial satellite.
50. Derive Newton's inverse square law.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

1. The weight of a body on the surface of moon is 1/6th of that on the Earth's surface. It is because acceleration due to gravity on the surface of moon is six times that on the surface of the Earth.
2. The dimensional formula of universal gravitational constant 'G' is $[M^{-1}L^3T^{-2}]$.
3. Heliocentric theory was proposed by Tyco Brahe.
4. If a heavenly object like an asteroid or a planetoid revolving around the sun moves into an orbit of smaller radius, its speed increases.
5. Acceleration due to gravity vanishes at an altitude equal to half the radius of the Earth.
6. For any given body, the centre of the mass of a body always coincides with its centre of gravity.
7. The direction of motion of an artificial satellite revolving in a geostationary orbit is opposite to the direction of the Earth's rotation.

Direction for questions 8 to 14

Fill in the blanks

8. The ratio of 'g' on two known planets 'A' and 'B' is $x : y$. If two identical bodies are projected with the same velocity on these planets, then the ratio of their time of descent is _____. (Neglect atmospheric resistance).
9. According to Kepler's laws of planetary motion, the orbits of planets are of _____ shape.
10. Two satellites of identical masses orbit the Earth at different heights. The ratio of their distances from the centre of earth is $d : 1$ and the ratio of the acceleration due to gravity at those heights is $g : 1$. Then the ratio of their orbital velocities is _____.
11. A football floating on the waves of ocean water is an example of _____ equilibrium.
12. Newton's inverse square law is deduced from Kepler's _____ law of planetary motion.
13. All the particles of a shuttle cock execute complicated motion, but its _____ describes the simplest path when it is projected.



14. The law that helps in determining the masses of the stars present in a double star is _____.

Directions for question 15

Match the entries given in Column A with appropriate ones in Column B.

Column A		Column B	
A	g_h	()	a. Outside the body
B	$T^2 \propto R^3$	()	b. 24 hours
C	Centre of mass of a hollow sphere	()	c. $6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
D	Universal gravitational constant	()	d. Kepler's law of periods
E	Time period of a geostationary satellite	()	e. $g_0 \left(1 - \frac{2h}{R}\right)$
F	Weight	()	f. Effect of latitude on 'g'.
G	Centre of gravity of a Boomerang	()	g. Mass
H	Common balance	()	h. $\sqrt{\frac{GM}{R}}$
I	$g_{\text{equator}} < g_{\text{poles}}$	()	i. Geometrical centre
J	Orbital velocity	()	j. Vector

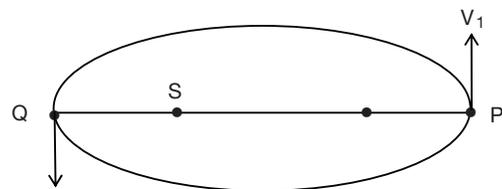
Direction for questions 16 to 45

For each of the questions, four choices have been provided. Select the correct alternative.

16. When a spring balance, which showed a reading of 30 divisions on earth, is taken to the moon, will show (for the same body)
- (a) 180 divisions. (b) 6 divisions.
 (c) 150 divisions. (d) 5 divisions.
17. The place where the value of 'g' is unaffected by the increase (or) decrease in the speed of rotation of the Earth about its own axis is
- (a) equator. (b) poles.
 (c) tropic of Cancer (d) tropic of Capricorn.
18. The centre of gravity C.G. of the bob of a given simple pendulum is at position 'x' on earth. What is its new position on the surface of the moon?
- (a) It remains at the same position 'x'.
 (b) It is above the position 'x'

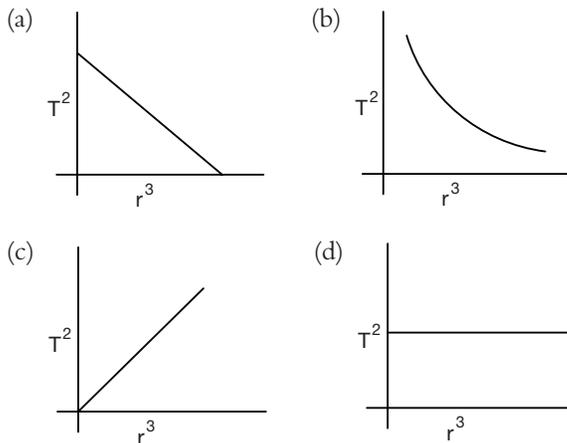
- (c) It is below the position 'x'
 (d) It shifts towards surface of the bob.

19. The weight of a body of mass 3 kg at a height of $12.8 \times 10^6 \text{ m}$ from the surface of the Earth is _____.
- (a) 9.75 N (b) 1.46 N
 (c) 3.26 N (d) 4.36 N
20. If the gravitational force between two bodies of masses 10 kg and 100 kg separated by a distance 10 m is $6.67 \times 10^{-10} \text{ N}$, then the force between the given masses would be _____ N if they are placed in a geostationary satellite without change in the distance between them.
- (a) 3.335×10^{-10} (b) 3.335×10^{-11}
 (c) 6.67×10^{-10} (d) 6.67×10^{-11}
21. A circus artist rides a bicycle, on a rope tied horizontally. This is an example of _____ equilibrium.
- (a) neutral (b) stable
 (c) unstable (d) dynamic
22. If the acceleration due to gravity on a planet is 6.67 m s^{-2} and its radius is $4 \times 10^6 \text{ m}$, then the mass of the planet is _____.
- (a) $16 \times 10^{23} \text{ kg}$ (b) $726 \times 10^{23} \text{ kg}$
 (c) $16 \times 10^{24} \text{ kg}$ (d) $26 \times 10^{24} \text{ kg}$
23. The figure shown below is an elliptical orbit along which a planet revolves round the sun. Let the velocity of the planet at points P and Q be V_1 and V_2 respectively. Then, the possible relationship between magnitudes of 'V₁' and 'V₂' is



- (a) $V_1 < V_2$ (b) $V_1 = V_2$
 (c) $V_1 > V_2$ (d) Both 1 and 2
24. What is the relation between the period of rotation (R_T) and period of revolution (R_V) of moon?
- (a) $R_T = R_V$ (b) $R_V > R_T$
 (c) $R_V < R_T$ (d) No relation exists
25. Which of the following graphs is true for the motion of a satellite revolving round the Earth. ('T' is the time period of a satellite and 'r' is the distance of the satellite from the Earth).





26. One revolution of a given planet around the sun is 1000 days. If the distance between the planet and the sun is made $\frac{1}{4}$ th of original value, then how many days will make one year?
- (a) 180 days (b) 400 days
(c) 125 days (d) 250 days
27. A cone and a cylinder having same base area and height are placed on a horizontal surface. What is the ratio of the heights of centre of gravity of the cone and the cylinder from the surface?
- (a) 5 : 3 (b) 3 : 5
(c) 3 : 2 (d) 1 : 2
28. A geostationary satellite is going round the Earth in an orbit. Then, which of the following statements are true?
- (A) It is like a freely falling body.
(B) It possesses acceleration throughout its journey.
(C) It is moving with constant speed.
(D) It is moving with constant velocity
- (a) ABC (b) BCD
(c) CDA (d) DAB
29. The length of a seconds pendulum on the surface of the Earth is 100 cm. Find the length of the seconds pendulum on the surface of the moon.
(Take, $g_M = \frac{1}{6}g_E$)
- (a) 1.66 m (b) 16.6 cm
(c) 33.2 cm (d) 3.32 m
30. If the force between bodies of mass 2 kg and 4 kg, separated by a distance 4 m, is 3.335×10^{-11} N, then the force between them if the bodies are shifted to the moon without altering the distance between them will be _____.
- (a) 0.03335 N (b) 3.335×10^{-11} N
(c) 5.558×10^{-12} N (d) 6.28×10^{-12} N
31. The weight of a body of mass 3 kg at the centre of the Earth is _____.
- (a) 9.75 N (b) 1.46 N
(c) zero (d) 4.36 N
32. Acceleration due to gravity of a body is independent of
- (a) mass of the body.
(b) altitude of the body.
(c) latitude of the body.
(d) depth below the Earth's surface.
33. If the ratio of the masses of two planets is 2 : 3 and the ratio of their radii are 4 : 7, then the inverse ratio of their accelerations due to gravity will be _____.
- (a) 49 : 24 (b) 7 : 8
(c) 24 : 49 (d) 8 : 7
34. What is the relation between period of rotation (R_T) of earth and period of revolution (R_r) for a geostationary satellite?
- (a) $R_T = R_r$ (b) $R_T < R_r$
(c) $R_T > R_r$ (d) No relationship
35. Spring balance measures _____ of a body in air.
- (a) actual weight of a body
(b) apparent weight of a body
(c) mass of a body
(d) both mass and weight of a body
36. According to Newton's Universal law of gravitation, the gravitational force between two bodies is
- (a) always attractive and depends on their masses.
(b) depends on the distance between them.
(c) does not depend on the medium between the bodies.
(d) All the above.
37. The ratio of the masses of two planets is 1 : 10 and the ratio of their diameters is 1 : 2. If the length of a seconds pendulum on the first planet is 0.4 m, then the length of the seconds pendulum on the second planet is _____.
- (a) 10 cm (b) 0.5 m
(c) 10 m (d) 1.0 m
38. The value of acceleration due to gravity on the Earth at a distance of 29,000 km from the surface is 0.3 m s⁻². The value of acceleration due to gravity at



the same height on a planet whose mass is 66.70×10^{22} kg and diameter is 8700 km is _____ m s^{-2} .

(Take $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$).

- (a) 0.05 (b) 0.04
(c) 0.06 (d) 0.09

39. As it falls, the acceleration of a body dropped from the height equal to that of radius of earth,
(a) remains the same.
(b) decreases.
(c) increases.
(d) initially increases then decreases.
40. Which is not correct about escape velocity?
(a) Escape velocity of a body depends on its mass.
(b) Escape velocity of a body is greater than its orbital velocity
(c) Escape velocity of a body is different on different planets.
(d) Escape velocity of a body on a planet depends on the mass of the planet.
41. The line joining the centre of gravity of a cuboid and the centre of the Earth will fall within the base of the body even after being disturbed by an external force. Then the body is said to be in _____.
(a) neutral equilibrium
(b) stable equilibrium
(c) unstable equilibrium
(d) dynamic equilibrium
42. According to Kepler's second law of planetary motion,

- (a) the line joining the centers of a planet's orbit and the planet covers equal areas in equal intervals of time.
(b) the line joining the centers of sun and the planet covers equal area in equal intervals of time.
(c) a planet covers equal distances along its orbit in equal intervals of time.
(d) area swept by the average radius of orbit of each planet in the solar system is equal.

43. If the time period of revolution of a planet is increased to $3\sqrt{3}$ times its present value, the percentage increase in its radius of the orbit of revolution is _____.
(a) 50 (b) 100
(c) 200 (d) 400
44. If the acceleration due to gravity at a height 'h' from the surface of the Earth is 96% less than its value on the surface, then $h = \text{_____} R$ where R is the radius of the Earth.
(a) 1 (b) 2
(c) 3 (d) 4
45. Given $g_d = g \left(1 - \frac{d}{R}\right)$ where g_d and g are the accelerations due to gravity at a depth 'd' km, and on the surface of the Earth, respectively, R is the radius of the Earth, then the depth at which $g_d = \frac{g}{2}$ is _____.
(a) R (b) $\frac{R}{2}$
(c) $\frac{R}{3}$ (d) $\frac{R}{4}$

Level 2

46. Given that d_e, d_m are densities of the Earth and moon, respectively, and D_e, D_m are the diameters of the Earth and the moon, respectively. g_e and g_m are the acceleration due to gravity on the surface of the Earth and moon, respectively. Find the ratio of g_m and g_e .
47. A cylindrical vessel containing liquid is placed on the floor of an elevator. When the elevator is made to accelerate in the upward direction with constant acceleration equal to g , discuss how the centre of gravity of the system containing vessel and liquid changes. Also, discuss how the centre of gravity of

the system containing vessel and liquid changes when the elevator accelerates in the downward direction. Also discuss how the 'weight' would vary in each case.

48. A hollow sphere is taken as bob of a simple pendulum. This hollow sphere is filled with fine sand. There is a small hole at the bottom of this sphere through which the fine sand leaks out. How does the time period of this simple pendulum alter? Discuss.
49. Two satellites of one metric ton and twelve metric tons masses are revolving around the Earth. The heights of these two satellites from the Earth are 1600 km and



25600 km, respectively. What is the ratio of their time periods and what is the ratio of the accelerations due to gravity at those heights?

(Radius of the Earth = 6400 km)

50. A body of mass 10 kg is dropped from a height of 10 m on a planet, whose mass and radius are double that of the Earth. Find the maximum kinetic energy the body can possess.
(Take $g_E = 10 \text{ m s}^{-2}$)
51. The escape velocity of a satellite from the surface of a planet is $\sqrt{2}$ times the orbital velocity of the satellite. If the ratio of the masses of two given planets is 1 : 4 and that of their radii is 1 : 2, respectively, then find the ratio of escape velocities of a satellite from the surfaces of two planets.
52. Find the height from the surface of the moon where the value of 'g' is equal to the value of 'g' at a height of 57,600 km from the surface of the Earth.
(Take, mass of the Earth, $M_E = 6 \times 10^{24}$ kg, Mass of the moon, $M_m = 7.3 \times 10^{22}$ kg, radius of the Earth, $R_E = 6400$ and radius of the moon, $R_m = 1740$ km)
53. What is the value of the acceleration due to gravity at a height equal to half of the radius of the Earth? Can we use the formula $g_h = g_0 \left(1 - \frac{2h}{R}\right)$? Explain
(Take $g_0 = 9.8 \text{ m s}^{-2}$).
54. The Earth exerts more force on heavier bodies than on lighter bodies. Why is it then that when dropped, heavier bodies don't fall faster than lighter bodies?
55. A coke can of negligible mass is in the shape of a cylinder. Its volume is 500 ml and its base area is $\frac{100}{3} \text{ cm}^2$. A person consumes nearly 25 ml of coke for every sip. After he consumes 12 sips of the drink, what is the height of the centre of gravity of the can from its base when placed vertically? If the mass of the can is not negligible, how would this answer vary?
56. If two bodies of masses 1 kg and 4 kg are released from the heights where gravitational force on them is equal, then find the height of the heavier body if the lighter body is dropped from a height of 1 km. Take radius of earth as 6400 km.
57. A mine worker measures his weight inside a mine and finds that it has decreased by 0.05% of that on the surface of the Earth. Then, find the depth of the mine
(Take the radius of the Earth = 6400 km and acceleration due to gravity on the surface of the Earth, $g = 9.8 \text{ m s}^{-2}$).
58. If the orbital velocity of the moon is 1020 m s^{-1} , find the time taken by the moon to complete one revolution around the Earth. Explain why this period is different from the period that is observed from the Earth, which is 29.5 days.
(Take the distance of the moon from the Earth as 3.4×10^8 m, and $\frac{1}{86400} = 1.157 \times 10^{-5}$).
59. Two asteroids (heavenly bodies) of equal masses revolve diametrically opposite to each other in a circle of radius 100 km. If mass of each asteroid is 10^{10} kg, then what would their velocities be.
(Take $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$).
60. What would the length of a seconds pendulum on the surface of the Earth be if the mass of the Earth remains constant but its volume shrinks to $\frac{1}{8}$ th of its original volume.
(Take original value of acceleration due to gravity as 9.8 m s^{-2})
61. Find the ratio of the upthrust on a certain body offered by a liquid placed on the surface of the Earth and on the surface of the moon.
(Take $g_m = \frac{1}{6} g_E$)
62. When a spring balance, showing a reading of 100 divisions at equator for a body, is taken to the poles, then find the reading shown by it
(Take $\frac{g_p}{g_E} = 1.01$)
63. Two satellites 'A' and 'B' of masses ten and twenty metric tons revolve around the Earth at two different heights h_1 and h_2 from the surface of the Earth. If earth's gravitational pull on these two satellites at these heights is equal, then find the ratio of their distances from the centre of the Earth. (Radius of the Earth = 6400 km)
64. Acceleration due to gravity on the surface of the Earth is 9.8 m s^{-2} . Find its new value if both the radius and mass increase by 20%.



65. A person can jump to a height of 3 m at the equator of the Earth. Considering the same initial velocity for jumping, to what height can he jump at the poles? The radius of the Earth at the poles and the equator is 6357 km and 6378 km, respectively.

$$\text{Given, } \frac{6357}{6378} = 0.9967$$

66. The weight of a person on the surface of the Earth is 490 N. Find his weight on the surface of Jupiter and the moon. Also, compare it with his weight on the Earth.

$$\text{Mass of moon} = 7.3 \times 10^{22} \text{ kg,}$$

$$\text{Mass of Jupiter} = 1.96 \times 10^{27} \text{ kg,}$$

$$\text{Radius of moon} = 1.74 \times 10^6 \text{ m and radius of Jupiter} = 7 \times 10^7 \text{ m}$$

$$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

$$\text{Given, } \frac{1}{1.742} = 0.33 \text{ and } g_e = 9.8 \text{ m s}^{-2}.$$

67. A sphere and a cube having same volume and height of cube is equal to the radius of the sphere placed on a horizontal surface. What is the ratio of the heights of their centre of gravities from the surface?
68. The leaning tower of PISA does not collapse inspite of being in a slanting position. Explain.
69. A cylinder and a hollow sphere are placed on a surface. If the height of the cylinder is equal to the diameter of the sphere, what is the ratio of the heights of centre of gravity of the cylinder and the sphere from the surface?
70. A person stood in an accelerating elevator. Explain how the apparent weight of this person varies.

Level 3

71. For planets revolving round the sun, show that $T^2 \propto r^3$, where T is the time period of revolution of the planet and r is its distance from the sun.

72. It is well known that there exists a gravitational force of attraction between the Earth and the sun. Then, why does the Earth not collide with the sun? Is it possible for three bodies of equal mass to be at rest relative to each other? Explain.

73. A water tank has a capacity of 1000 litres. It is in the shape of a cylinder. The length of the cylinder is 1 metre. An electric motor pump set is used to fill the water in the tank. This pumpset lifts 120 litres of water per minute. What is the velocity in the shift of centre of gravity of the water tank?

74. What is the force acting on a body of mass 10,000 kg on earth, due to the gravity of the sun? Also, find the force on the body due to the gravity of the moon. Which exerts more force, the sun or the moon?

$$\text{Mass of the sun} = 2 \times 10^{30} \text{ kg,}$$

$$\text{Mass of the moon} = 7.3 \times 10^{22} \text{ kg,}$$

$$\text{Distance between the sun and the Earth} = 1.5 \times 10^{11} \text{ m}$$

$$\text{Distance between the moon and the Earth} = 3.84 \times 10^8 \text{ m.}$$

$$\text{Radius of the Earth} = 6.4 \times 10^6 \text{ m}$$

75. The weight of a person on the surface of the Earth is ' W '. What is his weight at a height R from the surface of the Earth?

76. At a height (h) from the surface of the Earth, a simple pendulum of length $1/2$ m oscillates with a frequency equal to 0.5 Hz. Then find the value of ' h '.

Take, mass of the Earth, $M = 6 \times 10^{24}$ kg, radius of the Earth, $R = 6400$ km and $\pi^2 = 10$.

77. An athlete can jump to a maximum height of 4 m on the surface of the Earth. Considering the same initial velocity for jumping, to what height can he jump from the surface of the moon? [Take, acceleration due to gravity on earth (g_E) as 9.8 m s^{-2} and acceleration due to gravity on the surface of moon as $\frac{1}{6}g_E$]
78. If two spheres of mass 100 tonne each, revolve diametrically opposite to each other in a circle of radius 1 m, what should be their velocities? [Take $g = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$]

79. The orbital velocity of a satellite is given by the expression $V = \sqrt{\frac{GM}{(R+h)}}$, here M is the mass of the

Earth, R is the radius of the Earth and ' h ' is the height of the satellite from the surface of the Earth. Explain the reasons why the geostationary satellite is not possible to set in orbit around the Earth at two different heights from the surface of the Earth.

80. A body is dropped from a height of 40 m from the surface of the Earth. Its final velocity is 28 m s^{-1} . What would be the final velocity of the body, if it is dropped from the same height on another planet where the acceleration due to gravity is 2.5 m s^{-2} . Assume atmospheric conditions to be similar.

(Take earth = 10 m s^{-2} .)



CONCEPT APPLICATION

Level 1

True or false

1. False 2. True 3. False 4. True 5. False 6. False 7. False

Fill in the blanks

8. $y : x$ 9. elliptical 10. \sqrt{dg} 11. neutral 12. third 13. centre of mass
 14. Newton's law of gravitation

Match the following

15. A : e B : d C : i D : c E : b F : j G : a H : g I : f J : h

Multiple choice questions:

16. (d) 17. (b) 18. (a) 19. (c) 20. (c) 21. (c) 22. (a)
 23. (a) 24. (a) 25. (c) 26. (c) 27. (d) 28. (a) 29. (b)
 30. (b) 31. (c) 32. (a) 33. (c) 34. (a) 35. (a) 36. (d)
 37. (d) 38. (b) 39. (c) 40. (a) 41. (b) 42. (b) 43. (c)
 44. (d) 45. (b)

Explanations for questions 31 to 45:

31. Weight = mg

$$= m(0) = 0$$

(\because 'g' value at the centre of curvature is zero)

32. The acceleration due to gravity is independent of mass of a body.

$$33. \quad g_1 = \frac{GM_1}{R_1^2}$$

$$g_2 = \frac{GM_2}{R_2^2}$$

$$M_1 : M_2 = 2 : 3,$$

$$R_1 : R_2 = 4 : 7$$

$$\frac{g_1}{g_2} = \frac{GM_1}{R_1^2} \times \frac{R_2^2}{GM_2} = \frac{M_1 R_2^2}{M_2 R_1^2}$$

$$= \frac{2}{3} \times \frac{7^2}{4^2} = \frac{49 \times 2}{3 \times 16} = \frac{49}{24}$$

$$\therefore \frac{g_2}{g_1} = \frac{24}{49}$$

34. The position of a geostationary satellite appears to be fixed. Time period of rotation of earth and the time period of revolution of the satellite are equal.

35. Spring balance gives the actual weight of a body in air due to negligible upthrust of air.

36. Gravitational force of attraction between two bodies is directly proportional to the product of their

masses, inversely proportional to the square of the distance between them and it is independent of the medium.

37. $m_1 : m_2 = 1 : 10$

$$d_1 : d_2 = 1 : 2 \Rightarrow r_1 : r_2 = 1 : 2$$

$$\ell_1 = 0.4 \text{ m}$$

$$\ell_2 = ?$$

$$g_1 = \frac{GM_1}{R_1^2}; g_2 = \frac{GM_2}{R_2^2}$$

$$\frac{g_1}{g_2} = \frac{M_1}{R_1^2} \times \frac{R_2^2}{M_2} = \frac{1}{10} \times \frac{2^2}{1^2} = \frac{4}{10}$$

$$\frac{T_1}{T_2} \sqrt{\frac{\ell_1}{g_1} \times \frac{g_2}{\ell_2}} = \sqrt{\frac{0.4}{\ell_2} \times \frac{10}{4}}$$

$$\frac{2}{2} = \sqrt{\frac{1}{\ell_2}; \frac{1}{\ell_2}} = \frac{1}{1} \Rightarrow \ell_2 = 1 \text{ m}$$

$$38. \quad g = \frac{GM}{(R+h)^2} = \frac{6.67 \times 10^{-11} \times 66.7 \times 10^{22}}{\left[(4350 + 29,000) \times 10^3 \right]^2}$$

$$= \frac{444.889 \times 10^{11}}{(33350)^2 \times 10^6} = 0.04 \text{ m s}^{-2}$$

39. As the height above the surface of earth decreases, the acceleration due to gravity increases.

40. Escape velocity of a body is independent of its mass.



41. If the line joining centre of gravity of the body and the centre of the Earth passes through the base of the body, the body regains its position after being disturbed. Thus, the body is in stable equilibrium.

42. According to Kepler's second law of planetary motion, the line joining the centers of the sun and a planet covers equal areas in equal intervals of time.

43. According to Kepler's third law of planetary motion,

$$T^2 \propto R^3 \Rightarrow \left(\frac{R_2}{R_1}\right)^3 = \left(\frac{T_2}{T_1}\right)^2$$

$$\text{Given, } T_2 = 3\sqrt{3} T_1 \Rightarrow T_2^2 = 27T_1^2$$

$$\Rightarrow \left(\frac{R_2}{R_1}\right)^3 = 27 \text{ or } \frac{R_2}{R_1} = 3 \Rightarrow R_2 = 3R_1$$

The percentage increase in the radius of the orbit of revolution = $\left(\frac{R_2 - R_1}{R_1}\right)100 = 200$

44. Given, $g_h = g - 96\%$ of $g = \frac{4g}{100} = \frac{g}{25}$

$$\text{Also } g_h = g\left(\frac{R}{R+h}\right)^2 \Rightarrow \frac{g}{25} = g\left(\frac{R}{R+h}\right)^2$$

$$\Rightarrow h = 4R$$

45. Given, $g_d = g\left(1 - \frac{d}{R}\right)$

$$\text{If } g_d = \frac{g}{2} \text{ then } \frac{g}{2} = g\left(1 - \frac{d}{R}\right) \Rightarrow d = \frac{R}{2}$$

Level 2

46. Acceleration due to gravity on the surface of the Earth and the moon be g_E and g_M and its mass and radius be M_e, R_e and M_m, R_m , respectively.

$$\frac{g_E}{g_M} = \frac{GM_E}{R_e^2} \times \frac{R_m^2}{GM_m}$$

Here, diameters of the Earth and the moon are D_E and D_m , respectively.

$$\text{Then, } R_e = \frac{D_e}{2} \text{ and } R_m = \frac{d_m}{2}$$

Find the relation between acceleration due to gravity on the Earth and on the moon with their diameters.

47. (i) Please consider the factors that effect the centre of gravity of a regular and irregular bodies
 (ii) Consider the point as centre of gravity (G) of a body is affected, when elevator accelerates in upwards direction and downward direction

48. What is the effective length (l) of a simple pendulum? Is it equal to the distance between the centre of gravity (C.G.) of the bob and the point of suspension? What is the formula for time period (T) of the simple pendulum?

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

If bob of the simple pendulum is a hollow sphere, and is filled with sand, then C.G. lies at its centre.

If sand keeps leaking continuously from the bottom of the bob through the hole, will the C.G. shift downwards?

Then, this will increase the value of ' l '.

What is the relation between ' T ' and ' l '?

If l increases, then will the value of ' T ' also increase?

49. (i) Find the radius of the Earth from the given data.

Find the heights of the two satellites from the Earth.

What is Kepler's law of time periods?

$$\text{Is } T^2 \propto r^3?$$

Find the ratio of the time periods of the two

$$\text{satellites by the formula } \frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$

(ii) $T_1 : T_2 = 1 : 8$

$$g_1 : g_2 = 16 : 1$$

50. (i) Find the acceleration due to gravity on the planet, g_p by using the formula, $g_p = \frac{GM_p}{R_p^2}$ (1)

But, $M_p = 2M_E$ and $R_p = 2R_E$

Here, $g_E = \frac{GM_E}{R_E^2}$ (2)

Divide (1) by (2) and find the value of ' g_p '.



Then, velocity at the surface, $v_{\max} = \sqrt{2g_p h}$.

Then, maximum kinetic energy of the body is given by, $KE_{\max} = \frac{1}{2} M v_{\max}^2$

(ii) 500 J

51. (i) $V_e = \sqrt{2V_o}$

$$F = \frac{GMm}{R^2} = \frac{mv_o^2}{R}$$

$$v_o = \sqrt{\frac{GM}{R}}$$

$$\Rightarrow \frac{v_{e_1}}{v_{e_2}} = \frac{\sqrt{2}v_{o_1}}{\sqrt{2}v_{o_2}} = \sqrt{\frac{M_1}{R_1} \times \frac{R_2}{M_2}}$$

Given that,

$$\Rightarrow \frac{M_1}{M_2} = \frac{1}{4} \text{ and } \frac{R_1}{R_2} = \frac{1}{2}$$

Substitute the values of M_1 , M_2 , R_1 and R_2 and find the ratio of $\frac{V_{e_1}}{V_{e_2}}$

(ii) $1 : \sqrt{2}$

52. (i) The value of acceleration due to gravity at a height 'h' is given by, g^1

$$= \frac{GM}{(R+h)^2} \quad (1)$$

The value of g^1 is equal height h_E from the surface of the Earth h_m from the surface of the moon.

$$\Rightarrow g^1 = \frac{GM_E}{(R_E + h_E)^2} = \frac{GM_m}{(R_m + h_m)^2} \quad (2)$$

Substitute the values of M_E , M_m , R_E , h_E , R_m and find the value of h_m from equation (2).

(ii) 5300 km

53. (i) Consider the formula, $m_g = \frac{GMm}{R^2}$ (1)

Take acceleration due to gravity on the surface the eath as 'g_o' from equation (1).

Find the acceleration due to gravity (g_h) at a height (h) equal to half of the radius of the Earth from equation (1).

Find the ratio of g_o and g_h . (2)

Take the value of g_o as 9.8 m s^{-2} .

Find the value of 'g_h'.

(ii) 4.36 m s^{-2}

54. (i) Consider Newton's laws of motion and equations of motion.

(ii) When the bodies are dropped from the same height, with zero initial velocity, will the value of the acceleration due to gravity acting on the bodies remain constant (same)?

Will distance moved by the bodies under gravity depend on its weight?

Is factor of 'mass' involved in the equations of motions?

55. (i) Find the volume and base area of the coke can from the given data.

Find the centre of gravity (G_1), when the coke can is filled completely with coke.

Does this G_1 lie at half of the height of the cylinder?

Find the amount of coke consumed by the person after 12 sips.

Find the amount of volume of coke left after 12 sips.

Find the height of the coke in the can by the formula, $h = \frac{\text{volume}}{\text{base area}}$

Then, the centre of gravity (G_2) will be equal to ($h/2$).

If the mass of the can is not negligible, will this have its own centre of gravity?

Will the position G_2 shifts upwards?

(ii) 3 cm

56. (i) Find the height from where the lighter body of mass 1 kg is dropped from the given data.

Find the gravitational force of attraction on the lighter body when it is at the given height (1 km), using the formula,

$$F = \frac{GMm}{(R+h)^2} \quad (1)$$

If a body of mass 4 kg is to experience the same gravitational force of attraction as that of a body of 1 kg mass, find the required conditions.

Here, the force F is proportional to mass and inversely proportional to the $(R+h)^2$.

When mass is increased from 1 kg to 4 kg, then will the distance also increase?



Now, take the height of 4 kg mass as 'x'.

$$\text{Then, } \frac{GMm}{(R+h)^2} = \frac{GM(4m)}{(R+x)^2} \quad (2)$$

Find the value of 'x' by appropriate substitutions in equation (2).

(ii) 6402 km

57. (i) Let the weight of the mine worker on the surface of earth = $w_o = mg_o$ (1)

Acceleration due to gravity at a depth 'd' inside the Earth = $g_d = g_o \left[1 - \frac{d}{R} \right]$ (2)

The weight of the person inside the mine = $w_d = mg_d$ (3)

$$\text{The ratio of } \frac{w_d}{w_o} = \frac{mg_d}{mg_o} = \left[1 - \frac{d}{R} \right] \quad (4)$$

Find the ratio of w_d and w_o .

Solve the 4th equation and obtain the value of d.

(ii) 3200 m

58. (i) Here the force of attraction between the moon and the Earth can be obtained by using the formula

$$F = \frac{GM_E m_m}{r^2} = \frac{m_m v^2}{r}$$

Find the value of v and r from given data

$$\text{But, } v = \frac{2\pi r}{T}$$

Obtain the value of 'T'.

Since 1 day has 86400 s.

Find the number of days the moon takes for one revolution around the Earth as observed from earth.

Divide 'T' by 86400 s to get the value of 'T' in terms of the number of days.

What is a sidereal month and a synodic month?

(ii) 29.5 days

59. (i) Take the mass of the asteroid = m

Take the distance between the asteroid as = d

The attraction between the asteroid is given by,

$$F = \frac{Gm^2}{d^2} \quad (1)$$

The orbital velocity of each asteroid would be = v

$$\text{Then, } F = \frac{mv^2}{r} \quad (2)$$

Equate (1) and (2)

$$F = \frac{Gm^2}{d^2} = \frac{mv^2}{r}$$

Obtain the value of 'v'.

(ii) $1.29 \times 10^3 \text{ m s}^{-1}$

60. (i) The time period of a seconds pendulum = 2 s
 $= 2\pi \sqrt{\frac{\ell}{g}}$

When the volume (V_2) of the Earth shrinks to $\frac{1}{8}$ th of its original volume (V_1), then the radius of the Earth becomes half its original radius.

$$\Rightarrow V_2 = \frac{1}{8} V_1$$

$$\Rightarrow \frac{4}{3} \pi R_2^3 = \frac{1}{8} \left[\frac{4}{3} \pi R_1^3 \right]$$

$$\Rightarrow R_2 = \frac{R_1}{2}$$

$$\text{We know, } g = \frac{GM}{R^2}$$

where 'g' is acceleration due to gravity and 'M' is the mass of the Earth.

$$\Rightarrow g_1 = \frac{GM}{R_1^2} \text{ and } g_2 = \frac{GM}{R_2^2}$$

$$\text{Then, } 2 = 2\pi \sqrt{\frac{\ell_1}{g_1}} = 2\pi \sqrt{\frac{\ell_1}{g_1}}$$

Substitute, the value of 'g₂' and obtain the value of 'ℓ₂'.

(ii) 3.975 m

61. The upthrust formula, $U = V \text{ dg}$

$$\frac{\text{upthrust on the Earth}}{\text{upthrust on the moon}} = \frac{U_E}{U_M} = \frac{V \cdot d \cdot g_E}{V \cdot d \cdot g_m}$$

$$= \frac{g_E}{\frac{1}{6} g_E} = \frac{6}{1}$$

62. Let w_E and w_P be the readings at equator and at poles, respectively.

$$w_E = mg_E, w_P = mg_P \Rightarrow \frac{w_E}{w_P} = \frac{100}{w_P} = \frac{mg_E}{mg_P}$$

$$\Rightarrow w_P = 100 \left(\frac{g_P}{g_E} \right) = 100 \times 1.01 = 101$$



63. Given that, the weights of the two satellites A and B are equal at their heights h_1 and h_2 , respectively.

$$w_1 = w_2$$

Let, acceleration due to gravity at the two satellites be ' g_1 ' and ' g_2 ', respectively.

$$\Rightarrow m_1 g_1 = m_2 g_2$$

$$\Rightarrow (10 \text{ metric tonne}) \frac{GM_E}{(R+h_1)^2}$$

$$= (20 \text{ metric tonne}) \frac{GM_E}{(R+h_2)^2}$$

$$g = \frac{GM_E}{(R+h)^2} \Rightarrow \frac{(R+h_1)^2}{(R+h_2)^2} = \frac{1}{2}$$

$$\Rightarrow \frac{(R+h_1)}{(R+h_2)} = \frac{1}{\sqrt{2}}$$

Therefore, the ratio of their distances from the centre of the Earth = $1 : \sqrt{2}$

64. Take the mass and radius of the Earth as M_0 and R_0 .

The acceleration due to gravity as

$$g_0 = 9.8 \text{ m s}^{-2}.$$

Now, when the mass and radius of the Earth both increase by 20%, then acceleration due to gravity would become ' g_1 '.

Take the new mass and radius of the Earth as ' M_1 ' and ' R_1 '

$$\text{But, } g_0 = \frac{GM_0}{R_0^2}$$

$$\text{and } R_1 = \frac{120R_0}{100} = \frac{6}{5}R_0,$$

$$M_1 = \frac{120}{100}M_0 = \frac{6}{5}M_0$$

$$g_1 = \frac{GM_1}{R_1^2} = \frac{G \times \frac{6}{5}M_0}{\left(\frac{6}{5}\right)^2 \times R_0^2} = \frac{5}{6} \times 9.8 = 8.16 \text{ m s}^{-2}$$

65. The maximum height attained by a body is given by,

$$H = \frac{u^2}{2g}$$

In the case of a person taking a high jump, his initial velocity is same but ' g ' is different. We can write down

$$\frac{H_1}{H_2} = \frac{g_2}{g_1} \Rightarrow \frac{H_1}{H_2} = \left(\frac{R_1}{R_2}\right)^2$$

where H_1 and H_2 are heights attained by the person at pole and equator, respectively, and R_1 , R_2 are radii at pole and equator respectively. Substituting the values,

$$H_1 = 3 \times \left(\frac{R_1}{R_2}\right)^2 = 3 \times \left(\frac{6357}{6378}\right)^2 = 2.98 \text{ m}$$

66. The mass of the person is $\frac{W}{g} = \frac{490}{9.8} = 50 \text{ kg}$

Acceleration due to gravity on the moon, g_m is given by,

$$g_m = \frac{GM}{R^2}$$

substituting the values,

$$g_m = \frac{6.67 \times 10^{-11} \times 7.3 \times 10^{22}}{(1.74 \times 10^6)^2} = 161 \text{ ms}^{-2}$$

weight on the moon = $mg = 50 \times 1.61 = 80.5 \text{ N}$ the ratio of weight on the moon to earth is

$$= \frac{80.5}{490} = 0.16$$

Acceleration due to gravity on Jupiter is, (g_p)

$$g_p = \frac{GM}{R^2}$$

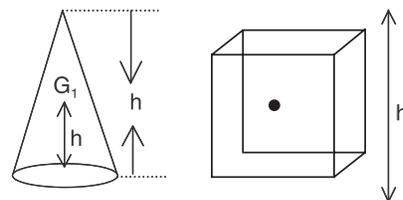
Substituting the values,

$$g_p = \frac{6.67 \times 10^{-11} \times 1.96 \times 10^{27}}{(7 \times 10^7)^2} = \frac{6.67 \times 1.96 \times 10^{16}}{49 \times 10^{14}} = 26.68 \text{ ms}^{-2}$$

weight of person on Jupiter is = $m \times g_p = 50 \times 26.68 = 1334 \text{ N}$

ratio of weight on Jupiter to weight on earth is

67.



The heights of the centre of gravity of the sphere and the cube from their respective bases are

$$h \text{ and } \frac{h}{2} \Rightarrow \frac{h}{\frac{h}{2}} = \frac{2}{1}$$

68. The line joining the centre of gravity of the building and the centre of the Earth falls within the base of the building. So, the building is in stable equilibrium.

69. Ratio of the height of the centre of gravity = $\frac{h}{2} : \frac{d}{2}$

$$= \frac{h}{2} : \frac{h}{2} = 1 : 1$$

70. When the elevator accelerates upwards, the apparent weight of the person who stood inside it increases. When the elevator accelerates downwards, the apparent weight of the person decreases.

Level 3

71. The centripetal force acting on the planet revolving round the sun with orbital velocity ' v ' is,

$$F = \frac{mv^2}{r} \quad (1)$$

Substitute,
$$v = \frac{2\pi r}{T} \quad (2)$$

where ' T ' is the time period of revolution of the planet.

The force of attraction between planet and sun is equal to $\frac{GMm}{R^2}$ (3)

Equate (1) and (3). Then obtain the relation $T^2 \propto r^3$ from the above solution.

72. What is centripetal and centrifugal force? What are the directions of the forces of attraction possible for three bodies of equal masses to be at rest relative to each other and revolving around a given centre. What is the direction of the net force acting on each mass? Will this net force produce centripetal force?

73. The values of the cylinder having 1000 litres capacity is 1 m^3 .

Find the area of the cross section and the height of the cylinder.

If 120 litres of water is pumped into the cylinder for every one minute, then the level of water rises up by the rate of $\frac{120}{1000} \text{ m}$. (1)

Will the C.G. of the water tank rise by $\frac{120}{2000} \text{ m}$ in one minute? (2)

Now, find the change in C.G. of the water tank in one second by dividing (2) by 60 seconds.

74. (i) Take the mass of the body on earth. Find the force of attraction on the body due to the gravity of the moon and sun using the formula,

$F = \frac{GMm}{R^2}$. Find the values of ' F ' due to the sun and moon and then compare the values.

75. (i) Here, the weight of the person on the surface of the Earth is ' w '. Then, $w = mg$

$$= \frac{GMm}{R^2} \quad (1)$$

Then, the weight of the person, (i.e.,) gravitational force of attraction on the person at a height ' h ' will be,

$$w_h = \frac{GMm}{(R+h)^2} \quad (2)$$

Given that height is equal to ' R '. Substitute, ' R ' in place of ' h ' in equation (2). Find the value of ' w_h ' in terms of ' w '.

(ii)
$$W_h = \frac{W}{4}$$

76. The frequency (n) of the given simple pendulum = 0.5 Hz.

Therefore, the time period (T) of the simple pendulum

$$= \frac{1}{n} = \frac{1}{0.5} = 2 \text{ s}$$

We know,
$$T = 2\pi \sqrt{\frac{\ell}{g}}$$

Let the acceleration due to gravity at height (h) from the surface of the Earth = g^1 .

$$\Rightarrow T = 2\pi \sqrt{\frac{\ell}{g^1}} \Rightarrow g_1 = 4\pi^2 \frac{\ell}{T^2}$$

$$= 4 \times 10 \times \frac{1}{(2)^2} = \text{ms}^{-2}.$$



$$\begin{aligned}
 g^1 &= \frac{GM}{(R+h)^2} \Rightarrow (R+h)^2 = \frac{GM}{g^1} \\
 \Rightarrow (64 \times 10^5 m + h)^2 &= \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{5} \\
 &= 6.67 \times 1.2 \times 10^{13} = 80.04 \times 10^{12} \\
 \Rightarrow (64 \times 10^5 m + h) &= \sqrt{80.04 \times 10^{12}} \approx 9 \times 10^6 \text{ m} \\
 h &= (9 \times 10^6 - 6.4 \times 10^6) \text{ m} \\
 h &= 2.6 \times 10^6 \text{ m}
 \end{aligned}$$

The position (h) of the simple pendulum from the surface of the Earth = $h = 2.6 \times 10^6$ m.

77. If the athlete jumps with the same velocity (v) on the surface of the Earth and the moon, then

$$\frac{1}{2}mv^2 = mg_E h_E = mg_m h_m$$

where g_E , h_E , g_m and h_m are acceleration due to gravity and height on earth and moon, respectively.

$$\Rightarrow g_E(4) = \frac{1}{6}g_m h_m \Rightarrow h_m = 24 \text{ m}$$

So, the athlete can jump to a height of 24 m.

78. The centripetal force required for the circular motion is provided by the gravitational force of attraction.

$$\text{We can write } \frac{mv^2}{r} = \frac{Gm^2}{4r^2}$$

$$v = \sqrt{\frac{Gm}{4r}}$$

Substituting the values where

$$m = 100 \text{ ton} = 10^5 \text{ kg}, r = 1 \text{ m and}$$

$$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

$$\begin{aligned}
 v &= \sqrt{\frac{6.67 \times 10^{-11} \times 10^5}{4}} = \sqrt{\frac{6.67 \times 10^{-6}}{4}} \\
 &= \sqrt{1.67} \times 10^{-3} \text{ ms}^{-1}
 \end{aligned}$$

79. Can there be two geostationary orbits?

– No –

The time period of geostationary satellite is 24 hrs (or) 86400 seconds.

$$\text{We know, } T = 2\pi \sqrt{\frac{l}{g}}$$

where $l = (R + h)$ (or)

(Radius of the Earth + height of geostationary orbit from the surface of the Earth)

g = acceleration due to gravity at the geostationary orbit.

$$\text{But, } g = \frac{GM}{(R+h)^2}$$

$$T = 2\pi \sqrt{\frac{(R+h)}{\frac{GM}{(R+h)^2}}} = 2\pi \sqrt{\frac{(R+h)^3}{GM}}$$

Here, G , M , R are constants $\Rightarrow T \propto (R+h)^{3/2}$ So, for only one value of ' h ', ' T ' will be equal to 24 hours. We can have only one geostationary orbit.

80. Final velocity $V_2 = \sqrt{2gh} = \sqrt{2 \times 2.5 \times 40}$
 $= \sqrt{5 \times 40}$
 $= \sqrt{200} = \sqrt{2} \times 10 = 14 \text{ ms}^{-1}$.



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Chapter 6

Hydrostatics



REMEMBER

Before beginning this chapter you should be able to:

- Recall the kinetic theory of matter
- Discuss the different types of pressures and define the Law of liquid pressure
- Study the different principles associated with the study of fluid pressure and atmospheric pressure
- Define properties of fluids like surface tension, upthrust, buoyancy, etc.

KEY IDEAS

After completing this chapter you should be able to:

- Understand how pressure varies with the height of fluid columns
- Learn the principle, construction and working of manometer and different barometers
- Explain Pascal's law and its applications in Bramah press, Hydraulic press and Hydraulic brakes
- Learn Archimedes' principle, laws of floatation and their applications
- Study construction, principle and working of hydrometers
- Understand surface tension and viscosity

INTRODUCTION

Did you at any time wonder, why a small iron nail sinks in water, whereas a huge ship of heavy mass floats on water? An astronaut wears a special suit while attempting to travel in space. Why do deep sea fishes die when brought to shallow water? A submarine can move vertically in water, i.e., it can sink in water as well as float. How does this happen? The answers to all these questions lie in studying and understanding fluid pressure and the principles involved therein. This branch of physics is called **hydrostatics**.

Matter exists in three states, namely solids, liquids and gases. Solids have a definite shape and size, whether regular or irregular. But liquids and gases do not have a definite shape. Both liquids and gases have a common property of ‘flowing’, and hence, are called ‘fluids’. Thus, fluid is a substance that can flow. The interaction of fluids with its surroundings when they are at rest, is studied in hydrostatics. In the current chapter, we deal with pressure exerted by a fluid, transmission of pressure through a fluid and its applications, pressure exerted by the atmosphere, the variation in atmospheric pressure and its measurement using various instruments, bodies which are floating and immersed in fluids and the principles related to them.

Differences between Liquids and Gases

As discussed above, liquids and gases are referred to as fluids. Though they have the common property of flowing, they have certain differences too.

Liquids	Gases
1 In liquids, molecules are loosely packed and the intermolecular forces are lesser than those in a solid.	In gases, molecules are farther apart and the intermolecular forces of attraction are much lesser than those in a liquid.
2 Liquids take the shape of the vessel in which they are contained and have a definite volume.	Gases do not have a definite volume. They occupy the total volume of the container in which they are contained.
3 Variation in the volume of liquids with changes in pressure and temperature is negligible.	Variation in the volume of gases with changes in pressure and temperature is high.
4 When force is applied on liquids, their volume decreases by a very negligible amount, and so, for all practical purposes, they are considered to be incompressible.	The volume of a gas can be decreased considerably by applying force, and so, they are highly compressible.
5 Density of a liquid does not change much when an external force is applied.	Density of a gas changes considerably when it is subjected to an external force.
6 A liquid is characterized by a free surface in a container.	As gases occupy the entire space in which they are enclosed, they do not have any free surface.

The fluids, i.e., liquids and gases can be subjected to forces from different directions and their interaction with their surroundings can be studied. Before we study the interaction of fluids that are at rest with the surroundings, we introduce certain terms and their definitions.

THRUST

To stick a postal stamp on an envelope, we apply a force perpendicular to the surface of the stamp. We leave foot-prints when we walk on sand, due to the weight of our body acting normal to the sand surface in contact with the feet. Such a force acting normal to the surface in contact is called thrust.

Thrust is defined as the force acting on a body normal (perpendicular) to its surface. The unit of thrust is same as the unit of force, i.e., dyne in C.G.S system and newton (N) in S.I. system. Thrust is also expressed in gravitational units called kg_{wt} (kilogram weight) or kg_f (kilogram force). 1 kg_{wt} or $1 \text{ kg}_f = 9.8 \text{ N}$. Similarly, 1 g_{wt} or $1 \text{ g}_f = 980 \text{ dyne}$.

PRESSURE

It is a common experience that, fixing a blunt nail to a wall is difficult compared to fixing a sharp one. In the two cases, even though the force applied on the nail by the hammer is equal, the force applied per unit area of the nail that is in contact with the wall is important. In the case of a blunt nail, this area is larger compared to that of a sharp nail, and so, it is easier to fix a sharp nail. This force or thrust (as the force is applied normal to the surface of nail) exerted per unit area is called pressure. Thus, thrust acting per unit surface area is defined as pressure.

Mathematically,
$$\text{Pressure, } (P) = \frac{\text{Thrust } (F)}{\text{area } (A)}$$

Pressure is measured in units of dyne per square cm (dyne cm^{-2}) in C.G.S system and newton per square metre (N m^{-2}) in S.I. system. One newton per square metre is also known as pascal (Pa) in honour of French scientist Blaise Pascal.

$$\begin{aligned} 1 \text{ Pa} &= 1 \text{ N m}^{-2} \\ 1 \text{ N m}^{-2} &= 10 \text{ dyne cm}^{-2} \end{aligned}$$

The gravitational unit of pressure is kilogram force per square metre ($\text{kg}_f \text{ m}^{-2}$), which is approximately equal to 10 Pa.

$$1 \text{ kg}_f \text{ m}^{-2} = 10 \text{ Pa.}$$

For meteorological purposes, the unit of pressure is taken as bar.

$$1 \text{ bar} = 10^5 \text{ Pa.}$$

Fluid Pressure

Consider a rubber balloon fixed to the bottom of a hollow glass tube as shown in Fig. 6.1. When water is poured into the tube, we observe that the balloon swells, as shown in Fig. 6.2. This indicates that the water poured in the tube exerts a force on the inner walls of the balloon. The force exerted by water on the inner walls of the balloon acts in all directions, as shown by arrows in Fig. 6.2. The force exerted per unit area is pressure, as discussed earlier, and thus, we can say that water exerts pressure on the inner surface of the balloon in all directions. Similar to water every fluid exerts pressure and this pressure exerted by a fluid is known as 'fluid pressure'.

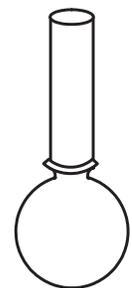


FIGURE 6.1

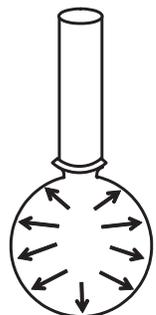
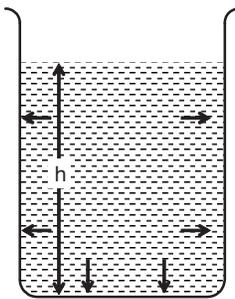


FIGURE 6.2

Fluids exert pressure in all possible directions. Such as, vertically downwards, vertically upwards and on the sides of a container. The pressure of the fluid acting sideways is known as its 'lateral pressure'.

In a fluid, the molecules are in random motion. Due to the random motion, they collide among themselves and also with walls of the container. As the walls of the container are strong, on colliding, the fluid molecules bounce back. In this process the molecules undergo a change in momentum. The change in momentum of the fluid molecules per second on colliding with walls of the container constitutes a force exerted by the fluid on the walls of its container. This force or thrust exerted per unit area is the pressure exerted by the fluid on the walls of its container.

Mathematical Expression for Fluid Pressure



Consider a liquid of density ' ρ ' in a beaker upto a height ' h ' as shown in the Fig. 6.3. The liquid exerts pressure in all directions. The force exerted on the lateral sides of the beaker by the liquid is equal in all directions at a horizontal level, and thus, net force acting on the walls is zero. There is a resultant force exerted on the bottom portion of the beaker by the liquid. If ' A ' is the area of cross section of the beaker and ' F ' is the force exerted by the liquid on the bottom of the beaker, then pressure

$$P = \frac{\text{Force}(F)}{\text{area}(A)} = \frac{F}{A}$$

FIGURE 6.3 The force (F) is equal to weight of the liquid.

\therefore weight of the liquid $w = mg$, where ' m ' is the mass of liquid, ' g ' is acceleration due to gravity.

$$\begin{aligned} \text{Mass } (m) &= (\text{volume}) (\text{density}) \\ &= (\text{area of cross section of beaker}) (\text{height of liquid column}) (\text{density of liquid}) \\ &= a h \rho \end{aligned}$$

$$\therefore w = a h \rho g$$

$$\text{Pressure, } P = \frac{F}{A} = \frac{W}{A} = \frac{Ah\rho g}{A} = h\rho g$$

$$P = \frac{F}{A} = \frac{W}{A} = \frac{ah\rho g}{a}$$

$$\therefore P = h\rho g$$

Thus, pressure exerted by a liquid at a point inside it is directly proportional to

1. the height of the liquid column above that point
2. the density of the liquid
3. acceleration due to gravity at that place

Consider a big water tank with taps at different levels as shown in the Fig. 6.4. The taps A and B are at equal height; but on diametrically opposite points in the tank. Similarly the taps C and D are at the same height but below the level of taps A and B. The taps E and F are at a height lower than the taps C and D. Initially the water in the tank is much above the height of the taps A and B. When all the taps are opened simultaneously, we observe water

flowing out of the taps as shown in the Fig. 6.4. This simultaneous flow of water from all taps demonstrates that the pressure inside a liquid is directly proportional to the depth from its surface. At a given depth the pressure is equal in all directions along a horizontal plane.

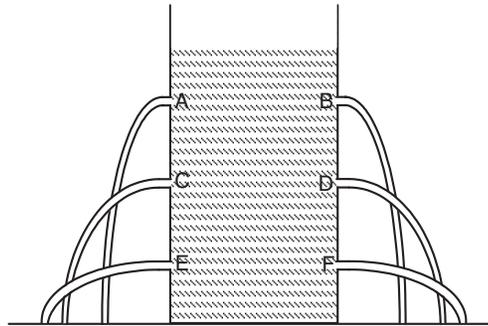


FIGURE 6.4

Irrespective of the shape and the size of containers, liquids seek their own level. Consider a vessel having a vessel having different glass tubes having different shapes and area of cross section connected through a horizontal tube at the bottom as shown in the Fig. 6.5.

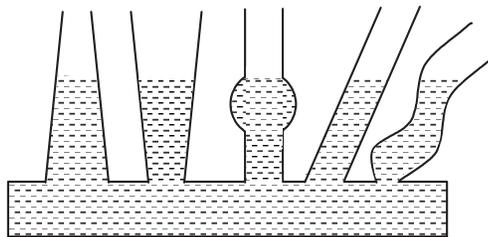


FIGURE 6.5

Pour some coloured water into the connected tubes through any one of the tubes. We find that the level of the coloured water in all the tubes is equal at any instant of time. This proves that **a liquid seeks its own level**. This principle is used by masons in determining the slope of a floor and fixing levels in building construction related activities.

Atmospheric Pressure

The thick blanket of air covering the entire earth's surface is called atmosphere. It extends from surface of earth to about 300 km above the Earth's surface. It is composed of a mixture of gases. The pressure exerted by these atmospheric gases on the surface of the Earth is known as atmospheric pressure.

The unit of atmospheric pressure is pascal (Pa) in S.I. system of measurement. But it is generally expressed in centimetre or millimetre of mercury column. The atmospheric pressure at 0°C and at sea level is 76 cm or 760 mm of mercury and is generally referred to as a unit called 'atmosphere' (atm). 1atm is the pressure exerted by a vertical column of mercury of 76 cm (or 760 mm) height.

Relation between 'atmosphere' and pascal:

$$\begin{aligned} \therefore 1 \text{ atm} &= 76 \text{ cm} \times 13.6 \text{ g cm}^{-3} \times 9.8 \text{ m s}^{-2} \text{ (using 'h}\rho\text{g' for pressure exerted by a liquid)} \\ &= 0.76 \text{ m} \times 13.6 \times 10^3 \text{ kg m}^{-3} \times 9.8 \text{ m s}^{-2} \\ &= 101292.8 \text{ N m}^{-2} \text{ or Pa} \\ &\approx 1.013 \times 10^5 \text{ Pa.} \end{aligned}$$

Other units usually used in measurement of pressure are 'torr' and 'bar'

$$1 \text{ torr} = 1 \text{ mm of Hg}$$

$$1 \text{ bar} = 10^5 \text{ Pa}$$

Measurement of Atmospheric Pressure

The instrument used for measuring atmospheric pressure is known as barometer. Generally, in a barometer a liquid is used for measuring atmospheric pressure. This liquid is known as 'barometric liquid'.

The Properties of a Barometric Liquid

1. A barometric liquid should have high density so that a short column of liquid can counter-balance the atmospheric pressure.
2. It should have negligible vapour pressure so that the pressure shown by the liquid column is the accurate atmospheric pressure.
3. The liquid should be in its pure form since any impurities present in the liquid may change its density and affect the measurement.
4. The liquid should be opaque so that it is easily visible and the length of column can be measured.
5. The liquid should not stick to the walls of the container because if it sticks to the container walls, it cannot give the accurate readings.

As mercury satisfies most of the above mentioned properties, it is generally used as the barometric liquid. The density of mercury is 13.6 g cm^{-3} , and so, the length of the mercury column which counter-balances the atmospheric pressure is not high and is only 76 cm at mean sea level. If water were used, its height would have been $13.6 \times 76 \text{ cm} \approx 10\text{m}$! Its vapour pressure is negligible and does not affect the atmospheric pressure.

The pressure at a point inside a liquid, as discussed earlier, is given by, ' $h\rho g$ ', where ' h ', ' ρ ' are the height of the liquid column and its density, respectively, and ' g ' is the acceleration due to gravity. For a given liquid of certain density, the pressure exerted by the liquid column increases with its height. Thus, it is convenient to express pressure exerted by a liquid in terms of its height or length of the liquid column. So, atmospheric pressure is measured in terms of height of a mercury column; instead of its S.I. unit pascal.

Simple Barometer

A glass tube of about one metre length, and 1 cm in diameter is filled completely with mercury as shown in Fig. 6.6a. The mouth of the tube is closed with the thumb so that no air

is trapped in the tube. Now the tube is inverted and dipped in a trough containing mercury such that the mouth of the tube closed with thumb is inside the mercury of the trough. Now, slowly the thumb is removed keeping the mouth of the tube inserted in the mercury of the trough; the mercury in the trough comes into contact with mercury of the tube. After some time, some of the mercury from the tube flows into the trough leaving a column of vacuum above the surface of mercury. This vacuum is called Torricellian vacuum, named after the scientist Torricelli who invented this barometer. The length of the mercury column in the tube was found to be 76 cm at sea level.

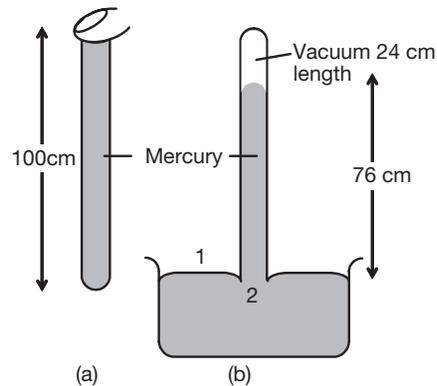


FIGURE 6.6 Simple barometer

The free surface of mercury (1) present in the trough is exposed to the atmosphere so the pressure exerted by atmosphere on the free surface of mercury in the trough is the atmospheric pressure. At the same level, inside the inverted glass tube, (2) the pressure is equal to the pressure exerted by 76 cm length of the mercury column. Hence, we say pressure exerted by 76 cm column of mercury is equal to the atmospheric pressure and it is taken as a standard for measurement of atmospheric pressure known as ‘one atmosphere’ as discussed earlier.

It is found that the vertical height of the mercury column inside the tube does not change with size and shape of the tube and also the orientation of the tube in the trough, i.e., even if the tube is tilted, the vertical height of mercury column inside the tube remains the same. This vertical height of mercury in the tube is known as ‘barometric height’.

Factors Affecting the Barometric Height

The following factors affect the barometric height in a barometer.

- 1. Moisture in mercury:** If the mercury in a barometer contains moisture, i.e., water vapour or any other liquid like alcohol, etc., it vapourizes in vacuum above the surface of mercury in the tube and these vapours exert pressure on mercury. So, the level of mercury falls and shows an inaccurate reading. The pressure due to the vapour present above the mercury column in a barometer is calculated by the following expression.

$$\text{Vapour pressure} = \text{True atmospheric pressure} - \text{pressure due to barometric liquid}$$

- 2. Dissolved impurities in mercury:** If mercury present in a barometer is impure, its apparent density is lowered. This increases the height of mercury column giving false reading of the atmospheric pressure at the given place.

- 3. Height from sea level:** As the vertical height from mean sea level increases, the atmospheric pressure decreases. Figure 6.7 shows the variation of atmospheric pressure with height above mean sea level. Thus, the vertical height of the mercury column in a barometer decreases as vertical height from mean sea level increases.

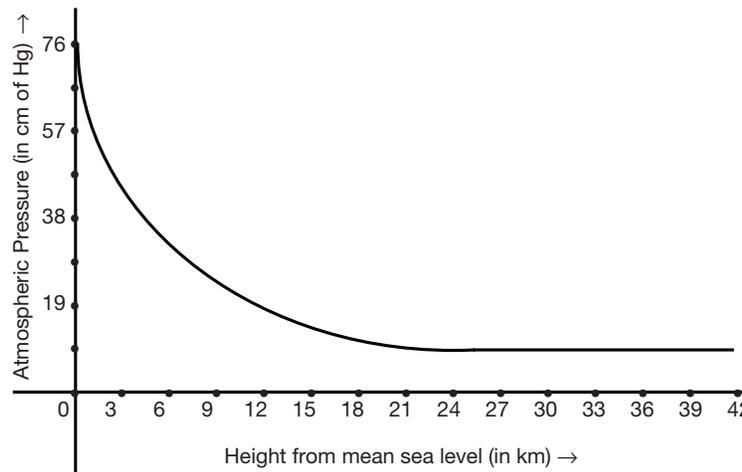


FIGURE 6.7 Variation of atmospheric pressure with altitude

- 4. Atmospheric temperature:** As the temperature rises, the density of atmospheric air decreases. This reduces the atmospheric pressure at a given height from mean sea level. So, the height of mercury in the barometer decreases. Similarly if the temperature decreases, the density of atmospheric air increases, and so, the atmospheric pressure at a given height from mean sea level also increases. This increases the height of the mercury column in a barometer.
- 5. Humidity:** Humidity is water vapour present in atmosphere. As humidity increases, the effective density of atmosphere decreases, and so, the height of mercury in a barometer decreases.

Disadvantages of a Simple Barometer

The simple barometer discussed above, however, has some disadvantages. They are as follows:

1. The surface of mercury in the trough does not always coincide with zero of the scale fitted to the glass tube because, due to change in atmospheric pressure, the level of mercury in the trough can change to account for the change in the length of mercury column. So, it is difficult to note the true atmospheric pressure.
2. It is not convenient to move the simple barometer from one place to another.
3. Since mercury in the trough of simple barometer is exposed to air, there is a chance of the mercury getting polluted due to dust.
4. There is no protection to the glass tube and this may result in the breakage of the tube.
5. Without proper support it is difficult to keep the glass tube in the vertical position and if the tube is inclined, it is difficult to measure the vertical height of the mercury column in the tube.

Fortin's Barometer

To overcome these defects another barometer called Fortin's barometer. It was developed and named after the scientist who developed it. The basic structure of a Fortin's barometer is similar to that of a simple barometer. Fortin's barometer has special features so as to adjust the level of mercury in the trough to zero mark. The glass tube is provided with a support so that it is always in vertical position. A vernier scale is provided along with the main scale attached to the glass tube containing barometric liquid, i.e., mercury, to have more accurate measurement. A Fortin's barometer consists of a mercury bowl, specially designed to eliminate zero error.

The bowl consists of a leather bag attached to a brass cylinder. To the bottom of the leather bag, a screw is arranged. By turning this screw the level of mercury in the trough is adjusted to the zero mark indicated by the ivory pointer fixed to a brass cap as shown in in the Fig. 6.8. The glass tube containing mercury is inserted into the bowl of mercury in inverted position with Torricellian vacuum above the mercury column.

This tube is fixed to an outer protective brass tube with a scale attached behind the glass tube. This scale is the main scale and another vernier scale is arranged sliding over the main scale. An adjustment screw is provided to fix the vernier scale in the desired position. The outer protective brass tube is provided with a slit so as to note the barometric readings. The total arrangement is fixed in a vertical position to the wall by means of a suspension hook provided at its top. The brass cap is provided with two holes, one for the barometer tube and another for air.

To note the barometric reading, first the mercury level in the bowl is made to coincide with zero mark with the help of leveling screw. Next, the least count of the vernier scale attached to the main scale is calculated, then the total reading is calculated by observing main scale reading and vernier coincidence.

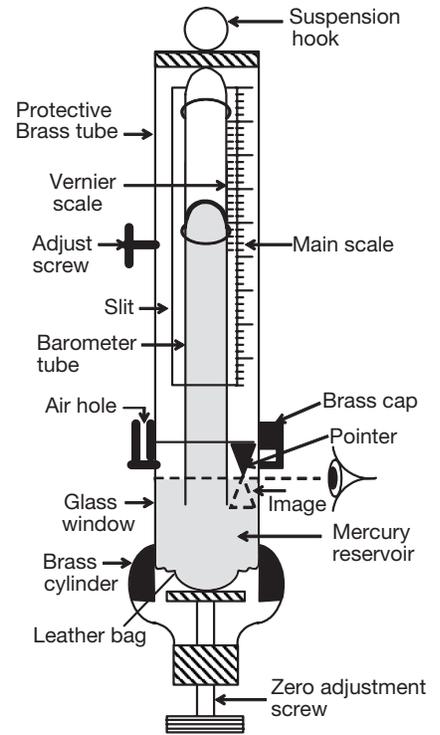
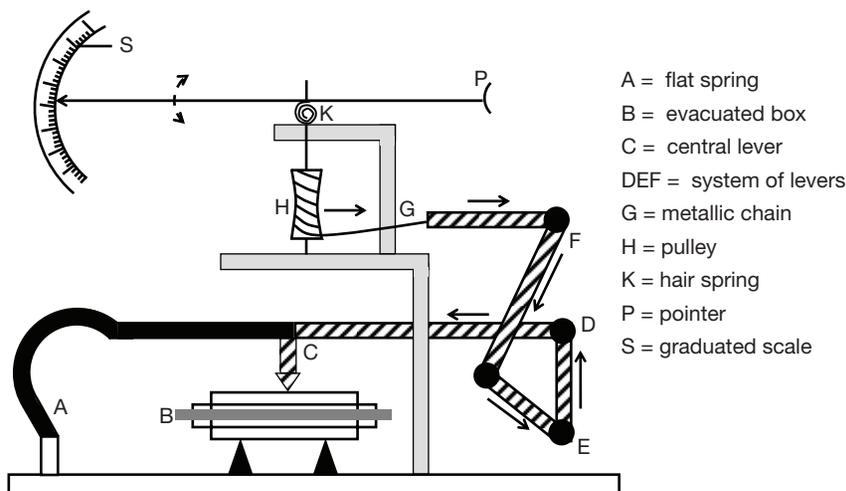


FIGURE 6.8 Fortin's barometer

Aneroid Barometer



- A = flat spring
- B = evacuated box
- C = central lever
- DEF = system of levers
- G = metallic chain
- H = pulley
- K = hair spring
- P = pointer
- S = graduated scale

FIGURE 6.9 Aneroid barometer

The Fortin's barometer discussed above contains large amount of mercury, is bulky and cannot be shifted from one place to another easily. It is not portable and shifting has to be done carefully so that mercury does not spill out from the mercury reservoir, i.e., the leather bag. To over-come these problems, a barometer is developed which does not contain a liquid and can be taken to any desired place. It is known as 'aneroid barometer'. Aneroid means 'not wet' in Greek. Thus, this barometer does not contain any liquid and also it is portable, convenient to carry anywhere and can be fixed in any plane.

It consists of a partially evacuated box B having a diaphragm. This box is supported by base of a circular wooden box. To the central portion of the diaphragm of the box, a central lever (C) is fixed and this lever is supported by a flat spring (A). This flat spring also protects the diaphragm from not collapsing. The central lever is connected to a pulley (H) through a system of levers (D, E, F) and a small chain (G). The pulley shaft is connected to a horizontal needle or a pointer which rotates over a circular scale (S). The hair spring (K) attached helps to restore the position of the needle.

When the atmospheric pressure is more, the diaphragm is pressed down moving the central lever down. The downward movement of the central lever causes pull of the chain and the pointer moves. In this process the hair spring gets wound up and when the pressure is normal or low, an opposite effect is produced resulting in rotation of pointer in the opposite direction.

Advantages of an Aneroid Barometer over Simple Barometer

1. An aneroid barometer does not use any liquid. So, the problem due to spillage of liquid does not arise.
2. Errors due to differential expansion of the liquid and the glass container do not arise in the case of an aneroid barometer.
3. An aneroid barometer is free from defects caused by impure or moist mercury.
4. It is light in weight, compact and portable.
5. It can be fixed in any plane unlike the mercury barometer which has to be fixed in an upright position.

Uses of Barometer

1. Barometer shows the atmospheric pressure and atmospheric pressure varies with the altitude from mean sea level. So, the barometers can be used to measure altitudes from mean sea level, and thus, can be used in 'altimeters', instruments used to find altitudes from the mean sea level. On rising to 105 m from surface of earth, atmospheric pressure falls by 1 cm of Hg. An aneroid barometer with its scale calibrated to read the altitude in metre, can be used as an altimeter.
2. At a given height from the surface of earth, atmospheric pressure can decrease either due to an increase in humidity or due to rise in temperature. So, these facts can be used to predict the weather conditions in a given area. If the fall in atmospheric pressure is due to temperature, without any increase in humidity, it may lead to a dust storm. If the decrease in atmospheric pressure is due to increase in humidity, there are two

possibilities that can take place. If the decrease in atmospheric pressure is gradual, the weather changes gradually to rainy condition. If there is a sudden fall in atmospheric pressure, it indicates a cyclonic condition.

Manometer

It is a device which is used to measure pressure of a gas. It consists of a hollow glass tube with uniform inner diameter bent in the shape of letter 'U' open at both ends. The tube contains liquid in both the arms as shown in Fig. 6.10.

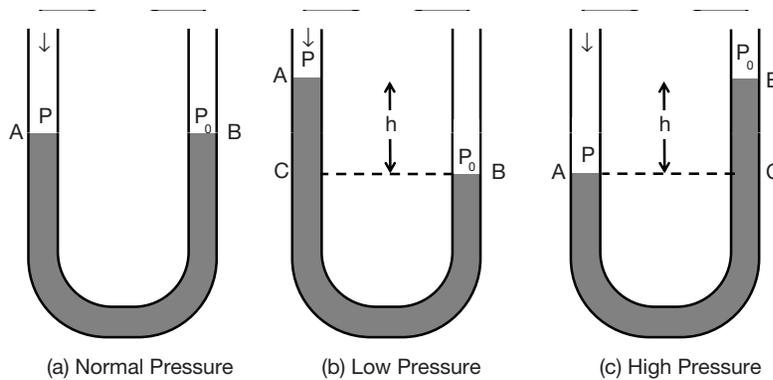


FIGURE 6.10 Manometer

When both the arms of the manometer are exposed to air, the level of liquid in both the arms is equal, as pressure at the surface of the liquid in both the arms is equal to the atmospheric pressure (P_0). One of the arms of the tube, say left arm, is connected to a container consisting of gas. When the level of liquid in both the arms is equal as shown in Fig. 6.10 (a), the pressure of the gas enclosed in the container (level A) is equal to the atmospheric pressure (level B). When the level of the liquid in the left arm is above the level of liquid in the right arm as shown in Fig. 6.10 (b), the pressure of the gas in the container (P) is less than the atmospheric pressure (P_0). Considering an equal level point 'C' in the left arm to level B in the right arm,

$$\begin{aligned} \text{Pressure at C} &= \text{Pressure at B} \\ \Rightarrow P + h\rho g &= P_0 \end{aligned}$$

where ' h ' is the difference in the levels of the liquid in both the arms, ' ρ ' is density of the liquid and ' g ' is acceleration due to gravity.

$$\therefore \text{Pressure of gas, } P = P_0 - h\rho g.$$

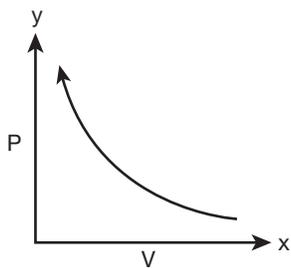
Similarly, when the pressure of the gas is more than the atmospheric pressure, the liquid in the left arm of the manometer is pushed down as show in Fig. 6.10 (c) and the pressure of the gas is given by, $P = P_0 + h\rho g$.

NOTE

Generally the liquid taken in the manometer tube is mercury. As atmospheric pressure is expressed in terms of height of mercury column, it is convenient to express pressure of a gas in terms of the height of the mercury column.

BOYLE'S LAW

Consider a glass cylindrical vessel having uniform diameter of about 40 cm and length about 150 cm. Let it be filled completely with water. If we create an air bubble at the bottom of the vessel with the help of a long, narrow glass tube, we observe that the air bubble created at the bottom of vessel, rushes to the surface of water. The interesting thing to be observed here is that as the bubble reaches the upper surface, its size increases. This implies that the volume of the air bubble increases as it moves to the top of the vessel. We are aware that the pressure exerted by water at a certain depth is ' $h\rho g$ ' where ' h ' is the depth of the water column, ' ρ ' is its density and ' g ' is acceleration due to gravity. As the bubble moves towards the surface of water, the depth at which the air bubble is present in the water decreases. Hence, the pressure exerted by water on the air bubble decreases gradually and simultaneously its volume increases as the bubble reaches the top. The pressure and volume of the air bubble vary such that their product remains constant. Thus, the volume of the air bubble is inversely proportional to its pressure. This is true for any gas at a constant temperature and is known as Boyle's law.



Thus, according to Boyle's law at a constant temperature, the volume (V) of a given mass of a gas is inversely proportional to its pressure (P). The relation between P and V is shown in graph given below.

Mathematically,
$$P \propto \frac{1}{V}$$

where ' P ' and ' V ' are pressure and volume of the given gas, respectively.

$$\Rightarrow PV = \text{constant.}$$

Area under $P - V$ graph is constant at given temperature for the given gas.

If P_1 and V_1 are the initial pressure and volume of a gas, respectively, and P_2 and V_2 are its final pressure and volume, respectively, then at constant temperature, $P_1 V_1 = P_2 V_2$.

EXAMPLE

At a given temperature, pressure of helium gas is P_a and its volume is 400 ml. Find volume occupied by it at $2P_a$.

SOLUTION

$$\begin{aligned} P_1 V_1 &= P_2 V_2 \\ \Rightarrow \frac{V_2}{V_1} &= \frac{P_1}{P_2} \\ V_2 &= \frac{x \times 2}{x} \times 400 \\ \Rightarrow V_2 &= 800 \text{ ml} \\ \therefore V_2 &= 800 \text{ ml} \end{aligned}$$

PASCAL LAW—TRANSMISSION OF FLUID PRESSURE

Sometimes, a word of caution is written on the rear side of heavy vehicles like buses and trucks as ‘Air brake, keep 50 feet distance’. Did you at any time, contemplate on the meaning of the caution? The caution indicates that air is used in applying brakes to the heavy vehicle! Similarly some vehicles like cars use oil in the brake system for the effective application of brakes. To have a complete comprehension of such a system, we need to understand a principle discovered by a French scientist Blaise Pascal.

An increase in pressure at any point inside a liquid at rest, is transmitted equally and without any change, in all directions to every other point in the liquid. This is known as **Pascal’s Law**. This law is useful in designing instruments like Bramah press, hydraulic press etc. It is the principle in the development of hydraulic brakes, that are used in automobiles. This law is also known as **the law of transmission of fluid pressure**.

Bramah Press

Bramah press is the concept based on Pascal’s law of transmission of fluid pressure. The idea involved in the concept is to lift a heavy load by applying much smaller effort.

Consider two cylinders ‘P’ and ‘Q’ having different areas of cross section ‘ a_1 ’ and ‘ a_2 ’ ($a_1 < a_2$), respectively, connected at the bottom by another horizontal tube as shown in the Fig. 6.11. The two cylinders are filled with a liquid and are fitted with air tight pistons. If a force ‘ F_1 ’ is applied on the piston of cylinder ‘P’, the pressure exerted on the liquid in the cylinder ‘P’ is

$$P_1 = \frac{F_1}{a_1}.$$

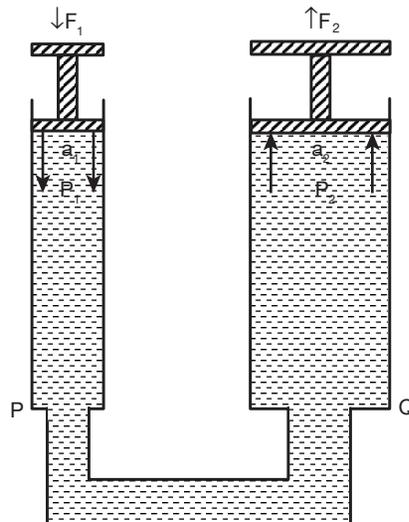


FIGURE 6.11 Bramahpress

According to Pascal’s law, this applied pressure is transmitted to every part of the fluid in all directions. So, the same pressure is applied on the piston of cylinder ‘Q’ in the upward direction.

If the pressure applied on piston of cylinder 'Q' is ' P_2 ', then $P_1 = P_2$. As the area of cross section of the cylinder 'Q' is ' a_2 ', the force exerted on the piston of cylinder 'Q' is given by, $F_2 = a_2 P_2$.

But
$$P_2 = P_1 = \frac{F_1}{a_1}$$

$$\therefore F_2 = a_2 \times \frac{F_1}{a_1} = \left(\frac{a_2}{a_1}\right) F_1$$

As $a_2 > a_1$, $F_2 > F_1$, thus, the force on piston of cylinder 'Q' is $\left(\frac{a_2}{a_1}\right)$ times the force applied on piston of cylinder 'P', thus, applying small force at one point, this force can be multiplied at the other point and a heavy load kept on the platform of piston of cylinder 'Q' is lifted.

EXAMPLE

The area of cross section of two cylinders of a Bramah press are 10 cm^2 and 50 cm^2 , respectively. In order to move up a weight of 100 N placed on the bigger piston, what force should be applied on the smaller piston of smaller area?

SOLUTION

Given $a_1 = 10 \text{ cm}^2$ and $a_2 = 50 \text{ cm}^2$

Also given $F_2 = 100 \text{ N}$, $F_1 = ?$

Pressure is equal on both the pistons $\Rightarrow P_1 = P_2$

$$\Rightarrow \frac{F_1}{a_1} = \frac{F_2}{a_2}$$

$$\Rightarrow F_1 = \left(\frac{F_2}{a_2}\right) a_1 = \left(\frac{100}{50}\right) 10 = 20 \text{ N}$$

Thus, 20 N force applied on the piston of smaller area is sufficient to lift a weight of 100 N placed on the piston of larger area.

Hydraulic Press

Bramah press schematically represents a hydraulic press, which is used in compressing cotton bales or straw bales and also has many applications in industries.

Construction

It consists of an underground water tank, to which two tubes, one called 'pump tube' or 'pump cylinder' and another called 'press tube' or 'press cylinder' having greater cross sectional area than the former are connected with the help of pipes as shown in the Fig. 6.12.

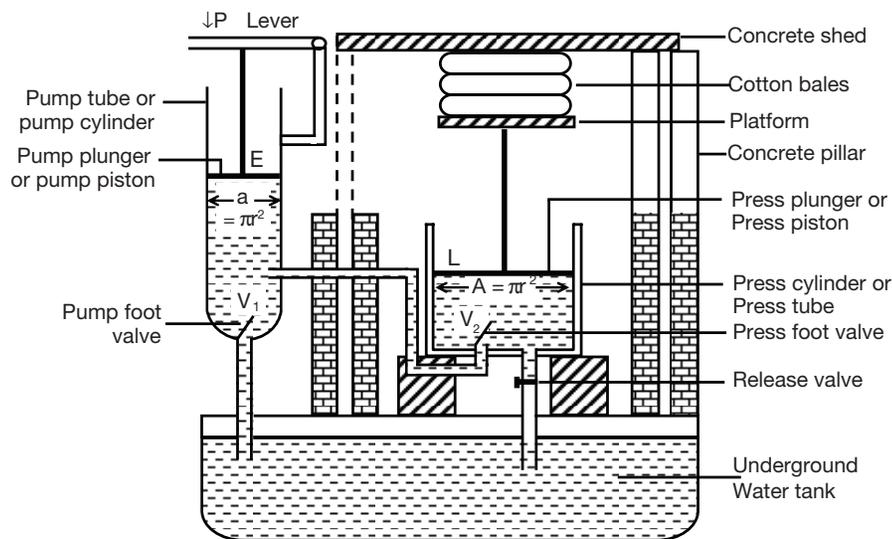


FIGURE 6.12 Hydraulic Press

A concrete shed is built around the press tube. The pump tube and press tube are connected by another horizontal tube as shown. The two tubes are provided with air tight pistons, named 'pump plunger' or 'pump piston' fitted to the 'pump tube' and 'press plunger' or 'press piston' fitted to the 'press tube'. The pipe connecting the pump tube and the under ground water tank is provided with a foot valve ' V_1 ' which opens in the upward direction. Similarly another valve ' V_2 ' is provided to the tube connecting pump and press tubes, which also opens in upward direction. A 'release valve' is provided in the pipe connecting press tube and the underground water tank. A lever is provided to the piston of the pump tube so as to regulate the action of the press.

Working

The material like cotton bales, etc., that are to be pressed are kept on the platform connected to the piston of the press tube, i.e., press plunger. The lever attached to the pump plunger is lifted up so as to draw water into the pump tube. In this process, the valve ' V_1 ' is open. The release valve of the press cylinder is in closed position.

On pressing the piston of pump tube, a pressure is applied on water in the pump tube which is transmitted to the water in the press tube, and due to this pressure, the valve ' V_1 ' is closed and valve ' V_2 ' is opened. The pressure transmitted to the water in the press tube, is exerted on the press plunger and a thrust acts on the plunger which moves the platform and the material placed on it in the upward direction. The material is then pressed against the ceiling of the concrete shed and gets compressed. To lower the platform of the press cylinder, the release valve is opened and water drains into the under ground tank. This results in the valve ' V_2 ' being in closed position.

As the area of cross section of press cylinder ($a_1 = \pi R^2$, where ' R ' is its radius) is larger than the area of cross section of the pump cylinder ($a_2 = \pi r^2$, where ' r ' is its radius), the thrust transmitted to the piston of the press cylinder increases proportionately.

Mechanical Advantage

The force exerted on the pump piston is the effort (E) and the weight lifted by the press piston is the load (L).

The pressure exerted by the pump piston on water in the pump cylinder = $\frac{\text{force}}{\text{area}} = \frac{E}{a_2} = \frac{E}{\pi r^2}$

\therefore The pressure acting on the water in the press cylinder = $\frac{E}{a_2}$

\therefore Thrust or force acting on the press piston in the upward direction

$$= (A) \times \left(\frac{E}{a} \right) = (\pi r)^2 \left(\frac{E}{\pi r^2} \right)$$

This thrust acting on the press piston upward = Load lifted by the piston (L)

$$\therefore L = (a_1) \left(\frac{E}{a_2} \right) \Rightarrow \frac{\text{Load } (L)}{\text{Effort } (E)} = \frac{a_1}{a_2}$$

But $\frac{\text{Load } (L)}{\text{Effort } (E)} = \text{Mechanical Advantage (M.A.)}$

$$\begin{aligned} \therefore \text{M.A.} &= \frac{\text{Area of cross section of press cylinder}}{\text{Area of cross section of pump cylinder}} = \frac{\pi R^2}{\pi r^2} \left(\frac{R}{r} \right)^2 \\ &= \frac{\text{Square of the radius of press cylinder}}{\text{Square of the radius of pump cylinder}} \end{aligned}$$

Uses

Hydraulic press has many applications. Some of them are as follows:

1. Hydraulic press is used in compressing cotton bales and straw bales.
2. It is used for punching holes in metallic sheets.
3. Hydraulic press is used to compress metallic scrap in industries.
4. Hydraulic press is used to bend metallic sheets and steel structural members into desired shapes.
5. It is used in the forging industry.
6. It is used in the extraction of oil from oil seeds.
7. Lifting of automobiles at service stations.

EXAMPLE

A car of mass 1400 kg placed on the platform in a service station has to be lifted up. The area of the press piston to which the platform is fixed is 5 m². Determine the force that has to be applied on the piston of pump cylinder having an area of cross section 0.25 m².
(Take $g = 10 \text{ m s}^{-2}$)

SOLUTION

Given, mass of the car, $m = 1400 \text{ kg}$

\therefore weight of the car = force on the press piston = $mg = 1400 \times 10 = 14000 \text{ N}$.

area of the press piston, $a_2 = 5 \text{ m}^2$

area of the pump piston, $a_1 = 0.25 \text{ m}^2$

Let the force to be applied on the pump piston be ' F_1 '

$$\begin{aligned} \therefore \frac{F_1}{a_1} &= \frac{F_2}{a_2} \\ \Rightarrow F_1 &= \frac{F_2}{a_2} \times a_1 = \frac{14000}{5} \times 0.25 = 700 \text{ N}. \end{aligned}$$

EXAMPLE

In the previous example, calculate the mechanical advantage of the vehicle lifting machine.

SOLUTION

Given area of the pump piston, $a_1 = 0.25 \text{ m}^2$

area of the press piston, $a_2 = 5 \text{ m}^2$

Mechanical advantage of the machine,

$$\text{M.A.} = \frac{\text{Area of the press piston } (a_2)}{\text{Area of the pump piston } (a_1)} = \frac{5}{0.25} = 20$$

HYDRAULIC BRAKES

Hydraulic brakes are generally used in automobiles having large mass like cars, trucks etc. When a heavy vehicle is moving with a high speed, in order to stop it within a required distance, a large amount of retarding force is required. In such a situation, a considerable amount of force cannot be applied on the wheels of the vehicle by ordinary lever brakes. So, hydraulic brakes are used.

Hydraulic brakes as shown in the Fig. 6.13 work on the principle of Pascal's law of transmission of fluid pressure.

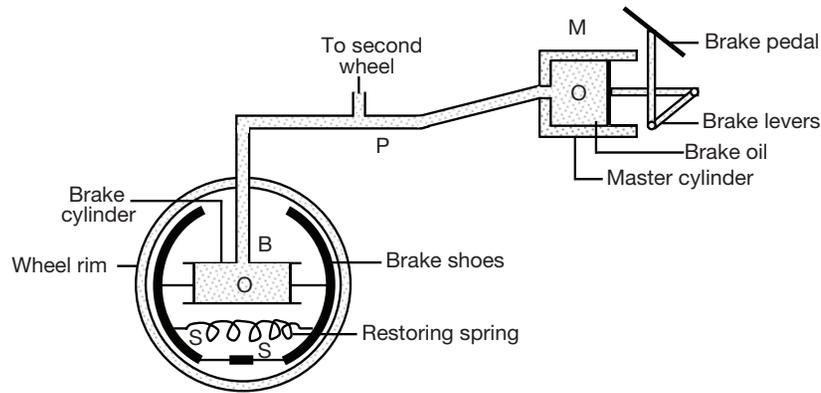


FIGURE 6.13 Hydraulic brakes

Hydraulic brakes system consist of a master cylinder (M) and a brake cylinder (B) connected by a thick metallic pipe, (P) filled with a thick oil, (O) generally called brake oil. The two cylinders are provided with air tight pistons. The piston of master cylinder is connected by levers to the brake pedal situated at the foot area of the driver. The brake cylinder is located in the wheel of the vehicle. The pistons of the brake cylinder are connected to brake shoes. A spring S is connected to the two brake shoes which restore the brakes to the normal position.

In the process of applying brakes, the driver applies a force on the brake pedal. This force is transmitted to the piston of the master cylinder through levers. The piston of the master cylinder, thus, moves forward applying pressure in the brake oil. This increase in pressure is transmitted to the oil in the brake cylinder, and thus, the pistons of the brake cylinder are pushed outward, there by pressing the brake shoes against the rim of the wheel. The friction between brake shoes and the wheel rim slows down or stops the vehicle.

If the driver relieves the force on the brake pedal, the pedal is restored to its original position with the help of a spring (not shown in figure) connected to the pedal. This releases the pressure on the brake oil and the pistons of the brake cylinder restore to their normal position with the help of the restoring spring.

UPTHRUST OR BUOYANT FORCE

When a body is immersed completely or partly in a fluid, the body experiences an upward thrust. This upward force exerted by the fluid on the immersed body is known as ‘upthrust’ or ‘buoyant force’. The property of a fluid to exert buoyant force on an object immersed in it is known as ‘buoyancy’.

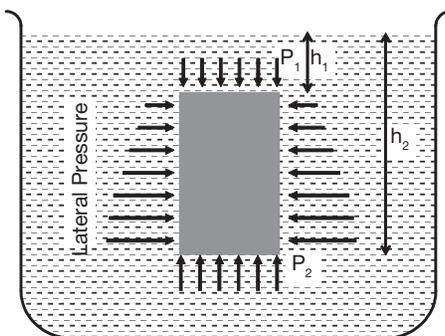


FIGURE 6.14 Upthrust

Upthrust—The Cause

Consider a cylindrical body of height ‘ h ’ and of uniform area of cross section ‘ a ’ immersed completely in a beaker containing a liquid, as shown in Fig. 6.14.

Pressure is exerted on the body by the liquid in all directions. Force exerted by the liquid per unit area on the sides of the body, i.e., lateral pressure at a level of liquid is equal in all directions. So, the net lateral

force exerted by the liquid on the body at a given level of the liquid is zero. The top surface of the body is at a depth ' h_1 ', from the free surface of the liquid; and ' P_1 ', is the pressure exerted on the body by the liquid at the point. So, downward force exerted by the liquid on the top surface of the body is given by, $F_1 = (\text{pressure}) (\text{area}) = P_1 (a)$. But $P_1 = h_1 \rho g$, where ' ρ ' is density of the liquid. Therefore, $F_1 = h_1 \rho g a$. This force F_1 acts downwards. Similarly ' P_2 ' is the pressure exerted by the liquid on the body at its bottom surface, and so, the force exerted by the liquid on the bottom surface of the body is given by, $F_2 = (P_2) (a) = h_2 \rho g a$, where ' h_2 ' is the depth of the bottom surface of the body from free surface of the liquid. This force F_2 acts upwards. As $h_2 > h_1$, $F_2 > F_1$.

So, there is a net force acting on the body in the upward direction given by,

$$F = F_2 - F_1 = (h_2 - h_1) \rho g a = h \rho g a,$$

where $h = h_2 - h_1$, the height of the body.

This net force is the thrust acting on the body in upward direction, and so, it is called 'upthrust' or 'buoyant force'.

Since ' $h \times a$ ' is the volume ' V ' of the body, the upthrust on the body is given by,

$$F = (\text{volume of body}) \times (\text{density of liquid}) \times (\text{acceleration due to gravity})$$

$$\therefore F = V \rho g$$

As the body is completely immersed in the liquid, the body displaces liquid, whose volume is equal to volume of the body. Thus, upthrust

$$F = [\text{volume of liquid displaced } (V)] \times [\text{density of liquid } (\rho) \times (\text{acceleration due to gravity } (g))]$$

$$= \text{mass of the liquid displaced} \times g$$

$$= \text{Weight of the liquid displaced}$$

Thus, 'upthrust acting on a body immersed in a liquid is equal to weight of the liquid displaced'. This statement is true for bodies immersed in a fluid either completely or partially. This fact was discovered by a Greek philosopher and scientist Archimedes and is known as Archimedes' principle.

ARCHIMEDES' PRINCIPLE

When a body is partially or completely immersed in a fluid at rest, it experiences an upthrust which is equal to the weight of the fluid displaced by it.

Due to the upthrust, acting on the body, it apparently loses a part of its weight and the apparent loss of weight is equal to the upthrust.

Thus, for a body either partially or completely immersed in a fluid, upthrust = weight of the fluid displaced = apparent loss of weight of the body.

Archimedes' Principle – Verification

Consider a solid body attached to the hook of a spring balance in air as shown in Fig. 6.15. Let its weight shown by the spring balance be ' W_1 '. Now the body is completely immersed in water present at full level in an overflow jar.

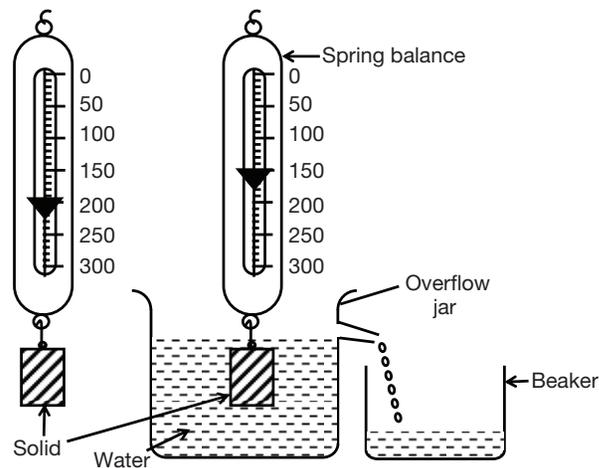


FIGURE 6.15 Verification of Archimedes Principle

The water displaced by the body is collected in an empty beaker placed below the spout of the overflow jar. Let the weight of the body immersed in water as shown by the spring balance be ' W_2 ', (which is less than ' W_1 '). Thus, apparent loss of weight of the body, $W = W_1 - W_2$. If the weight of water collected in the beaker is measured, it is found to be equal to ' W '. Thus, Archimedes principle is verified.

Density

It is defined as mass per unit volume. It is measured in gram per cubic centimetre (g cm^{-3}) in C.G.S. system and in kilogram per cubic metre (kg m^{-3}) in S.I. system. The relation between both the units is $1 \text{ g cm}^{-3} = 10^3 \text{ kg m}^{-3}$.

Relative Density

Often density of a substance is compared with the density of water at 4°C . This ratio is called relative density. Thus, 'relative density of a substance is defined as ratio of density of the substance to density of water at 4°C '.

$$\text{Mathematically, relative density (R.D)} = \frac{\text{Density of substance}}{\text{Density of water at } 4^\circ\text{C}}$$

Since relative density is the ratio of same quantity, it does not have units.

NOTE

Density of water is 1 g cm^{-3} in C.G.S system. So, relative density of a substance is numerically equal to its density in C.G.S system.

Example: density of mercury is 13.6 g cm^{-3}

So, relative density of mercury is 13.6

As $1 \text{ g cm}^{-3} = 10^3 \text{ kg m}^{-3}$, density of a substance in S.I. system = (Relative density of the substance) $\times 10^3 \text{ kg m}^{-3}$

Relative density of a solid substance

$$\begin{aligned}
 &= \frac{\text{Density of substance}}{\text{Density of water at } 4^{\circ}\text{C}} \\
 &= \frac{\text{Mass of the solid}}{\text{Mass of an equal volume of water at } 4^{\circ}\text{C}} \\
 &= \frac{\text{Weight of the solid in air}}{\text{Weight of water displaced by the solid}} \\
 &= \frac{\text{Weight of the solid in air}}{\text{Apparent loss of weight of the body in water}}
 \end{aligned}$$

$$\therefore \text{R.D. of a solid substance} = \frac{W_1}{W_1 - W_2} \quad \text{where } \begin{array}{l} W_1 = \text{Wt in air} \\ W_2 = \text{Wt in water} \\ \text{at } 4^{\circ}\text{C} \end{array}$$

If the given solid is soluble in water, the expression for the relative density of the solid is given as follows.

Relative density of a solid soluble in water =

$$\frac{\text{Weight of solid in air}}{(\text{Apparent loss of weight of the body in a liquid})} \times (\text{Relative density of the liquid})$$

$$\text{Relative density of a liquid} = \frac{\text{Apparent loss of weight of a body in liquid}}{\text{Apparent loss of weight of the same body in water}}$$

EXAMPLE

The mass of a body is 2 kg and its volume is 250 cm³. Find its relative density.

SOLUTIONS

Given mass of the body = 2 kg = 2000 g

Volume of the body = 250 cm³

$$\therefore \text{density of the body} = \frac{\text{mass}}{\text{volume}} = \frac{2000 \text{ g}}{250 \text{ cm}^3} = 8 \text{ g cm}^{-3}$$

\therefore The relative density of the body is 8

EXAMPLE

The specific gravity (or relative density) of gold is 19. Find the mass of a gold body that displaces 25 cm^3 of water when immersed in it.

SOLUTION

Given, specific gravity of gold = 19

\Rightarrow relative density of gold = 19

\therefore Density of gold = 19 g cm^{-3} .

When the gold body is immersed in water, it displaces 25 cm^3

\Rightarrow volume of the gold body = 25 cm^3

\therefore Mass of the gold body = (volume) (density)
 $= (25 \text{ cm}^3) (19 \text{ g cm}^{-3})$
 $= 475 \text{ grams}$

NOTE

Specific gravity is the ratio of the density of a substance to the density of a reference substance.

EXAMPLE

A body weights 75 g_f in air, 51 g_f when completely immersed in a liquid and 67 g_f when completely immersed in water. Find the density of the liquid.

SOLUTIONS

Given, weight of the body in air, $w_1 = 75 \text{ g}_f$

Weight of the body in water, $w_2 = 67 \text{ g}_f$

Weight of the body in the given liquid, $w_3 = 51 \text{ g}_f$

\therefore Apparent loss of weight of the body in the given liquid = $w_1 - w_3 = 75 - 51 = 24 \text{ g}_f$

Apparent loss of weight of the body in water = $w_1 - w_2 = 75 - 67 = 8 \text{ g}_f$.

Relative density of the liquid = $\frac{w_1 - w_3}{w_1 - w_2} = \frac{24}{8} = 3$

\therefore Density of the liquid = $3 \text{ g}_f \text{ cm}^{-3}$

FLOATATION

When a body is immersed in a fluid, two possibilities arise. The body may sink in the fluid or it may float. The floating or the sinking of a body in a fluid depends on the net force acting on the body in the fluid. The forces that act on the body in the fluid are its weight (mg) acting downwards along its centre of gravity and the upthrust (F_B) acting on the body by the fluid at the centre of buoyancy (the point where the total buoyant force due to the fluid displaced by the body acts).

If the weight of the body (mg) is greater than the upthrust, then a net downward force acts on the body and it sinks in the fluid [See Fig. 6.16(a)]. This happens when density of the body is greater than the density of the fluid.

If the weight of the body is equal to the upthrust, e.g., the weight of the fluid displaced by it, the net force acting on the body is zero and the body just floats in the fluid. The upper surface of the body coincides with the free surface of the fluid in this situation and this happens when the density of the body is equal to the density of the fluid [See Fig. 6.16(b)].

If the weight of the body is less than the weight of the fluid displaced by it, then a net upward force acts on the body and as a result, the body moves upward, and a part of the body floats above the free surface of the fluid such that weight of the liquid displaced is equal to the weight of the body. This happens when the density of the body is less than the density of the fluid [See Fig. 6.16(c)].

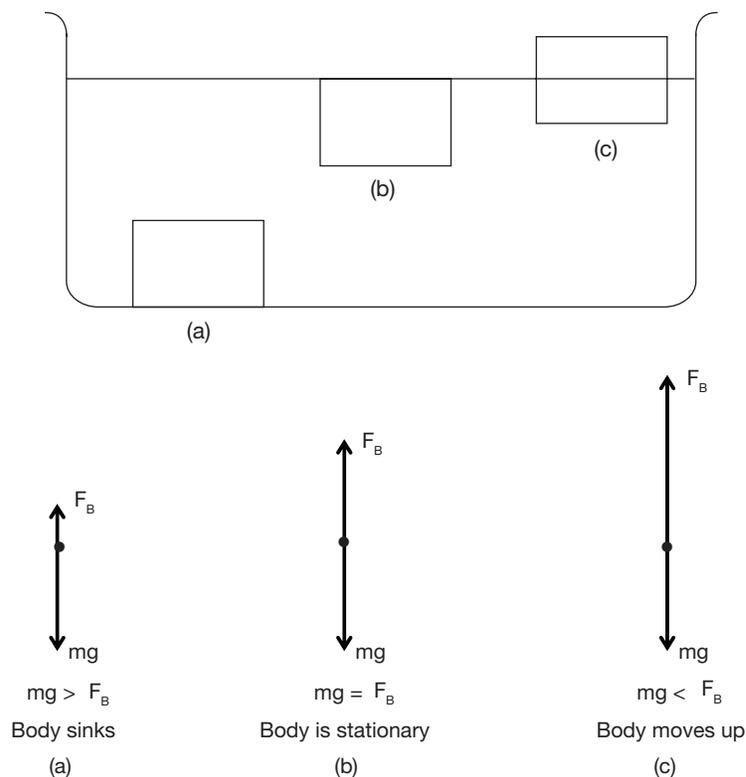


FIGURE 6.16

Laws of Floatation

1. The weight of a floating body in a fluid is equal to the weight of the fluid displaced by the body.
2. The centre of gravity of the floating body and the centre of buoyancy are in the same vertical line.

Characteristics of a Floating Body

The following are the characteristics of a floating body in a fluid.

1. Weight of a floating body = upthrust or buoyant force = Apparent loss of weight of the body in the fluid.

2. The net force acting on a body floating in a fluid is zero.
3. The apparent weight and apparent density of a body floating in a fluid is zero.

Floating Body—It's Relative Density

Consider a cylindrical wooden piece having uniform area of cross section 'a' immersed in a beaker of liquid as shown in the Fig. 6.17. Let ' h_1 ' be the total length of the cylindrical wooden piece and ' h_2 ' be the length of the immersed part in the liquid.

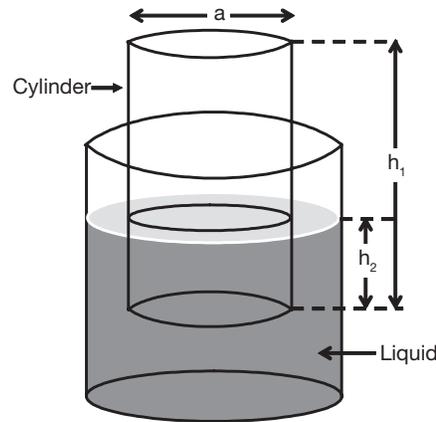


FIGURE 6.17

Total volume of the cylindrical wooden piece, $V = ah_1$.

If ' ρ_1 ' is the density of wood, mass of the wooden piece, $m = V\rho_1 = ah_1\rho_1$.

Thus, weight of the wooden piece,

$$W = mg = ah_1\rho_1g.$$

The volume of the part of the wooden piece immersed in the liquid $V^1 = ah_2$.

\therefore Volume of the liquid displaced by the wooden piece, $V^1 = ah_2$.

If ' ρ_2 ' is the density of the liquid, mass of the liquid displaced by the wooden piece, $m^1 = ah_2\rho_2$, and so, its weight $W^1 = ah_2\rho_2g$.

According to the first law of floatation, $W = W^1$

$$\Rightarrow ah_1\rho_1g = ah_2\rho_2g \Rightarrow h_1\rho_1 = h_2\rho_2 \text{ or } V\rho_1 = V^1\rho_2$$

$$\Rightarrow (\text{volume of the body}) \times (\text{density of the body})$$

$$= (\text{volume of the liquid displaced by the body}) \times (\text{density of the liquid})$$

$$\Rightarrow \frac{\text{density of the body}}{\text{density of the liquid}} = \frac{\text{volume of the liquid displaced by the body}}{\text{total volume of the body}}$$

$$= \frac{\text{volume of the body inside the liquid}}{\text{total volume of the body}}$$

= fraction of the volume of the body inside the liquid.

If the liquid considered is water, then the above expression becomes

$\frac{\text{Density of the body}}{\text{Density of water}} = \text{fraction of the volume of the body inside water}$

\Rightarrow relative density of the body = fraction of the volume of the body inside water.

If the body is in cylindrical shape and has uniform area of cross section, then relative density of the body = fraction of length of the body inside water.

EXAMPLE

A cylindrical body floats in water such that one-fourth of its volume lies above the surface of water. Find the density of the material with which the body is made of.

SOLUTION

Given, volume of the body above the surface of water = $\frac{1}{4}$ (volume of the body)

\therefore Volume of the body inside water = $\frac{3}{4}$ (volume of the body)

\Rightarrow fraction of the body inside water = $\frac{3}{4}$

\therefore Relative density of the material with the body is made of = $\frac{3}{4} = 0.75$

\therefore Density of the material = 0.75 g cm^{-3}

Center of buoyancy: The center of mass of the fluid displaced by a floating or submerged body.

Meta-centre and Equilibrium of Floating Bodies

At the beginning of the chapter, we wondered why a small iron nail sinks in water but a huge ship having larger mass floats. The density of the iron nail is more than the density of water. Thus, it sinks in water. In the case of a ship, even though its mass is huge compared that of an iron nail, its volume is increased many times such that the overall density of the ship is less than that of water. Thus, the ship floats on water. The amount of water displaced by the ship is also large, and so, the buoyant force on the ship by water is also large. When the ship is standing still in water, laws of floatation are applicable to it and we have the centre of gravity of the ship (G) and centre of buoyancy (B) lie on the same vertical line as shown in the Fig. 6.18.

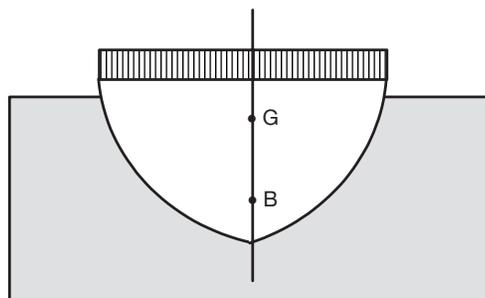


FIGURE 6.18

The ship floats on water, not only when it is at rest, but also when it is in motion. Even though the ship is slightly tilted to a side while in motion due to the disturbance created by water or wind, it regains its original state of position without getting immersed in water. Thus, we say that the ship is in dynamic equilibrium. Let us understand how the ship maintains its dynamic equilibrium.

When the ship is slightly titled, say, towards left (anti-clockwise direction) as shown in Fig. 6.19, the centre of buoyancy (B) and centre of gravity (G) of the ship do not lie on a single vertical line. But now the position of centre of buoyancy shifts to a new position (B^1).

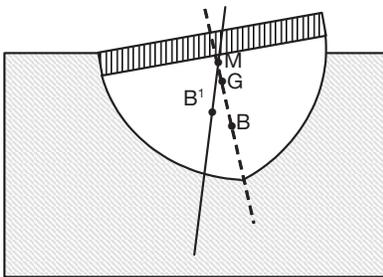


FIGURE 6.19

The vertical line through, the new centre of buoyancy (B^1) and, the line joining the centre of gravity (G) of the ship and the original centre of buoyancy (B) intersect at a fixed point irrespective of the tilt in the ship, at a point (M) as shown in the Fig. 6.19.

This point is known as ‘meta-centre’. The stability of any floating body depends on the relative positions of the meta-centre, centre of gravity of the floating body and the original centre of buoyancy.

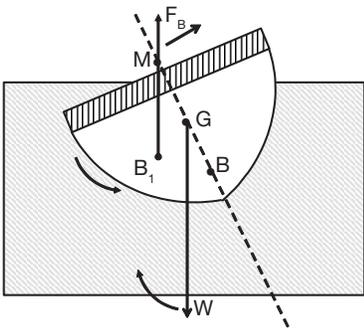


FIGURE 6.20

If the floating body has a heavy base, the centre of gravity of the floating body and the centre of buoyancy lie below the position of meta centre. Then, even if the floating body is tilted in, say, an anti-clockwise direction, the moment of force set by the weight of the body and up thrust acting on the body will be in clockwise direction as shown in the Fig. 6.20, and so, the body will regain its position. Thus, the body is in ‘stable equilibrium’.

If a floating body has a heavy top, the centre of gravity of the floating body lies above the centre of buoyancy and meta centre. Thus, if such a floating body is disturbed and tilted in, say, an anti-clockwise direction, the couple set up by the upthrust and the weight of the body is also in the anti-clockwise direction and the body cannot regain its original position as shown in the Fig. 6.21. Thus, the body is in an unstable equilibrium and it gets overturned.

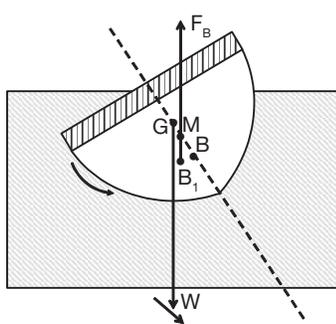


FIGURE 6.21

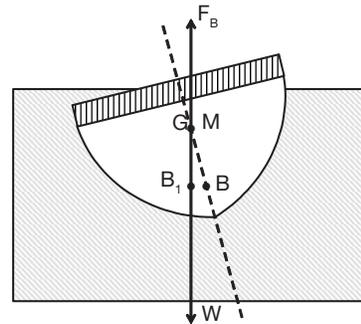


FIGURE 6.22

If the distribution of mass of a floating body is such that the meta centre coincides with centre of gravity of the floating body, then the body is subjected to a net nil couple due to its weight and upthrust. Thus, the body remains in neutral equilibrium as shown in the Fig. 6.22.

Laws of Floatation – Applications

1. A ship floats on water. The volume of water displaced by the ship is much less than the volume of the ship. Thus, the effective density of ship is less than density of water, and so, the ship floats on water.
2. Fish have floating tube laterally along their bodies which is generally filled with air. Due to this, the effective density of fish is less than the density of water, and so, fish can float on water.
3. A submarine is an air tight ship which mainly contains three important compartments namely, engine room, ballast tank and compressed air compartment. When the under belly doors of the ballast tank are opened, water gushes into the ballast tank, increasing its weight, and so, the submarine sinks in water. To resurface the submarine again, the compressed air in the steel cylinders placed in the compressed air compartment is allowed into the ballast tank, reducing its effective density. So, the submarine moves up.
4. Laws of floatation are applicable to hot air balloons.
5. Floatation of ice bergs is also an example for the application of laws of floatation.

HYDROMETER

It is an instrument used to measure the density of liquids directly. It works on the basis of laws of floatation. There are two types of hydrometers; viz, variable immersion hydrometers or common hydrometers and constant immersion hydrometers or Nicholson's hydrometers.

Common Hydrometer

It is also known as a commercial hydrometer. It consists of a hollow cylindrical glass bulb called floatation bulb having a fixed volume. To the bottom of this bulb, another small glass bulb, generally of a spherical shape is attached. It is filled with a heavy substance like iron shots, or lead shots or mercury. This small bulb is called gravity bulb. To the upper part of the floatation bulb, a long narrow glass stem with graduations marked on it is attached as shown in the Fig. 6.23(a).

There are two categories of common hydrometers, viz, the one which is used to find densities of lighter liquids and the another which is used to find the density of heavy liquids. The construction of both these types of hydrometers is the same except a few differences. The hydrometer for lighter liquids as shown in the Fig. 6.23(b) has a bigger floatation bulb and a small gravity bulb with a long narrow stem. The stem is calibrated in the descending order from bottom to top in the range 1.0 to 0.5. The hydrometer for heavy liquids has a small floatation bulb and bigger gravity bulb as compared with those hydrometers for lighter liquids. The hydrometer for heavy liquids has a lengthy stem than that of hydrometer for lighter liquids. This stem is calibrated in the descending order from its top to bottom in the range about 1.0 to 1.7 as shown in the Fig. 6.23(c).

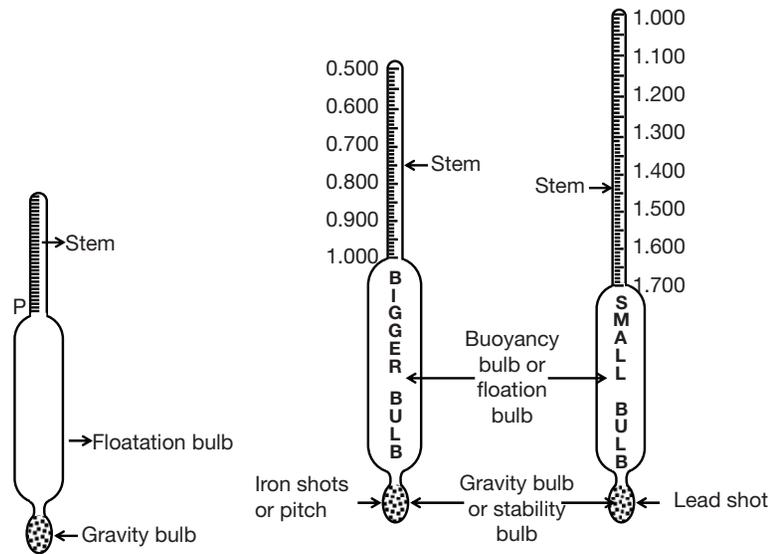


FIGURE 6.23

Hydrometer—Its Calibration

Consider a hydrometer floating in water such that the gravity bulb and flotation bulb are inside water and the stem of the hydrometer is above water upto mark ‘P’ as shown in the Fig. 6.23(a). Let ‘ $V \text{ cm}^3$ ’ be the volume of the hydrometer upto mark ‘P’. Then the volume of water displaced by hydrometer is ‘ V ’.

$$\therefore \text{weight of water displaced by the hydrometer} = (V \text{ cm}^3 \times 1 \text{ g cm}^{-3} \times \text{g cm s}^{-2}) = Vg \text{ dyne.}$$

Thus, according to law of floatation,

$$\text{weight of the hydrometer} = Vg \text{ dyne} \quad (6.1)$$

Now, let the same hydrometer be immersed in a liquid of density ‘ ρ ’ and consider that it sinks upto the mark ‘Q’ on the stem. If ‘ a ’ is the area of cross section of the stem and length $PQ = \ell$, then volume of liquid displaced by the hydrometer = $(V + \text{Regulara}) \text{ cm}^3$, and so, the weight of the liquid displaced by the hydrometer = $(V + \ell a) \rho g$ dyne.

Thus, according to law of floatation,

$$\text{Weight of the hydrometer} = (V + \ell a) \rho g \text{ dyne} \quad (6.2)$$

From equations (6.1) and (6.2), we get

$$\begin{aligned} (V + \ell a) \rho g &= Vg \\ \Rightarrow (V + \ell a) \rho &= V \\ \Rightarrow \ell &= \frac{V(1 - \rho)}{a\rho} \end{aligned}$$

Since ‘ V ’ and ‘ a ’ are constant, we get $\ell = k \left(\frac{1}{\rho} - 1 \right)$, where k is a constant.

The length ' ℓ ' of the stem for various densities of the liquids can be known and the hydrometer stem can be marked in terms of densities of the liquids so as to obtain their densities directly when the hydrometer is immersed in the corresponding liquids. This process is called 'calibration' of the stem/hydro meter.

LACTOMETER

The density of pure milk without extracting fat content from it is about 1.045 g cm^{-3} ; whereas density of water is 1.000 g cm^{-3} . Thus, the variation in density of pure water and that of whole milk is very less and a hydrometer employed for measuring density of heavier liquids is not suitable for measurement of density of whole milk. Thus, a hydrometer having more sensitivity is constructed for measuring the density of milk and this hydrometer is known as lactometer as shown in the Fig. 6.24. If water is mixed in milk, density of mixture changes. Thus, this fact is used to find out the extent of adulteration of milk with water using a lactometer. The sensitivity of the lactometer is increased by reducing the area of cross section of the stem and increasing its length. Also the gravity bulb and floatation bulb are combined into a single bulb. The gravity bulb is filled with material 'pitch', a black or dark brown resinous substance obtained from distillation of tar or turpentine. In the Fig. 6.24, UV means density pure water and M means density of pure milk.

The stem of the lactometer is calibrated, in terms of purity of milk for convenience. The main markings on the stem are ' W ' for water, ' M ' for 100% milk, $\frac{3}{4}M$ for 75% milk and so on.

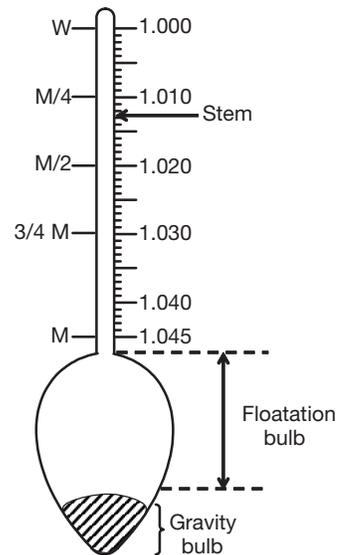


FIGURE 6.24 Lactometer

ACID BATTERY HYDROMETER

Sulphuric acid is the electrolyte used in the batteries employed in automobiles. The density of the acid varies from about 1.30 g cm^{-3} to 1.16 g cm^{-3} when the battery is charged and discharged, respectively. The battery cannot be recharged if the density of the acid falls below 1.16 g cm^{-3} , and thus, there is a necessity to check density of the acid in the battery periodically. It is not convenient to measure the density of the acid in the battery with the help of a hydrometer employed for measurement of density of heavier liquids. Thus, a specially designed hydrometer is used for this purpose. This hydrometer is known as 'acid battery hydrometer' as shown in the Fig. 6.25.

It consists of a big rubber bulb attached to wide glass tube at its top. At the bottom of the glass tube, there is a nozzle (N). The hydrometer is positioned inside the glass tube. The rubber bulb is compressed, and the nozzle is introduced into the battery and then the bulb is released to suck acid from battery into the wide glass tube. The hydrometer present inside the glass tube now floats in the acid and the density of the acid can be noted. On squeezing the rubber bulb, again acid is poured back into the battery.

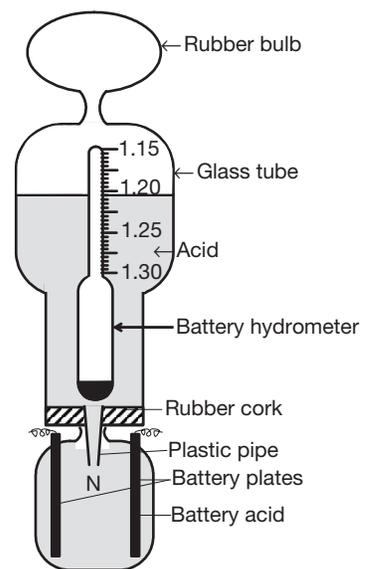


FIGURE 6.25 Acid battery hydrometer

VISCOSITY

Consider an arrangement in which three tubes are connected to a horizontal rod which can be rotated with the handle at one end as shown in the Fig. 6.26.

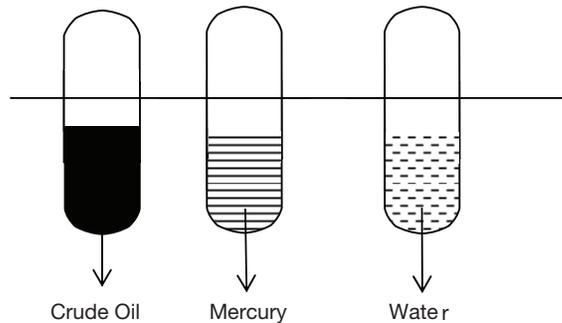


FIGURE 6.26

The tubes are closed at both the ends and half-filled with crude oil, mercury and water, respectively. As seen in the Fig. 6.26, they occupy lower half of tubes. Now rotate the handle so that all the tubes are inverted. The different liquids begin to flow down and take different times to reach the bottom. Other than the force of friction between the glass surface and liquids, forces of friction are set up between various layers of liquid which oppose the relative motion between them. This force is called viscous force. Since liquids took different times to reach the bottom, it is obvious that viscous force is different in different liquids. The less the viscous force, the more the mobility of the liquid. This property exhibited by liquids is called viscosity. Viscosity of liquid decreases as its temperature is increased.

SURFACE TENSION

Molecules always attract each other. The force of attraction between like molecules (of the same substance) is called cohesive force. The force of attraction between unlike molecules (of different substance) is called adhesive force.

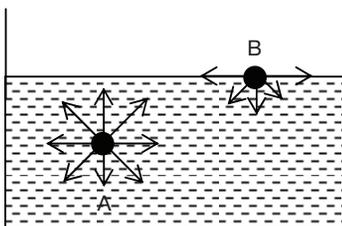


FIGURE 6.27

Consider a beaker containing a liquid as shown in the Fig. 6.27. A molecule 'A' inside the liquid experiences an equal cohesive force in all directions due to surrounding molecules. Hence, the net force acting on it is zero. Now consider a molecule 'B' on the surface of the liquid. It experiences a net force of attraction from the molecules below it, due to which it is pulled inside. The molecules below it, oppose this motion so that the surface behaves as a stretched membrane. This phenomenon is called surface tension. Due to surface tension, there is a tendency in the liquid to have minimum surface area. Therefore, liquid drops are spherical or oval in shape. It is also observed that the liquid surface in a narrow tube is curved.

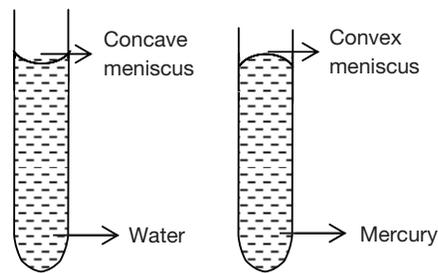


FIGURE 6.28

This is due to the difference between the cohesive forces between the liquid molecules and the adhesive force between the surface molecules at the sides of the tube and the liquid molecules at its surface. This curved surface is called meniscus. If the adhesive force is greater than the cohesive force like in the case of water in a glass tube, the surface is concave as shown in the Fig. 6.29. In mercury, the cohesive forces are very strong. Therefore, when mercury is poured in a narrow glass tube, its surface becomes convex as shown in the Fig. 6.30.

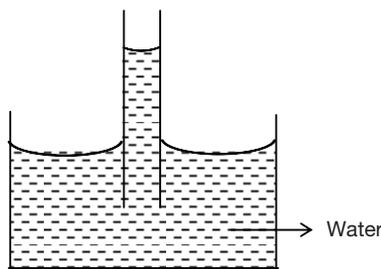


FIGURE 6.29

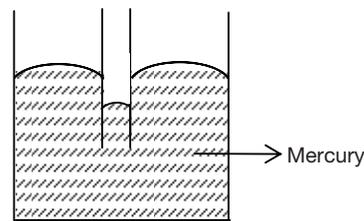


FIGURE 6.30

CAPILLARITY

Consider a glass tube of very narrow bore. When it is dipped in a beaker containing water, we find that the water rises up in the tube so that its level in the tube is higher than that in the beaker. Such a pipe is called capillary tube as shown in the Fig. 6.29.

If a capillary tube is dipped in mercury contained in a beaker, it is observed that the mercury level in the tube falls below its level in the beaker, thus, creating a depression as shown in the Fig. 6.30.

The phenomenon of rise or fall of a liquid in a capillary tube when it is dipped in a liquid is known as capillarity. Capillarity occurs due to surface tension of the liquid and the cohesive and the adhesive forces.

In oil lamps, there is no direct contact between the oil and the flame. The flame gets oil supply through the wick by capillary action as the other end of wick is immersed in oil. Even the roots of plants absorb water from ground through capillary action. There are many such applications of capillarity in our daily life.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

- State Archimedes' principle.
- Mention a difference between a common hydrometer and a lactometer.
- A hydrometer is used to measure _____ of liquids.
- If relative density of a liquid is 2.3, what is its density in S.I. system?
- State Pascal's law of transmission of fluid pressure.
- (a) What is a meniscus?
(b) How many types of meniscus are there and what are they?
- (a) What is the condition required so that a solid body sinks in a liquid?
(b) When does it just float in the liquid?
- What is the expression for mechanical advantage of a hydraulic press?
- Why does a liquid surface behave like a stretched membrane?
- What is the condition required so that a solid body floats in a liquid with some part of the body above the surface of the liquid?
- Mention two applications of Pascal's law of transmission of fluid pressure.
- What is viscosity and what is meant by a viscous liquid?
- Viscosity of liquids _____ with increase in temperature.
- On what principle does the hydraulic brakes in a vehicle work?
- Define cohesive and adhesive force.
- Name the device used to measure the density of a liquid.
- Define (i) atmospheric pressure (ii) one atmosphere.
- A container is filled with water to a height of 10 m. The pressure exerted by the water at the bottom of the container is _____.
- Define meta centre.
- Which instrument is used to measure atmospheric pressure?
- What is surface tension?
- State the law of floatation.
- Which barometer is generally used in laboratories to measure atmospheric pressure quite accurately?
- Name the instrument that can check the recharging capacity of a car battery.
- What is the shape of liquid drops and what is the cause for their shape?
- Which barometer does not contain any liquid?
- On what factors does the fluid pressure depend?
- If a cylindrical wooden piece of density 750 kg m^{-3} is floating in water, what fraction of the length of the cylinder is inside the water?
- If an object floats in water such that half of its volume is immersed in it, then the density of the object is _____ kg m^{-3} .

Short Answer Type Questions

- Explain the factors that affect barometric height.
- Derive an expression for the condition for a solid body immersed in a liquid to float in it.
- Mention the characteristics of a floating body.
- Define capillarity and mention applications of it.
- What are the disadvantages of a simple mercury barometer?
- Explain equilibria of a floating body.
- How does capillary action differ in water and mercury?
- Explain the cause of upthrust on a body immersed in a liquid.
- What is a hydrometer? Name the two categories of hydrometers and explain the principle on which its working is based.



39. Differentiate between liquids and gases.
40. Explain the verification of Archimedes' principle.
41. What are the advantages of an aneroid barometer over a simple barometer?
42. Derive an expression for fluid pressure.

Essay Type Questions

43. Explain capillarity in detail.
44. A block of wood floats in water such that half of its volume is below the water surface. But in a certain liquid, it floats with $(1/4)$ th of its volume below the liquid surface. Find the density of liquid.
(Ans: 2g cm^{-3})
45. Explain why water has concave meniscus while mercury has convex meniscus when poured in a uniformly narrow glass tube?
46. The mechanical advantage of a hydraulic press is 5. A car of mass 1500 kg is lifted by it when placed on a piston of a hydraulic press of area of cross section 5 m^2 . Find the area of cross section of piston where the effort is applied.
(Ans: 1 m^2)
47. Explain the phenomenon of viscosity in detail.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- Hydrometer works on the principle of 'Laws of floatation'.
- When one limb of a manometer is connected to a container filled with a gas, the level of the mercury in the other limb rises by ' h ' cm. Then the pressure of the gas in the container is $76 + h$ cm of Hg.
- The ratio of buoyant forces experienced by a solid body when immersed in two liquids whose relative densities are 1 and 0.5, respectively, is 2 : 1.
- The intermolecular forces of attraction are weaker in liquids when compared to those in solids.
- A body remains in neutral equilibrium when meta center coincides with the center of gravity.
- The net pressure acting at the bottom of a container filled with a liquid of density ' d ' to a height of h is hdg .
- Pressure of a gas enclosed in a container can be measured using a manometer.
- A wooden plank immerses upto 50% in water. Then _____% of it is immersed in a liquid of density 0.5 g cm^{-3} .
- The Mechanical Advantage of a hydraulic press is 5. The ratio of the distance travelled by the load to the effort is _____.
- The length of water column that can exert 1 atm pressure is _____.
- The blotting paper becomes completely wet when one end of the paper is kept in a liquid. This is an example of _____.
- An ice cube's $(1/n)$ th portion sinks in water, then the density of ice is _____.

Direction for questions 8 to 13

Fill in the blanks.

8. At constant temperature, if the pressure of a gas of volume V in a container is doubled, the change in its volume is _____.

Direction for question 14

Match the entries in Column A with the appropriate ones in Column B.

14.

Column A	Column B
A. Water supply in cities	() a. Pascal's law
B. Hydraulic brake	() b. Archimede's Principle



- C. Sucking of a cool drink by using a straw () c. Fluid pressure
- D. Fish weighs less in water than in air () d. Laws of floatation
- E. Relative density of solids () e. Upthrust
- F. Hydrometer () f. Atmospheric pressure
- G. Spherical shape of water drop () g. Lactometer
- H. Absorption of water from the ground by roots of plants () h. Surface tension
- I. Density of milk () i. Viscosity
- J. Mobility of liquids () j. Capillarity

Direction for questions 15 to 43

For each of the questions, four choices have been provided. Select the correct alternative.

15. Two metallic spheres of different materials immersed in water experience equal upthrust. Then both the spheres have equal
(a) weights in air (b) densities
(c) volumes (d) masses
16. The pressure at a point inside a fluid is
(a) dependent on the height of the fluid column
(b) dependent on the density of the fluid
(c) equal in all directions
(d) All the above are true
17. When an object is made to float in two different liquids of density ρ_1 and ρ_2 , the lengths of the object seen above the liquid surface are l_1 and l_2 , respectively. Which of the following is the correct alternative?
(a) $\rho_2 > \rho_1$, if $l_1 > l_2$ (b) $d_1 > d_2$, if $l_2 > l_1$
(c) $d_1 < d_2$, if $l_2 > l_1$ (d) $d_2 < d_1$, if $l_2 > l_1$
18. Kerosene lamp glows continuously until the kerosene is exhausted. This is due to the phenomenon of _____.
(a) anomalous expansion (b) capillarity
(c) thermal expansion (d) Both (1) and (2)
19. A liquid whose density is twice the density of mercury is used as a barometric liquid. Then one atmosphere pressure equals _____ cm of the liquid pressure.
(a) 76 (b) 38
(c) 152 (d) 380
20. When two liquids A and B of equal weight are filled inside two identical containers, the height of the liquid Column A is greater than the height of the liquid Column B. If P_A and P_B are the pressures exerted by A and B at the bottom of the containers, respectively, and ρ_A , ρ_B are the densities of A and B, respectively, which of the following statements is true?
(a) $P_A > P_B$ (b) $P_A < P_B$
(c) $P_A = P_B$ (d) $d_A > d_B$
21. The atmospheric pressure at a given place is dependent on
(a) the height of the air column
(b) the temperature
(c) humidity
(d) All the above
22. A spring balance shows 100 gf reading when a metallic sphere is suspended from its hook. When the balance is lowered such that the sphere is completely immersed in water, the reading shown by the balance is 75 gf. The relative density of the material of the sphere is
(a) 1 (b) 2
(c) 3 (d) 4
23. An object just floats in water. If common salt is added into the water,
(a) the volume of the object immersed in the liquid decreases.
(b) the object sinks.
(c) the object first sinks and then floats up.
(d) cannot be determined
24. A rubber balloon filled with hydrogen gas is left free in air. Then the balloon
(a) escapes into space.
(b) ascends upto a certain height in air and floats.
(c) ascends upto a certain height and then descends back to ground.
(d) ascends upto a certain height and explodes.
25. The radius of a press cylinder in a hydraulic press is double the diameter of the pump cylinder. Then



- (a) mechanical advantage is 16.
 (b) the work done on the load is equal to the work done by the effort.
 (c) mechanical advantage is 4.
 (d) both (a) and (b)
26. A substance floats in water, but sinks in coconut oil. The density of the substance
 (a) is less than the density of water.
 (b) is greater than the density of oil.
 (c) Both (a) and (b)
 (d) Cannot be decided based on the given information
27. The centre of gravity and the centre of buoyancy of a floating body, in stable equilibrium,
 (i) are always same.
 (ii) are always along a same vertical line.
 (a) Only (i) is true
 (b) Only (ii) is true
 (c) Both (i) and (ii) are true
 (d) Both (i) and (ii) are false
28. In the case of the liquids that do not wet the walls of the vessel.
 (a) cohesive forces are larger than adhesive forces.
 (b) adhesive forces are larger than cohesive forces.
 (c) Both adhesive and cohesive forces are equal in magnitude.
 (d) None of the above
29. When an object of weight W is immersed in a liquid, its weight in the liquid is found to be W_1 . When it is immersed in water, the weight of the water displaced is found to be W_2 . The relative density of the liquid is
 (a) $\frac{W_2}{W_1}$ (b) $\frac{W - W_1}{W_2}$
 (c) $\frac{W_2}{W - W_1}$ (d) $\frac{W_2}{W - W_1}$
30. The pressure exerted by a liquid column at the bottom of the liquid container is
 (a) does not depend on the area of cross-section of container.
 (b) dependent on the density of the liquid.
 (c) equal in all directions.
 (d) All the above are true
31. A manometer is connected to a gas container. Then the mercury level rises by 2 cm in the arm of the manometer which is not connected to the container. If the atmospheric pressure is 76 cm of mercury, then the pressure of the gas is _____ cm of mercury.
 (a) 80 (b) 76
 (c) 72 (d) 78
32. The radius of the press cylinder in a hydraulic press is equal to the diameter of its pump cylinder. Its mechanical advantage is _____.
 (a) 1 (b) 2
 (c) 3 (d) 4
33. Among the following liquids, the pressure inside them at a given depth is the highest in _____ at a constant temperature.
 (a) fresh water (b) petrol
 (c) sea water (d) alcohol
34. Which of the following is used to punch holes in thick metallic block?
 (a) Drilling machine.
 (b) Hydraulic press.
 (c) Hammer and anvil.
 (d) All the above
35. When a force is applied in the downward direction, for a short duration, on a body floating with its entire volume in water, the body will then
 (a) float with some part of it above the surface of water.
 (b) oscillate in vertical direction.
 (c) sink to the bottom.
 (d) oscillate in horizontal direction.
36. When equal quantities of an oil, water and mercury are poured into a beaker, the order in which the liquids arrange themselves from bottom to top is
 (a) mercury, water, oil.
 (b) water, mercury, oil.
 (c) water, oil, mercury.
 (d) mercury, oil, water.
37. In a hydrometer, the floatation bulb is large in size compared to the size of the gravity bulb because
 (a) it lowers the centre of gravity.
 (b) it decreases the buoyancy of liquids.



(c) it displaces a large amount of liquid, and thus, does not allow the hydrometer to sink completely in the liquid.

(d) None of these

38. A metal block of volume 500 cm^3 and density 2 g cm^{-3} is suspended from a spring balance and one-fourth of its volume is immersed in water. The reading on the spring balance is _____ N.

(Take $g = 10 \text{ m s}^{-2}$)

- (a) 8.575 (b) 10.175
(c) 500 (d) 8.750

39. A metal box is made up of an alloy of zinc and copper metals. It weighs 302 g and 320 g in a liquid of relative density 1.4 and water, respectively. The specific gravities (or relative densities) of zinc and copper are 7.4 and 8.9, respectively. Arrange the following steps in a proper sequential order to find the masses of metals in the alloy.

(a) Find the weight of the box in a liquid of relative density 1.4 and water along with the relative densities of zinc and copper from the information given in the problem.

(b) Note down the metals present in the metal box.

(c) Let the masses and volumes of copper and zinc be m_c , m_z , v_c and v_z , respectively. The weight (w) and volume (v) of the box would be equal to $m_c + m_z$ and $v_c + v_m$, respectively.

(d) The relative density of liquid $1.4 = \frac{w - 302}{w - 320}$. find the value of ' w '.

(e) The density of the alloy used for the box

is, $d = \frac{m_c + m_z}{v_c + v_z}$; substitute $v_c = \frac{m_c}{d_c}$ and

$v_z = \frac{m_z}{d_z} = \frac{(w - m_c)}{d_z}$, find the masses of m_c and m_z .

(f) The density of alloy, $d = \frac{w}{w - 320}$

- (a) beadfe (b) acbfed
(c) bcdafe (d) dacbef

40. Sudden fall in atmospheric pressure by a large value indicates _____.

- (a) arrival of storm
(b) arrival of dust-storm
(c) fair weather
(d) None of the above

41. Two stretched membranes of area 10 cm^2 and 20 cm^2 are held horizontally in a liquid, at the same depth. The ratio of pressures on them is _____.

- (a) 1 : 2 (b) 2 : 1
(c) 1 : 4 (d) 1 : 1

42. In a mercury barometer, if the tube containing mercury is tilted, then

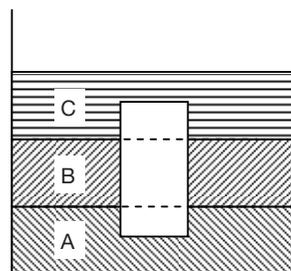
- (a) vertical height of the mercury column remains same.
(b) the length of mercury column in the tube increases.
(c) the vertical height of the mercury column decreases.
(d) Both (a) and (b)

43. At higher altitudes, the atmospheric pressure is lesser as, at higher altitudes

- (1) the length of air column exerting the pressure is less.
(2) density of air decreases.
(3) acceleration due to gravity decreases.
(4) All the above.

Level 2

44. An object floats in three immiscible liquids A, B and C of densities 3 g cm^{-3} , 2 g cm^{-3} and 1 g cm^{-3} , respectively as shown in the figure. When the object is placed in the liquids, the levels of liquid A, B and C rise by 3 cm, 5 cm and 8 cm, respectively. The areas of cross-sections of the container and the object are 10 cm^2 and 5 cm^2 , respectively. Calculate the density of the object.

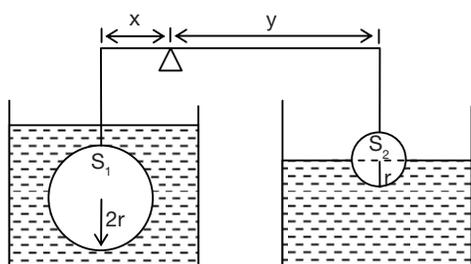


45. A hollow sphere of external and internal diameter 4 cm and 2 cm, respectively, floats in a liquid of density 3.5 g cm^{-3} . The level of the liquid coincides with the center of the sphere. Calculate the density of the material of the sphere.

46. Two spheres S_1 and S_2 made of the same material and having radii $2r$ and r , respectively, are immersed in water and suspended from either end of a beam as shown in figure.

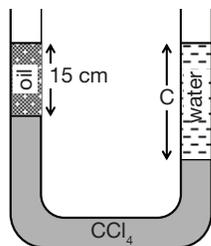
The beam is in equilibrium when $x : y = 1 : 3$

Determine the density of the object.



47. A simple barometer tube contains some air in it. The length of the tube above the mercury level in the trough is 80 cm. The height of mercury in the tube is 71 cm at normal atmospheric pressure. What is the actual decrease in the atmospheric pressure if the barometer reads 65 cm?

48. A 'U' tube contains oil, carbon tetrachloride and water as shown in the figure. The density of oil is 0.8 g cm^{-3} and that of carbon tetrachloride is 1.6 g cm^{-3} . If oil and water surfaces are at the same level, find the height of the water column.

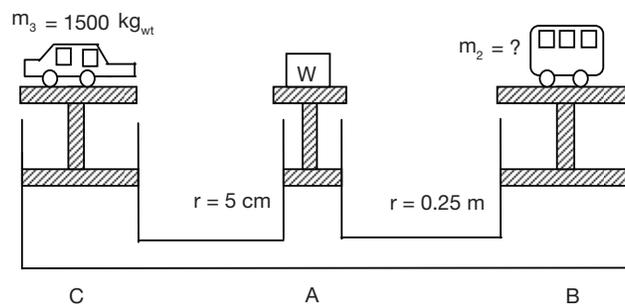


49. A metallic sphere is made of an alloy of two metals 'P' and 'Q' having specific gravities (or relative densities) 20 and 2, respectively. The sphere weighs 120 g_{wt} in air and 90 g_{wt} in water. Find the percentage of the mass of metal 'P' in the alloy.

50. A trough contains the two immiscible liquids 'A' and 'B' having densities ' ρ_A ' and ' ρ_B ' ($\rho_B > \rho_A$). A cylindrical body having uniform area of cross section is immersed completely and vertically in the liquids

such that $1/3$ rd of its length is in liquid 'B' and the remaining is in liquid 'A'. Find the density of the body.

51. In the figure shown below, cylinder A has pump piston, whereas B and C cylinders have lift pistons. If the maximum weight that can be placed on the pump piston is 50 kg_{wt} , what is the maximum weight that can be lifted by the piston in the cylinder B? Find the total mechanical advantage. (Take $g = 10 \text{ m s}^{-2}$).



52. An empty glass test tube floats vertically in water to a depth of 5 cm. Now, on introducing a 8 cm liquid column into the tube, its depth in water is further increased by 4 cm. Now if the empty test tube is allowed to float vertically in the liquid, 5 cm of the tube is seen in air. Find the total length of the tube.

53. Two metallic spheres 'P' and 'Q' weighing 200 gwt and 150 gwt, respectively, balance each other when immersed in water. If the relative density of 'P' is 2, find the specific gravity of 'Q'.

54. A gold ornament weighs 570 gram in air and 520 gram in water. If the specific gravity of gold is 19, find the difference in the volume of water displaced when the ornament is immersed in water and the actual volume of the gold in the ornament. How do you account for this difference in volume?

55. A container is filled with two immiscible liquids A and B of densities 2 g cm^{-3} and 3 g cm^{-3} , respectively. A wooden cube of side 1 cm floats on the surface of liquid A such that one-fourth of its total length is immersed in this liquid (A).

Now, the wooden cube is completely immersed in liquid A by suspending a sinker of volume 10 cm^3 which is completely submerged in liquid B. Determine the weight of the sinker.

56. A variable immersion hydrometer is used to measure the specific gravity of two liquids. When the hydrometer reads 0.8, half of the total length of the hydrometer stem is immersed in the liquid and when



the hydrometer reads 0.6, $\frac{3}{4}$ th of the total length of the hydrometer stem is immersed in the liquid. What is the maximum and minimum reading that can be measured by using this hydrometer?

57. An empty cylindrical tank having diameter 5 m is filled with water through a hose pipe having radius 25 cm. If the pressure at the bottom of the container increases at a rate of 10^3 Pa s^{-1} , calculate the speed of water flowing through the hose pipe.
(Take $g = 10 \text{ m s}^{-2}$)

Directions for questions 58 to 62

Understanding based questions

58. Equal volume of a liquid is poured into containers A and B where area of cross-section of container A is double the area of cross-section of container B. If P_A and P_B are the pressures exerted at the bottom of the containers, then find $P_A : P_B$.
59. The left arm of a manometer is connected to a container containing gas 'X' and the mercury level in the right arm is raised by 2 cm. Now without discon-

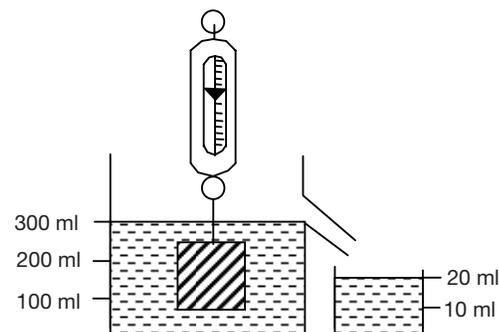
necting the container of gas X, the right arm of the manometer is connected to another container containing gas 'Y' and the mercury level in the right arm is pushed down by 5 cm. Find the pressure exerted by the gases 'X' and 'Y'.

60. An engineer was given a task to measure the rate of increase in pressure at the bottom of an empty cylindrical tank which is filled with water through hose pipe. If the speed of water coming out of the hose pipe is 10 m s^{-1} , diameter and radius of the cylinder and hose pipe are 5 m and 25 cm, respectively, find the result shown by the engineer. (Take $g = 10 \text{ m s}^{-2}$)
61. Two hydrogen gas balloons having the same pressure and whose volumes are in the ratio of 1 : 2, respectively, are released simultaneously into air on the surface of the Earth. Find the ratio of time taken to reach a height of 100 m from the ground. (Neglect the air friction)
62. A wooden plank immerses upto 50% in water. Then what percentage of its volume is immersed in a liquid of density 0.5 g cm^{-3} ?

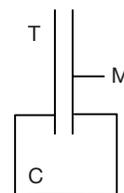
Level 3

63. ' n ' different liquids, which do not react chemically, are mixed to form a homogeneous mixture. If the densities of the liquids are $\rho_1, \rho_2, \dots, \rho_n$, respectively, then find the density of the homogeneous mixture when
- the masses of the liquids forming the mixture are equal
 - the volumes of the liquids forming the mixture are equal
64. Why is a lactometer more sensitive than a normal hydrometer? Explain how the sensitivity of a hydrometer can be increased.
65. An object suspended from a spring balance is immersed in water filled inside an overflow jar. The water displaced by the object is collected in an empty beaker placed below the spout of the overflow jar. If the reading on the spring balance is $180 \text{ g}_{\text{wt}}$, then calculate the pressure exerted due to the immersion of object at the bottom of the container. Will there be any change in pressure at the lower, if the object is dropped into water?

The height of the overflow jar upto the spout is 10 cm and the area of the lower face of the block is 4 cm^2 .



66. A metallic sphere of density 5 g cm^{-3} is projected upward from the bottom of a pond with a velocity 10 m s^{-1} . The velocity of the sphere on reaching the surface of the water is found to be 8 m s^{-1} . Determine the pressure exerted by water at the bottom of the pond. (Neglect the viscous force acting on the sphere).



67. A boy purchases 2 litre of milk from a shop. To find out the extent of adulteration he constructed a device



by using a capillary tube (T) and a cylindrical container (C) as shown in the figure. In order to make the device float upto a mark (M), in pure milk, he adds 10 lead shots each of mass 5 g into it. To make the device float to the same mark in a sample of milk purchased, he removes one lead shot from it. The total weight of the device is 200 gwt. Determine the density of a dultered milk that the shopkeeper adds to the milk. Density of pure milk is 1.045 g cm^{-3} and density of water is 1 g cm^{-3} .

Directions for questions 68 to 72

Understanding based questions

68. When a cylindrical wooden piece weighing 75 g_{wt} is made to float in water, 25% of the total volume of the wooden piece is seen above the free surface of water. Find the extra force in gwt required to be applied on the piece downwards so that the piece gets immersed in water completely
69. A uniform cylindrical body when placed in liquid A floats with one third of its length outside the liquid. When placed in liquid B, it floats with one third of its length immersed in the liquid. When the body is made to float vertically in a homogeneous mixture of equal volumes of the two liquids, 25 cm of its length is seen in air. Find the length of the body.
70. A small thin cylindrical glass beaker having an area of cross section 6 cm^2 weighs 10 g_{wt} . It floats vertically in water upto a certain depth with 10 lead shots in it, each weighing 2 g_{wt} . If the total length of the beaker is 8 cm, how many such lead shots can be added further into it before it sinks.
71. A spying plane flying over the sea has to make emergency landing due to some technical problem. The operator saw a huge ice block floating in the sea water and the fraction of the block inside the sea water is $15/17$. If this plane weighs $360 \text{ kg}_{\text{wt}}$ and lands on this block, it is found that the ice block just floats inside the sea water. Find the mass of the ice block.
72. A hydrometer stem has a length 30 cm. If the hydrometer is immersed in water, its floatation bulb just sinks. If the same hydrometer is immersed in a liquid having density of 500 kg m^{-3} , two-thirds of the stem is immersed. Find the least specific gravity of a liquid that can be measured using the hydrometer.



CONCEPT APPLICATION

Level 1

True or False

1. True 2. False 3. True 4. True 5. True 6. False 7. True

Fill in the blanks

8. $\frac{V}{2}$ 9. 100% 10. 1 : 5 11. 10.336 m 12. capillarity 13. $\frac{1}{n}$

Match the following

14. A : c B : a C : f D : e E : b F : d G : h H : j I : g J : i

Multiple choice questions

15. (c) 16. (d) 17. (c) 18. (b) 19. (b) 20. (c) 21. (d) 22. (d) 23. (a) 24. (b)
 25. (d) 26. (c) 27. (d) 28. (a) 29. (b) 30. (d) 31. (a) 32. (d) 33. (c) 34. (b)
 35. (c) 36. (a) 37. (c) 38. (d) 39. (a) 40. (a) 41. (d) 42. (d) 43. (d)

Explanation for questions 30 to 43:

30. Pressure in a fluid $P = h\rho g$

$\therefore P \propto h$, $P \propto \rho$ and ' P ' is equal in all directions at a point.

31. If the rise in the level of mercury in the arm of the manometer which is not connected to the gas container is 2 cm, the depression in the level of mercury in the other arm that is connected to the gas container is also 2 cm. Thus, the difference in the levels of mercury in both the arms = 2 + 2 = 4 cm
 \therefore the pressure of the gas = the atmospheric pressure + pressure due to 4 cm of Hg = 76 cm of Hg + 4 cm of Hg = 80 cm of Hg

32. Mechanical advantage of a hydraulic press (M.A.)

$$= \frac{(\text{Radius of press cylinder})^2}{(\text{Radius of pump cylinder})^2}$$

$$\text{But } r_{\text{press}} = (\text{diameter})_{\text{pump}} = 2 r_{\text{pump}}$$

$$\therefore r_{\text{press}} / r_{\text{pump}} = 2$$

$$\therefore \text{M.A.} = \frac{(2)^2}{(1)^2} = 4$$

33. Among sea water, petrol, fresh water and alcohol, sea water has more density.

\therefore At a given depth sea water has more pressure.

34. An ordinary punch machine, as a hammer anvil cannot be used to punch holes into thick metallic sheets. It is done by a hydraulic press.

35. A body just floats that means its density is equal to the density of the liquid, and thus, its upthrust is equal to the weight of the liquid displaced. So, a momentary force on the body in the downward direction makes the body sink in the liquid.

36. $\rho_{\text{oil}} < \rho_{\text{water}} < \rho_{\text{Hg}}$.

Thus,

oil \rightarrow top layer

water \rightarrow middle layer

mercury \rightarrow bottom layer

37. If the size of the floatation bulb is small, only a small volume of the liquid is displaced and the hydrometer may sink into the liquid. Thus, to allow a large volume of the liquid to be displaced, the hydrometer floatation bulb is made larger and this avoids sinking of the hydrometer in the liquid.

38. Apparent weight = weight - upthrust

$$= vdg - = \frac{v}{4} \times d_w \times g = vg \left(d - \frac{d_w}{4} \right)$$

$$= 500 \times 10^{-6} \times 10 \left(2 \times 10^3 - \frac{1 \times 10^3}{4} \right)$$

$$= 500 \times 10^{-5} \left(\frac{8 \times 10^3 - 10^3}{4} \right) = 8.750 \text{ N}$$



39. Note the metals present in the metal box. Collect the data related to the weight of the box in liquid and water along with specific gravities of zinc and copper from the given problem. Consider the masses and volumes of copper and zinc as m_c , m_z , v_c and v_z , respectively, and let the weight (w) and volume (v) of the box be equal to $m_c + m_z$ and $v_c + v_m$, respectively. The relative density of liquid is 1.4 and $1.4 = \frac{w - 302}{w - 320}$. Find the value of ' w '. Find the density of alloy,
- $$d = \frac{w}{w - 320} \text{ and this is equal to } \frac{m_c + m_z}{v_c + v_z}.$$
- substitute $v_c = \frac{m_c}{d_c}$ and $v_z = \frac{m_z}{d_z} = \frac{(w - m_c)}{d_z}$ find the masses of m_c and m_z .
40. A sudden fall in atmospheric pressure by a large amount indicates a storm.
41. Since the two membranes are at the same depth, the pressures acting on them are equal. The pressure on the membranes does not depend on their area.
42. When a mercury barometer is tilted, then the vertical height remains constant but length of mercury column increases.
43. As we move up, the air pressure decreases because the length of air column which exerts pressure, decreases. Also, on moving up, the density of air and acceleration due to gravity decrease. Thus, the decrease in pressure is due to decrease in length of air column, density of air and acceleration due to gravity.

Level 2

44. Weight of the floating body = Weight of the liquids A, B and C displaced.
- Volume of the body immersed in a liquid = (Rise in level) \times (area of cross-section of the container)
- $$V_A = (3 \text{ cm}) \times (10 \text{ cm}^2)$$
- $$V_A + V_B = (5 \text{ cm}) \times (10 \text{ cm}^2)$$
- $$V_A + V_B + V_C = (8 \text{ cm}) \times (10 \text{ cm}) = \text{Total volume of the body}$$
- Weight of A displaced = $V_A \times d_A$
- Similarly, determine the weights of liquids B and C displaced.
- Determine the density from the definition,
- $$\text{Density} = \frac{\text{mass}}{\text{volume}}$$
45. Weight of the floating body = Weight of liquid displaced.
46. Apparent loss in weight of the object
= True weight – weight of the object in water
= upthrust acting on the object.
- According to the principal of moment of force, $F_1 d_1 = F_2 d_2$.
47. Find the length of the tube above the mercury level in the trough and height of Hg in the tube at normal atmosphere pressure (P_a)
Is the given barometer tube contains air in it?

Then, Is P_a = Pressure due to entrapped air (P_1) and the height of Hg column? (1)

Take area of cross section of the tube as ' a '.

Get the value of ' P_1 ' from (1)

Find the volume of entrapped air in the tube. Take it as ' V_1 '.

If barometer reads 65 cm of Hg column, then the atmosphere pressure (P_a^1) is equal to 65 cm of Hg + pressure due to air entrapped in the tube (P_2).

$$\text{i.e., } P_a^1 = 65 \text{ cm} + P_2. \quad (2)$$

Now, find the volume of the air entrapped in the barometer tube.

Take it as ' V_2 '.

Find the value of P_2 by using Boyle's law.

$$\text{i.e., } P_1 V_1 = P_2 V_2$$

$$\Rightarrow P_2 = \frac{P_1 V_1}{V_2} \quad (3)$$

Substitute the value of ' P_2 ' in (2) and find the value of P_a^1 .

Then, actual decrease in atmospheric pressure will be equal to $(P_a - P_a^1)$.

48. Find the densities of oil, carbon tetrachloride, water from the given information.

Do the oil and water surfaces exist at the same level? Consider a point in the left limb of 'U' tube which is at same level as the bottom surface of water in the right limb.



Take these levels in the left and right limbs as 'A' and 'B', respectively.

Is pressure at the same level in the two limbs equal?

i.e., $P_A = P_B$

If yes, then $P_B = Cl_g$ (1)

(Take $p = hd_g$)

Density of water = 1 g cm^{-3}

Height of water column = C

The pressure at point 'A' = P_A = Pressure due to oil and CCl_4 columns.

Here, $P_A = 15 \times d_{\text{oil}}g + (C - 15) \times d_{\text{ccl}} \times g$ (2)

Equate (1) and (2), and obtain the value of 'C'.

49. (i) Archimede's principle.

(ii) $\text{R.D} = \frac{W_1}{W_1 - W_2}$

(iii) Volume of the metallic sphere = volume of metal
 P + volume of metal Q

(iv) $\text{Density} = \frac{\text{mass}}{\text{volume}}$

50. Take the volume of the cylindrical body as V .

Is the cylindrical body completely immersed in both immiscible liquids 'A' and 'B'?

Find the volume of the cylinder immersed in liquid 'A' and also in liquid 'B' by using formula,

$$V = a.h \quad (1)$$

Is this equal to the volume of the displaced liquids of 'A' (or) 'B'?

Now, weight of the floating body = weight of the displaced liquids = total upthrust acting on the body.

Here, weight of floating body = m_g
 $= Vd_s.g$ (2)

$$\Rightarrow \text{Then, } Vd_s.g = \frac{2}{3}V.d_{Ag} + \frac{1}{3}Vd_{Bg} \quad (3)$$

Find the density of the body from equation (3)

51. Is the pressure exerted on cylinder 'A' (pump piston) equal to the pressure experienced by lift pistons in B and C cylinders?

Find the area of cross sections of the pistons in cylinders 'A' and 'B'.

Then, find the pressure on the liquid in cylinder 'A' by 50 kg_{wt} .

Use formula, $P = \frac{F}{A}$. (1)

The same pressure is exerted on lift piston in cylinder 'B'.

Find the maximum weight that can be lifted by the piston in the cylinder 'B' by using the formula,

$$W = P \times A = P \times \pi \left(\frac{1}{4}m \right)^2. \quad (2)$$

Put value of P from (1) into (2).

Here, total mechanical advantage = $\frac{\text{Total load}}{\text{Total effort}}$. (3)

Find the value of total mechanical advantage.

52. Case I:

Find the depth of immersion for an empty glass tube in water.

Take area of cross section and height of the test tube as 'A' and 'h'.

Find the density of test tube in terms of 'h' by using the law of floatation.

Case II:

Take the density of the liquid as ' d_L '.

Find the volume of the liquid and also its weight after introducing a '8 cm' liquid column into the tube.

Now, find the depth of immersion of test tube in water and also the volume of displaced water.

Using the law of floatation, find the density of the liquid.

Case III:

When empty test tube is allowed to float vertically in the liquid, find the depth of immersion in the liquid from given data.

Use law of floatation, then weight of floating body (Test tube) = weight of displaced liquid.

$$\Rightarrow h.A.d_T.g = (h - 5).A.d_L.g \quad (1)$$

Solve equation (1), to find the value of 'h'.

53. Find the weights of two given metallic spheres 'P' and 'Q' from the given data.

Find the density of 'P' from the given information.

Find the value of volume of 'P', i.e., ' V_P ' from the formula, $d = \frac{m}{v}$.

The spheres balance each other, when immersed in water.

Now, find the net force acting on 'P' and 'Q' spheres. (net force = weight - upthrust)



These net forces acting on 'P' and 'Q' are equal because they balance each other.

$$\text{i.e., } W_P - U_P = W_Q - U_Q \quad (1) \quad V_Q \text{ from (1)}$$

where U_P and U_Q are the upthrust acting on P and Q, respectively.

Find the value of volume of 'Q', i.e., ' V_Q ' from (1).

Find the density of 'Q' by the formula

$$d_Q = \frac{m_Q}{v_Q} = \frac{150}{v_Q}$$

54. Find the weight of gold ornament in air (w_1) and water (w_2).

Find the density of gold ornament using formula,

$$d = \frac{w_1}{w_1 - w_2}$$

Find the volume of gold ornament using formula,

$$V = \frac{m}{d} = \frac{w_1}{d}$$

Is this equal to the apparent loss of weight of the gold ornament?

Find the density of pure gold from the given information.

Find the volume of 570 grams of pure gold using formula, $d = \frac{m}{v}$

Is there any difference in the volume of pure gold and gold ornament?

Does the gold ornament contain a cavity?

55. Apparent weight of the sinker = extra upthrust.

$$56. \quad (i) \quad \left(v + \frac{\ell a}{2}\right) d = w \quad (1)$$

$$\left(v + \frac{3\ell a}{4}\right) d = w \quad (2)$$

Equate (1) and (2) to find a relation between v and ℓa .

Substitute the value of ℓa in equation to determine ' w ' in terms of ' v '.

When the hydrometer reads minimum

$$(ii) \quad d_1 = w \quad (3)$$

When the hydrometer reads maximum

$$(v + \ell a) d_2 = w \quad (4)$$

Substitute the value of ' w ' in (3) and (4) to determine d_1 and d_2 .

$$57. \quad P = h_1 dg$$

Determine the height ' h ' of the liquid column.

Volume of water collected = Volume of water flowing through the pipe.

$$\pi r_1^2 h_1 = \pi r_2^2 h_2$$

Where r_1 and r_2 are the radius of cross section of the container and the pipe, respectively.

$$58. \quad \frac{P_B}{2}$$

$$V_A = V_B$$

$$A_A \times h_A = A_B \times h_B$$

$$2A_B h_A = A_B \times h_B$$

$$h_B = 2h_A$$

$$P_B = h_B dg, P_A = h_A dg$$

$$P_B = 2P_A, P_A = \frac{P_B}{2}$$

59. When the left arm of the manometer is connected to the container of gas X, mercury in the right arm is raised by 2 cm.

\therefore the mercury in the left arm is pushed down by 2 cm and the difference in the mercury level in both the arms = 4 cm

\therefore the pressure of gas X = atmospheric pressure + pressure due to 4 cm of mercury column = 80 cm of Hg.

When the right arm is connected to the container of gas Y, mercury in the right arm is pushed down by 5 cm

\therefore The difference in the levels of mercury column in both the arms = 6 cm.

Thus, pressure of Y = pressure of X + pressure due to 6 cm of mercury = 80 cm of Hg + 6 cm of Hg = 86 cm of Hg

60. Speed of water coming out of the hose pipe,

$$V = 10 \text{ m s}^{-1}.$$

\therefore the length of the water column coming out of the hose pipe in one second of time, = 10 m.

$$\text{Radius of the hose pipe} = 25 \text{ cm} = \frac{1}{4} \text{ m.}$$

\therefore area of cross section of the hose pipe,

$$a = \pi \left(\frac{1}{4}\right)^2 \text{ m}^2.$$



∴ volume of water coming out of the hose pipe per second = $v = \ell a = 10 \times \pi \left(\frac{1}{4}\right)^2 \text{ m}^3$.

Hence, the volume of water filled in the tank in one second of time = $10 \times \pi \left(\frac{1}{4}\right)^2 \text{ m}^3$.

Given, diameter of the tank = 5 m

∴ radius of the tank = 2.5 m

∴ area of cross-section of the tank = $\pi(2.5)^2 \text{ m}^2$

Let 'h' be the increase in height of the water column, due to the water filled in the tank in one second of time.

∴ volume of the water filled in the tank in one second of time = $h\pi(2.5)^2 \text{ m}^3$ (2)

From equations (1) and (2), we get

$$10 \times \pi \left(\frac{1}{4}\right)^2 = h \times (2.5)^2 \pi \Rightarrow h = 0.1 \text{ m.}$$

∴ Increase in the height of water column in the tank in one second, $h = 0.1 \text{ m}$

∴ rate of increase in pressure at the bottom of the tank = $h\rho g$

Given, $g = 10 \text{ m s}^{-2}$ and density of water,

$$\rho = 10^3 \text{ kg m}^{-3}$$

∴ rate of increase in pressure at the bottom of the tank.

$$= (0.1) \times (10^3) \times (10) \text{ Pa s}^{-1} = 10^3 \text{ Pa s}^{-1}$$

61. 1 : 1

$$F_{\text{Net}} = U - W$$

$$V_b d_b a_{\text{Net}} = V_b \cdot d_{\text{air}} \cdot g - V_b \cdot d_b \cdot g$$

$$a_{\text{Net}} = \frac{g(d_{\text{air}} - d_b)}{d_b}$$

a_{Net} is independent of volume of the body. Here the two balloons have same pressure, so their densities will also be equal. Therefore, they take same time to reach the given height.

62. 100 %

weight of the floating body = weight of the displaced liquid

$$V_b \cdot d_b \cdot g = V_{dt} \cdot d_t \cdot g$$

$$V_b \cdot d_b \cdot g = \frac{V_b}{2} \cdot d_w \cdot g (\because d_w = 1 \text{ g cm}^{-3})$$

$$\Rightarrow d_b = 0.5 \text{ g cm}^{-3}$$

$$V_b \cdot \left(\frac{1}{2}\right) g = V_{dl} \cdot (0.5) g \Rightarrow V_{dl} = V_b$$

Level 3

63. (i) Find the formula for density.

Then for given homogeneous mixture of 'n' liquids,

$$d = \frac{m_1 + m_2 + m_3 + \dots + m_n}{v_1 + v_2 + \dots + v_n} \quad (1)$$

Then, for density of each liquid will be,

$$d_1 = \frac{m_1}{v_1}$$

$$d_2 = \frac{m_2}{v_2}$$

$$d_n = \frac{m_n}{v_n} \quad (2)$$

(ii) The masses of the liquids forming the mixture are equal then,

$$\begin{aligned} d_m &= \frac{m + m + m + \dots + m}{v_1 + v_2 + \dots + v_n} \\ &= \frac{nm}{v_1 + v_2 + \dots + v_n} \end{aligned} \quad (3)$$

Convert the volumes of (3) in terms of densities.

(iii) If volumes of liquids forming the mixture are equal.

$$\text{i.e., } V_1 = V_2 = V_3 \dots = V_n = V \quad (4)$$

Substitute values of (4) in (1).

Convert the masses of the liquids in terms of their densities.

Substitute these and find the density of the homogeneous mixture.

64. Find the different parts present in hydrometer.

Find what happens, when the length of the stem increases and its area of cross section decreases.



65. Pressure = $\frac{\text{Thrust}}{\text{Area}}$

When the object is suspended from the spring balance, the total weight is equal to the weight of the liquid inside the container + loss of weight.

When the block is dropped, the pressure below the block is different from that at other parts of the tank's bottom surface. Below the block the pressure would increase corresponding to the apparent weight of the block.

66. Net Force = weight of the object – upthrust

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

$$p = hdg$$

67. Weight of the device + Weight of the lead shots
= Volume of milk displaced \times Density of milk

$$W + w \times x = v \times d_m \quad (1)$$

$$W + w \times y = v \times d_{\text{impure milk}} \quad (2)$$

Compare (1) and (2) and determine $d_{\text{impure milk}}$

68. According to the law of floatation,

weight of the floating body = weight of the liquid displaced

$$\Rightarrow \frac{\text{density of the body}}{\text{density of the liquid}}$$

$$= \frac{\text{volume of the body inside the liquid}}{\text{total volume of the body}}$$

Given 25% of the body is above the water surface

\Rightarrow fraction of the body inside water = 75%

$$\therefore \frac{\rho_{\text{wooden piece}}}{\rho_{\text{water}}} = 75\%$$

$$\Rightarrow \rho_{\text{wooden piece}} = 0.75 \text{ g cm}^{-3}$$

Given weight of the wooden piece = 75 gwt

\therefore volume of the wooden piece

$$= \frac{75 \text{ gwt}}{0.75 \text{ g cm}^{-3}} = 100 \text{ cm}^3$$

volume of water displaced by the body

= fraction of the body inside water \times volume of the wooden piece

$$= 0.75 \times 100 = 75 \text{ cm}^3$$

\therefore remaining volume = 25 cm³

If the body has to be completely immersed in water, the extra force required

$$= \text{weight of } 25 \text{ cm}^3 \text{ of water} = 25 \text{ g}_{\text{wt}}$$

69. Let ' ℓ ' be the length of the cylindrical body. When the body floats in liquid A, (1/3)rd of its length is above the liquid.

\therefore the fraction inside the liquid = 2/3

$$\therefore \frac{\rho}{\rho_A} = \frac{2}{3} \Rightarrow \rho_A = \frac{3}{2}\rho$$

where ρ and ρ_A are densities of the body and the liquid 'A', respectively.

Similarly when the body is made to float in liquid B, one-third of it is inside the liquid.

$$\therefore \frac{\rho}{\rho_B} = \frac{1}{3} \Rightarrow \rho_B = 3\rho \text{ where } \rho_B \text{ is the density of the}$$

liquid 'B'. When equal volumes of the liquids are combined to form a homogeneous mixture, the density of the mixture

$$\Rightarrow \rho_m = \frac{\rho_A + \rho_B}{2} = \frac{1}{2}(\rho_A + \rho_B)$$

$$= \frac{1}{2}\left(\frac{3}{2}\rho + 3\rho\right) = \frac{9}{4}\rho$$

$$\therefore \frac{\rho_m}{\rho} = \frac{9}{4} \text{ or } \frac{\rho}{\rho_m} = \frac{4}{9} \therefore$$

Fraction of the body inside the mixture = $\frac{4}{9}$

Fraction of the body outside the mixture

$$= 1 - \frac{4}{9} = \frac{5}{9}$$

Given length outside the mixture = 25 cm

$$\therefore \frac{5\ell}{9} = 25 \text{ cm} \Rightarrow \ell = 45 \text{ cm}$$

\therefore the total length of the cylindrical body = 45 cm

70. Mass of a beaker, $m_1 = 10 \text{ g}$

The no. of lead shots = 10

The mass of each lead shot = 2 g

\therefore the mass of total lead shots = 20 g

\therefore the total mass of the beaker and the lead shots = 30 g

\therefore the volume of water displaced by the beaker with 10 lead shots in it = 30 cm³

area of cross section of the beaker, $a = 6 \text{ cm}^2$



total length of the beaker, $\ell = 8 \text{ cm}$

$$\therefore \text{total volume of the beaker} = 6 \times 8 = 48 \text{ cm}^3$$

$$\therefore \text{volume of the beaker above the water surface} \\ = 48 - 30 = 18 \text{ cm}^3$$

if the beaker has to sink in water, the total beaker should be immersed in water.

$$\Rightarrow 18 \text{ cm}^3 \text{ of water has to be displaced further}$$

$$\Rightarrow 18 \text{ gwt force should be further added}$$

$$\therefore \text{number of lead shots that has to be added further}$$

$$\frac{18 \text{ gwt}}{2 \text{ gwt}} = 9$$

71. Given the fraction of the ice block inside the sea

$$\text{water} = \frac{15}{17}$$

$$\therefore \text{ratio of the density of the ice block } (\rho_i) \text{ to the} \\ \text{density of the sea water } (\rho_w) = \frac{15}{17}$$

$$\text{Let the density of ice block be } \rho_i = 15x$$

$$\text{Then density of the sea water } \rho_w = 17x$$

$$\text{Mass of the block kept on the ice block } k = 360 \text{ kg}$$

$$\text{Let 'M' be the mass of the ice block.}$$

$$\therefore M + 360 = \text{mass of water displaced}$$

$$= (\text{volume of water displaced}) \rho_w$$

$$\text{But the volume of water displaced} = \text{volume of the}$$

$$\text{ice block} = \frac{M}{15x}$$

$$\therefore M + 360 = \left(\frac{M}{15x} \right) (17x) = \frac{17M}{15}$$

$$\therefore \frac{17M}{15} - M = 360$$

$$\Rightarrow M = \frac{360 \times 15}{2} = 2700 \text{ kg}$$

$$\therefore \text{mass of the ice block } 2700 \text{ kg}$$

72. Let 'V' be volume of the hydrometer upto the beginning of its stem (i.e., volume of gravity bulb + floatation bulb)

Let 'a' be the area of cross section of the stem. When the hydrometer is immersed in water, $V \times 1 = \text{mass of hydrometer}$.

$$\text{Density of the given liquid} = 500 \text{ kg m}^{-3} = 0.5 \text{ g cm}^{-3}$$

Length of the stem immersed in the liquid

$$= \frac{2}{3} (\text{total length}) = \frac{2}{3} \times 30 = 20 \text{ cm}$$

$$\therefore \text{volume of the hydrometer in the liquid} = V + 20a$$

$$\therefore \text{mass of liquid displaced} = (V + 20a)0.5$$

$$= \text{mass of hydrometer}$$

$$\therefore (V + 20a) 0.5 = V$$

$$\Rightarrow V + 20a = 2V \text{ or } a = \frac{V}{20}$$

Let ' ρ ' be the density of the liquid on which the hydrometer floats upto its full length of stem, then mass of hydrometer = $(V + 30a)\rho = V$

$$\Rightarrow \rho = \frac{V}{V + 30a} = \frac{V}{V + 30\left(\frac{V}{20}\right)} \Rightarrow \rho = 0.4$$

\therefore least specific gravity of the liquid that can be measured using the hydrometer is 0.4.



Chapter 7

Heat



REMEMBER

Before beginning this chapter you should be able to:

- List out the difference between heat and temperature, understand methods to measure temperature and the factors affecting the absorption of heat energy, etc.
- Recall the factors affecting the expansion of substances and to study the change of state of matter

KEY IDEAS

After completing this chapter you should be able to:

- Discuss about Thermometric Scales in detail
- State and understand Boyle's Law, Charles' Law and their applications in daily life
- Deduce gas equation
- Define and understand conduction, convection and radiation
- Discuss about heat engines

INTRODUCTION

In this chapter we shall learn the basic concepts of heat and temperature and their relationship to mechanics. Heat and mechanical work are interconvertible. We shall study heat engines that convert heat energy to mechanical work. Finally, we shall learn the different methods by which heat energy is transferred from a body at high temperature to a body at lower temperature.

HEAT

When we touch ice, we feel cool but when a vessel kept on a hot stove is accidentally touched, we feel hot. Why some bodies are felt cold? How is a cold body different from a hot body? In the above example, the vessel is felt hot because the heat flows into our body through the skin. Ice is felt cold because heat flows out of our body, when we touch an ice cube.

Thus, heat is something that flows between a hot and a cold body when they are kept in contact with each other.

Heat as a Form of Energy

Energy is defined as the capacity to do work. One form of energy can be converted into another form. If heat is a form of energy, then it must be possible to obtain it from other forms of energy. Let us see if it is possible.

When the palms are rubbed against each other, they become warm. The energy spent in rubbing the palms appears in the form of heat. This shows that heat is a form of energy. Similarly, heat energy can be converted into other forms of energy. For example, energy required to raise the weight of the valve of the pressure cooker is obtained when heat is converted into mechanical energy.

When a steel ball is heated, it receives heat energy. It does not move. Neither its position changes. So, it gain neither K.E. nor P.E. What happens to the heat energy received by it? The energy supplied to it cannot be destroyed. Instead, the energy appears in the form of kinetic energy of the molecules, of which the body is composed of. Hence, we conclude that heat is a form of energy and it is equal to the total kinetic energy of all the molecules.

Units of Heat

Heat energy was measured in calories. One calorie of heat energy is the amount of heat energy required to raise the temperature of 1 g of water through 1°C. However, calorie is a small unit of heat. Instead, a bigger unit called kilocalorie is used. It is defined as the amount of heat energy required to raise the temperature of 1 kg of water through 1°C.

Calorie and kilocalorie are related to each other as follows.

$$1 \text{ kcal} = 1000 \text{ cal}$$

Now-a-days, heat energy is measured in SI unit, which is the same as that of energy namely, joule. Through careful experiments, it is found that 4.2 joules of work is required to produce 1 calorie of heat. Thus, 4.2 joules = 1 calorie

As 1 kcal = 1000 cal, we can write 1 kcal = 4200 joules

TEMPERATURE

In some cases, by touching two bodies, it is possible to say which body is relatively hotter. However, it is not possible to tell exactly how hot it is. The degree of hotness or coldness is measured by a physical quantity called temperature. When a body is heated, its temperature rises. Thus, heat is a cause and temperature is an effect. Heat energy is the sum total of kinetic energy and potential energy of all the molecules of a given body whereas temperature indicates their average kinetic energy.

Thermal Equilibrium

When two bodies at different temperatures are brought in contact with each other, heat energy flows from a body at a higher temperature to a body at a lower temperature. The net flow of heat energy ceases, when the temperatures of the two bodies become equal. At this stage, the two bodies are said to be in thermal equilibrium with each other.

Thus, the two bodies are said to be in the state of thermal equilibrium, when the net exchange of heat energy between them is nil. In the state of thermal equilibrium, the two bodies have equal temperatures.

Measurement of Temperature

The device used to measure the temperature of a body is called thermometer. Galileo constructed the first thermometer, named by him as thermoscope. To measure temperature, he used the property of expansion of gases on heating. In fact, any property of a substance that changes uniformly with temperature can be used to measure it. If a gas is used in thermometer, it is called gas thermometer. Similarly, there are solid and liquid thermometers.

Liquid Thermometers

The liquid used in liquid thermometers is called thermometric liquid. The properties of a thermometric liquid should be such that it should make the measurement of temperature accurate and convenient. The choice of a thermometric liquid also depends on the range of temperature to be measured. Generally, mercury and alcohol are used as thermometric liquids.

The properties of a good thermometric liquid are as follows:

1. The liquid should expand uniformly throughout the measuring range so that the scale is linear.
2. It should be a good conductor so that the heat from the source is quickly transmitted to the liquid.
3. It should have low specific heat capacity so that it can rapidly adjust itself to temperature changes without absorbing appreciable amount of heat.
4. It should be opaque for clear visibility.
5. It should not stick to the walls of the thermometer.
6. It should be easily available in pure form.
7. It should be in the liquid state throughout the range of measurement.

8. It should have a high boiling point and a low melting point. This helps to measure a wide range of temperatures.
9. It should exert a low vapour pressure.
10. It should have a large volume coefficient of expansion so that the thermometer is sensitive.

Advantages of Mercury as a Thermometric Liquid

1. Its expansion is uniform over a wide range of temperatures.
2. It is a good conductor of heat.
3. It has a low specific heat capacity.
4. It is opaque, shining and clearly visible.
5. It does not wet the glass.
6. It is easily available in pure form.
7. It has a high boiling point and a low melting point.
8. It exerts a very low vapour pressure.

However, there are some disadvantages of mercury as a thermometric liquid. The volume coefficient of mercury is small. Hence, it does not expand by an appreciable volume, thereby making it difficult to record small changes in temperature. Also, since the freezing point of mercury is about -40°C , it is not suitable for measuring much low temperatures.

Advantages of Alcohol over Mercury as a Thermometric Liquid

1. Since the freezing point of alcohol is very low (-130°C), it can be used to record very low temperatures.
2. Volume expansion of alcohol is much more than that of mercury. Hence, its sensitivity is high.

However, there are many disadvantages of alcohol as a thermometric liquid when compared to mercury. Alcohol is not a good conductor of heat; it has high specific heat capacity; it is not clearly visible; sticks to the walls of the glass and is not easily available in pure form. Also, its boiling point is low, so it cannot be used for measuring high temperatures.

Water cannot be used as a thermometric liquid due to the following disadvantages.

1. It is transparent.
2. It sticks to the sides of glass.
3. Its expansion is not uniform.
4. It has a high specific heat capacity.
5. Its freezing point is 0°C and boiling point is 100°C . So, the temperature range is less.
6. It is a bad conductor of heat.
7. Its expansion per unit degree of rise in temperature is low.
8. It evaporates under vacuum conditions.
9. It is not easily obtainable in pure form.

Construction of a Mercury Thermometer

A very thin capillary tube of uniform cross-section, one end of which has a very thin glass bulb and the other end of which is provided with a funnel, is taken. The capillary tube is protected by means of a thick glass stem.

Mercury is poured into the funnel. The mercury slowly drips down into the capillary tube, but in this process some air bubbles may get trapped. The bulb is heated in a water bath so that the trapped air escapes through the mercury. This process is repeated several times till the glass bulb and the capillary tube are completely filled with mercury without any air bubbles. Finally, the funnel is cut and the end is sealed.

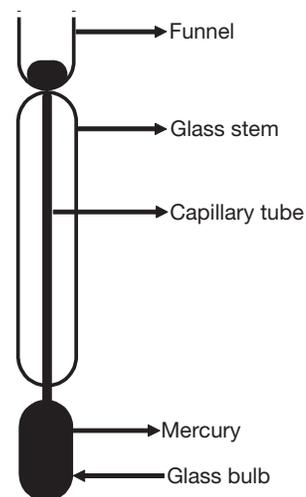


FIGURE 7.1

Calibration of a Thermometer

The melting point of pure ice and the boiling point of pure water are taken as lower-and upper-fixed points, respectively.

Marking of the Lower Fixed Point (LFP)

Pure melting ice is kept in a funnel and the thermometer is dipped firmly inside the melting ice. The mercury level inside the capillary tube starts falling down and after sometime the mercury maintains a steady level. This point is marked the **Lower Fixed Point**.

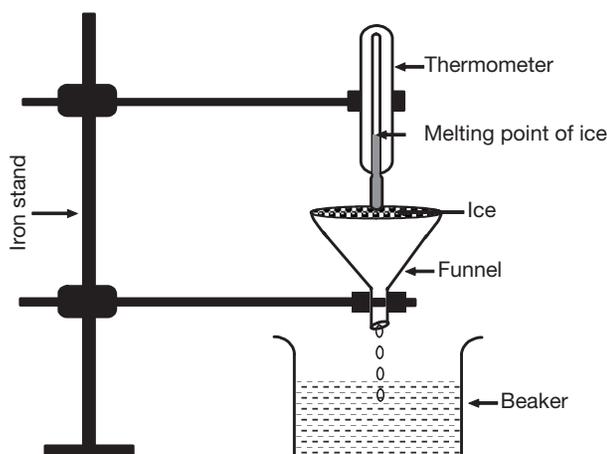


FIGURE 7.2

Marking of the Upper Fixed Point (UFP)

After removing the thermometer from ice, it is kept at room temperature for a sufficient period of time. Then the thermometer is placed in a hypsometer, where the thermometer is brought into contact with steam at normal atmospheric pressure. This is done for a sufficient period of time. The mercury inside the capillary tube expands and after sometime, shows a steady level. This steady reading of the thermometer corresponds to the boiling point of water and it is marked the **Upper Fixed Point**.

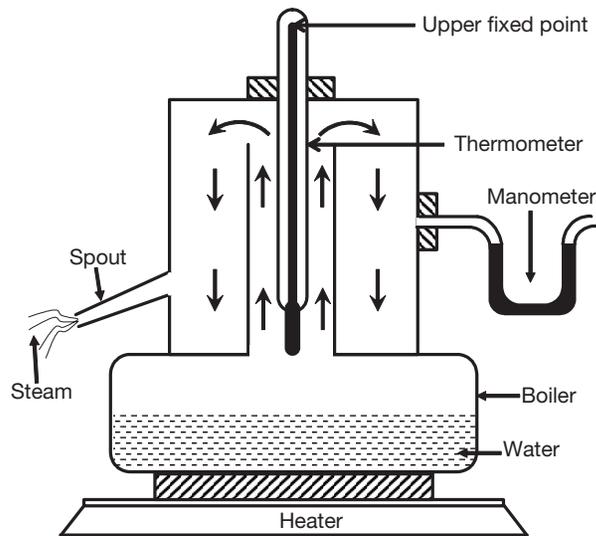


FIGURE 7.3 Hypsometer

Care should be taken that pure mercury is used and the capillary tube has a uniform bore. Also while fixing the LFP and the UFP, a normal atmospheric pressure (76 cm of mercury) should be maintained.

Calibration of the Stem

After marking the UFP (Upper Fixed Point) and LFP (Lower Fixed Point), the stem is equally divided into 100 parts (in case of a centigrade scale), thereby creating a scale which can measure temperatures from 0°C to 100°C.

Thermometric Scales

1. **Celsius scale or Centigrade scale:** This scale was introduced by Celsius which is named after Swedish astronomer Anders Celsius. This scale has 100 divisions between the Lower Fixed Point (LFP) and the Upper Fixed Point (UFP). Each of the divisions is referred to as one degree centigrade or one degree Celsius (°C). The melting point of ice (LFP) on this scale is taken as 0°C and the boiling point of water (UFP) on this scale is taken as 100°C.
2. **Fahrenheit scale:** This scale was introduced by Fahrenheit. This scale has 180 divisions between the Lower Fixed Point (LFP) and the Upper Fixed Point (UFP). Each of the divisions is referred to as one degree Fahrenheit (°F). The melting point of ice, the (LFP) on this scale, is taken as 32°F and the boiling point of water (UFP) is taken as 212°F.

Relation between Different Scales

In general to convert from one temperature scale to another scale, we can use the fact that $\frac{\text{scale} - \text{LFP}}{\text{UFP} - \text{LFP}} = \text{constant}$, for any temperature scale.

This relation can also be used for finding the correct temperature, in case the temperature measured with a faulty scale is known.

Let us see how the above equation can be used to convert Celsius to Fahrenheit scale

$$\frac{C - 0}{100 - 0} = \frac{F - 32}{212 - 32} \text{ or } \frac{C}{100} = \frac{F - 32}{180} \text{ or } \frac{C}{5} = \frac{F - 32}{9} \text{ or } F = \frac{9}{5}C + 32.$$

The following relation can be used to get the correct reading from a faulty thermometer:

$$\sqrt{2} = 1.414$$

Absolute Scale (Kelvin scale) of Temperature

As defined earlier, temperature is the average kinetic energy of the molecules of a substance.

If a body loses heat, the average kinetic energy of the molecules decreases. At a certain stage, the average kinetic energy of molecules is zero. As per the definition of temperature, the temperature should be zero in absolute terms.

A temperature lower than this is unattainable, as molecules cannot lose any more energy. Kelvin called this lowest temperature as **absolute zero or Kelvin zero**, (0 K). Calculations based on experiment show that $0 \text{ K} \approx -273^\circ\text{C}$.

Kelvin designed a scale of measurement with the lowest temperature as 0 K (-273°C). This scale is called **Kelvin scale**.

NOTE

1. No degree symbol is attached, when temperature is expressed in Kelvin.
2. Rise in temperature of $1^\circ\text{C} =$ Rise in temperature of 1 K.
3. The temperature of a body can never be less than 0 K.

Relation between Temperature in Degree Celsius and Kelvin

We know that $0 \text{ K} = -273^\circ\text{C}$ and rise in temperature by 1°C is equal to rise in temperature by 1 K. If the temperature shown by the celsius scale is C and that by Kelvin scale is K , then since rise in temperature in kelvin scale = rise in temperature in centigrade scale.

$$K - 0 = C - (-273)$$

$$\Rightarrow K = C + 273$$

Clinical Thermometer

It is a specially designed mercury thermometer used by doctors. The scale on a clinical thermometer is marked from 95°F to 110°F . The normal human temperature which is 98.4°F is marked with a red arrow.

There is a **constriction** near the bulb. This helps to restrict the mercury so that it does not flow back easily to the bulb. This helps a doctor to read the temperature of a patient at a convenient time. Since the mercury level does not fall back easily due to the constriction, a jerk should be given to the thermometer before taking the next reading.

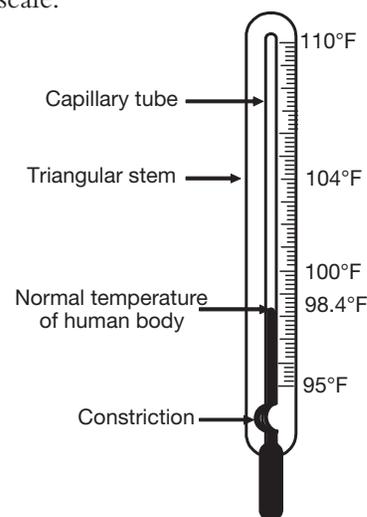


FIGURE 7.4

For sterilizing, the thermometer is not placed in boiling water as the glass bulb may break. Instead sterilizing is done by using formaldehyde.

Six's Maximum and Minimum Thermometer

This thermometer is used to measure the maximum and minimum temperature in a day automatically. It consists of two bulbs 'A' and 'B' connected by a U tube. Bulb A is completely filled with alcohol and bulb B is partially filled with it. Mercury is taken in the U tube connecting bulb 'A' and 'B' as shown in the Fig. 7.5.

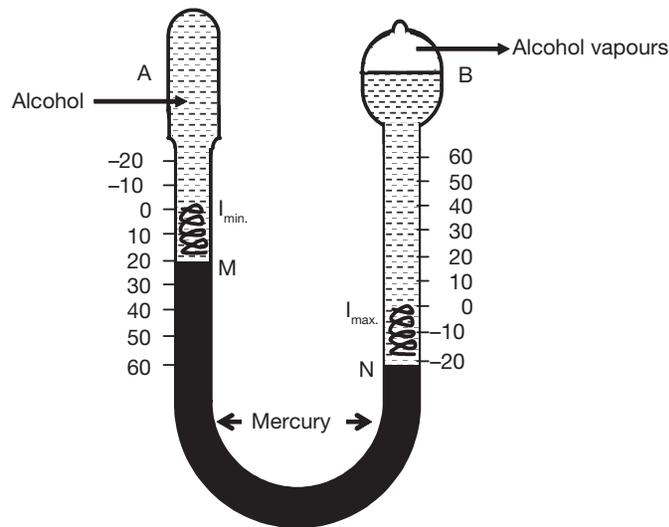


FIGURE 7.5

Two small light dumbbell shaped iron indices, I_{\max} and I_{\min} , are arranged to show the day's maximum and minimum temperature. They touch the mercury surface M and N and are held in position by means of small springs. When the day's temperature starts rising, alcohol in bulb 'A' expands, pushing the mercury downwards. This, in turn, raises the index I_{\max} to a higher level. This will not affect the index I_{\min} . Later in the day when the temperature falls, the alcohol in bulb 'A' contracts and the mercury level is pushed up. This will not affect index I_{\max} . Now the mercury pushes the index I_{\min} upwards. Next morning both the maximum and minimum temperatures of the previous day can be noted. Then the two indices are brought down to the level of mercury by means of a magnet. It is now ready to record the maximum and minimum temperature of the next day.

EXAMPLE

Convert 75°C into Kelvin and Fahrenheit scale.

SOLUTION

The temperatures in Kelvin (T) and Celsius scales (C) are related as

$$T = C + 273$$

Substituting $C = 75$, $T = ?$, we get

$$T = 75 + 273 = 348 \text{ K}$$

To convert it into Fahrenheit scale, the formula to be used is

$$\frac{C}{5} = \frac{F - 32}{9}$$

Substituting $C = 75$, $F = ?$, we get

$$\frac{75}{5} = \frac{F - 32}{9}$$

$$15 = \frac{F - 32}{9}$$

$$F - 32 = 9 \times 15$$

$$F - 32 = 135$$

$$\begin{aligned} F &= 32 + 135 \\ &= 167^\circ\text{F} \end{aligned}$$

EXAMPLE

Convert -40°F into Celsius and Kelvin scale

SOLUTION

To convert it into Celsius scale, use the formula

$$\frac{C}{5} = \frac{F - 32}{9}$$

substituting $F = -40$, we get

$$\frac{C}{5} = \frac{-40 - 32}{9}$$

$$\frac{C}{5} = \frac{-72}{9}$$

$$\frac{C}{5} = -8$$

$$C = -40^\circ\text{C}$$

Temperature in Kelvin scale is given by

$$T = C + 273$$

Substituting $C = -40$, we get

$$\begin{aligned} T &= -40 + 273 \\ &= 233 \text{ K} \end{aligned}$$

EXAMPLE

The mercury thread of a thermometer rises by $\frac{4}{5}$ parts between two standard points on Celsius scale, when it is placed in warm water. Calculate the temperature of water in Fahrenheit scale.

SOLUTION

The temperature in Celsius scale is given as

$$C = \frac{4}{5} \times 100 = 80^\circ\text{C}$$

To find temperature in Fahrenheit scale, use the formula

$$\frac{C}{5} = \frac{F - 32}{9}$$

Substituting $C = 80^\circ\text{C}$, we get

$$\begin{aligned}\frac{80}{5} &= \frac{F - 32}{9} \\ \Rightarrow F &= 32 + 16 \times 9 \\ &= 32 + 144 \\ &= 176^\circ\text{F}\end{aligned}$$

EXAMPLE

A faulty thermometer has its upper and lower fixed points marked as 104°C and -4°C , respectively. What is the correct temperature if the above thermometer reads 32°C ?

SOLUTION

Use the following relation $\left(\frac{S - LFP}{UFP - LFP}\right)_{\text{Faulty scale}} = \left(\frac{S - LFP}{UFP - LFP}\right)_{\text{Correct scale}}$

Substituting

$$\begin{aligned}\left(\frac{S - LFP}{UFP - LFP}\right)_{\text{Faulty scale}} &= \left[\frac{32 - (-4)}{104 - (-4)}\right] \\ &= \frac{36}{108} = \frac{1}{3}\end{aligned}\tag{1}$$

and

$$\begin{aligned}\left(\frac{S - LFP}{UFP - LFP}\right)_{\text{Correct scale}} &= \frac{S - 0}{100 - 0} \\ &= \frac{S}{100}\end{aligned}\tag{2}$$

Equating and solving (1) and (2), we get

$$\begin{aligned}\frac{S}{100} &= \frac{1}{3} \\ \Rightarrow S &= \frac{100}{3} = 33.33^\circ\text{C (approximately)}\end{aligned}$$

THERMAL EXPANSION OF SOLIDS

We know that matter expands on heating. When a solid is heated, it expands and its dimensions change. When a solid does not have appreciable breadth and thickness, the expansion takes place lengthwise. The expansion of solids along the length is referred to as **linear expansion**.

Similarly in solids having appreciable area with negligible thickness, the expansion is observed in area and the effect is called **superficial expansion**. The effect which involves a change in volume is called **cubical expansion**.

Coefficient of Linear Expansion

Consider a rod of length l_1 , let its temperature be θ_1 . On heating, the rod expands. Let its length be l_2 at a temperature θ_2 .

It is found that

1. the increase in length ($l_2 - l_1$) is proportional to the original length l_1 .
2. the increase in length ($l_2 - l_1$) is also proportional to the rise in temperature ($\theta_2 - \theta_1$).
3. the increase in length depends upon the material.

Mathematically, $(l_2 - l_1) \propto l_1$ and $(l_2 - l_1) \propto (\theta_2 - \theta_1)$

i.e., $\Delta l \propto \Delta l_1$ and $\Delta l \propto \Delta \theta$.

So, on combining, $\Delta l \propto l_1 \Delta \theta$

i.e., $\Delta l = \propto l_1 \Delta \theta$

$\therefore \Delta l = \alpha l_1 \Delta \theta$,

where the proportionality constant ' α ' is called **coefficient of linear expansion**.

$$\therefore \alpha = \frac{(l_2 - l_1)}{l_1(\theta_2 - \theta_1)} = \frac{\Delta l}{l_1 \Delta \theta}$$

The coefficient of linear expansion of a solid is defined as the ratio of the increase in length per unit length per degree rise in temperature. Unit of ' α ' = $^{\circ}\text{C}^{-1}$ or K^{-1} .

Give values of α a few materials.

Example:

α for iron = $0.000012^{\circ}\text{C}^{-1} = 12 \times 10^{-6} ^{\circ}\text{C}^{-1}$

α for brass = $0.000019^{\circ}\text{C}^{-1} = 19 \times 10^{-6} ^{\circ}\text{C}^{-1}$

Experiment to Demonstrate Linear Expansion in Solids

Take a long aluminium rod clamped at an end as shown in Fig. 7.6. The aluminium rod rolls over a glass rod placed perpendicular to its length on a wooden block. Two weight hangers W_1 and W_2 are attached to the aluminium rod to have a firm contact between glass rod and aluminium rod. A light pointer is attached to an end of the glass rod which moves over a paper scale. When the aluminium rod is heated, it expands and rolls over the glass rod and the pointer moves over the scale, confirming the expansion of the aluminium rod.

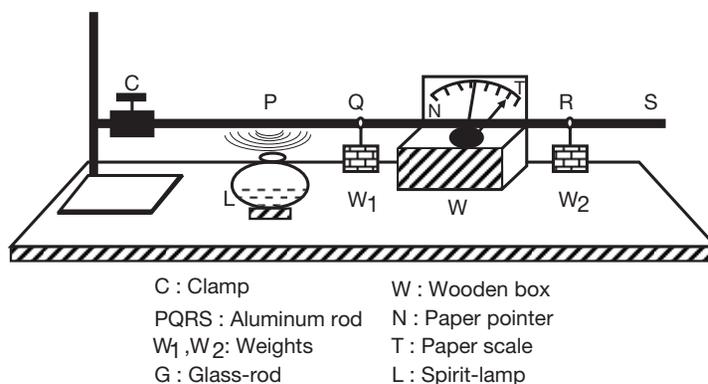


FIGURE 7.6

Coefficient of Superficial Expansion

Let the area of a metallic sheet at temperature θ_1 be equal to A_1 and at a temperature θ_2 be equal to A_2 .

It is found that

1. the increase in area, $(A_2 - A_1)$ is proportional to the original area A_1 .
2. the increase in area, $(A_2 - A_1)$ is proportional to the rise in temperature $(\theta_2 - \theta_1)$.
3. the increase in area also depends upon the material.

Mathematically, $(A_2 - A_1) \propto A_1$ and $(A_2 - A_1) \propto (\theta_2 - \theta_1)$

$\Rightarrow A_2 - A_1 = \beta A_1 (\theta_2 - \theta_1)$, where the proportionality constant ' β ' is called **coefficient of superficial expansion**.

$$\beta = \frac{(A_2 - A_1)}{A_1(\theta_2 - \theta_1)} = \frac{\Delta A}{A_1 \Delta \theta}$$

The coefficient of superficial expansion of a solid is defined as the ratio of increase in area per unit area per degree rise in temperature. The unit of ' β ' is $^{\circ}\text{C}^{-1}$ or K^{-1} .

Coefficient of Cubical Expansion

Let the volume of a solid body at temperature θ_1 be equal to V_1 and at temperature θ_2 be equal to V_2 .

It is found that

1. the increase in volume $(V_2 - V_1)$ is proportional to the original volume V_1 .
2. the increase in volume $(V_2 - V_1)$ is proportional to the rise in temperature $(\theta_2 - \theta_1)$.
3. the increase in volume also depends upon the material.

Mathematically, $(V_2 - V_1) \propto V_1$ and $(V_2 - V_1) \propto (\theta_2 - \theta_1)$

$\therefore (V_2 - V_1) = \gamma V_1 (\theta_2 - \theta_1)$, where the proportionality constant ' γ ' is called **coefficient of cubical expansion**.

$$\gamma = \frac{(V_2 - V_1)}{V_1(\theta_2 - \theta_1)} = \frac{\Delta V}{V_1 \Delta \theta}$$

The coefficient of cubical expansion of a solid is defined as the ratio of increase in volume per unit volume per degree rise in temperature. The unit of ' γ ' is $^{\circ}\text{C}^{-1}$ or K^{-1} .

The relation between coefficient of linear expansion, superficial expansion and cubical expansion is $\alpha : \beta : \gamma = 1 : 2 : 3$.

Derivation of the Relation between α , β and γ

Take a cube of length L_0 at 0°C , then the area of one of its faces $A_0 = L_0^2$.

Area at 0°C is $A_0 = (L_0)^2$

Area at $t^{\circ}\text{C}$ is $A_t = (L_t)^2$

We know that length at $t^{\circ}\text{C}$ is $L_t = L_0 (1 + \alpha t)$

Area at $t^{\circ}\text{C}$ is $A_t = (L_t)^2 = \{L_0 (1 + \alpha t)\}^2$

$$A_t = L_0^2 (1 + 2\alpha t + \alpha^2 t^2)$$

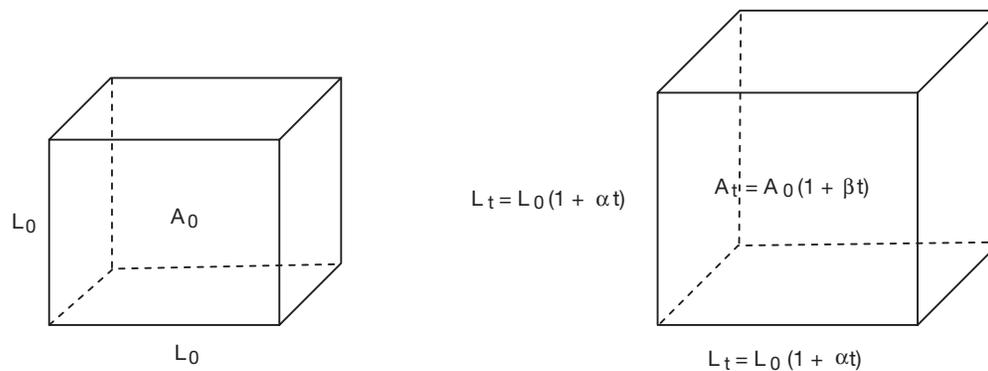


FIGURE 7.7

As ' α ' is small ' α^2 ' terms can be neglected, then $A_t = L_0^2 (1 + 2\alpha t)$

$$\text{Hence, } A_t = A_0 (1 + 2\alpha t) \text{ (as } L_0^2 = A_0) \quad (7.1)$$

$$\text{Since we know } A_t = A_0 (1 + \beta t) \quad (7.2)$$

From (7.1) and (7.2) above, we get $\beta = 2\alpha$.

Similarly, we can prove that $\gamma = 3\alpha$.

Let the volume of the cube be V_0 .

$$\therefore V_0 = L_0^3$$

Volume at $t^\circ\text{Celsius}$ $V_t = (L_t)^3$.

We know that length at $t^\circ\text{Celsius}$ is $L_t = L_0(1 + \alpha t)$

Volume at $t^\circ\text{C}$ is $V_t = (L_t)^3 = \{L_0(1 + \alpha t)\}^3$

$$V_t = L_0^3 (1 + 3\alpha t + 3\alpha^2 t^2 + \alpha^3 t^3)$$

As α is very small, the higher powers of α can be neglected. Then $V_t = L_0^3 (1 + 3\alpha t)$

$$\text{Hence, } V_t = V_0(1 + 3\alpha t) \text{ (as } L_0^3 = V_0) \quad (7.3)$$

$$\text{Since we know } V_t = V_0 (1 + \gamma t) \quad (7.4)$$

On comparing (7.3) and (7.4) above, we get $\gamma = 3\alpha$.

$$\therefore \alpha : \beta : \gamma = 1 : 2 : 3$$

Applications of Expansion of Solids

1. While laying railway track, a small gap is provided between two rails and connected by a fish plate. This is to avoid bending of tracks in summer when the rails expand.
2. In construction of bridges, a small space is left at one end so that the girder has space to expand when it gets heated in summer.
3. While laying concrete roads, a small gap is left between two patches to allow for expansion.
4. A sag is left while laying telegraphic and electric wires, which allows them to contract during winter without breaking.
5. A compensated pendulum is used to maintain correct time in different seasons.
6. The iron ring of a cart wheel has radius slightly less than that of the wooden wheel. The rim is heated and then fixed onto the wooden frame. On cooling, it holds the wheel firmly.

7. Bimetallic strips work on the principle that different materials have different coefficients of expansion. Bimetallic strips are used in automatic fire alarms and as thermostat in fridges.

EXAMPLE

The length of a brass rod is 1.5 m. Its coefficient of linear expansion is $19 \times 10^{-6} \text{ K}^{-1}$. Find the increase in length of the rod if it is heated through 20°C .

SOLUTION

Given length of the rod, $\ell = 1.5 \text{ m}$.

Coefficient of linear expansion, $\alpha = 19 \times 10^{-6} \text{ K}^{-1}$.

Increase in temperature, $\Delta\theta = 20^\circ\text{C}$

$$\begin{aligned} \therefore \text{Increase in length, } \Delta\ell &= \ell \times \alpha \times \Delta\theta \\ &= (1.5) \times (19 \times 10^{-6}) \times (20) = 5.7 \times 10^{-4} \text{ m.} \end{aligned}$$

EXAMPLE

The area of a rectangular copper sheet is 0.30 m^2 . If the sheet is heated through 10°C , its area increases by $1.02 \times 10^{-4} \text{ m}^2$. Calculate the coefficient of areal expansion of copper.

SOLUTION

Given area of the copper sheet, $a = 0.30 \text{ m}^2$

Increase in temperature, $\Delta\theta = 10^\circ\text{C}$

Increase in area, $\Delta a = 1.02 \times 10^{-4} \text{ m}^2$.

$\Delta a = a\beta\Delta\theta$, where β is the coefficient of areal expansion.

$$\begin{aligned} \text{Thus, } \beta &= \frac{\Delta a}{a \Delta \theta} = \frac{1.02 \times 10^{-4}}{0.3 \times 10^\circ\text{C}} = 3.4 \times 10^{-5} \text{ K}^{-1}. \\ &= 3.4 \times 10^{-5} \text{ }^\circ\text{C}^{-1}. \end{aligned}$$

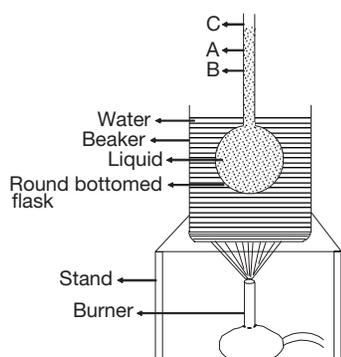
EXPANSION OF LIQUIDS

As liquids do not have their own shape, they take the shape of a container. Hence, when a liquid is heated, a part of the heat is absorbed by the container. Because of this, there are two types of expansion which we observe in liquids, namely, apparent expansion and real expansion.

Real and Apparent Expansions of a Liquid

Consider a liquid in a round bottomed flask having a narrow stem upto the level marked 'A'. The flask is kept in a water bath and heated as shown in the Fig. 7.8.

It is seen that the level of the liquid initially falls to a mark B as shown in the Fig. 7.8 and on further heating, the level rises to the mark C.

**FIGURE 7.8**

Reason for the Above Observation

1. When the flask containing a liquid is heated, the flask, i.e., the container itself, initially absorbs the heat and its volume increases.
2. When only the volume of the container is increasing without an increase in the volume of the liquid in it, the level of the liquid falls (A to B in the Fig. 7.8).
3. On further heating, the container starts transmitting the heat to the liquid in it and then the liquid starts expanding. Hence, we find an increase in the volume of the liquid (B to C in the Fig. 7.8). The liquid level actually increases from B to C, when it expands and the corresponding increase in its volume is known as '**real increase**' or '**real expansion**' of the liquid.

On the whole, the level of the liquid appears to rise from A to C, when it expands and the corresponding increase in the volume of the liquid is known as '**apparent increase**' or '**apparent expansion**' of the liquid.

Similar to the expression for volume of expansion of solids, we have expressions for volume expansion of liquids. They are given by,

1. $\Delta V_a = \gamma_a V \Delta \theta$ and
2. $\Delta V_r = \gamma_r V \Delta \theta$, where ' ΔV_a ' and ' ΔV_r ' are apparent and real expansions of the liquid, respectively. ' V ' is initial volume of liquid, ' $\Delta \theta$ ' is rise in temperature, ' γ_a ' and ' γ_r ' are constants and are called coefficients of apparent and real expansions, respectively.

Definition of γ_a and γ_r

The coefficient of apparent expansion of a liquid is defined as the apparent increase in its volume per unit, by per unit rise in temperature, i.e., $\gamma_a = \frac{\Delta V}{V_1 \Delta \theta}$.

The coefficient of real expansion of a liquid is defined as the real increase in its volume per unit volume per unit rise in temperature, i.e., $\gamma_r = \frac{\Delta V_r}{V^1 \Delta \theta}$.

Anomalous Expansion of Water

All liquids in general expand on heating. But water exhibits a peculiar behaviour. When water is heated from 0°C to 4°C, it contracts and, on further heating, it expands. This is called **anomalous expansion of water**.

HOPE'S EXPERIMENT

Hope's apparatus consists of a tall metallic cylinder (C), having a circular trough (T) attached to it at the central part. There are two openings; one at the bottom and another at the top so as to insert and fix two thermometers. Water at a temperature of about 10°C is poured into the long metallic cylinder till the cylinder is full. A freezing mixture (mixture of ice and common salt) is put in the trough. The freezing mixture decreases the temperature of water; at the central part of the cylinder, as the temperature reduces to 4°C, the density of water becomes the highest and this dense water moves to the bottom of the cylinder. This brings the water at the bottom to the central position in the cylindrical tank. As this process goes on, the thermometer below the trough shows 4°C and remains steady. The cooling process goes

on till all the water from bottom of the cylinder to the central part attains 4°C . The cooling still continues and decreases the temperature of water at the central portion beyond 4°C to 0°C . This makes the water in that region less dense and this less dense water tends to move upward. Hence, the thermometer at the top of the trough shows 0°C . This continues till all the water at the top of the trough reaches 0°C . This demonstrates the anomalous expansion of water.

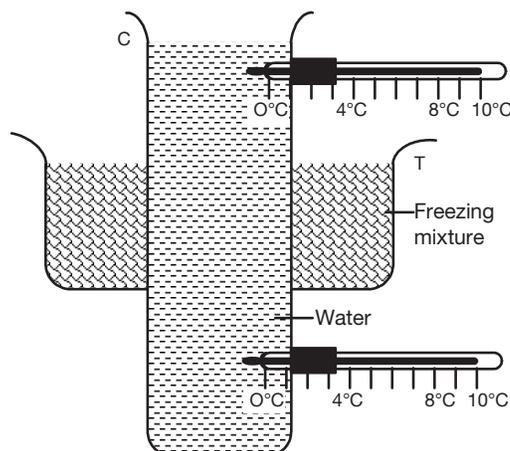


FIGURE 7.9 Hope's Apparatus

Consequences of anomalous expansion of water

1. Aquatic animals can survive in frozen water bodies because though the surface is frozen, the water below the surface is at 4°C , hence, in a liquid state.
2. In cold countries and hill stations, the water pipes generally burst in winter due to the expansion of water.
3. In extreme cold, vegetables and fruits can get damaged, as the water pressure can burst them open.

EXPANSION OF GASES

Like liquids, gases also expand on heating. The expansion of gases is much more than that of liquids. The expansion of container is negligible as compared to the volumetric expansion of gas. Hence, the expansion of the container can be ignored. Unlike liquids, all gases expand to the same extent for the same rise in temperature.

Air Thermometer

In the construction of an air thermometer, we use the property of volumetric expansion of gases on heating. Let us now see how to construct a simple air thermometer. Take an ordinary fused bulb, and take away the filament from it. Invert the bulb and plug its mouth with a rubber cork, having a small hole. Through the hole of the cork, insert one end of a capillary tube into the bulb. Fix the apparatus on a wooden board. Heat the bulb so that air in the bulb is at higher temperature. Hence, the volume of air in the bulb increase. Then insert the other end of the capillary tube in a beaker having coloured water. As the air in the bulb

cools to room temperature, the coloured water is absorbed into the capillary tube to a certain level. Paste a graph sheet on the wooden board beside the capillary tube.

The air thermometer is ready for use. We calibrate it with the help of a standard thermometer.

Since pressure variations in the atmosphere effect the temperature reading, it is not a reliable device. But the device is highly sensitive, due to the high volumetric expansion of air.

Differential Air Thermometer

Differential thermometer consists of one blackened bulb and one shining bulb joined by a U-tube as shown in Fig. 7.10. The U-tube is partially filled with alcohol. The tube is fixed on a board and a graduated scale is kept along the length of U-tube. This is for an easy reading of the difference in alcohol level in the two tubes.

When heat is incident on a differential air thermoscope, then heat is absorbed by the black bulb (A) as black is a good absorber. The shining bulb (B) reflects the heat, so it will not receive any radiation.

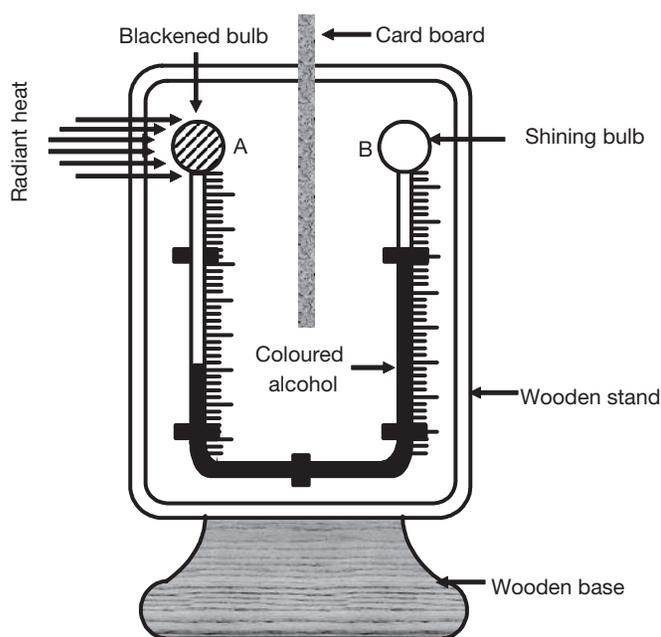


FIGURE 7.10

The air inside the black bulb absorbs the heat, expands and pushes the alcohol downward and the alcohol in the other limb raises. The difference in reading between the two limbs of the 'U' tube measures the incident heat radiations.

KINETIC THEORY OF GASES

To explain various properties of gases, Celsius, Boltzman and Maxwell proposed kinetic theory of gases, whose postulates are as follows.

1. The gases are made up of large number of tiny particles called molecules.
2. All the molecules of a given gas are identical in all respects like mass, volume, etc.

3. The molecules move randomly along a straight line with different velocities, in random direction.
4. While in motion, the molecules of gas continuously collide with each other and also with the walls of the container.
5. The distance covered by a molecule between any two successive collisions with other molecules of the gas is called free path.

Molecular Motion and Temperature

The results obtained by applying kinetic theory of gases shows that the average kinetic energy of the gas molecules is directly proportional to the absolute temperature of the gas.

This means the kinetic energy of gas molecules increases with rise in temperature and decreases with fall in temperature.

Absolute Zero

It is the lowest temperature which a gas or any other substance can attain. At this temperature, all molecules of a given substance stop moving.

BOYLE'S LAW

The relationship between volume and pressure of a gas was established by Robert Boyle. It is now known as Boyle's law. It states that at a constant temperature, the pressure of a given mass of a gas is inversely proportional to its volume. Let P and V be pressure and volume of a gas, respectively. Then, according to Boyle's law,

$$P \propto \frac{1}{V} \text{ (at constant temp)} \Rightarrow P = K \frac{1}{V}$$

where K is proportionality constant

or $P \times V = \text{constant}$

Verification of Boyle's Law Using Quill's Tube

A Quill's tube is a capillary glass tube, closed at one end and containing a mercury pellet inside it. Air gets trapped between the closed end and mercury pellet. A scale is attached to the Quill's tube. The Quill's tube can be fixed in different positions, as shown in the Fig. 7.11.

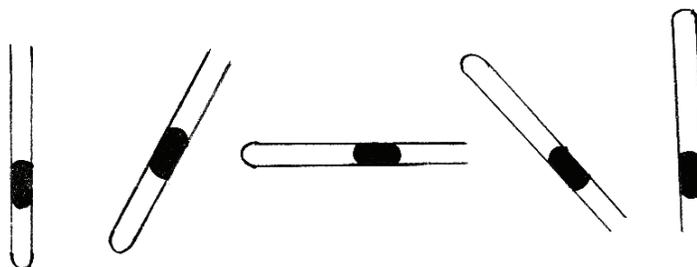


FIGURE 7.11 Various positions of Quill's tube

The pressure exerted by mercury pellet on enclosed gas is different for different positions of the Quill's tube, but atmospheric pressure remains the same.

Let the atmospheric pressure be ' H ' cm of Hg and length of mercury pellet be ' h ' cm. When the Quill's tube is fixed vertically with its open end up, the pressure acting on trapped air is $(H + h)$ cm of Hg. With the help of scale attached to the Quill's tube, note down the length ' ℓ ' of the enclosed gas and find the product $(H + h) \times \ell$.

Now, change the position of Quill's tube such that its open end is downward. In this position, the pressure on trapped air is $H - h$. In the horizontal position of the tube, pressure is H . Fix the Quill's tube in different positions and note down the vertical height of the mercury pellet, which gives the pressure acting on trapped air. Find the product of vertical height of the mercury pellet and the corresponding length of the gas column. The product is constant, proving Boyle's law.

CHARLES' LAW

Boyle's law established the relationship between pressure and volume of a gas, at a constant temperature. Charles' law gives the relationship between volume and temperature of a gas, at a constant pressure and between its pressure and temperature, at a constant volume.

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

Thus, $V \propto T$ (at constant pressure), i.e., $V = KT$, Where K is a proportionally constant.

$$\text{or } \frac{V}{T} = \text{constant}$$

From the above, we can also state that at constant volume, the pressure of a given mass of a gas is directly proportional to its absolute temperature.

$$P \propto T \text{ (at constant volume)}$$

$$\text{or } \frac{P}{T} = \text{constant}$$

If a graph of volume versus temperature (in Celsius scales) is drawn, a straight line is obtained that intersects the X -axis at -273.15°C , as shown in the Fig. 7.12. This temperature is called **absolute zero**.

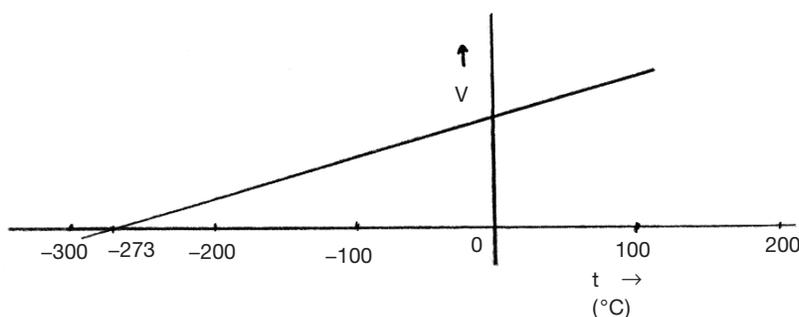


FIGURE 7.12 Volume versus temperature graph

A gas whose behaviour is in accordance with Boyle's and Charles' laws is called an ideal gas.

GAS EQUATION

From these two laws, we understand that the pressure, volume and absolute temperature of a gas are interrelated, and a change in any one produces a change in the other two. Consider a given mass of a gas. Let its initial volume, pressure and absolute temperature be V_1 , P_1 and T_1 , respectively. Now, change the pressure of the gas from P_1 to P_2 by keeping its temperature constant at T_1 . As the pressure is changed from P_1 to P_2 , the volume of the gas also changes. Let the new volume be V^1 . By applying Boyle's law,

$$\begin{aligned} P_1 V_1 &= P_2 V^1 \\ \Rightarrow V^1 &= \frac{P_1 V_1}{P_2} \end{aligned} \quad (7.5)$$

Next, let the temperature be changed from T_1 to T_2 , by keeping the pressure constant at P_2 . Due to change in temperature, let its volume change from V^1 to V_2 . Applying Charles' law,

$$\begin{aligned} \frac{V^1}{T_1} &= \frac{V_2}{T_2} \\ \Rightarrow V^1 &= \frac{V_2}{T_2} \times T_1 \end{aligned} \quad (7.6)$$

Equating (7.5) and (7.6), we get

$$\begin{aligned} \frac{P_1 V_1}{P_1} &= \frac{V_2 T_1}{T_2} \\ \frac{P_1 V_1}{T_1} &= \frac{P_2 V_2}{T_2} \text{ or } \frac{PV}{T} = \text{constant} \end{aligned}$$

the above equation is called gas equation.

Explanation for Pressure of a Gas

Consider a gas enclosed in a container. The gas consists of a large number of molecules, moving in all possible directions. As they move, they collide with each other and with the walls of the container, exerting force on it. The force exerted per unit area of the walls of the container is the gas pressure. With increase in temperature, the velocity of gas molecules increases and they exert more force and pressure. Thus, the pressure increases with temperature. The pressure exerted by gas molecules also depends on the number of collisions per unit area as they hit with the walls of the container. More the number of collisions per unit area, more is the pressure. When the volume of the container is reduced, the number of collisions, and hence, the pressure increases. Similarly, on increasing the volume, the number of collisions per unit area decreases and so the pressure also decreases.

The energy possessed by gas molecules in a container depends on their number per unit volume, their mass and velocity. The velocity of molecules of different gases at room temperature is given in the table below.

Velocity of Gas Molecules at 300 K

S.No.	Gas	Molecular weight 10^{-3} kg/mole	Velocity (m s^{-1})
1.	H ₂	2.82	1920
2.	H ₂ O (vapour)	18.0	645
3.	N ₂	28.0	517
4.	O ₂	32.0	483
5.	CO ₂	44.0	412
6.	SO ₂	64.1	342

EXAMPLE

The volume of a gas at 27°C is 1 litre. At what temperature, will its volume be 1.5 litres if the pressure remains constant?

SOLUTION

$$V_1 = 1 \text{ litre}$$

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

$$V_2 = 1.5 \text{ litre}$$

$$T_2 = ?$$

At constant pressure

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

$$\Rightarrow T_2 = \frac{V_2}{V_1} \times T_1 \text{ By Boyle's law}$$

$$\text{Substituting, we get } T_2 = \frac{1.5}{1} \times 300 = 450 \text{ K}$$

Temperature in Kelvin scale and Celsius scale are related as

$$T = t + 273,$$

where t is in Celsius scale, and T is the temperature in Kelvin scale. Thus, the temperature in Celsius scale = $450 - 273 = 177^\circ\text{C}$

EXAMPLE

The volume of a gas at STP is 273 ml. What will its volume be at a pressure of 38 cm of mercury column and a temperature of -23°C ?

SOLUTION

Given,

$$V_1 = 273 \text{ ml}$$

$$P_1 = 76 \text{ cm of Hg}$$

$$T_1 = 273 \text{ K}$$

$$V_2 = ?$$

$$P_2 = 38 \text{ cm of Hg}$$

$$T_2 = 273 - 23 = 250 \text{ K}$$

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

Substituting, we get

$$\frac{76 \times 273}{273} = \frac{38 \times V_2}{250}$$

$$V_2 = \frac{76 \times 250}{38} = 2 \times 250$$

$$V_2 = 500 \text{ ml}$$

CALORIMETRY

The branch of physics which deals with the measurement of heat energy is called **calorimetry**. We know that heat always flows from a body at higher temperature to a body at lower temperature till both the bodies attain the same temperature (equilibrium temperature). At equilibrium temperature, the energy does not stop flowing. But the rate of flow is same from one body to another. Also, the rate of flow of heat depends upon the difference in temperature between the two bodies.

Calorie is the C.G.S unit of heat and it is defined as the quantity of heat required to raise the temperature of a unit mass of water through one degree celsius. The S.I. unit of heat is **joule**.

$$1 \text{ calorie} = 4.186 \text{ J}$$

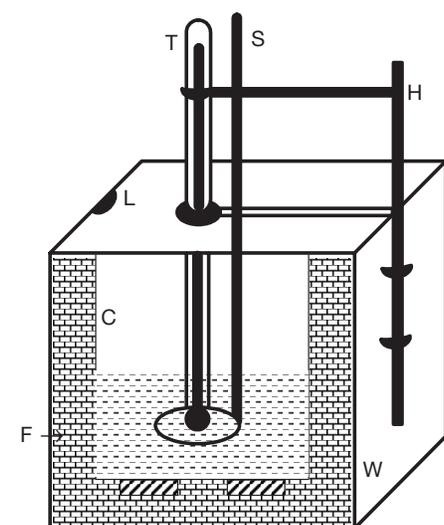
Mechanical Equivalent of Heat

It is the amount of mechanical work done to get one calorie of heat, i.e., $\frac{W}{H} = J$ where W is the work done, H is the heat produced and J is the mechanical equivalent of heat.

CALORIMETER

It is a highly-polished cylindrical copper vessel used to measure the quantity of heat. To minimize the loss of heat due to conduction, the vessel is kept in a wooden box.

The space between the box and the copper vessel is filled with glass wool (insulating material). A copper stirrer and a wooden cover with an opening to insert a thermometer and the stirrer are also present. The copper vessel is highly polished so as to prevent heat loss due to radiation.



W : Wooden box T : Thermometer
 F : Insulating material S : Stirrer
 C : Copper vessel H : Holder
 L : Lid

FIGURE 7.13

Principle of Calorimetry

When two bodies having different temperatures are brought into contact with each other, heat is transferred from the body at higher temperature to the body at lower temperature, till thermal equilibrium is attained.

That is, Heat lost by the body at higher temperature = Heat gained by the body at lower temperature.

SPECIFIC HEAT

It is found that the quantity of heat absorbed by a body is proportional to rise in its temperature and also proportional to the mass of the body.

i.e., $Q \propto \Delta T$ and $Q \propto m$

Hence, $Q \propto m \Delta T$ or $Q = ms\Delta T$

where the constant 's' is called specific heat capacity of the body. The value of specific heat (s) depends on the nature of the material.

As $s = \frac{Q}{m\Delta t}$ and for $m = 1 \text{ kg}$ and $\Delta t = 1^\circ\text{C}$, $s = Q$, **specific heat capacity** can be defined as the heat required to raise the temperature of a body of a unit mass by 1°C .

Determination of Specific Heat of Solids by the Method of Mixtures

Take an empty calorimeter with stirrer, let m_1 be the mass of this apparatus.

Take water to half the level of calorimeter and weigh it. Let the mass now be m_2 g.

Insert a thermometer in the calorimeter and note the temperature ($\theta_1^\circ\text{C}$).

Take the solid whose specific heat is to be found and heat it in a hypsometer to a steady temperature. ($\theta_2^\circ\text{C}$)

Transfer the solid quickly from hypsometer to calorimeter and stir the mixture well. The temperature of mixture starts rising. Note the final maximum temperature of mixture ($\theta_3^\circ\text{C}$). At the end measure the weight of the mixture (m_3 gm.).

Observation and Calculations

Let the mass of empty calorimeter with stirrer	= m_1 g
Mass of calorimeter + stirrer+ water	= m_2 g
Mass of calorimeter + stirrer +water + solid	= m_3 g
Let the initial temperature of calorimeter and water	= $\theta_1^\circ\text{C}$
Let the temperature of hot solid	= $\theta_2^\circ\text{C}$
Let the resultant temperature of mixture	= $\theta_3^\circ\text{C}$
Mass of water	= $(m_2 - m_1)$ g
Mass of solid	= $(m_3 - m_2)$ g
Rise in temperature of water and calorimeter	= $(\theta_3 - \theta_1)^\circ\text{C}$
Fall in temperature of hot solid	= $(\theta_2 - \theta_3)^\circ\text{C}$
Heat gained by calorimeter	= $m_1 s_c (\theta_3 - \theta_1)$
Heat gained by water	= $(m_2 - m_1) s_w (\theta_3 - \theta_1)$
Heat lost by hot solid	= $(m_3 - m_2) s_s (\theta_2 - \theta_3)$

where s_c , s_w and s_s are the specific heats of calorimeter, water and the solid.

By the principle of calorimetry, heat lost by the hot body = heat gained by the cold body.

$$(m_3 - m_2) s_s (\theta_2 - \theta_3) = m_1 s_c (\theta_3 - \theta_1) + (m_2 - m_1) s_w (\theta_3 - \theta_1)$$

$$s_s = \frac{m_1 s_c (\theta_3 - \theta_1) + (m_2 - m_1) s_w (\theta_3 - \theta_1)}{(m_3 - m_2) (\theta_2 - \theta_3)}$$

Precautions

The calorimeter should be highly polished to avoid heat loss due to radiation. The hot solid should be transferred quickly to avoid loss of heat during the transfer.

Determination of Specific Heat of Liquids by the Method of Mixtures

The method of determining the specific heat of liquids is same as the method of determining the specific heat of solids, but in this case water in the calorimeter is replaced with the liquid whose specific heat is to be found and a solid of known specific heat is taken.

As discussed in the last article,

$$(m_3 - m_2) s_s (\theta_2 - \theta_3) = m_1 s_c (\theta_3 - \theta_1) + (m_2 - m_1) s_L (\theta_3 - \theta_1)$$

$$s_L = \frac{(m_3 - m_2) s_s (\theta_2 - \theta_3) - (m_1) s_c (\theta_3 - \theta_1)}{(m_2 - m_1) (\theta_3 - \theta_1)}$$

where s_s , s_c and s_L are the specific heats of solid, calorimeter and the liquid.

Specific heat of water: Water has a specific heat of $1 \text{ cal g}^{-1}\text{C}^{-1}$. Because of its high specific heat, it is used for fomentation to relax body and in car radiators, to absorb large amount of heat from engine. Formation of land and sea breeze also takes place because of this fact.

JOULE'S EXPERIMENT TO FIND THE MECHANICAL EQUIVALENT OF HEAT

Joule found the relation between the SI unit (joule) and the CGS unit (calorie) of heat, by the following experiment.

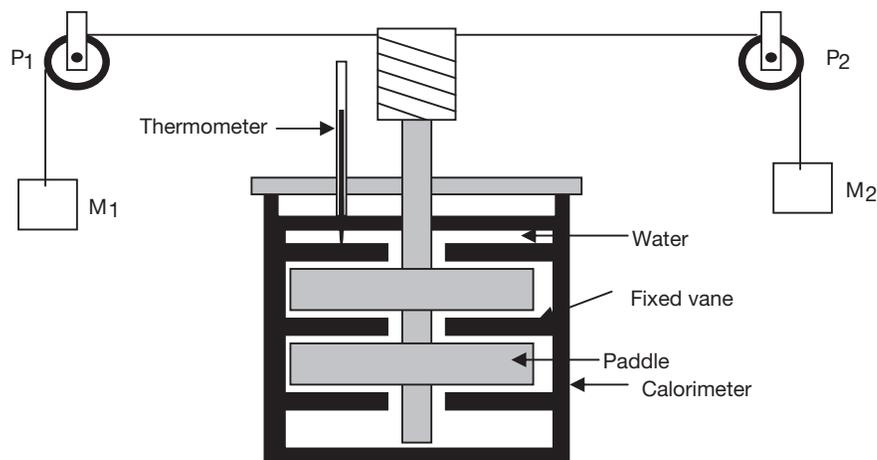


FIGURE 7.14

Joule's apparatus consists of a copper calorimeter containing water. The calorimeter has a number of fixed vanes. Two equal masses M_1 and M_2 are placed at the same height ' h ' above the ground by means of strings of equal lengths attached to it. The string passes over the pulleys, P_1 and P_2 , and wound round a cylinder kept over the calorimeter. The cylinder is connected to the paddle kept inside the calorimeter. It consists of vanes as shown in the Fig. 7.14. The masses M_1 , and M_2 fall down when released. This rotates the cylinder and the paddle, thereby churning the water. The motion of churning water is slowed down by the fixed vanes and due to the friction produced, the temperature of water increases. Hence, in this experiment the potential energy of the masses is converted to the kinetic energy of the paddle which, in turn, is converted to heat energy.

The loss of potential energy by the masses M_1 and M_2 in this process (W) = $2Mgh$

The amount of heat gained by water,

$$H = (\text{mass of water}) \times (\text{specific heat of water}) \times (\text{increase in temperature}) = ms\Delta t$$

From the experimental values, joule found that the amount of heat produced is directly proportional to the mechanical work done.

$$\therefore W \propto H \text{ or } W = JH$$

Hence,

$$J = \frac{W}{H}$$

Thus, mechanical equivalent of heat can be calculated. The above experiment gives the value of mechanical equivalent of heat as 4.18 J.

Thermal Capacity

It is defined as the heat energy required to raise the temperature of a body through 1°C or 1 K.

Let a given body absorb Q joules of heat and as a consequence, let its temperature rise by $\Delta\theta$. By definition, the thermal capacity C of a body is given by

$$C = \frac{Q}{\Delta\theta}$$

Substituting $Q = ms\Delta\theta$, we get

$$C = \frac{ms\Delta\theta}{\Delta\theta}$$

$$C = ms$$

The unit of thermal capacity in CGS system is calorie per degree celsius ($\text{cal}^\circ\text{C}^{-1}$) and in SI system is joule per kelvin. (J K^{-1})

Water Equivalent

Water equivalent of a body is defined as the mass of water that absorbs the same amount of heat as is absorbed by the body so that temperature of both rise by 1°C .

Let the heat absorbed (Q) by mass ' m ' of a given body of specific heat ' s ' so that its temperature rises by 1°C . Then we can write

$$Q = ms \tag{7.7}$$

Let M_1 mass of water absorb the same heat Q so that its temperature rises by 1°C . Taking specific heat of water as $1 \text{ cal g}^{-1} \text{ K}^{-1}$,

$$\begin{aligned} Q &= M_1 \times 1 \\ Q &= M_1 \end{aligned} \quad (7.8)$$

Equating (7.7) and (7.8),

$$M_1 = m \times s$$

By definition, M_1 is the water equivalent. Therefore, the water equivalent is given by the product $m \times s$.

The unit of water equivalent is gram in CGS system and kilogram in SI system. It is a scalar quantity and its dimensional formula is $[M^1L^0T^0]$. In C.G.S. units, the magnitudes of water equivalent and thermal capacity of a body are equal, as both are given by the product $m \times s$. However, thermal capacity refers to some amount of heat whereas water equivalent denotes a certain amount of water.

Change of State

Matter exists in three states viz, solid, liquid or gaseous. The physical state of matter can be changed by adding or removing heat energy from it. For example, when heat is added to ice, which is in solid state, it changes to water which is in liquid state. By adding heat further, water can be vapourized so as to change it into gaseous state. Similarly, a substance in gaseous state can be brought into liquid and then solid state by successively removing heat energy from it. When temperature of melting ice is recorded, say after every 10 minutes and a graph of temperature versus time is drawn, we get a graph as shown Fig. 7.15.

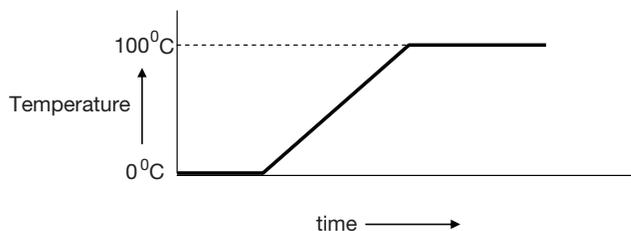


FIGURE 7.15

Note that the temperature remains constant at 0°C until all the ice melts. After that the temperature of water increases and remains constant again at 100°C till all the water vapourizes.

On heating, certain substances such as iodine change directly from solid to gaseous state.

Melting of a Substance

During change of state, the temperature of a substance remains constant. When a substance changes from solid to liquid state, the constant temperature at which the change of state takes place is called melting point of that substance. For example, melting point of ice is 0°C which means that ice changes from solid to liquid state at 0°C .

When water at 0°C freezes to form ice, the temperature remains constant at 0°C which is called freezing point.

When heat energy is added to a substance in solid state, the kinetic energy of its molecules increases and they start moving freely instead of being in the fixed positions. This state is the liquid state of a substance. In this state, though molecules are freely moving, they are still bound to each other. This is the reason why liquids have definite volume.

Evaporation

The process of vapourization of a liquid is called evaporation. The energy required for evaporation is taken from the surroundings. If you put a few drops of petrol or alcohol, the liquid evaporates by absorbing heat from the hand and vanishes.

Evaporation of liquid takes place at all temperatures but the rate of evaporation is different at different temperatures. The rate of evaporation increases with increase in temperature.

When a liquid boils, vapours are formed. The boiling of liquid takes place at a definite temperature called boiling point. At boiling point, a substance in liquid state changes to gaseous state.

In both evaporation and boiling, a liquid changes to gaseous state yet both the processes are different.

The difference between evaporation and boiling are listed below.

Evaporation	Boiling
1. It takes place at all temperatures.	1. It takes place at definite temperature.
2. Temperature may change during evaporation.	2. Temperature does not change during boiling.
3. The evaporation of liquid is confined only to the surface of liquid.	3. Boiling takes place throughout the liquid.
4. The rate of evaporation depends on the free surface area of the liquid.	4. The rate of boiling is independent of the surface area of the liquid.

Latent Heat

During the change in the state of a substance, its temperature remains constant, even though heat is being added (or removed) continuously. What happens to the heat supplied (or removed) during the change in the state? The heat energy supplied during change in the state is used to overcome forces of attraction among the molecules so as to increase their potential energy. The potential energy increases when distance between molecules increases. The heat energy absorbed during change in the state is called latent heat.

The amount of heat energy required to change 1 kg of solid into a liquid at its melting point is called specific latent heat capacity of fusion of that substance.

When a substance in liquid state absorbs heat energy, its temperature increases. At boiling point liquid changes into gaseous state. The amount of heat energy required to change 1 kg of liquid to gaseous state at its boiling point is called specific latent heat of vapourization of that liquid. The SI unit of specific latent heat is joule per kilogram which is written symbolically as J kg^{-1} . Since joule is a very small unit of heat, it is often convenient to use kilo joules (kJ). Therefore, the unit of specific latent heat becomes kJ kg^{-1} .

Specific latent heat is a scalar quantity. Its dimensions are $[M^0L^2T^{-2}]$. If ' m ' is the mass of a substance and ' L ' be its specific latent heat, then heat energy required to change it from one state to another state is given by

$$Q = mL$$

The following table gives melting point, boiling point, specific latent heat of melting and vapourization of some common substances.

The values of melting point, boiling point, latent heat of melting and latent heat of vaporization of some of the common substances (at normal atmospheric pressure)

Substance	Freezing point (°C)	Boiling point (°C)	Latent heat of Fusion (kJ / kg)	Latent heat of vaporization (kJ / kg)
Water	0	100	335	2260
Mercury	-39	357	11.7	272
Air	-212	-191	23.0	213
Hydrogen	-259	-252	58.6	452
Oxygen	-219	-184	13.8	213
Helium	-271	-268	–	25.1
Aluminium	658	1800	322	–
Gold	1063	2500	67.0	–

EXAMPLE

Find the heat energy required to convert 10 g ice at 0°C to steam at 100°C. Specific latent heat of melting and vapourization are 336 kJ kg⁻¹ and 2260 kJ kg⁻¹, respectively, and specific heat of water is 4200 J kg⁻¹ K⁻¹.

SOLUTION

The heat required to convert 10 g of ice at 0°C to water at 0°C is

$$Q_1 = m \times L$$

Substitute $m = 10 \text{ g} = 10^{-2} \text{ kg}$ and

$$\begin{aligned} L &= 336 \times 10^3 \text{ J kg}^{-1} \text{ in (1),} \\ Q_1 &= 10^{-2} \times 336 \times 10^3 \text{ J} \\ Q_1 &= 3360 \text{ J} \end{aligned} \quad (1)$$

The heat required to raise the temperature of water from 0°C to 100°C is

$$Q_2 = m \times s \times \Delta\theta \quad (2)$$

Substituting $m = 10^{-2} \text{ kg}$, and $s = 4200 \text{ J kg}^{-1} \text{ K}^{-1}$

$$\begin{aligned} \Delta\theta &= 100^\circ\text{C,} \\ Q_2 &= 10^{-2} \times 4200 \times 100 \\ Q_2 &= 4200 \text{ J} \end{aligned} \quad (3)$$

Substituting $m = 10^{-2} \text{ kg/L} = 2260 \times 10^3 \text{ J kg}^{-1}$

$$\begin{aligned} Q_3 &= m \times L = 10^{-2} \times 2260 \times 10^3 \\ Q_3 &= 22600 \text{ J} \end{aligned} \quad (4)$$

where Q_3 is the heat required to convert water at 100°C to vapour.

The total heat energy required is given by,

$$\begin{aligned} Q &= Q_1 + Q_2 + Q_3 \\ Q &= 3360 \text{ J} + 4200 \text{ J} + 22600 \text{ J} \\ Q &= 30160 \text{ J} \end{aligned}$$

Humidity

The amount of water vapour present in air changes with change in weather conditions. The higher the temperature, the more is the capacity of air to hold the water vapour. The amount of water vapour present in air at a given temperature is called '**humidity**'. When air contains maximum amount of water vapour at some particular temperature, it is called saturated air at that temperature. The following table gives the amount of water vapour present in 1 m^3 of saturated air, at various temperatures.

Temperature	Mass of water vapour in grams present in 1 m^3 of saturated air
10°C	9.3
15°C	12.7
20°C	17.1
25°C	22.8
30°C	30.0
35°C	39.2
40°C	51.0

If the temperature of saturated air is increased, then it becomes unsaturated but if the temperature is decreased, then it remains saturated with condensation of some water vapour.

The formation of dew during night is due to condensation of excess water vapour due to fall in temperature. During rainy season, the dew is formed as air is full of moisture with relatively low temperature.

Relative Humidity

Relative humidity measures how wet the air is. It is defined as the ratio of mass of water vapour actually present in 1 m^3 of air at a certain temperature to the mass of water vapour required to completely saturate 1 m^3 of air at the same temperature. The relative humidity is expressed as percentage.

EXAMPLE

At 30°C, the actual amount of water vapour present in 1 m³ of air is 15 g, whereas 30 g of water vapour is required to saturate air at the same temperature. Find the relative humidity.

SOLUTION

$$\text{Relative humidity} = \frac{15}{30} \times 100 = 50\% \text{ at } 30^\circ\text{C}$$

A relative humidity of about 50% is considered comfortable. However, if it is more than 50%, then it becomes uncomfortable as the perspiration from our body does not evaporate easily. If it is less than 20%, then the air becomes dry which, in turn, makes the skin dry.

Calorific Value of a Fuel

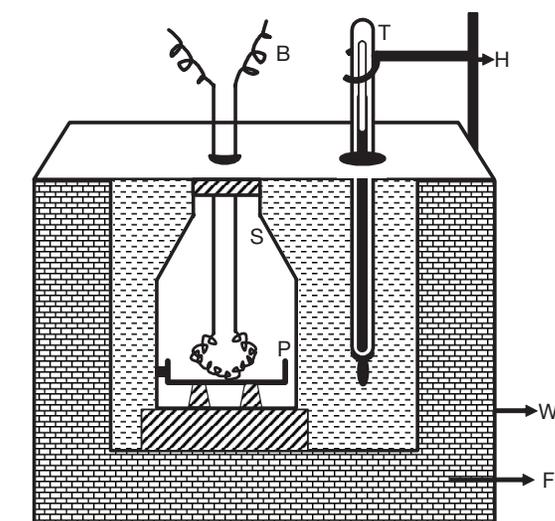
It is defined as the quantity of heat energy produced by completely burning a unit mass of the fuel.

$$\text{Calorific value} = \frac{\text{Heat produced}}{\text{mass}}$$

The unit of calorific value is calorie per gram in CGS system and joule per kilogram in SI system.

Bomb Calorimeter

The calorific value of a fuel or food is measured using a bomb calorimeter. It consists of two chambers, the internal chamber containing a holder to hold the fuel or food whose calorific value is to be determined. It is heated by an electric heater as shown in the Fig. 7.16. This arrangement is kept in an external vessel, which contains water and a thermometer to measure the temperature. The apparatus is kept in a wooden box filled with glass wool to avoid heat loss due to radiation.



W : Wooden box	F : Insulating material
P : Sample holder	S : Internal chamber
B : Current carrying wires	T : Thermometer
E : External chamber	H : Holder

FIGURE 7.16

A known current ' i ' is passed through the heating element for time (t).

If ' R ' is the resistance of the heating element, the heat energy supplied is given by i^2Rt .

The initial mass of fuel in tray was m_1 g and the final mass of fuel left in the tray was m_2 g.

Then the mass of the fuel burnt is $m = m_1 - m_2$. If ' S ' is the calorific value of fuel, then

$$mS = i^2 Rt \text{ or } S = \frac{i^2 Rt}{m}.$$

Thermal Efficiency of a Heating Device

It is defined as the ratio of heat utilized by a device to heat produced by it.

Thermal efficiency $\eta = \frac{Q_u}{Q_T} = \frac{ms\Delta\theta}{mC}$, where ' s ' is the specific heat of substance and ' C ' is the calorific value of fuel.

Thermal efficiency (η) does not have any units as it is the ratio of two similar quantities.

TRANSMISSION OF HEAT

The heat energy flows from a body at a higher temperature to a body at a lower temperature. The flow of heat energy between a hot and a cold body can take place by three different processes, namely conduction, convection and radiation.

Conduction

In this process, heat energy flows from one molecule to another molecule of a solid without its actual movement. For example, when one end of an iron rod is heated, the other end becomes hot. This can be explained on the basis of kinetic model. Accordingly, the molecules of solid, on receiving heat energy, start vibrating at greater speed and greater amplitude about their mean positions, thereby transferring a part of the kinetic energy gained to the neighbouring molecules. The transfer of energy among molecules takes place continuously and the cold end of the rod becomes hot.

The conduction process can also be explained on the basis of atomic model. According to this model, free electrons present in the solid are responsible for the transfer of heat energy. For example all metals contain a large number of free electrons which, on receiving the heat energy, gain kinetic energy and start moving away from the source of heat. The fast moving electrons transfer their kinetic energy to other molecules when they collide with them. At the same time, the less energetic electrons displaced towards the hot end gain kinetic energy and transfer kinetic energy to the molecules. The process continues and after sometime, the cold end of the iron rod becomes hot.

Good and Bad Conductors of Heat

When heat energy flows easily through a given substance by conduction, it is said to be a good conductor of heat. All metals are good conductors of heat, silver being the best followed by copper and aluminum. Among non-metals, graphite is a good conductor of heat.

Mercury, being a metal, is also a good conductor of heat, though it is a liquid. When a substance does not allow heat energy to pass through it easily, then it is called bad conductor of heat.

Among solids, glass, wool, rubber, plastic, etc., are bad conductors. Except mercury, all other liquids are bad conductors of heat.

All gases are bad conductors. In bad conductors, heat energy does not flow easily because they do not contain a large number of free electrons.

Thermal Conductivity

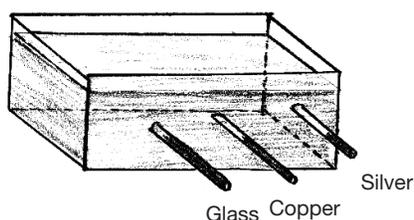


FIGURE 7.17

All metals are good conductors of heat, yet some are better conductors than others. The ability of a given solid to conduct heat is measured by thermal conductivity. The thermal conductivities of different metals are not equal can be proved by Ingen Housz's experiment. Take rods of different substances such as silver, copper, and glass of equal length and thickness and coat them with a thin, uniform layer of wax. Now, insert them in a rectangular metal box, as shown in the Fig. 7.17.

When boiling water is poured in the rectangular box, heat energy of the boiling water is conducted along the length of different rods. It is found that, in a given time, the wax present on silver rod melts to a maximum length followed by copper and glass. This proves that thermal conductivities of different materials are different.

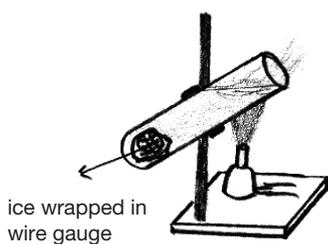


FIGURE 7.18 Experiment to show that water is a bad conductor of heat

Water and air are bad conductors of heat, which can be proved as follows. Take a hard glass tube and drop small pieces of ice, wrapped in copper wire gauze. Pour ice cold water so as to fill the glass tube upto $\frac{3}{4}$ of its length. The copper wire gauze prevents the ice from floating. Clamp the test tube as shown in Fig. 7.18.

Now, heat the test tube near its mouth with a Bunsen burner. It is observed that water near the mouth of the test tube starts boiling but the ice does not melt. This shows that heat is not conducted through water and that water is a bad conductor of heat.

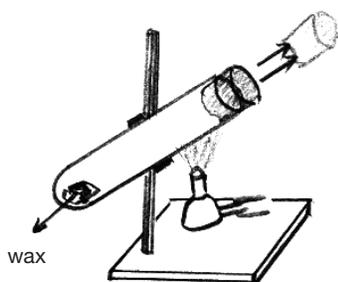


FIGURE 7.19 Experiment to show that gases bad conductors

That air is a bad conductor of heat can be shown as follows. Drop small pieces of wax in a hard glass tube and close its mouth with a cork. Clamp the glass tube on stand as shown in the Fig. 7.19.

Now, heat the glass tube near its mouth. After some time, it is observed that the cork blows away but wax at the bottom does not melt. The air near the mouth gets heated and its pressure increases. The high pressure of air pushes the cork and blows off but heat is not conducted through the air to the bottom where wax is present. This proves that air is a bad conductor of heat.

Applications of Good Conductors

Good conductors of heat find applications in daily life.

Some of them are listed below.

1. Cooking vessels are made of metals so that heat is conducted through them and is passed on to the food.
2. Mercury is used as thermometric liquid because it is a good conductor of heat.

3. Automobile radiators use tubes made of copper as it is a good conductor of heat. Being a good conductor, it absorbs the heat from the hot water from the engine and transmits it to the surroundings.

For the same reason, air conditioners and refrigerators use copper tubes.

4. The heat is passed onto the solder through the tip of soldering iron which is made of copper as copper is a good conductor of heat.
5. Boilers are made of metals.

Applications of Bad Conductors

Bad conductors of heat such as glass, wool, cotton, felt, asbestos, wood, air, etc., are used widely in various applications, some of which are discussed below.

We wear woollen clothes and use blankets in winter as they contain large amount of trapped air which is a bad conductor of heat, and therefore, does not allow heat energy to flow outward from our body. Thus, our body stops losing heat and we feel warm.

The fur found on the body of animals in cold countries keeps the body of the animals warm as it contains large amount of trapped air.

The houses made of mud and thatched roofs are cool in summer and warm in winter as the thatched roof contains large amount of trapped air and also mud is a bad conductor of heat. In summer, the outside heat cannot enter the house and in winter, inside heat cannot flow outside. This keeps the house cool in summer and warm in winter.

In cold storage, the air present between double walls prevents the heat energy from flowing in.

1. The gap between double walls of an ice box is filled with glass, wool, which is a bad conductor of heat. It prevents the heat from flowing in so that ice does not melt.
2. The handles of appliances like pressure cooker, electric iron, electric ovens, etc., are made of bad conductors of heat such as wood or plastic or ebonite so that while handling them, the heat is not conducted from the hot vessels to our hands.
3. The pipes carrying steam from a boiler are covered with asbestos or glass wool to prevent loss of heat to surroundings.

CONVECTION

In fluids, the heat energy flows by the process called convection. The molecules of a fluid are free to move within the mass of the fluid. When a fluid is heated, the molecules absorb heat energy from the source and they move away from it, making way for other molecules to move to the source of heat.

Thus, the kinetic energy of different molecules increases and in this way, the heat energy is transmitted. The above mode of transmission of heat due to movement of molecules from one place to another place is called convection.

In solids, convection is not possible because the molecules in solids are fixed and they are not free to move from place to place. The convection in liquids can be proved with the help of convection tube. It is a rectangular glass tube provided with a funnel, as shown in the Fig. 7.20.

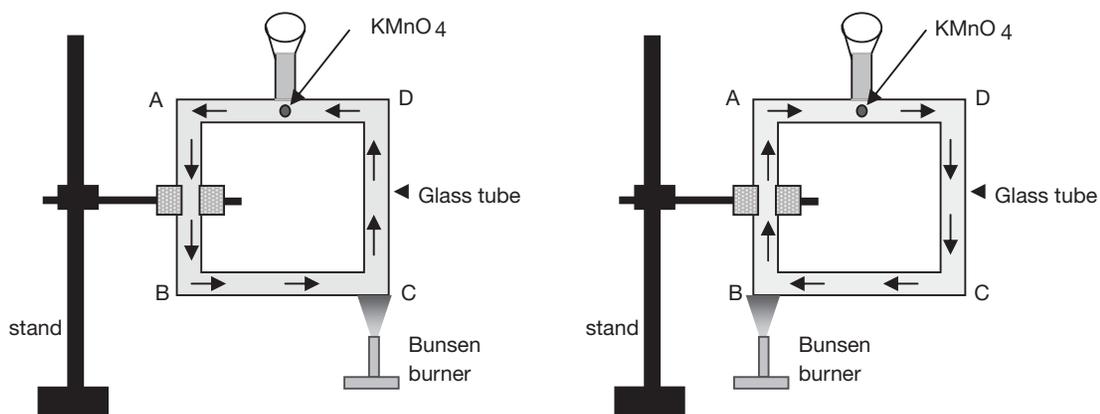


FIGURE 7.20

After filling the tube with water, add a few pieces of potassium permanganate through the funnel and heat the tube at point C.

It is observed that violet colour of potassium permanganate moves along A – B – C and D. The liquid at C, after absorbing heat energy, becomes light and moves upward creating low pressure at C. The heavy, cold liquid then moves along the path DABC, to take the place of hot liquid and in this way, a convection current is set up.

Applications of Convection Current in Liquids

1. Ocean water in the tropical regions becomes hot and moves towards cold polar regions, giving rise to hot ocean currents.

Similarly, the cold water in polar regions forms cold ocean currents which start moving towards hot regions. Ocean currents help in moderating weather as they carry large amount of heat energy.

2. **Car radiators:** The circulation of water in car radiators takes place due to convection current. The hot water, after losing heat energy in radiator, flows towards hot engine and hot water circulating around the engine moves to radiator.

Convection in Gases

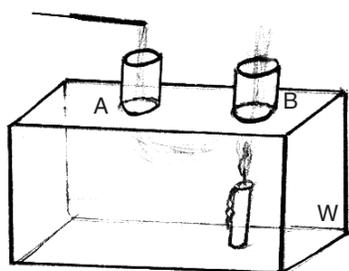


FIGURE 7.21

Gases are heated by convection. This can be demonstrated as follows.

Take a rectangular wooden box (W), provided with two glass chimneys, A and B, as shown in the Fig. 7.21.

Place a lighted candle below chimney B. Now, when a lighted incense stick is held over chimney A, the smoke given out by it is sucked in through chimney A and comes out through B.

The lighted candle heats the air present near the chimney B. The hot air, being light, rises up through B, thereby reducing the air pressure. The cold, heavy air then rushes in through chimney A, sweeping the smoke given out by incense stick.

Thus, on absorbing heat, the hot air molecules move away from the source of heat and molecules of cold air move towards the source of heat, forming convection currents.

Applications of Convection in Gases

- 1. Ventilation:** It is a process by which continuous circulation of air inside a room is maintained due to formation of convection current. The room is provided with a top exit called ventilators through which the hot air and moisture pass out. The fresh and cold air then enters the room through the windows and doors.
- 2.** The sea and land breezes are formed due to convection currents of air. During day time the land gets heated faster than sea water. Consequently, air above land becomes hot and rises up. The cold air above the sea then moves towards land, to take the place of hot air, thus, forming sea breeze. During night, land breeze flows from land to sea as the land gets cooled faster than sea.
- 3. Wind system in atmosphere:** A wind is formed when convection current is set up in air due to unequal heating of the Earth.

The air above the equatorial region becomes hot and rises up, reducing pressure. The air pressure on polar region moves as it is very cold. The air starts flowing from high pressure region towards low pressure regions. However, due to rotation of earth, flow of air from polar to equatorial region is greatly modified and a number of wind cycles are formed, as shown in the Fig. 7.22.

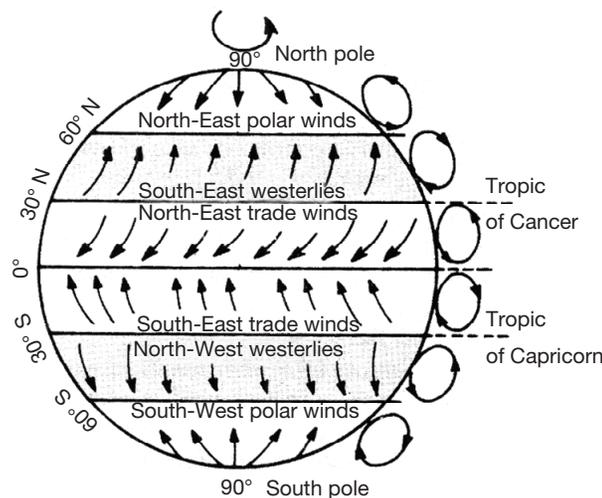


FIGURE 7.22

The wind cycles are known as trade winds, westerlies and polar winds. Trade winds blow between 30° north and 30° south in both hemispheres. In the northern hemisphere, they flow from Northeast to Southwest and in southern hemisphere, from Southeast to Northwest. Westerlies blow between 30° and 60° latitudes in both the hemispheres and polar winds blow between 60° latitude and polar region, as shown in the Fig. 7.22.

RADIATION

In this mode of transmission of heat, heat energy travels in the form of waves. A material medium may or may not be present between a hot and a cold body. The heat energy exchanged between the two bodies is called radiant heat or thermal radiations. The thermal radiations are electromagnetic waves like visible light, with the difference that their frequencies are smaller than, those of visible light. These waves are called infra red radiations. They are invisible.

Every body emits thermal radiations, i.e., infra red radiations at all temperatures except at zero kelvin. With increase in temperature of body, the frequency of radiant heat emitted by it increases.

Some materials absorb thermal radiations and become hot whereas some materials do not absorb thermal radiations and they do not get heated. For example, air at higher altitude is cool compared to air near ground, as it does not absorb thermal radiations present in the solar spectrum.

Properties of Thermal Radiations

1. Thermal radiations are electromagnetic waves and like all electromagnetic waves, they travel with a velocity of $3 \times 10^8 \text{ m s}^{-1}$ in vacuum.
2. Thermal radiations can travel through vacuum. We receive sun light which contains thermal radiations, even though between the Earth and sun.
3. Thermal radiations do not heat the medium through which they pass. For example, like visible light, thermal radiations can pass through certain materials such as glass and on passing through glass they do not heat the glass.
4. Heat radiations travel in straight lines. When we use an umbrella in hot sun, the thermal radiations cannot bend around the edges of the umbrella and reach us.
5. Thermal radiations can also be reflected and refracted, like visible light.
6. Thermal radiations given out by a body travel in all directions. For example, thermal radiations given out by a room heater spread through out the room.

Applications of Heat Radiation

1. We wear white clothes in winter and dull or dark colour dresses in summer as white clothes are good reflectors and dull and dark colours are good absorbers of thermal radiations.
2. Shining surfaces are good reflectors of heat, and so, the roofs of factories are painted white.
3. To keep tea hot for a long time, teapots are kept shining as shining surfaces are bad radiators.
4. The cooking utensils are blackened at the bottom so that heat energy is absorbed rapidly and have shining sides so that the absorbed heat is not radiated.
5. During the day, a green house absorbs short wavelengths of solar energy but does not give out longer wavelengths emitted from its interior, thus, making energy available for plant growth.

Detection of Heat Radiations

The thermal radiations can be detected by using a thermometer whose bulb is blackened. The black colour, being a good absorber of thermal radiations, raises the temperature of mercury and it rises rapidly in thermometer, indicating the presence of thermal radiations. A differential thermoscope, shown in the Fig. 7.23, can also be used to detect the thermal radiations.

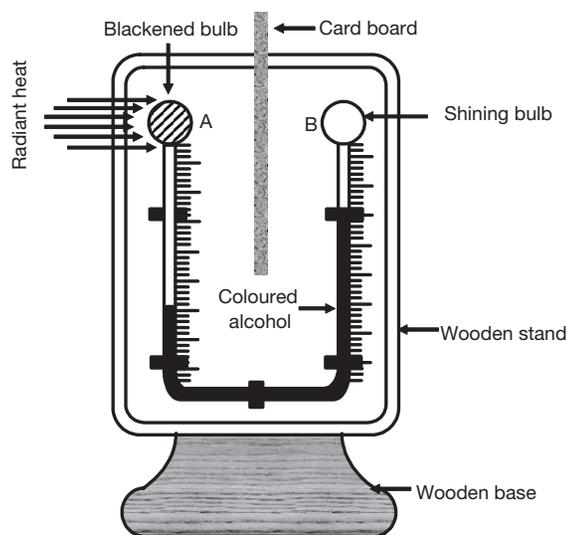


FIGURE 7.23

A differential air thermoscope detects the presence of thermal radiations by unequal expansion of air, when it absorbs thermal radiations. It consists of two glass bulbs A and B connected at the end of a U-shaped tube, which is partly filled with coloured alcohol. One of the bulbs, 'A' is blackened with lamp black and the other bulb 'B' is highly polished. When thermal radiations fall on blackened bulb, it absorbs more radiations than the polished one, which is a poor absorber. As a result, air present in the limb containing black bulb expands more than the air in the other limb, producing a difference in level of the coloured alcohol which is a measure of the thermal radiations.

A thermopile, shown in Fig. 7.24, is an extremely sensitive device used to detect thermal radiations.

It consists of a number of rods of antimony and bismuth connected in series, forming junctions at their ends. One set of junctions is exposed to the thermal radiations to be detected and the other set is shielded from the radiations. When the thermal radiations are incident on the exposed junctions, a temperature difference is developed across the two sets of junctions, thereby causing an electric current to flow which can be detected by a sensitive galvanometer, as shown in the Fig. 7.24. More intense thermal radiations cause more currents to flow. Thus, the magnitude of current through the galvanometer is a measure of the intensity of thermal radiations.

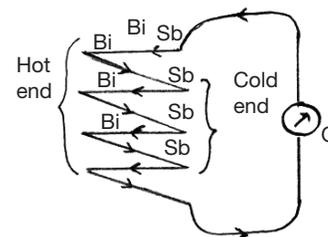


FIGURE 7.24 Thermopile

Reflection and Absorption of Thermal Radiations

When thermal radiations fall on a body, some of them are absorbed and some other are reflected depending on the nature of the surface. A good reflector is a bad absorber and vice versa. Black surfaces are good absorbers and polished surfaces are good reflectors of thermal radiations. The reflecting power of a body is defined as the ratio of the quantity of thermal radiations reflected by the surface of a body in one second to the total quantity of thermal radiations incident on the surface in one second.

The ratio of quantity of thermal radiations absorbed by surface of body in one second to the total thermal radiations falling on its surface in one second is called absorbing power of a body. Both reflecting and absorbing powers have no units and dimensions. The absorbing powers of different surfaces are not equal. Black surfaces are the best absorbers. This can be shown easily by taking two thermometers, one with blackened bulb and the other with shining bulb. When both are held in sunshine for the same duration of time, it is found that the temperature recorded by the blackened bulb thermometer is much higher than the other. This shows that different surfaces have different absorbing powers and black surfaces are better absorbers than shining polished surfaces.

Different surfaces have different emission powers. Black surfaces are better emitters of thermal radiations compared to other surfaces. This can be verified by filling two calorimeters, one with black surface and the other with shining surface, with boiling water. On recording temperatures after every ten minutes, it is found that temperature of water in the calorimeter with black surface falls rapidly compared to that with shining surface, as black surface absorbs more heat radiations than shining surface. The radiating power of a body is directly proportional to the fourth power of its absolute temperature. It is directly proportional to the surface area of the body and time. It also depends on the nature of the surface of a radiating body.

Reflecting Power and Absorbing Power of a Body

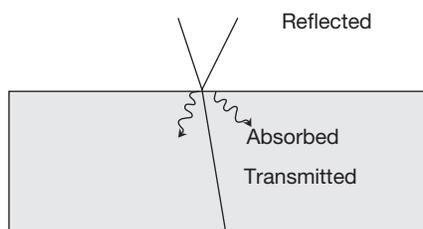


FIGURE 7.25

When heat energy falls on a body, part of it is reflected, a part of it is absorbed and a part of it is transmitted through it.

The **reflecting power** of a body is defined as the ratio of the quantity of heat energy reflected by the body per second to the quantity of heat energy incident on the body in one second.

Following are the factors affecting the reflecting power:

1. Temperature of the body
2. Temperature of the surrounding atmosphere
3. Surface area of the body
4. Nature of the body surface, such as dull, black or shining, etc.

The **absorbing power** of a body is defined as the ratio of quantity of heat energy absorbed by the body per second to the quantity of heat energy incident on the body in one second.

Both reflecting power and absorbing power have no units, as they are pure ratios.

THERMOS FLASK

A thermos flask is used to keep a hot liquid hot and a cold liquid cold.

Construction

It consists of a double walled glass vessel (Bottle). The air between the two walls is evacuated and sealed. This shining glass bulb is kept in a plastic or metal case. The space between the glass and plastic or metal is filled with cork which is a bad conductor of heat. The mouth is covered with a plastic cork over which a plastic cover is screwed.

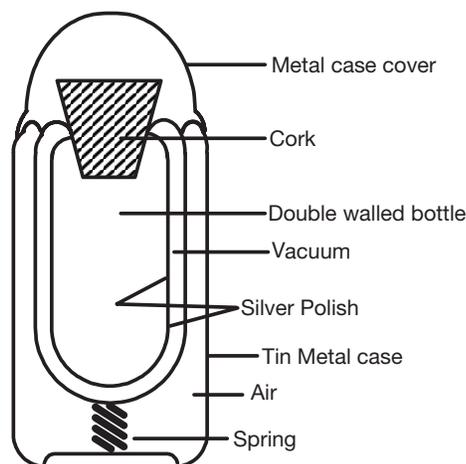


FIGURE 7.26

The different forms of heat loss are minimized in a thermos flask, due to the following reasons.

- 1. Conduction loss:** Since there is a vacuum, heat cannot be conducted by means of conduction. Further there is a cork and glass wool which are bad conductors of heat.
- 2. Convection loss:** Since there is a vacuum, loss due to convection is avoided.
- 3. Radiation loss:** Since the glass is shining, radiation loss is minimized.

Comparison between Conduction, Convection and Radiation

- 1.** Conduction and convection do not take place if no intervening medium is present. Radiation can occur without any material medium.
- 2.** In conduction and convection, there is change in temperature of the medium, but in radiation, there is no change in temperature of the medium.
- 3.** In vacuum thermal radiations travel with velocity of light, transferring heat energy at faster rate.
- 4.** In conduction, the heat energy is transferred from one particle to another particle of a medium, without the particles leaving their places. In convection, particles of medium move away from the source of heat after absorbing heat from the source. In radiation, heat energy is transmitted in the form of electromagnetic waves.
- 5.** Conduction and radiation take place in all directions. In convection, heated particles move towards cooler region.

HEAT ENGINES

The automobiles such as a motorcycle, car, lorry, bus, train, etc., use heat engines. Heat engines are the devices that convert heat energy (released when fuels are burned) into kinetic energy. Some more examples of heat engines are gas turbine, steam engine, jet engine and rocket engine. The working of heat engines can be understood from studying the toy thirsty bird. The thirsty bird toy is pivoted near the center of gravity and it continuously swings about the pivot. The energy required for motion is absorbed from surroundings. The bird's head and belly are made up of glass bulbs connected by a glass tube which forms the body of the bird, as shown in the Fig. 7.27.

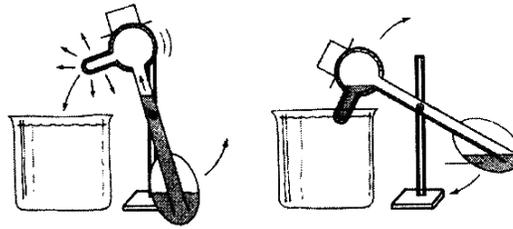


FIGURE 7.27 Thirsty bird – A cyclic heat engine

The belly is partly filled with highly volatile liquid such as ether or freon after removing air from inside. The head and beak of the bird are coated with water absorbent material such as felt. When the head or beak of the toy comes into contact with water, it is absorbed due to water absorbent coating present on the head and the beak. The absorbed water, then, evaporates by absorbing heat from vapour which, then, condenses. The condensation of vapour decreases the pressure and temperature inside the head, forcing the liquid to rise up the tube. This raises the CG and the toy tilts bringing the head down. In this position, the felt on the beak and the head of the bird absorb water once again and at the same time some of the liquid flows from head into the belly thereby increasing its weight. The bird does not remain in the tilted position for long. It straightens up and swings as the weight of belly is more than the weight of head. The above cycle is repeated. The working of thirsty bird is cyclic. It means, the same process is repeated again and again. The working of heat engines is also cyclic, like thirsty bird. However, the thirsty bird described above absorbs the energy from surroundings whereas heat engines derive it from the heat energy liberated from the burning fuels such as petrol, diesel, etc.

Types of Heat Engines

Heat engines are of two types, namely, external combustion engines and internal combustion engines.

External Combustion Engine: Steam Engine

Steam is produced in a boiler by using coal as fuel. The steam so formed is at high temperature and pressure. It is allowed to pass into the cylinder 'C' through valve A which is to the right side of the cylinder, as shown in Fig. 7.28.

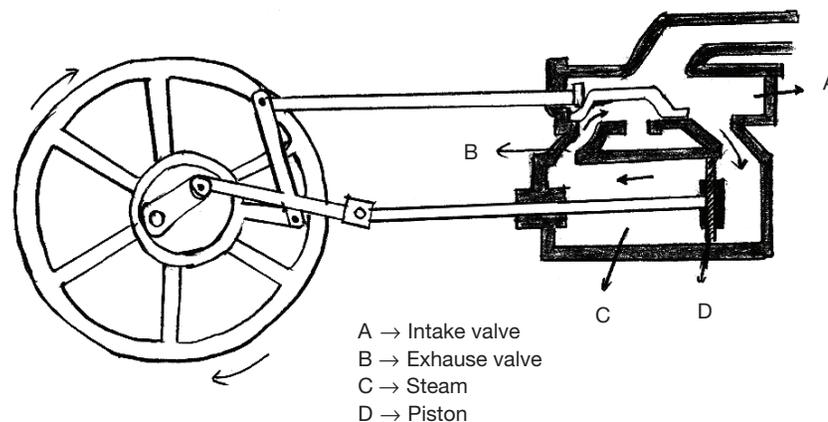


FIGURE 7.28 Steam engine

The piston is driven to the left. As the piston approaches close to the left end, the sliding valve closes and opens valve B. Now the steam enters through 'B' and pushes the piston to the right of the cylinder. As the piston moves close to the right, valve A is again open and steam rushes into the cylinder, thus, pushing piston to the left. The above process is repeated, at rapid rate. The to and fro motion of piston is converted into rotatory and finally to translatory motion.

Internal Combustion Engine

In steam engines, steam is generated by burning fuel outside the engine chamber. But in internal combustion engines, combustion takes place inside the engine chamber.

The internal combustion engines use petrol or diesel or gaseous fuels. The engines used in automobiles are internal combustion engines.

PETROL ENGINE

The working of a petrol engine can be explained by the four strokes as shown in the Fig. 7.29.

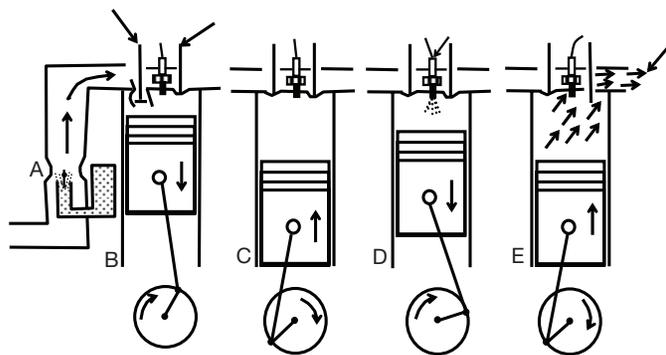


FIGURE 7.29 Four strokes in a petrol engine

The four strokes constitute one cycle of operation.

- 1. Intake stroke:** In this stroke, vapours of petrol mixed with air are admitted into a cylinder through the intake valve. This happens when the air pressure inside the cylinder decreases due to downward motion of the piston. The mixing of air and petrol takes place in carburetor.
- 2. Compression stroke:** At the end of intake stroke the intake valve closes and the piston starts moving up. The petrol – air mixture is compressed by the upward moving piston which heats the mixture. In high compression engines, the mixture is compressed to $\frac{1}{8}$ th of its initial volume. The efficiency of engine increases with increase in compression.
- 3. Power stroke:** After the compression stroke as the piston starts moving down due to the momentum, fuel in the mixture is ignited by a spark produced by the spark plug. The heat energy liberated by combustion of fuel raises the temperature of the mixture. The temperature becomes high. The pressure increases to about 25 atmospheres. Due to high temperature and pressure, the mixture expands pushing the piston down and in the process it does work. The temperature of the mixture falls during expansion.

4. **Exhaust stroke:** The exhaust valve opens up when the piston starts moving upward. Simultaneously, the spent gases are thrown out. The above four operations make one cycle of the heat engine. The cycle is repeated at rapid rate. The to and fro motion of piston is converted into rotational motion of wheels by the use of piston rod and crank.

DIESEL ENGINE

The diesel engine also works in four strokes as petrol engine but it does not contain carburetor and spark plug. At the end of compression stroke, diesel is admitted into the cylinder. The air is compressed to $\frac{1}{16}$ th of its initial volume and it is hot enough to ignite diesel.

The efficiency of a heat engine is defined as the ratio of work done by it to the amount of heat supplied. Thus, efficiency of the heat engine

$$= \frac{\text{work done}}{\text{Amount of heat supplied}}$$

The percentage efficiency is given by = $\frac{\text{work done}}{\text{Amount of heat supplied}} \times 100$

The efficiency of a diesel engine is more than the efficiency of a petrol engine. The efficiency of different engines is given in the table below.

Efficiency 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

EXAMPLE

Find the work done by a petrol engine on combustion of 1 kg petrol. The efficiency of the engine is 30% and calorific value of petrol is 47 MJ kg^{-1} .

SOLUTION

The heat energy liberated on combustion of 1 kg petrol is $47 \times 10^6 \text{ J kg}^{-1}$. The percentage efficiency is given by

$$\begin{aligned}
 &= \frac{\text{Work done } (W)}{\text{Amount of heat supplied}} \times 100 \\
 Q &= \frac{30 \times 47 \times 10^6}{100} \\
 &= 131 \times 10^5 = 1.31 \times 10^7 \text{ J}
 \end{aligned}$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

- Define melting and boiling points.
- What is the water equivalent of a substance of mass 2 kg and specific heat capacity $2.4 \text{ J g}^{-1} \text{ K}^{-1}$?
- In which mode of transmission of heat is the medium not necessary?
- $1 \text{ joule} = \underline{\hspace{2cm}}$ calorie
- Define specific latent heat of melting and specific latent heat of vaporization.
- In S.I system, the unit of heat energy is .
- Define 1 calorie and 1 kilocalorie. What is the use of calorimeter?
- Distinguish between internal and external combustion heat engines.
- What is evaporation? How the rate of evaporation is related to temperature?
- Define mechanical equivalent of heat. What is its value?
- Give a few examples of bad conductors of heat.
- Among petrol and diesel engines, which is more efficient?
- Define heat capacity and specific heat capacity. Give their S.I. units.
- What is a cyclic process?
- Does calorific value of fuel depend upon its mass?
- A is in thermal equilibrium with B and B is in thermal equilibrium with C. Are A and C in thermal equilibrium with each other?
- In which mode of transmission of heat do the particles of a medium move from one place to another place?
- Why does not a diesel engine have a spark plug?
- What is minimum possible temperature a body can have? Given its value in Kelvin and Celsius scale.
- Heat travels through vacuum as .
- Define relative humidity. State its S.I. unit.
- According to kinetic theory of gases, what is the cause of gas pressure?
- What is the use of a thermopile?
- State Boyle's and Charles' laws.
- Why are burns due to steam more harmful than those due to boiling water?
- The S.I. unit of specific latent heat of vapourization is .
- Define coefficients of linear, superficial and cubical expansions.
- Heat energy flows from a body at temperature to a body at temperature.
- What are the values of specific latent heat of melting of ice and specific latent heat of vaporization of water?
- Define coefficient of apparent and real expansion of a liquid.

Short Answer Type Questions

- Give some advantages of high specific heat capacity of water.
- If 1050 kJ of heat is required to raise the temperature of 18 kg of substance from 25°C to 35°C , find the thermal capacity and water equivalent of the substance.
(Ans: $25 \text{ kcal}^\circ\text{C}^{-1}$, 25 kg)
- What is a thermopile? Explain its working.
- A substance of mass 1.5 kg absorbs 45 kcal of heat energy. If its temperature rises from 28°C to 38°C , find its specific heat capacity.
(Ans: $12.6 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$)
- Explain how land and sea breeze occur.
- The density of mercury at 0°C is 13.6 g cm^{-3} . Find the density of mercury at 200°C if its coefficient of real expansion is $1.8 \times 10^{-4} \text{ }^\circ\text{C}^{-1}$.
(Ans: 13.127 g cm^{-3})



37. On what factors does the radiating power of a hot body depend?
38. Why do pendulum clocks made of ordinary metal go slow in summer?
(Ans: brass rod = 10 cm iron rod = 15 cm)
39. Find the quantity of water vapour at 100°C required just to melt 1 kg of ice at 0°C.
(Ans: 148 g)
40. Define apparent and real expansion of a liquid and derive a relation between them.
41. Explain why metals are good conductors of heat.
42. Distinguish between heat and temperature.

Essay Answer Type Questions

43. Differentiate between evaporation and boiling.
44. Derive the relation between the coefficients of thermal expansion, α , β and γ of a solid.
45. The difference in length of two rods, one made of brass and other iron, remains of constant as 5 cm at all temperatures. If α of iron = $12 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$ and that of brass = $18 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$, find length of the two rods at 0°C.
46. Compare conduction, convection and radiation.
47. Describe the construction of a bomb calorimeter.
48. Discuss properties of heat radiations.
49. Discuss some important applications of bad conductors.
50. Describe an experiment to find the specific heat of a solid by the method of mixtures.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- Heat engines convert mechanical energy into heat energy.
- As pressure increases, the melting point of ice decreases.
- Temperature determines the direction of flow of heat energy.
- Conduction process can be explained on the basis of both atomic model and kinetic model.
- Liquids have two types of volumetric expansion.
- Gas thermometers are more sensitive than liquid thermometers.
- Water has high specific heat capacity.

Direction for questions 8 to 14

Fill in the blanks.

- Specific heat capacity of water is _____ J kg⁻¹ K⁻¹.
- At constant volume, the pressure of a given mass of a gas is directly proportional to its _____.
- 500 joule of heat energy is supplied to a heat engine and 100 J of heat energy is dissipated due to friction

and as sound energy, then the efficiency of the heat engine is _____.

- A temperature of 50°C on Celsius thermometer corresponds to ____ on Fahrenheit thermometer.
- The relative humidity is expressed as _____.
- The quantity of heat produced when a unit mass of a substance is completely burnt is called its ____.
- A pendulum clock whose pendulum is made of a material like iron _____ time in winter.

Direction for question 15

Match the entries in column A with the appropriate ones in column B.

15.

Column A	Column B
A. Mechanical equivalent of heat	() a. $[M^1 L^0 T^0]$
B. Water equivalent	() b. $\frac{W}{H}$
C. Rate of evaporation	() c. measurement of calorific values



- D. Expansion of gases () d. area of the free surface of the liquid that is exposed to air.
- E. At constant volume $P \propto T$ () e. only volumetric
- F. Bomb calorimeter () f. hidden energy
- G. Latent heat () g. Charles law
- H. Specific heat capacity () h. carburetor
- I. Infrared rays () i. heat
- J. Petrol engine () j. $\text{cal g}^{-1} \text{ } ^\circ\text{C}^{-1}$

Direction for questions 16 to 30

For each of the questions, four choices have been provided. Select the correct alternative.

16. When heat energy is incident on a body, then
 (a) it is reflected
 (b) it is absorbed
 (c) it is transmitted through it
 (d) All the above
17. The ratio of the quantity of heat absorbed by the surface of a body to the quantity of heat falling on it in one second is called
 (a) reflecting power of the body
 (b) radiating power of the body
 (c) transmitting power of the body
 (d) absorbing power of the body
18. Among the following _____ represents the smallest temperature change
 (a) 1 K (b) 1°C
 (c) 1°F (d) Both 1 and 2
19. A sample of air containing certain amount of water vapour is saturated at a particular temperatures. If the temperature of the sample is raised further, then
 (a) the sample becomes supersaturate
 (b) the sample remains saturated
 (c) the sample becomes moist air
 (d) the sample becomes unsaturated
20. Temperature of a body is the measure of
 (a) sum total of kinetic and potential energy of the molecules of the given body.
 (b) amount of heat energy present inside the given body.
 (c) mechanical vibrations of the body.
 (d) only average kinetic energy of the molecules present inside the body.
21. 100 g of water at 60°C is added to 180 g of water at 95°C . The resultant temperature of the mixture is _____.
 (a) 80°C (b) 82.5°C
 (c) 85°C (d) 77.5°C
22. In a thermos flask, heat loss by conduction and convection can be avoided by
 (a) providing vacuum between the two walls of the flask.
 (b) filling the space between the two walls of the flask with cork which is a bad conductor of heat.
 (c) providing a shining glass.
 (d) All the above
23. When ice water is heated, its density
 (a) decreases
 (b) increases
 (c) first increases, then decreases
 (d) first decreases, then increases
24. Certain amount of gas enclosed in an air tight piston vessel is acted upon by one atmospheric pressure. The volume of the gas at 30°C is 90 cm^3 and when the temperature is raised to 40°C , the volume becomes 95 cm^3 . Then the volume coefficient of expansion of the given gas is _____.
 (a) 0.0005 K^{-1} (b) 0.05 K^{-1}
 (c) 0.05 K^{-1} (d) 0.005 K^{-1}
25. The unit for volume coefficient of expansion is
 (a) $^\circ\text{C}^{-1}$ (b) K^{-1}
 (c) $^\circ\text{F}^{-1}$ (d) All of these
26. The water equivalent of a body, whose mass is 'm' g and specific heat is 's' $\text{cal g}^{-1} \text{ } ^\circ\text{C}^{-1}$ in gram is given by _____.
 (a) $(m + s) \text{ g}$ (b) $\left(\frac{m}{s}\right) \text{ g}$
 (c) $\left(\frac{s}{m}\right) \text{ g}$ (d) $(ms) \text{ g}$
27. The amount of heat energy required to heat 1 kg of ice from -10°C to 10°C is
 (Given: specific heat of ice = $2.095 \text{ kJ kg}^{-1} \text{ } ^\circ\text{C}^{-1}$, specific heat of water = $4.2 \text{ J g}^{-1} \text{ } ^\circ\text{C}^{-1}$ specific latent heat of fusion of ice = 336 J g^{-1})
 (a) 398.95 kJ (b) 387.75 kJ
 (c) 337.75 kJ (d) 357.75 kJ
28. Efficiency of a heat engine is defined as the
 (a) product of the work done by the heat engine and amount of heat supplied to it.

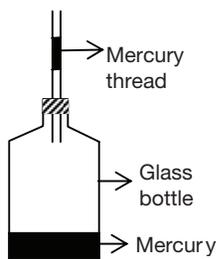


- (b) ratio of the amount of heat supplied to it and work done by the heat engine.
 (c) ratio of the work done by the heat engine and amount of heat supplied to it.
 (d) ratio of amount of heat supplied to it and amount of heat dissipated.
29. Two bodies A and B are said to be in thermal equilibrium with each other if they have same
 (a) mass
 (b) heat energy
 (c) temperature
 (d) specific heat capacities
30. The Quill's tube with its open end upwards is fixed in slanting position making 45° with the vertical line. If the atmospheric pressure be equal to ' H ' and the length of the mercury pellet in the Quill's tube be ' h ', then the pressure of air enclosed in the tube is equal to _____.
 (a) $H + h$ (b) $H - h$
 (c) $H + \frac{h}{\sqrt{2}}$ (d) $H - \frac{h}{\sqrt{2}}$
31. The principle used in the construction of air (gas) thermometer is
 (a) variation of volume with temperature at constant pressure.
 (b) variation of volume with temperature at constant heat energy.
 (c) variation of pressure with temperature at constant volume.
 (d) variation of pressure with temperature at constant heat energy.
32. The quantity of heat required to raise the temperature of a unit mass of a substance through one degree celsius is called _____.
 (a) latent heat
 (b) mechanical equivalent of heat
 (c) specific heat capacity
 (d) specific latent heat
33. Heat capacity of a body is
 (a) dependent on its shape.
 (b) dependent on its mass.
 (c) dependent on its temperature.
 (d) None of these.
34. The melting of ice by application of pressure and its resolidification on releasing the pressure is known as _____.
 (a) melting point
 (b) boiling point
 (c) regelation
 (d) super incumbent pressure
35. The boiling point of liquid depends on
 (a) its nature.
 (b) super incumbent pressure.
 (c) its purity.
 (d) All the above
36. Among the following statements, find the wrong one.
 (a) The presence of any impurities (dissolved) raises the boiling point of the solution.
 (b) The boiling point of a solution is always lesser than that of the pure solvent.
 (c) The boiling point of an aqueous solution of common salt is always greater than 100°C at normal atmospheric pressure.
 (d) Both (1) and (3) are true
37. 10 g of a fuel is combusted in the internal chamber of a bomb calorimeter because of which the temperature of 250 g of the water present in external chamber increases from 25°C to 75°C . Write the following steps in a sequential order to find the value of calorific value of the fuel. (Assume that the heat produced by the combustion of fuel is completely absorbed by the water).
 (a) Equate $m_f S = m_w s_w (\Delta t)$ and find the value of S .
 (b) Note the value of mass of fuel (m_f) and water (m_w) in bomb calorimeter from the given data.
 (c) Consider the change in the temperature (Δt) of the water to find the heat absorbed by water using, $Q = m_w s_w (\Delta t)$.
 (d) Let ' S ' be the calorific value of the fuel and heat produced by the combustion of the fuel is given by $Q = m_f S$.
 (a) abcd (b) bcad
 (c) bcda (d) cbad
38. Arrange the following steps in a sequential order to prove the convection in gases.
 (a) Place a lighted candle below chimney B and hold a lighted incense stick over chimney A.
 (b) The smoke given out by incense stick is sucked in through chimney A and comes out through B.
 (c) Take a rectangular wooden box and fix with two glass chimneys A and B on the top.
 (d) The lighted candle heats the air and reduces air pressure near the chimney B. The cold, heavy air washes in through chimney A, sweeping the smoke given out by incense stick.



49. Why does the temperature of the surroundings start falling when the ice of a frozen lake starts melting?
50. Why do the fish plates of railway tracks have oval shaped holes?
51. Is it possible to heat (boil) fluids by convection process in weightlessness condition?

52. A constant volume air thermometer is as shown in the figure below. Explain why the bottle is partly filled with mercury. Find the ratio of volume of mercury present in the bottle to the volume of the bottle if the volume coefficients of mercury and glass are $1.8 \times 10^{-4} \text{ K}^{-1}$ and $6 \times 10^{-5} \text{ K}^{-1}$, respectively.



53. Two copper cylinders 'A' and 'B' having their radii in the ratio 1 : 2 and lengths in the ratio 2 : 1 are supplied equal amount of heat. Find the ratio of the rise in their temperature.
54. A copper calorimeter of mass 100 g contains 200 g of ice at -10°C . The thermal energy is supplied to the calorimeter and its contents at the rate of 50 calories per second. What is the temperature of the calorimeter and its contents after ten minutes.
(Given, the specific heat of ice = $0.5 \text{ cal g}^{-1}\text{C}^{-1}$, the specific heat of copper = $0.1 \text{ cal g}^{-1}\text{C}^{-1}$ and latent heat of fusion of ice = 80 cal g^{-1})
55. 0.1 kg of a substance is taken as sample and combusted on sample holder of a bomb calorimeter. The temperature of 1 kg of ice present in external chamber has risen from 0°C to 50°C . What is the calorific

value of the given sample?

(Given that specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$)

Specific latent heat of fusion of ice = 336000 J kg^{-1}

56. A metallic ball of mass 100 g and specific heat capacity $2 \text{ J kg}^{-1} \text{ K}^{-1}$ was dropped from a height of 6 m on to a perfectly non-conducting surface. If 80% of its kinetic energy is converted into heat on striking the surface, find the change in temperature of the ball. (Take $g = 1000 \text{ cm s}^{-2}$).
57. A Centigrade and a Fahrenheit thermometer of same lengths (20 cm) are taken. Find the ratio of the lengths of mercury threads in the given temperature scales, respectively, if temperature rises from 0°C to 4°C . Take LFP and UFP for both the thermometers as freezing point and boiling point of water, respectively.
58. Two rods of equal length and of the same material but having different diameters, are heated through an equal rise in temperature. Of the two, thin and thick rods, which will experience a greater extension? Explain.
59. When 50 ml of a liquid is heated through 20°C , its apparent expansion is 0.5 ml. If the coefficient of linear expansion of the container is $9 \times 10^{-6} \text{ K}^{-1}$, find the coefficient of real expansion of the liquid.
60. What is the amount of heat energy required to heat 1 kg of ice from -5°C to 5°C (Given, specific heat of ice = $2.095 \text{ kJ kg}^{-1}\text{C}^{-1}$, specific heat of water = $4.2 \text{ J g}^{-1}\text{C}^{-1}$, specific latent heat of fusion of ice = 336 J g^{-1})

Level 3

61. A closed calorimeter of negligible water equivalent contains 1 kg of ice at 0°C , then 1 kg of steam at 100°C is pumped into it. Find the ratio of mass of steam to water remaining in the calorimeter after attaining equilibrium temperature. Take the efficiency of the calorimeter as 90%. Find the amount of heat lost to surroundings.
62. A hollow metallic sphere is heated. Explain the type of change produced in its
(a) internal radius (b) external radius
(c) volume (d) mass
(e) density
63. A metallic solid body of weight ' W_1 ' is immersed in a liquid, whose temperature is $t_1^\circ\text{C}$. The apparent weight of the body in the given liquid is ' W_2 '. Then the temperature of that liquid is changed to $t_2^\circ\text{C}$, the apparent weight of the body is ' W_3 '. If the density of this liquid at $t_1^\circ\text{C}$ and $t_2^\circ\text{C}$ was d_1 and d_2 , respectively, then find the volume coefficient of the solid body in terms of W_1 , W_2 , W_3 , d_1 , d_2 and $t_1^\circ\text{C}$ and $t_2^\circ\text{C}$.
64. A thermally insulated can (like thermal flask) containing a liquid is shaken vigorously. Will there be any change in the amount of heat energy present in it. If there is a change, discuss how it can be noticed.



65. As the altitude from the surface of the Earth increases, the atmospheric temperature falls. Explain.
66. Ravi read that a biscuit packet gives 450 k cal of energy per 100 g. Now, he wanted to find the calorific value of some other substance. He took 0.1 kg of that substance as a sample and combusted it on a sample holder of a bomb calorimeter. Because of this, the temperature of 1 kg of ice present in the external chamber rose from 0°C to 50°C . What is the calorific value of the given sample? It is given that the specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$, the specific latent heat of fusion of ice = 336000 J kg^{-1} .
67. Bose took 100 kg of paraffin oil and supplied $4180 \times 10^3 \text{ J}$ of heat energy to it. Because of this, the temperature of the oil was found to increase from 300 K to x . With this data, Bose found the value of x . Find his answer. [Assume that there is no loss of energy to the surroundings and take the specific heat of water as $4.18 \text{ J g}^{-1}\text{C}^{-1}$ (and water equivalent of 100 kg paraffin oil = 50 kg)].
68. Neelkamal took 200 g of water and wanted to boil it from 25°C . He took a gas burner that supplies 250 calories in one second, to heat the water. If the thermal efficiency of the burner is 80%, then how much time will he take to boil the water?
69. A Quill's tube of one metre is taken. A certain amount of ideal gas is trapped in it by a 20 cm length of Hg column. When the tube is held vertical with open end upwards, the length of the gas column is 50 cm. Find the pressure and length of the trapped gas, when the Quill's tube is kept in slanting position making 45° with the vertical open end upwards. (Take atmospheric pressure as 76 cm of Hg and $\sqrt{2} = 1.414$).
70. Calculate the amount of energy wasted on combustion of 2 kg of diesel in a diesel engine of efficiency 40%. The calorific value of diesel is 44,800 kJ/kg.



CONCEPT APPLICATION

Level 1

1. False 2. True 3. True 4. True 5. True 6. True 7. True

Fill in the blanks

8. 4200 9. absolute temperature 10. 80% 11. 112°F 12. Percentage
13. calorific value 14. gain

Match the following

15. A : b B : a C : d D : e E : g F : c G : f H : j I : i J : h

Multiple choice questions

16. (d) 17. (d) 18. (c) 19. (d) 20. (d) 21. (b) 22. (a)
23. (c) 24. (d) 25. (d) 26. (d) 27. (a) 28. (c) 29. (c)
30. (c) 31. (a) 32. (c) 33. (b) 34. (c) 35. (d) 36. (b)
37. (c) 38. (b) 39. (c) 40. (d)

Explanations for questions 31 to 40

31. The pressure exerted on the air thermometer is 1 atm and the volume of the air changes with temperature.

32. By definition, specific heat capacity of a substance is the amount of heat required to raise the temperature of unit mass of the given substance by unit temperature difference.

33. Heat capacity $c = ms$
 $C \propto m$ (depends on mass)

34. During regelation, ice melts due to pressure and once pressure is withdrawn the water formed gets converted into ice.

35. Boiling point of a liquid depends on its nature, super incumbent pressure, and also on the level of impurities present in it.

36. Impurities increase the boiling point of a given solvent.

37. $m_w = 250$ g, $m_F = 10$ g, $S_w = 1$ cal g^{-1} $^{\circ}C^{-1}$ (b)
 $\Delta t = (75 - 25)^{\circ}C = 50^{\circ}C$

$$\text{Heat absorbed by water} = m_w s_w (\Delta t) = 250 \times 1 \times 50 = 12500 \text{ cal (c)}$$

The heat liberated by the fuel,

$$Q_{\text{produced}} = m_F S = 10 S \text{ (d)}$$

We Know $Q = m_F S = m_w s_w (\Delta t)$

$$\Rightarrow s = \frac{m_w s_w (\Delta t)}{m_F} \text{ (a)}$$

$$S = \frac{12500 \text{ cal}}{10 \text{ g}} = 1250 \text{ cal } g^{-1}$$

38. Take a rectangular wooden box with two glass chimneys A and B on the top (c). Place a lighted candle below chimney B and hold a lighted incense stick over chimney A (a). The smoke given out by incense stick is sucked in through chimney A and comes out through B (b). The lighted candle heats the air and reduces air pressure near the chimney B. The cold, heavy air rushes in through chimney A, sweeping the smoke given out by incense stick (d). On absorbing heat, the hot air molecules move away from the source of heat and molecules of cold air move towards the source of heat, forming convection currents.

39. Safety valve opens when the pressure inside increases beyond the safety level. Thus, cooker is saved from bursting.

40. Take a hard glass tube containing cold water filled up to $\frac{3}{4}$ of its length and drop small pieces of ice, wrapped in copper wire gauge (c). Clamp the test tube in slanting position and heat the test tube near its mouth with a bunsen burner (a). It is observed that water near the mouth of the test tube starts boiling but the ice does not melt (d). This shows that heat is not conducted through water and water is a bad conductor of heat (b).



Level 2

41. Which among copper and steel has a greater coefficient of expansion?

Given that the copper vessel is stuck inside the steel vessel, which of heating or cooling the vessels, creates a space between them to get detached?

42. (i) Consider the pressure (P_1), volume (V_1) and temperature (T_1) of the air in the bubble in terms of S.I. units.

$$P_1 = 1 \text{ atm} = 10.336 \text{ m of water}$$

$$V_1 = \frac{4}{3} \pi r_1^3 = \frac{4}{3} \pi \left(\frac{10}{1000} \text{ m} \right)^3$$

$$T_1 = (42 + 273) \text{ K}$$

Find the volume (V_2) and temperature (T_2) of the air bubble at the bottom of the tank.

$$V_2 = \frac{4}{3} \pi r_2^3 = \frac{4}{3} \pi \left(\frac{6}{1000} \text{ m} \right)^3$$

$$T_2 = (27 + 273) \text{ K}$$

Apply the value of P_2 (in terms of pressure exerted by water columns) from (1)

Then, the height of the water column, $h = (P_2 - P_1) \text{ m}$

(ii) 35.273 m

43. (i) Use $Q = ms\Delta\theta$.

Express mass in terms of volume and density.

Volume of a sphere = $\frac{4}{3} \pi r^3$ where ' r ' is its radius.

(ii) 1 : 6

44. (i) The amount of heat absorbed by the ice at -10°C to just melt = Q .

$$\Rightarrow Q_1 = m_i S_i \Delta t + m_i L_F \quad (1)$$

The actual amount of heat energy supplied

$$= Q = R \times t \quad (2)$$

$$Q = 20 \times 450 \text{ cal}$$

Then find the amount of heat absorbed by vessel

$$= Q_2 Q - Q_1 \quad (3)$$

$$Q_2 = m_V S_V (\Delta T) \quad (4)$$

Find the value m_V from (4).

Now water equivalent = $M = m_V S_V$

(ii) 50 g

45. Is the expansion of the metallic sheet uniform?

If so, how is its length and breadth affected?

Recall the formula for area of a square.

46. (i) Given that the two spheres are of same material and have equal mass.

\Rightarrow the density (ρ) and mass (m) of the spheres is constant.

Equal rise in temperature $\Rightarrow \Delta\theta$ is constant.

Rate of heat supplied (K)

$$= \frac{\text{Heat supplied (Q)}}{\text{time (t)}}$$

$$\Rightarrow Q = Kt \quad (1)$$

$$\text{Also } Q = ms\Delta\theta \quad (2)$$

where ' s ' is the specific heat capacity (in this case it is same for both the spheres)

Equate (1) and (2) and apply it for both the spheres.

From the equations applied find the ratio of time taken to heat the spheres.

(ii) 2 : 1

47. (i) The relation comparing two scales is given by:

$$\left(\frac{S - LFP}{UFP - LFP} \right)_{\text{correct}} = \left(\frac{X - LFP}{UFP - LFP} \right)_{\text{faulty}} \quad (1)$$

First find the length of the mercury thread at 250°C in correct thermometer by comparing it with celcius scale by using (1). Take it as l_1 .

Similarly, find the length of mercury thread at 250°C in faulty thermometer by comparing it with celcius scale. Make use of (1) consider the length as l_2 . Find the value of $l_2 - l_1$.

(ii) 18 mm

48. (i) Recall the definition of water equivalent. Use the formula, $Q = C\Delta\theta$ where ' C ' is the heat capacity and $\Delta\theta$ is the rise in temperature.

Calculate the rise in temperature from the given data.

Is the rise in temperature equal on Celsius scale and Kelvin scale?

(ii) 50 kg

49. Does ice absorb or liberate heat while melting?

How does this affect the heat content in the surroundings of the ice?

50. (i) If the fish plates have circular (holes-shaped instead of oval-shaped), do the railway tracks have scope for horizontal thermal expansion?

(ii) 24°C



51. (i) Does the volume of the bottle increase on absorbing heat from the surroundings?

Does the mercury in the bottle too expand along with the bottle when heat is absorbed from the surroundings?

Hence, can we avoid expansion of air in the bottle by placing some mercury in it?

Now what is the condition required so that the volume of air in the bottle does not change?

Is it $\Delta V_{\text{mercury}} = \Delta V_{\text{bottle}}$?

Use $\Delta V = V\gamma\Delta\theta$

Is $\Delta\theta$ the same for the bottle and the mercury in it?

(ii) $\frac{3}{1}$

52. (i) Given the two metal cylinders are of the same material. Their specific heat capacity and density are the same.

In the equation $Q = ms\Delta\theta$, express mass in terms of volume and density.

Volume of a cylinder = $\pi r^2\ell$, where 'r' and 'l' are its radius and length, respectively.

Given heat supplied to both the cylinders is equal, $\Rightarrow Q_A = Q_B$.

Ratio of the lengths and ratio of the radii of the cylinders is given.

Hence, from the above equation, find the ratio of the rise in temperatures of the cylinders.

(ii) 2 : 1

53. (i) Heat is absorbed by both the calorimeter and the contents in it.

Calculate the total heat supplied in the given time, using $Q = (\text{rate of heat supplied}) \times \text{time}$.

Initial temperature of the calorimeter and the contents in it is the same.

Use $Q = mL$ and $Q = ms\Delta\theta$ as required.

(ii) 61.4°C

54. (i) Use $Q = mL$ and $Q = ms\Delta\theta$ according to the situation.

Use principle of calorimetry.

Total heat produced = (mass of the substance) \times (calorific value of the substance).

(ii) 5.46 MJ kg⁻¹

55. Kinetic energy at the bottom = Potential energy (mgh) at the given height.

$$\text{Heat gained} = \frac{80}{100} \times mgh = ms\Delta\theta$$

$$\Rightarrow \Delta\theta = \frac{80}{100} \times \frac{gh}{s}$$

$$\text{Given, } g = 1000 \text{ cm s}^{-2} = 10 \text{ ms}^{-2}$$

$$h = 6 \text{ m and } s = 2 \text{ Jkg}^{-1} \text{ K}^{-1}.$$

$$\Rightarrow \Delta\theta = \frac{80}{100} \times \frac{10 \times 6}{2} = 24^\circ\text{C or } 24 \text{ K}.$$

56. The length of Fahrenheit and centigrade thermometers is = 20 cm

When temperature raises from 0°C to 4°C, then the length of mercury thread in Celsius scale of temperature is = $\frac{20 \times 4}{100} = 0.8 \text{ cm}$.

$$\text{In Fahrenheit thermometer, } 0^\circ\text{C is represented by } 32^\circ\text{F and the number of divisions in it is } 180.$$

$$\frac{C}{5} = \frac{F - 32}{9} \Rightarrow F = \frac{9}{5}C + 32$$

When temperature in Celsius scale is 4°C, then its corresponding temperature in Fahrenheit scale is

$$F = \frac{9}{5}C + 32$$

$$F = \frac{9}{5} \times 4 + 32 = \frac{196}{5} = 39.2^\circ\text{F}$$

The rise in temperature in Fahrenheit scale

$$= 39.2^\circ\text{F} - 32^\circ\text{F} = 7.2^\circ\text{F}$$

When temperature raises from 32°F to 39.2°F, then the increase in the length of mercury level is

$$\Rightarrow \frac{7.20 \times 20}{180} = 0.8 \text{ cm}$$

Then the ratio of the length of mercury threads in centigrade and Fahrenheit temperature scales is

$$= \frac{0.8}{0.8} = \frac{1}{1} = 1 : 1$$

57. $\Delta\ell = \ell\alpha\Delta\theta$. Here, α for both the rods is same.

Given ℓ and $\Delta\theta$ for the rods are equal.

$\Rightarrow \Delta\ell$ is also equal for both the rods.

$\Delta\ell$ does not depend on thickness of the rods.

58. $\Delta V_{\text{real}} = \Delta V_{\text{apparent}} + \Delta V_{\text{container}}$

$$\Rightarrow \gamma_{\text{real}} = \gamma_{\text{apparent}} + \gamma_{\text{container}}$$



$$\gamma_{\text{apparent}} = \frac{\Delta V}{V \Delta \theta} = \frac{0.5}{50 \times 20} = 5 \times 10^{-4} \text{ K}^{-1}$$

$$= 500 \times 10^{-6} \text{ K}^{-1}$$

$$\text{Given } \alpha_{\text{container}} = 9 \times 10^{-6} \text{ K}^{-1}$$

$$\therefore \gamma_{\text{container}} = 27 \times 10^{-6} \text{ K}^{-1} [\because \gamma = 3\alpha]$$

$$\therefore \gamma_{\text{real}} = 500 \times 10^{-6} + 27 \times 10^{-6}$$

$$= 527 \times 10^{-6} \text{ K}^{-1}$$

$$59. Q = m s_{\text{ice}} (\Delta t_{\text{ice}}) + m L_F + m s_w (\Delta t)$$

$$= (1 \times 2.095 \times 5 \times 10^3) + (1 \times 336 \times 10^3) + 1 \times 4.2 \times 10^3 \times 5 = 367.475 \text{ kJ}$$

Level 3

60. (i) Find the total amount heat required to convert 1 kg of ice at 0°C to water at 100°C
- $$Q_1 = m_i L_F + m_i S_W (\Delta T) = m L_F + m S_W (100) \quad (1)$$
- Find the amount of steam that gets condensed into water 100°C
- Consider the efficiency of the calorimeter as 90%
- $$\Rightarrow \text{Then, } \frac{90}{100} (m_s L_V) = Q_1 \quad (2)$$
- Find the value of m_s from (2).
- Find the ratio of $\frac{m_s}{m_W}$.
- $$\text{Heat lost to the surrounding is} = \frac{1}{10} m_s L_V.$$
- (ii) 0.49, 84 kJ
61. Consider the following points to solve the problem.
- Is a sphere one, two or three dimensional body?
- Does the sphere have linear, areal or volumetric expansion? Does the mass of a body affected when it expands on heating?
62. (i) Take volumes of the body at $t_1^\circ\text{C}$ and $t_2^\circ\text{C}$ be V_1 and V_2 , respectively. Take the densities of the liquid at $t_1^\circ\text{C}$ and $t_2^\circ\text{C}$ as d_1 and d_2 , respectively. Find the apparent loss in weight of the body in liquid at $t_1^\circ\text{C}$ and $t_2^\circ\text{C}$.
- $$W_1 - W_2 = V_1 d_1 g$$
- and $W_1 - W_3 = V_2 d_2 g$
- The volume coefficient of the solid body
- $$= \gamma = \frac{\Delta V}{V_0 \Delta T} = \frac{V_2 - V_1}{V_1 (t_2 - t_1)} \text{ } ^\circ\text{C}^{-1}$$
- Convert V_1 and V_2 in terms of W_1 , W_2 , g , d_1 and d_2 .
- Substitute it in above equation and obtain required solution.
- (ii) $\frac{d_1(w_1 - w_3) - d_2(w_1 - w_2)}{d_2(t_2 - t_1)(w_1 - w_2)} \text{ } ^\circ\text{C}^{-1}$
63. When the thermally insulated can containing a liquid is shaken, there is some work done on it. The work done is transformed into energy.
64. In the troposphere, temperature decreases as altitude increases because Earth's atmosphere is heated upward from the lowest level.
65. Mass of substance, (m) = 0.1 kg
- The heat produced by combustion, (Q) = heat utilized in melting ice, (Q_1) + heat utilized in raising the temperature of water (Q_2)
- $$Q_1 = (1 \text{ kg}) (336000 \text{ J kg}^{-1}) = 3,36,000 \text{ J.}$$
- $$Q_2 = (1 \text{ kg}) (4200 \text{ J kg}^{-1} \text{ K}^{-1}) (50 \text{ K}) = 210000 \text{ J.}$$
- $$\therefore Q = 546 \text{ kJ}$$
- The calorific value of the substance
- $$= \frac{Q}{m} = \frac{546 \text{ kJ}}{0.1 \text{ kg}}$$
- $$= 5.46 \text{ MJ kg}^{-1}.$$
66. The mass of paraffin oil is $m = 100 \text{ kg}$.
- The temperature change, $\Delta t = (x - 300)$
- The amount of energy absorbed by paraffin oil = $4180 \times 10^3 \text{ J}$.
- The specific heat of water = $4180 \text{ J kg}^{-1} \text{ } ^\circ\text{C}^{-1}$.
- The specific heat of paraffin oil is
- Water equivalent $M = MS$ (formula)
- $$M_1 S_1 = M_2 S_2$$
- $$S_2 = \frac{M_1}{M_2} S_1$$
- $$= \frac{50}{100} \times 4180$$
- $$= 2090$$
- Specific heat capacity of paraffin oils = $2090 \text{ J kg}^{-1} \text{ } ^\circ\text{C}^{-1}$.
- $$\Delta t = \frac{\theta}{MS}$$
- $$= \frac{4180 \times 10^3}{100 \times 2090}$$
- $$= 20$$
- $$x = 300 \times \Delta t = 320 \text{ K}$$



Alternate method:

4180×10^3 J of energy will be 'x' kg of water. To raise its temperature by 20°C , i.e., water equivalent of paraffin oil.

$$x \Rightarrow \text{kg} = \frac{4180 \times 10^3}{4180 \times 20} = 50 \text{ kg.}$$

Therefore, the water equivalent of the given paraffin oil is 50 kg.

67. $\Delta\theta = 75^\circ\text{C}$

$$m = 200 \text{ g}$$

$$s = 1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$$

$$\therefore Q = ms\Delta\theta = (200 \text{ g}) (1 \text{ cal g}^{-1}\text{ }^\circ\text{C}^{-1}) (75^\circ\text{C}) = 15000 \text{ cal.}$$

The heat supplied = (Heat supply rate). (time)

The heat utilized = (thermal efficiency).
(heat supplied)

$$\Rightarrow 1500 \text{ cal} = \frac{80}{100} \times 250 \text{ cal s}^{-1} \times t$$

$$\Rightarrow t = 75 \text{ seconds.}$$

68. Let the pressure of the entrapped gas in vertical position be, $P_1 = P_{\text{atm}} + 20 = 76 + 20 = 96 \text{ cm of Hg}$

The length of the entrapped gas, $\ell_1 = 50 \text{ cm}$

When Quill's tube is in inclined position makes 45° with vertical, then by Pythagoras's theorem

$$2h^2 = 20^2$$

$$h = \sqrt{\frac{400}{2}} = \sqrt{200} = 10\sqrt{2} \text{ cm (or)}$$

$$\sin \theta = \frac{h}{20 \text{ cm}} \Rightarrow \frac{1}{\sqrt{2}} = \frac{h}{20 \text{ cm}}$$

$$\Rightarrow h = \frac{20}{\sqrt{2}} = \frac{20}{2}\sqrt{2} \text{ cm} = 10\sqrt{2} \text{ cm}$$

The pressure of the entrapped gas in slanting position is

$$P_2 = (76 + 10\sqrt{2}) \text{ cm of Hg}$$

Let the length of the entrapped gas be = ℓ_2

Applying Boyle's law,

$$P_1\ell_1 = P_2\ell_2 \Rightarrow \ell_2 = \frac{P_1\ell_1}{P_2}$$

$$= \frac{96 \text{ cm of Hg} \times 50}{(76 + 10\sqrt{2}) \text{ cm of Hg}}$$

$$= \frac{96 \times 50}{76 + 14.14} = \frac{4800}{9014} \times 100$$

$$\therefore \ell_2 = 53.25 \text{ cm.}$$

69. $E = \frac{\text{work done}}{\text{input}} \times 100$

$$40 = \frac{W}{2 \times 44,800} \times 100$$

$$W = 35,840 \text{ kJ}$$

$$\text{The amount of energy wasted} = 89600 \text{ kJ} - 35840 \text{ kJ} = 43760 \text{ kJ}$$



Chapter 8

Wave Motion and Sound



REMEMBER

Before beginning this chapter you should be able to:

- Remember the concept of oscillatory motion and also the laws of simple pendulum
- Tell the different types of waves and changes happening in the medium during the propagation of a wave
- Recognize sound as a mechanical wave and to discuss the different terms associated with the study of sound wave

KEY IDEAS

After completing this chapter you should be able to:

- Revise different types of motion and to represent simple harmonic motion graphically
- Explain the terms related to wave motion and to use them to understand the classification of waves
- Learn how sound is produced and the classification of sound based on its frequency
- Understand the formulae of velocity of sound and how it is different in different states along with the factors that affect the velocity
- Use Doppler effect in solving different numerical problems and understand the concept of mach number and sonic boom
- Learn about natural and forced oscillations and resonance
- Understand the formation of stationary waves in an organ pipe as well as a stretched string
- Explain reflection of sound and its applications, analog and digital recording of sound and the structure of the human ear

INTRODUCTION

In kinematics and dynamics, we have studied about bodies in motion and have classified the different types of motion as

1. translatory motion
2. vibratory or oscillatory motion
3. rotatory motion

In each of these cases, we find that the bodies possess kinetic energy and this kinetic energy can be transformed into other forms like potential energy, electrical energy, heat energy, sound energy, etc. Electrical energy can be transmitted from the generating stations through electrical conductors and transmission of heat energy takes place by conduction, convection and radiation. To understand the transmission of sound energy, we need to direct our attention to the particular effects of vibratory motion of particles.

PERIODIC MOTION OF PARTICLES

Before we move on to study the nature and transmission of sound, we need to understand the different types of vibratory or oscillatory motions.

A motion, such as that of the Earth around the sun, the movement of the hands of the clock, etc., is referred to as **periodic motion** since the motion of the object repeats itself at regular intervals of time. A to-and-fro motion, such as the swinging of a pendulum, vertical oscillations of a mass suspended from a spring, etc., is referred to as **harmonic motion**.

A harmonic motion in which the amplitude and time period of oscillation remain constant is particularly referred to as **simple harmonic motion (SHM)**. In a SHM the acceleration of the body or particle executing the motion is directly proportional to its displacement from the mean position and is directed towards the mean position. The total mechanical energy of the particle is conserved.

Graphical Representation of Simple Harmonic Motion—Its Characteristics and Relations

Consider a simple pendulum, which is set into oscillations in a vertical plane as shown in Fig. 8.1. 'O' is the mean position of the bob of the pendulum and 'A' and 'B' are its extreme positions. If the direction of motion of the bob towards 'A' is taken as positive, then the direction towards 'B' is negative.

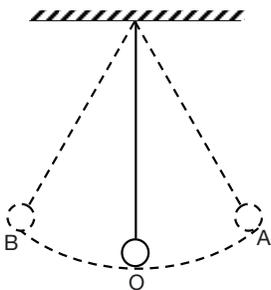


FIGURE 8.1

The pendulum oscillates to and fro and the time taken for one complete oscillation is known as **time period** (T). The magnitudes of the displacements from mean position is maximum when the bob is at either 'A' or 'B' and this maximum displacement of the vibrating particle from its mean position is known as '**amplitude**' (A).

A graph plotted between the displacement of the bob from its mean position and the time, is as shown in Fig. 8.2.

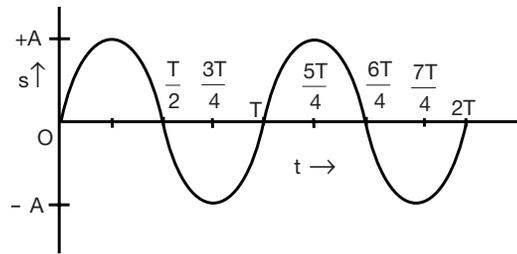


FIGURE 8.2

As the time increases, displacement increases to the maximum of 'A' at $t = T/4$ and then the bob comes to mean position at $t = T/2$, and so, displacement is zero. It continues to move towards negative side, and when the time $t = 3T/4$ its displacement is equal to the amplitude. When $t = T$, it comes back to the mean position completing one full vibration oscillation.

The number of vibrations the pendulum bob makes in unit time is known as **frequency** (n) and is measured in hertz (Hz) The time period and the frequency are related as $n = 1/T$. Here, we find that the graph (Fig. 8.2) is in the form of a wave that we see on the surface of water.

WAVE MOTION

When a pebble is thrown into still water, circular ripples are formed which spread out in all directions on the surface of water from the point where the stone hit the water surface. Thus, the kinetic energy of the stone is transferred to the water and that energy is distributed to the entire water in the pond in the form of ripples or waves. To check whether water moves along with ripples produced or not, we can observe a floating object like a cork or a leaf placed on the surface of water. As the ripples move in all possible directions on the surface of water from the point where the disturbance is produced, the leaf which is floating on the surface of water vibrates up and down, but does not have lateral translatory motion along the surface of water. We even observe that the leaf does not start vibrating till the first ripple reaches it from the point of disturbance. This is the characteristic of the propagation of waves.

The energy is transmitted from one point to another without actual translatory motion or transport of the particles across the medium. Thus, a 'wave is a disturbance produced at a point in a medium or a field and is transmitted to other parts of the medium or the field without the actual translatory motion of the particles'. The transfer of energy in the form of waves is known as 'wave motion'.

A **pulse** is a disturbance lasting for a short duration.



FIGURE 8.3

A **wave** on the other hand is a sustained disturbance lasting for a longer duration, like waves on the surface of water.

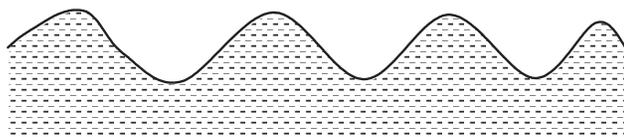


FIGURE 8.4

Before we proceed to study wave motion in greater detail let us first review the terms and physical quantities associated with wave motion.

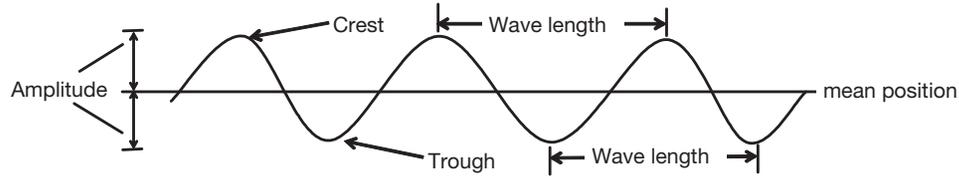


FIGURE 8.5

Crest is the point of maximum displacement of a particle in upward direction.

Trough is the point of maximum displacement of a particle in downward direction.

Amplitude is the maximum displacement of the particles (either upwards or downwards) from the mean position.

Wavelength (λ) is the distance between any two successive crests or troughs.

Time period (T) is the time taken by a particle to complete one oscillation or vibration.

Frequency (n) is the number of oscillations or vibrations made by a particle in one second.

$$n = \frac{1}{T}$$

The S.I. unit of frequency is hertz (Hz).

$$1 \text{ hertz} = 1 \text{ s}^{-1}$$

Velocity of a wave is the speed with which the wave propagates in the medium.

$$v = \frac{\lambda}{T}$$

$$v = n\lambda$$

PHASE

The motion of the vibrating particles and their direction is described in terms of its phase. Thus, particles in the same phase would be exactly at the same distance from their mean positions and have the same instantaneous velocity at that moment.

If the motion of two particles is such that their displacement, motion and velocity are dissimilar to each other, then they are said to have phase difference. If two particles have same magnitude of displacement from mean position and velocity but the direction of these vector quantities are opposite to each other, then they are said to be out of phase.

Transmission of Energy

Wave motion refers to the transmission of energy from one place to another without actual movement of the particles or entities of the medium.

CLASSIFICATION OF WAVES

It is found that certain type of waves require a medium for propagation, e.g., water waves, sound waves, etc., whereas there exist waves which do not require a medium for their propagation, e.g., light waves.

The direction of vibration of particles differ from the direction of wave motion from one type of wave to another. Similarly some waves move endlessly in a medium whereas some are confined between two points.

Based on these factors, waves can be classified into different types as follows:

1. Classification based on the necessity of medium—Mechanical waves and Electromagnetic waves.

Mechanical waves are the waves which require a material medium for their propagation. They are also called ‘elastic waves’ as the main cause for their propagation in the medium is a property of the medium called ‘elasticity’.

If an applied force on a body changes its shape or size or both, and when the force is taken away, (if the body regains its original shape and size) then the body is said to be ‘elastic’ and its property to regain its original shape and size after the applied force is removed is known as ‘elasticity’.

Electromagnetic waves are the waves which do not require medium for their propagation. They can propagate through material media as well as vacuum. Light waves are an example of electromagnetic waves.

2. Classification based on the direction of vibration of particles with respect to the direction of wave motion—Transverse and longitudinal waves.

When a mechanical wave propagates from one place to another in a medium, the direction of vibration of particles of the medium can be either parallel or perpendicular to the direction of wave motion.

If the direction of vibration of the particles of the medium is parallel to the direction of wave motion, the wave is called ‘longitudinal wave’ and if it is perpendicular to the direction of wave motion, the wave is called ‘transverse wave’.

Longitudinal Wave

Consider a long spring clamped at one of the ends, placed on a horizontal surface of a table in straight position, as shown in Fig. 8.6. The distance between any two adjacent rings along the length of the spring is constant. If the spring is slightly pulled and then released, the spring begins to vibrate. It can be observed that any two adjacent rings in some parts of the spring come very close to each other, while in other parts they move apart as shown in Fig. 8.7.

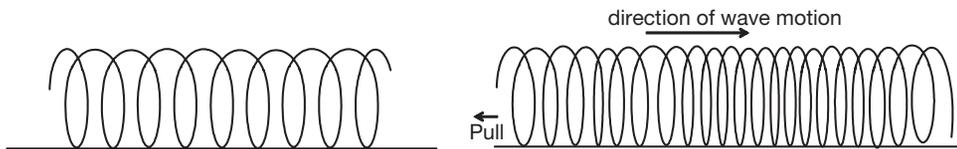


FIGURE 8.6

FIGURE 8.7 Longitudinal waves

The regions where the rings are very close to each other are called ‘compressions’ and the regions where they are far apart are called ‘rarefactions’. The wave set in the spring is a longitudinal wave as the direction of vibration of particles (here rings) is parallel to the direction of wave motion.

So, a longitudinal wave moves in a medium in the form of compressions and rarefactions. Whenever compressions and rarefactions are transmitted through a medium, a change in the

volume of the medium takes place in those locations. Due to elasticity of the medium, it regains its original volume. Thus, longitudinal waves can be set in a medium that opposes change in volume. Since all the states of matter, solids, liquids and gases have this property to oppose change in volume, longitudinal waves can propagate in solids, liquids and gases.

Transverse Wave

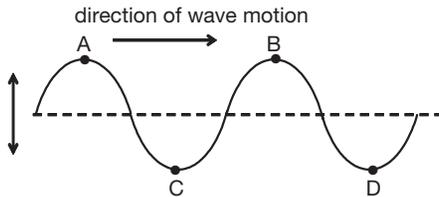


FIGURE 8.8 Transverse wave

When we take a long string along the horizontal position and vibrate it at one end in a direction perpendicular to the length of the string, a wave form is set up in the string as shown in Fig. 8.8. The original position of the string is shown by a dotted line. It is also called mean or rest position. Here the wave moves in the horizontal direction whereas the particles of the string vibrate in the perpendicular direction (vertical).

The displacement of the vibrating particles is measured from the mean position. The particles at positions 'A' and 'B' have maximum displacement in the upward direction and these points are known as '**crests**'. Similarly the particles at positions 'C' and 'D' have maximum downward displacement and these points are known as '**troughs**'. As the direction of particle vibration is perpendicular to the direction of wave motion, the wave set in the string is a transverse wave.

Thus, when a transverse wave is set in a medium, a series of crests and troughs propagate through the medium. These crests and troughs change the shape of the medium and due to elasticity, the medium regains its original shape. Hence, transverse waves can be set in a medium which opposes change in shape. For this reason, transverse waves can propagate only in solids and at the surface of the liquids but not through liquids and gases.

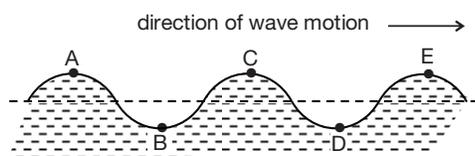


FIGURE 8.9

Consider the cross section of water surface when waves are propagating through its surface as shown in the Fig. 8.9.

The dotted line indicates the rest position of the water surface. As the wave propagates from the left to the right, the water particles vibrate up and down forming crests and troughs. The displacement of the particles at 'A' and 'C' from the mean position is equal and their direction of motion is the same. Thus, their status of vibration with respect to the direction of motion and the

displacement from the mean position, which is known as '**phase**' is equal and the particles at A, C and E are said to be '**in phase**'. Similarly particles at 'B' and 'D' are in phase. If particles at 'A' and 'B' are considered, their magnitude of displacement from their mean position is equal but their direction of motion is opposite. So, they are said to be '**out of phase**'. The minimum distance between the particles of the medium which are in the same phase is called '**wavelength**' of the wave, and is denoted by the Greek letter ' λ ' (lambda). So, the distance between 'A' and 'C' or that between 'C' and 'E' is the wavelength (λ). By the time the particle at 'A' completes one vibration, i.e., after one time period (T), the wave advances by one wavelength (λ). So, the velocity of propagation of the wave is given by,

$$v = \frac{\lambda}{T}$$

$$v = \frac{\text{distance travelled}}{\text{Time taken}} = \frac{S}{t} = \frac{\lambda}{T}$$

As
$$\frac{1}{T} = n \quad (\text{the frequency of the wave})$$

$$v = n\lambda$$

The velocity of the vibrating particles is not constant throughout their vibration. It is minimum at the extreme positions and maximum at the mean position. But the velocity of the wave propagating through the medium is constant.

The wave considered in Fig. 8.9 is a transverse wave, and it produces crests and troughs. Similarly when a longitudinal wave such as a sound wave propagates through a medium like gas, it causes compressions and rarefactions while propagating through the medium, causing change in density and pressure throughout the medium.

The graph of pressure (p) or density (d), of a gas, taken along the Y -axis versus the distance from the source of sound to the element of gas vibrating, taken along the X -axis is as shown in Fig. 8.10.

At positions 'A' and 'E' which correspond to compressions, the density and pressure of a gas are maximum and are more than the normal values. Similarly at positions 'C' and 'G' which correspond to rarefactions, the density and pressure of a gas are minimum and are less than the normal values. The positions, 'B', 'D', 'F', and 'H' show normal pressure and density of the gas.

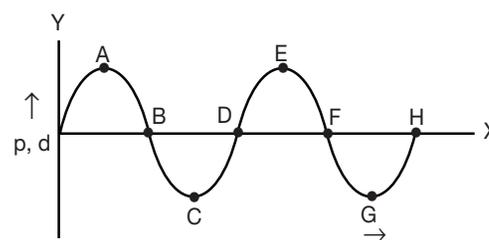


FIGURE 8.10 Distance of element of gas from source of sound

Comparative Study of Transverse and Longitudinal Waves

Transverse waves	Longitudinal waves
1. The direction of vibration of particles is perpendicular to the direction of propagation of a wave.	1. The direction of vibration of particles is parallel to the direction of propagation of a wave.
2. The wave propagates in the form of crests and troughs.	2. The wave propagates in the form of compressions and rarefactions.
3. These waves can travel through solids and on surface of liquids only, as the propagation of these waves causes change in the shape of the medium.	3. These waves can pass through solids, liquids and gases also, as the propagation of these waves causes change in the volume of the medium.
4. As there is no variation of volume, there is no variation in the density of the medium while the wave propagates through it.	4. When the wave propagates through a medium, there is a change in volume and this causes a variation in the density.
5. There is no difference in pressure created in the medium while the wave propagates.	5. Propagation of longitudinal waves causes pressure difference in the medium.
6. Distance between two consecutive crests or trough, is called 'wavelength'.	6. Distance between two consecutive compressions or rare functions is called wavelength.

4. Classification based on the limitations of motion—**Progressive** and **stationary** waves.

Some waves start at the point of origin of the waves and progress endlessly into other parts of the medium. Such waves are known as ‘Progressive waves’.

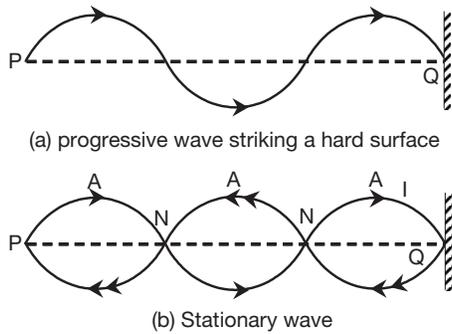


FIGURE 8.11

Consider a progressive transverse water wave moving from left (point P) to right and striking a hard surface at ‘Q’ as shown in Fig. 8.11(a). (It is called an incident wave) It then gets reflected at ‘Q’, and travels towards ‘P’. Thus, the two waves, one going from ‘P’ to ‘Q’ (It is called an incident wave) and the other going from ‘Q’ to ‘P’ called reflected wave overlap resulting in the formation of ‘nodes’ and ‘antinodes’. Points, where the displacement of a vibrating particle of the medium is zero or minimum are called ‘nodes’ (shown as N in Fig. 8.11) and points, where the displacement of the vibrating particles is maximum are called ‘antinodes’ (shown as A in Fig. 8.11). The closed figures so formed are called ‘loops’. Three loops are shown in Fig. 8.11.

On the whole, the wave appears to be standing or stationary, contained between two positions ‘P’ and ‘Q’, and so, called ‘standing’ or ‘stationary waves’.

Thus, a ‘progressive wave is a wave which is generated at a point in a medium and travels to all parts of the medium infinitely carrying the energy’ and a ‘stationary wave is a wave which is formed by a superposition of two identical progressive waves traveling in opposite directions’.

Comparative Study of Progressive and Stationary Waves

Progressive waves	Stationary waves
1. These waves start at a point and move indefinitely and infinitely to all parts of the medium or space.	1. These waves appear to be standing at a place and are confined between two points in a medium or space.
2. These waves transmit energy from one place to another.	2. These waves store energy in them.
3. The energy possessed by these waves is kinetic in nature.	3. The energy associated with these waves is potential in nature.
4. These waves contain crests and troughs or compressions and rarefactions.	4. These waves contain nodes and antinodes.
5. All the particles in the wave have equal amplitude	5. Different particles in the wave have different amplitudes.
6. There is a continuous phase difference between the particles in the wave.	6. The phase difference between the particles in a given loop in the wave is zero.
7. Distance between two consecutive crests or trough or compressions or rare fraction is λ .	7. Distance between two consecutive nodes or antinodes is $\lambda/2$. Distance between two alternate nodes or antinodes is λ .

SOUND

Sound is a form of energy. It causes sensation in our ears. It is produced by bodies which vibrate. Consider a tuning fork 'F' which is excited by hitting on a rubber hammer. When such a tuning fork is kept near our ears, we hear the sound but are unable to detect the vibrations of the tuning fork. When the fork producing sound is brought into contact with a pith ball B suspended from a rigid support by means of a thread, the ball is flicked by the fork (Fig. 8.12). The ball is flicked by the vibrations of the fork and this proves that sound is produced by vibrating bodies. However, the sound produced by all vibrating is not audible.

When we speak, sound is produced by the vibration of vocal chords present in a cavity called larynx, in our throat. Sound is transmitted in the form of mechanical waves. Thus, sound needs a medium to travel, since mechanical waves can propagate only through material medium.

Experiment to Prove that Sound Requires a Medium for Propagation

Consider an electric bell suspended in a glass jar containing an outlet. The bell is suspended from the lid (which is made of cork) of the jar through strings and there are two small holes to the lid through which electric wires are connected to the bell (Fig. 8.13). Initially, air is present in the jar and when the electric current is passed through the circuit of the bell by switching it on (switch not shown in the Fig. 8.13), the bell rings and the sound is heard, by a person standing near the jar.

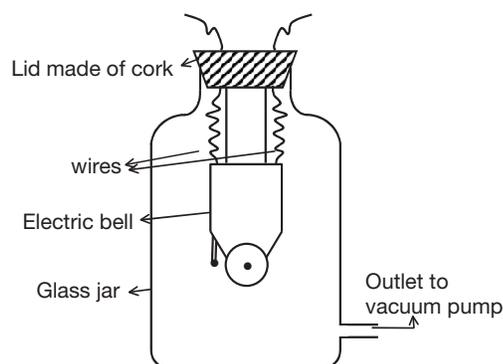


FIGURE 8.13 Bell-jar experiment

Now the jar outlet is connected to a vacuum pump and the air is removed from the jar. Thus, there is no medium surrounding the bell in the jar. If we switch on the circuit, we can see the bell ringing but the sound cannot be heard. This shows that sound cannot travel through vacuum.

Frequency (An Important Characteristic of Sound)

We know that sound is produced by a vibrating body. But we cannot sense the sounds produced by all vibrating bodies. For example, we cannot sense the sound produced by a vibrating pendulum. This is because the frequency of the pendulum is very less. We are able to sense the sounds having frequencies from 20 Hz to 20,000 Hz; and cannot sense the sounds having frequencies either less than 20 Hz or greater than 20,000 Hz. The frequency

which ranges from 20 Hz to 20,000 Hz is known as ‘**audible range**’. The sounds having frequency less than 20 Hz are known as ‘**infrasonics**’ and the sounds having frequency greater than 20,000 Hz are known as ‘**ultrasonics**’.

Uses of Ultrasonics

1. For homogenizing milk, ultrasonic waves are used.
2. These waves are used in dish washers in the process of cleaning the vessels.
3. These waves are used in ultrasound scanning technique, which is helpful in knowing the condition of the internal organs of a human body.
4. Bats are sensitive to ultrasonic waves and with the help of those waves, they can move easily in the dark.
5. Dolphins communicate with each other by using ultrasounds.
6. Dogs can hear sounds upto 40000 Hz, and hence, they can be trained to respond to these sounds using a Galton whistle, producing high frequency sounds outside the audible range for humans.

Comparison between Light Waves and Sound Waves

Light Waves	Sound Waves
1. These are electromagnetic waves and can pass through vacuum also.	1. These are mechanical waves and cannot pass through vacuum.
2. The velocity of light waves is not affected by temperature, humidity, etc.	2. The velocity of sound in air changes with temperature, humidity.
3. These waves excite the retina and produce the sense of vision.	3. These waves excite the ear drum and produce the sense of hearing.
4. These are produced due to transition of electrons from the excited state to the normal state.	4. These are produced by vibrating bodies.
5. These waves are transverse in nature.	5. These waves can be either transverse or longitudinal in nature depending on the medium in which they propagate.
6. The value of velocity of light in air is $3 \times 10^8 \text{ m s}^{-1}$.	6. The value of velocity of sound in air at normal temperature and pressure is 330 m s^{-1} . It is more in liquids and still more in solids.

Transmission of Sound

Sound can be transmitted from one place to another in the form of mechanical waves. It can be transmitted through solids and surface of liquids in the form of transverse or longitudinal waves but through gases only in the form of longitudinal waves.

Velocity of Sound

Velocity of sound in different media is different; but in a given medium its value is constant and depends mainly on two properties, namely, elasticity and density of the medium. If the medium is homogeneous, its density and elasticity do not change with direction, and so,

the velocity of sound in it remains constant. In solids, the velocity of longitudinal waves is greater than that of transverse waves. This is evident from the fact that primary shock waves produced during an earthquake which are longitudinal in nature reach the seismic station first and the secondary shock waves which are transverse in nature reach the seismic station later.

Sir Issac Newton gave a mathematical expression for the velocity of waves in an elastic medium as

$$v = \sqrt{\frac{E}{d}}$$

where ' v ', ' E ' and ' d ' are velocity of the wave in the medium, elasticity and density of the medium, respectively.

In case of solids, the elasticity is measured by its Young's modulus (Y), and so, velocity of sound in solids is given by,

$$v = \sqrt{\frac{Y}{d}}$$

When solids, liquids and gases are compared, the density is maximum in solids, comparatively less in liquids and least in gases. Yet, the velocity of sound in solids is maximum, less in liquids and least in gases. This is due to the fact that even though the density of solids is greater than that of liquids and gases, the elasticity of solids is many more times larger than that of liquids and gases.

Thus, the ratio of elasticity to density is more in solids, less in liquids and least in gases, and so, the decreasing order of velocity of sound is $v_s > v_l > v_g$ where v_s , v_l and v_g are velocity of sound in solids, liquids and gases, respectively.

In case of gases, the elasticity factor for gases is its pressure, and hence, the expression for velocity of waves in a gas was derived by Newton as

$$v = \sqrt{\frac{P}{d}}$$

where ' P ' and ' d ' are pressure and density of a given gas.

Sir Isaac Newton assumed that when a sound wave propagates through gas, the changes that take place in volume were isothermal (changes that take place at constant temperature), but it was proved to be wrong. The value of velocity of sound in a gas as presumed by Newton and calculated from his formula was found to be 280 m s^{-1} whereas its observed value by experimentation was about 330 m s^{-1} .

The expression given by Newton for the velocity of sound in a gas was modified by Laplace as

$$v = \sqrt{\frac{\gamma P}{d}}$$

where ' γ ' is a constant for a given gas and it is defined as the ratio of the specific heat capacity of the gas at constant pressure to its specific heat capacity at constant volume.

The modification was done as the changes that take place during the propagation of sound in a gas are rapid and said to be ‘adiabatic’ (changes that take place without any transfer of heat). The value of velocity of sound in air calculated using the Laplace formula coincides with the observed value obtained by experimentation. This is called Laplace’s correction.

Velocity of Sound in a Gas

- 1. Temperature:** The velocity of sound in a gas is directly proportional to the square root of its absolute or kelvin temperature.

Mathematically, $v \propto \sqrt{T}$, where v and T are the velocity of sound in a gas and its absolute temperature, respectively.

$$\therefore v = k\sqrt{T}$$

If v_1 and v_2 are the velocities of sound in a gas at absolute temperatures T_1 and T_2 , respectively, then

$$v_1 = k\sqrt{T_1} \quad \text{and} \\ v_2 = k\sqrt{T_2}$$

So,

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

- 2. Molecular weight:** The velocity of sound in a gas is inversely proportional to the square root of its molecular weight.

Mathematically,

$$v \propto \frac{1}{\sqrt{M}}$$

where ‘ v ’ is the velocity of sound in a gas and ‘ M ’ is its molecular weight.

If v_1 and v_2 are the velocities of sound in two gases whose molecular weights are M_1 and M_2 at a constant temperature, then

$$\frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}}$$

- 3. Density:** The velocity of sound in gas is inversely proportional to the square root of its density.

Mathematically

$$v \propto \frac{1}{\sqrt{d}}$$

where ‘ v ’ and ‘ d ’ are the velocity of sound in a gas and its density, respectively. If ‘ v_1 ’ and ‘ v_2 ’ are the velocities of sound in two gases whose densities are ‘ d_1 ’ and ‘ d_2 ’, respectively, at a constant temperature, then

$$\frac{v_1}{v_2} = \sqrt{\frac{d_2}{d_1}}$$

Factors that Affect Velocity of Sound in Air

- 1. Temperature:** The velocity of sound in air is directly proportional to the square root of its absolute temperature.

Mathematically, $v \propto \sqrt{T}$. So, if v_1 and v_2 are the velocities of sound in air at temperatures

T_1 and T_2 Kelvin, then

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

On simplification, we get $v_t = v_o$

$$\left(1 + \frac{t}{546}\right)$$

where v_o and v_t are the velocities of sound in air at 0°C and at $t^\circ\text{C}$, respectively. Thus, the velocity of sound in air increases by approximately 0.61 m s^{-1} for 1°C rise in its temperature.

- 2. Density:** The velocity of sound in air varies inversely as the square root of its density. Mathematically,

$$v \propto \frac{1}{\sqrt{d}}$$

So, if v_1 and v_2 are the velocities of sound in air at densities ' d_1 ' and ' d_2 ', then

$$\frac{v_1}{v_2} = \sqrt{\frac{d_2}{d_1}}$$

- 3. Humidity:** Humidity is the percentage of water vapour present in air. As the humidity increases, the percentage of water vapour in air increases and this decreases the density of air resulting in the increase of velocity of sound. So, increase in the humidity of air, increases the velocity of sound in air.
- 4. Wind:** Air in motion is called wind. So, depending on the direction of wind the velocity of sound would either increase or decrease. If wind blows in the direction of sound propagation, the velocity of sound increases. If the wind blows opposite to sound propagation, the velocity of sound decreases.

Factors that do not Affect the Velocity of Sound in Air

- 1. Amplitude:** Velocity of sound does not depend on the amplitude of the vibrations.
- 2. Frequency (n):** Velocity of sound in air or any other medium does not depend on its frequency. We know that $v = n\lambda$. As the frequency (n) increases, its wavelength (λ) decreases but does not affect the velocity of the wave.
- 3. Wavelength (λ):** The velocity of sound in air or any other medium does not depend on its wavelength (λ)

4. **Pressure:** The velocity of sound in air or any gas is given by,

$$v = \sqrt{\frac{\gamma P}{d}}$$

where ' γ ' is a constant, ' P ' is the pressure and ' d ' is the density. When the pressure of a gas is changed, (keeping its temperature constant) its density also changes such that the ratio ' P/d ' is always a constant. Hence, the variation of pressure of a gas does not affect the velocity of sound in it.

DOPPLER EFFECT

When a train approaches a station at high speed while blowing the horn, for a person standing on the platform, the frequency of the horn would appear to be different from the real frequency. The pitch of the sound appears to increase when the train approaches an observer, and appears to be lower than its true pitch when the train passes by and moves away from the observer.

Similarly, while traveling in a vehicle towards a factory blowing the siren, changes in the frequency of the sound produced can be observed. This phenomenon of apparent change in the frequency of sound whenever there is a relative motion between the source of sound and the observer, is called Doppler Effect.

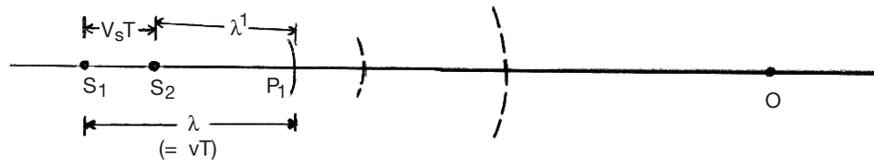


FIGURE 8.14

Consider a train (source of sound) at S_1 , moving with a uniform velocity v_s towards an observer at O as shown in the Fig. 8.14.

Let v be the velocity of sound and λ be its wavelength. T is the time period of sound wave, i.e., the time interval between the generation of two waves, then the distance traveled by the first wave in T seconds would be $S_1P_1 (= vT)$ which is equal to the real wavelength λ . During this time, the train would move a distance of $S_1S_2 (= v_s T)$. Thus, the next wave would be generated at S_2 instead at S_1 and the apparent wavelength would be $S_2P_1 (\lambda^1)$.

$$\begin{aligned} \therefore \text{Apparent wavelength, } \lambda^1 &= S_2P_1 \\ &= S_1P_1 - S_1S_2 \\ &= vT - v_s T \\ &= T(v - v_s) \\ &= \frac{v - v_s}{n} \end{aligned}$$

where ' n ' is the real frequency which is the reciprocal of the time period.

But the velocity of sound v remains constant.

$$\begin{aligned}\therefore v &= n\lambda = n^1\lambda^1 \\ \lambda^1 &= \frac{v}{n^1} \\ \therefore \frac{v}{n^1} &= \frac{v - v_S}{n} \\ n^1 &= n \left[\frac{V}{V - V_S} \right]\end{aligned}$$

Thus, when the source is moving towards a stationary observer, the frequency of the sound heard increases. The following table gives the expressions for each of the other cases where either the source or the observer is moving towards/away from the other.

Velocity of source	Velocity of observer	Apparent frequency	
$-v_S$	zero	$n \left[\frac{V}{V - V_S} \right]$	Source moving towards the stationary observer
$+v_S$	zero	$n \left[\frac{V}{V + V_S} \right]$	Source moving away from the stationary observer
Zero	$+v_O$	$n \left[\frac{V + V_O}{V} \right]$	Observer moving towards the stationary source
Zero	$-v_O$	$n \left[\frac{V - V_O}{V} \right]$	Observer moving away from the stationary source

When v = velocity of sound in air.

In general the ratio of apparent frequency to real frequency is the ratio of velocity of sound with respect to the observer to that with respect to the source.

MACH NUMBER AND SONIC BOOM

From the concept of Doppler effect, we understand that the speed of a moving object as compared to the speed of sound in the surrounding medium is important. The speed of sound at sea level at 15° C is about 340.3 m s⁻¹ (1225 km h⁻¹). Generally, vehicles moving on land have speeds much less than this value. The fastest French TGV recorded a speed of 574.8 km h⁻¹ (160 m s⁻¹). The Japanese maglev trains too have claimed speeds in this range.

However, an aircraft can travel at much higher speeds. While studying the aerodynamics of objects moving at higher speeds, it would be important to consider the ratio of the speed of the moving object to that of sound in the surrounding air (fluid). This ratio is called mach number in honour of an Austrian physicist Ernst Mach.

$$\text{Mach number, } M = \frac{\text{Velocity of the object}}{\text{Velocity of sound in the surrounding medium}}$$

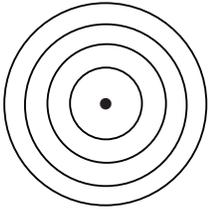


FIGURE 8.15

Consider a stationary source A (Mach number, $M = 0$). The sound waves produced would be concentric spheres as shown in Fig. 8.15.

Now if the source of sound moves with a velocity V_S less than the velocity of sound V (Mach number $M < 1$), the spherical wave compressions would be shifted in the direction of motion of the source. (Fig. 8.16)

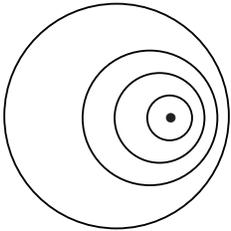


FIGURE 8.16

However, if the source travels at the speed of sound corresponding to Mach number $M = 1$, the wavefronts would be bunched together at the object as shown in the Fig. 8.17. In this case, the sound waves would reach the observer along with the source. Thus, the sound cannot be heard until the source reaches him.

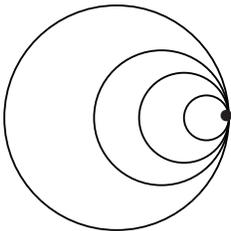


FIGURE 8.17

If the source travels at a speed greater than the speed of sound, when the corresponding Mach number, M is greater than 1, the source precedes the sound produced by it and the wavefronts lagging behind the source would form a cone as shown in Fig. 8.18. Thus, as the source has passed the observer, wavefronts (compressions) coming from opposite directions would produce an intense thumping sound.

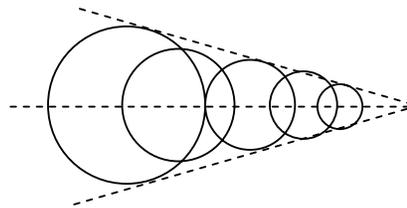


FIGURE 8.18

This sound of high intensity is called sonic boom. The thunder is an example of a sonic boom we observe in nature. Such sonic boom would cause the rattling of doors, windows and other objects.

Speeds less than $M = 1$ are called subsonic, speeds at $M = 1$ are called transonic and speeds greater than $M = 1$ are called supersonic.

VIBRATIONS

We have seen that vibrating bodies produce sound and vibrations in the audibility range (20 Hz to 20 kHz) only are heard by humans. The vibrations produced in bodies are generally of two types—free vibrations and forced vibrations. The oscillations of a vibrating spring, a simple pendulum and a vibrating tuning fork are examples of free or natural vibrations.

Natural Vibrations

When an object is set into oscillations and left on its own, it begins to vibrate with a certain characteristic frequency. This frequency is independent of cause of oscillation and it depends on the characteristics of the object like elasticity, size, etc. This is called natural frequency of the object and the vibrations are called natural vibrations.

Example:

1. vibrations of a stretched string
2. oscillations of a swing, etc.

When the strings of a string instrument such as a violin, veena, sitar, etc., vibrate, the sound box and the air in the sound box also vibrate. Such vibrations are examples of forced vibrations in which the vibrations of one body vibrating at its natural frequency induce vibrations in another body. The frequency of the forced vibrations in the second body may or may not match its natural frequency.

FORCED OSCILLATIONS

If a periodic force is used to set an object into oscillations, then the object starts oscillating with the same frequency as that of the applied periodic force. Such vibrations are called forced vibrations/oscillation.

Example: The vibrations of air in the sound box of musical instruments is an example of forced vibrations.

The forced oscillations take place by the transfer of energy from source to the object. This transfer of energy can be maximum when the natural frequency of an object is equal to that of the applied force.

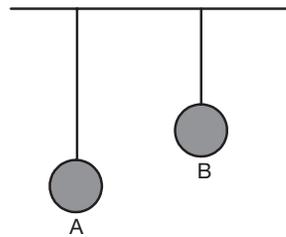


FIGURE 8.19

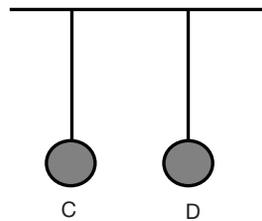


FIGURE 8.20

Example: Consider two arrangements as shown in Figs. 8.19 and 8.20 above. In Fig. 8.19 the two pendulums A and B have different lengths, and thus, their natural frequencies are different. In Fig. 8.20, the two pendulums C and D possess same natural frequencies. Better to use 'pendula' rather than pendulums.

When the pendulums A and C are set into oscillations, the pendulums B and D also starts oscillating. But the pendulum D is observed to oscillate with a larger amplitude. This happens because of maximum transformation of energy from C to D. This phenomenon is called **resonance**.

Resonance is a special case of forced oscillations. When the natural frequency of an object matches with that of the applied force, the object vibrates with a larger amplitude. This is called **resonance**.

Example: Consider two sound boxes facing each other as shown in Fig. 8.21. Place one tuning fork on each sound box. Excite one of the tuning forks with a rubber hammer. Then, it can be observed that the tuning fork on the other box also vibrates. The sound produced by the second tuning fork will be maximum if its frequency is same as that of the excited tuning fork. The vibrations of second tuning fork are called 'sympathetic vibrations'. If a pith ball is suspended close to the second tuning fork, it is flicked away indicating the forced vibrations in the second tuning fork.

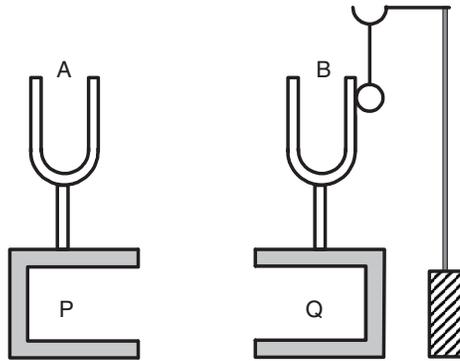


FIGURE 8.21 Resonance in sound boxes

Reflection of Sound Waves to Form Stationary Waves

Sound wave is nothing but a pressure wave which can reflect if there exists any discontinuity in its path. The reflection of sound wave at a rigid obstruction is different from the reflection at the interface of two layers of different densities.

Reflection at Rigid (Denser) End

When a sound wave strikes a rigid end, it reflects back and interferes with the incoming wave. This leads to a zero displacement in the particles close to the rigid wall. A node is, therefore, always formed at the rigid end. Thus, at rigid boundary a compression is reflected back as a compression and rarefaction is reflected as a rarefaction.

Reflection at Rarer Boundary

Consider a small narrow, open tube, when a pressure wave is produced at one end, on reaching the other end it reflects back with a phase change of π radians forming an antinode at the open end. Thus, at an open end, a rarefaction is reflected back as a compression and vice versa.

If any air column enclosed in an open end tube or closed end tube is made to vibrate, a standing wave will be formed because of superposition of reflected waves over the incident waves.

ORGAN PIPE

Organ pipe is a narrow tube with a mouth piece, and a leaf. When air is blown through the mouth piece, the leaf vibrates and creates vibrations in the air column.

Stationary Waves in an Open end Pipe

When the air is blown through an open pipe, the vibrations produced in the air column reflect back at the open end with a phase change of π radians. Always an antinode forms at the open end.

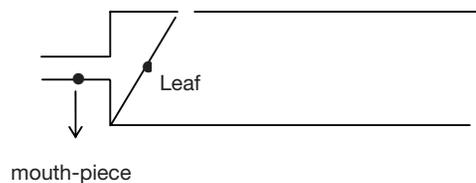


FIGURE 8.22

Thus, when a sound wave is allowed to pass through a narrow tube, open at both the ends, the air column vibrates with all possible modes in which antinodes are formed at the open ends.

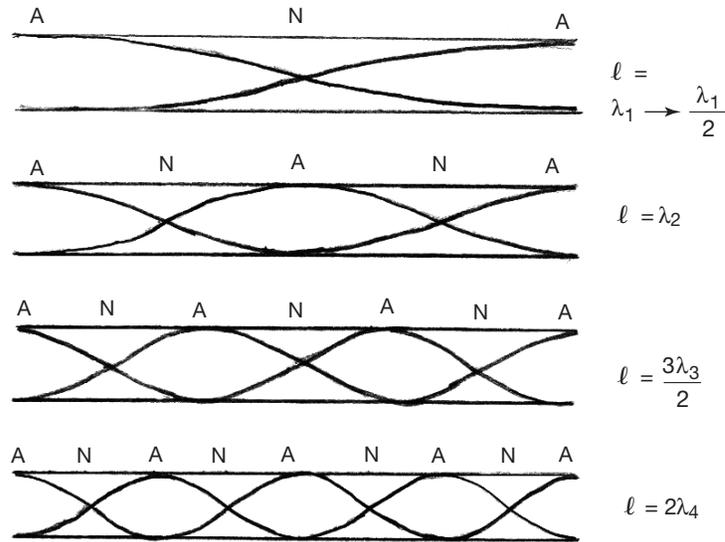


FIGURE 8.23 Modes of Vibrations in an Open Pipe

1st harmonic

$$\frac{\lambda_1}{2} = l$$

$$\lambda_1 = 2l$$

2nd harmonic

$$\lambda_2 = l$$

3rd harmonic

$$\frac{3\lambda_3}{2} = l$$

$$\Rightarrow \lambda_3 = \frac{2l}{3}$$

4th harmonic

$$2\lambda_4 = l$$

$$\Rightarrow \lambda_4 = \frac{l}{2}$$

Frequency of Fundamental Mode

In fundamental mode of vibration,

$$\lambda_1 = 2l$$

Let ' v ' be the velocity of wave. Then, frequency n_1 is given by,

$$n_1 = \frac{v}{\lambda_1} = \frac{v}{2l}$$

First Overtone (or) Second Harmonic

Wavelength, $\lambda_2 = \ell$
 \Rightarrow frequency of first overtone

$$n_2 = \frac{v}{\ell} \left(\because n = \frac{v}{\lambda} \right)$$

$$\Rightarrow n_2 = 2 \left(\frac{v}{2\ell} \right) = 2n_1$$

Second Overtone (or) Third Harmonic

Wavelength, $\lambda_3 = \frac{2\ell}{3}$
 Frequency, $n_3 = \frac{v}{\lambda_3} = \frac{3v}{2\ell} = 3n_1$
 $\Rightarrow n_3 = 3n_1$

Frequency of p th harmonic (or) $(p - 1)$ th overtone is, $n_p = pn_1$

$$n_p = p \left(\frac{v}{2\ell} \right)$$

\therefore In an open pipe,

$$n_1 : n_2 : n_3 : n_4 \dots = 1 : 2 : 3 : 4 : \dots$$

Stationary Waves Formed in Closed End Organ Pipe

Organ Pipe

The vibrations produced in the air column reflect back without change in phase and always a node forms at this end, but at the open end an antinode is formed.

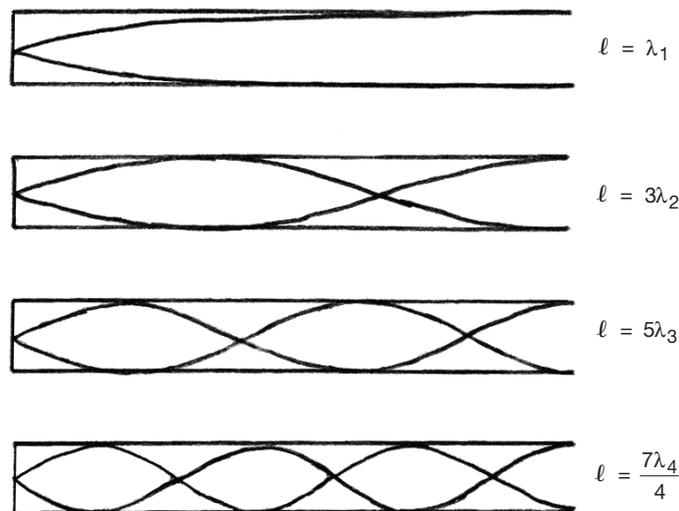


FIGURE 8.24 Modes of Vibrations in closed Pipes

Fundamental mode:

$$\frac{\lambda_1}{4} = \ell \Rightarrow \lambda_1 = 4\ell$$

First overtone:

$$\frac{3\lambda_2}{4} = \ell \Rightarrow \lambda_2 = \frac{4\ell}{3}$$

Second overtone,

$$\frac{5\lambda_3}{4} = \ell \Rightarrow \lambda_3 = \frac{4\ell}{5}$$

Third overtone:

$$\frac{7\lambda_4}{4} = \ell \Rightarrow \lambda_4 = \frac{4\ell}{7}$$

Fundamental Frequency

Wavelength of first harmonic, $\lambda_1 = 4\ell$

Frequency, $n_1 = \frac{v}{4\ell}$

First Overtone or Second Harmonic

Wavelength, $\lambda_2 = \frac{4\ell}{3}$

Frequency, $n_2 = \frac{3v}{4\ell} = 3\left(\frac{v}{4\ell}\right) = 3n_1 \Rightarrow n_2 = 3n_1$

Second Overtone or Third Harmonic

Wavelength, $\lambda_3 = \frac{4\ell}{5}$

Frequency, $n_3 = \frac{5v}{4\ell} = 5\left(\frac{v}{4\ell}\right) = 5n_1 \Rightarrow n_3 = 5n_1$

Similarly, frequency of the p th overtone or $(p + 1)$ th harmonic is

$$n_{p+1} = (2p + 1)n_1 = (2p + 1)\left(\frac{v}{4\ell}\right)$$

The resonance can occur when the frequency of the vibrating air column matches the frequency of the tuning fork.

Thus, the first resonance occurs when the length of air column $\ell_1 = \frac{\lambda}{4}$

The second resonating length, $l_2 = \frac{3\lambda}{4}$

$$l_2 - l_1 = \frac{3\lambda}{4} - \frac{\lambda}{4} = \frac{2\lambda}{4} = \frac{\lambda}{2}$$

$$\Rightarrow \lambda = 2(l_2 - l_1)$$

$$\therefore v = n\lambda$$

$$\Rightarrow v = n \times 2(l_2 - l_1)$$

$$\Rightarrow v = 2n(l_2 - l_1)$$

Formation of Stationary Waves Along a Stretched String

On plucking, strings of a veena produce musical notes. When a string is plucked at different positions, it vibrates with different frequencies and produces notes of different pitch. When the stretched string is plucked, a stationary, transverse wave is produced in the string. Depending on the position of plucking, the string vibrates in different modes. These different modes are called harmonics. As the ends of string are tied rigidly, the ends always correspond to nodes.

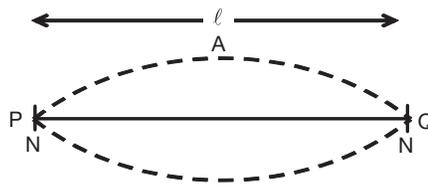


FIGURE 8.25 Stationary waves in strings; string vibrating in fundamental mode

When the string is plucked at the centre, it vibrates with one loop as shown in Fig. 8.25. When it is plucked at one-fourth of its length, it vibrates with two loops (Fig. 8.26) and when it is plucked at one-sixth of its length, it vibrates with three loops as shown in Fig. 8.27. Of all the possible modes of vibrations, a string possesses minimum frequency when it vibrates with a single loop. This mode is called fundamental mode of vibration. The frequency of all the other possible modes are integral multiples of the fundamental frequency. These are called overtones.

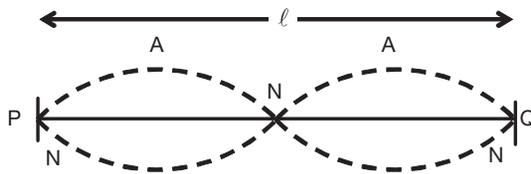


FIGURE 8.26 String vibrating in second harmonic

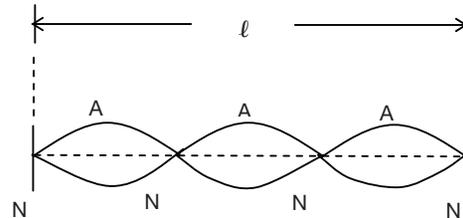


FIGURE 8.27

FUNDAMENTAL NOTE

When the string vibrates with a single loop, it is called fundamental mode or first harmonic. In this mode of vibration, the wavelength of the note produced will be twice its length.

$$\lambda = 2l$$

Velocity of wave = $v = n_1 \lambda_1$

$$\Rightarrow n_1 = \frac{v}{\lambda_1} = \frac{v}{2\ell}$$

$$n_1 = \frac{v}{2\ell}$$

is called fundamental frequency.

First Overtone (or) Second Harmonic

In this mode of vibration the string vibrates with two loops. Thus,

$$\begin{aligned}\lambda_2 &= \ell \\ n_2 &= \frac{v}{\lambda} = 2 \frac{v}{2\ell} \\ &= 2n_1 \\ n_2 &= 2n_1\end{aligned}$$

Third Harmonic (or) Second Overtone

In this mode of vibration, (see Fig. 8.27) string vibrates with three loops, where

$$\begin{aligned}\lambda_3 &= \frac{2\ell}{3} \\ n_3 &= \frac{3v}{2\ell} = 3n_1 \\ n_3 &= 3n_1\end{aligned}$$

Thus, in general, the frequency of the p th harmonic can be written as $n_p = pn_1 = p(v/2\ell)$. The fundamental frequency of a stretched string depends on the tension in string, length and linear density of the string.

LAWS OF VIBRATIONS OF A STRETCHED STRING

Law of Tension

The fundamental frequency of a stretched string varies directly with the square root of the tension in it, while its length and linear mass densities are kept constant, i.e.,

$$n_1 \propto \sqrt{T}$$

Law of Linear Mass Density

Mass per unit length of a string is called linear mass density. Its S.I. unit is kgm^{-1} . The fundamental frequency of a stretched string varies inversely with the square root of the linear mass density (m) of the string, while its length and tension are maintained constant, i.e.,

$$n_1 \propto \frac{1}{\sqrt{m}}$$

Law of length

The fundamental frequency of a stretched string is inversely proportional to its length, while the linear mass density and the tension in it are kept constant, i.e.,

$$n_1 \propto \frac{1}{\ell}$$

Thus,

$$n_1 \propto \sqrt{T}$$

$$\propto \frac{1}{\sqrt{m}}$$

$$\propto \frac{1}{\ell}$$

\Rightarrow fundamental frequency of a stretched string, $n_1 \propto \frac{1}{\ell} \sqrt{\frac{T}{m}}$

It can be proved that

$$n_1 = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$$

These laws of vibrations of a stretched string can be verified with the help of an instrument called sonometer.

Sonometer

It consists of a hollow wooden box B with holes on its lateral sides. Through these holes, air can flow freely. At one of its ends, a peg is arranged to which a uniform metal wire is tied. The other end of the wire passes over a frictionless pulley. Two wooden bridges B_1 and B_2 are used to change the vibrating length of the wire.

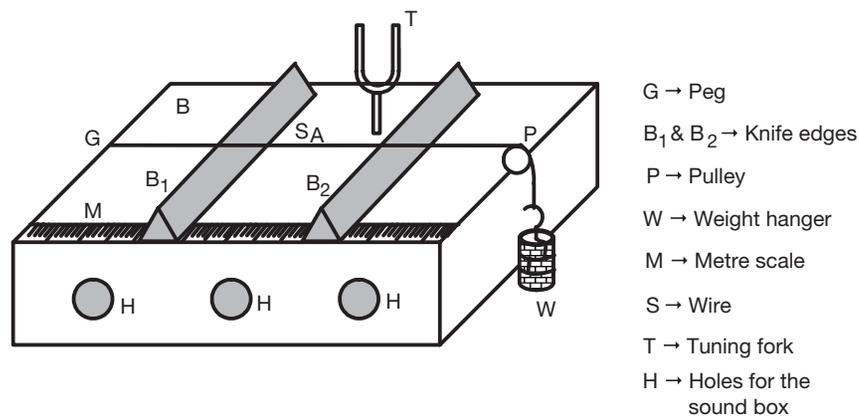


FIGURE 8.28 Sonometer

The wire of this sonometer can be allowed to vibrate forcibly by using a vibrating tuning fork. If the natural (fundamental) frequency of vibrating length of the string between two knife edges is same as that of the tuning fork used, then it starts vibrating with maximum amplitude, i.e., resonance occurs. If a paper rider is placed at the centre of vibrating portion of the string, then in resonating state, it is thrown off from the string.

LAW OF LENGTH

This law can be verified experimentally by using a sonometer. During the experiment the string tied to sonometer and weight suspended from it should not be changed. Adjust the two knife edges close to each other and place the stem of a vibrating tuning fork of known frequency (n) on the box of the sonometer. The distance between the two knife edges are varied till the resonance occur, i.e., until the paper rider placed at centre of string is thrown off the string. Now note down the vibrating length (ℓ) of the string. Same procedure can be repeated with different tuning forks to determine the corresponding resonating length(ℓ) of the string. On calculating product of ' n ' and ' ℓ ' in each case, it can be observed that the value of ' $n \times \ell$ ' remains the same in all cases.

Thus,
$$n\ell = \text{constant}$$

$$\Rightarrow n \propto \frac{1}{\ell}$$

S.No.	frequency of tuning fork(n) in Hz	resonating length(ℓ) in m	$n \times \ell$ Hz m

LAW OF TENSION

We have
$$n \propto \frac{1}{\ell} \sqrt{\frac{T}{m}}$$

If n and m are maintained constant, (\sqrt{T} / ℓ) will be a constant.

Thus, the law of tension can be proved by proving (\sqrt{T} / ℓ) is a constant.

Suspend a known weight [$W = T$] from the free end of string, excite a tuning fork of known frequency and keep it on the sonometer box. Adjust the knife edges till resonance occurs and note down the resonating length(ℓ). Increase the weight in regular steps and note down the resonating length(ℓ) in each case using the same tuning fork.

S.No	Tension in string $T =$ weight suspended (N)	Resonating length (ℓ) m	$\frac{\sqrt{T}}{\ell} = \text{constant}$

LAW OF MASS

It can be proved by proving that $\ell\sqrt{m}$ is a constant. During the experiment the weight suspended from the string should be constant. Experiment can be carried out by using strings of different lengths, mass and materials and finding out the resonating lengths for a tuning fork of known frequency.

Tension, $T = \text{constant}$

Frequency, $n = \text{constant}$

As $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$, it implies that $\ell\sqrt{m} = \text{constant}$.

S.No.	Linear mass density of string (m) kgm^{-1}	Resonating length (ℓ) m	$\ell\sqrt{m}$

Thus, sonometer can be used to verify the laws of transverse waves in a stretched string.

REFLECTION OF SOUND

Sound waves, like other mechanical waves and light waves (electromagnetic waves), undergo reflection when they strike a hard, smooth surface. This reflection of sound obeys the laws of reflection, which is demonstrated in the following activity.

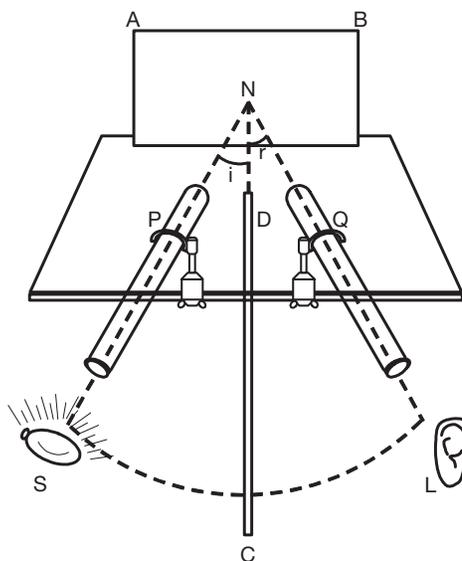


FIGURE 8.29 Reflection of Sound

A hard, smooth surface is mounted vertically over a horizontal board on which two tubes P and Q, pointing towards the surface AB are clamped as shown in the Fig. 8.29. The sound waves from a source, like a ticking clock, are directed to the surface AB through the pipe P inclined at an angle to AB. The tube Q is adjusted such that the listener at L would be able to hear the ticking of the clock clearly. The board CD acts as a screen to prevent the sound waves from the source being heard directly by the listener. By measuring the angles the tubes make with the surface AB, the following can be verified.

1. Angle of incidence is equal to the angle of reflection.
2. The incident wave SN and the reflected wave NL are on the same plane.

SOME PRACTICAL APPLICATIONS OF REFLECTION OF SOUND

Mega Phone or Loud Speaker

The main part of the mega phone or the loudspeaker is a horn shaped tube. This tube prevents the spreading of sound waves in all directions. The sound entering in tube undergoes multiple reflections and comes out of the tube with a high directionality and it can propagate longer distances.

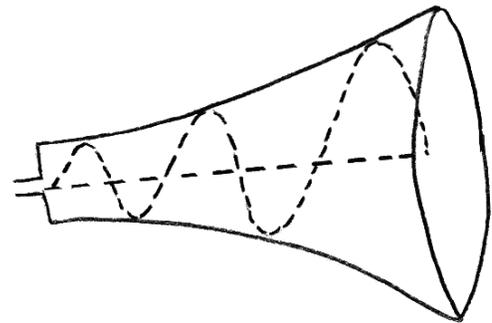


FIGURE 8.30 Mega phone

Hearing Aid

The hearing aid used by the persons who are hard of hearing is also called ear trumpet. The sound enters hearing aid or the trumpet through a narrow opening and undergoes multiple reflections and comes out from the wide end with a large amplitude.

Sound Boards

These boards are very useful for the uniform spreading of sound in big auditoria, etc. If any sound is produced at the focus of concave reflector, it can be reflected back as parallel waves, and thus, the sound distributes uniformly.

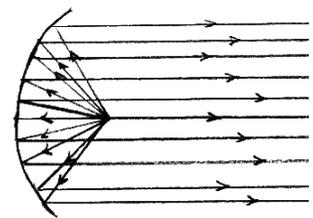


FIGURE 8.31 Sound board

Whispering Gallery

Whispering gallery is a big circular hall. Around a big round pillar a dome is constructed. If a person whispers near the pillar, the sound undergoes multiple reflections and can be heard throughout the hall.

Sonar

It is an abbreviation for 'Sound Navigation and Ranging'. It is a special technique which is used in ships to calculate the depth of ocean beds and several other purposes. The main principle used in SONAR is reflection of sound.

At the bottom of a ship two devices, one for the production of ultrasonics and the other for the detection of the reflected ultrasonics from the ocean bed are fixed as shown in Fig. 8.32.

If ' v ' is the velocity of ultrasonics in the ocean water and ' t ' is the time taken to receive the reflected ultrasonics from the ocean bed, the depth of the ocean bed can be found by $d = \frac{vt}{2}$.

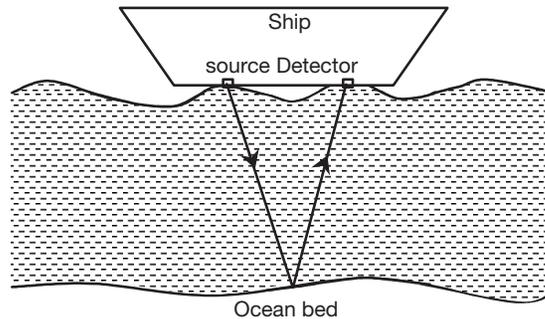


FIGURE 8.32 Working of sonar

Echo

When a sound wave strikes a smooth and hard surface, it is reflected back to the listener. The repetition of sound a short time after it is produced is called 'echo'. When a person claps standing in front of a reflecting surface like a big wall, he will hear two sounds; viz, one produced by him and the other one which is reflected from the wall surface. In order to distinguish between these two sounds, a time gap of at least 0.1 second (which is known as **persistence of hearing**) is required.

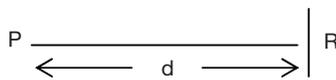


FIGURE 8.33 Echo

If the time gap is less than 0.1 second, the person will not be able to hear the echo. If ' v ' is the velocity of sound in air at a given temperature, ' d ' is the distance between the source of sound (the person) ' P ', and the reflector ' R ' of sound Fig. 8.33, the time taken to hear the echo is ' t ' seconds, then from Fig. 8.33,

we get
$$v = \frac{2d}{t} \text{ or } d = \frac{vt}{2}$$

If $t = 0.1$ second, then
$$d = \frac{v \times 0.1}{2} = \frac{v}{20}$$

Thus, the minimum distance required to hear an echo is 1/20th part of the magnitude of the velocity of sound in air. If we take the velocity of sound as 330 m s^{-1} , this minimum distance would be 16.5 m.

Determination of Velocity of Sound Using an Echo

Consider a person standing at P in front of a hill or a big wall and producing a sound (Fig. 8.34). Let ' t_1 ' be the time taken to hear an echo. Now the person moves towards the reflector by a distance ' d ' to a position Q and again produces a sound. Now, the echo is heard after ' t_2 ' time. From the Fig. 8.34,

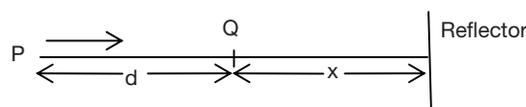


FIGURE 8.34

we have,
$$v = \frac{2(d+x)}{t_1} \text{ and } v = \frac{2x}{t_2}$$

$$\therefore 2(d+x) = vt_1 \text{ and } 2x = vt_2$$

$$\therefore 2d + 2x = vt_1$$

Eliminating x , we have $2d + vt_2 = vt_1$

$$\therefore vt_1 - vt_2 = 2d$$

or
$$v = \frac{2d}{t_2 - t_1}$$

If the initial and final positions of the person are 'Q' and 'P' and ' t_1 ' and ' t_2 ' are the time intervals to hear the echo at these positions, respectively, then $v = \frac{2d}{t_2 - t_1}$.

Reverberation

If sound is produced by a source 'S' in a closed enclosure as shown in the Fig. 8.35, the observer of sound 'O', can hear the sound directly coming from the source and also reflected from the roof or walls of the enclosure. If the reflections are multiple, the observer continues to hear the sound even after the source of sound has stopped producing the sound.

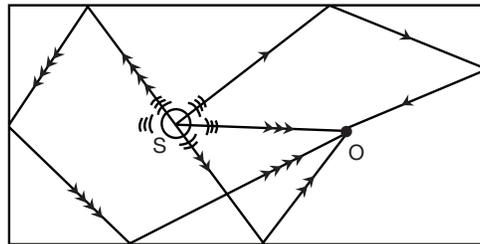


FIGURE 8.35 Reverberation

This persistence of sound in a closed enclosure, due to continuous reflections at the walls or the floor or the ceiling of the enclosure, even after the source has stopped producing sound is known as 'reverberation'.

Acoustics of Buildings

In theatres, auditoria, big halls, etc., the reverberation of sound is a common problem. Due to this, the music or the speech rendered becomes uninteresting or unintelligible. The reverberation of sound can be optimized by taking certain precautions while the theatres are being constructed.

1. The wall of the hall should be covered with some absorbing material like wallpaper or the walls should be painted to make it rough.
2. There should not be any concave reflectors in the halls.
3. The stairs, seats should be covered with absorbing materials.
4. The windows, doors, etc., should be provided with thick curtains, or windows should be provided with double or triple doors.

Recording and Reproduction of Sound

In the nineteenth century even as the technology of photography and production of movies had developed the recording and reproduction of voices and music remained unknown and unexplored for several years. The credit of the first successful attempt to record and reproduce sounds goes to Thomas Alva Edison, an American inventor, who in 1877 designed and patented phonograph a device having the sounds recorded on a cylinder. Major technological developments led to the invention of gramophone disc.

The sound recording and reproduction is the creation of mechanical or electrical impressions of the sound waves. The two main classes of sound recording are analog and digital recording. Gramophone discs and magnetic tapes are examples of analog recording whereas CD's, DVD's, Apple iPod, etc., are examples of digital recording.

The analog recording and reproduction is based on the principle of electromagnetic induction. Sound waves are converted to mechanical vibrations of a needle called stylus through induction coils. The stylus rests on a rotating zinc disc coated with a compound of beeswax in a solution of benzyne. The vibrations of the stylus produces indentations on the wax coated disc. This wax disc is then washed in a bath of chromic acid which etches a groove in the disc where the stylus removed the wax.

For reproduction of the recorded sound the stylus is allowed to run in the etched groove of the rotating disc. The vibrating stylus attached to the diaphragm of a loudspeaker reproduces the sound recorded on the disc.

Magnetic Tapes

Recording and reproduction of sound on magnetic tapes was first developed by the Germans who initially used paper-based tapes. A magnetic tape basically consists of a thin plastic strip with a coating of magnetic material. Fritz Pflemmer (1926) was the first to successfully design and construct a magnetic tape recorder with iron oxide coating on a long strip of paper.

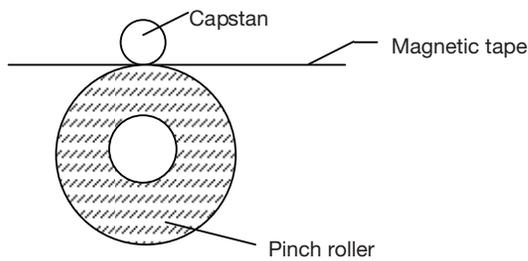
The basic principle of audio-tape is electromagnetism. An electromagnet of the size of a tamarind seed consists of an iron core wrapped with a thin wire. Electrical signals generated by the audio-signals produce a fringe pattern of magnetic flux as shown in the Fig. 8.36.



FIGURE 8.36

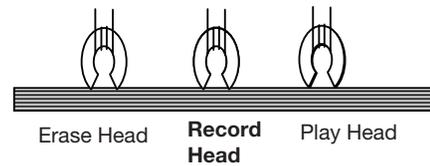
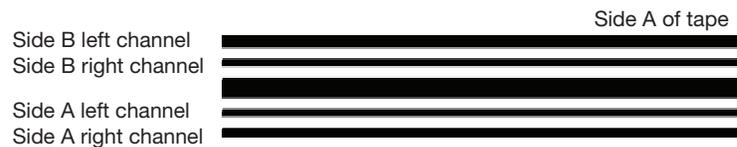
This varying fringe flux causes the magnetic molecules of oxide coating to rearrange themselves in accordance with the flux. Thus, the magnetic tape 'remembers' the sounds recorded on it.

During playback the movement of the tape with reoriented magnetic molecules on the tape induces varying magnetic field in the electromagnet. This in turn induces an electrical signal in the coil which is converted into sound signal in the loudspeaker. The constant speed of the tape (4.67 cm s^{-1}) is maintained with the help of a capstan-pinch roller combination as shown in the Fig. 8.37.

**FIGURE 8.37**

The pinch roller is generally made of rubber which keeps the tape pressed against the capstan. Generally a tape recorder player consists of three 'heads' (electromagnets)—the erase head, player head and recording head.

The erase head precedes the record head. The strong high frequency alternating current erases the magnetic patterns formed previously on the tape. For complete erasure of the magnetic patterns the gap in the erase head is wider so that the tape takes time to pass it.

**FIGURE 8.38****FIGURE 8.39**

Normally, in a cassette player two electromagnets, together half as wide as the tape, are placed as a pair. This pair of record heads produce the two channels of a stereo-track program. When the cassette is turned over in the player, the other half of the tape is aligned with the head.

Recording of Sound on Motion Picture Films

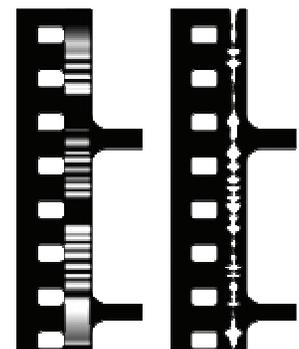
In the early 20th century the technology of recording sound on film along with the optical images revolutionized the film industry.

If you take a close look at the motion picture film, you would observe along the sprocket holes on one edge a dark strip with the wavy pattern of bright patch. This forms the optical image of the sound track. Generally, two methods are adopted for optical recording of the sound track.

1. Variable density recording which uses changes in the darkness of the film.
2. Variable area recording which uses change in the width of the dark strip to represent the soundtrack.

The Process of Recording

A narrow beam of light is reflected on to the film by a mirror attached to a phosphor—bronze coil. The varying intensity of sound is converted through a microscope to varying electrical signals which pass through the phosphor bronze coil. These variations in the electrical current through the coil produces vibrations in the coil which is placed between the poles of a powerful electromagnet, and the width of the strip on

**FIGURE 8.40**

the film is altered, thus, producing an optical image of the sound track.

Playback of the Sound Track

Light passing through the part of the film corresponding to the sound track is detected by a high sensitive electrical device and is converted into an electric signal which is converted into sound in a loudspeaker.

Human Ear

Like the human eye gives us the sensation of vision or sight, the human ear is a sense organ enabling us to hear the sounds produced in the surroundings. Just as the optical images produced on the retina are conveyed to the brain by the optic nerve, the sound waves are sensed by the delicate parts in the ear and is conveyed to the brain by the auditory nerve.

To understand the process involved in hearing, let us study the internal structure of the ear.

The human ear as shown in the Fig. 8.41 here is divided into three parts—the outer ear, the middle ear and the inner ear.

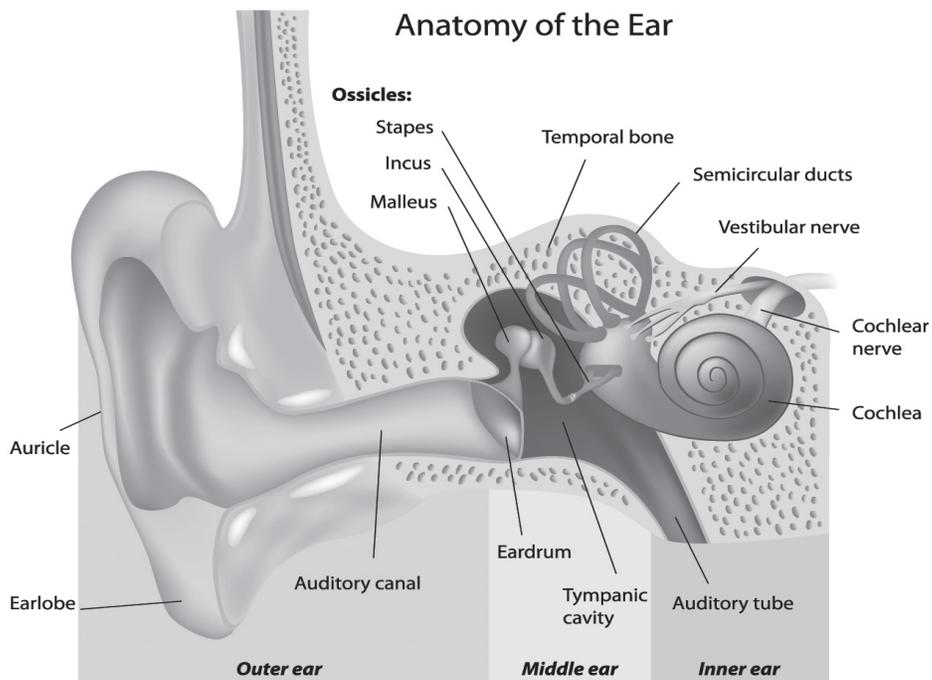


FIGURE 8.41

As we know sound is transmitted as longitudinal waves consisting of compressions and rarefactions. The pinna of the outer ear helps in diverting these compression/rarefactions to the eardrum through the ear canal or auditory canal which too is a part of the outer ear. The eardrum, also known as tympanic membrane forms the gateway to the middle ear. It is lightly stretched membrane of about 0.8×10^{-4} m thick.

The thin and delicate ear drum has another delicate bone attached to it, which is the first of the three bones constituting the middle ear. The first, called hammer, is in contact with the eardrum at one end and the anvil, the second bone at the other end.

The compressions and rarefactions of the external sound make the ear drum to vibrate and these vibrations are conveyed through the anvil to the third bone called stirrup which is in contact with the oval window leading to the inner ear. The middle ear is connected to the throat through the eustachian tube for equalising the pressure on either side of the eardrum.

The inner ear consists of the spiral shaped cochlea containing a fluid. The minute vibrations of the oval window coming from the outer and middle ears agitate this fluid causing the hair-like projections on a membrane in the cochlea to vibrate. The resonant vibrations of the hair-like structures generate signals in the auditory nerve connected to the brain to be interpreted as sounds with corresponding frequencies.

EXAMPLE

A source of longitudinal waves vibrates 320 times in two seconds. If the velocity of this wave in the air is 240 m s^{-1} , find the wavelength of the wave.

SOLUTION

Velocity of wave, $v = 240 \text{ m s}^{-1}$

Frequency of the wave, $n = \frac{320}{2} = 160 \text{ hertz}$

Velocity of wave, $v = n\lambda$

Wave length, $\lambda = \frac{v}{n} = \frac{240}{160} = 1.5 \text{ m}$

EXAMPLE

The distance between any two successive antinodes or nodes of a stationary wave is 0.75 m. If the velocity of the wave is 300 m s^{-1} , find the frequency of the wave.

SOLUTION

Wavelength of the wave, $\lambda = 0.75 \text{ m} \times 2 = 1.5 \text{ m}$

Velocity of the wave = 300 m s^{-1}

frequency, $n = \frac{v}{\lambda} = \frac{300}{1.5} = 200 \text{ hertz}$

EXAMPLE

An engine of a train is moving towards a platform with a velocity of 100 m s^{-1} . If the frequency of sound produced is 200 Hz, find the apparent frequency of the sound as observed by an observer standing on the platform (Taking velocity of sound = 320 m s^{-1}).

SOLUTION

Given = Velocity of sound = 320 m s^{-1}

v = Velocity of source = 100 m s^{-1}

ν_s = Frequency of sound = 200 Hz

$$\begin{aligned}
 n = \text{Apparent frequency of sound} &= \frac{vn}{v - v_s} \\
 &= \frac{320 \times 200}{320 + 100} = \frac{6400}{420} \cong 152 \text{ Hz.}
 \end{aligned}$$

EXAMPLE

A source of sound and a listener are moving towards each other. The velocity of the source is 20 m s^{-1} and that of the observer is 15 m s^{-1} . If the velocity of sound is 340 m s^{-1} and its frequency is 640 Hz , find the apparent frequency of the sound.

SOLUTION

$$\text{Apparent frequency, } n = \left(\frac{V + V_O}{V + V_1} \right) n = \left(\frac{340 + 15}{340 - 20} \right) 640 = 710 \text{ Hz}$$

EXAMPLE

The fundamental frequency of a stretched string fixed at both the ends is 50 Hz . If the velocity of transverse wave created in string is 10 m s^{-1} , find its length.

SOLUTION

$$\text{Fundamental frequency, } n = \frac{v}{2\ell}$$

$$v = 100 \text{ m s}^{-1}$$

$$\text{Length of string, } \ell = \frac{v}{2n} = \frac{100}{2 \times 50} = 1 \text{ m.}$$

EXAMPLE

A string of 2 m length is fixed at both the ends. The transverse wave created in it propagates with a speed of 50 m s^{-1} . If the string is made to vibrate with three loops, find the frequency of the wave produced.

SOLUTION

$$\text{Fundamental frequency, } n = \frac{v}{2\ell}$$

$$= \frac{50 \text{ m s}^{-1}}{2 \times 2 \text{ m}} = \frac{50}{4} = 12.5 \text{ Hz}$$

$$\text{The frequency of third harmonic} = 3n$$

$$= 3 \times 12.5 = 37.5 \text{ Hz.}$$

EXAMPLE

The mass suspended from the stretched string of a sonometer is 2 kg and the frequency of the tuning fork used is 100 Hz . If the length of the string between the wedges is 50 cm ,

find the linear mass density of the string. (Taking $g = 10 \text{ m s}^{-2}$).

SOLUTION

Tension in the string = $mg = 2 \text{ kg} \times 10 = 20 \text{ N}$

Frequency = 100 Hz

Length of string = 50 cm = 0.5 m

Fundamental frequency, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}} \Rightarrow n^2 = \frac{T}{4L^2 m}$

$$\begin{aligned} \Rightarrow m &= \frac{T}{4l^2 n^2} = \frac{20}{4 \times \frac{1}{4} \times (100)^2} \\ &= 2 \times 10^{-3} \text{ kg m}^{-1} \end{aligned}$$

EXAMPLE

An air column enclosed in an open pipe is vibrating in its fundamental mode. The fundamental frequency is 30 Hz. If the velocity of sound in air is 300 m s^{-1} , find the length of the pipe and frequency of 3rd overtone.

SOLUTION

Fundamental frequency of an open organ pipe = $\frac{v}{2\ell}$

$$\Rightarrow 30 \text{ Hz} = \frac{300 \text{ m s}^{-1}}{2\ell}$$

$$\Rightarrow \ell = \frac{300}{2 \times 30} = 5 \text{ m}$$

Frequency of the third overtone = $4 \times n = 4 \times 30 = 120 \text{ Hz}$

EXAMPLE

In an experiment conducted to determine the velocity of sound by the resonating air column method, the first resonating length is noted as 30 cm for a tuning fork of 250 Hz frequency. What is approximate value of second resonating length and what is the approximate value of velocity of sound.

SOLUTION

The fundamental frequency of air column = 250 Hz.

Length of air column = 30 cm

Second resonance can occur when the air column vibrates in overtone mode.

The second resonating length = $3 \times 30 = 90 \text{ cm}$

Velocity of sound = $2n(\ell_2 - \ell_1)$

$$= 500 \times 60 = 30000 \text{ cm s}^{-1} = 300 \text{ m s}^{-1}$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. What is a compression?
2. What is wavelength?
3. What is a rarefaction?
4. Mention the audible range in terms of the time period of waves.
5. What is a node?
6. Arrange the three states of matter in the decreasing order of velocity of sound in them.
7. What is a wave?
8. Why sound cannot travel through vacuum?
9. What is a transverse wave?
10. Expand SONAR.
11. What is a longitudinal wave?
12. Why transverse waves cannot propagate through gases or inside liquids?
13. What is a mechanical wave?
14. What is frequency?
15. What is an electromagnetic wave?
16. The points of maximum displacement in a stationary wave are known as _____.
17. What is a progressive wave?
18. What is an audible range?
19. What is a stationary wave?
20. What is time period?
21. What is a crest?
22. What are infrasonics?
23. What is a trough?
24. What is an antinode?
25. What are ultrasonics?
26. What is phase?
27. S.I. unit of frequency is _____.
28. What do we mean by the term 'in phase'?
29. On what factors, does the velocity of sound in a medium, depend?
30. What do we mean by the term 'out of phase'?

Short Answer Type Questions

31. Distinguish between progressive and stationary waves.
32. The frequency of fundamental mode of vibration of a stretched string fixed at both the ends is 25 Hz. If the string is made to vibrate with 7 nodes, what is the frequency of vibration? If the length of string is 3 m, what is the frequency of the 4th harmonic?
33. Explain simple harmonic motion in the case of a simple pendulum.
34. The first resonating length of an air column, for a given tuning fork, is 16.5 cm and the second resonating length is 49.5 cm. If the velocity of sound in air is 330 m s^{-1} , find the frequency of tuning fork used.
35. Derive the equations $v = n\lambda$, where n and λ are frequency and wavelength.
36. The frequency of fundamental mode of vibration of an air column enclosed in a closed end pipe is 250 Hz. If its length is 33 cm, find the velocity of sound in air.
37. What is SONAR? Mention its uses.
38. Explain different types of waves.
39. From the string of a sonometer a constant weight is suspended. The resonating length of the string is noted as 50 cm for a tuning fork of 200 Hz. If a tuning fork of 250 Hz is used, what should be the distance between the two knife edges to get resonance?
40. Explain the factors on which the velocity of sound in a gas depends.
41. Distinguish between mechanical and electromagnetic waves.
42. Explain the factors on which the velocity of sound in air does not depend.
43. A source of sound is moving away from an observer at rest with a velocity of 50 m s^{-1} . If the frequency of sound is 200 Hz, find the apparent frequency observed by the observer. (Take velocity of sound = 300 m s^{-1}) (**Ans:** 171 Hz)?
44. Distinguish between longitudinal and transverse waves.
45. What are ultrasonics and mention their uses?



Long Answer Type Questions

46. Describe an experiment to demonstrate the laws of reflection of sound waves.
47. Describe the resonating air column method to determine the velocity of sound.
48. Explain through an experiment that sound requires a material medium for its propagation.
49. Describe experiments to prove the laws of transverse waves along stretched string.
50. State and explain 'sonic boom' and 'reverberation'.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- There is no phase difference between the particles within a loop, of a stationary wave.
- During resonance, the body undergoing forced vibrations vibrates with a larger amplitude.
- The velocity of sound in a gas is directly proportional to the square root of the temperature of the gas taken in degree celsius.
- The frequencies of stationary waves formed in closed-end organ pipes are in the ratio 1:3:5:7.....
- Light waves are transverse in nature.
- In simple harmonic motion, the acceleration of the body is inversely proportional to its displacement from the mean position.
- Velocity of sound in solids is affected by their density.

Direction for questions 8 to 14

Fill in the blanks.

- The fundamental frequency of a stretched string is directly proportional to $\frac{1}{\sqrt{m}}$, where 'm' is the _____ of the string.
- Jet planes which move with speeds greater than the speed of sound are called _____.
- If the motion of an object repeats itself at regular intervals of time, it is called _____ motion.
- The velocity of sound is _____ when the density of a gas is quadrupled, with the pressure remaining constant.
- In a stationary wave, the phase difference between the particles in a given loop is _____.

- The audible frequency range of the sound for human beings is _____.
- In a closed-end organ pipe of length 50 cm, the frequency of first harmonic is _____, the velocity of sound in air being 330 m s^{-1} .

Direction for question 15

Match the entries in Column A with the appropriate ones in Column B.

15.

Column A	Column B
A. Simple harmonic motion	a. Ultra sonic sounds
B. Pulse	b. Independent of amplitude of vibration
C. Other name for mechanical waves	c. Phase change of π radians
D. Dolphins	d. Total mechanical energy is conserved
E. Velocity of sound in air	e. $n \propto \sqrt{\frac{T}{m}}$
F. Supersonic speeds	f. Pressure waves
G. Intensification of sound	g. Disturbance for a short duration
H. Reflection of sound wave in an open tube	h. SONAR
I. Law of vibration of a stretched string	i. Resonance
J. Tracking of fish in an ocean	j. Mach number > 1 .



Direction for questions 16 to 45

For each of the questions, four choices have been provided. Select the correct alternative.

16. The fundamental frequency of a stretched string is given by _____.

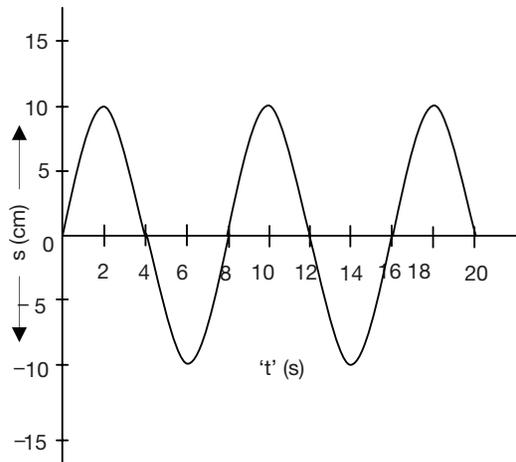
(ℓ , T , m have their usual meaning)

- (a) $n = \ell \sqrt{\frac{T}{m}}$ (b) $n = \ell^2 \sqrt{\frac{T}{m}}$
 (c) $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$ (d) $n = \frac{1}{2\ell^2} \sqrt{\frac{T}{m}}$

17. The special technique used in ships to calculate the depth of ocean beds is

- (a) LASER (b) SONAR
 (c) sonic boom (d) reverberation

18. The following graph shows the displacement of the bob from its mean position versus time. The time period and the amplitude of the bob are:



- (a) 4 s, 5 cm (b) 8 s, 10 cm
 (c) 4 s, 10 cm (d) 8 s, 5 cm

19. The minimum distance between the particles in a medium vibrating in same phase is known as

- (a) amplitude (b) wavelength
 (c) frequency (d) phase

20. The velocity of ultrasonic sound in water is 1400 m s^{-1} . The depth of the ocean as detected by SONAR, if the time taken to receive the reflected wave is 15 s, is _____.

- (a) 21 km (b) 10.5 km
 (c) 105 m (d) 1500 m

21. The tuning of a radio transistor is based on the principle of _____.

- (a) beats (b) resonance
 (c) echo (d) reverberation

22. If the fundamental frequency of a wave in an open pipe is 540 Hz, the frequency of the $(p - 1)^{\text{th}}$ harmonic is _____ Hz.

- (a) $(p - 1)540$ (b) $p(540)$
 (c) $(p + 1)540$ (d) 0

23. The minimum distance to hear an echo is (Taking the velocity of sound in air to be 330 m s^{-1})

- (a) $1/20 \text{ m}$
 (b) 16.5 m
 (c) 20 m
 (d) Cannot be determined

24. A medium should possess the property of _____ for the propagation of mechanical waves.

- (a) permeability (b) inertia
 (c) elasticity (d) both (b) and (c)

25. The velocity of sound in a gas is 30 m s^{-1} at 27°C . What is the velocity of the sound in the same gas at 127°C ?

- (a) 20 m s^{-1} (b) 30 m s^{-1}
 (c) $20\sqrt{3} \text{ m s}^{-1}$ (d) 60 m s^{-1}

26. If the direction of the vibration of particles is parallel to the direction of the propagation of a wave, then the wave is a

- (a) transverse wave (b) longitudinal wave
 (c) electromagnetic wave (d) All the above

27. Which of the following is false regarding progressive waves?

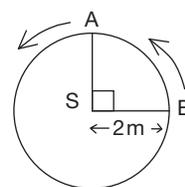
- (a) They carry energy and momentum from one place to another.
 (b) The energy possessed by these waves is kinetic in nature.
 (c) There is no phase difference between the particles in a wave.
 (d) When they propagate in a medium, crests and troughs or compressions and rarefactions are formed.

28. When the pressure of a gas is changed, then

- (a) the density of the gas also changes.
 (b) the ratio of the pressure to the density remains unaffected.
 (c) the velocity of the sound remains unaffected.
 (d) All the above



29. A body travelling with a speed of more than the velocity of sound in air is said to travel with
 (a) supersonic speed (b) hypersonic speed
 (c) ultrasonic speed (d) infrasonic speed
30. The correct statement among the following is
 (a) sounds with frequency greater than 20 kHz are known as ultra-sonics.
 (b) Dogs can hear ultrasonic sounds.
 (c) In SONAR, ultra-sonics are used.
 (d) All the above
31. A particle executing SHM completes 120π vibrations in one minute. What is the frequency of this motion?
 (a) 5 Hz (b) 2π Hz
 (c) 1 Hz (d) None of the above.
32. If wind blows in a direction opposite to the sound propagation, then the velocity of the sound
 (a) increases
 (b) decreases
 (c) remains constant
 (d) Cannot be determined
33. The phenomenon of apparent change in the frequency of sound whenever there is relative motion between the source of sound and the observer is called _____.
 (a) Photo electric effect (b) Doppler effect
 (c) Reflection (d) Refraction
34. A sound wave propagates in a medium which has the property/properties of
 (a) inertia
 (b) elasticity
 (c) Both (a) and (b)
 (d) Neither (a) nor (b)
35. At S.T.P. the ratio of volumes occupied by 1 mole of each O_2 and CO_2 gases, respectively, is _____.
 (a) 4 : 1 (b) 1 : 4
 (c) 1 : 2 (d) 1 : 1
36. A source which is situated at the centre of a circle is producing sound. Then the change in frequency (f) of sound heard by two persons at 'A' and 'B' if they move with velocities 20 m s^{-1} and 10 m s^{-1} , respectively, along the circular path as shown in figure is _____. (Velocity of sound is 330 m s^{-1})



- (a) $2f$ (b) f
 (c) zero (d) None of these
37. If ' v ' is the velocity of sound in a gas, then ' v ' is directly proportional to (here M , d and T represents molecular weight of gas, density of gas and its temperature, respectively.)
 (a) \sqrt{M} (b) $\frac{1}{\sqrt{d}}$
 (c) \sqrt{T} (d) Both (b) and (c)
38. When a sound wave passes from a highly polluted region to a pollution-free area, which of the following physical quantities remain unaltered?
 (a) Amplitude (b) Velocity
 (c) Frequency (d) Wavelength
39. Velocity (v) of sound in air, by vibrating resonating column is found by _____. (ℓ_1 , ℓ_2 and n are first second resonating lengths and frequency of tuning fork used, respectively).
 (a) $v = 2(\ell_2 - \ell_1)$ (b) $\frac{v}{n} = (\ell_2 - \ell_1)$
 (c) $v = \frac{(\ell_2 - \ell_1)}{2n}$ (d) $v = 2n(\ell_2 - \ell_1)$
40. Which of the following is not the law of a stretched string? (n , ℓ , T and m are frequency of vibration, length of vibrating string, tension in string and linear mass density, respectively.)
 (a) $n \propto \frac{1}{\sqrt{T}}$ (b) $n \propto \frac{1}{\ell}$
 (c) $n \propto \frac{1}{\sqrt{m}}$ (d) All the Above
41. Arrange the following steps in a sequential order to verify the laws of reflection.
 (a) A hard, smooth surface (AB) is mounted vertically over a horizontal board on which two tubes P and Q, point towards the surface AB.
 (b) The tube Q is adjusted such that the listener would be able to hear the ticking sound clearly at the end away from AB.



- (c) The sound waves from a source, like ticking clock, are directed to the surface AB through the pipe P inclined at an angle to AB.
- (d) By measuring the angles the tubes make with the surface AB, the laws of reflection are verified.
- (a) abcd (b) acbd
(c) dcba (d) cdab

42. The mass suspended from the stretched string of a sonometer is 4 kg and the linear mass density of string is $4 \times 10^{-3} \text{ kg m}^{-1}$. If the length of the vibrating string is 100 cm, arrange the following steps in a sequential order to find the frequency of the tuning fork used for the experiment.

- (a) The fundamental frequency of the vibrating string is, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$.
- (b) Get the value of length of the string (ℓ), and linear mass density (m) of the string from the data in the problem.
- (c) Calculate the tension in the string using, $T = mg$.
- (d) Substitute the appropriate values in $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$ and find the value of ' n '.
- (a) bcad (b) abcd
(c) dcba (d) badc

43. Write the following statements in a sequential order to find the depth of the ocean bed by using sonar.

- (a) The depth of the ocean bed can be found by $d = \frac{vt}{2}$.
- (b) At the bottom of a ship two devices, one is transmitter which produces ultrasonics and a receiver for the detection of the reflected ultrasonics from the ocean bed are fixed.

(c) The velocity of ultrasonics in ocean water is ' v ' and the time taken to receive the reflected ultrasonics from the ocean bed be ' t '.

- (d) If the depth of ocean bed is ' d ', then $v = \frac{d+d}{t} = \frac{2d}{t}$.
- (a) abcd (b) bdca
(c) bcda (d) bcad

44. An experiment is conducted to determine the velocity of sound by resonating air column method where the first and second resonating lengths are 20 cm and 60 cm, respectively, for a tuning fork of frequency 100 Hz. Arrange the following steps in a sequential order to determine the velocity of sound.

- (a) Note the frequency of the tuning fork (n) that is used to produce resonance in the closed organ tube.
- (b) This will be the fundamental frequency of air column.
- (c) The velocity of sound in air, $v = 2n(\ell_2 - \ell_1)$.
- (d) Identify the first and second resonating lengths when the tuning fork of frequency (n) is used from the given information. Let it be ℓ_1 and ℓ_2 , respectively.
- (a) abdc (b) abcd
(c) dcba (d) adbc

45. A swimming pool is constructed in the shape of a square of side 10 m. If a stone is dropped at the centre of the pool so that it produces waves of frequency 100 Hz and wavelength 5 cm, then the time taken by the first water wave to reach one of its walls is _____ s.

- (a) 0.5 (b) 1
(c) 2 (d) 4

Level 2

46. The frequency of a tuning fork is 350 Hz. Find how many vibrations it executes while the sound produced by it travels a distance of 70 m. (Velocity of sound in air 330 m s^{-1}).

47. A SONAR system fixed in a submarine operates at a frequency 50 kHz. It is moving towards a rocky hill present inside water with a speed of 432 km h^{-1} . What is the apparent frequency of sound observed at the submarine after reflection by the rocky hill? (Take velocity of sound in water to be 1450 m s^{-1})

48. The fundamental frequency of an open pipe is 450 Hz and that of a closed pipe is 350 Hz. The two pipes are joined together to form a longer pipe. Find the fundamental frequency of this new pipe. Take velocity of sound as 330 m s^{-1} .

49. How does a stethoscope help a doctor to hear the sound of a patient's heart-beat?

50. A man standing at a point on the line joining the feet of two cliffs fires a bullet. If he hears the 1st echo after



4 seconds and the next after 6 seconds, then what is the distance between the two cliffs? (Take the velocity of sound in air as 330 m s^{-1})

51. Do the velocity, frequency and wavelength of a sound wave increase, decrease or remain constant, when it is reflected from an obstacle? Explain.
52. A string vibrating with a fundamental frequency of 8 Hz has tension T_1 . This string vibrates with a fundamental frequency of 15 Hz when the tension is T_2 . Find the fundamental frequency of the string when its tension is $T_1 + T_2$.
53. S. P. Balasubrahmanyam is conducting a musical night in an open auditorium in New York. Taking into account, two persons, one who is sitting in the auditorium at a distance of 1 km from the stage and the other who is watching the live program on a television set sitting in front of it in Hyderabad, who will hear him first? Explain.
54. What should the length of an open pipe be if it is to resonate with a closed pipe 1 m long at their fundamental frequencies?
55. Two trains A and B are approaching each other with 108 km h^{-1} and 126 km h^{-1} , respectively. If the train A sounds a whistle of frequency 500 Hz, find the frequency of the whistle as heard by a passenger in the train B.
 - (a) before the trains cross each other and
 - (b) after the trains cross each other. (Take velocity of sound as 330 m s^{-1})
56. Under similar conditions of temperature and pressure, two gases (x and y) of equal masses are taken such that x and y occupy volumes of 2 l and 50 l, respectively. When sound waves are passed through both the gases, in which gas does sound travel with a greater velocity?
57. Why cannot transverse waves be produced in air?
58. The driver of a car approaching a cliff with a uniform velocity of 15 m s^{-1} sounds the horn and the echo is heard by the driver after 3 seconds. If the velocity of sound is 330 m s^{-1} , calculate the distance between the cliff and the point where the horn was sounded? Also calculate the distance between the cliff and the point where the echo is heard?
59. A rope of length 2 m is tied between two ends. If the speed of transverse waves propagating in the rope is 4 m s^{-1} and the tension in the rope is 2 N, find the mass of the rope in C.G.S units.
60. Two diatomic gases A and B of masses 12 g and 32 g occupy volumes of 1200 ml and 1920 ml, respectively. When sound waves are passed through these gases, in which gas does sound travel with least velocity and also by how many times? Assume that the pressure and temperature are same in both the gases.
61. In a loud-speaker, sound is produced by a diaphragm on supplying electrical energy. Explain what type of motion the diaphragm exhibits while producing the sound? How is sound produced in a loud speaker?
62. In a certain experiment, a sound wave was observed to have undergone a change in its velocity and wavelength but the frequency remained the same. In another experiment, no change was observed in the velocity, wavelength or frequency but there was a change in the phase. If the direction of the wave propagation is changed in both the cases, identify the phenomena that took place in the two experiments. Give reasons for the changes in the physical quantities.
63. A source of wave vibrates with a frequency 500 Hz. The wave travels 33 m in 0.1 s. How far does the waves travels when the source executes 150 vibrations?
64. The distance between two adjacent particles which are in the same phase in a progressive wave is 20 cm. Determine the velocity of the wave if its frequency is 10Hz.
65. The average speed of the bob of a seconds pendulum is 2 m s^{-1} . Determine the (a) linear amplitude (b) angular amplitude and the (c) frequency of oscillation.

Level 3

66. A road runs parallel to a vertical cliff at a distance of 495 m as shown in the figure. A car standing at A blows the horn and the driver of the car hears the echo after 3 s. But a person standing at B hears the sound of horn twice within an interval of 2 s. Explain why the person at 'B' heard the sound twice. Also find the distance between the car and the person.





67. Why are sirens of mills heard upto longer distances in the rainy season as compared to the summer season?
68. The shock waves and sonic booms produced by supersonic jets can cause hearing loss in people living near the air bases and not in those living in areas away from these bases. Explain.
69. By placing tuning forks of different frequencies at the open end of a pipe, it is found that the pipe, has a resonating frequency at 450 Hz and the next harmonic at 750 Hz. Find whether the pipe is closed at one end or open at both ends. Also find the fundamental frequency of the pipe.
70. Why are the ultrasonic sounds preferred to audible and infrasonic sounds in detecting the tumors in a physical body.
71. Ravi filled two cylinders with two gases (X and Y) of equal masses such that under similar conditions of temperature and pressure they occupy volumes of 2ℓ and 50ℓ , respectively. If he produces sound through both the gases inside the cylinders, then in which gas does sound travel with greater velocity?

Explain (Given that the value of γ is same for both the gases.)

72. A scooterist moves towards a vertical wall with a speed of 54 km h^{-1} . A person is standing on the ground and is behind the scooter, hears the sound. If the scooterist sounds the horn of frequency 400 Hz, calculate the apparent frequency sound heard by the person when
- it is coming directly from the horn.
 - coming after reflection from the vertical wall. (Take speed of sound to be 330 m s^{-1}).
73. Two monoatomic gases of equal masses are in two different containers at S.T.P. If the ratio of velocities of sound in them is $1 : 2$, then find the ratio of their volumes.
74. Anil and Sunil brought two rods 'A' and 'B' of length 5 m each, respectively. The Young's modulus of elasticity of rod A is twice that of rod B, and the density of rod A is 8 times that of rod B. When a sound wave is allowed to traverse through each rod, Anil and Sunil claimed that the sound waves travel faster in their respective rods. Find in which rod will the sound wave take lesser time?
75. The frequency of fundamental mode of vibration of an air column enclosed in a closed end pipe is 250 Hz. If its length is 33 cm, then find the velocity of sound in air.



CONCEPT APPLICATION

Level 1

True or false

1. True 2. True 3. False 4. True 5. True 6. False 7. True

Fill in the blanks

8. linear mass density 9. supersonic jets 10. periodic 11. halved 12. zero
13. 20 Hz to 20 kHz 14. 165 Hz

Match the following

15. A : d B : g C : f D : a E : b F : j G : i H : c I : e J : h

Multiple choice questions

16. (c) 17. (b) 18. (b) 19. (b) 20. (b) 21. (b) 22. (a) 23. (b) 24. (d) 25. (c) 26. (b) 27. (c) 28. (d)
29. (a) 30. (d) 31. (b) 32. (b) 33. (b) 34. (c) 35. (d) 36. (c) 37. (d) 38. (c) 39. (d) 40. (a) 41. (b)
42. (a) 43. (c) 44. (a) 45. (b)

Explanations for questions 31 to 45:

31. Frequency = $\frac{120\pi}{60} = 2\pi$ Hz

32. If the wind blows in the opposite direction to the direction of propagation of sound, the velocity of sound decreases.

33. The phenomenon of apparent change in the frequency of sound whenever there is relative motion between the source of sound and observer is called “Doppler effect”.

34. The medium through which the sound waves are propagated must have both inertia and elasticity.

35. At S.T.P all gases of one mole occupies equal volume of 22.4 litre.
∴ Ratio of their volumes is 1 : 1.

36. As both the persons are moving at equal distance from the source along circular track, there is no change in frequency of sound heard by A and B.
∴ Change in frequency of sound = zero.

37. If v is the velocity of sound in a gas, then it is directly proportional to the square root of absolute temperature of gas and inversely proportional to square root of its mass and density.

38. Frequency of sound depends on the source.

39. Velocity of sound in resonating air column is found by $v = 2n(\ell_2 - \ell_1)$.

40. Laws of stretched strings are:

$$n \propto \frac{1}{\ell} \text{ (law of length)}$$

$$n \propto \sqrt{T} \text{ (law of tension) and}$$

$$n \propto \frac{1}{\sqrt{m}} \text{ (law of linear mass density)}$$

41. A hard, smooth surface (AB) is mounted vertically over a horizontal board on which two tubes P and Q, point towards the surface AB (a). The sound waves from a source, like ticking clock, are directed to the surface AB through the pipe P inclined at an angle to AB (c). The tube Q is adjusted such that the listener would be able to hear the ticking sound clearly at the end away from AB (b). By measuring the angles the tubes P and Q make with the surface AB, the laws of reflection are verified (d).

42. Given, $l = 100$ cm
 $m = 4 \times 10^{-3}$ kg m⁻¹ (b)
 $T = mg = 4 \times 9.8 = 39.2$ N (c)

Consider, the fundamental frequency of the vibration string is, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$ (a)

Substitute the values of ℓ , T and m in $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$

and calculate the value of ‘ n ’ and this is the frequency of tuning fork (d).

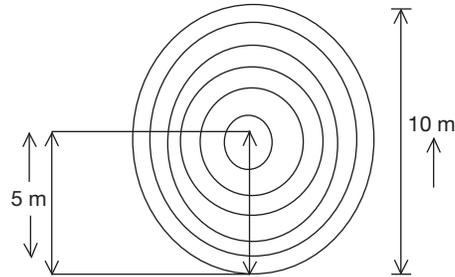


43. At the bottom of a ship two devices, one is transmitter which produces ultrasonics and a receiver for the detection of the reflected ultrasonics from the ocean bed are fixed. (b). The velocity of ultrasonics in ocean water is ' v ' and the time taken to receive the reflected ultrasonics from the ocean bed be ' t ' (c). If the depth of the ocean bed is ' d ', then $v = \frac{2d}{t}$ (d) The depth of the ocean bed can be found by $d = \frac{vt}{2}$ (a).

44. Note the frequency of the tuning fork (n) that is used to produce resonance in the closed organ tube (a). This will be the fundamental frequency of the air column (b). Identify the first and second reso-

nating lengths when tuning fork of frequency (n) is used from the information given. Let it be ℓ_1 and ℓ_2 , respectively. (d) The velocity of sound in air, $v = 2n(\ell_2 - \ell_1)$ (c).

45.



$$\lambda = 5 \text{ cm} = 0.05 \text{ m}$$

$$V = n\lambda = 100 \times 0.05 = 5 \text{ m s}^{-1}$$

$$\text{Time} = \frac{\text{distance}}{\text{velocity}} = \frac{5}{5} = 1 \text{ s}$$

Level 2

46. (i) $v = n\lambda$, $s = vt$

(ii) Hz

47. (i) Doppler effect,

$$n^1 = n \left(\frac{v}{v - v_s} \right); n^{11} = n^1 \left(\frac{v + v_o}{v} \right)$$

- (ii) Consider the two cases.

In the first case, consider the submarine as the source and rocky hill the observer of sound. Calculate the frequency as heard at the rocky hill using the expression for apparent frequency (Doppler's effect). The frequency of sound reflected by the rocky hill is the same as that incident on it. In the second case consider the rocky hill as the source and the submarine as the observer of sound.

Now find the apparent frequency of sound as heard at the submarine using the expression for apparent frequency.

- (iii) 59 k Hz

48. (i) Sum of lengths of open pipe and closed pipe gives length of longer pipe

$$(ii) n_o = \frac{v}{2\ell_o}, n_c = \frac{v}{4\ell_c}$$

$$n_{long} = \frac{v}{4(\ell_o + \ell_c)}$$

- (iii) 135 Hz

49. Is the tube connecting the diaphragm of a stethoscope and its ear phones hollow or solid?

Does the tube reflect the sound at different points in the process of transmitting it from the diaphragm to the head phones?

50. (i) $v = \frac{2d}{t}$

(ii) Apply the formula $d = vt$ for both the cliffs.

Then add the two distances to get the distance between the two cliffs.

- (iii) 1650 m or 1.65 km

51. Velocity of sound in a given medium

52. (i) Relation between frequency and tension of a stretched string.

$$(ii) n \propto \sqrt{T}$$

- (iii) 17 Hz

53. (i) Difference between velocities of mechanical and electromagnetic waves.

(ii) Is it the mechanical or electromagnetic form of sound that is received by the observer

(a) in the auditorium?

(b) watching the live program?

Which of electromagnetic and mechanical waves have larger velocity?



- (iii) Person in Hyderabad
54. (i) Equating fundamental frequencies of open and closed end pipes.
 (ii) $n_o = \frac{V}{2\ell_c}$, $n_c = \frac{V}{4\ell_c}$
 (iii) twice
55. (i) $n^1 = n \left(\frac{v+v_0}{v-v_s} \right)$; $n^2 = n \left(\frac{v-v_0}{v+v_s} \right)$
 (ii) Identify which of the trains A and B is the source and which the observer of sound is.
 Recall the expression for apparent frequency in Doppler's effect.
 The source and the observer approach each other before the trains cross each other.
 The source and the observer recede after the trains cross each other.
 (iii) 608 Hz
 (iv) 410 Hz
56. (i) $v \propto \frac{1}{\sqrt{d}}$
 (ii) Use $v \propto \frac{1}{\sqrt{d}}$, where 'v' is the velocity of sound in a gas and 'd' is the density of the gas.
 Compare the densities of the given two gases with the help of the given data.
 Then compare the velocity of sound in both the gases.
 (iii) Gas 'x'
57. (i) Advantages of ultra sounds
 (ii) Changes that take place in the medium when transverse waves propagate.
58. (i) 517.5 m, 472.5 m
 (ii) Equation for echo and velocity of sound
 (iii) Draw a rough linear figure depicting the positions of the car approaching the cliff when it sounded the horn, and when the echo is heard by its driver and the position of the cliff.
 From the figure find the distance travelled by the sound in the given time interval.
 For this consider the distance travelled by the car in the given time interval.
 Using the formula, velocity of sound = $\frac{\text{Distance travelled by the sound}}{\text{time to hear the echo}}$,
- estimate the distance of the car from the cliff when it sounded the horn.
59. (i) $v = \sqrt{\frac{T}{m}}$
 (ii) 250 g
60. (i) Dependence of velocity of sound on density of a gas.
 (ii) $V \propto \frac{1}{\sqrt{d}}$, $d = \frac{m}{V}$
 (iii) Gas B, $V_A = 1.3 V_B$
61. A diaphragm exhibits vibratory motion to produce sound. As the diaphragm moves forward, it compresses the air in front of it, hence, density of air increases at that place. This part of air causes next layer of air to compress and the wave travels in the air with certain speed creating compressions.
 When a membrane moves backwards, it drags back the air layer near it decreasing the density of air in the adjacent layer. Thus, the wave advances in the air in the form of rarefaction.
62. Velocity of a wave changes whenever sound travels from one medium to another medium. Change in the velocity results in refraction. When a sound wave is reflected by an accountably hard, smooth surface, velocity and wavelength (thus, frequency too) remain constant, but phase changes by 180° . Thus, the first experiment refers to refraction of sound waves and the second experiment refers to reflection of sound waves.
63. The frequency of the tuning fork = 500 Hz. The time taken for one wave to pass = $\frac{1}{500}$ s
 \therefore Therefore the time taken for 150 vibrations (waves)

$$= \frac{1}{500} \times 150 = 0.3 \text{ s}$$
 Hence, the distance travelled by sound in 0.3 s is
 $= 0.3 \times 330$
 $= 99.0 \text{ m}$
64. Distance between two adjacent particles in phase
 $= 20 \text{ cm} = \frac{\lambda}{2}$
 $\Rightarrow \lambda = 40 \text{ cm} = 0.4 \text{ m}$
 Frequency(f) = 10 Hz
 \therefore Velocity = $\lambda \times f = 0.4 \times 10 = 4 \text{ m s}^{-1}$

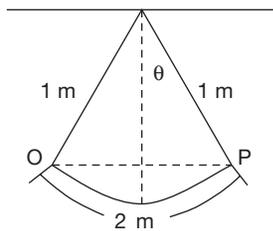


65. The time period of a seconds pendulum = 2s.
Length of a seconds pendulum = 1 m.

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}}$$

$$\therefore \frac{d}{2} = 2$$

$$d = 4 \text{ m.}$$



$$\text{Amplitude} = \frac{d}{4} = \frac{4}{4} = 1 \text{ m.}$$

In the figure, $2 = 1 \times 2$

$$2\theta = 2$$

Angular amplitude $\theta = 1^\circ$

$$\text{Frequency} = \frac{1}{T} = \frac{1}{2} = 0.5 \text{ Hz.}$$

Level 3

66. (i) Equation of echo, Pythagoras theorem

$$(ii) v = \frac{2d}{t_1}$$

(distance covered by sound waves) +

$$v = \frac{\text{(distance between driver and person)}}{t_2}$$

Pythagoras theorem

- (iii) 412 m

67. (i) Factors affecting velocity of sound in air.
(ii) Recall the factor that affects the velocity of sound in air.
Out of rainy and summer seasons, in which season the humidity of air is higher?

68. How does the intensity of sound vary with distance of the point of observation from the source of sound?

69. (i) Closed pipe, 150 Hz
(ii) Expression for pth harmonic of open and closed-end pipes.
(iii) Ratio of harmonics in a pipe closed at one end is 1 : 3 : 5

70. (i) Directionality of ultrasonics, applications of ultrasonics, imaging on internal organ

- (ii) Is the wavelength of ultrasonics larger or shorter when compared with that of audible and infra-sonic sounds?

When are the waves reflected sharply at the boundaries of an obstacle? Is it possible when their wavelength is shorter or longer?

71. Given, temperature and pressure of two gases are similar when equal masses of gases are taken.

Let the volume of 1st gas be $V_X = 2 \ell$

Let the volume of 2nd gas be $V_Y = 50 \ell$

If sound waves are passed through both the gases, speeds of sound waves depends only on the density of gases (Since temperature and pressure are similar).

$$\therefore S \propto \frac{1}{\sqrt{d}} \Rightarrow \frac{S_X}{S_Y} = \sqrt{\frac{d_Y}{d_X}}$$

$$\frac{S_X}{S_Y} = \sqrt{\frac{m}{V_Y} \times \frac{V_X}{m}} \left(\text{Since } d = \frac{m}{v} \right)$$

$$\frac{S_X}{S_Y} = \sqrt{\frac{2}{50}} = 1:5; \frac{S_X}{S_Y} = \frac{1}{5}$$

$$S_Y = 5.S_X$$

Speed of a sound waves in gas 'y' is 5 times that in gas 'x'.

72. The speed of scooter = 54 km h^{-1}

$$= 54 \times \frac{5}{18} = 15 \text{ m s}^{-1}$$

The frequency of the sound of horn = 400 Hz

(a) The observer with reference to the ground is at rest

\Rightarrow Velocity of observer 0 m s^{-1}

The source is moving away from observer.

\therefore The velocity of source = 15 m s^{-1}

The apparent frequency heard by the observer is

$$= n' = \frac{V - V_o}{V + V_s} n = \frac{330 - 0}{330 + 15} \times 400$$

$$= 0.956 \times 400 = 382.4 \text{ Hz}$$



(b) The apparent frequency of sound received after reflection from the wall is

$$= n'' = \frac{V + V_o}{V - V_s} n = \frac{V}{V - V_s} n$$

$$n'' = \frac{330}{330 - 15} \times 400 = \frac{330}{315} \times 400 = 419 \text{ Hz}$$

[This is possible because the vertical wall reflects the sound without changing the frequency].

73. Ratio of the velocities of sound in them = 1 : 2 We know that velocity of sound in a gas is inversely proportional to square root of molecular weight.

$$\therefore V \propto \frac{1}{\sqrt{M}}$$

$$M \propto \frac{1}{v^2}$$

$$\frac{M_1}{M_2} = \left(\frac{v_2}{v_1}\right)^2 = \left(\frac{2}{1}\right)^2 = 4 : 1$$

But $pv = n \cdot RT$

$$v = nR \left(\frac{T}{p}\right)$$

$$v \propto \frac{m}{M} \left[\because T, p \text{ and } R \text{ are constant and } n = \frac{m}{M} \right]$$

$$\therefore V \propto \frac{1}{M} \left[\because m \text{ is also constant} \right]$$

$$\therefore \frac{v_1}{v_2} = \frac{M_2}{M_1} = 1 : 4$$

Alternate method:

$$V \propto \frac{1}{\sqrt{d}} \text{ or } v \propto \frac{1}{\sqrt{\frac{m}{V}}} \text{ or } \frac{v_1}{v_2} = \sqrt{\frac{V_1}{V_2}}$$

$$\therefore \frac{V_1}{V_2} \frac{v_1^2}{v_2^2} = \frac{1}{2^2} = \frac{1}{4}$$

74. Given that $Y_1 = 2Y_2$

$$d_1 = 8 d_2$$

$$V_1 \text{ (velocity of sound waves in 1st rod)} = \sqrt{\frac{Y_1}{d_1}}$$

$$V_1 = \sqrt{\frac{Y_1}{d_1}}$$

$$V \text{ (velocity of sound waves in 2nd rod)} = \sqrt{\frac{Y_2}{d_2}}$$

$$V_2 = \sqrt{\frac{Y_2}{d_2}}; \therefore \frac{V_1}{V_2} = \frac{\sqrt{\frac{Y_1}{d_1}}}{\sqrt{\frac{Y_2}{d_2}}}$$

$$\frac{V_1}{V_2} = \sqrt{\frac{2Y_2}{8d_2} \times \frac{d_2}{Y_2}}$$

$$\frac{V_1}{V_2} = \frac{1}{2}$$

Given that a distance of 5m is transversed in each rod by the sound waves.

$$\text{But } V = \frac{d}{t}$$

$$\frac{V_1}{V_2} = \frac{d_1}{t_1} \times \frac{t_2}{d_2}; \frac{1}{2} = \frac{5}{t_1} \times \frac{t_2}{5}$$

$$\therefore t_1 = 2t_2$$

Hence, the time taken for the sound is lesser in the second rod

75. The frequency of fundamental mode of vibration

$$n_1 = 250 \text{ Hz.}$$

The length of air column, $l = 33 \text{ cm.}$

Let wavelength of fundamental mode be $= \lambda_1.$

$$\Rightarrow \lambda_1 = 4l = 4 \times 33 = 132 \text{ cm}$$

We know: $v = n_1 \lambda_1$

$$= 250 \times 132$$

$$= 33000 \text{ cm s}^{-1} = 330 \text{ m s}^{-1}$$



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Chapter 9

Light



REMEMBER

Before beginning this chapter you should be able to:

- Define different terms related to the study of light, Reflection of light by plane mirror and spherical mirrors
- Review the phenomenon of bending of light rays and their applications
- Understand splitting of white light into its constituent colours

KEY IDEAS

After completing this chapter you should be able to:

- Apply the principle of rectilinear propagation of light like the formation of shadow, working of pinhole camera
- Understand the reflection of light by plane mirror and spherical mirrors in detail
- Explain the phenomenon of refraction with the help of different examples
- Understand the formation of rainbow, different colours of objects, etc., and the principle involved in the working of different optical instruments

INTRODUCTION

Light enables us to see several thousands of objects everyday. Though light is invisible, it makes objects around us visible. The primary source of light is the Sun. Other sources of light are an incandescent bulb, a fluorescent bulb, LET (Light Emitting Diode) the stars, etc. In an incandescent bulb, the filament is heated to a high temperature, and thus, the heat energy is converted into light. Thus, light is a form of energy which enables vision.

The bodies which give light on their own are called luminous bodies for example, the Sun, the stars, a glow worm, an electric bulb, a candle, etc.

The bodies which do not give out light on their own, but are made visible due to the reflection of light are called non-luminous bodies.

Example: chairs, walls, the moon, etc.

Light is an electromagnetic radiation and can travel through vacuum. The medium through which light passes is called an optical medium.

Optical media are further classified into homogenous and heterogenous.

An optical medium like pure water or glass have uniform composition and such media are called homogenous media.

Optical media like air or muddy water, which have different composition, are called heterogenous media.

Media like glass, water, etc., which allow most of the light to pass through them, are called transparent media.

Tissue paper or fog allows only a part of the light energy to pass through it, such media are called translucent media.

Substances like iron plates, stones, bricks, etc., do not allow light to pass through them, such media are referred to as opaque media.

Point Source of Light

A source of light which is infinitesimally (very) small is called point source of light. Light coming out from a pin hole in a closed enclosure is practically the closest to a point source of light. Thus, a point source is the size of a pin head and the source of light greater than the size of the pin head is called an extended source.

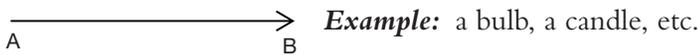
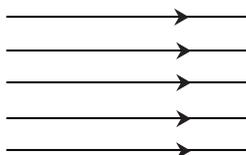


FIGURE 9.1

In a homogenous medium, light travels along a straight line. The straight line path of light is called ray.

The arrow mark gives the direction in which the light ray travels.



A bundle of light rays is called beam of light.

If the light rays in a beam of light travel parallel to each other, the beam of light is called parallel beam.

FIGURE 9.2 Parallel Beam

If the light rays converge and meet at a point, then the beam of light is called convergent beam or a converging beam of light.

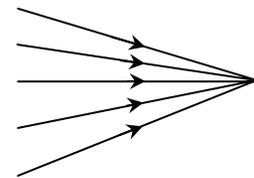


FIGURE 9.3 Convergent Beam

If two or more rays appear to spread out from a point, then such a collection of rays is called divergent beam.

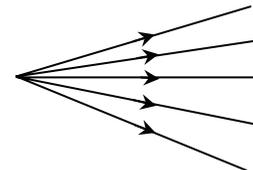


FIGURE 9.4 Divergent beam

Rectilinear Propagation of Light

Light consists of tiny energy packets called photons. These photons are associated with electric and magnetic fields which are perpendicular to each other and to the direction of propagation of light. Thus, the photon moves along a straight line. This property of electromagnetic radiations by which light rays travel in a straight path is called rectilinear propagation of light.

Examples: Rectilinear propagation of light.

The light emerging from a torch or the head light of a vehicle at night appears to travel straight. Sunlight entering through the small openings in doors or windows appears as a straight line.

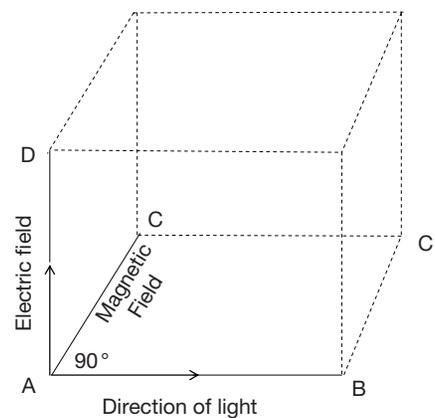


FIGURE 9.5

Experiment to Prove Rectilinear Propagation of Light

Take three cardboards *A*, *B* and *C*, of the same size. Make a pin hole at the centre of each of the three cardboards. Place the cardboards in the upright position, such that the holes in *A*, *B* and *C* are in the same straight line, in the order. Place a luminous source like a candle near the cardboard *A* and look through the hole in the cardboard *C*. We can see the candle flame. This implies that light rays travel along a straight line *ABC*, and hence, candle flame is visible. When one of the cardboards is slightly displaced, candle light would not be visible. It means that light emitted by the candle is unable to bend and reach observer's eye. This proves that light travels along a straight path only. This proves the rectilinear propagation of light.

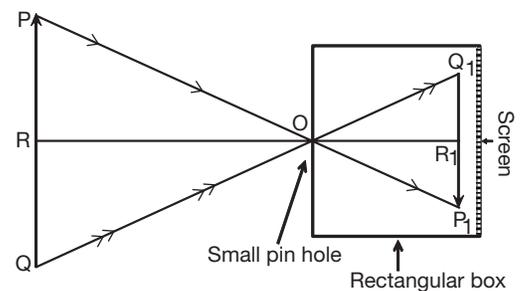


FIGURE 9.6 Pinhole camera

PINHOLE CAMERA

A pinhole camera Fig. 9.6 is a device which can be used to take photographs of objects. It is based on the principle of the rectilinear propagation of light.

The pinhole camera consists of a rectangular cardboard box, with one of its side made of ground glass screen inside. A hole of pin head size is made on the face opposite to the ground glass. The inner walls of the box are blackened so as to absorb the light entering the box.

If an object is placed in front of the pinhole camera, the rays of light which originate from the various points of the object, enter the camera through the pinhole and strike the screen. The ray originating from the point P travels along straight line PO and strikes the screen at the point P_1 . The ray from the point Q , takes the path QO and gets projected at Q_1 . All the other rays get projected in between the points P_1 and Q_1 . This leads to the formation of a small diminished image. If a photographic plate is used instead of a glass screen, a real photograph of an object can be obtained. This can be done by covering the camera with a thick black cloth, then turning the camera towards the object. On removing the black cloth, light enters the box. On allowing the light to be incident on the photographic plate for a few minutes, an image is formed on the plate, which is then developed and printed to get photographs.

The ratio of the height of the image formed, to the height of the object, is known as linear **magnification**.

$$\therefore \text{Linear Magnification} = \frac{\text{Size of image}}{\text{Size of object}} = \frac{\text{Distance of image from the pinhole}}{\text{Distance of object from the pinhole}}$$

The Factors that Affect the Image Formed in a Pinhole Camera

1. *Size and shape of the pinhole:* If the size of the pinhole is increased, many rays enter the camera from a given point on the object and strike the screen at different points, producing a number of images. These images, due to overlapping give rise to a blurred image.
The shape of the pinhole does not affect the image formation, as long as its size is constant.
2. *On changing the object distance:* The size of the image increases when the object is moved closer to the screen. It decreases when the object moves away from the pinhole.
3. *On changing the distance of the screen from the pinhole:* The size of the image decreases when the screen is moved closer to the pinhole.

Advantages of a Pinhole Camera

1. It is easy to construct and operate and is not expensive.
2. Unlike in an ordinary camera, in a pinhole camera lens is not used. Thus, the pinhole camera is free from the defects of lens.
3. A very sharp image of a still object can be obtained.

Disadvantages of a Pinhole Camera

1. It cannot take images of moving objects.
2. The image gets blurred or distorted if the size of the hole increases.
3. Time required to take photographs is a very large.

Characteristics of the Image Formed in the Pinhole Camera

1. The image is real as it can be formed on the screen.
2. The image is inverted.

3. The shape of the pinhole does not have any effect on the shape of the image.
4. The pinhole camera does not require a lens. Hence, it is free from the defects of images called chromatic observation and spherical observation.

Casting of shadows and formation of eclipses are due to an opaque body obstructing the straight line path of light.

SHADOW

When a book, or any opaque object, is introduced between the flame of a lighted candle and the wall in a dark room, a dark patch is formed on the wall. This dark patch is known as a shadow.

The shadow of a person is cast on a road due to the obstruction of the path of sunlight. A shadow usually consists of two regions, namely, umbra and penumbra.

Umbra is the region of total darkness and penumbra is the region of partial darkness.

A point source casts a shadow of total darkness when the light rays from the source are obstructed by an opaque body.

Formation of a Shadow by a Point Source

Place a cardboard with a pin hole, in front of a lighted source like a candle flame. The cardboard with a pin hole will act as a point source. Place a white screen on the other side of the cardboard.

Introduce a coin or a metal disc between the point source and the screen. A shadow $A'B'$ of total darkness is formed on the screen. The region $A'B'$ does not receive any light rays from the point source. This region is called umbra region. If the distance between the screen and the opaque object decreases, the size of the umbra region decreases.

By varying the distance between the opaque object and the screen, the size of the umbra region can be varied.

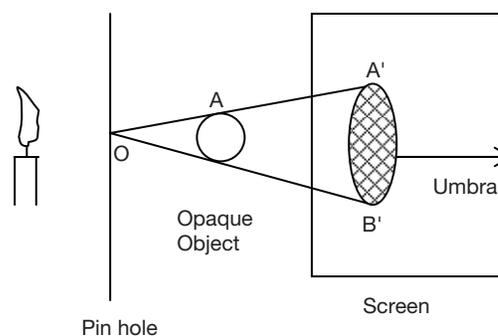


FIGURE 9.7

Formation of Shadows Using an Extended Source

In the above experiment, if the cardboard with a single pinhole is replaced by a cardboard with two pinholes, the shadow observed on the screen would have two regions. The central region of the shadow, i.e., the umbra, is completely dark and around this region is the penumbra. A_1B_1 is the shadow of AB due to point source S_1 . Similarly the rays starting from S_2 meet the screen A_1 or B_2 . Thus, A_2B_1 is the shadow of AB due to point source S_2 .

From the screen, the region A_1B_2 does not receive any light, and hence, the region is umbra. But the region A_1A_2 receives light as shown in Fig. 9.8. Thus, the A_1A_2 is a penumbra.

Similarly, the region B_1B_2 receives light as shown in Fig. 9.8. from the extended source except from S_1 , hence, the region BB^1 is a penumbra.

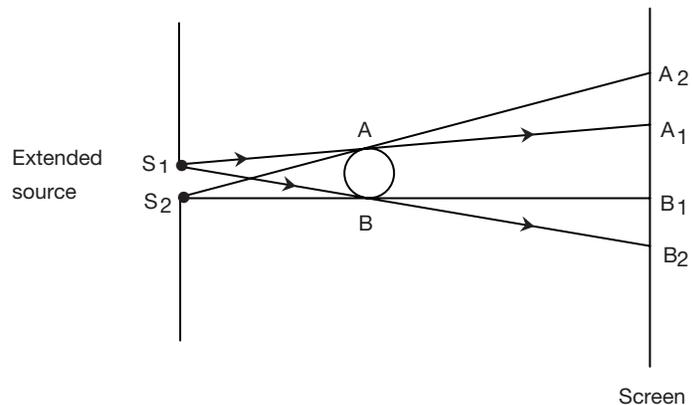


FIGURE 9.8

When the extended source is smaller than the opaque object and if the distance between the screen and the object is increased, the umbra and penumbra region increases. But if the distance between the source and the opaque object is increased the umbra and penumbra region decreases.

If the extended source is smaller than the opaque body, the umbra region is comparatively larger than the penumbra region.

If the extended source is bigger than the opaque body, the shadow formed by the object will have a smaller umbra region than the penumbra region and if the distance between the screen and object is increased, the penumbra increases and the umbra decreases. If the source of light is moved away from the object, the penumbra decreases and the umbra increases.

An incandescence bulb which is smaller in size forms a large umbra. Hence, a tube light, which is longer, is preferred to an incandescent bulb as a source of light.

When light rays travel from one homogenous medium to another medium, a part of the light is transmitted, a part of it is absorbed and the remaining is bounced back to the first medium.

REFLECTION OF LIGHT

The phenomenon, in which a light ray incident on a surface bounces back into the same medium through which it travelled earlier, is called reflection of light.

If a parallel beam of light is incident on a surface and the reflected light is also a parallel beam, then such a reflection which takes place at smooth surfaces, is known as a regular reflection. If the reflected light rays are not parallel, then such a reflection is known as an irregular reflection. This type of reflection takes place when the surface is not smooth.

Examples: Regular reflection—glass, glycerine.

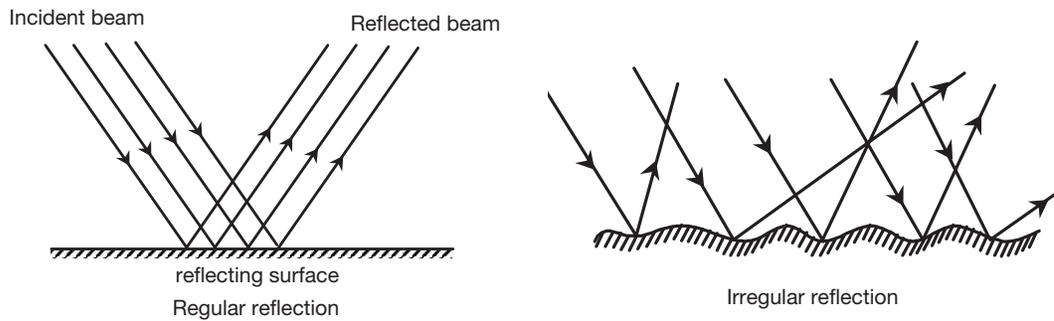


FIGURE 9.9

Examples: Irregular reflection—wall, tree, etc.

Reflection can be on plane surfaces like plane mirrors or curved surfaces like spherical mirrors. Most of the light is reflected on a mirror whether it is plane or spherical. The optical impression of an object formed by rays of light after reflection or refraction is known as an **image**. If the image can be obtained on a screen, it is called '**real image**' and if it is not possible to obtain the image on a screen it is called '**virtual image**'.

Difference between Virtual and Real Image

Real image	Virtual image
1. It can be formed on a screen.	It cannot be obtained on a screen.
2. The image is always inverted.	Image is always erect.
3. The reflected or refracted rays converge at a point producing a real image.	The reflected rays or the refracted rays appear to diverge from a point, producing a virtual image.

Definitions Related to Reflection of Light

Consider an object at a point P , let MM^l be a highly polished plane surface of a mirror.

1. The ray PO from the object, travelling towards the mirror is called **incident ray**.
2. The point ' O ' at which the incident ray meets the mirror is called **point of incidence**.
3. The ray OQ which bounces off the surface of the mirror after reflection is called **reflected ray**.
4. The perpendicular (ON) drawn to the surface of the mirror at the point of incidence is called **normal**.
5. The angle between the incident ray (PO) and the normal (ON) is called '**angle of incidence**' and is denoted by ' i '.
6. The angle between the reflected ray (OQ) and the normal (ON) is called '**angle of reflection**' and is denoted by ' r '.

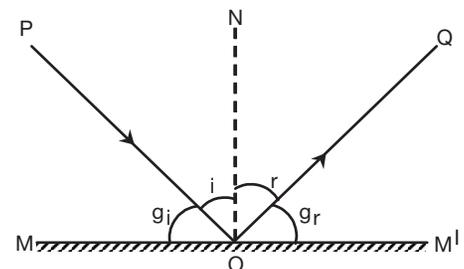


FIGURE 9.10 Reflection on a plane mirror

7. The angle between the incident ray (PO) and the reflecting surface (MM^1) is called 'glancing angle of incidence'.
8. The angle between the reflecting surface (MM^1) and the reflected ray (OQ) is called 'glancing angle of reflection'.

LAWS OF REFLECTION

It obeys the following laws:

1. The angle of incidence is equal to the angle of reflection, $\angle i = \angle r$.
2. The incident ray, the reflected ray and the normal at the point of incidence, all lie in the same plane.

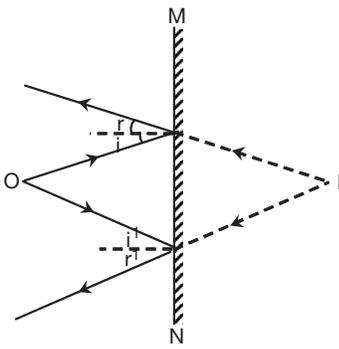


FIGURE 9.11 Reflection of a point object in a plane mirror

MIRROR

It is a smooth polished surface from which regular reflection takes place.

Reflection of a Point Object in a Plane Mirror

Consider a point object 'O' placed in front of a plane mirror as shown in the figure. To get the position of its image, we take two divergent rays from the object and consider the reflection of these two rays. The two reflected rays are divergent and do not meet each other. Hence, when we produce them backwards, they meet at the point 'I'. The point I from where the two divergent reflected rays appear to originate is the position of the image.

Reflection of an Extended Object in a Plane Mirror

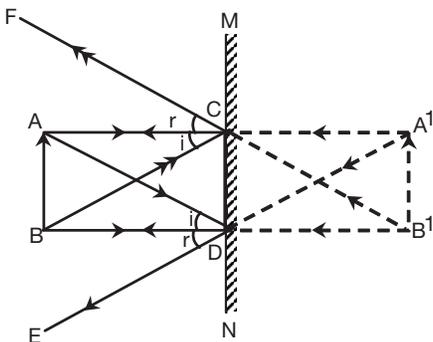


FIGURE 9.12 Reflection of an extended object in a plane mirror

Consider an extended object 'AB' placed in front of a plane mirror MN as shown in the given figure.

Consider a light ray 'AC' from position 'A' incident on the mirror at 'C'. Since the angle of incidence is zero, the angle of reflection is also zero and the light ray retraces its path and travels along 'CA'. Another light ray 'AD' from position 'A' of the object is incident on the mirror at 'D' and gets reflected along 'DE'. The two reflected rays, 'CA' and 'DE' when produced back, intersect at position 'A₁'.

The image of point 'A' of the object is formed at 'A₁'. Similarly reflection of the extended object takes place throughout the body 'AB'. When similar rays are plotted for the bottom most position of the object 'B', its image is found to be formed at position 'B₁'. Thus, the total image of the object 'AB' is formed as 'A₁ B₁'. The distance of object 'AB' from the plane mirror is equal to the distance of the image from the mirror.

Verification of the Laws of Reflection

Apparatus required: Plane mirror, pins, drawing board, white sheet, scale and a protractor.

Procedure

Fix a white sheet of paper on a drawing board with the help of drawing pins. Draw a line MM^1 and a normal NN^1 to the line. Place a plane mirror at MM^1 line vertically to the plane of paper.

Draw a line NP such that it makes an acute angle with the normal. This line represents the path of the incident ray. Fix two pins at P and Q on the path of the incident ray. From the other side of the normal look in to the mirror for the image of the pins placed at P and Q . Fix two pins P^1 and Q^1 in line with the images of the pin placed at P and Q . Remove the plane mirror. Join P^1 and Q^1 and extend the line to intersect the line PQN at N . This line NP^1 gives the path of the reflected ray. Measure $\angle PNN^1$, the angle of incidence (i) and $\angle P^1NN^1$, the angle of reflection (r). Repeat the experiment for different angles of incidence and enter the results in a tabular column.

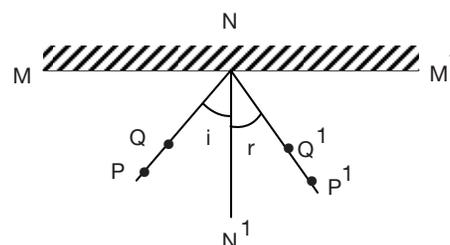


FIGURE 9.13

Observation No.	Angle of incidence = $\angle i$	Angle of reflection = $\angle r$

Observation

1. It is found that the angle of reflection is always equal to the angle of incidence.
2. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane which is perpendicular to the plane of the paper.

Conclusion

This verifies the laws of reflection.

To prove geometrically that the distance of the image from the plane mirror is equal to the distance of the object from the mirror.

Consider an object O placed at a certain distance (OB) from a plane mirror MM^1 . AN is the normal to the mirror surface. A ray such as OB incident along the normal retraces its path since the angle of incidence is equal to zero. But a ray such as OA incident at an angle ' i ' is reflected by the plane mirror AC at an angle ' r ' where, r is the angle of reflection. From the laws of reflection,

$$\angle i = \angle r \quad (9.1)$$

When the reflected ray CA and OB are produced backwards, they meet at the point I . I is the position of the virtual image of the object O .

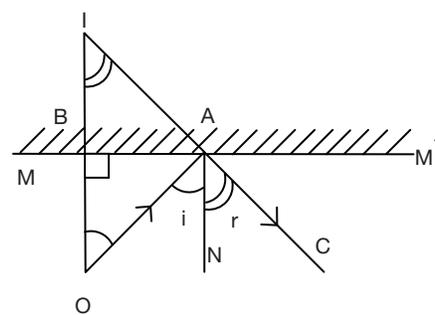


FIGURE 9.14

In the Fig. 9.14,

$$\angle BOA = \angle i \quad (9.2) \text{ (alternate angles)}$$

$$\angle BIA = \angle r \quad (9.3) \text{ (corresponding angles)}$$

from equation (9.1), (9.2) and (9.3)

$$\angle BOA = \angle BIA \quad (9.4)$$

In triangles BOA and BIA .

$$\angle BOA = \angle BIA$$

$$\angle ABI = \angle ABO \text{ (right angle)}$$

AB is common to both the triangles.

$$\therefore \triangle BOA \cong \triangle BIA.$$

Hence, $OB = IB$.

Thus, the object distance is equal to the image distance.

Effect on the Reflected Ray Due to the Rotation of a Plane Mirror

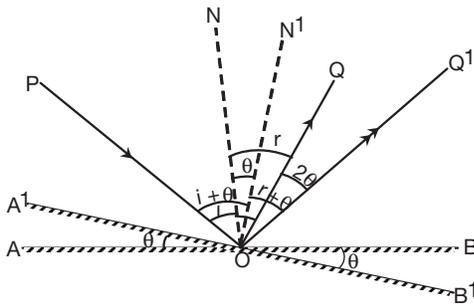


FIGURE 9.15 Effect of rotation of a plane mirror

Consider a plane mirror ‘ AB ’ as shown in the Fig. 9.15. Let ‘ PO ’ be the incident ray, ‘ O ’ the point of incidence, ‘ ON ’ the normal ray to the mirror at ‘ O ’ and ‘ OQ ’ be the reflected ray.

The angle PON is the angle of incidence $\angle i$ and the angle QON is the angle of reflection $\angle r$.

According to the laws of reflection, $\angle i = \angle r$. Now keeping the incident ray at the same position, the mirror is rotated, through a small angle ‘ θ ’ about the point of incidence to a new position ‘ A^1B^1 ’. Due to this, the normal to the mirror at the point of incidence also rotates through an angle ‘ θ ’ and the new position of the normal is ‘ ON^1 ’. Now the angle of incidence is $\angle PON^1 = \angle i + \angle \theta$. The incident ray now reflects along the path ‘ OQ^1 ’, such that the new angle of reflection is $\angle N^1OQ^1 = \angle r + \angle \theta$.

It can be seen that the reflected ray is rotated through an angle QOQ^1 .

$$\angle QOQ^1 = \angle POQ^1 - \angle POQ = [\angle PON^1 + \angle N^1OQ^1] - \angle POQ = [(i + \theta) + (r + \theta)] - [i + r]$$

$$\text{Since } i = r, \angle QOQ^1 = [(i + \theta) + (i + \theta)] - [i + i] = (2i + 2\theta) - 2i = 2\theta$$

So, when a plane mirror is rotated through an angle ‘ θ ’ about the point of incidence, the reflected ray rotates through an angle ‘ 2θ ’, irrespective of the angle of incidence.

Lateral Inversion and Inversion

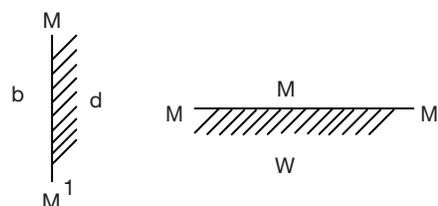


FIGURE 9.16

Lateral inversion	Inversion
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In lateral inversion the left hand side appears as the right hand side and vice versa. The image rotates around 180° about the vertical axis

In inversion, the top of the object appears as the bottom side of the image and viceversa. The image rotates around 180° about the horizontal axis.

Formation of Images by Two Mirrors

Consider two plane mirrors XY and XZ placed at right angles to each other. Let O be an object placed in front of the two mirrors. The image O_1 is formed by the mirror XZ and O_2 is the image formed by the mirror XY . O_1 acts as a virtual object for the virtual mirror XY^1 (image of XY) and O_2 acts as a virtual object to the virtual mirror XZ' (image of XZ). The images formed by the virtual objects formed by the image mirrors coincide at O_3 . Since O_3 lies behind both the mirrors, no further reflections take place. Thus, only three images can be formed when two plane mirrors are kept perpendicular to each other.

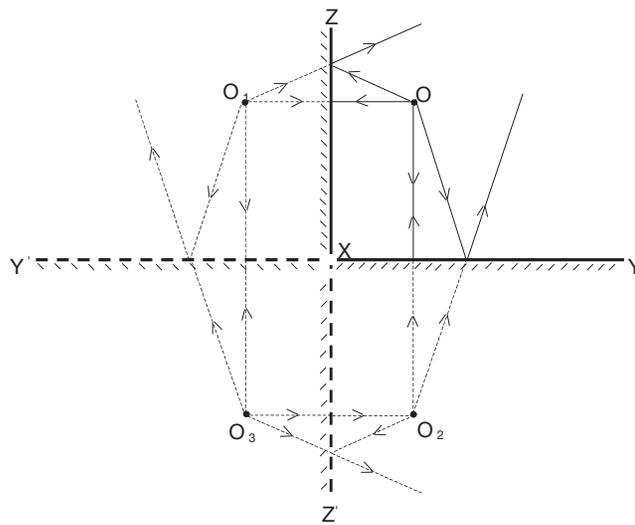


FIGURE 9.17

2. When two mirror are kept parallel to each other.

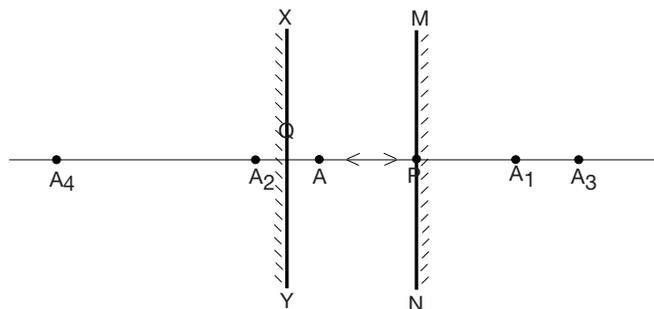


FIGURE 9.18

Consider two mirrors MN and XY placed parallel to each other, as shown in the figure. Let A be an object placed between them (see Fig. 9.18).

A_1 is the image of the object formed by the mirror MN . A_1 acts as an object for the mirror XY and the mirror XY forms an image A_2 . Image A_2 falls in front of the mirror MN , and hence, image A_3 is formed by the mirror MN . This continues, and hence, an infinite number of images are formed by the two parallel mirrors. But in practice we are unable to see infinite number of images, because the intensity of light from the images decreases after each successive reflection and the eye is unable to resolve the image once it is formed beyond the far point of the eye.

If two mirrors are inclined at an angle θ , the number of images formed is given by,

$$n = \frac{360}{\theta} - 1$$

Minimum Length of a Plane Mirror Required to View Full Image

It is not possible for us to view our full image in a small plane mirror. At the same time, a full length mirror is also not required to view a full-length image. What is the minimum length of the plane mirror required to observe our full image? This can be determined by observing the following ray diagram (Fig. 9.19).

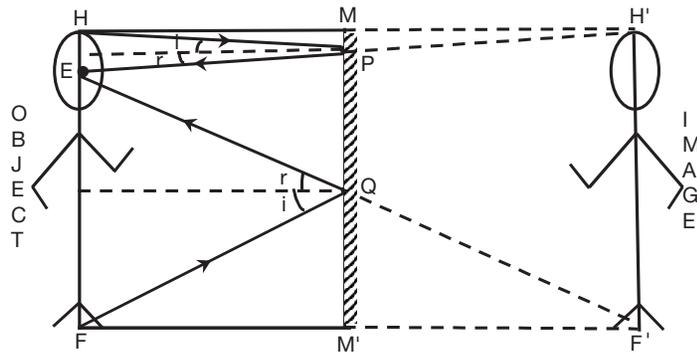


FIGURE 9.19

From the figure, it is clear that the portion PQ of the full length mirror MM' alone is sufficient to view the full-length image of a person. To find the length of the effective mirror PQ and the length QM' at which it has to be placed above the ground level, let us consider the ΔHPE and ΔEQF as illustrated in the Fig. 9.20.

Draw PR and QS perpendicular to HF .

Since $\angle i_1 = \angle r_1$, and $\angle i_2 = \angle r_2$ (i.e., angle of incidence = angle of reflection),

$$HR = RE = \frac{HE}{2} \tag{9.1}$$

$$SF = ES = \frac{EF}{2} \tag{9.2}$$

Now, $PQ = RS$

$$= RE + ES = \frac{HE}{2} + \frac{EF}{2} \text{ (from equation 9.1 and 9.2)}$$

$$= \frac{HE + EF}{2} = \frac{HF}{2} = \frac{1}{2} \text{ (The height of the person viewing his image)}$$

Also, $QM' = SF = \frac{1}{2}EF$ (The eye level from the ground)

We can conclude the following about the image formed by a plane mirror:

1. Same size as that of the object.
2. At same distance behind the mirror as the object is in front of the mirror.
3. Erect but laterally inverted.
4. Virtual.
5. Keeping the incident ray constant, if the mirror is rotated by an angle ' θ ', the reflected ray is rotated by an angle ' 2θ '.
6. When two plane mirrors are kept inclined such that they make an angle of ' θ ' with each other, multiple images are obtained. The number of images formed is given by, the expression,

$$n = \frac{360}{\theta} - 1$$

Uses of Plane Mirrors

1. Plane mirrors are primarily used as looking glasses.
2. Since a combination of mirrors can produce multiple images, they are used to provide false dimensions in showrooms.
4. They are also used as reflectors in solar cookers.
5. Plane mirrors are used in the construction of a periscope.

Reflecting Periscope

It consists of a wooden or a cardboard tube bent twice at right angles Fig. 9.21. The inner side of the tube is blackened to prevent reflection. Two plane mirrors M_1 and M_2 are placed at the bent portion of the tube. The mirrors are placed such that the light rays are incident at an angle of 45° . The light rays are incident on the plane mirror M_1 and the reflected rays from this mirror are incident on the second mirror M_2 at the same angle of incidence. Thus, the light rays undergo a reflection for a second time at an angle of 45° , and emerge from the lower tube, where the image of the object is viewed.

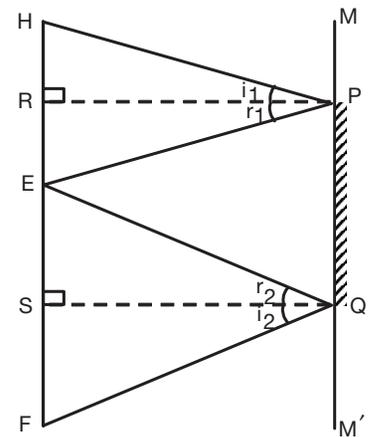


FIGURE 9.20

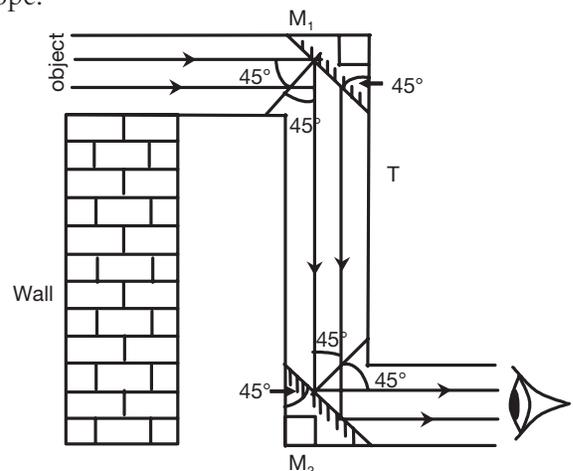


FIGURE 9.21 Reflecting periscope

Uses of a Reflecting Periscope

1. It is used by soldiers to view the enemy movements during wars.
2. It is used in submarines to see objects above the water surface.

Disadvantages of a Reflecting Periscope

1. The periscope cannot be used in places of dust and fog. The deposition of the dust does not give rise to proper reflection.
2. The final image is not bright due to successive reflections.

SPHERICAL MIRRORS

Mirrors used by dentists, the rear view mirrors in vehicles, the reflectors in electric torches, the mirrors used for monitoring in shops, etc., are not plane mirrors, but are mirrors with spherical surfaces.

Spherical mirrors are a part of hollow glass spheres.

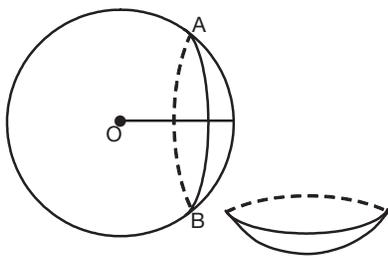


FIGURE 9.22 Hollow glass sphere and a section of it

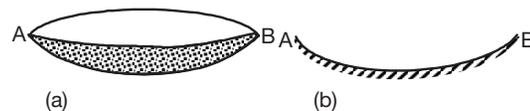


FIGURE 9.23 (a) Concave mirror formed by silver coating the outer side (b) Symbolic representation of a concave mirror

If a portion of a hollow sphere is silvered or polished on the inner side, the outer side or the bulging side becomes the reflecting surface and this is referred to as a convex mirror.

If the bulging side or the outer side is silvered, then the inner side becomes the reflecting surface and this mirror is referred to as a concave mirror.

General Terms Related to a Spherical Mirror

To understand reflection at spherical surface, we need to know some of the terms related to spherical mirrors.

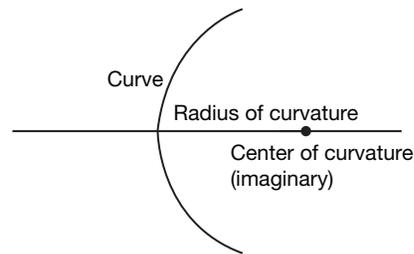
Aperture: The portion of the mirror which reflects light or where light is incident is called an aperture. APB is the aperture.

Pole: The mid point of the aperture is the pole. P is the pole.

Centre of curvature: It is the centre of the hollow sphere of which the spherical mirror is a part. It is denoted by C .

Principal axis: The line passing through the pole and the centre of curvature is called principal axis. Thus, the line passing through P and C is the principal axis.

Radius of curvature: The reflecting portion of a spherical mirror is a part of a sphere. Thus, the radius of the sphere from which the spherical mirror is made is called radius of curvature.



Principal Focus

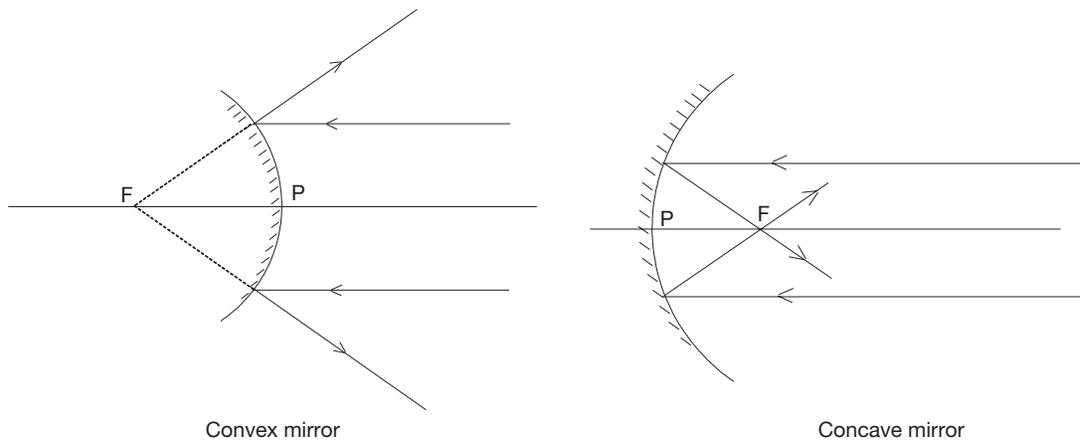


FIGURE 9.24

It is the point on the principal axis where the incident rays of light parallel to the principal axis after reflection at the spherical mirror converge in the case of a concave mirror or appear to diverge from, in the case of a convex mirror. This point is represented by F . Thus, concave mirror is a converging mirror and convex mirror is a diverging mirror.

Focal length: It is the distance between the principal focus and the pole of the spherical mirror. The distance between P and F is the focal length. It is denoted by ' f '.

Relation between Focal Length and Radius of Curvature

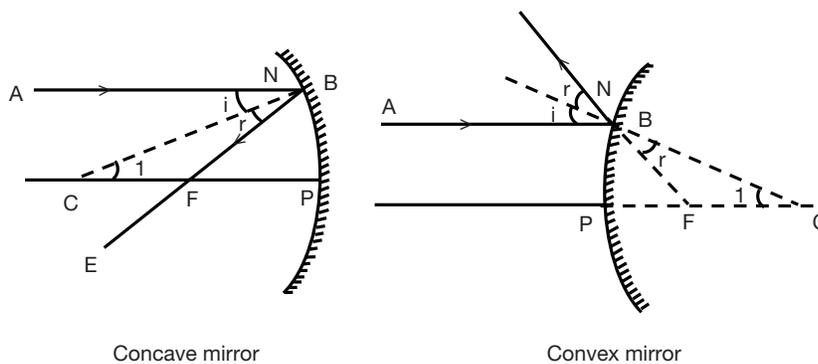


FIGURE 9.25

Consider a spherical mirror of radius of curvature R and focal length $PF = f$. CN is the normal to the spherical surface of the mirror. (A line drawn through the centre of a circle is normal to the circle at the point of intersection).

A ray AB parallel to the principal axis incident at an angle i is reflected along BE at an angle ' r '. The reflected ray passes through the principal focus F in the case of concave mirror and it appears to come from principal focus, in the case of convex mirror.

From the laws of reflection

$$\angle i = \angle r \quad (9.1)$$

From the figure

$$\angle i = \angle 1 \quad (9.2)$$

(Alternate angles in figure of concave mirror and corresponding angles in figure of concave mirror).

Comparing equation (9.1) and (9.2), we get

$$\begin{aligned} \angle r &= \angle 1 \\ \therefore BF &= FC \end{aligned} \quad (9.3)$$

For small apertures, i.e., for rays close to the principal axis,

$$\therefore BF \text{ is nearly equal to } PF \quad (9.4)$$

\therefore from equation (9.3) and (9.4)

$$PF = FC \quad (9.5)$$

The radius of curvature

$$PC = PF + FC$$

$$PC = PF + PF (\because \text{from (9.5) } FC = PF)$$

$$\therefore R = 2PF$$

$$R = 2f$$

$$\text{or } f = \frac{R}{2}$$

NOTE

The relation is applicable only to small apertures where the incident rays are close to the principal axis.

Rules for the Construction of Ray Diagrams Formed in Spherical Mirrors

To know the position and nature of the image of an object formed by a spherical mirror, any two of the following light rays coming from a point on the object are taken.

1. A light ray parallel to the principal axis incident on a spherical mirror, after reflection, passes through the principal focus in the case of a concave mirror and appears to come from the principal focus in the case of a convex mirror (Fig. 9.26).

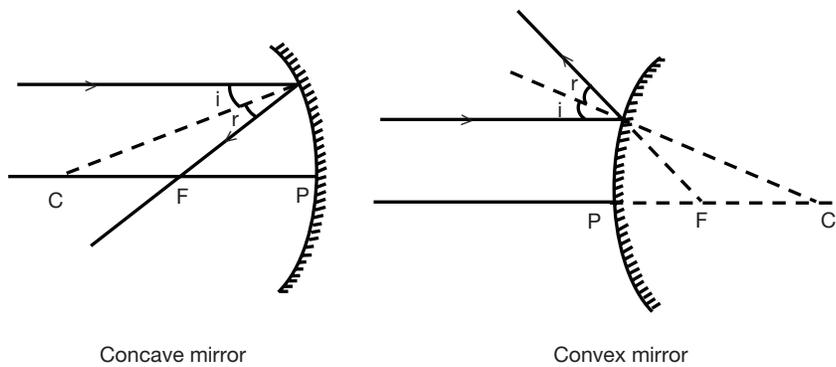


FIGURE 9.26

2. A light ray passing through the principal focus and incident on a concave mirror, or a light ray which is directed towards the principal focus and is incident on a convex mirror, is reflected parallel to its principal axis.

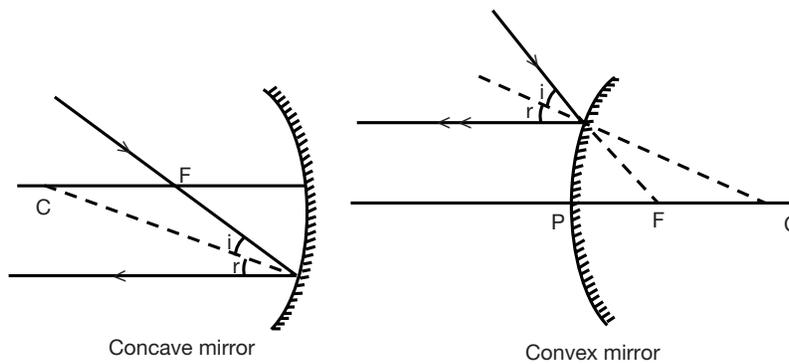


FIGURE 9.27

3. A light ray passing through the centre of curvature and incident on a concave mirror, or a light ray directed towards the centre of curvature and incident on a convex mirror, after reflection, retraces its path.

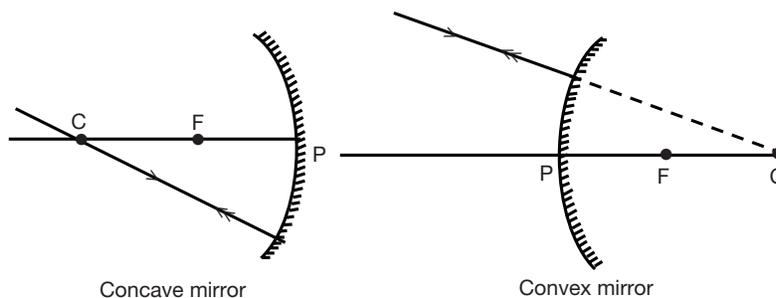


FIGURE 9.28

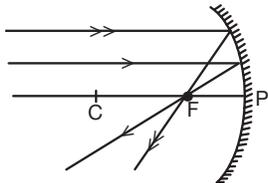
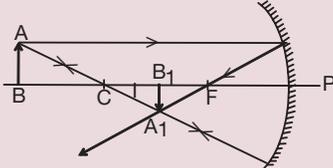
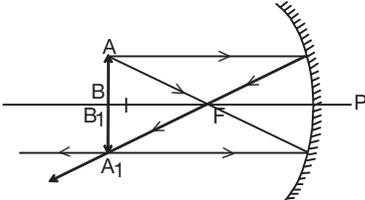
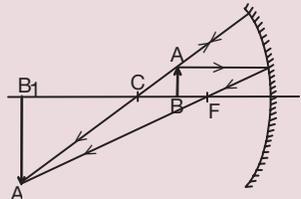
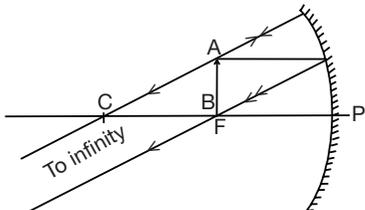
Geometrical Construction of the Formation of an Image in a Spherical Mirror

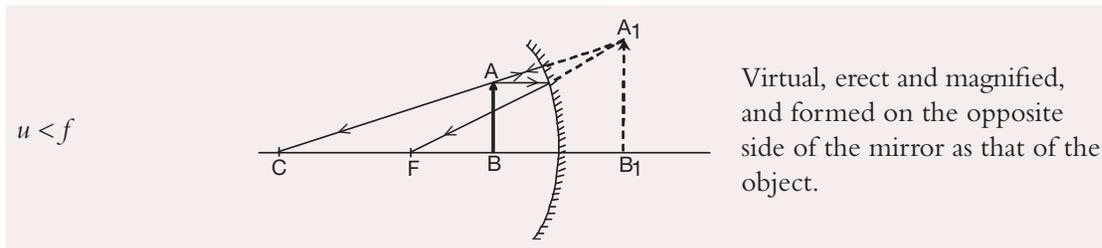
Draw an object AB (as a vertical line with an arrow-head at the top) such that the base of the object is on the principal axis. From the tip of the arrow-head, say A, draw any two of

the three rays, one passing parallel to the principal axis, one passing through principal focus F and one passing through C . From the point of incidence of these rays on the spherical mirror, draw the corresponding reflected rays as per the rules indicated earlier. The two reflected rays could be 1. parallel to each other 2. converging rays 3. diverging rays.

1. If the reflected rays are parallel to each other, the position of the image is said to be at infinity.
2. If the rays are converging rays, the point of their intersection say A' , gives the position of the real image of the point A . From this point, draw a perpendicular to the principal axis and this perpendicular line would represent the real image of the object.
3. If the reflected rays are diverging rays, produce the rays backwards to intersect at a point behind the mirror. This point of intersection say A' gives the position of virtual image of the point A . The perpendicular from A' to the principal axis gives the position of the virtual image of the object.

Table for Formation of Images in a Concave Mirror

Object distance	Ray diagram	Nature and position of image
$u = \infty$		Real, inverted and highly diminished, $v = f$ formed at the focus (F).
$R < u < \infty$		Real, inverted and diminished, formed between F and C . $f < v < R$
$u = R$		Real, inverted and of equal size as that of object, $v = R$, formed at C .
$f < u < R$		Real, inverted and magnified, $v > R$, formed beyond C .
$u = f$		Real, inverted and highly magnified, $v = \infty$



When the object is at infinity and the rays are not parallel to the principal axis, then the image is real, inverted and highly diminished and forms on the focal plane.

Formation of Images by a Convex Mirror

Wherever the object is placed, the image formed by a convex mirror is always erect, virtual and diminished. The only difference is that when the object is at infinity, the image is highly diminished and is formed at the principal focus. When the object is placed at any other position, the position of the image lies between the principal focus and the pole of the mirror as shown in the following figure.

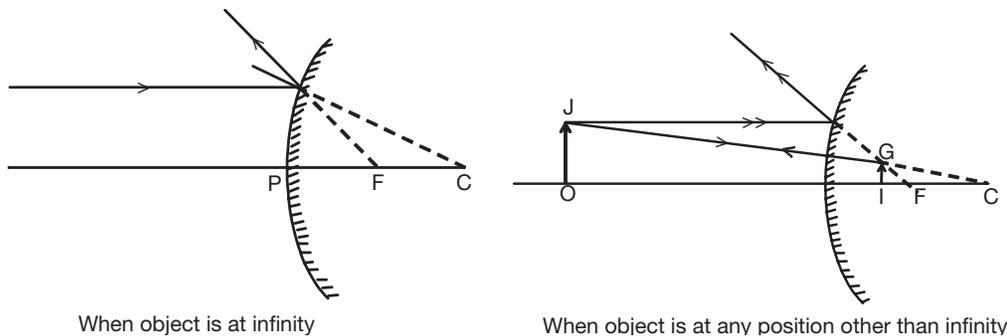


FIGURE 9.29

Mirror Formula and Cartesian Sign Convention

The mirror formula is as, $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ where f , u and v are focal length of spherical mirror, object distance, and image distance, respectively. This formula is applicable to both convex and concave mirrors.

In order to solve numerical problems related to images formed by spherical mirrors in an easy manner, positive and negative signs are adopted. These rules are known as the Cartesian sign convention. They are as follows:

1. All distances parallel to the principal axis are measured from the pole of the spherical mirror.
2. The distances measured in the direction of the incident light are taken as positive.

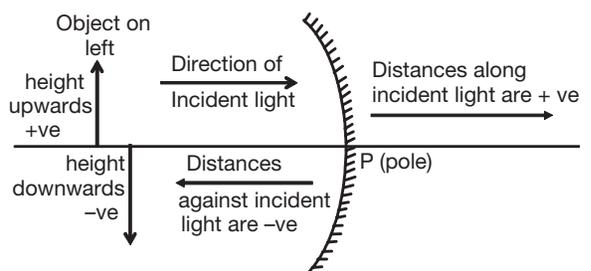


FIGURE 9.30 Cartesian sign convention

3. The distances measured in a direction opposite to the direction of incident light are taken as negative.
4. The heights of objects or images measured upwards (above the principal axis) and perpendicular to the principal axis are considered as positive.
5. The heights of objects or images measured downwards (below the principal axis) and perpendicular to the principal axis are considered as negative.

Relation Between Object Distance, Image Distance and Focal Length of a Spherical Mirror : Mirror Formula

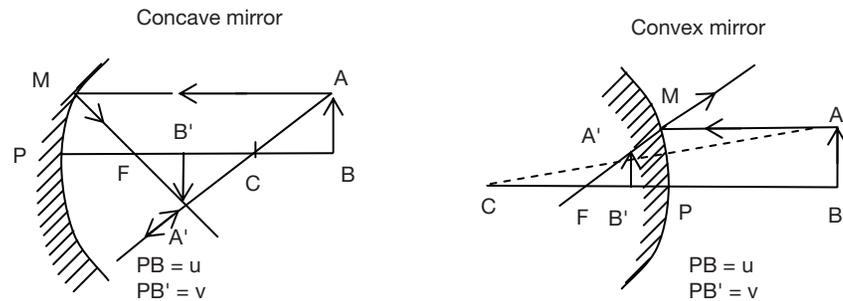


FIGURE 9.31

Consider a spherical mirror of radius of curvature R . Let AB be an object placed at a distance ' u ' from the pole P of the mirror. Making use of the ray diagram, image $A'B'$ is obtained. Let ' v ' be the distance of the image from the pole.

From similar triangles ABC and $A'B'C$

$$\frac{AB}{A'B'} = \frac{BC}{B'C} \quad (9.1)$$

From similar triangles $A'B'F$ and PMF

$$\frac{PM}{A'B'} = \frac{PF}{B'F} \quad (9.2)$$

But $PM \cong AB$ (for small apertures, and when incident rays are close to the principal axis)
 \therefore equation (9.2) can be written as

$$\frac{AB}{A'B'} = \frac{PF}{B'F} \quad (9.3)$$

comparing equation (9.1) and (9.3)

$$\frac{PF}{B'F} = \frac{BC}{B'C} \quad (9.4)$$

$$PF = \text{focal length} = f$$

$$PC = R$$

$$PB = u$$

$$PB' = v$$

Concave Mirror

$$\frac{PF}{PB' - PF} = \frac{PB - PC}{PC - PB'}$$

using sign convention

$$\frac{-f}{-v - (-f)} = \frac{-u - (-R)}{-R + v}$$

$$\frac{-f}{-v + f} = \frac{-u + R}{-R + v}$$

$$fR - fv = +uv - vR - uf + fR$$

$$fv = uv - vR - vR - uf \text{ or}$$

$$-uv + vR - vf + uf = 0$$

$$\text{But } R = 2f$$

$$\therefore -uv + v(2f) - vf + uf = 0$$

$$-uv + 2vf - vf + uf = 0$$

$$-uv + vf + uf = 0$$

Dividing the above equation by uvf

$$\frac{-1}{f} + \frac{1}{u} + \frac{1}{v} = 0 \text{ or } \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Convex Mirror

$$\frac{PF}{PF - PB'} = \frac{PB + PC}{PC - PB'}$$

using sign convention

$$\frac{f}{f - v} = \frac{-(u) + R}{R - v}$$

$$\frac{f}{f - v} = \frac{-u + R}{R - v}$$

$$fR - fv = -uf + uv + fR - vR \text{ or}$$

$$-fv = -uf + uv - vR$$

$$\text{But } R = 2f$$

$$\therefore -fv = -uf + uv - v(2f) \text{ or}$$

$$uf - uv + 2vf - vf = 0$$

$$uf - uv + vf = 0$$

Dividing throughout by uvf

$$\frac{1}{v} - \frac{1}{f} + \frac{1}{u} = 0 \text{ or } \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \text{ is called mirror formula.}$$

The mirror formula is the same whether the mirror is concave or convex.

Magnification

It is the ratio of the height of the image to that of the object.

$$\therefore \text{magnification, } m = \frac{\text{height of image}(hi)}{\text{height of the object}(ho)} = \frac{AB}{A'B'}$$

$$m = \frac{-v}{u}$$

m is negative for a real image and positive for a virtual image.

Uses of Spherical Mirrors

1. Convex mirror is a diverging mirror and it produces virtual, diminished image. So, it is used as a side view mirror for vehicles so that the driver can observe a wide range of vehicles coming behind his vehicle.
2. Convex mirrors, at times, are placed at the traffic junctions where signals are not provided so that during the day time, drivers of the vehicles moving along one direction can be aware of any vehicle moving across their path.

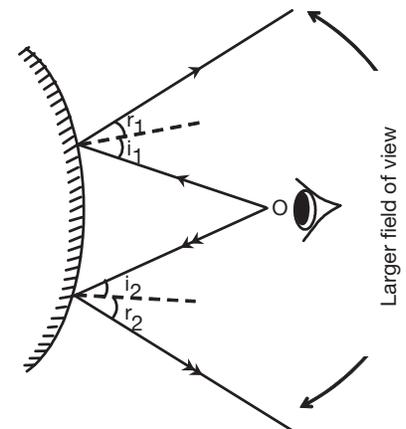


FIGURE 9.32

- Convex mirrors are also placed in some of the ATM centres at a certain height above the machine. This is done as a security measure. The person operating the ATM machine will be aware of others who are behind him by observing in the convex mirror.

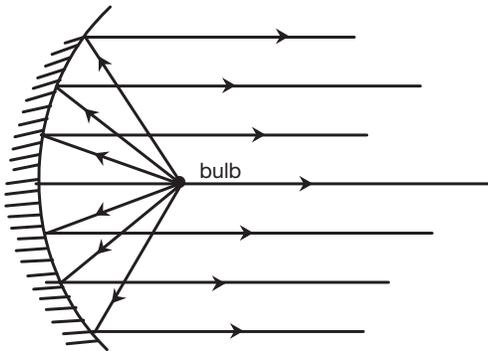


FIGURE 9.33

- Concave mirrors are used to produce magnified virtual images. So, these can be used as shaving mirrors.
- Due to their ability to produce magnified virtual images, these mirrors are used by dentists and E.N.T. specialists to view the interior portions of a body clearly.
- Concave mirrors can be used as reflectors of light. When a bulb is kept at the focus of the mirror, we obtain a parallel beam of light reflected from the mirror as shown in the figure.
- Concave mirrors are used in solar devices to reflect light rays.

Experiment to Find the Radius of Curvature of a Concave Mirror

Apparatus

Concave mirror, mirror stand, illuminated wire mesh or an illuminated object, source of light, scale and a screen.

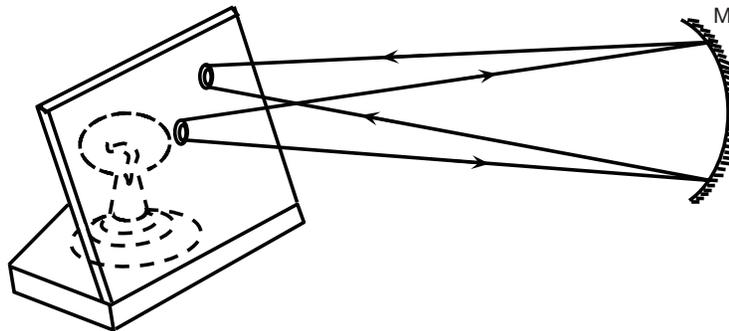


FIGURE 9.34 Radius of curvature of a concave mirror

Procedure

- Mount the given concave mirror on the mirror stand.
- Place the mirror in front of an illuminated wire mesh or a candle.
- Adjust the distance of the mirror so that a well defined image of the object is formed on the screen placed by the side of the object.
- Measure the distance between the object and the concave mirror. This gives the radius of curvature of the given mirror.

Determine the Focal Length of a Concave Mirror

1. By Distant Object Method

Apparatus required: Concave mirror, mirror stand, screen and a meter scale.

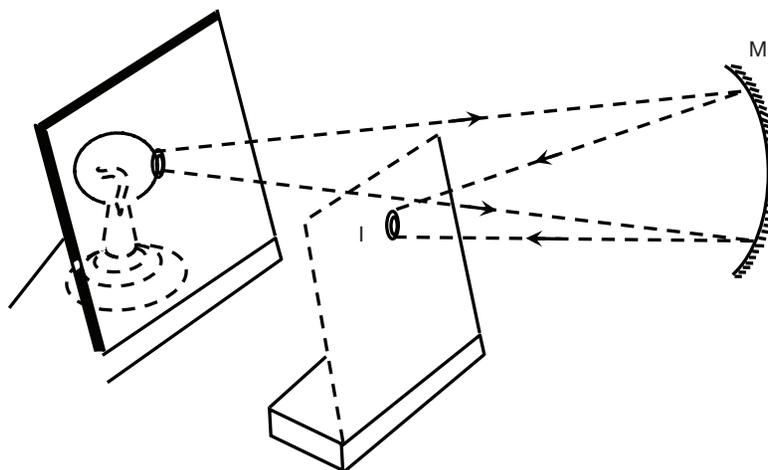


FIGURE 9.35

Procedure

1. Mount the given concave mirror on a mirror stand.
2. Turn the mirror towards a distant object such as a tree or a window.
3. Place a white screen in front of the mirror and adjust the position of the screen until a sharp image of the object is obtained, on the screen.
4. Measure the distance between the screen and the mirror. This distance gives the focal length of the given mirror (as the incident rays of light are parallel to the principal axis, they converge on the principal focus, after reflection).

2. By $u - v$ Method

Apparatus required: Concave mirror, mirror stand, an illuminated object, screen and a meter scale.

Procedure

1. Mount the given concave mirror on a mirror stand.
2. Place an illuminated object at a certain distance in front of the mirror.
3. Introduce a screen between the object and the mirror.
4. Adjust the screen, until a sharp, well defined inverted image of an object is obtained.
5. Measure the distance between the object and the mirror. This gives the object distance, u .
6. Measure the distance between the screen and the mirror. This gives the image distance, v .

7. The focal length of the lens is calculated using the formula

$$f = \frac{uv}{u+v} \left[\begin{array}{l} \because \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \\ \frac{1}{f} = \frac{v+u}{uv} \end{array} \right]$$

8. Repeat the experiment for different object distances and note down the image distance and find its focal length. Tabulate the result.

Observation No.	u in m	v in m	$f = \frac{uv}{u+v}$ m

The focal length of a given concave mirror can be calculated graphically too.

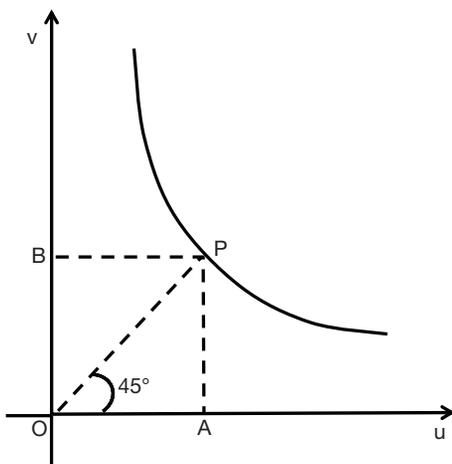


FIGURE 9.36 Focal length of a concave mirror –uv method

Graphical method: The experiment is conducted as described above and the results are tabulated.

A graph is plotted taking a suitable scale with u along the X-axis and v along the Y-axis. A curve is obtained as shown Fig 9.36.

Draw a straight line OP from the origin making an angle of 45° with X-axis and intersecting the curve at point P. Drop perpendiculars from P to the X and Y-axes meeting them at A and B, respectively.

Measure the distance OA as well as OB.

It will be found that OA and OB are almost equal to each other. This 'R' is equal to the radius of curvature of the concave mirror.

$$\text{Focal length} = \frac{\text{Radius of curvature}}{2}$$

EXAMPLE

A convex mirror is made by cutting a hollow sphere of radius of curvature 20 cm. Find the focal length of the mirror.

SOLUTION

In the given problem, radius of curvature, $R = 20$ cm.

$$\text{Focal length of the mirror} = \frac{\text{Radius of curvature}}{2}$$

$$\therefore \text{focal length, } f = \frac{20}{2} = 10 \text{ cm.}$$

EXAMPLE

An object is placed at 20 cm from the pole of a concave mirror. It forms real image at a distance of 60 cm from the pole. Find the focal length of the concave mirror.

SOLUTION

In the given problem,

Object distance, $u = -20$ cm (using Cartesian sign convention)

image distance, $v = -60$ cm (using Cartesian sign convention for real image)

Focal length of the mirror is given by,

$$\begin{aligned}\frac{1}{f} &= \frac{1}{u} + \frac{1}{v} \\ \frac{1}{f} &= \frac{-1}{20} - \frac{-1}{60} \\ \frac{1}{f} &= \frac{-(60 + 20)}{60 \times 20} = \frac{-80}{1200} \\ f &= \frac{-1200}{80} = -15 \text{ cm}\end{aligned}$$

The focal length of the given concave mirror is 15 cm.

EXAMPLE

An object is placed at a distance of 10 cm from the pole of a convex mirror of focal length 15 cm. Find the nature and position of the image.

SOLUTION

In the given problem,

Object distance, $u = -10$ cm (By using Cartesian sign convention)

Focal length of a convex mirror, $f = +15$ cm (By sign convention)

$$\begin{aligned}\frac{1}{f} &= \frac{1}{u} + \frac{1}{v} \\ \Rightarrow \frac{1}{v} &= \frac{1}{f} - \frac{1}{u} \\ \Rightarrow \frac{1}{v} &= \frac{1}{15} - \frac{1}{-10} \\ v &= \frac{150}{25} = 6 \text{ cm.}\end{aligned}$$

Positive sign indicates that the image is virtual.

$$\text{Magnification} = \frac{-v}{u} = \frac{-6}{-10} = 0.6$$

Since ' m ' is positive and less than one, the image is erect and diminished.

An erect, virtual, and diminished image is formed at 6 cm from the pole, behind the mirror.

EXAMPLE

A concave mirror of focal length 8 cm forms an inverted image of an object placed at a certain distance. If the image is twice as large as the object, where is the image formed?

SOLUTION

In the given problem,

magnification, $m = -2$ (since the image is inverted m is negative).

$m = \frac{hi}{ho} = -2$ where ' hi ' and ' ho ' are heights of the image and the object, respectively.

$$m = \frac{-v}{u}$$

$$\therefore m = \frac{v}{u} = 2$$

$$v = 2u$$

focal length of a concave mirror = -8 cm.

(using sign convention)

From mirror formula,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{-8} = \frac{1}{u} + \frac{1}{2u}$$

$$-8 = \frac{2u}{3}$$

$$2u = 3 \times (-8)$$

$$u = \frac{3 \times -8}{2} = 3 \times (-4) = -12 \text{ cm}$$

The object is placed at a distance of 12 cm from the pole of the concave mirror.

Image distance $v = 2u$

$$v = 2 \times (-12)$$

$$v = -24 \text{ cm.}$$

The image is formed at a distance of 24 cm from the pole, and is formed on the same side of the mirror where the object is kept.

Refraction of Light

Any object seen through a paper weight made of glass appears distorted. This is due to the bending of light rays when they travel from glass to air.

The Sun appears slightly elliptical at sunrise and sunset due to a similar phenomenon involving bending of light rays as they pass through different layers of the atmosphere.

Activity

Place a coin in an empty bowl and look for the coin through the edge of the bowl, the coin is invisible. Fill the cup with water and look for the coin. It will be visible and will appear to be raised up. This again is due to a phenomenon based on the bending of light rays as they travel from water to air.

Whenever a light ray travels from one transparent medium to another transparent medium, it bends at the interface. This bending of light when it travels from one transparent medium to another is known as refraction.

The bending of light when it travel from one transparent medium to another occurs due to the difference in the optical densities of the media.

In the figure, 'PO' indicates the incident ray, 'O' is the point of incidence and 'OQ' is the refracted ray. 'MON' is line drawn at the point of incidence, perpendicular to the boundary separating the two media and is called 'normal'.

The angle between the incident ray 'PO' and the normal is known as the angle of incidence (i) and the angle between the normal and the refracted ray 'OQ' is known as the angle of refraction (r).

In the absence of the second medium, the light ray would go along 'POR'. Since the light ray has encountered a different medium, it deviates from its original path and travels along 'POQ'. Hence, the amount of deviation can be measured by $\angle ROQ$ and is known as the angle of deviation which is equal to the difference in the angle of incidence and the angle of refraction ($i \sim r$). It is denoted by S.

$$\therefore S = i - r$$

Refractive Index

Light is considered to be travelling in the form of waves. A wave has some characteristics like wavelength, frequency and velocity.

These three parameters (i.e., physical quantities which can be measured) are related as $v = n\lambda$ where v , n and λ are velocity, frequency and wavelength, respectively.

When light travels from one transparent medium to another, a change in the wavelength of light occurs due to change in the density (more specifically optical density, because density is considered with reference to propagation of light) of the medium. But the frequency of light (i.e., the number of light waves produced in unit time) does not change. This results in a change in the velocity of light when it travels from one transparent medium to another.

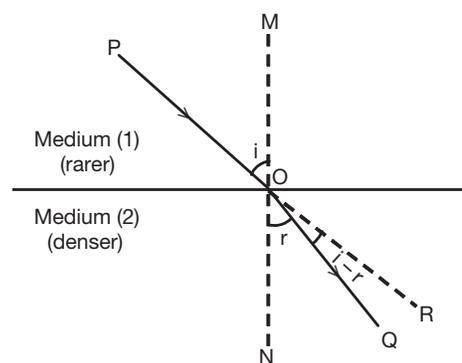


FIGURE 9.37 Refraction of light

For a given pair of media, the ratio of the velocity of light in the two media is constant, which is known as the refractive index of one medium with reference to the other medium.

Consider a light ray travelling from air, or vacuum, to glass. Let ‘ c ’ and ‘ v ’ be the velocity of light in air, or vacuum, and glass, respectively. Then the ratio $\frac{c}{v}$ is constant and is known as the absolute refractive index of glass. The standard symbol for denoting refractive index is ‘ μ ’.

$$\therefore \mu = \frac{c}{v}$$

We define refractive index, or absolute refractive index, of a material as “the ratio of velocity of light in air or vacuum to the velocity of light in the medium”.

To calculate the refractive index of any medium, air or vacuum is taken as the reference medium. Velocity of light is higher in rarer mediums than in denser mediums. For a given pair of media, the refractive index is calculated for denser medium with reference to rarer medium.

Thus, refractive index of a denser medium with respect to a rarer medium, μ_{dr} is defined as ‘the ratio of the velocity of light in rarer medium to the velocity of light in denser medium’.

i.e.,

$$\mu_{dr} = \frac{v_r}{v_d}$$

If v_1 and v_2 are the velocities of light in the rarer (1st) and denser (2nd) medium, respectively, then the refractive index of the 2nd medium with reference to the 1st medium is given by,

$$\mu_{21} = \mu_2 / \mu_1$$

If ‘ c ’ is the velocity of light in air or vacuum, then refractive index of the 1st medium with respect to air or vacuum (or simply known as refractive index of 1st medium) is given by,

$$\mu_1 = \frac{c}{v_1}$$

Similarly refractive index of the 2nd medium is given by,

$$\mu_2 = \frac{c}{v_2}$$

$$\text{But, } \mu_{21} = \frac{v_1}{v_2}$$

$$\Rightarrow \mu_{21} = \frac{\left(\frac{c}{\mu_1}\right)}{\left(\frac{c}{\mu_2}\right)}$$

$$\therefore \mu_{21} = \frac{\mu_2}{\mu_1}$$

Sometimes μ_{21} is also represented as ${}_1\mu_2$ or ${}^1\mu_2$.

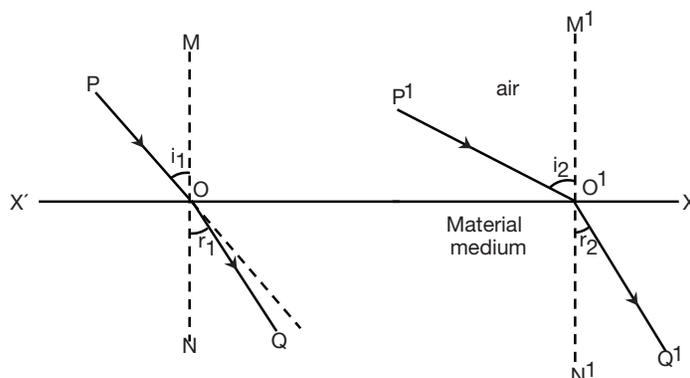
NOTE

1. Optical density is an optical property of a transparent material and refractive index is the measure of that property.
2. The higher the refractive index of a material, the more the light bends.
3. Since refractive index is the ratio of two velocities, it does not have any unit.

SNELL'S LAW

It is difficult to calculate the refractive index of a transparent material by means of measuring the velocity of light in the medium, Snell has developed a formula which helps us to easily calculate the refractive index of a given medium.

Consider a light ray 'PO', travelling through air. It is now incident on the plane surface X'X of a transparent material, as shown in Fig. 9.38.

**FIGURE 9.38**

As the light ray travels from air (rarer) to a material medium (denser), it bends towards the normal and moves along 'OQ'. The angles of incidence and refraction are shown as ' i_1 ', and ' r_1 ', respectively. If another light ray ' P^1O^1 ' is incident at another point ' O^1 ' with an increased angle of incidence, say ' i_2 ', the angle of refraction too increases to ' r_2 '.

In both the cases, the ratio of sine of the 'angle of incidence' to sine of the 'angle of refraction' is found to be constant, and is numerically equal to the refractive index of the material.

Mathematically,

$$\mu = \frac{\sin(i)}{\sin(r)} = \frac{\sin(i_1)}{\sin(r_1)} = \frac{\sin(i_2)}{\sin(r_2)}$$

where ' i ' and ' r ' are the angles of incidence and refraction, respectively, and ' μ ' is the refractive index of the medium. The above mathematical expression is known as Snell's law.

As it is easy to measure the incident and refracting angles, it becomes easy to calculate the refractive index of a given material.

Laws of Refraction

Whenever a light ray undergoes refraction at a point, it obeys the following laws:

1. The incident ray, the refracted ray, and the normal to the interface at the point of incidence – all lie in the same plane.
2. For a given pair of media, and for a given colour, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant.

$$\frac{\sin i}{\sin r} = \text{constant}$$

ATMOSPHERIC REFRACTION

Earth is surrounded by an atmosphere. The density of air in the atmosphere is not the same throughout. The refractive index which depends on density varies in the atmosphere. Higher the density of air greater will be the refractive index.

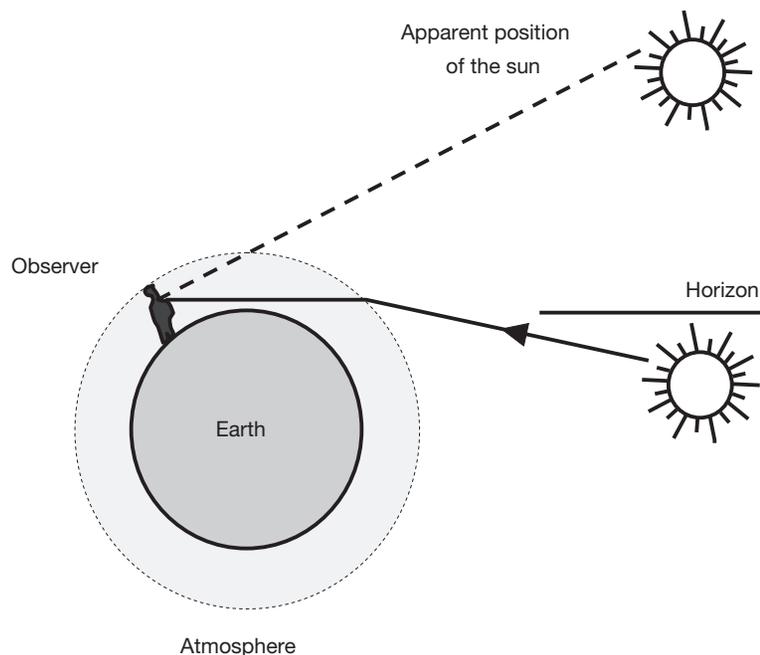


FIGURE 9.39 Atmospheric refraction effects at sunrise and sunset

At sunrise or at sunset, the sun is either at the horizon or just below the horizon. Hence, the light rays from the sun have to travel a longer distance through the atmosphere than when the sun is at any other position. As the rays travel from rarer medium to denser medium, they bend more and more towards the observer or the normal. Hence, there is change in the altitude of the sun. Thus, the sun appears at a higher position than it actually is Fig. 9.39. Moreover, when the sun is at the horizon, the rays from the lower region of the sun's disc travel a longer distance than the rays from the upper region of the sun. As a result, the rays from the lower region of the sun bend more than those from the upper region. Hence, the lower region or the lower portion of the disc of the sun is raised more than the upper portion of the disc. Hence, the Sun appears slightly oval in shape Fig. 9.40.

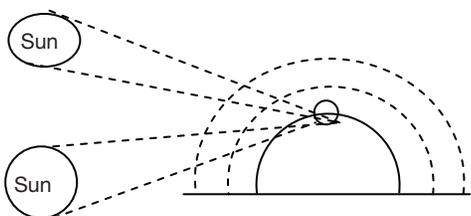


FIGURE 9.40

Twinkling of Stars

The twinkling of stars is due to atmospheric refraction. Light rays from the stars travel through the atmosphere of varying densities. As a result, the path of the light ray changes continuously. This causes a continuous variation in the amount of light reaching the eye. Hence, the stars appear to twinkle. The stars at the horizon twinkle more than the stars at higher positions in the sky.

Critical Angle

When a light ray travels from a denser medium to a rarer medium, it bends away from the normal, and hence, the angle of refraction is greater than the angle of incidence. As the angle of incidence in the denser medium is increased gradually, the angle of refraction in the rarer medium also increases and at a particular angle of incidence in the denser medium, the angle of refraction in the rarer medium is 90° , as shown in the Fig. 9.41.

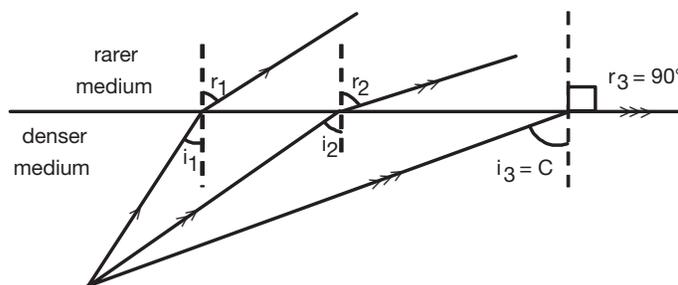


FIGURE 9.41 Critical angle

This angle of incidence in the denser medium, for which the angle of refraction in the rarer medium is 90° , is known as critical angle (C).

Since the light ray can retrace its path, if ' r_1 ' is the angle of incidence in the rarer medium, the corresponding angle of refraction in the denser medium is ' i_1 '. Similarly, if ' r_2 ' is the angle of incidence in the rarer medium, the corresponding angle of refraction in the denser medium is ' i_2 '. So, we can write the refractive index of the given denser medium with reference to the rarer medium as

$$\mu_{21} = \frac{\sin r_1}{\sin i_1} = \frac{\sin r_2}{\sin i_2} = \frac{\sin r_3}{\sin i_3}, \text{ since } r_3 = 90^\circ$$

$$\mu_{21} = \frac{\sin r_3}{\sin i_3} = \frac{\sin 90^\circ}{\sin C} \therefore \mu_{21} = \frac{1}{\sin C}$$

Here, ' C ' is the critical angle of the given denser medium with respect to the given rarer medium.

The critical angle of a given denser medium with respect to a given rarer medium is defined as 'the angle of incidence of the light ray in the given denser medium, for which the refracted ray grazes the surface of separation of the two media.'

If the rarer medium taken is air, then the critical angle of the medium can be taken as the absolute critical angle.

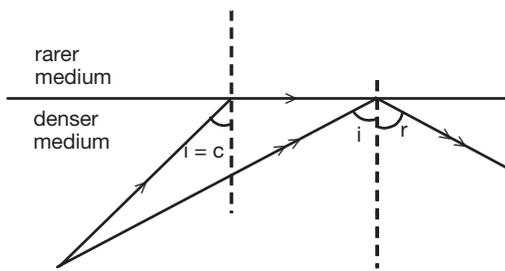


FIGURE 9.42 Total internal reflection

Total Internal Reflection

When a light ray travels from a denser medium to a rarer medium, and if the angle of incidence is greater than the critical angle of the medium, then refraction of light into the rarer medium does not take place. Instead, the light ray gets reflected back into the denser medium, as per the laws of reflection; this phenomena is known as total internal reflection (T.I.R.).

Condition Required for Total Internal Reflection to Occur

1. The light rays should travel from denser medium to rarer medium.
2. The angle of incidence should be greater than the critical angle for the given pair of media.

Consequences of Total Internal Reflection

1. Due to total internal reflection, an air bubble in water appears to be shining.
2. The surface of water in a glass beaker appears to be shining, when viewed from the lateral side of the beaker (See Fig. 9.43), due to total internal reflection.

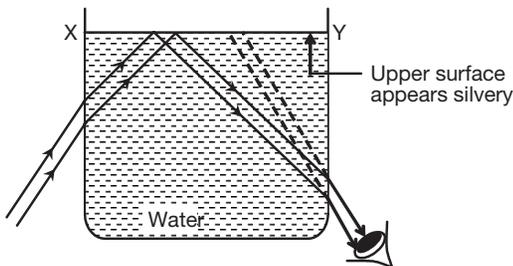


FIGURE 9.43

3. An empty test tube when partially immersed in a glass beaker containing some water and viewed from the top, appears to be shining, due to total internal reflection.
4. Mirage is an optical illusion appearing in the tropical region on hot summer days. It is due to total internal reflection.

On a hot summer day, the density of air in contact with the ground is less than that of the upper layers. As a result, the refractive index of any one layer is greater than that of an immediately lower layer. Thus, rays of light traveling from a distant object, like those from the top of a tree, travel from an optically denser medium to a rarer medium, and the rays bend more and more away from the normal.

At a certain stage, the rays may be incident at an angle greater than the corresponding critical angle, and the rays will undergo total internal reflection. As a result, an inverted image of the object is observed. The inverted image creates an impression that the image is formed in a pool of water. The refractive index of air keeps changing and this makes the image quiver, giving an impression that the quivering of the image is due to ripples in the pool of water.

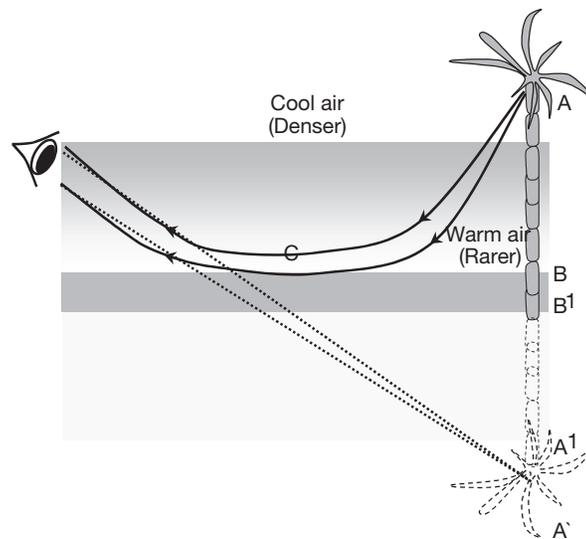


FIGURE 9.45

5. Glittering of diamond is due to total internal reflection.
6. Looming is an optical phenomenon observed in cold countries due to total internal reflection, wherein objects like ships, which are normally below the horizon appear to be hanging in air.
7. The concept of T.I.R. is used in the preparation of optical fibres which find their application in the telecommunication and the medical sector.
8. Formation of rainbow is due to total internal reflection, and dispersion of light.

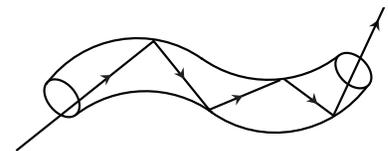


FIGURE 9.46 Optical fibre

Refraction Through a Prism

A prism is a solid block of glass with five faces, three rectangular and two triangular, as shown in the Fig. 9.47.

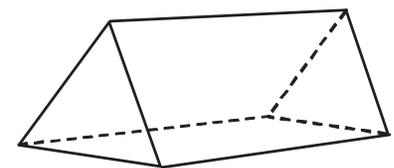


FIGURE 9.47 A prism

If we cut the prism parallel to the triangular face and perpendicular to its length, the cross section obtained is known as principal cross-section as shown in the Fig. 9.48.

'AB' and 'AC' are known as the refracting faces of the prism. The angle between these two refracting faces (A) is known as the '**angle of the prism**'.

In the given (Fig. 9.48) 'PQ' is an incident ray, 'QR' is the refracted ray and 'RS' is the emergent ray.

$\angle i_1$ and $\angle r_1$ are the angles of incidence and refraction, respectively, for refraction on the face AB, ' r_2 ' is the angle of incidence when light falls on the face AC, and ' i_2 ' is the angle of emergence.

'EF' and 'FG' are the normals on 'AB' and 'AC' at points 'Q' and 'R', respectively. The face 'BC' of the prism is known as its base. In the

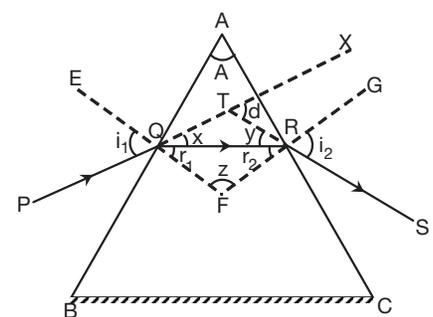


FIGURE 9.48 Refraction through a prism

absence of the prism, the incident light ray would have travelled along the path 'PQT', but, due to the prism, it refracts and emerges along 'TRS'. Thus, the light ray is deviated from its original path and the amount of deviation is measured by the angle 'XTS' and is known as the angle of deviation (d).

NOTE

The emergent ray always bends towards the base of the prism.

As 'AQFR' is a quadrilateral,

$$\angle A + \angle A Q F + \angle z + \angle A R F = 360^\circ$$

But

$$\angle A Q F = \angle A R F = 90^\circ$$

(\because EF and GR are normal to AB and AC, respectively)

$$\therefore \angle A + \angle z + 180 = 360^\circ$$

$$\Rightarrow \angle A + \angle z = 180^\circ \tag{9.1}$$

As 'QFR' is a triangle,

$$\angle r_1 + \angle r_2 + \angle z = 180^\circ \tag{9.2}$$

From equations (9.1) and (9.2)

$$\angle A + \angle z = \angle r_1 + \angle r_2 + \angle z$$

$$\Rightarrow \angle A = \angle r_1 + \angle r_2$$

or

$$A = r_1 + r_2 \tag{9.3}$$

As $x = i_1 - r_1$, $y = i_2 - r_2$ and $x + y = d$, (In triangle TQR)

$$i_1 - r_1 + i_2 - r_2 = d$$

or

$$i_1 + i_2 - r_1 - r_2 = d$$

$$\Rightarrow i_1 + i_2 - (r_1 + r_2) = d$$

$$\Rightarrow i_1 + i_2 - A = d \text{ (from Eq 9.3)}$$

or

$$i_1 + i_2 = A + d \tag{9.4}$$

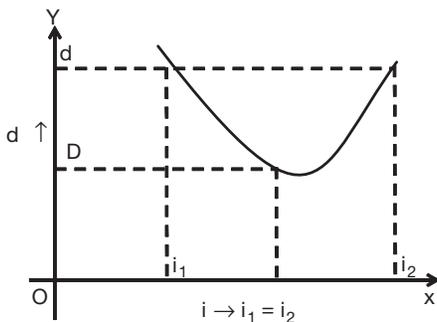


FIGURE 9.49 'i' Vs 'd' graph

As the angle of incidence is gradually increased, the angle of deviation decreases to a certain value and on further increasing the incident angle, the angle of deviation increases. If a graph is plotted between angle of incidence (i) taken along X-axis and angle of deviation (d) taken along Y-axis, the nature of the graph is a curve as shown in the given figure.

This curve is called $i - s$ curve or derivation curve.

This indicates that for a given value of angle of deviation, we can have two angles of incidence ' i_1 ' and ' i_2 ' out of which if one (i_1) is the incident angle, the other (i_2) is the emergent angle.

If ' i_2 ' is the incident angle, we get ' i_1 ' as the emergent angle and the deviation value remains same. At a particular minimum deviation angle (shown as D in the Fig. 9.49), both the angles of incidence and emergence are equal, i.e., $i_1 = i_2$ and $r_1 = r_2$ and in that situation, the refracted ray ' QR ' will be parallel to the base ' BC ' of the prism.

So, in the minimum deviation position of the prism, we have $i_1 = i_2 = i$ (say) and $r_1 = r_2 = r$ (say), then the equations (9.3) and (9.4) reduce to

$$r + r = A \Rightarrow 2r = A, \text{ or } \Rightarrow r = \frac{A}{2} \quad (9.5)$$

and
$$i + i = A + D \Rightarrow 2i = A + D; \Rightarrow i = \frac{A + D}{2} \quad (9.6)$$

From Snell's law, we have, for refraction at point Q ;

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin \left(\frac{A + D}{2} \right)}{\sin \left(\frac{A}{2} \right)}$$

This is the expression for refractive index of the material of a prism and is applicable to the situation where the 'angle of deviation' of the prism is minimum.

To determine the refractive index of the material of an equilateral prism by minimum deviation method

Apparatus required: Equilateral prism, drawing board, white paper, pins, protractor, graph sheet, and a scale.

Procedure

1. Fix a white paper on a drawing board.
2. Place a given equilateral prism on the white paper fixed to the drawing board.
3. Trace the boundary, ABC , of the prism. ABC represents principal section of the prism. AB and AC represent the refracting faces and BC represents base of the prism.
4. Remove the prism.
5. With the help of a protractor, draw a normal line AB . (QM is the normal to AB).
6. Draw a line PQ such that it makes an acute angle i with the normal QM .
7. The line PQ will act as an incident ray.
8. Restore the prism to its original position.
9. Fix two pins P_1 and P_2 on the line PQ , such that they are perpendicular to the plane of the paper.

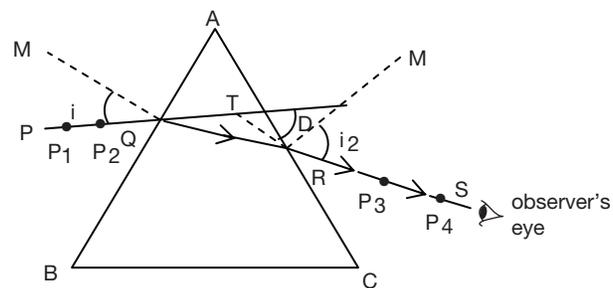


FIGURE 9.50

10. Looking through the second refracting face AC of the prism, find the images of pins P_1 and P_2 .
11. Fix two more pins P_3 and P_4 on the board such that the feet of P_3 and P_4 and the images of P_1 and P_2 are collinear.
12. Mark the points of the pins P_1, P_2, P_3 and P_4 .
13. Remove the prism.
14. Join P_3 and P_4 to meet AC at R . Thus, RS gives the emergent ray.
15. Produce PQ and RS such that the two rays intersect at a point T .
16. Angle STZ gives the angle of deviation (d). Measure it with a protractor.
17. Repeat the experiment for different angles of incidence.
18. Tabulate the result in the tabular column.

Trial No.	$\angle i_1$	$\angle d$

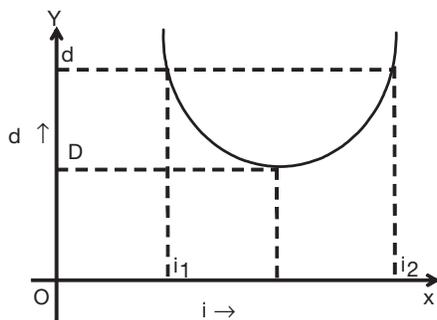


FIGURE 9.51 'i' vs 'd' graph

19. Plot a graph of angle of deviation against angle of incidence by taking the angle of deviation along the positive Y -axis and the angle of incidence along the positive X -axis.
20. The graph is obtained as shown.
21. From the graph, identify the angle of minimum deviation, D . (i.e., the bottom of the curve).
22. Calculate the refractive index of the material of the prism using the formula

$$\mu = \frac{\text{Sin}\left(\frac{A + D}{2}\right)}{\text{Sin}\left(\frac{A}{2}\right)}$$

Dispersion of White Light by a Glass Prism

When a narrow beam of sunlight falls on one of the faces of a glass prism placed in a dark room, it is found that a band of colours resembling those of a rainbow is observed on a white screen placed on the other side of the prism.

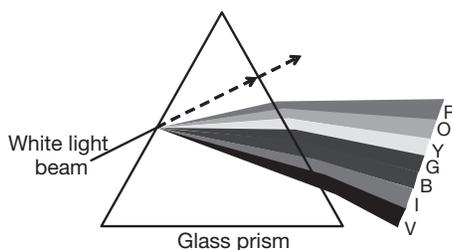


FIGURE 9.52 Spectrum of white light

The order of colours from the base of the prism is violet, indigo, blue, green, yellow, orange and red, and may be abbreviated as **VIBGYOR**.

This phenomenon of splitting of light into its component colours is known as **dispersion**.

The band of colours obtained on the screen, when white light splits into its component colours is called **spectrum**.

If the bands of colours have sharp and well-defined boundaries, then the spectrum is referred to as a **pure spectrum**.

If the bands of colours do not have sharp, well-defined boundaries, but merge with each other, then the spectrum is called **impure spectrum**. An example is the spectrum of sunlight obtained from a prism and rainbow.

Recombination of Light Using Two Prisms

Place two prisms made of the same material and of same refracting angle next to each other, with the second prism inverted, as shown in the Fig. 9.53. Allow a narrow beam of white light to pass through the first prism. A screen is placed on the opposite side to obtain the image of the emergent beam. On the screen, we find a patch of white light.

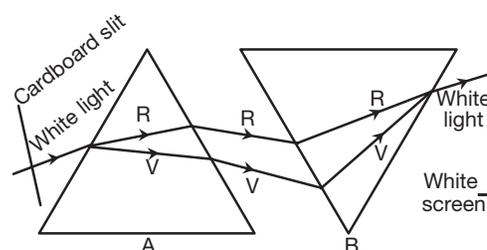


FIGURE 9.53

Conclusion

The second prism combines the different colours incident on it into white light. Each of the colours entering the second prism bends towards the base in accordance with the laws of refraction and they recombine to form white light.

Recombination of Colours Using Newton's Colour Disk

Cut a circular piece of cardboard and paste a white sheet of paper on it. Divide the disc into seven sectors in the same ratio as that of the width of the coloured bands found in the spectrum of sunlight. Paint each one of the sectors with the corresponding colours and mount the disc on a nail or a thin rod. When the disc is rotated at a high speed, we observe all the colours merging together forming a dull white patch.

Conclusion

As the persistence of vision for human eye is $1/16$ second, the eye is not able to distinguish between the colours and the brain perceives them all together as a white light.

Sunlight consists of seven colours. Different colours have different wavelengths. When white light is incident on the surface of a prism, it undergoes refraction twice, as a result different wavelengths are deviated to different extents.

Example: The wavelength of red is greater than that of violet, thus, violet deviates the most and red the least.

Rainbows are formed due to refraction of sunlight or white light by water droplets present in the air or the atmosphere. When light from the sun is incident on the top layer of the water droplet, it undergoes dispersion and splits into seven colours. These seven colours undergo total internal reflection before emerging out from the lower half of the droplet. Thus, sun light undergoes refraction twice and total internal reflection once. The white light is split into seven colours.

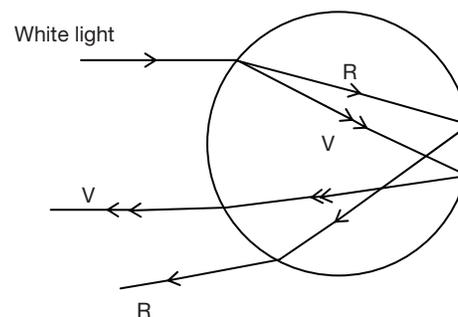


FIGURE 9.54

COLOURS

The brain has the ability to distinguish the electromagnetic radiations of different wavelengths in the visible spectrum. These radiations produce different sensations in the brain and are known as colours.

Light consisting of a single wavelength (single colour) is known as monochromatic light, whereas light consisting of a range of wavelengths of visible light, is called polychromatic.

When light is incident on a surface, radiations of certain wavelengths are absorbed by the surface and the remaining radiations are reflected. The wavelengths of the reflected radiations determine the colour of the surface.

If red light is focused on to a leaf, all the radiations corresponding to the red colour would be absorbed.

Primary Colours of Light

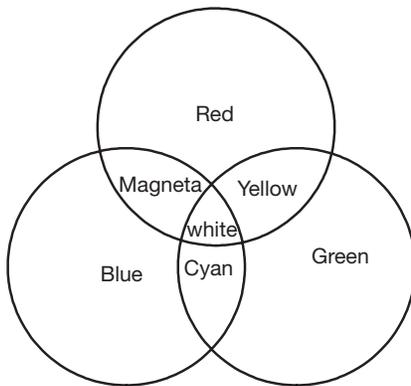


FIGURE 9.55

Red, blue and green are the three primary colours of light, as these cannot be obtained by mixing any two or more colours.

Colours produced by mixing the primary colours in a proper proportion, or the colours produced by subtracting one of the primary colours from white light, are known as composite colours or secondary colours.

Magenta, cyan and yellow are secondary colours.

Red + Blue = Magenta

Blue + Green = Cyan

Red + Green = Yellow

Red + Green + Blue = White light

A primary colour and a secondary colour which combine to produce the white light are called complementary colours.

Red + Cyan = White

∴ Red and Cyan are complementary colours.

Similarly, Green + Magenta = White

Blue + Yellow = White

Colours of Opaque Objects

Opaque objects are objects which do not allow light to pass through them.

Examples: Stone, brick, wood, etc.

A brick appears red because it absorbs all the colours except red and reflects red. Opaque objects reflect the light of the colour we see them to be, but absorb light of all the other colours. If an opaque object absorbs all the colours it appears black, and if the opaque object reflects all colours, it appears white.

A transparent body which transmits light of certain wavelengths (colours) only and absorbs all the other wavelengths is known as a **colour filter**.

For example, a green filter would absorb all the colours except green and transmit only the green colour. Hence, when we see through a green filter, a red coloured object would appear black, and a yellow coloured object would appear green.

Similarly, a cyan filter would absorb all colours except blue and green and would transmit only the blue and green colours. Hence, a red coloured object would appear black and a magenta coloured object would appear blue when seen through a cyan filter.

Uses of Colour Filters

1. Used in photographic camera.
2. In auditoriums to produce or change the colour of the lights during dance or dramas.

PIGMENTS

These are optically active substances of mineral, animal, vegetable or synthetic origin, which absorb most of the colours of white light, but selectively reflect one or more colours.

For example, the pigment chlorophyll in green leaves absorbs all the colours except green. Thus, the leaf appears to be green in colour.

Pigments themselves have no colour and would appear black in a dark room.

No pigment is pure, that is, every pigment reflects a major colour and two minor colours. For example, blue pigment exposed to white light would reflect mostly blue (major colour) and the adjacent colours of the spectrum, *viz.* indigo and green (minor colours); the intensity of the minor colours is comparatively less.

When two or more pigments are mixed, colours reflected by one pigment are absorbed by another pigment, except the common colours. Hence, **pigment mixing** is a **subtractive process**.

Pigments are classified as primary pigments and secondary pigments.

Primary Pigments

These are the pigments which absorb one primary colour and reflect the other two primary colours.

Example: Magenta pigment absorbs green colour but reflects red and blue when light is incident on it.

Magenta, cyan and yellow are primary pigments.

Secondary Pigments

Secondary pigments are pigments which absorb two primary colours and reflect one primary colour.

Example: Red, green and blue are secondary pigments.

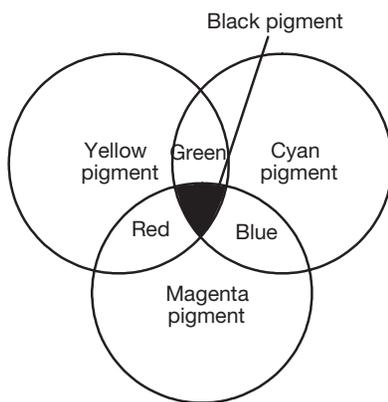


FIGURE 9.56

Cyan, yellow and magenta are called primary pigments.

The various colours produced by mixing primary pigments:

Yellow pigment + Cyan pigment + Magenta pigment = Black pigment

Cyan pigment + Magenta pigment = Blue pigment

Magenta pigment + Yellow pigment = Red pigment

Yellow pigment + Cyan pigment = Green pigment

SCATTERING OF LIGHT

Scattering of light is the irregular or diffused reflection of light when it travels through a medium.

Light from the Sun, before reaching the Earth, is scattered by dust, air particles, smoke, etc. Light of shorter wavelengths is scattered more than the light of longer wavelengths. Thus, red light is scattered least. Scattering of light takes place when the particles are smaller or of the same size as the wavelength of light. If the air particles are larger in size, all the wavelengths are scattered to the same extent.

For example, when factories give out excess smoke, the surrounding atmosphere is filled with dust particles of larger size. As a result, all the colours are scattered to the same extent. Thus, the light does not reach us, and the sky above the region looks grey.

Blue Colour of the Sky

Suspended particles present in the atmosphere are responsible for the scattering of light. Since violet, blue and indigo have shorter wavelength these colours are scattered most and in all directions, hence, the sky appears blue.

The ocean also appears blue for the same reason. Only a small percentage of blue light is scattered making the sky appear blue. A major part of the blue colour, along with the other colours, reaches the Earth. Hence, the light reaching the Earth is white light.

The Sun Appearing Red at Sunrise and Sunset

At sunrise and at sunset, the Sun is at the horizon and the light from the sun traverses a greater distance than at other times. Hence, most of the light of shorter wavelengths is scattered and the colours corresponding to these wavelengths do not reach us. The longer wavelength like red, orange and yellow reach the Earth from the rising sun, making the sun and the sky appear of those colours.

Danger lights, stop lights, and the reflectors on vehicles are red in colour because red is scattered the least and can be seen from a longer distance. Signboards used on roads such as those put up at pedestrian crossings, and railway tracks are yellow because yellow is brighter than red, and is used to caution, rather than, as a direction to stop.

ELECTROMAGNETIC SPECTRUM

It is known that a beam of sunlight passing through a glass prism would disperse producing a diverging beam of its constituent colours—violet, indigo, blue, green, yellow, orange and red,

which are electromagnetic radiations of different wavelengths. The electromagnetic radiations are not limited to this visible range alone. The radiations beyond the visible spectrum do not cause a sensation of vision on the retina and are referred to as **invisible spectrum**.

They travel at a speed of $3 \times 10^8 \text{ m s}^{-1}$ in vacuum. The following table gives the classification of the electromagnetic waves based on their wavelength.

Wavelength range	Spectrum
0.0001nm to 0.1 nm	γ rays
0.001 nm to 10 nm	X-rays
1nm to 0.4 μm	Ultraviolet spectrum
0.4 μm to 0.7 μm	VIBGYOR spectrum
0.7 μm to 100 μm	Infrared spectrum
10 μm to 10m	Microwaves
1m to 100 km	Radio waves

Infrared Rays (IR)

We feel hot when we stand near a fire. This is due to infrared radiations emitted by the fire. Infrared radiations are produced by hot bodies. Sun is the main source of IR rays.

Infrared rays have higher wavelength than visible light. The wavelength of infrared rays ranges from 0.7 μm to 100 μm .

Uses of Infrared Radiations

1. The heat energy received from the sun by the Earth is in the form of infrared radiation.
2. Due to the heating effect they produce, the radiations are used in physiotherapy to treat swollen joints, muscles, etc.
3. Since the wavelength of these waves is larger, they are not scattered in fog or smoke. Thus, these radiations can be used to take infrared photographs in foggy weather.
4. They are also widely used in astronomy.
5. Night vision spectacles or view finders make use of IR rays. This device is used by soldiers to detect obstacles in the dark.
6. Remote control of a TV set makes use of IR rays.
7. Some Photographic films are sensitive to IR rays, and hence, IR rays are used to photograph objects in dark.

Ultra Violet Rays (U.V)

Ultra violet rays are a part of the electromagnetic spectrum and have lesser wavelength than the visible region. UV rays have wavelength ranging from 1 nm to 0.4 mm.

1. Long exposure to UV rays causes skin tan.
2. Exposure to intense UV rays causes skin cancer.

UV and IR rays can be detected by chemical change that they produce on photographic plates.

Ozone layer present in the atmosphere acts a protective blanket by blocking UV rays from entering the Earth.

Any damage to the ozone layer leads to a hole in the ozone layer which will allow UV rays to reach the Earth. Thus, any damage to ozone layer causes hazards to the living beings on earth. A hole in the ozone layer is called ozone depletion. One such depletion is found above the north pole.

Uses of Ultraviolet Radiations

1. Ultraviolet radiations can be used to detect fake currency notes.
2. They can be used for sterilization of surgical instruments, as they have the capability to kill the microorganisms.
3. They can be used to distinguish original diamonds from fake ones.
4. They can be used to check adulteration in ghee.
5. They can be used to stimulate the body to produce vitamin D.
6. They help in the conversion of oxygen to ozone, in the upper layers of the atmosphere.

Fluorescence

Some dolls look brighter or shine in dark. This is due to fluorescence.

Certain materials or substances like Zinc sulphide, Barium platino cyride, etc., absorb shorter wavelengths of light and emit light in the longer wavelength region. This property of the substance is known as fluorescence.

LENSES

Lens is an optical device made of glass which is bounded by two refracting surfaces. A lens can have either one or both of its surfaces curved. A lens can be formed by combining two glass spheres or by the combining a plane surface and a spherical surface.

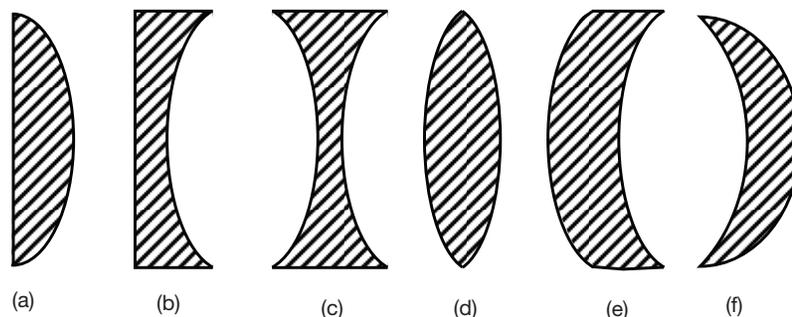


FIGURE 9.57

The figures depict the different types of lenses. They are

1. Plano-convex lens
2. Plano-concave lens
3. Bi-concave or concave lens

4. Bi-convex or convex lens
5. Convexo-concave lens
6. Concavo – convex lens

Refraction Through a Lens

When a light ray is incident on a lens, it undergoes refraction at the first surface of the lens and bends towards the normal. The refracted ray from the first surface undergoes further refraction at the second surface and bends away from the normal as it emerges out from the denser to the rarer medium. Thus, light rays undergo refraction twice in the case of lenses.

Refraction Through Thin Lens

A thin lens is one whose thickness is less when compared to its radius of curvature.

A lens can be considered as made up of a number of prisms.

In a convex lens, the prisms in the upper half have their bases downwards and in the lower half of the lens the bases of prisms are upwards. At the centre of the convex lens the two prisms meet at their bases. Hence, the convex lens is thicker at the centre.

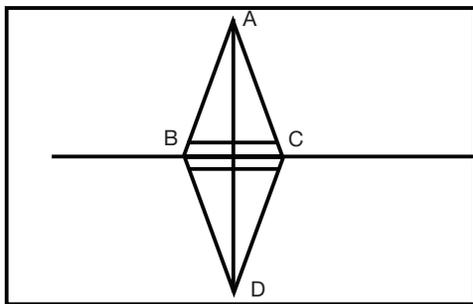


FIGURE 9.58 ABC and DCB: prisms

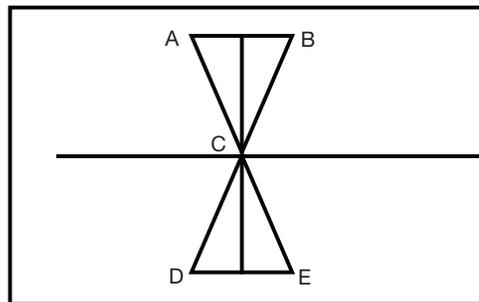


FIGURE 9.59 ABC and CDE: prisms

In a concave lens, the prisms in the upper half have their bases upwards and the prism in the lower half of the lens have their bases downwards. At the centre, the two prisms meet at the vertex. Hence, this lens is thinner at the centre.

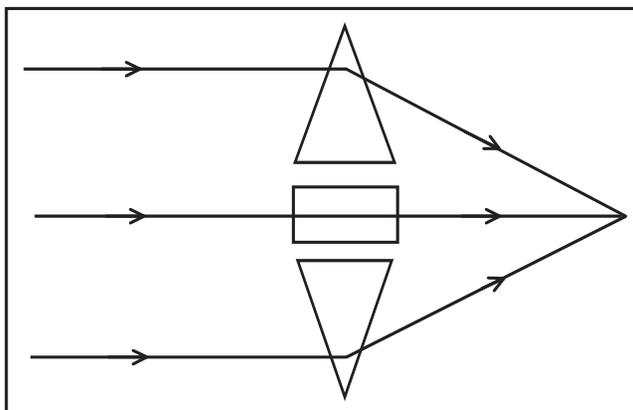


FIGURE 9.60

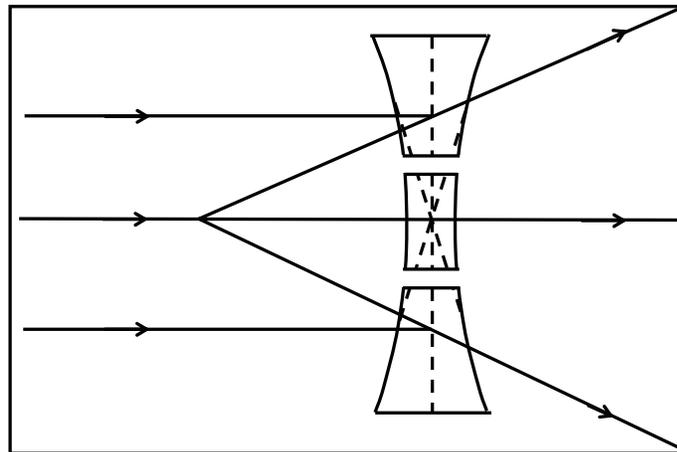


FIGURE 9.61

When light rays are incident on the prisms of the convex lens, the refracted ray bends towards the base. The emergent rays from the prism meet at a point. Hence, a convex lens is a converging lens.

If light rays which are parallel are incident on the prisms of the concave lens, the rays after refraction diverge from each other or the refracted rays bend towards the base of the prisms. Thus, the distance between the emergent rays goes on increasing. Such a beam is called divergent beam. Hence, a concave lens is a diverging lens.

General Terms Related to a Spherical Lens

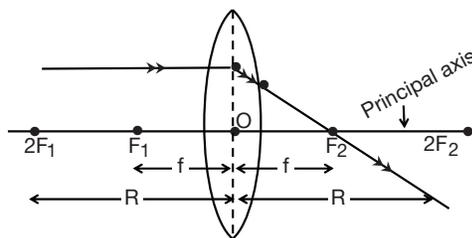


FIGURE 9.62

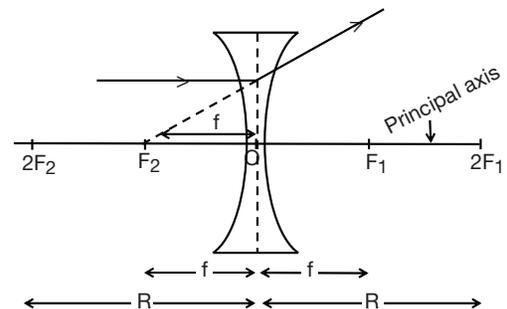


FIGURE 9.63

1. **Optic centre:** The geometric centre of a lens is known as its optic centre. In both the above figures, 'O' is the optic centre.
2. **Centre of curvature:** The centre of the sphere of which the given spherical surface of the lens is a part is known as the centre of curvature.
 Since a bi-convex lens or a bi-concave lens has two spherical surfaces they have two centres of curvature, one for each surface. In the Figs. 9.62 and 9.63, $2F_2$ and $2F_1$ are the two centres of curvature for 1st and 2nd surfaces, respectively.
3. **Principal axis:** An imaginary line passing through the centres of curvature of the two surfaces of the lens and its optic centre is known as the principal axis.
4. **Principal Focus:** If a parallel beam of light, parallel to the principal axis is incident on a surface of the lens, they are refracted at the two surfaces of the lens and converge at

(in a convex lens) or appear to diverge from (in a concave lens) a point on the principal axis. This point is known as principal focus.

There are two principal foci for a bi-convex or bi-concave lens. In the Figs. 9.62 and 9.63. ' F_1 ' and ' F_2 ' are the principal foci.

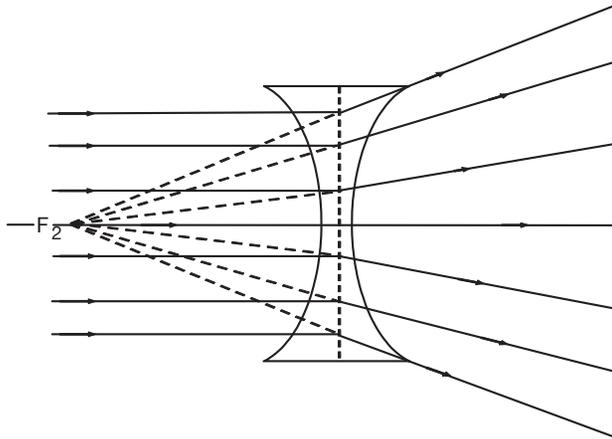


FIGURE 9.64

- 5. Radius of curvature (R):** The radius of the sphere of which the spherical surface of a lens is a part is known as radius of curvature (R).

But for all practical purposes, i.e., for lens with small aperture, radius of curvature is measured from optic centre of the lens to its centre of curvature.

- 6. Focal length (f):** The distance of the principal focus from the optic centre of a lens is known as its focal length (f).
- 7. Object distance:** The distance of an object placed in front of a lens from its optic centre is known as object distance and is denoted by ' u '.
- 8. Image distance:** The distance of an image formed by a lens from its optic centre is known as image distance and is denoted by ' v '.

Refraction by Spherical Lenses

Any two of the following rays coming from an object placed in front of a lens are taken into consideration to know about the image formation in lenses.

1. A light ray from an object parallel to the principal axis after refraction at the two surfaces of the lens converges at (in a convex lens) or appears to diverge from (in a concave lens) the second principal focus.
2. A light ray passing through the first principal focus (in a convex lens) or appearing to meet at it (in a concave lens) emerges parallel to the principal axis after refraction at the two surfaces of the lens.
3. A ray of light passing through the optic centre of a thin lens, emerges without any deviation after refraction at the two surfaces of the lens.

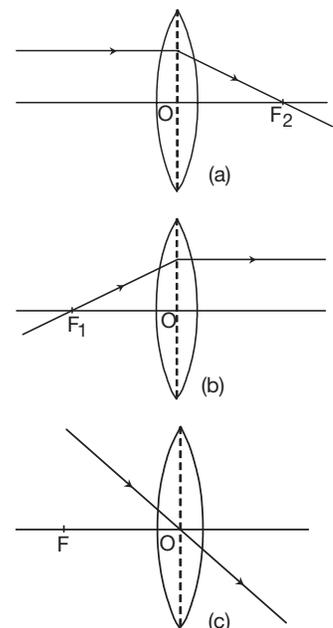


FIGURE 9.65

Formation of Images by a Convex Lens

The image of an object placed in front of a convex lens depends on the distance of the object from the lens. The distances of the object and its image formed by a lens are measured from optic centre of the lens.

When the object is at infinite distance from the lens, the image is formed on the other side of the lens, highly diminished, real and inverted.

As the object moves towards the lens, the image moves away from the lens gradually and even the size of the image formed increases.

Nature of Images Formed by a Convex Lens

Position of object	Ray diagram	Nature and position of image
At infinity i.e., $u = \infty$		Real, inverted and highly diminished and formed at the principal focus \Rightarrow i.e., $v = f$.
Beyond the centre of curvature i.e., $u > 2f$		Real, inverted and diminished. Formed between F_2 and $2F_2$ i.e., $f < v < 2f$
At the centre of curvature. i.e., $u = 2f$		Real, inverted and of equal size as the object, formed at i.e., $v = 2f$
Between F_1 and $2F_1$ i.e., $f < u < 2f$		Real, inverted and magnified, and formed beyond $2F_2$ i.e., $v > 2f$
At F_1 i.e., $u = f$		Real, inverted and highly magnified and formed at infinity i.e., $v = \infty$
Between focus (F_1) and optic centre i.e., $u < f$		Virtual, erect and magnified. Formed on the same side of the lens as the object.

Formation of Image by a Concave Lens

The nature of the image does not change with a change in the object distance, in the case of a concave lens, as illustrated in the following figures except that there will be a difference in the magnification. When the object is at infinity, the image is highly diminished and is formed at F_2 . When the object is at other places, it is diminished and is formed between O and F_2 .

Nature of Images Formed by a Concave Lens

Position of object	Ray diagram	Nature and position of image
At infinity i.e., $u = \infty$		Erect, virtual and highly diminished. Formed at the focus. i.e., $v = f$
At any position other than infinity.		Erect, virtual and diminished; formed between focus and the optic centre. i.e., $v < f$

Sign Convention for Lenses

1. All distances parallel to the principal axis are measured from optic centre of the lens.
2. The distances measured in the direction of incident light are considered to be positive.
3. The distances measured in the direction opposite to the direction of incident light are taken as negative.
4. The heights of objects or images measured upwards (above the principal axis) and perpendicular to it are considered as positive.
5. The heights of objects or images measured downwards (below the principal axis) and perpendicular to it are considered as negative.

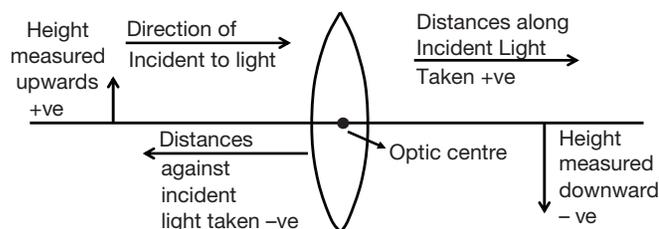


FIGURE 9.66 Sign convention in lenses

Difference Between Image Formation by Convex and Concave Lenses

Convex lens	Concave lens
Incident rays parallel to the principal axis after refraction at the two surfaces meet at a specific point called principal focus.	The incident rays parallel to principal axis after refraction at the two surfaces diverge and the refracted rays appear to diverge from a fixed point called principal focus.
The virtual image formed by this lens is always enlarged.	The virtual image formed by this lens is always diminished.
A virtual image is obtained only when the object is placed between the optic centre and the principal focus.	The image of an object is always virtual irrespective of the position of the object.

LENS FORMULA

The object distance (u), the image distance (v) and the focal length ' f ' are related by the equation

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

This is known as the lens formula and is applicable to both convex and concave lenses.

Experiment to find the focal length of a convex lens, and hence, find the nature of the image.

1. By Distant Object Method

Apparatus required: convex lens, lens holder, screen and measuring scale.

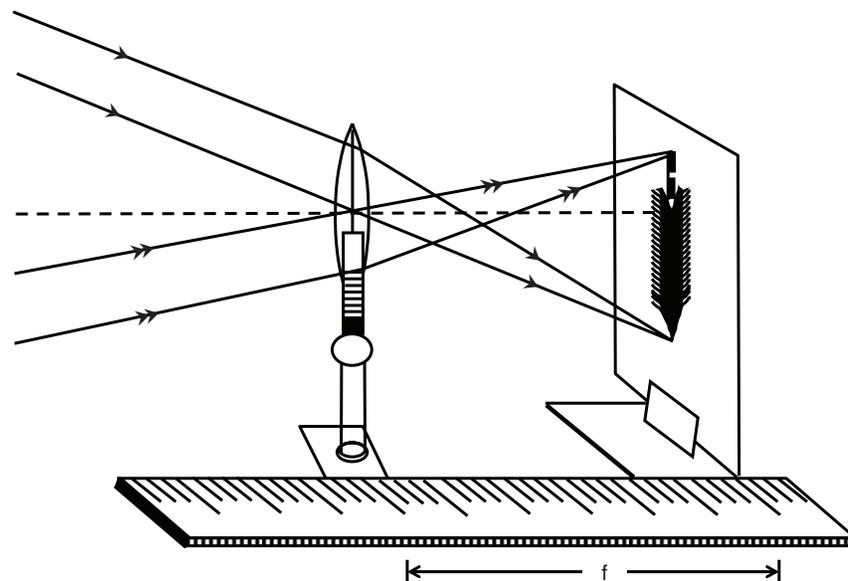


FIGURE 9.67 Distant object method

Procedure

1. Place the lens in the lens holder.
2. Focus the lens to a distant object such as a distant tree.
3. Place the screen on the other side of the lens.
4. Adjust the distance between the screen and the convex lens until a sharp, well defined image of the object is formed.
5. Measure the distance between the lens and the screen. This gives the focal length of the lens.
6. Find the nature of the image

Observation

1. A real image is formed on the screen.
2. The image is highly diminished.
3. The image is inverted.

2. By $u - v$ Method

Apparatus required: convex lens, lens holder, screen, illuminated object and metre scale.

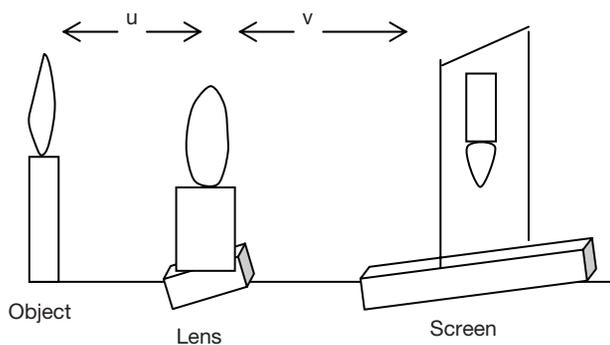


FIGURE 9.68

1. Place the lens on a lens holder and place it in front of the object such as an illuminated wire gauge or a candle.
2. Place a white screen on the opposite side of the lens.
3. Adjust the position of the screen such that a sharp image of the object is formed on the screen.
4. Measure the distance between the object and the lens. This gives the object distance (u).
5. Measure the distance between the lens and the screen. This gives the image distance v .
6. Focal length of the lens is calculated using the formula

$$f = \frac{uv}{u + v}$$

7. Repeat the experiment for different values of the object distance and tabulate them.
8. Determine the focal length in each case and also note down the nature of the image.

Trial	u in cm	v in cm	$f = \frac{uv}{u+v}$ in cm	Nature of the image

OPTICAL INSTRUMENTS

Lenses find variety of application in construction of microscopes, telescopes, camera, etc. But the most important and versatile instrument in nature is the human eye.

Human Eye

Human eye is nearly spherical in shape having diameter of nearly 2.5 cm. Image of an object is obtained when the incident light is refracted by a crystalline lens located in the front part of the eye ball. This eye lens is convex in nature and it helps in forming real images. The eye lens forms a real and inverted image of an object on the retina located at the back of the eye ball. Thus, the retina acts as a screen. The retina consists of nerve cells. The nerve cells send the message to the brain through the optic nerve in the form of a signal. The brain interprets the signal and enables us to see the objects.

The focal length of the crystalline lens is adjusted by the ciliary muscles in the inner layer of the eye-ball called choroid. This adjustment of the eye lens to form sharp images of objects at different distances is known as accommodation.

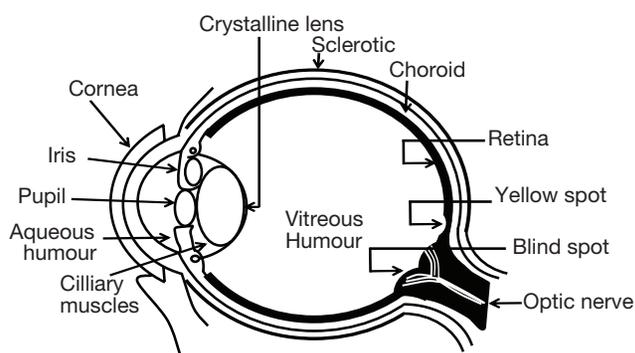


FIGURE 9.69 The Structure of the Human Eye

The central opening or aperture, called pupil allows the light to enter the eye and is black in colour due to the dark interior of the eye ball. The amount of light entering the eye is adjusted by a coloured diaphragm called iris.

The outer covering of the eye ball called sclerotic – a tough and opaque white substance – forms a bulging, transparent cornea in the front which protects the eye lens and helps in the refracting the incident light.

The inability of the eye lens to properly focus an image on the retina is referred to as defect of the eye. The defect might be due to ageing or hereditary effects. Sometimes defects result from abuse—not taking proper care of the eyes.

The major defects of the eye

1. Myopia or short-sightedness
2. Hypermeteropia or long-sightedness

Myopia

A person having a myopic eye can see nearby objects clearly but cannot see the distant objects clearly. This is because the eye lens does not focus the rays from a distant object on to the retina but focuses them a little in front of the retina (See Fig. 9.70).

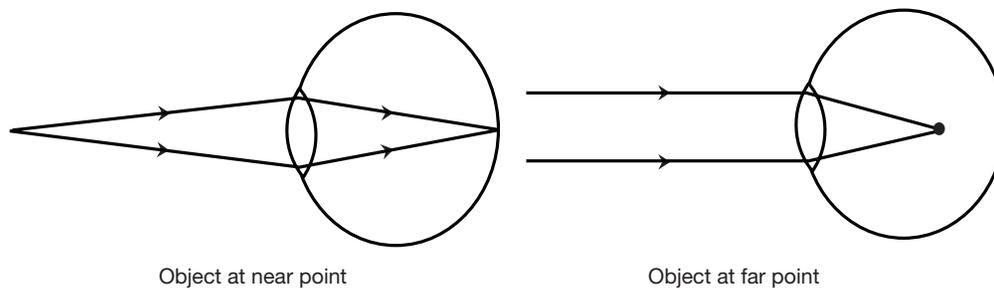


FIGURE 9.70 Image formation in person having myopia

Thus, the focal length of the crystalline lens in a person suffering from myopia, is less than the diameter of the eye ball. As a consequence, the refracted rays in the eye converge more.

Hence, this defect can be corrected by using a concave lens (diverging lens) of suitable focal length which enables the eye lens to focus the image of the distant object on the retina.

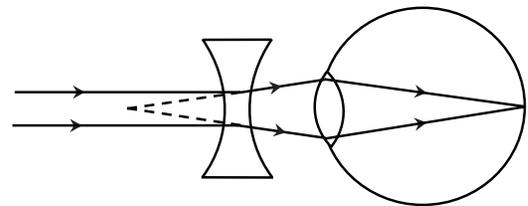


FIGURE 9.71 Correction of myopia

Hypermeteropia

A person suffering from long sight can see distant objects clearly but cannot see the nearby objects with the same clarity. This is because the eye lens focuses the rays behind the retina.

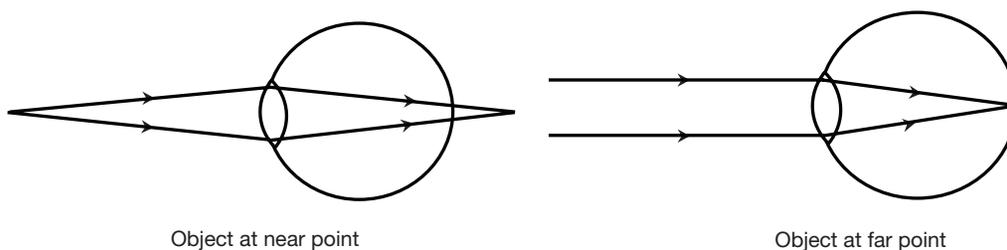


FIGURE 9.72 Image formation in a person having hypermeteropia

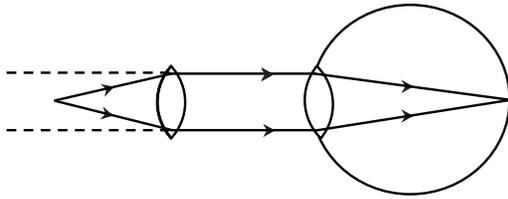


FIGURE 9.73 Correction of hypermetropia

This implies that while viewing objects at shorter distance, the focal length of the eye lens is more than the diameter of the eye ball. Thus, the crystalline lens is not able to converge the rays sufficiently.

Hence, this defect can be corrected by using a converging lens—convex lens—of suitable focal length so that light rays from nearby objects can focus on the retina.

Dioptric Power of Lens

Power of a lens is defined as the reciprocal of its focal length.

Power, $P = \frac{1}{f}$ where f is the focal length in metres.

The unit of power of a lens is diopter and is represented by D .

Power of lens is positive for convex lens and negative for concave lens. The power of combination of two or more lenses is the algebraic sum of their individual powers.

$$P = P_1 + P_2 + P_3 + \dots$$

Camera

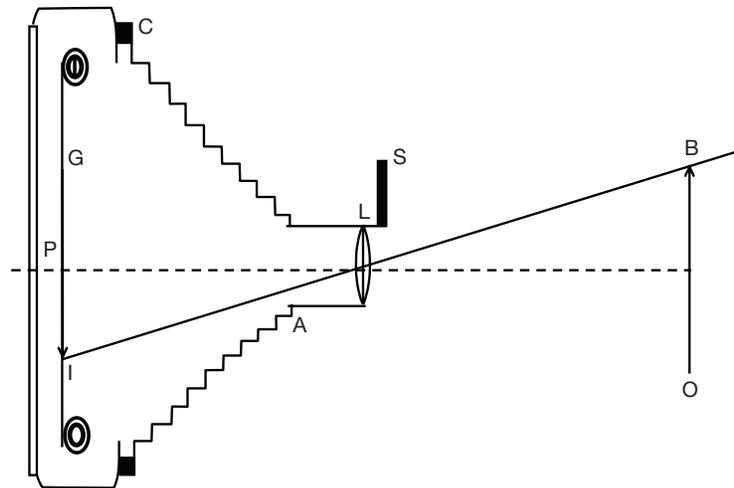


FIGURE 9.74 Box Camera

OB = Object, S = Shutter, L = Convex lens, A = Adjustable frame, C = Light proof box, IG = Image and P = Photo sensitive film

Camera is a device which is used to record the image of an object permanently on a light-sensitive (photosensitive) material.

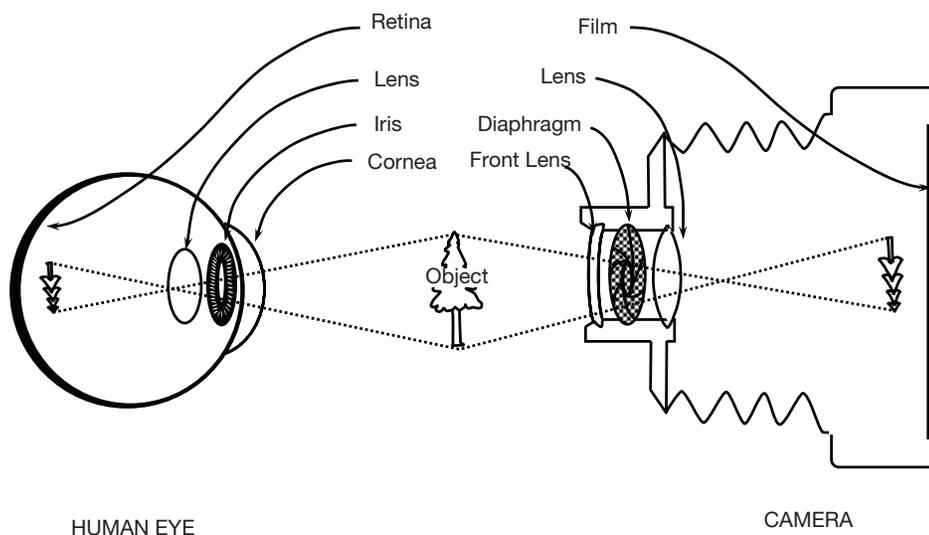


FIGURE 9.75 Human eye and camera – A comparison

Camera consists of light-tight box. The interior of the box is blackened to avoid internal reflection. At one end of the box, is fixed a convex lens of shorter focal length and the other end of box has a provision for placing photo sensitive film. The film acts as a screen. A shutter is provided in front of the lens. The shutter allows the light to fall on the lens only when it is opened. The shutter is opened to receive the light from the object and by adjusting the distance between the lens and the film, the image of an object is focused on the film. The film is removed and further processed to obtain permanent photographic prints.

In order to study details of minute objects like cells and distant objects like planets, we make use of optical instruments to extend the range of vision of a human eye.

Optical instruments like microscopes, telescopes, etc., are used as magnifying devices.

SIMPLE MICROSCOPE

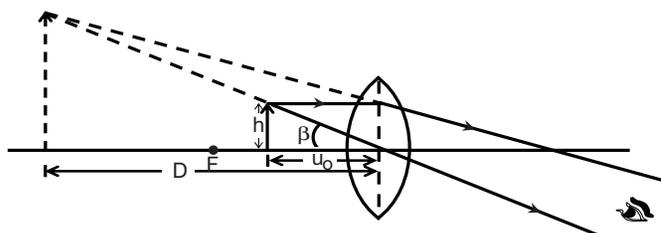


FIGURE 9.76 Simple Microscope

Simple microscope is a convex lens of short focal length, which is held near the eye to get a magnified or enlarged image of small objects.

The object is placed within the principal focus or at the principal focus and the eye is placed just behind the lens.

An erect, virtual and magnified image of the object is obtained.

The magnification factor is the ratio of the size of the image to the size of the object.

$$M = \frac{\text{height of image}}{\text{height of object}} = \frac{v}{u}$$

Uses

1. A simple microscope (also called magnifying glass) is used by watchmakers, jewelers, palmists, etc., to get a magnified image of an object.

A simple microscope has limited magnification. Hence, for larger magnification, we make use of a compound microscope.

COMPOUND MICROSCOPE

A compound microscope consists of two convex lenses. The lens with the shorter focal length is placed near the object and is called 'objective'. The other lens with larger focal length and larger aperture is used for viewing the object and is called 'eye piece'. The objective is placed in hollow, long cylindrical metal tube and the eye piece is mounted in smaller cylindrical metal tube, which slides inside the bigger tube. The distance between the objective and the eye piece can be adjusted. The two lenses are placed co-axially.

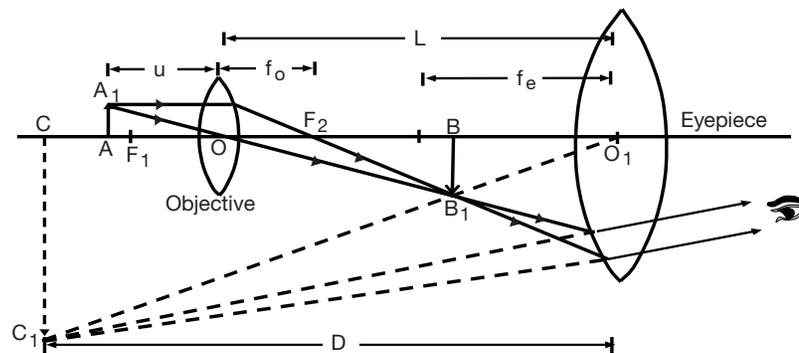


FIGURE 9.77 Compound microscope

An object AA_1 to be viewed is placed between F_1 and $2F_1$ (closer to F_1) of the objective. A real, inverted and magnified image BB_1 is formed beyond $2F_2$, on the other side of the objective. The image BB_1 serves as an object for the eye piece.

Position of the eye piece is adjusted in such a way that the image, BB_1 falls within the principal focus of the eye piece. The eye piece forms a virtual, magnified and inverted final image, CC_1 of the object AA_1 .

TELESCOPE

It is a device used to get enlarged view of a distant object. Telescopes are of two types namely (1) astronomical telescope and (2) terrestrial telescope.

Astronomical telescope has two convex lenses fitted at the two ends of a long cylindrical tube. The convex lens with a large focal length is placed towards the distant object and is called objective. The objective refracts light from the distant object AA_1 and forms a real,

inverted and diminished image BB_1 at its focus. The distance between the objective and the eye piece is adjusted such that the image BB_1 formed by the objective falls within the focus of the eye piece. The final image CC_1 , formed by the eye piece is virtual and inverted with respect to the object.

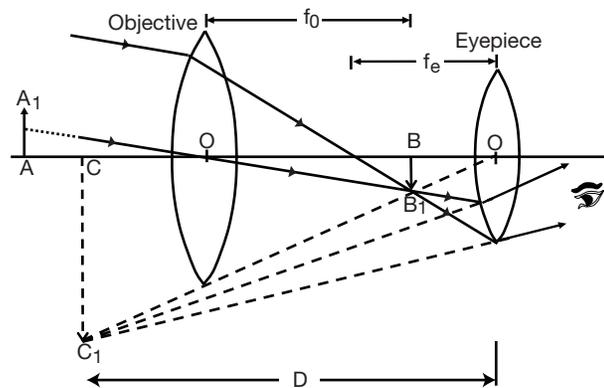


FIGURE 9.78 Astronomical telescope

Terrestrial Telescope

Terrestrial telescope is used to view distant objects on earth. The construction of terrestrial telescope is similar to that of an astronomical or celestial telescope with this difference that in the terrestrial telescope, one more convex lens is introduced between the objective and the eye piece. The lens introduced between eye piece and the objective acts as an erecting lens.

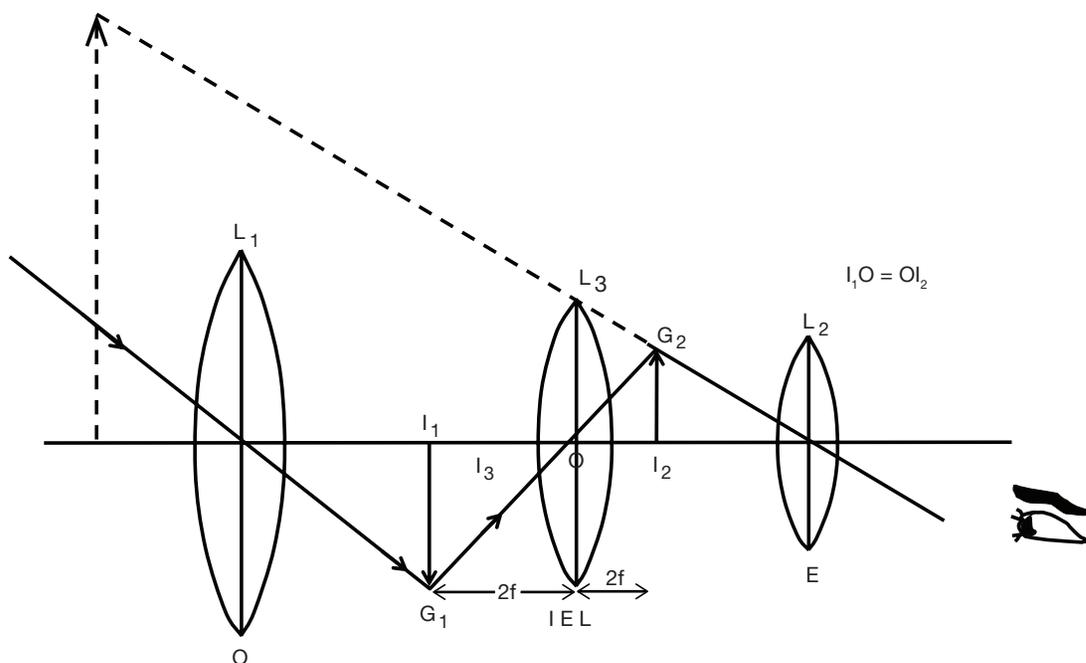


FIGURE 9.79 Terrestrial telescope

The objective (O) of the telescope forms a real inverted image I_1G_1 of the object at a distance of $2f$ from the erecting lens (IEL) where f is its focal length. This image I_1G_1 serves as an object for the erecting lens and the erecting lens forms an image I_2G_2 erect with respect

to the object, at $2f$ distance from the erecting lens on the other side of the erecting lens as of I_1G_1 . The second image is formed within the principal focus of the eye piece and this forms a third image I_3G_3 which is virtual, magnified erect with respect to its object.

EXAMPLE

An object is placed at a distance of 30 cm from a convex lens of focal length 20 cm.

SOLUTION

In the given problem

Object distance, $u = -30$ cm (from sign convention)

Image distance, $v = ?$

Focal length of the lens $f = 20$ cm

From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{20} = \frac{1}{v} - \frac{1}{-30}$$

$$\frac{1}{20} = \frac{1}{v} + \frac{1}{30}$$

$$\frac{1}{v} = \frac{1}{20} - \frac{1}{30}$$

$$\frac{1}{v} = \frac{30 - 20}{30 \times 20} = \frac{10}{600}$$

$$v = \frac{600}{10} = 60 \text{ cm.}$$

$$\text{Magnification, } m = \frac{\text{height of the image}}{\text{height of the object}} = \frac{v}{u}$$

$$M = \frac{60}{-30} = -2.$$

Negative sign indicates that the image is inverted. Since, m is greater than one, the image is magnified.

Since v is positive, the image is real.

The image is formed 60 cm on the other side of the lens and it is real, inverted and magnified.

EXAMPLE

An object is placed in front of a convex lens of focal length 12 cm. If the size of the real image formed is half the size of the object, calculate the distance of the object from the lens.

SOLUTION

In the given problem,

Focal length of a concave lens, $f = 12$ cm

(using sign convention)

height of the image (h_i) = $\frac{1}{2}$ × height of the object (h_o)

i.e., $h_i = \frac{1}{2} h_o$.

Magnification of the lens $m = \frac{v}{u} = \frac{h_i}{h_o}$

v is the image distance

u is the object distance.

$$\begin{aligned} m &= \frac{h_i}{h_o} = \frac{1}{2} \frac{h_o}{h_o} = \frac{1}{2} \\ m &= \frac{v}{u} \\ \frac{1}{2} &= \frac{v}{u} \\ \Rightarrow v &= \frac{u}{2} \end{aligned}$$

From lens formula.

$$\begin{aligned} \frac{1}{f} &= \frac{1}{v} - \frac{1}{u} \\ \frac{1}{12} &= \frac{1}{\frac{u}{2}} - \frac{1}{u} \\ \frac{1}{12} &= \frac{2}{u} + \frac{1}{u} \\ \frac{1}{12} &= \frac{2+1}{u} \\ \frac{1}{12} &= \frac{1}{u} \\ u &= 36 \text{ cm.} \end{aligned}$$

The object is placed at a distance of 36 cm from the lens.

EXAMPLE

Calculate the power of the eye lens of the normal eye, when it is focused at far point and near point, given the diameter of the eye is 2.5 cm. Find the maximum variation in the power of normal eye lens.

SOLUTION

The far point of a normal eye is infinity. When the object is at infinity, the image is formed at the focus, i.e., image distance $v = f$, where f is the focal length.

Diameter of the eye = distance between lens and the focus = 2.5 cm (given)

$$\therefore f = 2.5 \text{ cm} = 2.5 \times 10^{-2} \text{ m.}$$

$$\text{Power of the lens, } P = \frac{1}{f}$$

$$P = \frac{1}{2.5 \times 10^{-2}} = \frac{10^2}{2.5} = 40 \text{ D.}$$

2. The near point of a normal eye is 25 cm

= object distance

$$= -25 \text{ cm} = u$$

(from sign convention)

$$v = 2.5 \text{ cm}$$

= distance of the eye lens from the retina (i.e., the focus)

$$\frac{1}{f} = \frac{1}{2.5 \times 10^{-2}} - \frac{1}{-25 \times 10^{-2}}$$

$$\frac{1}{f} = \frac{100}{2.5} + \frac{100}{25}$$

$$\frac{1}{f} = 40 + 4$$

$$\frac{1}{f} = 44$$

$$\text{Power} = \frac{1}{f} = 44 \text{ D.}$$

Thus, the maximum variation in the power of the lens is $44 \text{ D} - 40 \text{ D} = 4 \text{ D}$.

TEST YOUR CONCEPTS

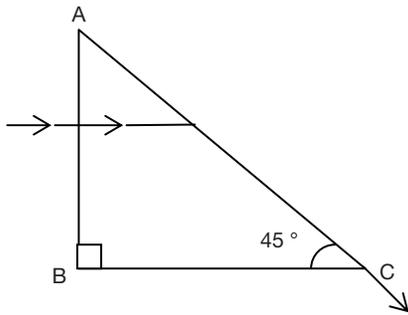
Very Short Answer Type Questions

- Is the virtual image formed by a concave mirror always magnified?
- State Snell's law.
- Define dispersion.
- Under what conditions, it is possible to obtain a virtual image with the help of a convex lens?
- Define primary colours.
- How are shadows cast?
- What is a mirror formula?
- Mention two uses of IR rays.
- Red and cyan are called _____ colours.
- What are umbra and penumbra?
- What is total internal reflection?
- What is fluorescence?
- What is a lens formula?
- What is a spherical mirror?
- Define optic centre of a lens.
- Define critical angle.
- What is a pigment?
- Define refraction of light.
- How many images of an object are formed when two plane mirrors are inclined to each other facing each other at an angle of 60° ?
- What is meant by scattering of light?
- Define spectrum.
- Define refractive index.
- What is irregular reflection?
- Why is a concave mirror called converging mirror?
- Among the different colours of white light, the colour, which undergoes the maximum scattering, is _____.
- Give two uses of uv rays.
- What is a rainbow?
- Define focal length of a lens.
- A light ray travels from oil to water medium. Does it bend towards the normal or away from the normal?
- When an object is placed at infinite distance from a concave mirror, what is the position of the image?

Short Answer Type Questions

- Explain the formation of a rainbow.
- A concave mirror is made from a hollow sphere of radius 30 cm. If an object 2 cm high is placed at 10 cm from the pole of the mirror, determine (1) the position, (2) nature and (3) size of the image.
- Why does the sun appear red in colour at sun rise and sun set?
- Light rays from the sun after reflection at a plane mirror pass through a hole in a wall. After some time due to the shift in the position of the sun, the angle of incidence of sun light increases by 10° . By what angle, should the mirror be rotated, such that the reflected rays continue to pass through the hole in the wall?
- State and explain sign conventions used in spherical mirrors.
- What is the refractive index of the material of the glass prism shown in the figure, if a ray of light incident normally at the face AB emerges along the face AC ?





37. With the help of a ray diagram, show the formation of an image of an object placed between principal focus and centre of curvature of a concave mirror.
38. In an optical instrument, a convex lens of focal length 20 cm is used in combination with a concave lens of focal length 40 cm. What is the power of this combination?

Essay Type Questions

45. Prove that focal length of a spherical mirror is equal to half the radius of its curvature.
46. Explain an experiment to determine the focal length of a concave mirror by $u - v$ method.
47. Describe an experiment to determine the refractive index of the material of an equilateral prism.
48. Obtain an expression for mirror formula (either for concave or convex mirror).
49. Explain the working of astronomical telescope with the help of a neat diagram.
50. What is atmospheric refraction? Explain with an example.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for question 1 to 7

State whether the given statements are true or false.

- Red, green and blue pigments are primary pigments.
- When an object is placed between two plane mirrors which are inclined at right angle, the number of images formed is four.
- The power of a rectangular glass slab is zero.
- Virtual image produced by convex mirror is always smaller in size and located between focus and the pole.
- Rainbow is an impure spectrum caused by sunlight.

- Define power of a lens and write its unit.
- Write two advantages and two disadvantages of a pin hole camera.
- What are the differences between a microscope and a telescope?
- Two mirrors inclined to each other produce 8 images of an object placed between them. Through how much angle should one of the mirror be rotated to get only two images?
- What is lateral inversion of images? Explain with an example.
- An object is placed on the principal axis of a convex mirror of focal length 15 cm. If the distance of the object from the mirror is 30 cm, where should a plane mirror be placed such that the images produced by the two mirrors coincide?

- The rays passing through the optic centre of a thin lens suffers no lateral displacement.
- A light ray passing through the centre of curvature of a concave mirror after reflection travels parallel to the principle axis.

Direction for questions 8 to 14

Fill in the blanks.

- When a light ray passes from a denser medium into a rarer medium, the angle of incidence for which the angle of refraction is maximum is called _____



9. _____ mirror is used for obtaining real images.
10. The colour, we observe, when white light passes through yellow and red filters in that order is _____.
11. The image of an object at infinite distance is formed at _____ of a concave mirror.
12. Power of the lens is the _____ of the focal length.
13. Fog is an example of _____ medium.
14. The refractive index of a medium (2) with respect to medium (1) is x and refractive index of medium (2) with respect to medium (3) is ' y ' then the refractive index of the medium (3) with respect to medium (1) is _____.

Direction for question 15

Match the entries given in column A with appropriate ones from column B.

15.

Column A	Column B
A. Object at infinite distance	() a. light
B. Shadow	() b. light travels with less velocity
C. Real image	() c. dispersion of light
D. Optically denser medium	() d. angle of incidence = angle of emergence
E. Elliptical shape of the setting sun	() e. convex lens.
F. Angle of minimum deviation	() f. concave lens
G. Rainbow	() g. parallel beam of light rays
H. Myopia	() h. rectilinear propagation
I. Sensation of vision	() i. refraction of light

Directions for questions 16 to 45

Select the correct alternative from the given choices.

16. V_v , V_R , V_G are the velocities of violet, red and green light, respectively, in a glass prism. Which among the following is a correct relation?
 (a) $V_v = V_R = V_G$ (b) $V_v > V_R > V_G$
 (c) $V_v < V_G < V_R$ (d) $V_v < V_R < V_G$
17. As an object moves towards a convex mirror, the image
 (a) magnification increases
 (b) moves towards the mirror
 (c) Neither (a) nor (b) happens
 (d) Both (1) and (2) happen
18. When a light ray passes from an optically denser medium into an optically rarer medium,
 (a) its velocity increases
 (b) frequency remains same
 (c) wavelength increases
 (d) All the above
19. Time taken by the sunlight to pass through a window made of glass of 5 mm thickness is _____ s. ($\mu_{\text{glass}} = 1.5$)
 (a) 2.5×10^{-11} (b) 0.4×10^{-8}
 (c) 4×10^{-8} (d) 2.5×10^{-5}
20. A man at the bottom of a pool wants to signal to a person lying at the edge of the pool. The man should beam his water proof light _____.
 (a) vertically upwards
 (b) at an angle to the vertical which is less than the critical angle.
 (c) at an angle to vertical which is equal to the critical angle.
 (d) at an angle to the vertical which is greater than critical angle.
21. Choose the correct statement.
 (a) The final image formed by a terrestrial telescope is inverted.
 (b) The final image formed by an astronomical telescope is erect.
 (c) The final image of an astronomical telescope is magnified.
 (d) Both (a) and (b)
22. Light appears to travel in a straight line because
 (a) it passes by the atmosphere
 (b) its wavelength is very small
 (c) its velocity is very large
 (d) it is a form of energy
23. Choose the correct statement
 (a) The combination of a convex lens and a concave lens is a concave lens if the focal length of the convex lens is numerically less than that of concave lens.
 (b) The power of the combination of a concave lens and convex lens is more than the power of individual lenses.
 (c) The combination of a convex lens and concave lens of equal focal length behaves as a glass slab.
 (d) All the above



24. The power of two lenses are + 6D and - 4D, the power of the combination two lenses is
 (a) 6D (b) 4D
 (c) 2D (d) 3D
25. The angle which the incident ray makes with the mirror is called
 (a) angle of incidence
 (b) angle of reflection
 (c) right angle
 (d) glancing angle of incidence
26. A magenta pigment absorbs _____ colours
 (a) red (b) blue
 (c) green (d) magenta
27. A concave mirror is placed on a table with its pole touching the table. The mirror is rotated about its principal axis in clockwise direction. The image of a person looking straight into it
 (a) rotates in clockwise direction
 (b) rotates in anti-clockwise direction
 (c) is inverted
 (d) does not rotate
28. If two plane mirrors are placed with the reflecting surfaces perpendicular to each other, which of the following statement is true?
 (a) The rays incident on the first mirror and the rays reflected from the second mirror are always parallel.
 (b) The rays incident on the first mirror and the rays reflected from the second mirror are perpendicular.
 (c) The angle of deviation lies between 90° and 180° .
 (d) None of the above
29. Which of the following statements is true, if a planet is observed with the help of an astronomical telescope?
 (a) The image of the planet is erect.
 (b) The objective is larger than the eye piece.
 (c) Eye piece has greater focal length than the objective.
 (d) Eye piece is of convex lens and the objective is of concave lens.
30. A convex lens forms a virtual image if the object is placed.
 (a) between the lens and its focus.
 (b) at the focus of the lens.
 (c) between F and $2F$.
 (d) at infinity
31. Light propagation is considered as rectilinear _____.
 (a) it passes through the atmosphere.
 (b) its wavelength is very small.
 (c) its velocity is very large.
 (d) it is a form of energy.
32. When a point source of light is kept near a plane mirror
 (a) only the reflected rays close to the normal meet at a point when produced backwards.
 (b) only those rays reflected at small angles meet when produced backwards.
 (c) light of different colours form images of different sizes.
 (d) all the reflected rays meet at a point when produced backwards.
33. Arrange the following steps in a sequential order to determine the focal length of a concave mirror by distant object method.
 (a) Place a white screen in front of the mirror and adjust the position of the screen until a sharp image is formed.
 (b) Focus the mirror towards a distant object.
 (c) Mount the concave mirror on a mirror stand.
 (d) Measure the distance between the screen and the mirror. This gives the focal length.
 (a) c a b d (b) c b a d
 (c) b a c d (d) a b d c
34. If μ_v , μ_r , μ_b are refractive indices of violet, red and blue, respectively, in a given medium, then
 (a) $\mu_v = \mu_b = \mu_r$ (b) $\mu_v > \mu_b < \mu_r$
 (c) $\mu_v > \mu_b > \mu_r$ (d) $\mu_v < \mu_r < \mu_b$
35. A lens behaves as a diverging lens in air and converging lens in water. The refractive index of the material of the lens is _____.
 (a) greater than refractive index of water
 (b) equal to refractive index of water
 (c) between 1 and refractive index of water
 (d) equal to unity
36. Write the following steps in a sequential order to determine the focal length of a concave mirror by using graphical method.



- (a) Determine the object distance and image distance, by placing the object at different places in front of convex lens.
- (b) Draw a line (OP) which makes an angle 45° with the X -axis.
- (c) Mark the values of u on the X -axis and the corresponding values of v on the Y -axis and join the points to obtain a curve.
- (d) Mark the point where the line OP intersects the curve.
- (e) Draw perpendiculars PA and PB to the X -axis and Y -axis from the point (P).
- (f) Draw a graph by taking object distance (u) on the X -axis and image distance (v) on the Y -axis.
- (g) It is found that the value OA and OB are equal which is equal to the radius of curvature and the focal length $f = \frac{\text{Radius of curvature}}{2}$
- (a) a d b f e c g (b) a b c d f e g
 (c) a f c b d e g (d) a f c b g e d
37. When red and green light fall on certain region of a screen simultaneously, the region will look _____.
 (a) red (b) blue
 (c) yellow (d) white
38. Cameras used in remote sensing make use of
 (a) visible light (b) ultraviolet radiation
 (c) radio waves (d) infrared radiation
39. The focal length of the normal human eye is _____ cm.
 (a) equal to 2.5 (b) > 2.5
 (c) < 2.5 (d) Both (a) and (c).
40. Which of the statements is true in case of an astronomical telescope?
 (a) The image of the object is erect when viewed through it.
 (b) The objective is larger in size than the eye piece.
 (c) Eye piece has greater focal length than the objective.
 (d) Eye piece is a convex lens and the objective is a concave lens.
41. The diaphragm in a photographic camera
 (a) controls the exposure time of the film.
 (b) controls the amount of light entering the camera.
 (c) varies the focal length of the lens.
 (d) prevents internal reflection of light.
42. When light emitted by a point source of light is passed through a prism, after dispersion, the emerging light would produce on the screen
 (a) a pure spectrum
 (b) an impure spectrum
 (c) a line spectrum
 (d) None of these
43. On mixing the colours yellow and cyan, the colour obtained is _____.
 (a) red (b) blue
 (c) green (d) black
44. During total internal reflection, the energy of the incident light
 (a) is absorbed by the reflecting surface.
 (b) is not absorbed by the reflecting surface.
 (c) increases.
 (d) None of the above
45. For a given glass prism, as the angle of incidence increases, the angle of emergence _____.
 (a) decreases (b) increases
 (c) remains the same (d) None of the above

Level 2

46. A student with a normal eye observes the reading on a vernier scale using a magnifying glass of focal length 10 cm. What are the minimum and the maximum distances between the scale and the magnifying glass at which he can read the scale when viewing through the magnifying glass?
47. A light ray incident on a plane mirror gets reflected from it. Another plane mirror is placed such that the reflected ray from the first mirror is incident on it. If the reflected ray from the second mirror travels perpendicular to the incident ray on the first mirror, determine the angle between two plane mirrors.
48. Why do clouds appear white?
49. Two plane mirrors X and Y are placed parallel to each other and are separated by a distance of 20 cm. An object is placed between the two mirrors at a distance



5 cm from the mirror X. Find the distance of the first three image formed in the mirror X.

50. An object is placed between two identical convex mirrors X and Y of focal length 15 cm at the mid point on their common principal axis. If the two mirrors are separated by a distance of 20 cm, determine the distance of the first two images formed in the mirror Y.

51. A rod of length $(f/2)$ is placed along the axis of a concave mirror of focal length f . If the near end of the real image formed by the mirror just touches the far end of the rod, find its magnification.

52. A diver under water sees a bird in air, vertically above him. If the actual height of the bird above the water surface is ' h ', then does it appear at the same height ' h ' to the diver? Explain giving reasons. If μ_w is the refractive index of water, find the shift in the bird's position as observed by the diver.

53. A ray of light is incident on a plane mirror placed horizontally. When the mirror is rotated through an angle 30° the reflected ray is found to be directed along the vertical. Determine the angle of incidence at the initial position of the mirror.

54. A ray of light is incident at an angle of 60° on a prism whose refracting angle is 30° . The ray emerging out of the prism when produced backward makes an angle of 30° with the incident ray produced forward. Find the refractive index of the material of the prism.

55. A light ray passes from air to denser medium of certain thickness and emerges on the other side. If the emergent ray is parallel to the incident ray, the distance travelled by the ray of light in the denser medium is 6 cm, and the angle of incidence and refraction are 60° and 30° , respectively, find the lateral displacement of the light ray.

56. A postal stamp is placed on a surface and a glass cube of refractive index $\frac{3}{2}$ is placed over it. When observed through the glass slab, the stamp appears at a height of 1.5 cm from the bottom. Another glass cube made of different material and having the same thickness is placed over the first glass cube. When observed from the top, the stamp now appears to be at a height of 4 cm from the bottom. Determine the refractive index of the second glass cube.

57. A telescope has an objective of focal length 100 cm and eye piece of focal length 6 cm and the least distance of distinct vision is 25 cm. The telescope is focused for distinct vision of an object at a distance 100 m from the objective. What is the distance of separation between objective and eye piece?

58. Which radiation is used to photograph in smoke or fog? Explain why?

59.

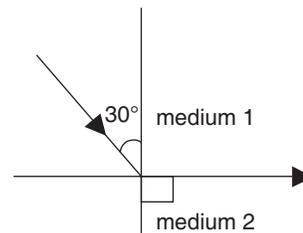


An object and the image obtained from the lens are as given above.

If the distance between the object and the image is 36 cm and the magnification is -2 , find the focal length of the lens and draw the ray diagram to show the position of the lens.

60. Determine the thickness of the glass through which light can pass in 5×10^{-11} seconds (Take $\mu_{\text{glass}} = 1.5$).

61. A light ray travels from a medium 1 to medium 2 as shown in the figure. If the refractive index of medium 1 is $2\sqrt{2}$, determine the refractive index of medium 2.



62. The power of two lenses are $+6\text{ D}$ and -4 D , determine the power of the combination of two lenses.

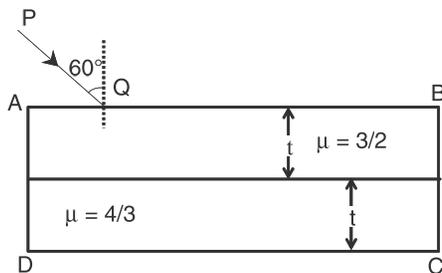
63. The refractive index of a medium (2) with respect to medium (1) is x and refractive index of medium (2) with respect to medium (3) is ' y ' then what is the refractive index of the medium (3) with respect to medium (1).

64. The ciliary muscles can change the focal length of the eye lens. Find the ratio of focal lengths of the eye lens when it is focused on two different objects, one at a distance of 2 m and the other at a distance of 1 m. The diameter of normal eye is 2.5 cm.

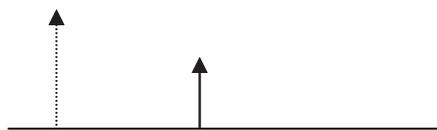


Level 3

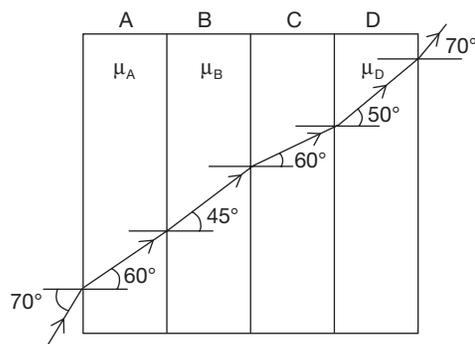
65. A glass slab $ABCD$ is made of two different grades of glass of refractive indices $\frac{3}{2}$ and $\frac{4}{3}$ of equal thickness, and a ray PQ is incident on the face AB . Trace the ray as it passes through the slab and find the angle of emergence and the angle of deviation. Find the effective refractive index of the slab.



66. The base of a rectangular glass slab of thickness 10 cm and refractive index 1.5 is silvered. A coloured spot inside the glass slab at a distance of 8 cm from the base. Determine the position of the image formed by the mirror as observed from the top.
67. A boy holds a convex lens 30 cm above the base of an empty vessel. The real image of the bottom of the vessel is formed 20 cm above the lens. The boy fills a liquid in the vessel up to a depth of 25 cm and finds that the real image of the bottom of the vessel is now 30 cm above the lens. Find the refractive index of the liquid.
68. A fish under water observes a freely falling stone in air. If the refractive index of water is $\frac{4}{3}$, what is the apparent acceleration of the stone as observed by the fish?
69. An object and its image are as shown in the diagram below. If the object image distance is 4 cm and the magnification is 3, find type of the lens used and ratio $u : v : f$. Draw the ray diagram to show the position of the lens and the principal focii.



70. A , B , C and D are four transparent sheets of equal thickness and made of material of refractive indices μ_A , μ_B , μ_C , and μ_D . If a light ray propagates through them as shown in the figure, compare their refractive indices and also find if any of them have the same refractive index.



71. A convex lens and a convex mirror are separated by a distance of 10 cm such that the reflecting surface of the mirror faces the lens. The image of an object placed in front of the convex lens at a distance of 20 cm is found to coincide with the object. If the focal length of the convex lens is 15 cm, determine the focal length of the mirror.
72. An object is placed at a distance of 20 cm from a convex mirror of radius of curvature convex cm. At what distance from the object should a plane mirror be placed so that the images due to the mirror and the plane mirror are on the same plane?
73. In a college hostel, a clever warden in order to know what the students are doing in the room in his absence during night he switched off the light in the corridor and watched the room through a glass partition from the corridor. Explain why the objects in the room are more clearly visible when he switched off the corridor lights than when there is light in the corridor.
74. A tree, which is 200 m away from the pinhole, produces an image of height 1 cm, in a pinhole camera of width 20 cm. Find the height of the tree.



CONCEPT APPLICATION

Level 1

True or false

1. False 2. False 3. True 4. True 5. True 6. True 7. False

Fill in the blanks

8. Critical angle 9. Concave 10. red 11. Focal plane 12. reciprocal
 13. Translucent or heterogeneous. 14. $\frac{x}{y}$

Match the following

15. A : g B : h C : e D : b E : i F : d G : c H : f I : a

Multiple choice questions

16. (c) 17. (d) 18. (d) 19. (a) 20. (c) 21. (c) 22. (b) 23. (c) 24. (c) 25. (d)
 26. (c) 27. (d) 28. (a) 29. (b) 30. (a) 31. (b) 32. (d) 33. (b) 34. (c) 35. (c)
 36. (c) 37. (c) 38. (d) 39. (d) 40. (b) 41. (b) 42. (b) 43. (c) 44. (b) 45. (a)

Explanations for questions 31 to 45:

31. Light appears to travel in straight line as its wavelength is very small when compared with the size of the object on which it falls.
32. When a point source is kept near a plane mirror, all the reflected rays appear to meet at a point when produced backwards.
33. The concave mirror is mounted on the stand (c). The mirror is focussed towards the object (b). A white screen is placed in front of the mirror and its position is adjusted to get a clear image (a). The distance between the screen and the mirror gives the focal length (d).
34. When white light passes through a prism, the deviation of violet is more than the deviation of blue and deviation of blue is more than the deviation of red. As such $\mu_v > \mu_b > \mu_r$.
35. When the light ray travels from air to lens, then it acts as a diverging lens. The same lens can act as a converging lens if light enters the lens from a denser medium. As such, the refractive index of the material of lens is less than the refractive index of water.
36. Initially the object distance (u) and image distance (v) are measured by placing the object at different posi-

tions (a). A graph is drawn by taking u on the X-axis and v on the Y-axis (f). Mark the values of u and v on the graph and join the points to obtain a curve (c). Draw a line which makes an angle 45° with the X-axis (b). Mark the point (P) where the line intersects with the graph (d). Draw perpendiculars PA and PB to the X-axis and Y-axis from the point ' P ' (e). The distance PA and PB are equal. Thus, it is the radius of curvature.

Hence, the focal length of concave mirror

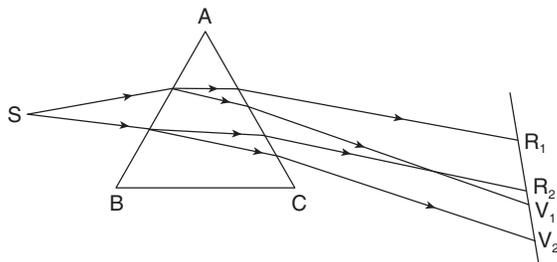
$$= \frac{OA}{2} \text{ or } \frac{OB}{2} \text{ (g)}$$

37. When red and green lights combine, they form yellow light.
38. Remote sensing cameras use infrared radiation.
39. Normal diameter of human eye is 2.5 cm. When the eye is focussed on a distant object, the ciliary muscles are relaxed so that the focal length of the eye has its maximum value equal to the diameter of the eye. When the eye is focussed on a closer object, ciliary muscles are strained and the focal length of the eye-lens decreases.
40. For an astronomical telescopes, the objective is larger than the eye piece.



41. The diaphragm in a photographic camera controls the amount of light entering the camera.
42. Due to point source of light, a prism gives impure spectrum.

This is shown by diagram below



43. When the colours red and green are mixed, we get the colour yellow.

$$R + G = \text{yellow} \quad (1)$$

Also, when blue and green are mixed we get the colour cyan.

$$\text{Blue} + \text{Green} = \text{Cyan} \quad (2)$$

Adding eqn (1) and (2)

$$\text{Yellow} + \text{cyan} = (R + G + B) + G = W + G = G$$

Hence, by mixing yellow and cyan, we get the colour green.

44. During total internal reflection, the energy of the incident light is not absorbed by the reflecting surfaces.

45. For a given glass prism

$$\frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2} = \mu \quad (1)$$

Where i_1 and r_1 are angle of incidence and refraction at the first refracting surface, i_2 and r_2 are angle of incidence and refraction at second refracting surface from (1) we can write

$$\frac{\sin i_1}{\sin r_1} = \mu$$

As μ of the material of the prism remains constant, with increase in angle of incidence i_1 angle of refraction r_1 also increases.

Now, $A = r_1 + r_2$

But for a given prism, A remains constant

$$\therefore r_1 + r_2 = \text{constant.}$$

In the above equation, if r_1 increases due to increase in i_1 then r_2 must decrease.

With decrease in r_2 , angle of emergence

decreases, as $\mu = \frac{\sin i_2}{\sin r_2}$

Level 2

46. (i) What is the least distance of distinct vision of human eye?

What is the minimum distance between an object and a convex lens to obtain the virtual image?

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{substitute } f = 10 \text{ cm and } v = \infty \text{ to obtain 'u'}$$

- (ii) $u_1 = 7.14 \text{ cm}$
 $u_2 = 10 \text{ cm}$

47. (i) Angle of incidence = angle of reflection
Sum of the three angles of a triangle = 180°
Draw the ray diagram and determine the sum of the angle of incidences and angle of reflections
(ii) 45°

48. The blue colour of the sky is due to the scattering of radiations of shorter wavelength.
This scattering is due to the small radii of air molecules.

But the particles of cloud are relatively large in size and all radiations get scattered by it.

49. (i) The object distance for the second image ' X ' = $a + d = b$.

Where ' d ' is the distance between the two mirrors and a is the first image distance on Y .

The second image on Y is formed at a distance $b + d$ where b is the first image distance on ' X '.

The third image on X is formed at $d + b + d$.

- (ii) 5 cm, 35 cm, 45 cm

50. (i) Find the image distance by using $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Now the first image formed by the mirror x acts as the virtual object for the mirror ' y '.

\therefore The object distance for the formation of second image = $V_1 = d$

Where V_1 is the first image distance and ' d ' is the distance between two mirrors.

- (ii) 6 cm, 7.5 cm



51. (i) Draw a ray diagram representing the given situation.

Let AB be the object and A be the near end of the object and B be the far end of the object.

Let $A'B'$ be the image formed.

As B' coincides with the end B at the centre of curvature,

\therefore the distance of B from the mirror $= 2f$.

Let the length of the object be $\frac{f}{2}$.

The end A is at a distance of $\left(2f - \frac{f}{2}\right)$.

By using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$,

Determine the distance of $A'B'$, from the mirror and find the length of the image. $u = 2f - d$

The magnification, $m = \frac{\text{length of the image}}{\text{length of the object}}$

- (ii) $m = 2$

52. (i) What happens to the light ray when it enters an optically denser medium from an optically rarer medium?

Will the light rays entering water appear to come from the original position?

When a person observes an object in water the

refractive index, $\mu_w = \frac{\text{Real depth}}{\text{apparent depth}}$

How does the above formula change if the person observes the object in air from water?

- (ii) Shift $= h(\mu_w - 1)$

53. (i) When a plane mirror is rotated through an angle θ , the reflected ray is rotated through 2θ .

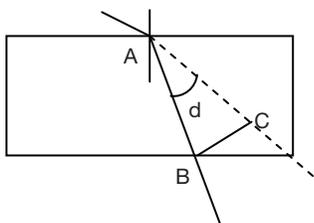
The initial angle of incidence $i_1 = i_2 + r_2$

When i_2 and r_2 are the angle of incidence and angle of reflection after rotating the mirror.

- (ii) 60°

54. $\sqrt{3}$

55. (i) Angle of deviation $d = i - r$



In triangle ABC

$$\frac{BC}{AB} = \sin d.$$

AB is the distance travelled by the light ray inside the denser medium and BC is the lateral shift.

- (ii) 3 cm

56. 2.25

57. (i) The image formed on the objective is real.

Let the image distance be v_1

This image serves as the object for eye piece. Determine the object distance for the eye piece (u_2)

\therefore The distance between objective and eye piece $= v_1 + u_2$

- (ii) 106.89 cm

58. How is the scattering of the radiation related to its wavelength?

Can radiation of higher wavelengths travel longer distances?

How does the scattering of light effect on the photographs taken?

59. (i) The magnification, $m = \frac{v}{u}$
 $\therefore v = mu$ (1)

The distance between object and the image

$$= v + u \quad (2)$$

From (1) and (2) determine the object distance ' u '.

By substituting the value of u in one of the equations, determine the value of ' v '.

Now the focal length can be determined as

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad (3)$$

(Take sign convention for only 3rd equation).

Identify the lens used from the nature of the image formed and draw the ray diagram.

- (ii) 8 cm

60. $5 \times 10^{-11} \text{ s} = \frac{\text{optical path}}{\text{speed in vacuum}} = \frac{\mu d}{c} = \frac{1.5d}{3 \times 10^8}$

\therefore Thickness (d) = 10 mm

61. $\frac{1}{\sin c} = \frac{\mu_1}{\mu_2}$

$$\frac{1}{\sin 30} = \frac{2\sqrt{2}}{\mu_2} \Rightarrow 2 = \frac{2\sqrt{2}}{\mu_2} \Rightarrow \mu_2 = \sqrt{2}$$



62. $P = P_1 + P_2$
 $= +6 + (-4) = +2 \text{ D}$

63. ${}^1\mu_3 = x/y$
 ${}^1\mu_2 = x, {}^3\mu_2 = y.$

$${}^1\mu_3 = \frac{\mu_3}{\mu_1} = \frac{\mu_3}{\mu_1} \times \frac{\mu_2}{\mu_2} = \frac{\mu_3}{\mu_2} \times \frac{\mu_2}{\mu_1} = {}^2\mu_3 \times {}^1\mu_2$$

$$\Rightarrow \frac{{}^1\mu_2}{{}^3\mu_2} = \frac{x}{y}$$

64. When the eye is focused on an object at a distance of 2 m, then
 $u = -2 \text{ m} = -200 \text{ cm}$

$$v = 2.5 \text{ cm}; f_1 = ?$$

$$\frac{1}{f_1} = \frac{1}{v} - \frac{1}{u} = \frac{1}{2.5} - \frac{1}{(-200)}$$

$$f_1 = \frac{500}{202.5} \text{ cm}$$

$$u = -1 \text{ m} = -100 \text{ cm}$$

$$v = 2.5 \text{ cm}; f_2 = ?$$

$$\frac{1}{f_2} = \frac{1}{2.5} - \frac{1}{(-100)}$$

$$f_2 = \frac{250}{102.5} \text{ cm}$$

$$\frac{f_1}{f_2} = \frac{500}{202.5} \times \frac{102.5}{250} = \frac{205}{202.5} = 82 : 81$$

Level 3

65. (i) Apparent shift $= t \left(1 - \frac{1}{\mu} \right)$

Find the apparent shift in each glass slab S_1 and S_2 and the total shift (S) $= S_1 + S_2$

But $S = t \left(1 - \frac{1}{\mu_e} \right)$ when μ_e is the effective refractive index

(ii) $\mu = \frac{24}{17}$

66. (i) $\mu = \frac{R.d}{A.d}$

Determine the actual position of the ink mark by using the above relation.

Determine the actual position of the image formed by the plane mirror.

(ii) 11.33 cm

67. (i) Let the focal length of the lens be f .

$$f = \frac{u_1 v_1}{v_1 - u_1}$$

Determine the value of f and let the bottom of the vessel appear to be at a depth ' u_2 ' from the lens when the beaker is filled with a liquid.

$$\frac{1}{u_2} = \frac{1}{v_2} - \frac{1}{f}$$

where v_2 is the image distance when the beaker is filled with water.

Now the shift of the bottom of the vessel
 $= u_1 - u_2$

The apparent depth of the water in the container
 $= d - (u_1 - u_2)$ where ' d ' is the depth of the water in the container.

$$\therefore \text{Refractive index} = \frac{\text{Real depth}}{\text{Apparent depth}} = \frac{d}{d - (u_1 - u_2)}$$

(ii) $\mu = 1.66$ or $\frac{5}{3}$

68. (i) Let h_1 and h_1^1 be the real and apparent height of the stone at $t = 0 \text{ s}$.

Let h_2 and h_2^1 be the real and apparent height of the stone at $t = 1 \text{ s}$

The real distance travelled

$$S = h_1 - h_2$$

Apparent distance travelled $h_1^1 - h_2^1 = S^1$

$$\mu = \frac{h_1}{h_1^1}, h_1^1 = \frac{h_1}{\mu} \text{ and } h_2^1 = \frac{h_2}{\mu}$$

Use the relation $s = ut + \frac{1}{2}t^2$

In both the cases, determine the apparent acceleration.

(ii) 13.1 ms^{-2}



69. (i) As the magnification is more than 1, lens must be convex lens.

(ii) Magnification $m = \frac{v}{u}$ (1)
 $v = u + d$

where 'd' is the distance between the image and the object.

Substitute the values of v in (1) and determine the values of u and v by using (1).

Now the focal length ' f ' may be determined as

$$f = \frac{uv}{(u + v)}$$

Find the ratio of u , v and f .

$$2 : 6 : 3$$

70. Let us represent angles of incidence and angles of refraction in A, B, C, D as $i_A, i_B, i_C, i_D, r_A, r_B, r_C$ and r_D , respectively.

$$r_B < i_A \Rightarrow \mu_B > \mu_A$$

$$r_C > i_B \Rightarrow \mu_B > \mu_C$$

$$r_C = r_A \Rightarrow \mu_C = \mu_A$$

$$r_D < i_C \Rightarrow \mu_D > \mu_C$$

$$r_B < r_D \Rightarrow \mu_B > \mu_D$$

$$\text{as such } m_A = \mu_C < \mu_D < \mu_B$$

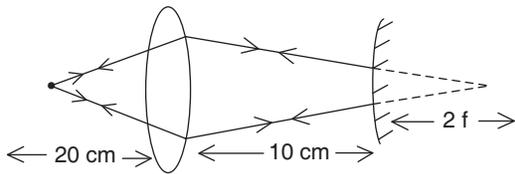
71. If the mirror were not present

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{15} = \frac{1}{v} - \left(-\frac{1}{20}\right)$$

$$\frac{1}{v} = \frac{1}{15} - \frac{1}{20}$$

$$\frac{20 - 15}{300}, v = 60 \text{ cm}$$



The image would be formed at a distance of 50 cm from the mirror.

When the mirror is placed the image is formed at the position of the object.

That is the rays are reflected back along the same path.

This is possible only when the light rays are incident normally.

$$\therefore 10 + R = 60 \text{ cm}$$

$$R = 50 \text{ cm}$$

$$f = 25 \text{ cm}$$

72. Focal length = $\frac{\text{radius of curvature}}{2} = \frac{40}{2} = 20 \text{ cm}$

Object distance $u = -20 \text{ cm}$ (from sign convention)

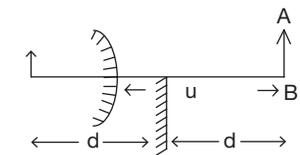
From mirror formula,

$$\frac{1}{f} = \frac{1}{v} = \frac{1}{u}$$

$$\frac{1}{20} = -\frac{1}{20} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{40}{400}$$

$$v = \frac{400}{40} = 10 \text{ cm}$$



$$\begin{aligned} 2d &= u + v \\ &= 20 + 10 \\ &= 30 \text{ cm} \\ \therefore d &= 15 \text{ cm} \end{aligned}$$

Distance between the object and the image is $20 + 10 = 30 \text{ cm}$.

Since for plane mirror object distance is equal to image distance, the plane mirror should be placed at a distance $\frac{30}{2} = 15 \text{ cm}$ from the object, for the image of the plane mirror and spherical mirror to be in the same plane.

73. Light from the corridor is reflected by the glass pane separating it from the dark room. This reflected light enters our eye along with the light from inside the dark room. Since reflected light is more than the light from the room and also more intense, we cannot see the things inside the room. When the lights in the corridor are switched off, the light from the room now enters our eyes and the visibility improves.

74. In case of a pinhole camera, Magnification

$$= \frac{\text{image size}}{\text{object size}} = \frac{\text{distance of the image}}{\text{distance of the object}}$$

$$\frac{1 \text{ cm}}{x} = \frac{20 \text{ cm}}{200 \times 100 \text{ cm}} \Rightarrow x = \frac{200 \times 100}{20}$$

$$= 1000 \text{ cm} = 10 \text{ m}$$



Chapter 10

Electricity

REMEMBER

Before beginning this chapter you should be able to:

- Recall the structure of an atom and terms related like electrification, electrostatic force, properties of charges, methods of charging a body, detection and testing of charges, atmospheric electricity
- Define electric current and resistance

KEY IDEAS

After completing this chapter you should be able to:

- Explain the properties of electric charges at rest and the different methods of charging bodies
- Restate the concept of electric field and electric potential
- Explain the different properties of electric charges in motion
- Understand the concept of electric current, electric resistances, heating effect of electricity and domestic wiring



INTRODUCTION

Electricity, the most convenient form of energy for transformation into other forms with minimum loss, is a part of modern life. Without electricity, most of the present day activities would come to a halt. The time of discovery of electricity is not exactly known but in today's human life, its applications are innumerable. From a small phenomenon like the glowing of a bulb to huge engineering applications, we hardly find a place where electricity is not used.

The study of electricity as a branch of physics involves the study of charges, which are either stored in bodies or in motion through bodies. In some of the applications of electricity, we need to store electric charge in devices like capacitors, wherein the charges are at rest. The branch of electricity which deals with the phenomena related to or applications regarding charges at rest is known as 'static electricity'. In some applications of electricity, we study the motion of charges from one place to another within a body or from one body to another through a material that allows the motion of charges through it and the effects such charge movement can produce. This branch of electricity is known as 'current electricity'. In the present chapter, we deal with the basics of current electricity. Before proceeding further let us have a brief review of some points related to static electricity, these points would help us understand current electricity in a better way.

STATIC ELECTRICITY

Electric Charges

Ancient Greeks knew that when amber, a fossilized gum, is rubbed against wool, it acquired a property of attracting light objects like leaves, dry straw, etc. William Gilbert in the seventeenth century showed that glass on rubbing against silk, ebonite on rubbing against cat's skin or sealing wax on rubbing against wool also acquire this property. The substances which develop this property are said to be charged or electrified and the process is called electrification from 'electron', the Greek word for amber.

Further, Gilbert observed that when two glass rods, each rubbed against silk, are brought closer, they repel each other. Similarly, two ebonite rods rubbed against cat's skin repel each other. On the other hand, a glass rod rubbed against silk and an ebonite rod rubbed against cat's skin on being brought closer attract each other. Thus, like charges repel and unlike charges attract. He was also able to establish that various bodies which get electrified on rubbing either acquired charges similar to those acquired by glass rod or that acquired by ebonite rod.

Charge

The matter consists of atoms and in an atom the electrons revolve around the nucleus in elliptical orbits. The electrons in the outermost orbit of an atom are loosely bound to it and a small amount of energy is required to make them free.

When a body is rubbed against another, transfer of free electrons takes place between the bodies, and thus, they acquire charge. It is denoted by ' Q ' or ' q '. By convention, in an atom, electrons are considered to be charged negatively and protons are considered to be charged positively. The magnitudes of charge on an electron and a proton are equal. The number of electrons in an atom is equal to the number of protons in it, thus, the total amount of negative charge in it is equal to the total amount of positive charge, and thus, the atom is said to be

electrically neutral. The elementary entity of an electric charge is considered to be an electron, and thus, the charge on any body is expressed in terms of an integral multiple of charge on an electron.

Thus, when a glass rod is rubbed against silk, the electrons in outer most orbits of glass atoms at its surface acquire sufficient energy and become free and get deposited on silk. Glass rod loses electrons and has more number of protons than electrons and becomes positively charged. Silk has excess of electrons and becomes negatively charged. In case of an ebonite rod rubbed against cat's skin, the latter loses electrons to the ebonite rod. Thus, cat's skin becomes positively charged and ebonite rod becomes negatively charged.

Units of Charge

The SI unit of charge is coulomb (C) named after Charles Coulomb. It is a scalar quantity. Its dimensional formula is $[M^0 L^0 A^1 T^1]$

Properties of Charges

The following are the properties of electric charges:

1. There are two types of charges, namely, positive and negative.
2. The magnitudes of the charge on an electron and a proton are equal, but they are unlike charges. An electron is charged negatively whereas a proton is charged positively.
3. Two charged bodies repel each other, if they contain like charges, i.e., both positive or both negative. Two charged bodies attract each other if they contain unlike charges.
4. A neutral body becomes positively charged on losing electrons and not because of gaining protons.
5. A neutral body becomes negatively charged, when it gains electrons.
6. The amount of charge present in a body, either positive or negative, is expressed in terms of an integral multiple of the charge of an electron, which is considered the elementary entity of an electric charge. Because number of electrons in a body is natural number. If ' q ' is the magnitude of charge on any body, then $q = ne$ where ' n ' is any natural number and ' e ' is the elementary charge and is approximately equal to 1.6×10^{-19} C. This is known as 'quantization of electric charge'.
7. The charge on a body gives the information about the excess or deficiency of electrons in the body but does not give an account of the total charge, either positive or negative, present on the body.
8. When no net charge is present on a body, it is said to be electrically neutral since the amount of positive charge present on it is equal to the amount of negative charge on it.
9. When two bodies are rubbed, one against the other, and if one of them acquires a positive charge by losing some electrons, the second body acquires a negative charge by gaining the same number of electrons lost by the first body. Thus, the total electric charge on both the bodies put together, before and after electrification, remains the same. It is said that, the charge is conserved and this is known as the law of conservation of charge.
10. If some amount of charge is supplied to a spherical conductor, the charge gets distributed over its surface uniformly irrespective of the place on the conductor at which the charge is supplied. The amount of charge present per unit surface area is called 'charge density' and is denoted by ' σ ' (Greek alphabet sigma). It is measured in coulomb per square metre ($C\ m^{-2}$). For a spherical conductor the charge distribution over its surface

is uniform. But if the surface of a conductor has higher curvature in certain parts or any pointed tips, at those positions, more charge accumulates. (Fig. 10.1)

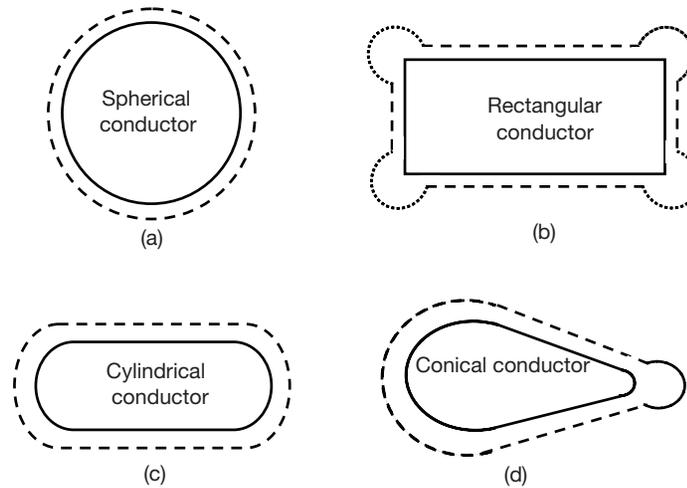


FIGURE 10.1 Distribution of charge on various conductors

CONDUCTORS AND INSULATORS

The electrons in the outer most orbit of an atom are weakly attracted by the nucleus. Hence, these electrons can move about within a substance but cannot escape from it. These electrons are called free electrons. Usually metals have a large number of free electrons and non-metals have very few free electrons. As the free electrons are in random motion, there is no drift in one particular direction. However, the free electrons can be made to drift in one particular direction by maintaining electric potential difference across the substance. The substances which have fairly large number of free electrons which can be made to drift rapidly are called electric conductors.

The charge supplied to an insulator (also called dielectric) is not distributed over its entire surface and remains at the supplied position on the insulator.

The charge supplied to a conductor always resides on its surface and is not present inside the body. This was proved in experiments conducted by scientists, Biot and Faraday.

Examples: All metals, graphite, acid and alkali solution in water, rubber, wood, etc.

The substances which do not have a large number of free electrons so that very few electrons get drifted on the application of electric potential difference are called insulators or bad conductors of electricity.

Examples: All gases, glass, mica, non-metals, etc.

Flow of Electric Charges

Consider a positively-charged conductor being connected to a negatively-charged conductor by a copper wire. Charges begin to flow through the copper wire. Till 16th century it was not clear whether charges flow from positive to negative or vice versa. The positive charges

were considered to have high potential, while negative charges were considered to have low potential and it was assumed that charges flow from high to low potential. However, later it was discovered that electrons move from negatively-charged conductor to positively-charged conductor. Free positive charges as such do not exist as protons as they are tightly held in the nucleus. Movement of charges, thus, involves movement of free electrons.

The Earth is electrically neutral. The number of electrons contained in it is so large that even if a few billions of electrons are added to it or removed from it, it still can be considered to be electrically neutral.

When a positively-charged body is connected to the Earth or the ground through a conductor, electrons from the Earth flow into the body till all the positive charges are neutralized. When a negatively-charged body is earthed, the excess electrons from it flow into the Earth.

CHARGING A CONDUCTOR

The process of supplying an electric charge to a conductor is known as 'charging'. The charging of a conductor can be done in different ways.

Charging by Friction

As discussed earlier, when a body is rubbed against another, transfer of electrons takes place from one body to another. This transfer takes place due to friction between the bodies and the charge, thus, obtained on the bodies is called 'frictional charge'. This method of charging a body is known as 'electrification by friction'.

It is found that not only a glass rod and a silk cloth, but many other materials also can acquire frictional charge. The type of charge they acquire depends on their nature. Following is the list of some objects placed in an order such that if two objects among them are rubbed, the object that appears first in the list acquires a positive charge and the object that appears later acquires a negative charge.

1. cat's skin
2. fur
3. glass
4. cotton
5. silk
6. wood
7. Indian rubber
8. resin
9. amber
10. sulphur
11. ebonite

Charging by Conduction

When a uncharged conductor body is brought in contact with a charged conductor, then transfer of charge takes place from the charged body to the uncharged conductor as shown Figs. 10.2 and 10.3. This type of charging is known as ‘charging by conduction’.

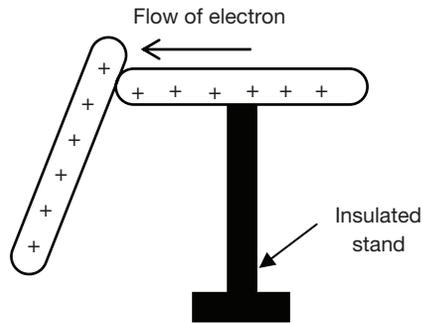


FIGURE 10.2

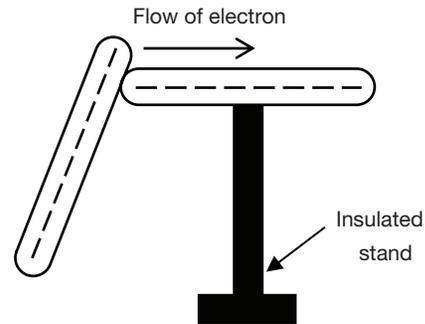


FIGURE 10.3

Charging by Induction

When a positively-charged glass rod is brought close to an uncharged copper sphere mounted on an insulating stand as shown in Fig. 10.4, the positive charge on the glass rod repels the positive charge on the copper sphere, simultaneously attracting the negative charge on the sphere towards it. This induces a net negative charge on the copper sphere towards the glass rod side and a net positive charge on the far side of it.

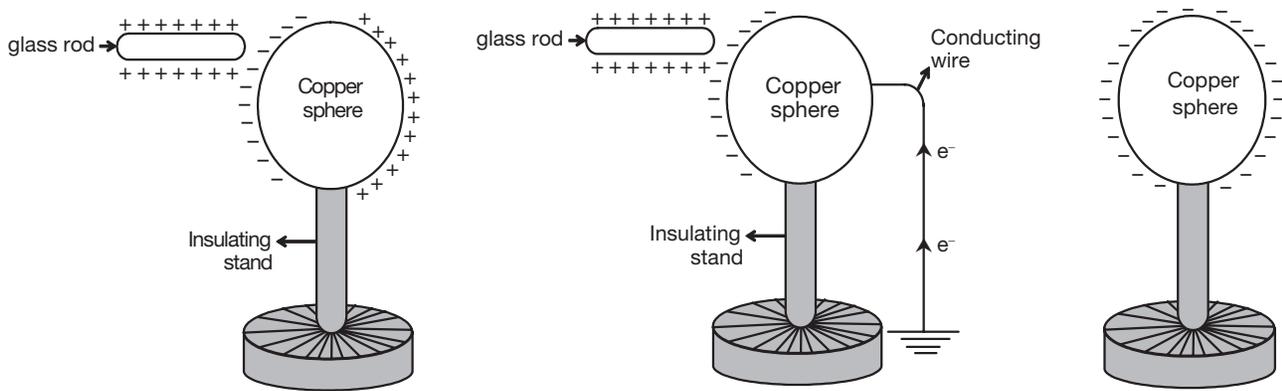


FIGURE 10.4

When the other side of the copper sphere is connected to the ground, with the help of a conducting wire, the positive charges on the sphere are lost to the Earth. (In fact, electrons are transferred from the Earth to the portion of the sphere where there is deficiency of electrons) (Fig. 10.4). Now, when the charged glass rod is taken away from the vicinity of the sphere, the negative charge present on the sphere is uniformly distributed over its surface (Fig. 10.4). This process of charging a conductor without actually bringing it in contact with another charged body is known as ‘charging by induction’. The charges on the sphere that are towards the glass rod in Fig. 10.4, i.e., negative charges in this case, are called ‘bound

charges' and the charges that are away from the glass rod, i.e., positive charges in this example, are called 'free charges'.

The process of inducing charges on a body by bringing another charged body near to it is known as 'electrostatic induction'.

DETECTION OF CHARGE ON A BODY

Electroscope

It is an instrument to detect the presence of an electric charge on a body. It is also used to find the nature of charge on a body, i.e., whether the charge is positive or negative. There are many kinds of electroscopes, among which a pith ball electroscopes and a gold leaf electroscopes are the basic models.

Pith Ball Electroscopes

A pith ball electroscopes consists of a pith ball suspended from a copper hook by means of a silk thread, and the copper hook is attached to an insulating stand as shown in the Fig. 10.5 (a).

If a positively-charged glass rod is brought into contact with the pith ball, the ball gets attracted to the rod initially [Fig. 10.5 (b)]. Once the rod touches the ball, the ball acquires the positive charge and gets repelled by the rod in the next moment (Fig. 10.5c). Now the pith ball is charged positively, and if any other positively-charged body is brought near to it, it gets repelled. If a negatively-charged body is brought near to the pith ball, it shows attraction. The amount of repulsion or attraction increases with an increase in magnitude of the charge on the body brought near to the pith ball.

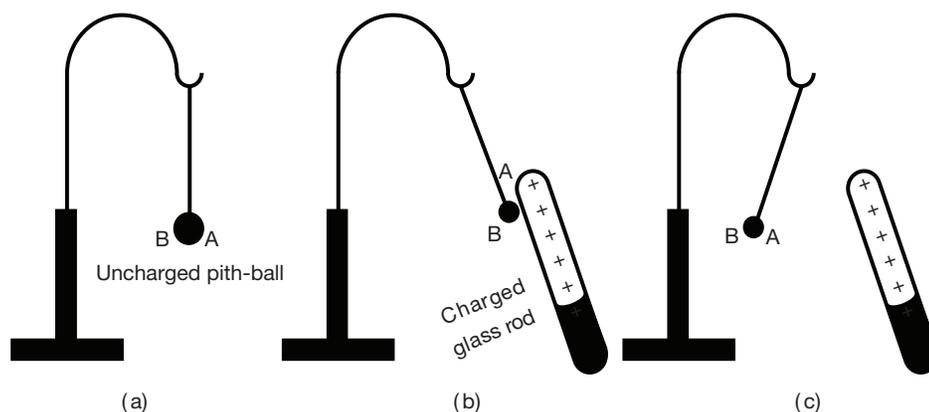


FIGURE 10.5 Pith Ball electroscopes

Gold Leaf Electroscopes

A gold leaf electroscopes consists of a glass jar J placed on a non-conducting surface S like wood as shown in Fig. 10.6. The mouth of the glass jar is sealed with shellac material. A brass rod passes through the seal. Inside the jar, the lower end of the brass rod is flattened like a strip and a small gold foil is fixed at the lower end of the brass rod parallel to the brass strip.

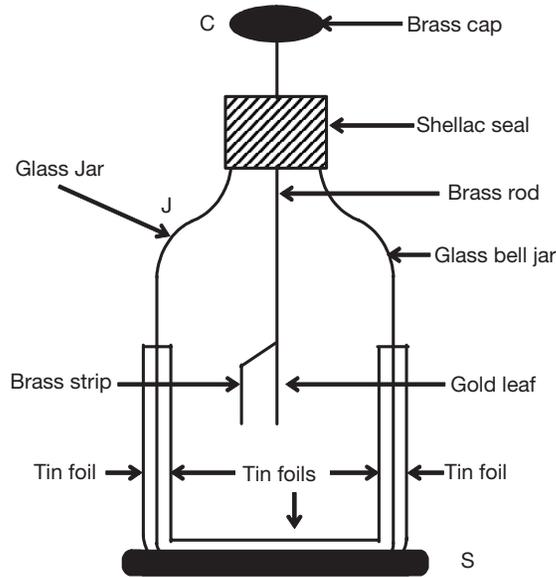


FIGURE 10.6 Gold leaf electroscope

At the bottom and lower lateral sides of the jar, tin foils are fixed, which help the charge to stay on the gold foil for longer time. A brass cap C is provided at the upper end of the brass rod.

Working

Initially, the brass cap of the electroscope is touched with hand so that any charge present on the foils or the brass rod is absorbed by hand and conducted to earth through our body. Now if a glass rod that is charged positively is brought into contact with the brass cap of the electroscope, the positive charge is conducted to the brass strip and to the gold foil at the lower end of the brass rod. Thus, the lower end of the gold leaf (foil) diverges from the brass strip; indicating the presence of charge on the electroscope. Now if another body charged positively is brought into contact with the brass cap, the divergence of the gold leaf increases indicating that the body brought in contact with the brass cap is charged positively. If the divergence of the gold leaf decreases on touching the brass cap, it can be concluded that the body is charged negatively.

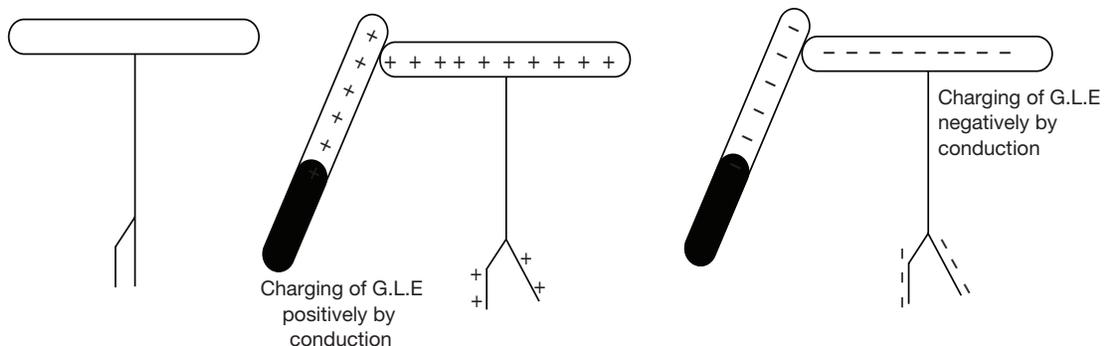


FIGURE 10.7 Charging by conduction

Proof Plane

If the size of a body to be tested is very large, we use a device which makes it easier to carry the charge from the body to an electroscope. Such an instrument is called proof plane.

A proof plane consists of a brass disc with an insulated handle at its centre. When the disc is brought in contact with a large charged body, the charge on the body is shared by the brass disc (the proof plane). When the disc is detached from the body, it carries the charge of the body. Now the proof plane can be brought near a gold leaf electroscope to detect the charge on its surface. Thus, the proof plane is used to carry charge from a large charged body to an electroscope for detecting the charge on the body.

It can be shown that, on electrification two kinds of charges are produced simultaneously. Fit a cat's skin cap over an ebonite rod. Rub the rod with the cap so that both are charged as shown in fig. 10.9.

Touch the rod along with the cap to the disc of gold leaf electroscope. The leaves show no divergence indicating the absence of charge. Now remove the cap with the help of the thread attached to it and bring the ebonite rod near a negatively-charged electroscope. The leaves of the electroscope diverge more indicating the presence of negative charge on the rod. Similarly, when the cap is brought near a positively-charged electroscope, the leaves diverge more, indicating the presence of positive charge on the cap. On rubbing with cat's skin, ebonite rod acquires electrons from cat's skin and becomes negatively charged whereas cat's skin becomes positively charged. The magnitudes of charges on both are equal but opposite. Hence, the leaves of electroscope showed no divergence in the first case. When both are touched to electroscopes separately, the leaves show divergence due to the presence of net charge on them.

Biot's and Faraday's experiments prove that the charge given to a conductor, whether hollow or solid, always reside on its outer surface.

BIOT'S EXPERIMENT

Biot's spherical conductor 'C' fitted to an insulating stand is electrically charged. Two hemispherical and hollow conductors, P and Q provided with insulating handles and exactly fitting the spherical conductor 'C' are (Fig. 10.10) allowed to touch 'C'. Once 'P' and 'Q' are taken away from 'C', it is found that no charge exists on 'C' and the charge is transferred to the outer surfaces of 'P' and 'Q'.

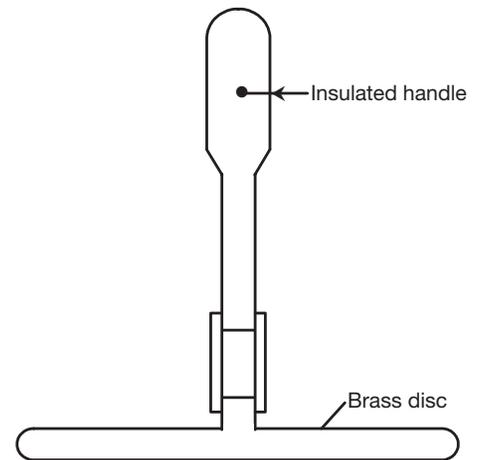


FIGURE 10.8 Proof Plane

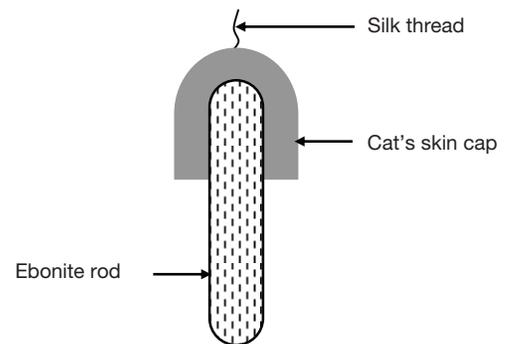


FIGURE 10.9

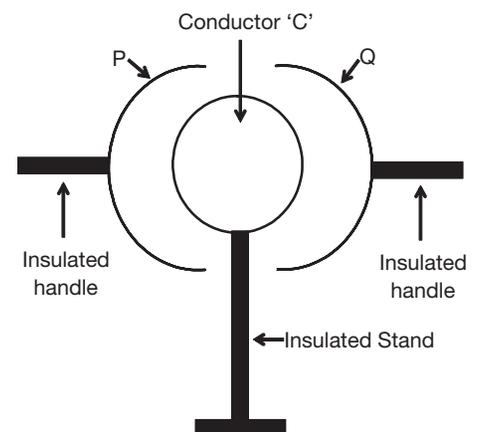


FIGURE 10.10 Biot's Experiment

FARADAY'S EXPERIMENT

Faraday conducted an experiment with a butterfly net made of linen and mounted on a brass ring that is supported on an insulated stand. The pointed tip of the net is connected to a silk thread that extends to both sides of the net and makes it convenient to pull the net inside out and vice versa.

The net is charged in its inner surface, but when tested for presence of charge, it was not found on the inner surface of the net. Instead, the charge was found on its outer surface. When the outer surface was made inner by pulling the silk thread, the charge was found again to be on outer surface. This proves that charge on a conductor resides only on its outer surface.

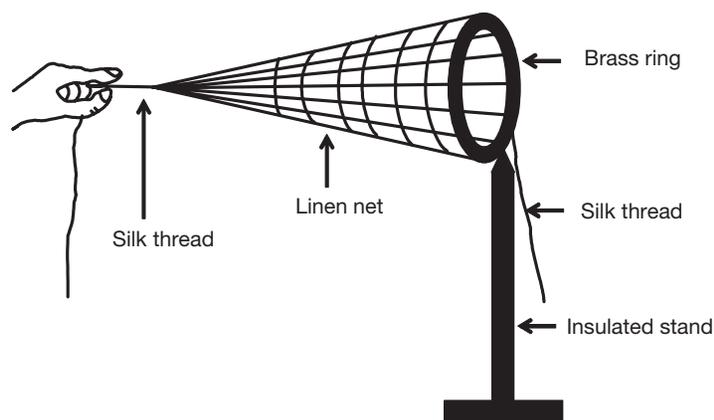


FIGURE 10.11 Faraday's experiment

Atmospheric Electricity

Benjamin Franklin was the scientist who discovered the cause of lightning. Through his experiment, he proved that lightning is due to electric discharge among charged clouds. He made a kite with a silk cloth and the central spar of the kite with an iron wire. To this central spar of kite, he attached a silk string, to fly the kite. The lower end of the silk string was wound around the end of an iron key. To the other end of the iron key he tied a long ribbon. He flew the kite on a dark cloudy day when rain was expected, holding the long ribbon. When there was no rain, and when he brought his knuckles close to the iron key, nothing happened. But once it started raining, he observed a spark between the key and his knuckles when he brought his knuckles close to the iron key. This spark was due to the electric discharge between the key and his knuckles. Thus, he concluded that clouds contain electric charge and that when it rains, electricity passes through the conducting silk kite, through the silk thread to the iron key.

Clouds are formed due to accumulation of water vapour particles, evaporated due to sun's heat from the water bodies on the surface of earth. During the accumulation, these particles of water vapour acquire electric charge due to friction. Thus, clouds accumulate electric charge. When two clouds come close to each other, one cloud having a net positive charge induces an opposite charge, i.e., negative charge on the other cloud. When they approach each other much closer, an electric discharge between the clouds takes place, in the form of lightning. Simultaneously, pressure waves are produced and transmitted in all possible directions, and these are the thunders that we hear.

Sometimes, the streak of light, i.e., lightning which is the result of an electric discharge causes a devastating effect. If the lightning is intense, it reaches the Earth and strikes any conductor nearest to it. Thus, buildings of greater heights are more prone to receive the lightnings. During rain, as these buildings would be wet, they act as conducting material and transmit the electric discharge to the Earth through them, causing fire in the building. In order to avoid such destructions due to nature, tall buildings and sky-scrapers are provided with lightning rods (a conducting rod most preferably made of copper) at the top of the buildings. These rods have pointed tips towards the sky and they are connected to a copper plate buried in earth at the basement of the building through a thick copper wire. If a lightning strikes the building, it would strike the lightning rod at the highest point on the top of the building and the electric discharge passes through the copper wire to the Earth, providing safety to the building.

COULOMB'S LAW

An electrically charged body exerts a force of attraction or repulsion on another charged body depending on whether the two charges are unlike or like, respectively. The magnitude of the electrostatic force between two charged bodies depends on the magnitude of charge on each body, the distance between them and also the medium surrounding them. This was studied and established by Coulomb and is known as Coulomb's law.

The force of attraction or repulsion between any two point charges is directly proportional to the product of the magnitude of the charge on the bodies.

If ' q_1 ' and ' q_2 ' are the magnitudes of two point charges and the force between them is ' F ', then $F \propto q_1 q_2$ (10.1)

The force of attraction or repulsion between two point charge is inversely proportional to the square of the distance between them. This is known as 'inverse square law'. If ' r ' is the distance between two point charges having charges ' q_1 ' and ' q_2 ' and the force between them is ' F ', then

$$F \propto \frac{1}{r^2} \quad (10.2)$$

Combining proportionalities (10.1) and (10.2), we have

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

$$\Rightarrow F = K \frac{q_1 q_2}{r^2}$$

where ' K ' is constant of proportionality.

This expression is known as Coulomb's law. Hence, according to Coulomb's law, 'The electrostatic force between point charges bodies is directly proportional to the product of the magnitude of charge on them and is inversely proportional to the square of the distance between them'. The electrostatic force is a vector quantity, having direction along the line joining the two charges. The value of the constant (K) depends on the medium in which the charges are present. In SI system, if air is the medium or the charges are in vacuum, then the constant k written as is k written as $\frac{1}{4\pi\epsilon_0}$ where ' ϵ_0 ' is called 'permittivity of vacuum or of air'. If the medium surrounding the charges is other than vacuum or air, then the constant is

$\frac{1}{4\pi\epsilon}$, where ' ϵ ' is the 'permittivity of the medium. Thus, we have $F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$ when the medium surrounding the charges is air or the charges are placed in vacuum.

Similarly, $F = \frac{1}{4\pi\epsilon_m} \frac{q_1q_2}{r^2}$ when the charges are placed in a medium.

If air or vacuum is the medium and the quantities are measured in C.G.S. system, then the constant of proportionality is equal to one.

Permittivity of a medium is the property of the medium which decides the force between two charged bodies placed in the medium separated by certain distance. SI unit of permittivity is coulomb square per newton per metre square ($C^2 N^{-1} m^{-2}$).

The magnitude of permittivity of air or of vacuum is $8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$. For all practical purposes, $\frac{1}{4\pi\epsilon_0}$ is taken to be equal to $9 \times 10^9 N m^2 C^{-2}$.

The dimensional formula for permittivity is $[M^{-1} L^{-3} T^4 A^2]$

EXAMPLE

A force of $45 \times 10^{-3} N$ acts between two like charge bodies separated by 4 m in the air. If the magnitude of one of the charges is $8 \mu C$, find the magnitude of the other charge.

SOLUTION

Given $q_1 = 8 \mu C = 8 \times 10^{-6} C$

Distance between two charges, (r) = 4 m

Electrostatic force of repulsion, (F) = $45 \times 10^{-3} N$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 N m^2 C^{-2}$$

$$q_2 = ?$$

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$$

$$\therefore 45 \times 10^{-3} = 9 \times 10^9 \times \frac{8 \times 10^{-6} \times q_2}{(4)^2} \Rightarrow q_2 = 10 \mu C$$

EXAMPLE

Two point charged bodies $q_1 = 3 \mu C$ and $q_2 = 4 \mu C$ are separated by 2 m in air. Find the magnitude of electrostatic force between them.

SOLUTION

Given $q_1 = 3 \mu C = 3 \times 10^{-6} C$

$q_2 = 4 \mu C = 4 \times 10^{-6} C$

$r = 2 m$

Medium is air

$$\begin{aligned} \therefore \text{Force, } F &= \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \\ &= \frac{9 \times 10^9 \times 3 \times 10^{-6} \times 4 \times 10^{-6}}{(2)^2} \\ &= \frac{9 \times 10^9 \times 3 \times 10^{-6} \times 4 \times 10^{-6}}{4} = 27 \times 10^{-3} \text{ N} = 27 \text{ mN} \end{aligned}$$

ELECTRIC FIELD AND ELECTRIC FIELD STRENGTH

An electrostatic force exists between two charged bodies, and this force is inversely proportional to the square of the distance between them. Hence, when the distance between two charged bodies increases, the force between them decreases, and when the distance approaches infinity, the force is zero. This implies that a charged body experiences an electrostatic force when placed within a certain region surrounding another charged body. This region surrounding a charged body where its effect is felt by another charged body is known as an 'electric field'.

Consider two positive point charges 'Q' and 'q', separated, by distance 'r' in air. Then the magnitude of force between them is given by, $F = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$. If $q = +1$ C, then the force between them is given by, $F = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$. This is the force exerted by a charge 'Q' on a unit positive charge placed at a distance 'r' from it, and it is known as electric field strength (E).

Thus, electric field strength 'E' at a distance 'r' from a charged body having charge 'Q' in air or vacuum is given by, $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$.

Instead of a unit positive charge, if a charge 'q' is placed at the point 'r' distance away from charge 'Q', then the force between them is given by

$$F = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$$

But

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

$$\therefore F = Eq. \Rightarrow E = \frac{F}{q}$$

Thus, the unit of electric field strength is newton per coulomb (N C^{-1}). It is a vector quantity, having the same direction as that of force acting on a positive charge. The dimensional formula for electric field strength is $[\text{MLT}^{-3} \text{A}^{-1}]$.

EXAMPLE

Find the magnitude of a charge whose electric field strength is $18 \times 10^3 \text{ N C}^{-1}$ at a distance of 5 m in air.

SOLUTION

Given,

Electric field strength (E) = $18 \times 10^3 \text{ N C}^{-1}$

Distance (r) = 5 m

Charge (q) = ?

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

$$18 \times 10^3 = 9 \times 10^9 \times \frac{q}{(5)^2} \Rightarrow q = 50 \times 10^{-6} \text{ C}$$

$$\Rightarrow q = 50 \mu\text{C}$$

EXAMPLE

Calculate the electric field strength at a distance of 3 m from a charge of 32 nC placed in air.

SOLUTION

Given $q = +32 \text{ nC} = 32 \times 10^{-9} \text{ C}$

$r = 3 \text{ m}$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} = 9 \times 10^9 \times \frac{32 \times 10^{-9}}{(3)^2} = 32 \text{ N C}^{-1}, \text{ which is away from the charge.}$$

EXAMPLE

The force exerted on a 3 C of charge placed at a point in an electric field is 9 N. Calculate the electric field strength at the point.

SOLUTION

Given, $q = 3 \text{ C}$, $F = 9 \text{ N}$

$$\therefore \text{The electric field strength, } E = \frac{F}{q} = \frac{9 \text{ N}}{3 \text{ C}} = 3 \text{ N C}^{-1}.$$

EXAMPLE

Find the electric field strength due to $5 \mu\text{C}$ of charge at a point 30 m away from it in air.

SOLUTION

Given, $Q = 5 \mu\text{C} = (5 \times 10^{-6} \text{ C})$

$r = 30 \text{ m}$

$$\therefore \text{The electric field strength } E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} = 9 \times 10^9 \left(\frac{5 \times 10^{-6}}{(30)^2} \right) = 50 \text{ N C}^{-1}$$

EXAMPLE

The electric field strength at a point in an electric field is 30 N C^{-1} . Find the force experienced by a charge of 20 C placed at that point.

SOLUTION

Given, electric field strength $E = 30 \text{ N C}^{-1}$

Charge, $q = 20 \text{ C}$

\therefore The force on the charge $F = Eq = (30)(20) = 600 \text{ N}$

ELECTRIC POTENTIAL

At a point at a distance ' r ' from Q ,

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

Consider a positive charge ' Q ' placed in air. The electric field strength at a point at a distance ' r ' from Q is given by $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$. Now if ' r ' is infinity, then E is zero.

Thus, at an infinite distance from a charge ' Q ', the electric field strength due to the charge is zero. The charge ' Q ' has no effect on a unit positive charge placed at an infinite distance from it. But if we need to move a unit positive charge from infinite distance, to a point near the charge ' Q ', we need to overcome the repulsive force between them. In order to overcome the repulsive force between the positive charge ' Q ' and the unit positive charge, and move it towards ' Q ', work has to be done on the unit positive charge. This work done on unit positive charge to move it from infinite distance to ' r ' near to a charge against repulsive force is known as 'electric potential' (V) at the point and is measured in volt (V).

Electric potential is a scalar quantity. Let ' w ' joule of work be done in moving a charge ' q ' coulomb towards a charged body from infinity. Then the amount of work done in moving the unit positive charge, i.e., the potential (V) is given by $V = w/q$. Thus, electric potential is measured in units of 'joule per coulomb', which in the *SI* system is called volt (abbreviated as V). The volt is named in the honour of the Italian physicist Alessandro Volta, who invented the Daniell cell. 'When one joule work is done in bringing one coulomb positive charge from infinity to a point in an electric field, then the electric potential at that point is said to be one volt'.

The dimensional formula of electric potential is $[\text{ML}^2 \text{T}^{-3} \text{A}^{-1}]$.

EXAMPLE

A charge of 10 C is brought from infinity to a point P near a charged body and in this process, 200 J of work is done. Calculate the electric potential at point P .

SOLUTION

Given $q = 10 \text{ C}$ and $w = 200 \text{ J}$

\therefore Electric potential, $V = \frac{w}{q} = \frac{200 \text{ J}}{10 \text{ C}} = 20 \text{ J C}^{-1}$ or 20 V

EXAMPLE

The work done in bringing 5 C of charge from infinity to a point A near a charged body is 20 J. Find the potential at point, A.

SOLUTION

Given, charge, $q = 5 \text{ C}$

Work done, $w = 20 \text{ J}$

$$\therefore \text{The electric potential, } V = \frac{w}{q} = \frac{20 \text{ J}}{5 \text{ C}} = 4 \text{ V}$$

EXAMPLE

The electrical potential at a point in an electric field is 6 V. Find the work done in bringing 12 C of charge from infinity to that point.

SOLUTION

Given, electric potential, $V = 6 \text{ V}$

The electric charge, $q = 12 \text{ C}$

$$\therefore \text{Work done, } w = Vq = 6 \times 12 = 72 \text{ J}$$

EXAMPLE

Find the magnitude of a charge that can be moved from infinity to a point in an electric field where the potential is 20 V, by spending 600 J of work.

SOLUTION

Given, electric potential, $V = 20 \text{ V}$

Work done, $W = 600 \text{ J}$.

We know, $W = Vq$

$$\therefore q = \frac{W}{V} = \frac{600}{20} = 30 \text{ C.}$$

Potential Difference

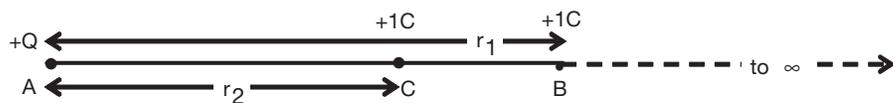


FIGURE 10.12

Consider a charge ‘+Q’ placed at a point ‘A’ in air as shown in Fig. 10.12. Consider two points ‘B’ and ‘C’ at distances ‘ r_1 ’ and ‘ r_2 ’ from ‘Q’, respectively. Let +1 C of charge be brought from infinity to the point ‘B’, and to do so, let W_1 be the amount of work done. This is the work done in bringing a unit positive charge from infinity to a point at a distance

' r_1 ' from the charge '+ Q ', and so, it is the potential at 'B' due to 'Q' (V_1). Similarly, let W_2 be the work done in bringing a unit positive charge from infinity to a point 'C' at a distance ' r_2 ' from the charge 'Q'. Then, this is the potential at the point 'C' due to 'Q' (V_2). As the point 'C' is nearer to 'Q' than 'B', more work has to be done in bringing a unit positive charge from infinity to 'C' than in bringing it from infinity to 'B'. Thus, $W_2 > W_1$ or we can say $V_2 > V_1$. If a unit positive charge already exists at 'B', then the extra work needed to move it from 'B' to 'C' in the electric field of 'Q' is equal to the difference in the works W_1 and W_2 , i.e., it is equal to $W_2 - W_1$. This difference in the work ($W_2 - W_1$) is equal to the difference in the potential at the two points, $V_2 - V_1$ and is called potential difference between the two points in the electric field.

Thus, 'potential difference between two points in an electric field is defined as the work done in moving a unit positive charge between the two points in the electric field against its direction'. The unit of electric potential is volt, and so, the potential difference is also measured in volt. Both potential and potential difference are nothing but the work done in moving a unit positive charge, and so, these two physical quantities are scalars.

The potential difference is denoted by ΔV , and so, $\Delta V = V_2 - V_1$. Instead of one coulomb of positive charge, if ' q ' coulombs of charge is moved between the two points, then work done, $W = \Delta Vq$.

EXAMPLE

A charge of 5 C is moved between two points in an electric field and 20 J of work was done to do so. Calculate the potential difference between the two points.

SOLUTION

Given, work done, $w = 20$ J and charge $q = 5$ C

\therefore The potential difference between the points,

$$\Delta V = \frac{w}{q} = \frac{20 \text{ J}}{5 \text{ C}} = 4 \text{ volt .}$$

EXAMPLE

Calculate the work done to move 500×10^{18} electrons between two points in an electric field where the potential difference between the two points is 1 millivolt. ($e = 1.6 \times 10^{-19}$ C)

SOLUTION

The number of electrons, $n = 500 \times 10^{18}$

The charge of each electron, $e = 1.6 \times 10^{-19}$ C

\therefore The total charge, $q = ne = 500 \times 10^{18} \times 1.6 \times 10^{-19} = 80$ C

The potential difference between the two points,

$$\Delta V = 1 \text{ millivolt} = 10^{-3} \text{ V}$$

\therefore Work done, $w = \Delta Vq = 10^{-3} \times 80 = 0.08$ J

CAPACITANCE AND CAPACITORS

When a conductor is supplied by some amount of charge, its potential rises. Thus, the potential (V) of a conductor is directly proportional to the charge (Q) supplied to it.

$\therefore Q \propto V$ or $Q = CV$ where ' C ' is a constant of proportionality called 'capacitance' of the conductor.

Therefore, capacitance of a conductor is defined as the ratio of charge on a conductor to its potential. $C = \frac{Q}{V}$.

The unit of capacitance is farad (F). Farad is named in the honour of British scientist Michael Faraday. Thus, one farad is the capacitance of a conductor. Since one farad is a huge quantity, capacitance is usually expressed in microfarad ($1\mu F = 10^{-6} F$) and pico farad ($1pF = 10^{-12} F$). A device which can store charges supplied to it at low potential is known as a capacitor or a condenser. There are several types of capacitors available. Some of them are parallel plate capacitor, cylindrical capacitor, spherical capacitor, button type capacitor, etc. These capacitors have capacitance varying from pico farads to a few farads.

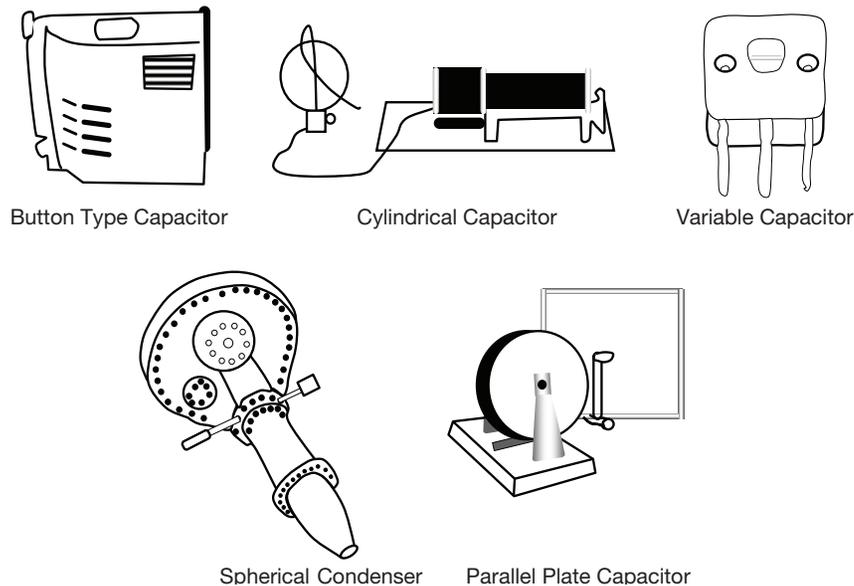


FIGURE 10.13 Different types of capacitors

Uses of Capacitors

Capacitors are used to store large amounts of charge in minimum possible volume of a substance. Hence, these are used in electrical devices like fans, motors, etc. They are also used in tuning circuits of radio, television, etc.

EXAMPLE

A conductor holds $25 \mu\text{C}$ of charge at a potential of 5 V . Calculate its capacitance.

SOLUTION

Given, charge on the conductor, $q = 25 \text{ C}$

Potential of the conductor $V = 5 \text{ V}$

$$\therefore \text{Capacitance of the conductor } C = \frac{q}{V} = \frac{25 \mu\text{C}}{5\text{V}} = 5 \mu\text{f}$$

EXAMPLE

The capacitance of a capacitor is $3 \mu\text{F}$. If a charge of $108 \mu\text{C}$ exists on it, calculate its potential.

SOLUTION

Given, capacitance of the capacitor, $C = 3 \mu\text{F}$

Charge on the capacitor, $q = 108 \mu\text{C}$.

$$\therefore \text{Potential of the capacitor, } V = \frac{q}{C} = \frac{108 \mu\text{C}}{3 \mu\text{F}} = 36 \text{ V.}$$

ELECTRIC CURRENT

Consider two water tanks A and B having different cross sectional areas, at the same level as shown in Fig. 10.14. The cross sectional area of tank B is more than that of tank A. The level of water in tank A is higher than the level of water in tank B. Both the tanks are connected by a pipe at the bottom, with a tap in between. Let the volume of water in tank A be less than that in tank B. When the tap is closed, no water flows between the tanks. But when the tap is opened, water flows from tank A to tank B, even though the quantity of water in tank A is less than that in tank B.

The flow of water continues from tank A to tank B as long as there is a difference in the levels of water in the tanks, and the water flow ceases when the levels of water in both the tanks become equal. Thus, it is the difference in the level of water in the two tanks and not the difference in the quantity of water in them that causes the flow of water. The initial level of water in tank A is comparatively higher than that in tank B, and so, we can say that the water in tank A is at a higher potential than the water in tank B. And similarly, the water in tank B is at a lower potential than the water in tank A.

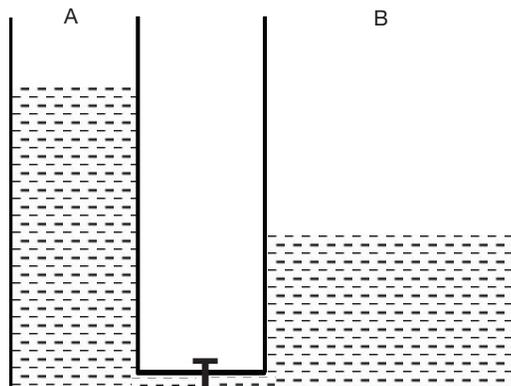


FIGURE 10.14

Thus, water flows from a place at a higher potential to a place at a lower potential when connected by a carrier of water, i.e., pipe. Similarly, when two charged bodies, one at a higher potential and another at a lower potential are connected by an electrical conductor, positive charge flows (actually electrons flow in opposite direction) from the body at higher potential to the body at lower potential, as long as there is a potential difference between them. A body that is charged positively is considered to be at a higher potential and a body that is charged negatively is considered to be at a lower potential.

The ability of a conductor to hold charge is called its capacitance (C) and as discussed earlier it is given by the ratio of its charge to its potential $\left(C = \frac{q}{V}\right)$. Thus, the potential of a conductor depends on the charge that exists on it as well as its capacitance $\left(V = \frac{q}{C}\right)$.

For example, consider four identical spherical conductors 'A', 'B', 'C' and 'D' having equal capacitance containing charges +5 C, +3 C, -2 C, and -8 C, respectively. The charges on 'B' and 'C' are +3 C and -2 C, respectively. Thus, 'B' is at a higher potential compared to 'C'. The charges on 'A' and 'B' are +5 C and +3 C, respectively. Thus, 'A' is at a higher potential compared to 'B'. The charges on 'C' and 'D' are -2 C and -8 C, respectively. Thus, 'C' is at a higher potential compared to 'D'. Now, if the bodies 'A' and 'B' are connected by a conducting wire, charge flows from 'A' to 'B'. Similarly, charge flows from 'B' to 'C', 'C' to 'D', 'A' to 'C', 'A' to 'D' or 'B' to 'D' when they are connected by conducting wires.

Now consider two conductors, 'P' and 'Q' having charges +2 C and +5 C and capacitances 0.5 F and 2 F, respectively. Then the potential of 'P' is $V_P = \frac{2C}{0.5F} = 4V$ and the potential of 'Q' is $V_Q = \frac{5C}{2F} = 2.5V$. So, when P and Q are connected by a conducting wire, charge flows from 'P' to 'Q' as $V_P > V_Q$, even though the charge on 'Q' is greater than that on 'P'. Thus, it is the potential of two conductors that decides the flow of charge between them and not the quantity of charge that exists on them. This flow of charge between two bodies at different potentials through a conducting material constitutes an electric current.

In the early stages of development of electricity, it was thought that the motion of positive charges constitutes the electric current. Thus, electric current was supposed to be due to the motion of positive charges from a body at a higher potential to a body at a lower potential. Later on, it was discovered that it is not the motion of positive charges that constitutes the electric current. A conductor contains a large number of free electrons and it is the motion of these free electrons through a conductor that constitutes the electric current. By the time, this fact was known, there were some other developments that took place in the field of current electricity and some new theories were established, based on the prior assumption that the flow of positive charges constitutes electric current. So, scientists retained that concept and it was considered that electric current due to the motion of positive charges as 'conventional electric current' and the electric current due to the motion of electrons as the 'real or actual or electronic current'. Thus, the directions of conventional current and electronic current (or actual current) are opposite to each other.

As discussed earlier, a conducting material contains a large number of free electrons (Fig. 10.15a). When two bodies at different electric potentials are connected by a conducting

substance like a metallic wire, these free electrons drift through the body of the wire continuously as long as there exists a potential difference between the two bodies (Fig. 10.15b). This continuous drift of electrons, i.e., the negative charges, constitutes the electric current through solid conductors. If the conducting material is a liquid like an electrolyte, there is a continuous motion of negative ions in one direction and simultaneously there exists a continuous motion of positive ions in a direction opposite to that of negative ions. This continuous motion of negative and positive ions in opposite directions in the electrolyte constitutes electric current in liquid conductors.

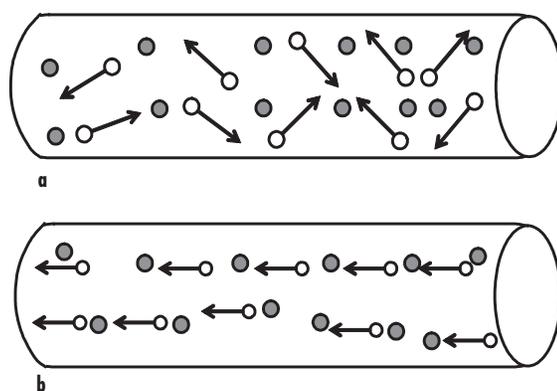


FIGURE 10.15 (A) Free electrons in a conducting wire
(b) Conduction in a wire through electron drift

It is now evident that moving charges constitute electric current. If one has to measure the flow or motion of these charges through a conductor, it is done by measuring the rate of charge flow and this rate of charge flow through a conductor determines the strength of electric current. Thus, the strength of the electric current is defined as the rate at which charges move across a cross-section of a conductor. Mathematically, $i = \frac{q}{t}$, where ' i ' is the strength of electric current, ' q ' is the amount of charge flowing through a given cross-section of a conductor and ' t ' is the time in which the flow of charge takes place.

$$\text{The unit of strength of electric current} = \frac{\text{Unit of charge}}{\text{Unit of time}} = \frac{1 \text{ coulomb}}{1 \text{ second}} = 1 \text{ C s}^{-1}$$

And 1 coulomb per second is called 1 ampere (A). Thus, $1A = 1 \text{ C s}^{-1}$.

Since the electric charge can be expressed in terms of an integral multiple of charge of an electron ($q = ne$), we can also express the strength of electric current in terms of the number of electrons that pass through a given cross section of a conductor in unit time.

i.e.,

$$i = \frac{ne}{t}$$

EXAMPLE

Calculate the electric current through a wire if 10 coulombs of charge flow through a cross section of the wire in 2 seconds.

SOLUTION

Given charge, $q = 10 \text{ C}$

Time, $t = 2 \text{ milli second} = 2 \times 10^{-3} \text{ s}$

$$\therefore \text{The electric current, } i = \frac{q}{t} = \frac{10 \text{ C}}{2 \text{ s}} = 5 \text{ A}$$

EXAMPLE

An electric current passing through a conductor is 5 A. Calculate the number of electrons that pass through a given cross-section of the conductor in $1 \mu\text{s}$.

The charge of an electron, $e = 1.6 \times 10^{-19} \text{ C}$.

SOLUTION

Given, $i = 5 \text{ A}$, $t = 1 \mu\text{s} = 10^{-6} \text{ s}$

$$e = 1.6 \times 10^{-19} \text{ C}, n = ?$$

$$i = \frac{ne}{t}$$

$$\therefore n = \frac{it}{e} = \frac{5 \times 10^{-6}}{1.6 \times 10^{-19}} = 3.125 \times 10^{13}$$

ELECTRIC CELL

It is obvious that the water flows from tank 'A' to tank 'B' in the example quoted earlier (refer to Fig. 10.14) when the tap in the pipe connecting the two tanks is opened. The water flow is maintained as long as there is a difference in the levels of water in both the tanks. Also, the rate of water flow decreases, as the difference in the levels of water in the tanks decreases. Thus, to maintain continuously a constant rate of water flow between the tanks, the levels of water in both the tanks have to be maintained. This is possible by pumping the water continuously from the tank 'B' to the tank 'A' at the same rate at which water flows from tank 'A' to tank 'B' through the pipe.

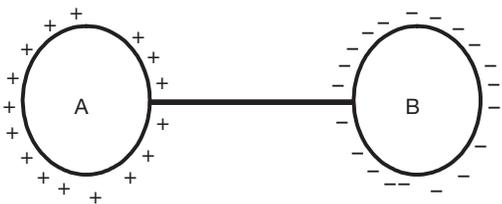


FIGURE 10.16

In a similar way, if it is desired to maintain an electric current of constant strength through a conductor, a constant potential difference has to be maintained across the ends of the conductor. Consider two identical conducting bodies (spheres) 'A' and 'B' connected by a metallic wire, as shown in Fig. 10.16. Body 'A' is charged positively and is at a higher potential. Body 'B' is charged negatively and is at a lower potential. When these two bodies are connected by a conducting wire, charges flow from 'A' to 'B'. After some time, the charges on both the bodies become equal and the flow of charge comes to a stop. To have an incessant flow of charge from 'A' to 'B', the potentials of 'A' and 'B' have to be maintained. In order to maintain the

potentials on 'A' and 'B' at their original levels, i.e., to maintain a constant potential difference across the ends of the conducting wire, charges on 'B' have to be shifted to 'A' at the rate at which charge flows through the wire from 'A' to 'B'. This shifting of charges from a lower potential (at 'B') to a higher potential (at 'A') is done by a device called 'electric cell' or an 'emf device'. In an electric cell, chemical energy of the cell is utilized in transferring charges from a lower to a higher potential. Thus, chemical energy is transformed into electric energy in a cell.

There are two kinds of cells, namely, primary and secondary. In a primary cell, chemicals are used up in transforming chemical energy into electrical energy and the original composition of the chemicals is not retained. A Voltaic cell, dry cell, etc., are some examples of primary cells. In a secondary cell, the original composition of the chemicals of the cell can be regained by passing electric current through the cell in opposite direction to the direction in which the cell generates electric current. The process of regaining the original composition of chemicals of the cell by passing electric current through it so that the cell can be used again is called 'charging'.

All rechargeable cells like lead-acid accumulators fall under the category of these secondary cells.

ELECTRO MOTIVE FORCE (EMF)

When current is not being drawn from a cell, the potential difference that exists between the terminals of the cell is called its electromotive force. Thus, it is the potential difference provided by the cell when it is in open circuit condition. Its unit is volt (V). The higher potential at the anode and the lower potential at the cathode in the cell are maintained as long as the chemical reactions take place in it. That is how a sustained charge flow is maintained in the external conducting wire connected across the terminals of the cell. As the chemicals are used gradually, the emf decreases, and so, the electric current decreases. Thus, a primary cell has some disadvantages over a secondary cell. Let us differentiate between a primary and a secondary cell.

Primary cell	Secondary cell
1 In a primary cell, chemical energy is readily transformed into electrical energy.	In a secondary cell, initially, electrical energy is stored in the chemical form and then that is converted into electrical form on drawing current from it.
2 Chemical reactions are irreversible.	Chemical reactions are reversible.
3 These cells cannot be recharged.	These cells can be recharged.
4 The large amount of current cannot be drawn from these cells.	These cells can be used to draw a large amount of current.
5 The restriction to the flow of charges through these cells is higher compared to that in secondary cells.	The restriction to the flow of charges through these cells is lower compared to that in primary cells.

OHM'S LAW

We are aware that the rate of charge flow through a conductor is the strength of electric current (I) through it. We are also aware that the cause of electric current through the conductor is the potential difference (V) across its ends. It is found that the strength of the

electric current (I) through a conductor is directly proportional to the potential difference (V) across its ends. Thus, $V \propto I$ or $V = IR$, where ' R ' is a constant and this constant is the resistance of the conductor. This expression $V = IR$ is known as Ohm's law.

$$\text{Thus, } R = \frac{V}{I}.$$

$$\text{So, } 1 \text{ ohm}(\Omega) = \frac{1 \text{ volt}(V)}{1 \text{ ampere}(I)}.$$

Thus, 'One ohm is defined as the resistance offered by a conductor when a potential difference of 1 volt establishes an electric current of 1 ampere in it'.

ELECTRICAL RESISTANCE

It is common experience that a water pipe, unused for a considerably long time, accumulates some dust in it and when used for the flow of water after a long time, offers some opposition to the flow of water. The opposition is due to the accumulated dust and salts, if any, in the pipe. The water particles have collisions with the dust particles while flowing through the pipe and that is the cause for opposition of water flow through the pipe. This opposition to the water flow increases with length of the pipe, i.e., the more lengthier the pipe, the more is the opposition to the water flow. Similarly, as the diameter of the pipe increases, this opposition to water flow decreases. Thus, the more the area of the cross section of the water pipe, the less is the opposition for the water flow through the pipe.

In this sense, the electric current in a conducting wire is analogous to the water flow through a pipe, and there is an opposition to the charge flow through a conductor. As discussed earlier, a solid conductor contains a large number of free electrons and the drifting of these electrons through the body of the conductor constitutes the electric current. Now, while these free electrons drift through the conductor, they encounter collisions with the atoms of the conductor and this gives rise to opposition in their free flow. This opposition to electric current through a conductor is called 'electric resistance'. It is denoted by ' R '. The electric resistance of a conductor is measured in 'ohm' (Ω).

Electric Resistance—Factors Affecting it

The electric resistance of a conductor, is analogous to the opposition of water flow through a pipe. Thus, the factors affecting the electric resistance of a conductor are similar to the factors affecting the opposition to water flow through a pipe.

Length of the Conductor

The more is the length of a conductor of constant thickness and at constant temperature, the more is its electric resistance. Thus, we conclude that the resistance of a conductor (R) is directly proportional to its length (ℓ).

$$\Rightarrow R \propto \ell \text{ or } \frac{R}{\ell} = \text{constant for a conductor, provided its area and temperature are constant.}$$

Area of Cross Section

The more the area of the cross section of a conductor of constant length and at constant temperature the less is its electric resistance. Thus, the electric resistance (R) of a conductor is inversely proportional to its area of cross section (a),

$R \propto \frac{1}{a}$ or $Ra = \text{constant}$ for a conductor, provided length and temperature of the conductor are kept constant.

Temperature

When the temperature of a conductor is increased, the average kinetic energy of the molecules of the conductor increases, and so, the number of collisions of the free electrons make while passing through the conductor also increases. Thus, the resistance of a conductor increases with temperature.

Nature of Material

The number of free electrons per unit volume is different for different materials. So, even though all the factors discussed above are identical for two conductors made of different materials, the opposition to the flow of electrons through them is different, i.e., the electric resistance for the two conductors is different.

Resistors—Their Combinations

A conductor having certain resistance is called 'resistor'. Each resistor has a fixed value of resistance. It is symbolically represented as .

Consider two resistors ' R_1 ' and ' R_2 ' as shown in Fig. 10.17(a). The terminals of ' R_1 ' are ' A ' and ' B ' and the terminals of ' R_2 ' are ' C ' and ' D '. These two resistors can be combined in two different ways. In one type of combination, the terminals ' B ' and ' C ' are joined so that the same current passes through ' R_1 ' and ' R_2 '. This type of combination is called series combination [Fig. 10.17(b)]. In another type of combination, the terminal ' A ' is joined to ' C ' and the terminal ' B ' is joined to ' D ' so that the total current that passes through them divides according to the values of their resistances. This type of combination is called parallel combination [Fig. 10.17(c)].

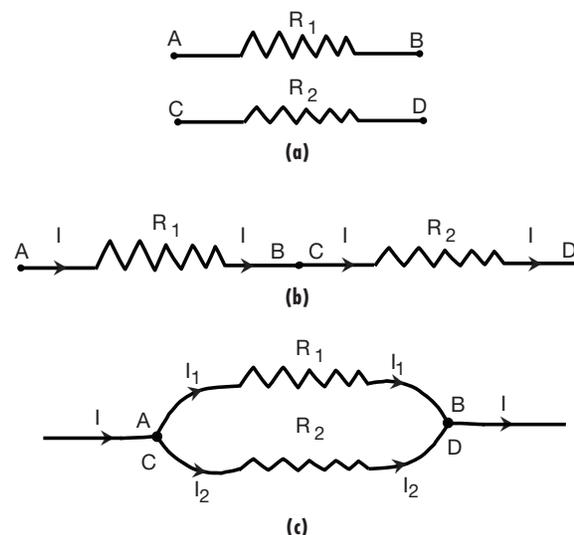


FIGURE 10.17 (a) Two separate resistors R_1 and R_2 (b) Series combination (c) Parallel combination

Thus, there are two types of basic combinations of resistors possible. One type of combination of resistors is called ‘series combination’ or ‘series arrangement’. In a series combination of resistors, the end point of one resistor is connected to the starting point of second resistor. Then the effective resistance of the combination is equal to the sum of the resistances of individual resistors.

If R_1 and R_2 are the resistances of two resistors connected in series combination, their effective or net resistance is given by $R_{\text{net}} = R_1 + R_2$. This is true for ‘ n ’ number of resistors connected in series combination. Thus, we have $R_{\text{net}} = R_1 + R_2 + R_3 + \dots + R_n$, where $R_1, R_2, R_3, \dots, R_n$ are the resistances of ‘ n ’ resistors connected in series arrangement.

Thus, the net resistance of the combination obtained is greater than the largest value of resistance in the combination. In this type of combination, the potential difference across the combination of resistors is divided among the resistors according to the values of their resistances. Hence, the resistors in this type of combination act as dividers of potential difference. This type of combination is useful for the situations that require a high value of resistance than the individual resistance of the given resistors.

The second type of combination of resistors is called ‘parallel combination’. In a parallel combination of resistors, the starting points of two or more resistors are joined together and similarly their end points are joined together. In this case, the reciprocal of the effective or net resistance of the combination is equal to the sum of reciprocals of the resistances of the individual resistors. If R_1 and R_2 are the resistances of two resistors connected in parallel combination, then their net resistance is given by the expression $\frac{1}{R_{\text{net}}} = \frac{1}{R_1} + \frac{1}{R_2}$.

If there are ‘ n ’ number of resistors with different resistances connected in parallel, then we have

$$\frac{1}{R_{\text{net}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

Thus, the net resistance of the combination obtained is lesser than the least value of resistance in the combination. In this type of combination, the potential difference across all the resistors in the combination is equal, but the total current through them is divided among them according to the resistance values of the individual resistors. Hence, the resistors in this type of combination act as dividers of electric current. This type of combinations are useful for the situations that require a low value of resistance than the individual resistance of the given resistors.

ELECTRIC CIRCUITS AND CIRCUIT DIAGRAMS

The arrangement of all the electrical components and their connections is called an electric circuit and a symbolic or schematic representation of these components and their connections is known as a ‘circuit diagram’. There are various electric components used in circuits. Some of the components and their symbols are shown in the following table.

Electric component	Symbol
A cell	
A battery	
Alternating current source	
Plug key	
Switch	
Tapping Key	
Conducting Wire (connecting wire)	
An ammeter	
A voltmeter	
A resistance (fixed value)	
A variable resistance or rheostat	
Galvanometer	
Load	
Heater	
Bulb	

A simple electric circuit can be represented by the following diagram (Fig. 10.18). Here 'C' represents the cell that supplies electrical energy, 'K' represents the plug key that is used to connect or disconnect the cell from rest of the circuit and 'L' represents the load, i.e., any device that utilizes electrical energy. When the plug key is shown with a dot in between, i.e., (●), it represents the circuit with connection made with the cell and current flows through the circuit. In this condition, we say, the circuit is closed. When the plug key is shown without a dot between, i.e., (), it represents the circuit that is disconnected from the cell and no current flows in the circuit. In this condition, we say, the circuit is open. If an ammeter, i.e., a device that measures electric current through the circuit is to be connected, it is always connected in series in the circuit. Similarly, if a voltmeter, i.e., a device that measures potential difference across a conductor or a resistor is to be connected in a circuit, it is always connected in a position that is parallel to the conductor or the resistor as the case may be. The following Figs. 10.19 and 10.20 show an ammeter and a voltmeter connected in the circuit in open and closed conditions, respectively.

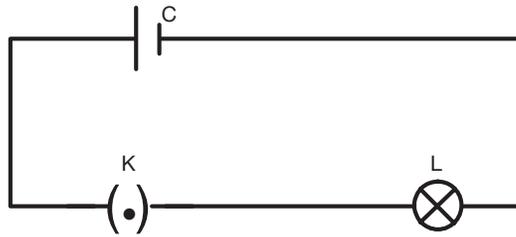


FIGURE 10.18 A Simple circuit

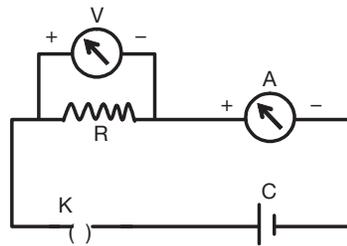


FIGURE 10.19 An open circuit

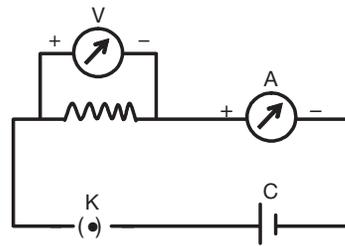


FIGURE 10.20 A Closed circuit

Open Circuit

A circuit in which there is an insulator, or all components are not connected to each other, i.e., there is a break in between or switch is open so that current cannot flow through the circuit is called an open circuit (see Fig. 10.19).

Closed Circuit

A circuit, in which all components are connected to each other by conductors without any break such that there exists a closed continuous path for the current from positive terminal to the negative terminal of the source, is called closed circuit (see Fig. 10.20).

ELECTRICAL POWER

When an electric current flows, work is done in moving charges across the circuit. The rate at which this electric work is done is called electric power.

$$\text{Electric power, } (P) = \frac{\text{electric work } (W)}{\text{time } (t)}$$

But $W = V \times q$

where, V = potential difference across conductor

q = charge flowing through conductor

$$q = It \left(\because I = \frac{q}{t} \right)$$

$$\therefore W = V \times I \times t$$

$$\therefore P = \frac{W}{t} = \frac{V \times I \times t}{t}$$

$$P = VI$$

$$\therefore P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$$

EXAMPLE

Calculate the power of an electric bulb which consumes 2400 J in a minute

SOLUTION

Given

Energy consumed (E) = 2400 J

Time (t) = 1 minute = 60 s

Power (P) = ?

$$P = \frac{W}{t} = \frac{E}{t} = \frac{2400 \text{ J}}{60 \text{ s}}$$

$$= 40 \text{ J s}^{-1}$$

$$\therefore P = 40 \text{ J s}^{-1} = 40 \text{ W.}$$

EXAMPLE

Power of an electric heater is 1000W and it is run for 1 hour. Calculate the energy consumed by it.

SOLUTION

Given

Power (P) = 1000 W

Time (t) = 1hr = $60 \times 60 = 3600 \text{ s}$

Energy consumed (E) = ?

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

$$\therefore E = Pt$$

$$E = 1000 \times 3600 = 3600000 = 3.6 \times 10^6 \text{ J}$$

Calculation of Electrical Energy Consumed and Electrical Billing

In the above numerical, you have seen that a 1000 W electric heater consumes an energy of 3.6 MJ when used for one hour. Thus, the power ratings of a device gives us the information regarding the energy it consumes in a given time.

$$\text{Electrical energy} = \text{Power} \times \text{Time}$$

To formulate the unit for energy consumption for commercial or household purposes, power is expressed in kilowatt and time in hour. Thus, commercial unit of electric energy is kilowatt hour (kW h)

Kilowatt hour: The energy consumed by an electric appliance of power 1 kW in 1 hour is called an kilowatt hour.

As we have already seen, $1 \text{ kW h} = 3.6 \text{ MJ} = 1 \text{ unit}$

EXAMPLE

Calculate the electrical energy consumed in units when a 60 W bulb is used for 10 hours

SOLUTION

$$\text{Electric power, } (P) = 60 \text{ W} = \frac{60}{1000} = 0.06 \text{ kW}$$

$$\text{Time, } (t) = 10 \text{ hrs}$$

$$\text{Electric energy} = P \times t$$

$$= 0.06 \times 10 = 0.6 \text{ kW h} = 0.6 \text{ unit}$$

EXAMPLE

Calculate the units of electricity consumed in the month of September from the following details.

- (i) One 40 W bulb used for 5 hours daily.
- (ii) One 100 W bulb used for 4 hours daily.
- (iii) One 240 W electric fan used for 10 hours daily.

Also calculate the monthly bill at the rate of Rs 3 per unit.

SOLUTION

Electric energy = electric power \times time

$$E = Pt$$

- (i) Electric bulb

$$E_1 = 40 \text{ W} \times 5 \text{ h}$$

$$= 0.40 \times 5 = 0.2 \text{ kW h. Thus, this bulb consumes 0.2 units daily}$$

There are 30 days in the month of September

$$\therefore \text{Energy consumed by the bulb for 30 days is } 0.2 \times 30 = 6 \text{ kW h or 9 units.}$$

- (ii) Electric bulb

$$E_B = 100 \text{ W} \times 4 \text{ h}$$

$$= 0.1 \times 4 = 0.4 \text{ kW h} = 0.4 \text{ units daily}$$

$$\text{For 30 days } E_r = 0.4 \times 30 = 12 \text{ kW h} = 9 \text{ units.}$$

- (iii) Electric fan = 1 kW \times 2 h =

$$E_3 = E_h = 0.24 \text{ W} \times 10 \text{ h} = 2 \text{ kW h} = 2 \text{ units daily}$$

$$\text{For 30 days, } E_h = 2.4 \times 30 = 72 \text{ units}$$

Total energy consumed in the month of November is $E_b + E_B + E_h$

$$= 6 + 2 + 72 = 90 \text{ units}$$

The cost of electricity is ₹2.50 per unit

Energy consumed is 90 units

∴ Monthly bill for November = $78 \times 3 = ₹270$

EXAMPLE

An electric heater has a rating of 3 kW, 220 V. Calculate the following

- (i) Current.
- (ii) Resistance offered by the heater.
- (iii) Cost of running the heater for 10 hours at the rate of ₹3.50 per unit.

SOLUTION

Given

$$\begin{aligned} \text{Electric power } (P) &= 3 \text{ kW} \\ &= 3000 \text{ W} \end{aligned}$$

$$\text{Potential difference } (V) = 220 \text{ V}$$

$$\therefore P = VI$$

where I = electric current

$$\therefore I = \frac{P}{V} = \frac{3000}{220} = 13.63 \text{ A}$$

$$\begin{aligned} \text{Electric resistance } (R) &= \frac{V}{I} \\ &= \frac{220}{13.63} = 16.14 \text{ } \Omega \end{aligned}$$

$$\begin{aligned} \text{Electric energy } (E) &= \text{Power} \times \text{Time} \\ &= 3 \text{ kW} \times 10 \text{ h} \\ &= 30 \text{ kW h} \\ &= 30 \text{ units} \end{aligned}$$

$$\begin{aligned} \therefore \text{Cost of 30 units of energy} &= 30 \times 3.50 \\ &= ₹105 \end{aligned}$$

EXAMPLE

Calculate the resistance offered by 3 HP water pump which runs on 220 V supply.

SOLUTION

$$\text{Electric power } (P) = 3 \text{ HP} = 3 \times 746 \text{ W} = 2238 \text{ W}$$

$$P = VI$$

$$\therefore I = \frac{P}{V}$$

Substituting $P = 2238 \text{ W}$, $V = 220 \text{ V}$

$$I = \frac{2238}{220} = 10.17 \text{ A}$$

Electric resistance (R)

$$= \frac{V}{I} = \frac{220}{10.17} = 21.63 \Omega$$

DOMESTIC WIRING

The electricity is generated at power stations and brought to our houses through overhead wires on the poles or through underground cables. Three insulated thick copper wires L, N and E are taken into the house from the pole as shown in Fig. 10.21. L is live or phase wire connected to high potential of 220 V. N and E are neutral and earth wires, respectively, and both are at zero potential. The Earth wire is connected to the body of kW h meter (M) which is used to measure the electric energy consumed by the household. Before the live and neutral wires enter the kW h meter, a fuse wire (F_1) of high rating of about 50 A is installed in series with the live wire.

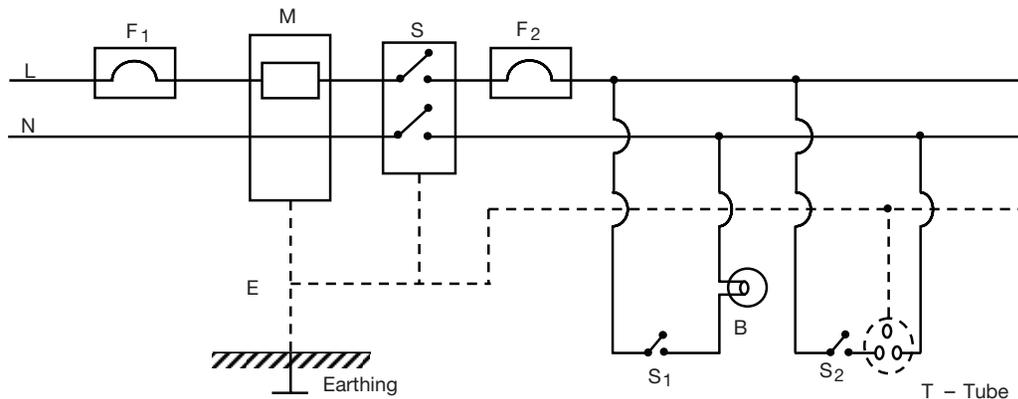


FIGURE 10.21 Domestic wiring

This fuse wire melts if the household draws more than allocated current and breaks the circuit. Fuse wire is made with an alloy of lead and tin having low melting point. If due to any malfunction or fault, excessive current begins to flow through the circuit, the fuse wire immediately melts due to the heat generated by the flowing current. The circuit is broken and the excess current, which may damage equipments is prevented from flowing. From the kW h meter, both live and neutral wires are connected to a switch called main switch (S). It is used to switch off the supply to the entire house whenever it is necessary to repair any fault in the wiring (a safety measure or a precaution).

Every house has two different circuits, viz., lighting circuit and heating circuit. Each has its own separate fuse wire of rating 5 A and 15 A, respectively. If any fault arises in any circuit, its fuse wire fuses without affecting the other circuit. The three wires used in household wiring have different colours. Live wire is red in colour while neutral and earth are black and green, respectively. The colour code makes them easily identifiable. The function of the Earth wire is to prevent electric shocks. One end of the Earth wire is connected to a copper plate buried deep under the Earth. It conducts any leakage current in the circuit to the ground. Various

electrical appliances like tube light, fan, television, etc., are connected in parallel across the live wire and each has its own switch S_1 , S_2 , etc., in series along the live wire.

Electrical Hazards and Safety Measures

Now-a-days, electricity is being used very extensively. All appliances, machines, etc., work on electric energy. Thus, electricity is a boon to us. But it can be highly dangerous if not used properly and certain precautions are not followed.

Careless use of electricity can lead to the following electrical hazards:

1. Do not touch the electric wire which has lost its insulation.
2. If a person or an animal comes in contact with a live wire and earth, current flows through their body to the Earth causing an electric shock. This may prove fatal.
3. Electricity is one of the major causes for fire outbreak. This may occur due to:
 - (a) faulty or defective electric appliance,
 - (b) excess of electric current in the circuit and
 - (c) defective circuit components and loose connections and contacts.
4. An electric appliance may be damaged and may cause fire accidents if connected improperly and without considering its ratings.

Precautions in the Use of Electricity

1. The main switch should be turned off immediately if electric fire starts or a person touches a live wire accidentally to avoid further damage.
2. Only electricians or experts should attempt to rectify problems that arise in the electric circuits and appliances.
3. Following precautions should be taken while handling live circuit or while repairing electric devices.
 - (a) Always use rubber hand gloves and rubber soled shoes.
 - (b) Stand on a dry wooden plank without iron rails.
 - (c) Make sure that a tester has a properly insulated handle.
4. Fuse should always be connected to live wires only. In case a fuse melts, mains should be switched off. It should be replaced by a fuse of proper ratings.
5. Each electric circuit should be earthed properly. Three pin plugs and sockets should be used for electric appliances which are physically handled. This bypasses any leakage current to the Earth and prevents electric shocks.
6. Electricity board should be consulted for problems regarding electric poles, meter and mains.
7. To remove any piece of conducting wire, a dry wooden or plastic stick should be used.
8. Proper care should be taken so that transmission lines do not touch trees, are sufficiently away from the buildings and are never touched with long metal pipes or bars.
9. It is not just dangerous but also a crime to tap connections from the electric pole without prior permission from the electricity board.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Define capacitance of a conductor.
2. What is electric resistance?
3. Define the unit of capacitance of a conductor.
4. Define live and neutral wires.
5. What is the magnitude of charge of an electron?
6. Define conductor and insulator giving examples.
7. The potential difference between the terminals of a cell in an open circuit is called _____.
8. When is a body charged negatively?
9. What is potential difference?
10. How many types of combination of resistors are there and what are they?
11. What is static electricity?
12. Define electric energy and electric power. Give their units.
13. _____ is a sure test for electrification.
14. What is quantization of electric charge?
15. What is an electric circuit?
16. Give the colour code for electric wiring.
17. What is an electroscope?
18. Define electric current.
19. State the commercial unit of electric energy.
20. What is electrostatic induction?
21. The solids in which the number of conduction electrons is large are called _____ of electricity.
22. What are conventional current and electronic current?
23. What is lightning?
24. Define electric field.
25. What is an electric cell?
26. State Ohm's law.
27. State Coulomb's law for electric force between two charged bodies.
28. The resistance of a good conductor decreases when its temperature _____.
29. What is emf of a cell?
30. Define electric potential.

Short Answer Type Questions

31. Describe Benjamin Franklin's experiment to study electricity in atmosphere.
32. Draw the diagram of a simple circuit showing a bulb, an ammeter, a plug key connected to a battery.
33. What are lightning conductors and how do they protect buildings of greater heights from destruction due to lightning?
34. Explain quantization of electric charge.
35. How is electric energy measured for commercial purposes?
36. Distinguish between conventional and electronic current.
37. Explain Biot's experiment.
38. Show that $1\text{ kW h} = 3.6\text{ MJ}$
39. Describe the construction and working of a Voltaic cell briefly.
40. Explain charging by induction or electrostatic induction.
41. Explain the factors on which electric resistance of a conductor is dependent.
42. Explain electric power.
43. Describe a pith ball electroscope and explain its working.
44. Distinguish between primary and secondary cells.
45. Describe a proof plane and its working.



Essay Type Questions

46. Describe an experiment to prove that on electrification, both kinds of charges are produced simultaneously.
47. Write a note on electrical hazards.
48. Describe the construction and working of a gold leaf electroscope.
49. Explain in detail domestic wiring.
50. Explain the properties of electric charges.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- Within the cell, conventional current flows from its negative to the positive terminal.
- Only when an electric field is set up in a conductor, the electrons in it start moving.
- The magnitude of the charge on 6250×10^{15} number of electrons is equal to 1 coulomb.
- When a few billion electrons are added to the Earth, its electric potential rises.
- The charge supplied to a glass rod at one of its ends stays at the same place.
- Two conductors of the same size, shape and material have the same capacitance.
- When charge is supplied to a good conductor, less charge will be distributed at pointed tips or on higher curvatures of the conductor.

Direction for questions 8 to 14

Fill in the blanks.

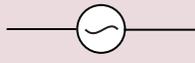
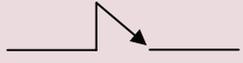
- A body charged positively is considered to be at a _____ potential and a body that is charged negatively is considered to be at a _____ potential.
- If 100 billion electrons are added to earth, then the potential of the Earth _____.
- _____ is defined as the rate at which the charges move across any cross section of a conductor.

- The dimensional formula of capacitance is _____.
- The purpose of _____ is to prevent electric shocks.
- The obstruction offered to the passage of electric current by a material is called _____.
- The dimensional formula of potential difference is _____.

Direction for question 15

Match the entries given in Column A with appropriate ones from Column B.

15.

Column A	Column B
A. Greek word for Amber	() a. Coulomb
B. S.I. unit of charge	() b. Electron
C. Proof plane	() c. magnitude of permittivity of vacuum
D. Cause of lightning	() d. a scalar physical quantity
E. $8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$	() e. to transfer charge from a charged body
F. Electric potential difference	() f. 
G. Variable resistor	() g. electric discharge
H. Alternating current source	() h. 
I. Reversible chemical source	() i. secondary cell
J. Tapping key	() j. 



Direction for questions 16 to 40

For each of the questions, four choices have been provided. Select the correct alternative.

16. A bulb is connected to a cell and the potential difference across the terminals of the bulb is 24 V. If 3 A of current flows through the bulb, then the resistance of its filament is _____ Ω .
- (a) 8 (b) 72
(c) 24 (d) 3
17. The ratio of resistances of two resistors A and B connected in series is 1 : 4 and the current passing through them is 10 A. Then the ratio of current that flows through them when connected in parallel is _____.
- (a) 4 : 1 (b) 1 : 4
(c) 1 : 2 (d) 2 : 1
18. A gold leaf electroscope is used for
- (a) measuring the charge present on charged bodies.
(b) detecting the current flowing between two charged bodies.
(c) measuring the potential of charged bodies.
(d) detecting the nature of the charge present on charged bodies.
19. A unit positive charge is moved along the circumference of a circle of radius, r with a $-5\text{C } \mu\text{C}$ charge at the centre of the circle. Then, the work done in the process is _____.
- (a) negative work of 100 J
(b) positive work of 100 J
(c) zero
(d) $\frac{Q.1}{4\pi\epsilon_0 .r}$
20. If one ampere current flows through a conductor, the number of electrons flowing across the cross section of the conductor in 2 seconds is _____.
- (Take the charge on electron equal to $1.6 \times 10^{-19}\text{ C}$)
- (a) 1.6×10^{-19} (b) 1.25×10^{19}
(c) 6.25×10^8 (d) 3.2×10^{18}
21. The force of attraction between two charged bodies depends on
- (a) the quantity of charge present on each charged body
(b) distance between the charged bodies
(c) the medium separating the charged bodies
(d) All the above
22. A device that measures current through a circuit is called
- (a) an ammeter and is always connected parallel to the circuit
(b) an ammeter and is always connected in series in the circuit
(c) a voltmeter and is always connected parallel to the circuit
(d) a voltmeter and is always connected in series in the circuit
23. The capacity of a sphere, which, when a charge of 0.5 C is placed on it, raises its potential by 100 volt is _____ farad.
- (a) 50 (b) 200
(c) 5×10^{-3} (d) 0.5
24. The resistance of a current carrying wire depends on
- (a) the area of cross-section of the conducting wire.
(b) the length of conducting wire.
(c) the material of the wire.
(d) All the above factors
25. A dielectric is
- (a) a bad conductor of electricity
(b) a good conductor of electricity
(c) also called a capacitor
(d) an electric device having two magnetic poles
26. If ' n ' number of identical resistors are connected in parallel combination, then the effective resistance of the combination is _____.
- (a) nR (b) $\frac{n}{R}$
(c) $\frac{R}{n}$ (d) $nR - \frac{n}{R}$
27. An electric device which converts chemical energy into electrical energy is _____.
- (a) a D.C. generator (b) an A.C. generator
(c) an electric cell (d) Both (1) and (2)
28. Two charged bodies with a distance ' d ' between them are placed first in water and then in air. Then the force between them _____.
- (Dielectric constant of water is more than one)
- (a) increases
(b) decreases
(c) remains the same
(d) first decreases then increases



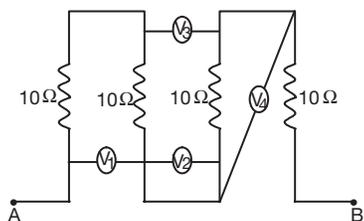
29. On increasing the number of resistances connected in series, the total resistance of the series combination _____
- increases
 - decreases
 - remains the same
 - decreases with time
30. If the charge on two point charged bodies and the medium surrounding them are kept unchanged and the distance between them is reduced by 50%, then the force between them _____.
- is doubled
 - is quadrupled
 - becomes half
 - decreases to $\frac{1}{4}$ th of their original force
31. Consider two bodies A and B of same capacitance. If charge of -10 C flows from body A to body B, then
- the potential of body A increases.
 - the potential of body B decreases.
 - the magnitude of change in potential in both bodies is same.
 - All the above
32. When two charged bodies at different potentials are connected by a conducting wire, then the charge flows from one body to another body
- till the charge is completely transferred from one body to another.
 - as long as temperature difference exists between them.
 - as long as there exists a potential difference between them.
 - None of the above
33. The charge on a solid conductor resides
- always on its outer surface.
 - always inside the conductor.
 - on its outer surface for high temperatures only.
 - inside the conductor for high temperatures only.
34. A resistor of $80\ \Omega$ is connected to a cell and the potential difference across the resistor is 40 V . Then the amount of current that flows through the given resistor is _____ A.
- 0.25
 - 0.5
 - 5.0
 - 2.5
35. A cell of emf 5 V can supply a total energy of 9000 J , then the total charge that can be obtained from the cell would be _____ C.
- 180
 - 18000
 - 1800
 - 18
36. If two resistors of resistance $30\ \Omega$ and $40\ \Omega$ are connected in parallel across a battery, then the ratio of potential difference across them is _____.
- 1 : 1
 - 2 : 1
 - 3 : 4
 - 4 : 3
37. Two wires of resistances $10\ \Omega$ and $5\ \Omega$ are connected in series. The effective resistance is _____ Ω .
- 15
 - 20
 - 30
 - 40
38. The device used to measure potential difference between two points in an electric circuit is _____.
- voltmeter
 - voltmeter
 - ammeter
 - galvanometer
39. The ratio of the resistances of two resistors connected in parallel is $2 : 3$. The ratio of the currents flowing through them, when this parallel combination is connected to a cell is
- 3 : 2
 - 2 : 3
 - 1 : 1
 - 5 : 3

Level 2

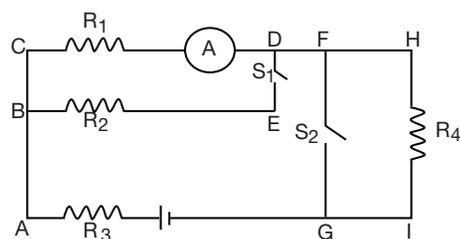
40. An electric kettle of 2000 W is used to boil 20 litres of water. Find the time required to boil the water from its initial temperature of 20°C . (Take specific heat of water as $4200\text{ J kg}^{-1}\text{K}^{-1}$. Density of water = 1000 kg m^{-3})
41. A circle is constructed of a uniform wire of resistance of 2 ohm per cm and is connected in a circuit such that it offers maximum resistance. Find the maximum resistance. (Take radius of the circle as 7 cm).



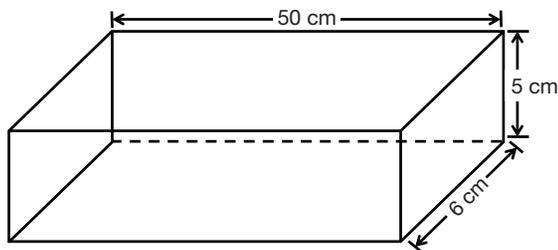
42. An electrostatic force of attraction between two point charges A and B is 1000 N. If the charge on A is increased by 25% and that on B is reduced by 25% and the initial distance between them is decreased by 25%, find the new force of attraction between them.
43. A capacitor of $10 \mu\text{f}$ stores charge 10 mc at given potential difference. If capacitance of capacitor is doubled, then find charge shared for same potential difference.
44. Calculate the electric energy consumed by a 2 HP pump if it is used for 2 hours. If the pump is used to fill an overhead tank, which is at a mean height of 10 m, find the quantity of water lifted by the pump. (Take $g = 10 \text{ m s}^{-2}$).
45. In the following diagram, if the potential difference across AB is 10 V what is the reading shown by V_2 ? How are the readings of V_1 and V_3 related? Between V_1 and V_4 , which reading is higher? Explain your answer. (All volt metres are identified)



46. Two α particles are separated by a distance of 4 fermi (in air). Find the Columbian force between them.
47. An electric current of 8 A is made to flow through a room heater of resistance 30Ω . Calculate
- (1) the potential difference across the heater.
 - (2) the power supplied to the heater.
 - (3) the amount of heat energy liberated from it in one minute.
 - (4) If the heater is used for 10 hours daily in the month of December, then find the number of units of electrical energy consumed by it.
48. The resistors R_1 , R_2 , R_3 and R_4 are connected as shown in the figure. S_1 and S_2 are two switches. Discuss the flow of current through the resistors when
- (1) S_1 and S_2 both are closed.
 - (2) S_1 and S_2 both are open.
 - (3) S_1 is closed and S_2 is open.

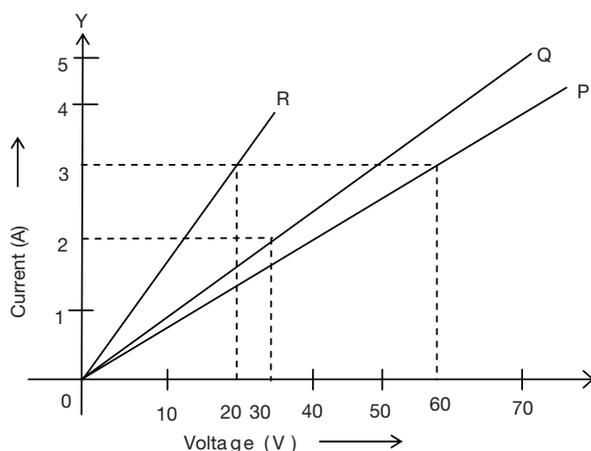


49. Two wires of equal length and diameter, one made of copper and the other of nichrome, are connected in series and the current through them is slowly increased. Which of the two wires heats up faster? Explain.
Also explain what happens if the two are connected in parallel.
50. Calculate the excess number of electrons that must be placed on each of the two similar uncharged spheres that are located 5 cm apart (in air), such that the force of repulsion between them is $36 \times 10^{-19} \text{ N}$.
51. For the block shown in the figure below, find the ratio of maximum to minimum resistance, that the block can offer when connected in a circuit.



52. A stream of electrons with kinetic energy equal to 100 keV pass across a cross section of a conductor in 0.5 s. If the potential difference between the ends of conductor is 5 V find the number of electrons that pass across the conductor in one second. (The charge on an electron is $1.6 \times 10^{-19} \text{ C}$).
53. Two point sized charged bodies repel each other with a force of 20 N when 30 cm apart in air. If their combined charge is $30 \mu\text{C}$, find the charge present on each body.
54. The graph of current versus voltage drop across the three resistors P, Q, R is as shown above. Find the ratio of their resistances.





55. Find the magnitude of a charge which produces an electric field of strength is $18 \times 10^3 \text{ N C}^{-1}$ at a distance of 5 m in air.

56. Calculate the electric field strength at a distance of 3 m from a charge of 32 NC placed in air.
57. The force exerted on a 3 C of charge placed at a point in an electric field is 9 N. Calculate the electric field strength at the point.
58. A charge of 10 C is brought from infinity to a point near a charged body and in this process, 200 J of work is done. Calculate the electric potential at that point near the charged body.
59. Calculate the units of electricity consumed in the month of November from the following details. One 60 W bulb used for 5 hours daily.
One 100 W bulb is used for 3 hours daily.
One 1 kW electric heater is used for 2 hour daily.
Also calculate the monthly bill at the rate of 2.50 per unit.

Level 3

60. Two conducting wires A and B (made of same material) of lengths 1 m and 2 m and area of cross sections 1 cm^2 and 100 mm^2 , respectively, are taken. If the resistance of a wire of length 5 m and thickness 2 cm made of same material as A and B is 5Ω , then find the resistance of the new wire of length 5 m formed by melting A and B.
61. Two capacitors are charged individually to potentials 80 V and 100 V, respectively. They can store charge 20 upto μC and $30 \mu\text{C}$, respectively. Find the ratio of their capacitances.
62. The metallic bob of a simple pendulum of mass 0.5 kg carries a positive charge of 0.25 C. If the pendulum is suspended in an electric field of strength 15 N C^{-1} directed from east to west, state the forces acting on the bob and derive the condition for equilibrium. Also find the angle subtended at the equilibrium.
(Take $g = 10 \text{ m s}^{-2}$)
63. An electron moves from a point A to a point B in an electric field and gains kinetic energy. Which of A and B is at a higher potential? Explain.
If the potential difference between A and B is 1 volt, find the gain in kinetic energy of the electron.
64. A charge 'Q' is divided into two parts A and B and the two parts are separated by a certain fixed distance. Find for what charges on A and B would the force between them be maximum and comment when the force is minimum.
65. A, B and C are three conductors with capacitances of $0.4 \mu\text{F}$, $2.5 \mu\text{F}$ and $2.5 \mu\text{F}$, respectively. If the charges on them are $4 \mu\text{C}$, $10 \mu\text{C}$ and $20 \mu\text{C}$, respectively, find the direction of flow of positive charge when each is connected with the other with a conducting wire.
66. A proton when released from point A moves to a point B in an electric field. Which of A and B is at a higher potential? Explain.
If the potential difference between the points A and B is 5 V, find the amount of work done in moving a proton from B to A
(Take charge of proton as $+1.6 \times 10^{-19} \text{ C}$).
67. Two identical spheres, one positively charged and the other negatively charged are held d cm apart. If the magnitude of the charges on the two spheres are equal, find the electric potential at a point midway on the line joining the centres of the two spheres.
68. Find the acceleration of an electron placed in an electric field of strength $18.2 \times 10^{-6} \text{ N C}^{-1}$.
69. A conductor of length ' ℓ ' is stretched to thrice the initial length. Find the ratio of currents flowing through it, before and after stretching if it is maintained at the same potential difference.



CONCEPT APPLICATION

Level 1

True or false

1. True 2. False 3. True 4. False 5. True 6. True 7. False

Fill in the blanks

8. higher, lower 9. remains unchanged 10. strength of electric current 11. $[M^{-1}L^{-2}T^4A^2]$
 12. earthing 13. resistance. 14. $[M^1L^2T^{-3}A^{-1}]$

Match the following

15. A : b B : a C : e D : g E : c F : d G : j H : f I : i J : h

Multiple choice questions

16. (a) 17. (a) 18. (d) 19. (c) 20. (b) 21. (d) 22. (b)
 23. (c) 24. (d) 25. (a) 26. (c) 27. (b) 28. (a) 29. (a)
 30. (b) 31. (d) 32. (c) 33. (a) 34. (b) 35. (c) 36. (a)
 37. (a) 38. (a) 39. (a)

Explanations for questions 31 to 39:

31. When a charge of -10 C flows from A to B, the net charge on A and B would become $+10$ C and -10 C, respectively. The potential on A increases and on B decreases but the magnitude of change in potential remains same.

32. The charge continues to flow as long as there exists a potential difference between them.

33. The charge on a solid conductor resides always on its outer surface.

34. We know, $V = iR \Rightarrow i = \frac{V}{R} = \frac{40V}{80\Omega} = 0.5A$.

35. We know, $V = \frac{w}{q} \Rightarrow q = \frac{w}{V} = \frac{9000J}{5V} = 1800C$.

36. The potential difference across the resistors which are connected in parallel is same

37. $R = R_1 + R_2 = 10\Omega + 5\Omega = 15\Omega$.

38. Voltmeter is used to measure the potential difference.

39. When resistors are connected in parallel, the same potential difference exists across all the resistors.

$$i_1R_1 = i_2R_2 \Rightarrow \frac{i_1}{i_2} = \frac{R_2}{R_1} = \frac{3}{2}$$

Level 2

40. (i) Power $P = \frac{E}{t}$ (1)

Energy supplied by the electric kettle is used to increase the temperature of 20 litres of water from 20°C to 100°C . But heat energy $Q = ms\Delta\theta$.

Calculate the heat energy absorbed by the water.

Substituting the value of energy and power in equation (1) we can determine the time.

(ii) 56 minutes

41. (i) Find the length of the wire forming circle, $\ell = 2\pi r$

(ii) The effective resistance of a parallel combination is always less than least value of resistance in the combination.

(iii) Take such that the value of resistance of the segment from the circle has maximum possible resistance.

(iv) $\frac{1}{R_{\text{effective}}} = \frac{1}{R_1} + \frac{1}{R_2}$



- (v) Take $R_1 = R_2 = (2 \text{ ohm cm}^{-1}) \times \frac{44 \text{ cm}}{2}$
 (vi) Find R_{eff} from (2).
 (vii) 22Ω
42. (i) Given the force of attraction between two point charges q_1 and q_2 is $= F_1$

$$= \frac{1}{4\pi\epsilon_0 k} \frac{q_1 q_2}{d^2} = 1000 \text{ N}$$
 When charge on q_1 increases by 25%, then it becomes $\frac{125}{100} q_1$
 When change on q_2 decreases by 25%, then it will be $= \frac{75}{100} q_2$
 The initial distance (d) has reduced by 25%, then the present distance becomes $\frac{75}{100} d$
 Now, electrostatic force would

$$= F_2 = \frac{1}{4\pi k \epsilon_0} \frac{\frac{125}{100} q_1 \frac{75}{100} q_2}{\left(\frac{75}{100} d\right)^2}$$
 Find the value of F_2 in terms of F_1 .
 (ii) 1666.67 N
43. $\frac{C_1}{C_2} = \frac{Q_1}{Q_2}$
 $Q_2 = \frac{C_2}{C_1} \times Q_1$
 $= 20 \text{ mc}$
44. (i) Power $= \frac{E}{t}$ (1)
 Work done by the pump is utilized to lift the water to a height of 10 m. That is the energy stored in the form of potential energy.
 But potential energy $= mgh$.
 By substituting the value of power, height, time and acceleration due to gravity, we can determine the mass of the water.
 (ii) 2.984 kWh, 107424 kg
45. Simplify the electric circuit and determine the effective resistance across the terminals.
 Compare the potential difference V_1, V_2, V_3 and V_4 .
 The potential difference recorded by each voltmeter $V = iR$,

where R is the effective resistance and ' i ' is the current flowing in the voltmeters.

46. (i) An α particle consists of two protons and two neutrons.
 Determine the charge of each α particle as
 $q = n \times e$
 where n is the number of protons and e is the charge of each proton.
 convert 1 Fermi into metres.
 Use the Coulomb's law

$$F = \frac{1}{4\pi\epsilon_0} \times \frac{q_1 q_2}{r^2}$$
 to determine the force.
 (ii) 57.6 N
47. (i) 1. $V = iR$
 2. $P = V \times I$
 3. $Q = V \times i \times t$
 4. $Q = P \times t$
 5. 1 kW h = 1 unit
 (ii) 240 V; 1.92 kW; 115.2 kJ; 595.2 units
48. Will any electric current flow through an open circuit?
 If the two terminals of a resistor are connected together in an electric circuit, it is said to be short circuited and no current flows through the resistor.
49. Heat energy produced in a wire when electric current passes through it increases with resistance.
 Which among the two wires has higher resistance?
 What happens to the effective resistance when two wires are connected in parallel?
 How will it affect the heat produced in the wire if the effective resistance is less than the individual resistances?
50. (i) The uncharged spheres are neutral.
 Use Coulomb's law

$$F = \frac{1}{4\pi\epsilon_0} \times \frac{q_1 q_2}{r^2}$$
 Substitute the value of f, ϵ_0 and
 $\frac{1}{4\pi}$ and determine the value of $q_1 q_2$.
 But $q_1 = q_2 = ne$
 Where n is the number of electrons and e is the charge on each electron.
 $(e = 1.602 \times 10^{-19} \text{C})$
 Find out the value of n from the above relation.
 (ii) $n = 6250$



51. (i) Recall the laws of resistance

$$R \propto \ell$$

$$R \propto \frac{1}{A}$$

To have the maximum resistance, the length of the wire should be maximum and the area of cross section of the wire should be minimum.

To have the minimum resistance, the length of the wire should be minimum and the area of cross section of the wire should be maximum.

$$R_{\max} = \frac{e \times 0.5}{0.06 \times 0.05} = \frac{500}{3}, R_{\min} = e \times \frac{0.05}{0.5 \times 0.06}$$

$$(ii) \frac{R_{\max}}{R_{\min}} = \frac{500}{3} \times \frac{3}{5} = 100\Omega$$

52. (i) Use the formula, P.D,
- $V = \frac{w}{q}$

$$V = \frac{KE}{ne} \quad (1)$$

(since, $q = ne$)

Find the value of 'n' from (1)

This many number of electrons pass in 0.5 seconds.

Double this number of electrons passes across the conductor in one second.

$$(ii) 4 \times 10^4 \text{ electrons}$$

53. (i) Let
- q_1, q_2
- be the charge of each particle.

$$q_1 + q_2 = 30 \mu\text{C}.$$

According to Coulomb's law

$$F = \frac{1}{4\pi\epsilon_0} \times \frac{q_1 q_2}{r^2}$$

Determine the value of q_1, q_2 from the given information.

$$\text{Use the relation } (q_1 - q_2)^2 = (q_1 + q_2)^2 - 4q_1q_2$$

And find $q_1 - q_2$.

Solve $q_1 + q_2$ and $q_1 - q_2$ to obtain the value of q_1 and q_2 .

$$(ii) q_1 = 10 \times 10^{-6} \text{ C}; q_2 = 20 \times 10^{-6} \text{ C}$$

$$q_1 = 20 \times 10^{-6} \text{ C}; q_2 = 10 \times 10^{-6} \text{ C}$$

54. (i) We know, Ohm's law is
- $V = iR$

From graph, get the values of voltages and corresponding currents for P, Q and R resistors.

$$R_P = \frac{V_R}{i_R}$$

$$R_Q = \frac{V_Q}{i_Q}$$

$$R_R = \frac{V_R}{i_R}$$

Find the ratio of $R_P : R_Q : R_R$

$$(ii) R_P : R_Q : R_R = 20:15:\frac{20}{3} \text{ (or) } 12 : 9 : 4$$

55. Given Electric field strength

$$(E) = 18 \times 10^3 \text{ N C}^{-1}.$$

Distance (r) = 5 m.

Charge (q) = ?

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}; 18 \times 10^3 = 9 \times 10^9 \times \frac{q}{(5)^2};$$

$$\therefore q = 2.25 \times 10^{11} \text{ C}$$

56. Given
- $q = +32 \text{ nC} = 32 \times 10^{-9} \text{ C}; r = 3 \text{ m}$

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} = 9 \times 10^9 \times \frac{32 \times 10^{-9}}{(3)^2} = 30 \text{ NC}^{-1}.$$

57. Given,
- $q = 3 \text{ C}, F = 9 \text{ N}$
- .

$$\therefore \text{The electric field strength, } E = \frac{F}{q} = \frac{9 \text{ N}}{3 \text{ C}}$$

58. Given
- $q = 10 \text{ C}$
- and
- $w = 200 \text{ J}$
- .

$$\therefore \text{Electric potential, } V = \frac{w}{q} = \frac{200 \text{ J}}{10 \text{ C}}$$

59. Electric energy = electric power
- \times
- time.

$$E = Pt.$$

- (i) 60 W electric bulb.

$$E_{b1} = 60 \text{ W} \times 5 \text{ h} = 0.06 \times 5 = 0.3 \text{ kW h}$$

bulb consumes 0.3 units daily.

$$\therefore \text{Energy consumed by the bulb for 30 days}$$

in the month of November E_{b1} is 0.3×30
= 9 kW h or 9 units.

- (ii) 100 W electric bulb.

$$\text{Electricity used } E = 100 \text{ W} \times 3 \text{ h}$$

$$= 0.1 \times 3 = 0.3 \text{ kW h} = 0.3 \text{ units daily.}$$

$$\text{for 30 days } E_{b2} = 0.3 \times 30 = 9 \text{ kW h} = 9 \text{ units.}$$

- (iii) Electric heater

$$E_h = 1000 \text{ W} \times 2 \text{ h} = 2 \text{ kW h} = 2 \text{ units daily.}$$

$$\text{Electricity used for 30 days, } E_h = 2 \times 30 = 60 \text{ units.}$$



Total energy consumed in the month of November is $E_{b1} + E_{b2} + E_h$
 $= 9 + 9 + 60 = 78$ units.
 The cost of electricity is ₹2.50 per unit.

Energy consumed is 78 units.
 \therefore Monthly bill for November = 78×2.50
 $= ₹195$

Level 3

60. (i) Volume of new wire (C) = $V_C = V_A + V_B$
 (ii) area of cross section of new circle (C)

$$= A_C = \frac{V_A + V_B}{\ell_C}$$

(iii) $R = \rho \frac{\ell}{A}$

- (iv) Find the value of ρ from given information

$$\rho = \frac{RA}{\ell}$$

$$= \frac{50 \Omega \times \frac{22}{7} \times 1 \text{ cm}^2}{500 \text{ cm}}$$

- (v) we know, $R_C = \rho \frac{\ell_C}{A_C}$
 substitute the values and find the value of R_C .

- (vi) 25Ω .

61. (i) $C = QV$,

$$C_1 = Q_1 V_1$$

$$C_2 = Q_2 V_2$$

(ii) $C_1 : C_2 = \frac{Q_1}{Q_2} \times \frac{V_2}{V_1} = \frac{2}{3} \times \frac{100}{80} = \frac{5}{6}$

$$C_1 : C_2 = 5 : 6$$

62. (i) On resolving the vectors $W = mg$ and $F = qE$, we get $mg \sin \theta = qE \cos \theta$ (1)
 (at equilibrium position)

- (ii) From (1)

$$\tan \theta = \frac{qE}{mg}$$

Substitute the values of q , E , m and g and obtain the angle subtended by the pendulum with the vertical.

- (iii) $\theta = \tan^{-1}(0.75)$

63. (i) What is the direction of the flow of electrons through a wire of the two ends if the wire is connected to a cell.

The positive terminal of a cell can be considered as higher potential and the negative terminal can be considered as lower potential.

$$\text{Electric potential } V = \frac{w}{q}$$

where w is the work done.

q is the charge on the electron.

- (ii) $1.6 \times 10^{-19} \text{ J}$

64. (i) $F = \frac{1}{4\pi\epsilon_0 k} \frac{Q_1 Q_2}{d^2}$

Then, $\frac{1}{4\pi\epsilon_0 k d^2}$ are constant.

$$\Rightarrow F \propto Q_1 \cdot Q_2$$

Here take $Q_1 = \frac{Q}{n}$ then $Q_2 = \left(Q - \frac{Q}{n}\right)$

$$= \left(\frac{n-1}{n}\right) Q$$

$$\Rightarrow F \propto \frac{Q}{n} \frac{(n-1)Q}{n} = \frac{(n-1)Q^2}{n^2}$$

F is maximum, when n is minimum

F is minimum, when n is maximum.

- (ii) $Q/2, Q/2$.

65. $V = Q/C$

$$\text{Potentia of } A = V_A = \frac{Q_A}{C_A} = \frac{4\mu\text{C}}{0.4\mu\text{F}} = 10 \text{ V}$$

$$\text{Potentia of } B = V_B = \frac{Q_B}{C_B} = \frac{10\mu\text{C}}{2.5\mu\text{F}} = 4 \text{ V}$$

$$\text{Potential of } C = V_C = \frac{Q_C}{C_C} = \frac{20\mu\text{C}}{2.5\mu\text{F}} = 8 \text{ V}$$

Positive charge always flows from a body at high potential to a body at low potential. It flows from A to both B and C . Charge also flows from B to C .

66. The charge of a proton, $Q = +1.6 \times 10^{-19} \text{ C}$

The proton moves from A to B , the point A is at higher potential than point B .

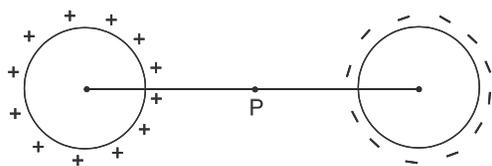


The P.D. between A and B is 5 V.

We know

$$V_A = \frac{w}{q} \Rightarrow w = V \times q = 5 \text{ V} \times 1.6 \times 10^{-19} \text{ C} = 8 \times 10^{-19} \text{ J}$$

67. Let the two spheres be placed as shown in the diagram below. Let the midpoint of the line joining the centres of the two spheres be P . Let a positive charge q be brought from infinity and placed at the point P . Then let w be the work done in bringing the charge q from infinity to point P against the positively-charged body. As the two bodies are identical and point P is at the same distance from the two charged spheres, $-w$ J of work is done in moving charge q from infinity to P against negatively-charged sphere. Hence, the total work done is $w - w = 0$



As the total work done is zero, the potential,

$$V = \frac{w}{q} = \frac{0}{q} = 0$$

\therefore The potential at P is zero.

68. Electric field strength $E = 18.2 \times 10^{-6} \text{ N C}^{-1}$
 Charge of an electron $e = 1.6 \times 10^{-19} \text{ C}$
 Mass of an electron $m = 9.1 \times 10^{-31} \text{ kg}$

$$E = \frac{F}{q}$$

$$F = Eq = 18.2 \times 10^{-6} \times 1.6 \times 10^{-19}$$

$$\text{But } F = ma$$

$$\therefore 9.1 \times 10^{-31} \times a = 18.2 \times 10^{-6} \times 1.6 \times 10^{-19}$$

69. Given,

$$\ell_2 = 3\ell_1$$

As volume remains constant, $\ell_1 a_1 = \ell_2 a_2$

$$\Rightarrow a_2 = \frac{\ell_1 a_1}{\ell_2} = \frac{\ell_1 a_1}{3\ell_1} = \frac{a_1}{3}$$

We know $R_1 = \rho \frac{\ell_1}{a_1}$ and $R_2 = \rho \frac{\ell_2}{a_2}$

$$R_2 = \rho \frac{3\ell_1}{\frac{a_1}{3}} = 9R_1$$

we know $V = iR \Rightarrow i = \frac{V}{R} \Rightarrow i \propto \frac{1}{R}$

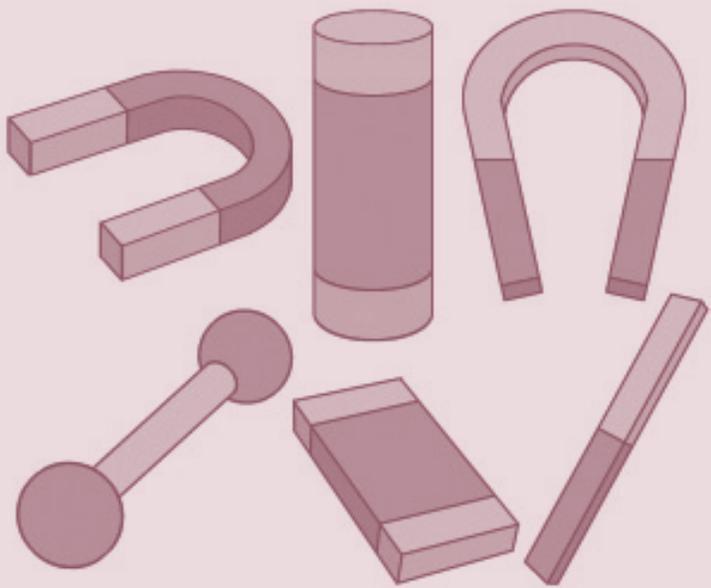
$$\frac{i_1}{i_2} = \frac{R_2}{R_1} = \frac{9R_1}{R_1} = 9 \Rightarrow i_1 = 9 : 1$$



Chapter

11

Magnetism



REMEMBER

Before beginning this chapter you should be able to:

- Define magnets, magnetic Induction, artificial magnets, bar magnet, magnetic field lines, etc.
- Recall basic methods of magnetization and methods of demagnetization

KEY IDEAS

After completing this chapter you should be able to:

- State the important properties of a magnet, artificial magnets, advanced methods of magnetization and demagnetization, magnetic field
- Explain Ewing's molecular theory, modern theory of magnetism and based on it the classification of magnetic substance
- Discuss about the different elements of earth's magnetic field and magnetic field produced by bar magnet in the Earth's magnetic field in different orientations
- Understand the concept in electromagnetism and different instruments using magnetic effect of electric current

INTRODUCTION

A naturally occurring black coloured substance called lodestone can attract pieces of iron kept nearby. In early days, the Greeks observed this property of lodestone, an oxide of iron called magnetite (Fe_3O_4). This type of naturally occurring substance is called natural magnet. Magnets are also made artificially in various shapes and sizes depending on their use. The common magnet used is a bar magnet whereas horse shoe magnets and electromagnets are also widely used.

The branch of physics which deals with the study of magnets, their properties and applications is called magnetism. Magnets are used extensively in televisions, computers, compact disks, MRI scanning, electric motors, generators, etc. Many applications are based on electric effect of magnets or magnetic effects of electric current. This aspect is dealt with in the later part of this chapter.

Important Properties of a Magnet

- 1. Attractive property:** A magnet attracts small pieces of iron, nickel, cobalt, etc., towards itself. The magnetic force of attraction is maximum in small regions near the ends of the magnet. These are called poles of the magnet.
- 2. Directive property:** A freely suspended magnet always points in north-south direction. The end pointing towards north is called north seeking pole or north pole. The other end which points towards south is called south seeking pole or south pole.
- 3. Law of magnetic poles:** Like poles repel and unlike poles attract. Thus, if two poles are both north or both south poles, there occurs repulsion between them. A north pole, on the other hand, always attracts a south pole and vice versa.
- 4. Pair property:** Magnetic poles always exist in pairs. All magnets have a north and a south pole. If a given magnet is cut into a number of small pieces, each piece is still a complete magnet having both the poles. It is impossible to have an isolated magnetic pole.
- 5. Repulsion is sure test of magnetism:** All magnets attract opposite poles of other magnets and also a few substances like iron, nickel and cobalt. Thus, if an unknown substance is attracted by a magnet, we cannot be sure whether it is a magnet. But like poles of magnet repel each other. Hence, if there is repulsion between an unknown substance and a magnet, we can be sure that the unknown substance is a magnet. The substances which are attracted by magnets are called magnetic substances.

Example: Iron, nickel and cobalt.

The substances like wood, plastic, paper, etc., which are not attracted by magnets are called non-magnetic substances. Magnetic substances can also get magnetized. Hence, they are used to make artificial magnets.

ARTIFICIAL MAGNETS

Artificial magnets come in various sizes, shapes and magnetic strength depending on the requirement.

Some commonly used artificial magnets are listed below:

- 1. Bar magnet:** It is a magnet in the form of a rectangular bar.

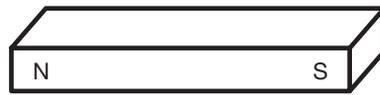


FIGURE 11.1 Bar magnet

2. **Magnetic needle:** It is a small and a thin magnet tapered towards both ends and pivoted at the centre. It is free to rotate in a horizontal plane. It is used to check the direction of a magnetic field and to map the lines of force of other magnets.
3. **Horse-shoe magnet:** It resembles a horse shoe, hence the name. A horse-shoe magnet is usually more powerful than a bar magnet. As both the poles of horse-shoe magnet face each other, the attractive power is doubled.



FIGURE 11.2 Magnetic needle

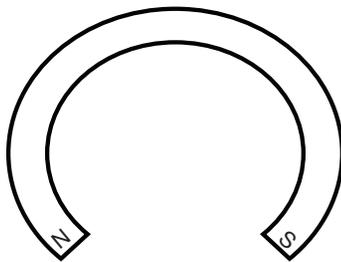


FIGURE 11.3 Horse-shoe magnet

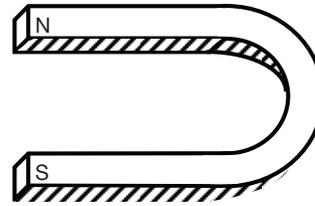


FIGURE 11.4 Horse-shoe magnet

4. **Magnetic compass:** It consists of a magnetic needle pivoted at its centre and encased in a brass box with a glass top. It is used to find directions.

Artificial magnets are preferred to natural magnets. The strength of an artificial magnet is much more than that of a natural magnet and it can be increased to desired level. Natural magnets come in irregular shapes whereas artificial magnets can be casted into any desired shape or size.

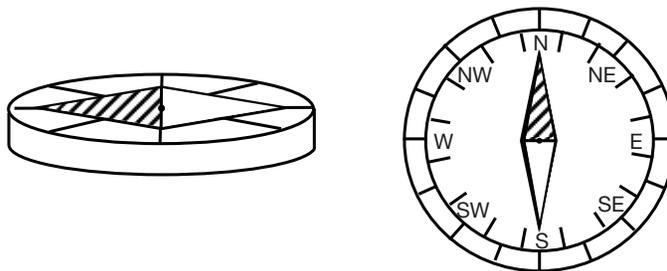


FIGURE 11.5 Magnetic compass

BAR MAGNET

Given below are few important terms associated with a bar magnet:

1. The geometric ends (A and B) of a bar magnet are called its **geometric poles** (see Fig. 11.6).

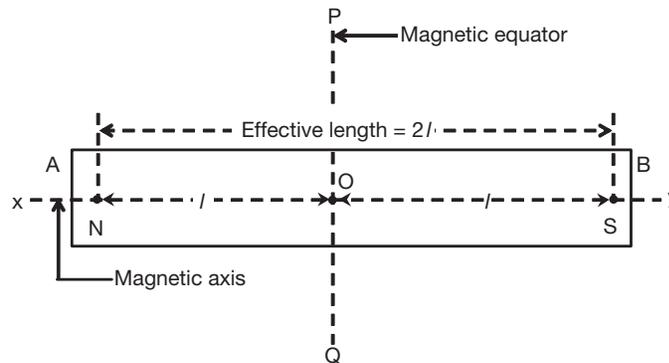


FIGURE 11.6 A Bar Magnet

2. The property of a magnet to attract small pieces of iron is very high, in small regions at each end of the magnet. These regions are called **magnetic poles**, these poles lie slightly within the ends of a magnet.
3. A freely suspended magnet aligns itself in the north-south direction. The end of the magnet which points towards the geographic north is called north seeking pole or magnetic north pole and the end which points towards the geographic south is called south seeking pole or magnetic south pole.
4. The line joining the north pole and the south pole of a magnet is called **magnetic axis of the magnet**.
5. The distance (ℓ) between any one of the magnetic poles and the centre of the magnet is called **length of the magnet**.
6. The distance between the north pole and the south pole of the magnet is called **effective length** of the magnet. This is slightly less than the physical length of the magnet and is taken to be equal to 2ℓ .
7. The product of the pole strength and the effective length of the magnet is called **magnetic moment**. It is SI unit of Am^2 .
8. A vertical plane passing through the magnetic axis of a freely suspended magnet is called its **magnetic meridian**.
9. An imaginary line passing through the centre of the magnet and perpendicular to the magnetic axis is called **magnetic equator**.
10. A vertical plane passing through the magnetic equator of a freely suspended bar magnet is called its **equatorial meridian**.

Locating the Actual Position of the Magnetic Poles of a Bar Magnet

On a wooden drawing board, fix a white sheet of paper and draw a straight line at its centre. Place a magnetic needle on this line and turn the board till the needle is aligned with the straight line. The drawing board is now in magnetic meridian.

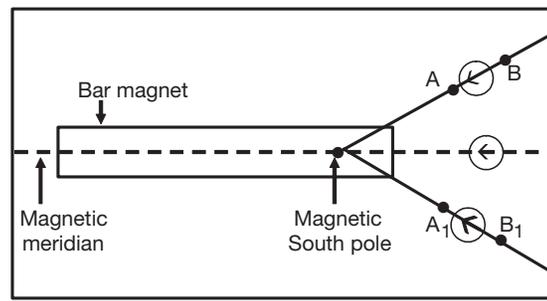


FIGURE 11.7 Locating the Actual Position of the Magnetic Poles of a Bar Magnet

Remove the needle and place a bar magnet axially on the line. Trace its outline. Now, place a magnetic needle near its one end. The needle is acted upon by the magnetic force due to the pole of the bar magnet which deflects it. Mark the two ends of the needle as A and B . Now place the needle at another position near the same end of the magnet and mark its position as A_1 and B_1 . Join A and B , A_1 and B_1 by straight lines, which when produced backwards meet at a point inside the outline of the bar magnet. This point represents the position of a pole of the magnet. Similarly, the position of the other pole can be located.

METHODS OF MAGNETIZATION

The process by which a magnetic substance such as iron is converted into a magnet is called magnetization. A few methods of magnetization are given below:

1. Single Touch Method

1. Keep the steel bar to be magnetized on a wooden table.
2. Take a strong permanent magnet and bring one pole (say north pole) of the magnet near one end of the steel bar and gently rub from one end to the other as shown in the Fig. 11.8.

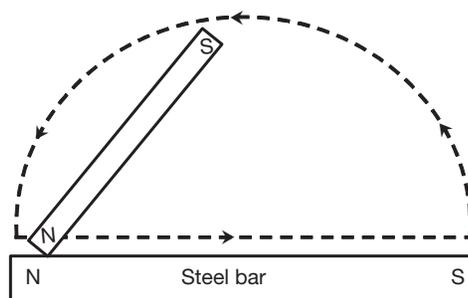


FIGURE 11.8 Single Touch Method

3. Once reached the other end, lift the magnet gently away from the steel bar and again bring it to the starting end.
4. Repeat this process several times.
5. Now the steel bar will be magnetized with the starting end as the north pole and the other end as the south pole.

6. If we start rubbing the steel bar with the south pole of the magnet, then the starting end will become the south pole and the other end will be the north pole.

2. Divided Double Touch Method

1. Keep the steel bar AB to be magnetized (as shown in the Fig. 11.9) on the top of two permanent magnets. (M_1 and M_2).
2. Bring two other permanent magnets M_3 and M_4 with opposite poles and touch the middle of the steel bar and rub and move as shown in the Fig. 11.9.

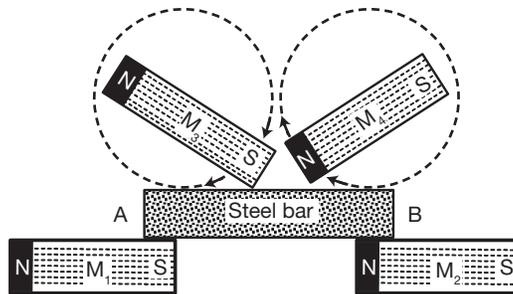


FIGURE 11.9 Divided Double Touch Method

3. Repeat this several times.
4. The end A of the steel bar at which south pole of the magnet leaves become the north pole. The end B of the steel bar at which the north pole of the magnet leaves becomes the south pole.

3. Double Touch Method

1. Two permanent magnets separated by a piece of wood or cork are held together such that their opposite poles are together.
2. This combination is placed on a piece of soft iron or steel in (AB) the centre and moved to and fro from one end to the other without lifting (see Fig. 11.10).
3. The polarities of the magnetized bar are opposite to those of the nearest stroking magnets as shown in the Fig. 11.10.

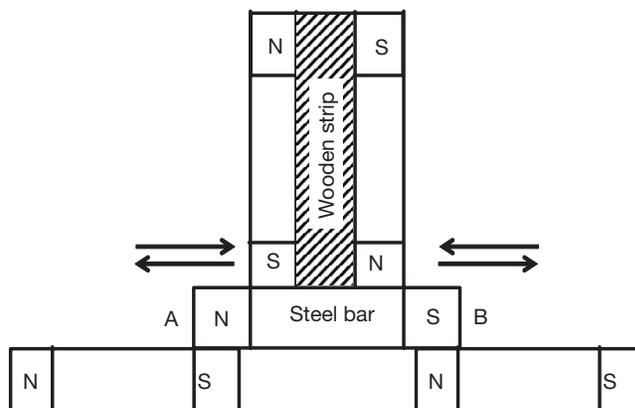


FIGURE 11.10 Double Touch Method

- For better and stronger magnetization, the piece to be magnetized may be placed over two permanent magnets as shown.

4. Electrical Method

- Keep the steel bar (XY) to be magnetized inside a long coil ' C ' of insulated copper wire.
- Pass a strong current through the coil for some time, with the help of a battery ' B '.
- The steel bar will get magnetized.
- The end at which current enters in an anti-clockwise direction will become the north pole and the other end becomes the south pole.

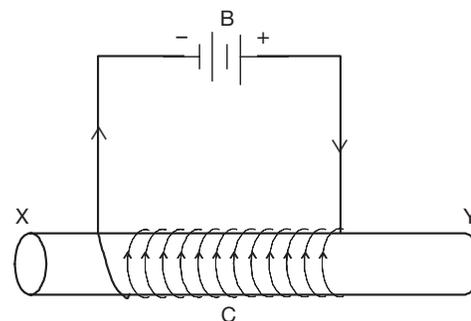


FIGURE 11.11 Electrical Method

Instead of a steel bar, if we keep a soft iron bar. It acts as a magnet as long as there is a current in the coil. Once the current stops flowing, it loses its magnetic effect. Such a magnet is known as a temporary magnet. Similar magnets are also called electromagnets.

METHODS OF DEMAGNETIZATION

The process used for destroying the magnetism (the magnetic properties) of a magnet is called demagnetization. Following are some of the methods of demagnetization:

- By rough handling
 - Heating the magnet and allowing it to cool while it is lying in east–west direction
 - By passing high frequency electric current
 - A magnet may lose its magnetism by self-induction.
- Electrical method:** If alternating current of a high frequency is passed through an insulated copper wire wound over a magnet (XY), the molecular magnets rapidly change their orientation as the current changes its direction. The orderly alignment of molecules is broken and the magnet is demagnetized.

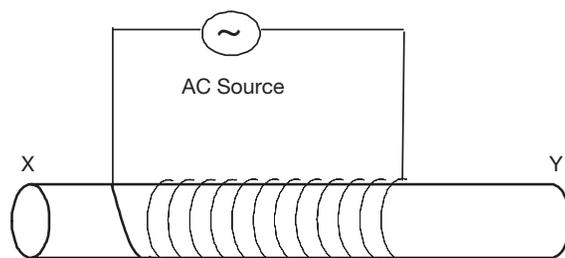


FIGURE 11.12 Electrical Method

- Heating:** To demagnetize, a magnet is heated to a high temperature and allowed to cool in east–west direction. As the magnet is heated, its molecules gain thermal energy which cause a rise in their kinetic energies. The straight line molecular chain is broken

and the magnet is demagnetized.

- 3. Rough handling:** A magnet loses its magnetism when hammered or dropped repeatedly. In both the cases, the kinetic energy of molecules increases which breaks their orderly alignment.
- 4. By induction:** When a magnet is kept near another magnet of similar strength with their like poles facing each other, both get demagnetized due to induction in a few days of time.
- 5. By self demagnetization:** A single magnet left to itself also loses magnetism, due to induction between its molecules. Thus, it is called self **demagnetization**.

MAGNETIC INDUCTION

Bring the south pole of a strong bar magnet near the south pole of a magnetic needle. The needle, being free to rotate, gets deflected. Increase the distance between the two so that the needle is not affected by the bar magnet and retains its original orientation (Fig. 11.13). Now, place a bar of soft iron between the two as shown in Fig. 11.14.

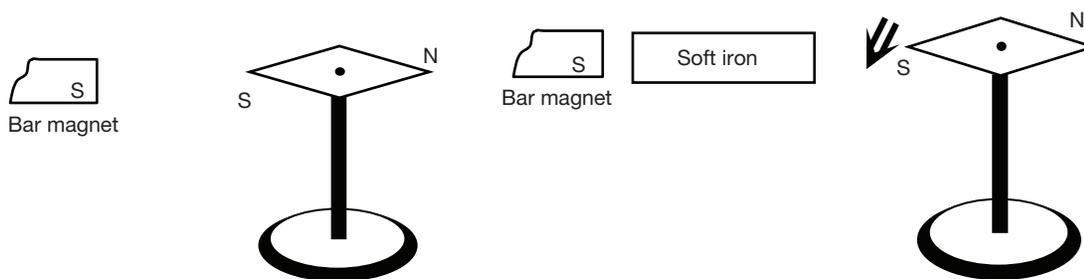


FIGURE 11.13

FIGURE 11.14

Then the south pole of the needle gets deflected again. Remove either the soft iron bar or the bar magnet. The needle comes back to its original position.

This experiment shows that a soft iron bar when placed near a strong magnet gets magnetized. The end of an iron bar facing the south pole of a bar magnet becomes north pole (i.e., an opposite pole) while the far end of the iron bar becomes south pole (i.e., the same pole). These poles are called induced poles. Also the iron bar loses its magnetism when moved away from the magnet. Thus, the magnetism acquired by it is temporary. If a steel bar is used instead of an iron bar, the deflection in the magnetic needle is less pronounced but it remains even if the bar magnet is removed.

This shows that the steel bar becomes less powerful but a permanent magnet. Its retentivity is higher than that of soft iron. The process in which a magnetic substance like iron or steel becomes a magnet when kept near a powerful magnet is called magnetic induction. Table below gives a few differences between permanent and temporary magnets.

Sl.No.	Permanent magnet	Temporary magnet
1.	Made of steel.	Made of soft iron.
2.	Cannot be magnetized easily.	Can be easily magnetized.
3.	Retentivity is high.	Retentivity is low.

Classification of Substances

All substances can be broadly classified as ferromagnetic substances, paramagnetic substances and diamagnetic substances.

- 1. Ferromagnetic substances:** The substances which are strongly attracted by a magnet are called ferromagnetic substances. These substances can be easily magnetized to make strong magnets.

Example: (a) Iron, nickel and cobalt

(b) Alloys like steel and alnico (Al + Ni + Co + Fe)

- 2. Paramagnetic substances:** The substances which are feebly attracted by a magnet are called paramagnetic substances.

Example: Aluminium, manganese, zinc and platinum.

- 3. Diamagnetic substances:** The substances which are feebly repelled by a magnet are called diamagnetic substances.

Example: Bismuth, copper, antimony and water.

EWING'S MOLECULAR THEORY OF MAGNETISM

If we break a bar magnet, each of the pieces formed acts as an independent magnet. This process can be continued upto molecular level. This means that each molecule of that bar magnet acts as a magnet.

According to molecular theory of magnetism,

- 1.** Each molecule of a magnetic substance is an independent magnet.
- 2.** In magnetized substances, i.e., in magnets, all the molecules are arranged in the form of long straight chains such that all north poles point towards one direction and all south poles towards the other. [Fig. 11.15(b)] In this way one end becomes the north pole and the other the south pole.
- 3.** In unmagnetized substances [Fig. 11.15(a)], the molecular magnets are in the form of closed chains, and thereby, neutralize the magnetic effect of each other.

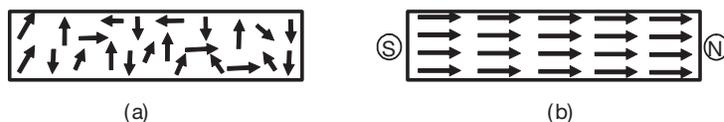


FIGURE 11.15 (a) Unmagnetized Substances; (b) Magnetized Substances

Based on the molecular theory, the following properties of a magnet can be explained:

- 1.** The north pole and the south pole of a magnet have equal strengths.
- 2.** When all the molecular magnets are arranged in the form of long straight chains, the substance is said to be saturated with magnetism. Once a given magnetic substance is saturated with magnetism, it cannot be magnetized further.
- 3.** When an iron bar is magnetized, its magnetic length slightly increases due to the straight chain arrangement.

4. When a twisted bar is magnetized, there will be a change in its curvature.
5. During magnetization or demagnetization of a substance, the kinetic energy of the molecules increases resulting in the conversion of kinetic energy into heat energy.
6. When a magnet is strongly heated, the molecular magnets start vibrating vigorously, thereby breaking the straight chain arrangement. This results in demagnetization.

Failures of Ewing's theory

1. It could not explain why the individual molecules of a magnetic material behave as tiny magnets.
2. It could not explain why the molecules of a non-magnetic substance do not behave like magnets.
3. It could not explain why substances like copper are repelled by a strong magnetic field.

MAGNETIC FIELD

The space surrounding a magnet within which the magnetic effect is felt is called magnetic field. Magnetic field is three dimensional. When a unit north pole is placed at a point in a magnetic field, the force experienced by it is called intensity of the magnetic field at that point. The intensity of the magnetic field decreases with an increase in the distance of the point from the magnet, i.e., the intensity of the magnetic field at a point is inversely proportional to the distance of the point from the magnet. If a unit north pole is placed in a magnetic field, as it is repelled by the north pole and attracted by the south pole, it follows a path which leads it towards the south pole of the magnet. This path along which a free north pole moves in a magnetic field is called **line of force**. Hence, the magnetic lines of force act as pictorial representation of a magnetic field.

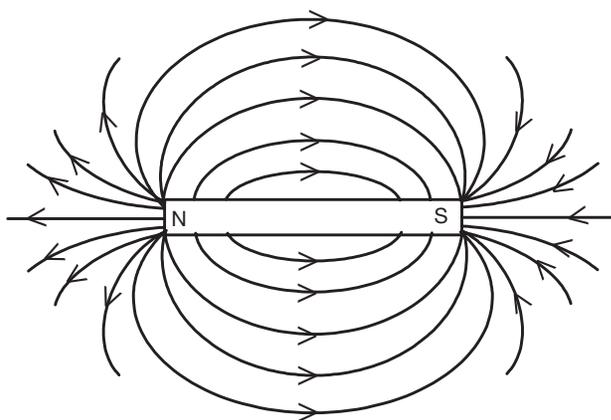


FIGURE 11.16 Magnetic Field Lines

Properties of Lines of Force

1. Magnetic lines of force always form closed curves.
2. They leave the north pole and enter the south pole externally.

3. They move from the south pole to the north pole within the magnet.
4. They tend to contract laterally.
5. They repel each other, because no two lines intersect each other.

Patterns of Lines of Force

Place a cardboard on a magnet or a set of magnets and scatter some iron filings over the cardboard. Now tap the board slightly. It will be observed that filings arrange themselves in curved lines forming a pattern. We discuss the pattern of the lines of force in some standard cases.

1. Pattern formed by single bar magnet.
2. Pattern formed by two bar magnets with opposite poles facing each other.

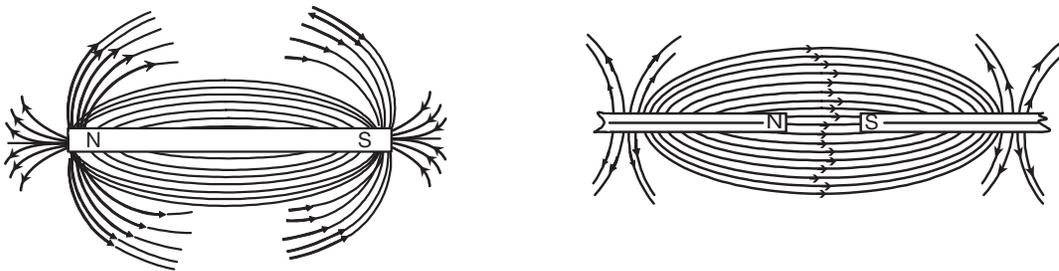


FIGURE 11.17 Patterns of Magnetic Field Lines

3. Pattern formed by two bar magnets with similar poles facing each other.
4. Pattern formed by a horse-shoe magnet.

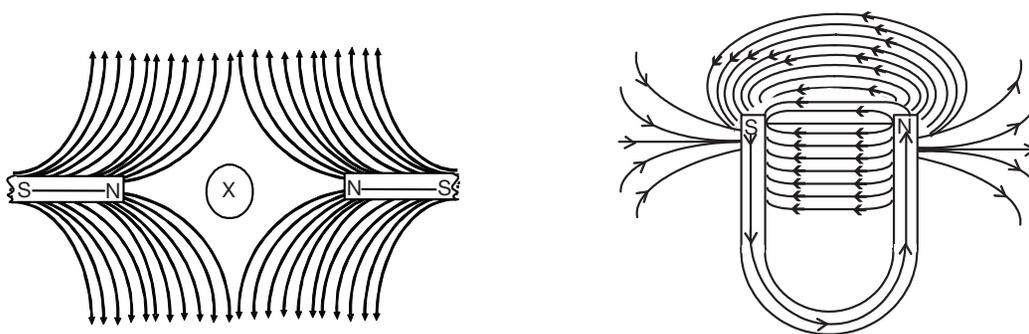


FIGURE 11.18 Patterns of Magnetic Field Lines

A neutral point (X) is obtained between the two like poles. The space between two opposing magnetic fields, where the resulting magnetic field is zero is called neutral point.

TERRESTRIAL MAGNETISM

The branch of physics that deals with the study of the Earth's magnetic field is called terrestrial magnetism or geomagnetism. It is observed that when a magnet is suspended freely, it aligns itself in the north-south direction. In the earlier days, it was assumed that it was the pole star

which was responsible for this effect, but later it was proved by Glibert that the effect was due to the magnetic field of the Earth. The Earth acts as a huge magnet, the exact cause of this magnetism is unknown, but for simplicity it is assumed that a huge bar magnet in the interior of the Earth is responsible for the magnetism.

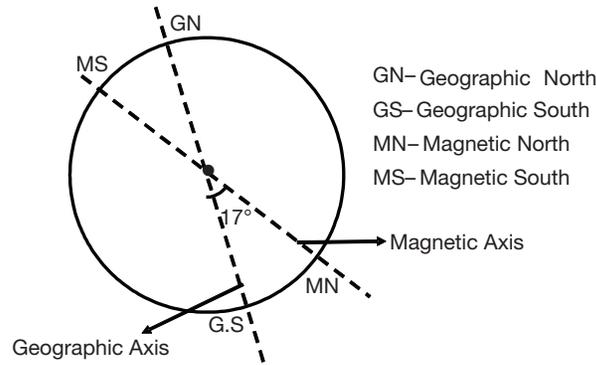


FIGURE 11.19 Earth's axes

The north pole of this magnet is found to be very close to the geographical south and the south pole of the magnet is found to be very close to the geographical north. Hence, the magnetic meridian and the geographical meridian do not coincide.

Since north poles of all magnets on the Earth point towards north, the Earth's magnetic south pole must be at geographic north and its magnetic north pole at geographic south. The Earth's geographic and magnetic poles do not coincide. The magnetic south pole of the Earth is situated north of Hudson bay in Canada and its magnetic north pole to the south of Australia. The Earth's magnetism at a given place can be described completely by knowing its certain characteristics. These are called elements of earth's magnetic field and are listed below.

1. Angle of dip or inclination
2. Angle of declination
3. Horizontal component of the Earth's magnetic field

Elements of the Earth's Magnetic Field

1. **Declination:** As discussed earlier, the geographic meridian and the magnetic meridian of the Earth do not coincide. The angle of declination at a given place is the angle between the geographic meridian and the magnetic meridian. The angle of declination varies from place to place.

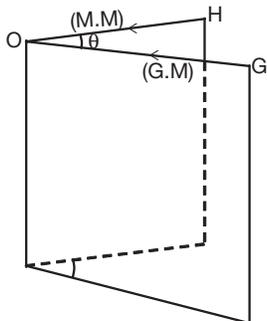


FIGURE 11.20

In the Fig. 11.20, MM is the magnetic meridian and GM is the geographic meridian and θ is the declination. The geographic meridian at a given place is an imaginary plane passing through the geographical north pole and the south pole. Magnetic meridian at a given place is an imaginary plane passing through the magnetic north and the south pole. Angle of declination is very useful to navigators. The magnetic compass points in magnetic north-south and not in the geographic north-south direction. If the route taken is according to compass, it may not lead to correct destination. Hence, the route has to be altered according to the angle of declination at a given place.

- 2. Angle of Dip or Angle of Inclination:** A magnetic needle rests itself in the direction of the Earth's resultant magnetic field when it is pivoted at its centre and free to rotate in a vertical plane. The angle through which the north pole dips down with respect to the horizontal is called angle of dip.

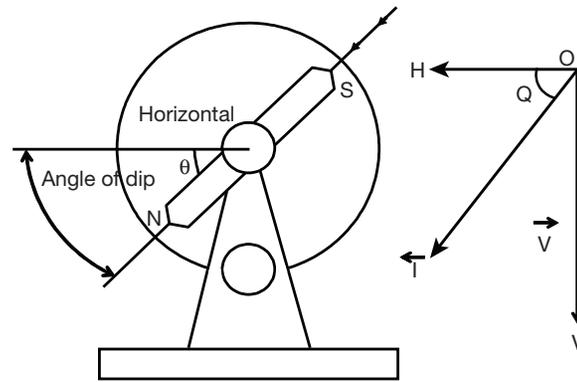


FIGURE 11.21

Angle of dip can also be defined as the angle between the resultant intensity of the Earth's magnetic field (I) and its horizontal component (H) at a given place.

Cause and Variation of Dip

The intensity of the Earth's magnetic field is maximum at its poles and minimum at its equator. As we move from the magnetic equator towards the north pole, the total intensity of the Earth's magnet makes increasing angle with the horizontal, and hence, angle of dip increases. The same happens when a magnetic needle is moved in southern hemisphere.

1. The angle of dip is zero at the magnetic equator and 90° at the magnetic poles.
2. The angle of dip increases as we move towards the north or the south pole.
3. In the northern hemisphere, the north pole of the magnetic needle dips whereas in the southern hemisphere, its south pole dips.
4. Dip at a place is determined by an instrument called dip circle.

Horizontal Component (I) of the Earth's Magnetic Field: As shown in the Fig. 11.22, the resultant intensity I of the Earth's magnetic field can be resolved into two components, viz horizontal component H and vertical component V , where d is the angle of dip.

From the Fig. 11.22,

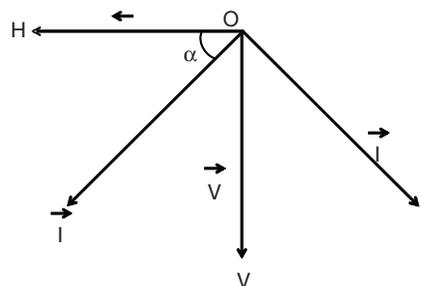


FIGURE 11.22

$$H = I \cos \delta \quad (11.1)$$

$$V = I \sin \delta \quad (11.2)$$

Dividing (11.2) by (11.1), we get

$$\tan \delta = \frac{V}{H} \quad (11.3)$$

Squaring and adding equations (11.1) and (11.2), we get

$$I^2 = H^2 + V^2 \quad (11.4)$$

At a given place, the magnetic lines of force due to the Earth's magnetic field are straight lines. This indicates that the Earth's magnetic field is uniform. These straight lines are approximately along the geographic south to the north.

Some Important Terms

1. Isoclinic line is a line joining all the places on the globe having the same angle of dip or inclination.
2. A clinic line or magnetic equator is a line joining all the places having zero angle of dip or inclination.
3. Isogonic line is a line which joins all the places on the Earth having the same angle of declination.
4. Agonic line is a line which joins all the places on earth having zero angle of declination.

Magnetic Field Due to a Bar Magnet in the Earth's Magnetic Field

1. **South Pole Pointing Towards Geographical North:** Place a bar magnet on a white paper along magnetic meridian such that the south pole of the bar magnet points towards the geographic north. Now draw the lines of force by using a compass needle.

At two points on the axial line of the magnet, neutral points are obtained (Fig. 11.23). At the neutral point, which is denoted by X in the Fig. 11.23, the field due to the bar magnet is equal and opposite to the field due to earth.

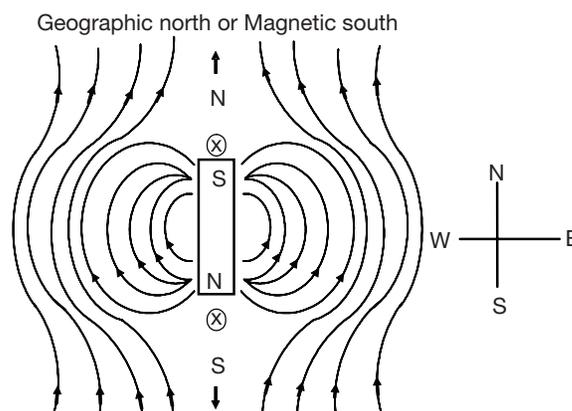


FIGURE 11.23 South pole pointing towards geographical north

- 2. North Pole Pointing Towards Geographical North:** Now, lines of force are drawn keeping the bar magnet on white paper such that its north pole points towards the geographic north.

In this case, the neutral points, denoted by X are obtained on the equatorial line (Fig. 11.24).

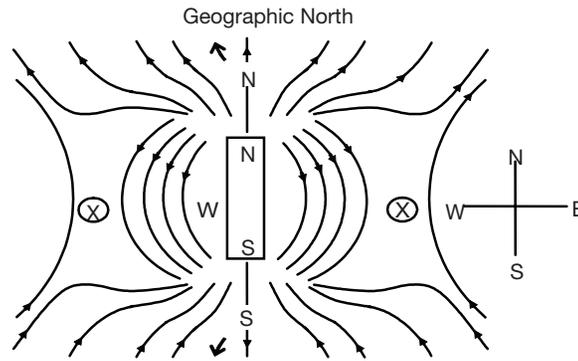


FIGURE 11.24 North Pole Pointing Towards Geographical North

Magnetic Effect of Electricity

Denmark born German scientist Hans Christian Oersted, while demonstrating an experiment to his students in his laboratory, found that a magnetic needle placed below a wire showed some deflection whenever there was current flowing through the wire. This gave rise to the discovery of a link between moving charges and magnetism. It was established that an electric current, (i.e., a stream of electrons), creates a magnetic field surrounding itself. Since magnetic field has both magnitude and direction, it is regarded as vector quantity. Since the cause of magnetism is electricity, it is called 'electromagnetism' and today electromagnetism has several applications.

Experiment I

Oersted's Experiment

Connect an insulated copper wire to a battery and a switch. Place a magnetic needle pivoted at its centre below it. Turn the switch on so that current flows through the wire in south-north direction. The north pole of the needle deflects towards west.

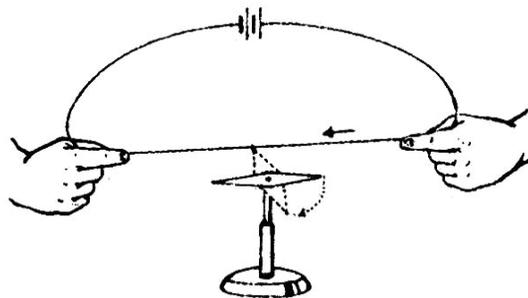


FIGURE 11.25

As the current is increased, the deflection in the needle also increases. If the direction of the current is reversed, the north pole of the needle deflects to the east. If the needle is kept above the copper wire, the needle deflects in directions opposite to that in above two cases. This experiment proves that a magnetic field is created around a current carrying conductor. A magnetic needle kept near the conductor tries to align itself in the direction of this field, hence, it deflects.

ELECTROMAGNETIC FIELD—ITS DIRECTION

The direction of electromagnetic field due to a current carrying conductor can be found using Maxwell's right-hand grip rule.

Maxwell's Right-Hand Grip Rule

Imagine you are holding current carrying conductor in your right hand as shown in Fig. 11.26. If the thumb indicates the direction of current through the conductor, then the direction of the other four fingers curled around the rod indicates the direction of the magnetic field produced by the current through the conductor.

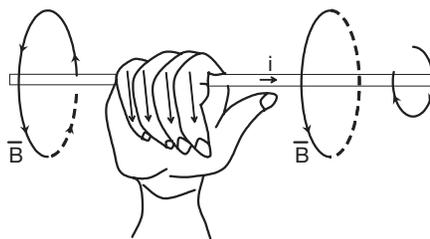


FIGURE 11.26

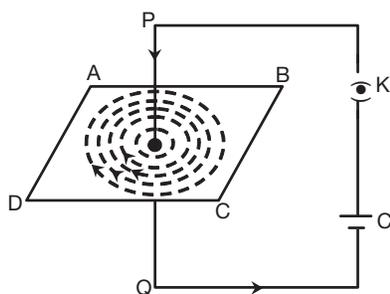


FIGURE 11.27

Magnetic Field Due to Current in a Straight Conductor

The following experiment demonstrates the nature of magnetic field around a straight current carrying conductor. Take a plane cardboard 'ABCD' of square shape as shown in Fig. 11.27. Make a small hole at its centre so as to allow an insulated wire 'PQ' to pass through it such that the length of the wire is perpendicular to the plane of the cardboard. Connect the wire to a plug key and a cell.

Sprinkle some iron filings on the cardboard. Insert the plug in the key so that current starts flowing through the conductor PQ. Gently, tap the cardboard. We observe that the iron filings are arranged in concentric circles with the centre at the hole on the cardboard as shown in Fig. 11.28. The concentric circles indicate the direction of the magnetic field around the current carrying conductor.

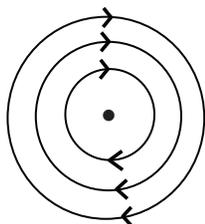


FIGURE 11.28

Magnetic Field Around a Circular Conductor (Coil)

Consider a circular loop PQRS passing through two holes 1 and 2 on a rectangular cardboard ABCD. Some iron filings are sprinkled on the cardboard. When the circular loop is connected to a cell, via a plug key and the circuit is switched on, we observe that the iron filings are arranged like concentric circles around the two holes 1 and 2 as shown

in Fig. 11.29. The concentric circles formed by the iron filings represent the directions of the magnetic field surrounding the circular loop, i.e., they represent the magnetic field lines due to the current carrying loop. The lines are straight at the centre of the loop. A small magnetic needle placed at the centre of the loop on the plane of the cardboard, points north towards edge AD of the cardboard. This implies that the circular loop acts like a magnet with its south pole towards the edge BC and north pole towards edge AD.

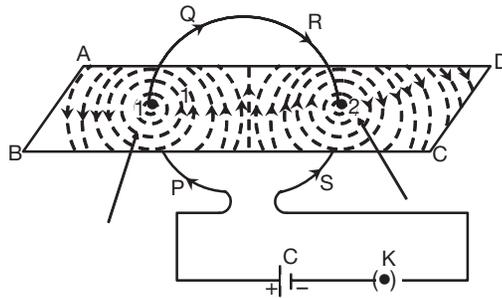


FIGURE 11.29 Magnetic Field Around a Circular Conductor

GALVANOSCOPE

We have seen the nature of the magnetic field due to circular coil carrying a current. If the same current is flown through a number of such coils connected to each other, the magnetic fields due to each add, giving a stronger magnetic field. Thus, even when a weak current is passed through coils, the magnetic field generated is sufficient to deflect a magnetic needle. A galvanoscope works on this principle. It consists of a coil having about fifty turns wound around a brass box as shown in the Fig. 11.30. Inside the box, a small magnetic needle is pivoted which rotates in a horizontal plane.

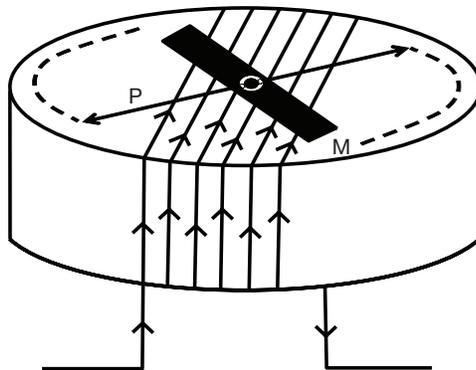


FIGURE 11.30 Galvanoscope
M – Magnetic needle P – Pointer

The arrangement is placed along south-north direction with a magnetic needle at its centre. If the two ends of the coil are connected to a weak cell, the needle gets deflected. The needle deflects in opposite direction if the current is reversed. Thus, galvanoscope not only detects current in a circuit, but also gives its direction.

INSTRUMENTS USING MAGNETIC EFFECT OF ELECTRIC CURRENT

Many instruments which we use frequently are based on conversion of electric energy into magnetic energy. The same principle is applied in instruments which are used to measure physical quantities associated with electricity.

A galvanometer is an electrical device used to detect the presence of current. Ammeter is an instrument used to measure an electric current, in a circuit. Galvanometer is available in different forms like moving coil galvanometer and tangent galvanometer.

Voltmeter is a device which is also based on magnetic effect of electric current and is used to measure the potential difference across the ends of a conductor. It is also used to measure the emf of an electric cell.

Solenoid

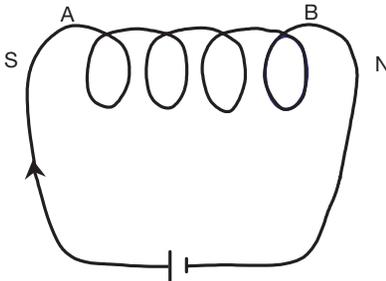


FIGURE 11.31 Solenoid

It is a conducting wire of spiral shape. When electricity is passed through the wire, it produces magnetic field, the direction of which is detected by using the Maxwell's right hand cork-screw rule. If, at the end A of the solenoid shown in Fig. 11.31, the current is in anti-clockwise direction, a north pole is produced and at the end B a south pole is produced. If the direction of the current is reversed, the polarity of the solenoid gets reversed. If a magnetic material like soft iron in the shape of a rod is introduced the solenoid, the magnetic field intensity increases. Such an arrangement is called electromagnet. Iron rod is called its core.

If the core of the solenoid is replaced with a steel rod, the steel rod becomes a permanent magnet when a current is passed through the solenoid.

Electromagnet

Solenoid with an iron core inside it can act as an electromagnet. It behaves like a magnet as long as current flows through it and loses its magnetism once the current is stopped. Electromagnets are used widely. Some of its applications are discussed below.

Magnetic Crane

Magnetic crane uses a powerful electromagnet. Heavy loads like iron scrap, cars, etc., can be lifted by passing current through the electromagnet. The crane moves the load to the desired place and current is stopped. The heavy load which was attached to the electromagnet then falls down.

An Electric Bell

The circuit diagram of an electric bell is as shown in Fig. 11.32. The U-shaped soft iron bar around which a conducting wire is wound acts like an electromagnet. Once the push button is switched on, current flows through the circuit and the electromagnet attracts the armature (a soft iron bar). Once the armature is attracted towards the electromagnet, it breaks the circuit at the contact points and then the electromagnet loses its magnetism. Thus, the

armature moves back to its original position and again the contact is made, allowing the current to pass through the circuit. Thus, making and breaking of circuit takes place, making the hammer attached to the armature ring the gong.

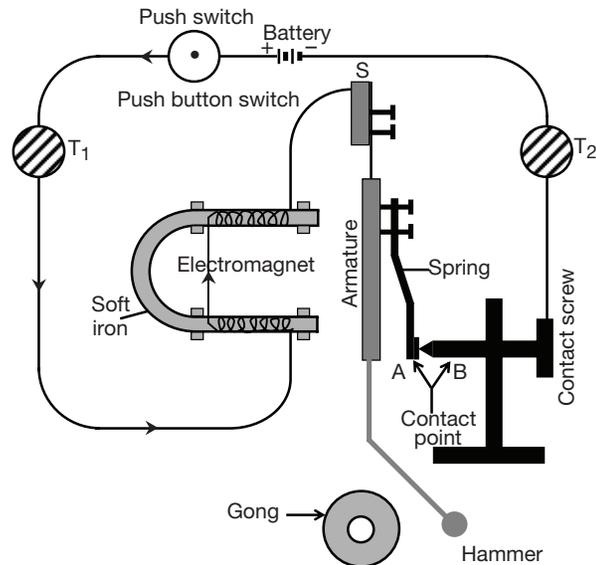


FIGURE 11.32 An electric bell

Electromagnetic Relay

An electromagnetic relay is used to control the working of a switch in some other circuit. Its working is based on electromagnet.

The relay consists of an electromagnet operated by an independent switch (S_1) and placed near the switch (S_2) which has to be controlled. When the relay is switched on, (Fig. 11.33b) the electromagnet is magnetized and attracts the switch (S_2) near it turning it on. The bulb connected in this circuit glows. When the electromagnetic relay is turned off, the switch controlled by it is no longer attracted towards the electromagnet and is turned off. Then the bulb in the circuit doesn't glow.

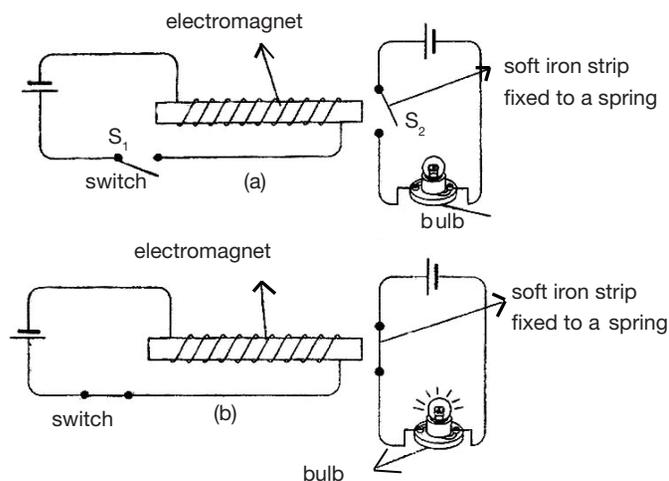


FIGURE 11.33

An electromagnetic relay which itself works on low voltage is used to control electric circuit operating at high voltage.

Relay Switch for a Car Starter

The current drawn by the starter motor in a car is about 100 A. The switch which operates this motor cannot be incorporated in dash board of the car for safety reasons. Therefore, an electro- magnetic relay operating on low voltage is used to operate the starter motor.

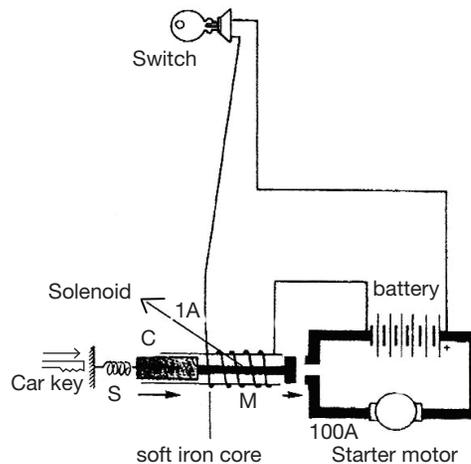


FIGURE 11.34

The car key itself acts as a switch. When it is on, current flows through an electromagnet. (M) The soft iron core (C) attached to a spring (S) is drawn towards the motor circuit. When a contact between the two is made, the starter circuit is complete. When the key is removed, the current flowing through the relay is stopped. The restoring spring brings back the soft iron core breaking the starter circuit. An electromagnetic relay works on low voltage, hence, thin and long wire is used in relay circuit. The starter circuit, on the other hand, uses a thick and short wire.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

- Define:
 - magnetic field
 - magnetic field lines.
- State Maxwell's right hand grip rule.
- The line which joins all the places having zero angle of declination is called an _____.
- Define:
 - ferromagnetic
 - paramagnetic
 - diamagnetic substances.
- Cobalt is a _____ substance.
- A straight conductor carrying current from north to south deflects magnetic needle placed parallel and above it, towards _____.
- Define terrestrial magnetism.
- State the nature of lines of force due to a circular coil carrying current.
- Magnetism is concentrated at the _____ of a magnet.
- Define natural and artificial magnets.
- Define neutral point and state the locations of neutral points when the north pole of a bar magnet points towards the geographic north.
- Define neutral point and state the locations of neutral points when the north pole of a bar magnet points towards the geographic south.
- What is the use of a galvanoscope?
- Define pole, axis, equator and magnetic meridian of a bar magnet
- Define a solenoid.
- The angle between resultant intensity of the Earth's magnetic field and its horizontal component at a given place is called _____ at that place.
- The branch of physics which deals with the study of magnets is called _____.
- Define magnetic and non-magnetic substances.
- Define an electromagnet.
- The direction of magnetic field due to a current carrying conductor can be determined by Ampere's _____ rule.
- A solenoid with an iron core acts as _____.
- What is magnetic induction?
- Define an electromagnetic relay.
- Define angle of dip.
- Define angle of declination.
- Define geographic and magnetic meridian of the Earth.
- The effective length of a bar magnet is equal to _____.
- What is electromagnetism?
- What is the angle of dip at a given place on the Earth if both vertical and horizontal components of the Earth's magnetic field are equal?
- What is the nature of lines of force due to a straight current carrying conductor?

Short Answer Type Questions

- Magnetic induction precedes attraction. Explain.
- Explain isogonic and agonic lines.
- State the factors which affect the strength of magnetic field around a circular current carrying coil.
- What are the different types of artificial magnets?
- Repulsion is the sure test for magnetism. Explain.
- What is horizontal component of the Earth's magnetic field?
- Explain galvanoscope.
- State various methods of magnetization.
- Explain the cause for variations in the angle of dip.
- Explain working of an electromagnet.



41. How will you determine the polarity of the ends of a solenoid?
42. State various methods of demagnetization.
43. Explain isoclinic and aclinic lines.
44. What determines the direction of lines of force due to a straight current carrying conductor?
45. State properties of magnetic lines of force.

Essay Type Questions

46. State and explain Ewing's molecular theory. Mention its merits and demerits.
47. With the help of neat drawn diagrams, explain how will you locate the neutral points due to a bar magnet when
(1) its north pole points towards geographic north?
(2) its south pole points towards geographic north?
48. Explain important properties of a magnet.
49. With the help of a well-labeled diagram explain the working of
(1) an electric bell and
(2) a relay switch for car starter
50. With the help of a labelled diagram, explain the following methods of magnetization
(a) single-touch method
(b) divided double-touch method
(c) double-touch method
(d) electrical method

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false

- A steel bar can be magnetized by passing alternating current through a coil wound on the steel bar.
- The angle of dip increases as we move from the Earth's magnetic equator to its magnetic poles.
- Both the poles of a magnet have the same strength.
- The angle of declination cannot be equal to zero.
- Diamagnetic substances are feebly attracted by magnets.
- In a single-touch method of magnetization, the end of the steel bar where the magnet leaves develops a polarity opposite to that of the magnet.
- Magnetic lines of force around a current carrying conductor are circular.

Direction for questions 8 to 13

Fill in the blanks

- The intensity of magnetic field due to a short bar magnet at a given point on its axis is inversely proportional to _____.

- The product of pole strength and the magnetic length of a magnet is called _____.
- Earth's geographic north pole is very close to its magnetic _____.
- During magnetization, the kinetic energy of the molecular magnets is converted to _____ energy.
- The point at which the resultant magnetic effect is zero is called _____.
- A freely suspended magnet lies in the horizontal plane at _____ of earth.

Direction for question 14

Match the entries in column A with the appropriate ones in column B.

14.

Column A	Column B
A. Magnetic poles of earth	() a. magnetic effect of electric current
B. Sure test of magnetism	() b. horizontal component is equal to the total intensity of magnetic field



- C. Galvanoscope () c. diamagnetic substance
 D. Vertical plane passing through magnetic axis () d. to detect the flow of current
 E. Steel () e. temporary magnet
 F. Oersted's experiment () f. zero angle of dip
 G. Magnetic equator of earth's magnetic field () g. horizontal component of earth's magnetic field is zero
 H. Copper () h. repulsion
 I. Aclinic line () i. permanent magnet
 J. Soft iron () j. magnetic meridian

Direction for questions 15 to 29

For each of the questions, four choices have been provided. Select the correct alternative.

15. The magnetic field due to a bar magnet _____.
 (a) has the same direction at any point
 (b) is uniform.
 (c) is non-uniform.
 (d) does not exist
16. At the null point _____.
 (a) horizontal component of earth's magnetic field is zero.
 (b) horizontal component of earth's magnetic field is equal to the magnetic field of the bar magnet.
 (c) intensity of earth's magnetic field is zero.
 (d) intensity of earth's magnetic field is equal to the magnetic field of the bar magnet.
17. Which of the following is a property shown by a magnet?
 (a) Attractive property (b) Directive property
 (c) Induction (d) All the above
18. The strength of a magnetic field increases as _____.
 (a) the number of magnetic lines of force passing through a given area increases.
 (b) strength of the magnetic poles increases.
 (c) distance between the magnetic poles increases.
 (d) does not exist
19. A conducting wire can give magnetic poles when it is _____.
 (a) bent into the form of a circular ring.
 (b) placed in an external magnetic field.
 (c) suspended freely in air.
 (d) All the above
20. Which of the following is an artificial magnet?
 (a) Bar magnet
 (b) Horse-shoe magnet
 (c) Magnetic needle
 (d) All the above
21. The magnetic field near the centre of a current carrying coil is uniform and _____.
 (a) parallel to the plane of coil.
 (b) perpendicular to the plane of coil.
 (c) circular.
 (d) Both (b) and (c)
22. Which of the following statements is false of a place closer to the north pole?
 (a) $V > H$
 (b) V is nearly equal to I
 (c) H is nearly equal to I
 (d) $V = \sqrt{I^2 - H^2}$
23. The torque acting on a current carrying loop placed in an external uniform magnetic field does not depend on the _____.
 (a) shape of the loop
 (b) strength of current through it
 (c) strength of the magnetic field
 (d) area of the loop
24. The ability of a galvanoscope to detect weak current increases with _____.
 (a) decrease in number of turns
 (b) increase in its diameter.
 (c) decrease in its diameter.
 (d) increase in number of turns
25. Consider the following statements A and B, and select the correct choice.
 A: Repulsion is a sure test of magnetism.
 B: Magnetic induction precedes attraction.
 (a) Only A is true (b) Only B is true
 (c) Both are true (d) Both are false
26. Retentivity is high in the case of _____.
 (a) steel (b) copper
 (c) soft iron (d) aluminium
27. A solenoid is _____.
 (a) an electromagnet
 (b) a temporary magnet



- (c) a permanent magnet
(d) Both (a) and (b)

28. Consider the statements A and B given below and select the correct choice.

A: an EM relay operates on high voltage.

B: an EM relay controls high voltage circuit.

- (a) Only A is true (b) Only A is false
(c) Both are true (d) Both are false

29. When a magnet is bent into the form of 'L', its magnetic moment _____.

- (a) increases
(b) decreases
(c) remains same
(d) Cannot be determined

30. The effective length of a bar magnet is equal to _____.

- (a) the distance between its poles
(b) the distance between any one pole and its centre
(c) the distance between its geometric ends
(d) the distance between any one geometric end and its centre

31. The space surrounding a magnet within which its magnetic effect is felt is called

- (a) magnetic field
(b) intensity of magnetic field
(c) magnetic meridian
(d) magnetic field lines

32. What is the angle of dip at the magnetic south of earth is?

- (a) 30° (b) 45°
(c) 60° (d) 90°

33. Given below are two statements. Which of the statements is/are true?

Statement A: When the south pole of a bar magnet points towards the geographic north pole, the neutral points are along the equatorial line.

Statement B: At the neutral point, the Earth's magnetic field is zero.

- (a) A is true, B is false.
(b) Both A and B are false.
(c) A is false, B is true.
(d) Both A and B are true.

34. A conductor carrying current from south to north deflects the magnetic needle placed parallel and above it towards _____.

- (a) east (b) west
(c) north (d) south

35. If the lines of force due to a current carrying straight conductor are in anti-clockwise direction and lie in the plane of paper, the current is flowing _____.

- (a) parallel to the plane of paper
(b) perpendicular to and directed into the paper
(c) perpendicular to and directed out of the paper
(d) parallel to the conductor

36. Magnetization can be done by _____.

- (a) heating (b) self induction
(c) single-touch method (d) electrical method

37. Cobalt is a _____ substance.

- (a) ferromagnetic (b) paramagnetic
(c) diamagnetic (d) All of these

38. The angle of dip increases as we move from

- (a) poles to equator (b) equator to poles
(c) Dip is equal at all places (d) All of these

39. Which of the following statements is true?

- (a) Magnetic equator is also called clinic line.
(b) On an agonic line, the angle of declination is zero.
(c) Two places on an isoclinic line have the same angle of inclination.
(d) All the above.

40. The direction of magnetic field at the two diametrically opposite points on a circular magnetic line of force around a current carrying conductor is _____.

- (a) tangent to the magnetic line of force and opposite in direction
(b) tangent to the magnetic line of force and in the same direction
(c) along the length of the wire and in opposite direction
(d) along the length of the wire and in the same direction

41. Write the following steps in a sequential order involved in the working of a relay switch for a car starter.

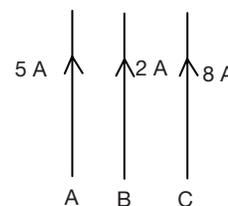
- (a) The soft iron core attached to a spring is drawn towards the motor circuit.



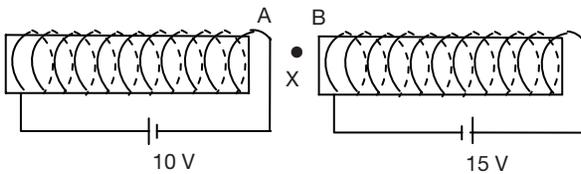
- (b) When key is removed, the current flowing through the relay is stopped and the circuit breaks.
- (c) When the car key is switched ON, the current flows through the electromagnet.
- (d) The soft iron core comes in contact with the starter circuit.
- (a) c d a b (b) a b c d
(c) a c b d (d) a d c b
42. Write the following steps in a sequential order involved in the working of an electric bell.
- (a) The armature is pulled towards the electromagnet.
- (b) The soft iron behaves as an electromagnet.
- (c) The circuit breaks and the electromagnet loses the magnetic property.
- (d) The hammer hits the gong.
- (e) Armature goes back and the circuit gets closed.
- (f) The process is repeated and the bell rings continuously.
- (g) The circuit is closed.
- (a) a b g d e c f (b) g b a d c e f
(c) g b a c d f e (d) b a c d e f g
43. Write the following steps in a sequence to locate the neutral points when south pole of a bar magnet is placed towards geographical north.
- (a) Draw the magnetic lines of force due to the bar magnet by using a magnetic compass.
- (b) Locate the north and south poles of a bar magnet by using a magnetic compass.
- (c) Place a bar magnet on the white paper such that the south pole of the bar magnet point towards geographic north.
- (d) Note the points in the magnetic field where the magnetic compass does not show any particular direction.
- (a) cbad (b) acbd
(c) cabd (d) bcad
44. Write the following steps in a sequential order to map the magnetic lines of force due to a current carrying straight conductor.
- (a) Pass a wire through the centre of a rectangular shaped card board.
- (b) Close the circuit.
- (c) Tap the card board.
- (d) Sprinkle some iron filings on the card board.
- (e) Connect the wire to a battery and a key.
- (f) Observe that the iron filings are arranged in concentric circular paths with wire at the centre.
- (a) aedbcf (b) aedcbf
(c) adecbf (d) aebdfc

Level 2

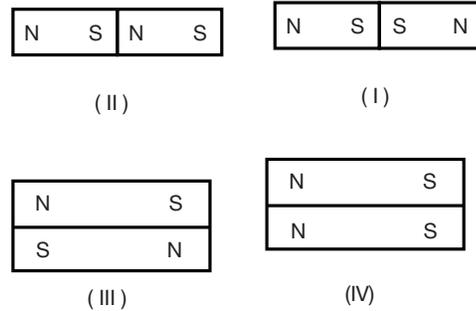
45. In spite of deflecting a magnetic needle kept near it, a straight current carrying wire doesn't possess magnetic poles. Explain
46. Why is it not possible to magnetize an iron bar beyond the saturation point?
47. A current carrying wire can deflect a magnetic needle. What is its effect on another current carrying wire kept near it?
48. Explain the nature of force between two adjacent turns of a solenoid. How does this force affect its length?
49. A magnet is cut into two parts by cutting it along its length. Is the crowding of the magnetic lines of force at the poles of the new magnet the same as it was in the old magnet? Explain your answer.
50. The value of horizontal component, vertical component and the intensity of magnetic field in SI unit at three different places A, B and C are tabulated as follows. Complete the tabular column and arrange the places in the increasing order of their angle of dip.
- | Place | H | V | I |
|-------|--------------------|--------------------|---------------------|
| A | 4×10^{-5} | 3×10^{-5} | -- |
| B | 8×10^{-5} | -- | 10×10^{-5} |
| C | -- | 5×10^{-5} | 13×10^{-5} |
51. What is the working principle of a galvanoscope? How can its sensitivity be increased?
52. Three straight wires A, B and C are placed in a plane parallel to each other and separated by equal distance, carrying currents as shown in the figure. Determine the direction of force on B.



53. Why are the magnetic poles of a bar magnet not situated at the ends, but located slightly inside? (Or) Why is the effective length of a bar magnet different from its actual length?
54. A magnetic compass is placed at the point 'X', the mid point of the line segment joining AB along the axis of the coils of the electromagnets in a horizontal plane. What would be the direction of the magnetic compass? Explain.



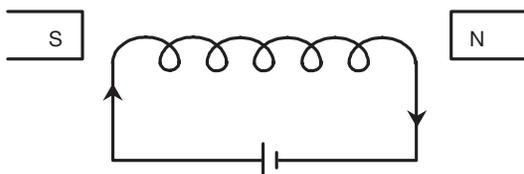
55. Which among the following dimensions of a bar magnet affect its pole strength and the magnetic moment? Explain.
- (1) Length
 - (2) Breadth
 - (3) Thickness
56. We know that a current carrying conductor placed in a magnetic field experiences a force. What happens if we place a rectangular coil in an external magnetic field?
57. Two bar magnets are kept so that each magnet is in contact with another magnet as shown in the figure below. In which of the arrangements do the magnets lose magnetism faster? Why?



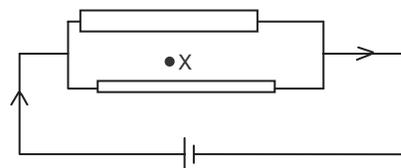
58. Will the angle of dip in Russia be greater or lesser than that in India? Explain.
59. If a magnetic compass and a dip circle are taken to the magnetic poles of the Earth, what would be the directions of their needles? Explain giving reasons.
60. Compare the magnetic lines of force around a bar magnet and a solenoid.
61. What effect is seen on a current carrying coil when it is placed between two powerful unlike magnetic poles? How can this effect be increased further?
62. A steel bar is magnetized by keeping it inside a long coil of insulated copper wire and passing a current through the coil. Discuss what happens to the pole strength of the magnet as the time for which the electric current passes through the coil increases.
63. The magnetic moment of a bar magnet is 2 A m^2 . If the magnetic length of the bar magnet is 5 cm , determine the force acting on it in an external magnetic field of strength 0.6 T .
64. Determine the magnetic moment of a bar magnet of magnetic length 5 cm and pole strength 2 A m .

Level 3

65. Can the combination of a current carrying wire and a solenoid produce neutral points?
66. A coil is made of an insulated copper wire and current is passed through the coil. Now, two magnets are kept at each end of the coil with the polarity as shown in the figure below. If the magnets do not move, will there be any change in the length of the coil? What will happen on reversing the direction of current?



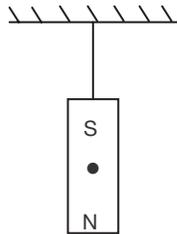
67. Two wires of equal length and different areas of cross section are kept parallel to each other and are connected to a battery as shown in the figure. A magnetic compass is placed exactly at the centre of the line joining the two wires in a plane perpendicular to the length of the two wires. What would be the direction of the north pole of the magnetic compass?



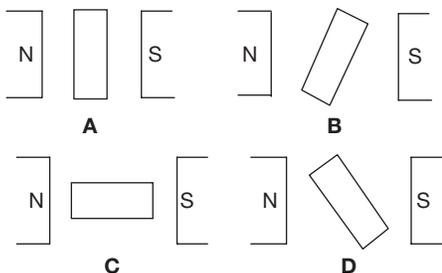
68. A bar magnet is suspended vertically from a rigid support at earth's magnetic south pole such that its



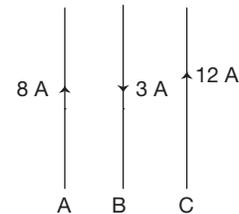
north pole points downward, as shown in the figure. What would be the geometrical shape obtained if we join all the null points along a horizontal plane passing through the centre of the magnet. How is the size of this geometric shape related to the pole strength of the magnet?



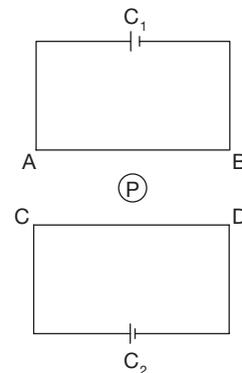
69. A galvanoscope used to detect the flow of current through a circuit should be placed in such a way that the axis of its coil is along the east-west direction. Explain.
70. How many neutral points can be obtained in a given plane perpendicular to the length of the two parallel wires conducting current in the same direction? Explain, Neglect earth's magnetic field of a bar magnet NS..
71. When a student of physics placed four different pieces of a substance, in a magnetic field, they arranged themselves as shown in the figure. Which of the following figures represents the orientation of a thin bar made of
- diamagnetic substance.
 - paramagnetic substance.
 - ferromagnetic substance.



72. Three straight current carrying conductors A , B and C are placed parallel and adjacent to each other by an electrician as shown in the figure. Then determine the direction of resultant force acting on the wire B .



73. A student read from his physics book that a piece of soft iron placed in a uniform magnetic field behaves as a magnet. Draw the magnetic lines of force in the region of space around the soft iron.
74. Two current carrying straight wires AB and CD are kept one above the other, and a magnetic needle is kept between and at the same distance from both wires at P as shown in the figure. Discuss the direction of magnetic field at point P . What happens if the polarity of the cell ' C_1 ', is reversed. (Assume that same amount of current passes through the two wires).



CONCEPT APPLICATION

Level 1

True or false

1. False 2. True 3. True 4. False 5. False 6. True 7. True

Fill in the blanks

8. distance 9. magnetic moment 10. south pole 11. magnetic energy 12. neutral point
13. magnetic equator

Match the following

14. A : g B : h C : d D : j E : i F : a G : b H : c I : f J : e

Multiple Choice Questions

15. (c) 16. (b) 17. (d) 18. (d) 19. (a) 20. (d) 21. (b) 22. (c) 23. (a) 24. (c) 25. (c) 26. (a) 27. (d)
28. (b) 29. (b) 30. (a) 31. (a) 32. (d) 33. (b) 34. (a) 35. (c) 36. (c) 37. (a) 38. (b) 39. (d) 40. (a)
41. (a) 42. (b) 43. (d) 44. (a)

Explanations for questions 30 to 44

30. The distance between the north pole and the south pole of a bar magnet is called effective length of the magnet.
31. The space surrounding a magnet within which the magnetic effect is felt is called magnetic field.
32. Angle of dip $\alpha = 90^\circ$ at magnetic poles of the Earth.
33. When the south pole of a magnet points towards the geographic north pole, the null points are obtained at two points on the axial line of the magnet. At the null point, the resultant magnetic field is zero.
34. Direction of current is from south to north, so according to right hand grip rule, the direction of magnetic field above the conductor is towards east.
35. If the lines of force due to current carrying straight conductor are in anti-clockwise direction, then according to right-hand grip rule the current flow is perpendicular to the plane of paper and directed out of the paper.
36. Magnetization can be done by single-touch method.
37. Cobalt is a ferromagnetic substance.
38. The angle of dip increases as we move from the equator to the poles.
39. Isoclinic line is a line joining all the places on the globe having the same angle of dip or inclination. A

clinic line or magnetic equator is a line joining all the places having zero angle of dip or inclination. Agonic line is a line which joins all the places on earth having zero angle of declination.

40. The direction of magnetic field at a point on a magnetic line of force is tangent to it and the direction of magnetic field at two diametrically opposite points on a magnetic line of force are opposite.
41. (i) When the car key is switched on, the current flows through the electromagnet.
(ii) The soft iron core comes in contact with the starter motor.
(iii) The soft iron core attached to a spring is drawn towards the motor current.
(iv) When key is removed, the current flowing through the relay is stopped and the circuit breaks.
42. (i) The circuit is closed.
(ii) The soft iron behaves as an electromagnet.
(iii) The armature is pulled towards the electromagnet.
(iv) The hammer hits the gong.
(v) The circuit brakes and the electromagnet loses the magnetic property.
(vi) Armature goes back and the circuit gets closed.
(vii) The process is repeated and the bell rings continuously.



43. (i) Locate the north and south poles of a bar magnet by using a magnetic compass.
 (ii) Place a bar magnet on the white paper such that the south pole of the bar magnet faces geographic north.
 (iii) Draw the magnetic lines of force produced due to the bar magnet by using a magnetic compass.
 (iv) Note the points in the magnetic field where the magnetic compass does not show any particular direction.
44. (i) Pass a wire through the centre of a rectangular shaped card board.
 (ii) Connect the wire to a battery and a key.
 (iii) Sprinkle some iron filings on the card board.
 (iv) Close the circuit.
 (v) Tap the card board
 (vi) Observe that the iron filings are arranged in concentric circular paths with wire at the centre.

Level 2

45. Recall the definition of magnetic poles.
 Is there any point in a wire conducting electricity where all the magnetic lines of force are concentrated?
46. How is the strength of a bar magnet is related to the number of molecular magnets arranged in a orderly way?
 Can we increase the strength of a bar magnet if maximum number of molecular magnets are arranged in an orderly way?
47. A current carrying wire produces a magnetic field around it.
48. Use the clock rule to determine the magnetic poles when electric current passes through a circular coil. Will the adjacent faces of two coils act as similar poles?
49. How does the number of free molecular magnets at the ends of the magnet vary when it is cut along its length?
 How does it affect the pole strength of the magnet and the number of magnetic lines of force?
50. A \rightarrow 5×10^{-5}
 B \rightarrow 6×10^{-5}
 C \rightarrow 12×10^{-5}
 $\theta_A = \theta_B > \theta_C$
51. Why does the pointer of a galvanoscope deflect when an electric current passes through it?
 How can we increase the strength of magnetic field produced around a current carrying conductor?
 The sensitivity depends upon the strength of the magnetic field produced around it.
52. Determine the direction of external magnetic field by using the right hand grip rule and determine direction of force on the wire by using Fleming's left hand rule.
53. The magnetic pole is a point inside a magnet where its attractive power is maximum.
 Where do the magnetic lines of force entering or leaving at the ends of a magnet appear to come from?
54. The magnetic field of the electromagnet.
 Resultant magnetic field.
 Identification of magnetic poles of an electromagnet.
55. Pole strength of a magnet depends upon number of ferromagnetic poles at the ends.
56. The direction of force on a wire conducting electric current placed in an external magnetic field. The formation of couple due to force.
57. In which among them does the molecular magnet rearrange randomly faster?
 How is the alignment of the molecular magnets related with the direction of the external applied magnetic field applied?
58. (i) What does a dip circle indicate?
 (ii) What is the direction of the Earth's magnetic field?
59. What is the direction of earth's magnetic field at the poles?
 Is a magnetic compass free to rotate in a vertical plane?
 Is the magnetic needle inside a dip circle free to rotate in a vertical plane?
60. A bar magnet consists of two poles. Outside the magnet, the lines of force originate from the north and terminate at the south pole. Inside it, the lines of



force travel from south to north pole forming a closed continuous loop. A solenoid consists of a number of insulated circular loops joined together forming a helical structure. Each current carrying loop acts like a magnetic dipole. All the north poles of coils face in one direction and south poles in the opposite direction. The effect is added and one end of the solenoid behaves like a north pole and the other behaves like a south pole. Each loop of the solenoid can be considered as a tiny bar magnet and the complete solenoid acts as a large bar magnet. The lines of force enter it at south pole and leave it at north pole. Inside the solenoid the lines of force are directed from the south to north pole. Hence, the pattern of lines of force of a solenoid is similar to that of a bar magnet.

61. When current flows through a coil, its one face acts as a north pole and the other face acts as a south pole. When this coil is placed between opposite magnetic poles, due to interacting magnetic fields, a turning effect is produced in the coil and it rotates such that its north pole faces the south pole. This turning effect or torque acting on the coil increases on increasing the number of turns and the current flowing through it.

62. When current passes through the coil, the end at which current enters in an anti-clockwise direction will become the north pole and the other end becomes the south pole. As we are increasing the current more number of molecular magnets are arranged in the form of long straight chains, when all the molecular magnets are arranged in the form of long straight chains, the substance is said to be saturated with magnetism. Once a given magnetic substance is saturated, it cannot be magnetized further.

63. Magnetic moment, $M = 2 \text{ A m}^2$
Magnetic length, $2l = 5 \text{ cm} = 5 \times 10^{-2} \text{ m}$.
Magnetic field, $B = 0.6 \text{ T}$

$$B = \frac{\text{force}}{\text{pole strength (m)}}$$

$$F = B \times m; M = m \times 2l$$

$$2 = m \times 5 \times 10^{-2}$$

$$m = \frac{2 \times 100}{5} = 40 \text{ Am}$$

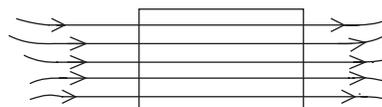
$$\therefore F = 0.6 \times 40 = 24 \text{ N}$$

64. Magnetic moment = pole strength \times magnetic length
 $= 2 \times \text{Am} (5 \times 10^{-2})^m = 1 \times 10^{-1}$

Level 3

65. The null points are obtained due to the cancellation of two magnetic fields equal in magnitude and opposite in direction.
Current carrying conductor can produce a magnetic field around it.
66. Direction of magnetic field due to a current carrying conductor.
Relation between thickness of the wire and strength of the current.
Relation between strength of the current and strength of the magnetic field.
67. The magnetic field around a magnet is three dimensional and the strength of the magnetic field at certain distance around the magnet is equal.
68. The magnetic fields get cancelled at a particular point between the two wires as their directions are opposite to each other. Therefore, only one null point can be obtained.

69. The bar of diamagnetic material aligns perpendicular to the magnetic field. The bar of paramagnetic and ferromagnetic material aligns in the direction of the magnetic field. Thin bar in figure *A* is made up of diamagnetic, in figure '*C*', made up of ferromagnetic substance and in figures *B* and *D*, made up of paramagnetic substance.
70. The wire *B* is repelled by both the wires *A* and *C* as they carry current in the opposite direction to that of *B*. However, as '*C*' carries large current, it repels '*B*' with greater force than '*A*'. Hence, '*B*' moves towards *A*.
71. Soft iron is a ferromagnetic substance. So, the magnetic lines pass through it.



72. Direction of current flowing through the wire '1' is from A to B and in wire '2' is from C to D , i.e., the current flows through the wires in the same direction. According to right hand grip rule the direction of magnetic field at the point ' P ' due to the wire '1' is into the plane of the paper and that of the wire '2' is out of the plane of the paper so net magnetic field

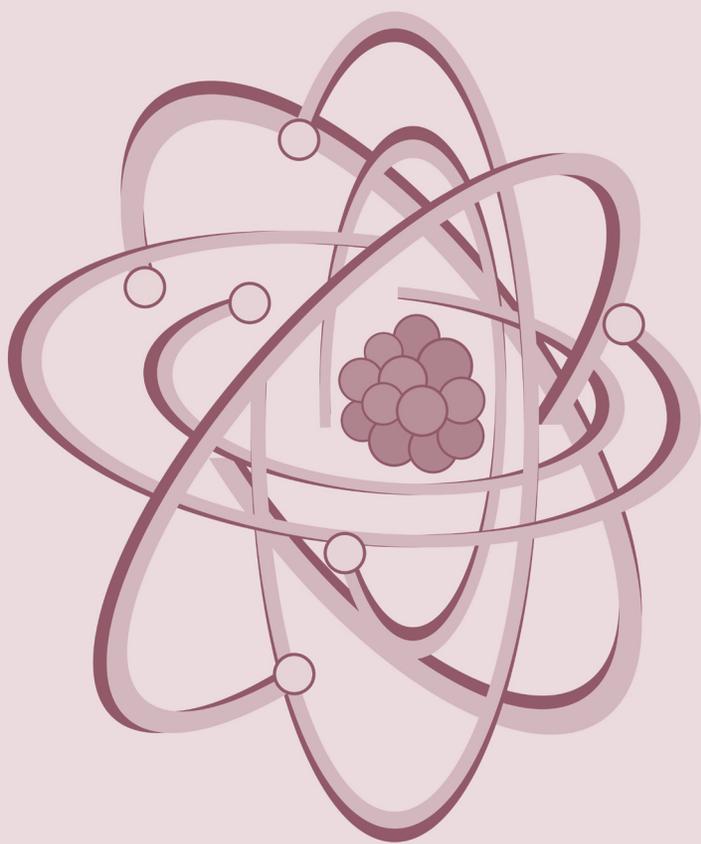
at the midpoint is zero. When the polarity of cell ' C_1 ' changes, current flows through the wire from B to A . So, the direction of magnetic field at the point ' P ' due to the two wires is out of plane of the paper. So, net magnetic field is away from the plane of the paper.



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Chapter 12

Modern Physics



REMEMBER

Before beginning this chapter you should be able to:

- Define atom and subatomic particles
- Revise discovery of sub-atomic particles—electrons, protons and neutrons

KEY IDEAS

After completing this chapter you should be able to:

- Learn about atomic structure and various atomic models related
- Study about discharge of electricity through gases by different experiments, such as Millikan's and Goldstein's experiment
- Understand about mass spectrometry and x -rays
- Learn about radioactivity and types of radiations

INTRODUCTION

The developments made in a research directed towards understanding the chemical and physical properties of the matter led the scientists in Europe, during the later half of the 19th century and the early part of 20th century, to unravel the mysteries of the microcosmic world of atom. One experiment led to the other and the conclusions drawn from one experiment or a hypothesis proposed by one scientist would be proved wrong or validated by another enthusiastic researcher. Several phenomena, which could not be explained on the basis of Newtonian theories of classical physics could be explained with ease with the help of the theories of modern physics. From medicine to space research, from agriculture to warfare, humanity has benefited by these long strides made by Science and Technology.

Here, we shall study the initial developments made in the research of X-rays and radioactivity

ATOMIC STRUCTURE

Scientists had recognized atom as the smallest particle of an element. The differences in the physical and chemical properties of different elements were attributed to the differences in the atoms of the respective elements. While exploring the structure of an atom, to understand the differences in the properties of the various elements, Dalton, Rutherford, Bohr and others had proposed atomic models for that purpose. The following conclusions may be drawn from these models.

1. Every atom (except Hydrogen atom) is composed of three subatomic particles:
 - (a) negatively-charged electrons,
 - (b) positively-charged protons and
 - (c) neutrons having no net electric charge on it.
2. In a neutral atom, the number of protons is equal to the number of electrons.
3. The mass of an electron is approximately $1/1837$ times the mass of a proton.
4. The mass of a proton is approximately equal to the mass of a neutron.
5. The mass of a subatomic particle is generally expressed in 'unified atomic mass units' (u), which is defined as $1/12$ th the mass of a C-12 atom.
6. The protons and neutrons are held together in the nucleus by a nuclear force.
7. The atomic number (Z) is the number of protons in a nucleus.
8. The mass number (A) refers to the total number of nucleons—number of neutrons and protons together.
9. Electrons revolve around the nucleus in fixed circular orbits having well defined energies.
10. When an electron moves from a higher energy level to a lower energy level, i.e., moves closer to the nucleus, the difference in the energy levels is emitted as radiation.
11. When an electron moves to an energy level farther from the nucleus, i.e., it moves from a lower energy level to a higher energy level, the difference in energy is absorbed.
12. Isotopes are those elements whose atoms have the same atomic number but different mass number, e.g., Hydrogen (${}_1\text{H}^1$) and Deuterium (${}_1\text{H}^2$).

13. The charge to mass ratio of an electron (e/m ratio) is $1.76 \times 10^{11} \text{ C kg}^{-1}$.
14. The magnitude of charge of an electron is $1.6 \times 10^{-19} \text{ C}$.
15. The mass of an electron is nearly $9.1 \times 10^{-31} \text{ kg}$.

Let us review some of the experiments conducted by Sir J.J. Thomson (1856–1940), Goldstein (1886) and Robert E. Millikan (1868–1953) which helped in drawing some of the above mentioned conclusions.

DISCHARGE OF ELECTRICITY THROUGH GASES

All gases are bad conductors of electricity at room temperature and at normal pressure. The same can be said about air which is a mixture of different gases. However, gases become conductors when high potential difference is applied at low pressures. An electric discharge tube is a device that is used to study the flow of charges through gases. It consists of a glass tube with two electrodes fused into it, as shown in the Fig. 12.1.

The discharge tube is filled with a gas through which flow of charges is to be studied and a high voltage is applied between the electrodes. If the pressure of the gas inside the tube is at normal atmospheric pressure, no current flows.

On reducing the pressure to about 10 mm of Hg, a luminous discharge with crackling sound is observed between the two electrodes. On further reduction of the pressure, the entire space between the electrodes is filled with a nearly uniform luminous glow. The colour of the glow depends on the gas present in the tube. When the tube is filled with air, magenta–red glow is observed.

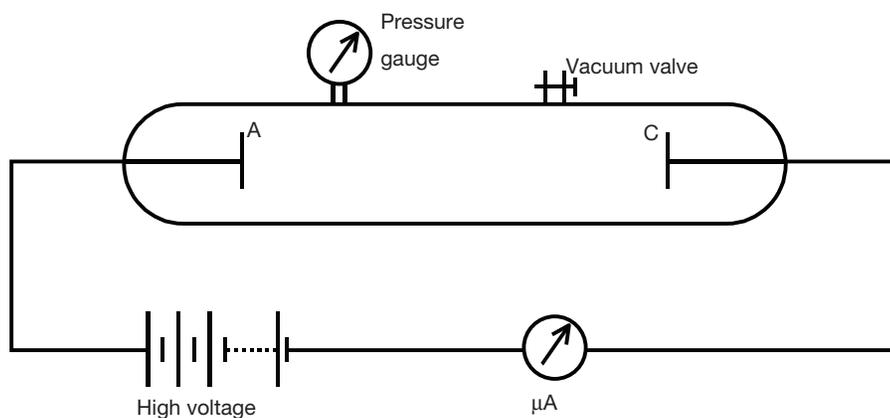
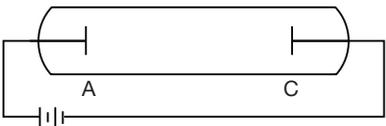
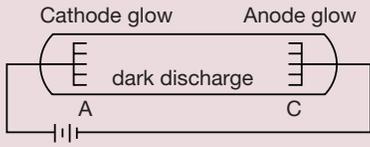
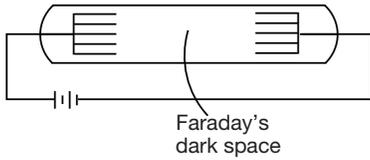
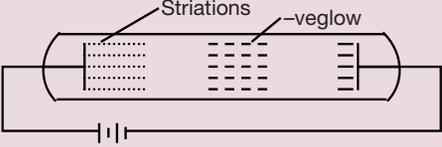
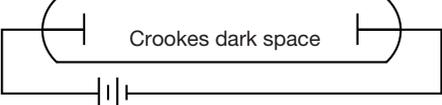


FIGURE 12.1 An Electric Discharge Tube

On further evacuation of the gas from the tube, at about 4 mm of Hg, the milliammeter shows deflection indicating conduction of electricity by gases at low pressure. Though no visible light is seen at this pressure, slight luminous effects are observed at the electrodes. The glow is interrupted with ‘Faraday’s dark space’. This is called dark discharge.

At a pressure of about 1 mm of Hg, a faint pink glow called ‘cathode glow’ is observed at the cathode and ‘Crookes dark space’ is observed between the cathode glow and the cathode. Alternate bright and dark patches are seen. These patches are perpendicular to the length of the tube and are referred to as striations.

At around 0.01 mm of Hg, fluorescence of the tube is observed in the form of greenish yellow light in the region behind the cathode. The fluorescence is caused by the rays emitted from the cathode, and hence, called cathode rays. Simultaneously, rays called anode rays are emitted from the anode travelling in the opposite direction and can be seen if the cathode is perforated as in Goldstein's experiment. At 0.01 mm of Hg, the whole tube is filled with Crookes dark space and at a very low pressure of 0.001 mm of Hg, the discharge stops completely.

S.No.	Pressure in discharge tube	Observations	
1.	≥ 12 mm of Hg	No current flows through the gas.	
2.	4 mm of Hg	An illumination is observed at the electrodes and the rest of the tube appears dark, called dark discharge or Faraday's dark space	
3.	1 mm of Hg	The whole space between the electrodes is filled with luminous column. This is called 'negative glow'. At the same time, the positive column shrinks towards the anode. Crookes dark space is also observed between the cathode and the cathode glow.	
4.	0.1 mm of Hg	The positive column breaks into striations.	
5.	0.01 mm of Hg	The walls of the tube begin to show fluorescence. The whole tube is filled with Crookes dark space	

To study the deflecting property of the cathode rays, J.J. Thomson constructed a modified discharge tube as shown in the Fig. 12.2.

The cathode rays were observed to deflect towards the positive plate while passing through an electric field. By measurement of the deflection and knowing the strength of the electric field, Thomson determined the charge to mass ratio of the cathode rays ($e/m = 1.76 \times 10^{11}$ C kg⁻¹). These observations led to the discovery of the electron.

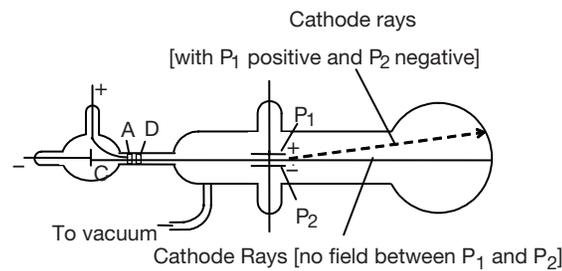


FIGURE 12.2 A Modified Discharge Tube

The modern television picture tube, glow signs, domestic fluorescent tube lights, cathode ray oscilloscopes are all modified discharge tubes.

MILLIKAN'S EXPERIMENT

Robert Millikan, American Scientist in his experiment allowed atomized oil droplets to fall through a vertical electric field. Due to atomization, the oil droplets picked up charge and by measuring the velocity of the droplets as they passed through the electric field, he calculated the charge on each droplet. From this, he discovered that the charge on a droplet was always an integral multiple of $1.6 \times 10^{-19} \text{C}$. Combining this value with the e/m ratio determined by Thomson, the mass of the cathode ray particle (electron) was calculated.

$$m = \frac{e}{\frac{e}{m}} = \frac{1.6 \times 10^{-19}}{1.76 \times 10^{11}} = 9.1 \times 10^{-31} \text{ kg}$$

GOLDSTEIN'S EXPERIMENT

Goldstein's modified discharge tube had two chambers separated by a perforated cathode. He observed that on application of high potential difference between the anode and the cathode, the cathode ray discharge was accompanied by a simultaneous discharge in the chamber behind the cathode. These rays called 'canal rays' were noticed by the glow produced by them in the chamber.

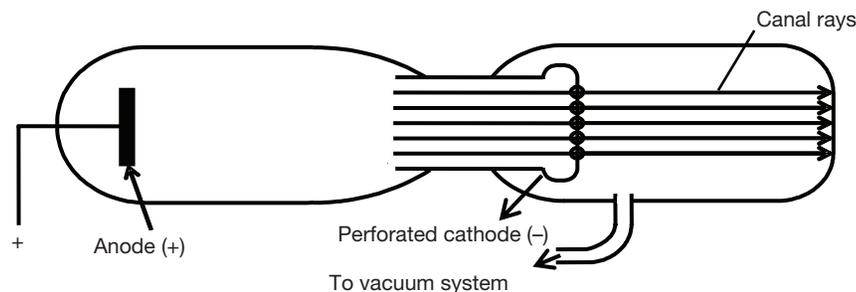


FIGURE 12.3 Goldstein's experiment

Wilhelm Wien, further modified the double chamber of Goldstein, by making a single hole in the centre of the cathode and providing an electric field perpendicular to the axis of the second chamber. He observed that application of electric field (about 2 kV) produced deflection of the rays, and used Thomson's method to determine the charge to mass ratio of the 'canal rays'.

MASS SPECTROMETRY

J.J. Thomson went one step ahead by applying simultaneous magnetic and electric fields parallel to each other, and observed arc shaped images on a photographic plate. While the variations in the electric field produced vertical deflections, variations in the magnetic field produced lateral deflections. (Fig. 12.4)

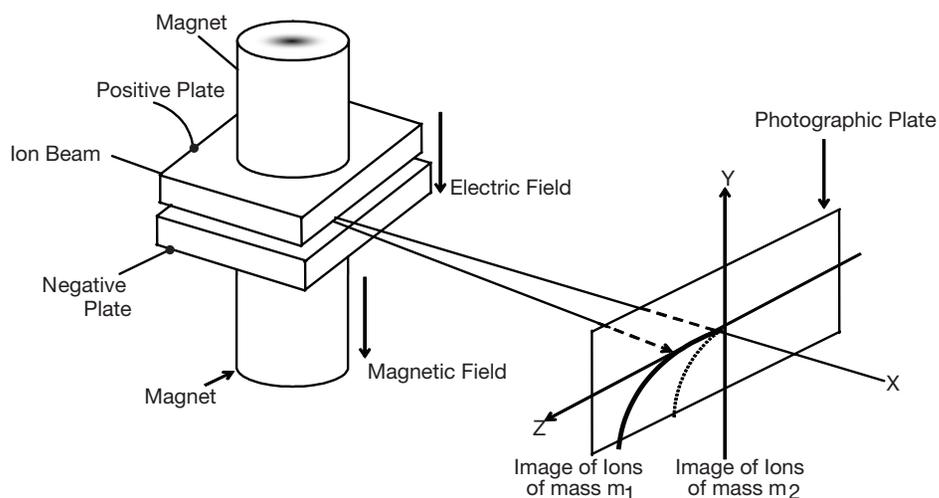


FIGURE 12.4

This has formed the basis of mass spectrometry, a method used to identify different atomic and molecular content in vapours and to determine the composition of materials.

X-RAYS

While conducting experiments with the discharge tube, Wilhelm K. Röntgen discovered that some unknown radiations were emitted from those parts of the discharge tube struck by the cathode rays, when the applied voltage is high. Sometimes referred to as Roentgen rays, these radiations were commonly called X-rays, meaning unknown radiations.

The gas chamber used for producing X-rays was constructed by Coolidge. A filament 'F' connected to a low voltage supply acts as a cathode. The anode is connected to the target 'T'. Generally heavy metals like molybdenum, lead, etc., are used as target. Electric and magnetic fields at the plates P and Q control the acceleration of the cathode rays from the filament.

High speed cathode rays emitted by the filament strike the target and emit X-rays. The intensity of the X-rays is controlled by the filament voltage and the voltage applied across the electrodes determines the energy of the X-rays produced.

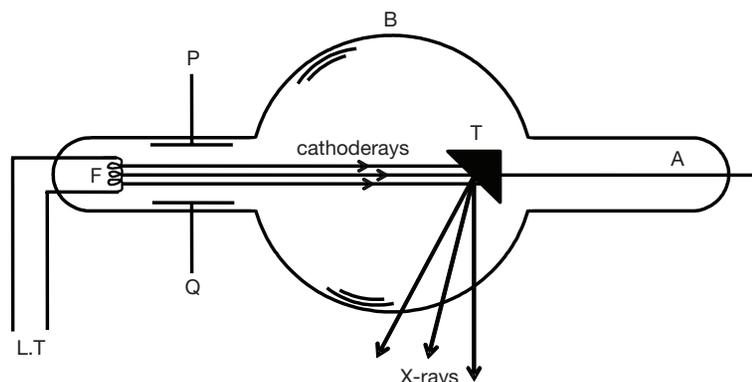


FIGURE 12.5 Coolidge tube

X-rays are now widely used in medical field for not only scanning the internal organs, but also in treatment of cancer. However, they have harmful side effects. X-rays are electromagnetic radiations and the range of their wavelength is 0.1 \AA to 100 \AA . Like all other electromagnetic radiations, they also travel in straight line with a speed of $3 \times 10^8 \text{ m s}^{-1}$.

Unlike cathode rays or canal rays, X-rays are not affected by electric or magnetic fields indicating that they are not charged particles. They can penetrate through matter which is normally opaque to visible light. This property is useful not only in X-ray photography of internal organs but also in scanning luggage for security reasons at places like airports, Metro Stations, etc.

Their ability to penetrate matter is used in X-ray diffraction to study molecular and crystal structures of substances, detecting defects in castings, etc.

RADIOACTIVITY

Certain substances like salts of uranium, emit visible light when irradiated by ultra-violet rays, and continue emission of visible light even after the exposure to UV rays is stopped. While investigating the connection between this phenomenon called phosphorescence and the X-rays, Henri Becquerel discovered that the uranium salts affect photographic plates irrespective of whether they were exposed to sunlight (UV rays) or not. This prompted him to conclude that the uranium salts continuously emitted some special rays which he called 'weak X-rays'. They were also initially referred to as 'Becquerel rays'.

It was subsequently found that thorium also exhibited similar property. Madam Mary Curie and Pierre Curie discovered that a substance which they later named as Polonium, isolated from the mineral pitchblende is 400 times stronger than uranium in emitting the 'Becquerel rays'. They were also able to isolate radium which was found to be 900 times stronger than uranium, when in small concentrations, and a million times more powerful when in pure form.

It was found that several other substances with atomic number greater than that of lead were emitting such radiations. This process in which the unstable nuclei of certain elements have the property of self-disintegration and spontaneous emission of radiations is called 'radioactivity'. Further research on these radiations revealed that this spontaneous emission of radiations is independent of the chemical and physical state of the element, and the radioactive property could be observed even when those substances were detonated with explosives.

α , β , γ RADIATIONS

Analysis of the ionizing rays (radiations) emitted by the radioactive substances revealed that these radiations consisted of primarily three types of rays— α rays, β rays and γ rays.

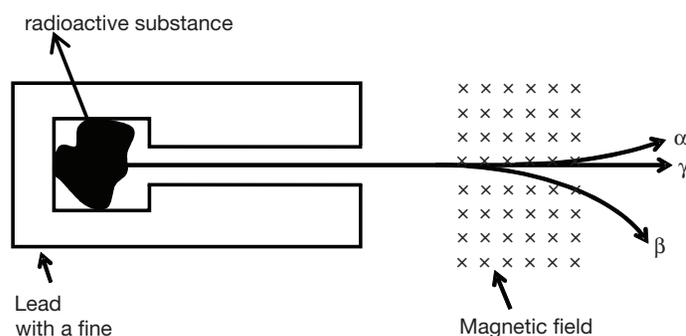


FIGURE 12.6

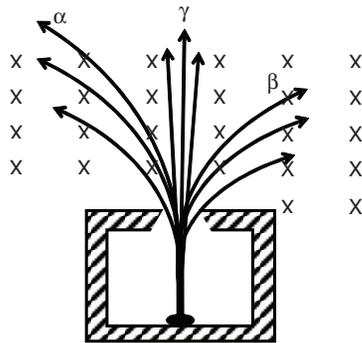


FIGURE 12.7 Deflection in Magnetic field

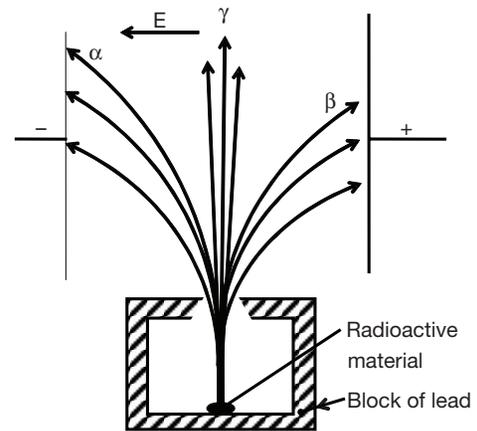


FIGURE 12.8 Deflection in Electric field

Properties of α , β , γ -rays

1. α -rays (alpha rays)

- Ionized helium atoms.
- Positively-charged particles.
- Deflect towards the negative plate when passing through an applied electric field.
- Deflect in magnetic field, in accordance with Fleming's left-hand rule.

2. β -rays (Beta rays)

- Highly-energized electrons.
- Negatively-charged particles.
- Deflect towards the positive plate when passing through an electric field.
- Deflect in magnetic field, in accordance with Fleming's left-hand rule.

3. γ -rays (gamma rays)

- High energy electromagnetic radiation.
- Electrically neutral.
- Emerges undeflected when passing through electric or magnetic fields.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Towards which electrode, do the canal rays deflect?
2. In J.J. Thomson's experiment, the portion of the tube opposite cathode starts glowing due to _____.
3. What is a discharge tube?
4. The observation of greenish-yellow light in the discharge tube at very low pressures led to the discovery of _____ rays.
5. What is the ratio of the charge to mass of the cathode rays?
6. Discharge is stopped in a discharge tube at a pressure nearly equal to _____.
7. Under what conditions, do gases become conductors of electricity?
8. γ -rays travel with the speed of _____.
9. What are weak X-rays?
10. X-rays are produced in _____.
11. What are cathode rays? State their specific charge (charge to mass ratio). What is the charge on an electron?
12. Faraday's dark space is observed at _____ pressure.
13. How can the intensity and energy of X-rays be changed?
14. The original name given to the radiations emitted by radioactive substances is _____ rays.
15. At what pressure, are cathode rays produced?
16. _____ are used in customs department to detect smuggled goods.
17. Give wavelength range of X-rays.
18. Radioactivity is _____ by the chemical and physical states of the material.
19. At what pressure, is Crooke's dark space observed?
20. The radiations from uranium discovered by Becquerel are _____.
21. Write down any two uses of X-rays.
22. Phosphorescence is the emission of visible light when substances are irradiated with _____.
23. What happens when cathode rays are subjected to a strong electric field?
24. _____ are useful in studying the crystal structures.
25. Name the experiment that determined the charge on electron.
26. What is radioactivity?
27. Cathode ray particles have a mass of _____ times that of hydrogen nucleus.
28. Name the method used to identify different atomic and molecular content in vapours.
29. _____ rays are used in the treatment of cancer.
30. What are canal rays?

Short Answer Type Questions

31. What are the applications of X-rays?
32. Give the properties of cathode rays.
33. How are X-rays produced?
34. Give the properties of X-rays.
35. Essentially, a Coolidge tube is a discharge tube. How is it different from the Crookes tube used to study the cathode rays? What is the function of the additional components?
36. What conclusions can be drawn from J.J. Thomson's experiment on discharge phenomenon?
37. Distinguish between β -rays and cathode rays.
38. Write short notes on canal rays.
39. How do X-rays detect a fracture in a bone?
40. Give a short note on Millikan's oil drop experiment.
41. X-rays are electromagnetic waves. Justify.



42. Write short notes on X-rays.
43. What are the differences between cathode rays and canal rays?
44. What is a discharge tube? Explain its construction.
45. What is radioactivity? What is the cause for natural radioactivity?

Essay Type Questions

46. Describe J.J. Thomson's experiment on discharge phenomenon. What are the observations and the conclusions from this experiment?
47. Describe Wilhelm Wien's experiment on canal rays.
48. Explain the discharge tube phenomenon and give an account of the observations at various pressures.
49. Describe Goldstein's experiment on canal rays.
50. Compare the properties of alpha, beta and gamma radiations.

*For Answer Keys, Hints and Explanations, please visit: www.pearsoned.co.in/IITFoundationSeries

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7

State whether the following statements are true or false.

- X-rays are electromagnetic radiations of wavelength greater than that of visible light.
- $\frac{e}{m}$ of cathode rays differ at different temperatures.
- α , β and γ radiations have the same velocity as light.
- All gases at normal temperature and pressure are good conductors of electricity.
- Alpha rays are highly-energized electrons.
- Cathode rays in a discharge tube are made up of electrons emitted from the plate that is connected to the negative terminal of the DC voltage source.
- Canal rays are positively charged.

Direction for questions 8 to 14

Fill in the blanks.

- Alpha particles are _____ charged.
- X-rays travel at a speed of _____ m s^{-1} .
- β rays are emitted from the _____.
- _____ rays are highly energized electrons.

- The accelerated positive ions in a discharge tube collide with _____ to eject electrons.
- _____ photographs are used to detect fracture of bones.
- The discharge tube is filled with uniform _____ column glow at low enough pressure of the gas in the tube.

Direction for question 15

Match the entries given in Column A with appropriate ones in Column B.

15.

Column A	Column B
A. Canal rays	() a. blue light
B. Cathode rays	() b. helium nuclei
C. α -rays	() c. electrically neutral
D. X-rays photography	() d. discovery of radium
E. γ -rays	() e. J.J. Thomson
F. Hydrogen in discharge tube	() f. $1.76 \times 10^{11} \text{ C kg}^{-1}$
G. Study of cathode rays	() g. emitted from anode rays
H. Discovery of X-rays	() h. discovery of radioactivity
I. Marie curie	() i. William Roentgen
J. Henri Bequerel	() j. Medical diagnosis



Direction for questions 16 to 30

For each of the questions, four choices have been provided. Select the correct alternative.

16. If one of the radioactive atoms emits radiation at time ' t ' minutes, then the next nuclei emits radiation after _____.
 (a) $2t$ minutes (b) $2t$ seconds
 (c) $2t$ hours (d) any time
17. The rays that are unaffected by a magnetic field are _____.
 (a) canal rays (b) γ -rays
 (c) cathode rays (d) alpha-rays
18. The rate of emission of radiation, when a radioactive sample is placed in water, _____.
 (a) increases
 (b) decreases
 (c) remains the same
 (d) Cannot be determined
19. X-rays are produced by impinging _____ on a target.
 (a) α particles (b) protons
 (c) electrons (d) neutrons
20. X-rays are produced in _____.
 (a) high vacuum tubes
 (b) in tubes having inert gases at low pressure
 (c) in tubes having inert gases at high pressure
 (d) in tubes having only CO_2 at high pressure
21. The 'weak X-rays' emission from uranium salts, discovered by Becquerel, could _____.
 (a) ionize gases
 (b) affect photographic plates
 (c) penetrate through matter
 (d) All the above
22. The conditions for the discharge of electricity through gases in a discharge tube is _____.
 (a) high potential and high pressure
 (b) high potential and low pressure
 (c) low potential and high pressure
 (d) low potential and low pressure
23. A modified discharge tube is used as _____.
 (a) cathode ray oscilloscope
 (b) fluorescent tube
 (c) X-ray tube
 (d) All the above
24. In a Coolidge tube, an electric field is applied _____.
 (a) to increase the charge on the cathode rays.
 (b) to accelerate the cathode rays.
 (c) to produce fluorescence.
 (d) to decrease the charge on the cathode rays.
25. The fluorescence of the glass (discharge) tube at very low pressure is characteristic of _____.
 (a) the phosphors in the material of the glass
 (b) the gas used in the tube
 (c) the cathode
 (d) the emitted particles
26. The false statement about X-rays is _____.
 (a) X-rays are not particles
 (b) X-rays are uncharged
 (c) X-rays can penetrate through all bodies
 (d) X-rays cause fluorescence when they are incident on cadmium sulphide
27. X-rays are deflected by _____.
 (a) electric field
 (b) magnetic field
 (c) gravitational field
 (d) None of these
28. A light paddle wheel placed in the path of _____ will rotate.
 (a) cathode rays (b) α -rays
 (c) β -rays (d) All the above
29. The electric field applied in vertical direction to the cathode rays moving horizontally deflect them in _____.
 (a) horizontal direction
 (b) vertical direction
 (c) Both (a) and (b)
 (d) None of these
30. Becquerel rays can _____.
 (a) affect photographic plate
 (b) penetrate through matter
 (c) ionize gases
 (d) All the above



Level 2

31. If an α -ray and a β -ray have same kinetic energy, which of them has greater velocity and why?
32. In Millikan's oil drop experiment, the charge on an oil drop was found, due to an experimental error, to be $8.88 \times 10^{-18} \text{C}$. Why can't such a quantity of charge be present on the oil drop? Explain. (Charge on an electron is $1.6 \times 10^{-19} \text{C}$)
33. The total electric charge on a certain number of electrons is found to be 96368 C. What is the mass of these electrons?
34. Can — of singly-ionized atoms of the same element can have different values? Explain.
35. If the entire mass of the body (45.5 kg) is assumed to be made up of electrons, how many electrons are present in mass of an electron is $9.1 \times 10^{-31} \text{ kg}$?
36. X-rays are produced by cathode rays which are a beam of electrons. Explain what happens to the electrons on hitting the target.
37. When a charged particle of charge $x \text{ C}$ moves through a potential difference of $y \text{ V}$, the gain in kinetic energy is equal to $xy \text{ J}$.
- An electron and an alpha particle have their masses in the ratio of 1:7200 and charges in the ratio of 1:2. If they start moving from rest through the same electrical potential difference, find the ratio of their velocities.
38. To produce X-rays in a Coolidge tube, why is it necessary to accelerate cathode rays?
39. The mass of a proton is 1836 times that of an electron. If they fall through the same potential difference, find the ratio of their velocities.
40. Can X-rays be produced in a discharge tube? Explain why Coolidge tube is preferred to a discharge tube to produce X-rays.
41. The velocity of electrons in cathode rays is $0.1c$, where c is the velocity of light. However, when they are accelerated through a potential difference of 20,000 V, their velocity is found to be $8.4 \times 10^7 \text{ m s}^{-1}$. What is the percentage increase in the kinetic energy of electrons? (Take $c = 3 \times 10^8 \text{ m s}^{-1}$)
42. The nuclei of atoms of all elements are made up of protons and neutrons. Then why do only a few of them show radioactivity?
43. What happens if cathode rays are stopped by a metal?
44. A radioactive element ${}_Z X^A$ whose atomic mass is A and atomic number is Z emits an α -particle and γ -rays. What is the atomic number and atomic mass of the newly formed (daughter) atom?
45. Explain how the discharge phenomenon is applied in fluorescent lamps and neon lamps.

Level 3

46. An α particle and a proton fall through the same potential difference. Find the ratio of their momenta if the mass of the α particle is four times that of the proton.
47. In a discharge tube, why do different gases emit different colours of light?
48. If an electron falls through a potential difference of 1V from its initial position of rest, then find its acceleration at a distance of 5 cm from its initial position if it moves in a straight line.
- $\left(\frac{e}{m} \text{ of electron is } 1.76 \times 10^{11} \text{ C kg}^{-1} \right)$
49. Does the law of conservation of energy hold good in the production of X-rays? Is the kinetic energy conserved? Discuss.
50. How can one explain the existence of more than one proton inside the same nucleus in spite of the electrostatic repulsive forces between them?



CONCEPT APPLICATION

Level 1

True or false

1. False 2. False 3. False 4. False 5. False 6. True 7. True

Fill in the blanks

8. positively 9. $3 \times 10^8 \text{ m s}^{-1}$ 10. nucleus of an atom
 11. Cathode rays and beta 12. cathode 13. X-ray 14. luminous or positive

Match the following

15. A : g B : f C : b D : j E : c F : a G : e H : i I : d J : h

Multiple choice questions

16. (d) 17. (b) 18. (c) 19. (c) 20. (b) 21. (d) 22. (b) 23. (d) 24. (b) 25. (a)
 26. (c) 27. (d) 28. (d) 29. (b) 30. (d)

Level 2

32. Is it possible for a body to have charge less than $1.6 \times 10^{-19} \text{ C}$ as it is the charge of a fundamental particle? Is $8.88 \times 10^{-18} \text{ C}$ an integral multiple of $1.602 \times 10^{-19} \text{ C}$?

33. (i) Determine the number of electrons using the value of charge on each electron as 1.6×10^{-19}
 Total mass = number of electrons \times mass of each electron.

(ii) -0.55 mg

34. Recall the definition of isotopes.

Is there any difference between the masses of ${}^1_1\text{H}^+$ and ${}^2_1\text{H}^+$?

35. (i) If there are n number of electrons in it and mass of each electron is x , the total mass of the substance is nx .

(ii) 5×10^{31}

36. What are X-rays?

Recall the law of conservation of energy.

Will there be any increase in temperature of the target when an electron hits it?

37. (i) Given

$$\frac{m_1}{m_2} = \frac{1}{7200}$$

$$\frac{x_1}{x_2} = \frac{1}{2} \text{ and } \gamma_1 = \gamma_2$$

Total energy gained (xy) = change in kinetic energy

$$\left(\frac{1}{2} m(v^2 - u^2) \right)$$

$$u_1 = u_2 = 0$$

$$\therefore \frac{v_1^2}{v^2} = \frac{m_2 x_1 \gamma_1}{m_1 x_2 \gamma_2}$$

(ii) $60 : 1$

38. X-rays are electromagnetic radiations that consists of energy. What is the source of this energy? What happens to the kinetic energy of electrons if they are accelerated?

39. (i) What are the factors affecting the work done on a charged body in an electric potential?

How is the kinetic energy related to the mass and velocity?

$$\left(\frac{1}{2} m_p v_p^2 = \frac{1}{2} m_e v_e^2; m_p = 1836 m_e \right)$$

(ii) $\frac{V_p}{V_e} = \frac{1}{\sqrt{1836}}$

40. Compare the arrangement of Coolidge tube to produce X-rays with the discharge tube.



41. 684%
42. Compare the nucleus of the radioactive elements with other elements.
Recall the different factors which effect the stability of a nucleus.
43. Moving cathode ray particles have energy and when they are stopped energy is conserved. Into what forms can this KE be transformed?
44. An α -particle consists of two protons and two neutrons but γ rays are electromagnetic rays. They are emitted by the nucleus of an element.
45. Consider the conditions for the gas in the discharge tube to glow and the fluorescence of the glass tube.
46. (i) Compare the velocity of an α particle with that of a proton in the same potential difference. To compare the velocities equate the kinetic energy.
We know that momentum $p = mv$.
Compare mass and velocity of α particle with that of proton to find the relation between their momenta.
(ii) $\sqrt{8} : 1$
47. What is light? How light is emitted in a discharge tube?
How is the frequency of light related to the energy of the photons?
How is the frequency of light related to the colour?
48. (i) Recall the definition of electric work done on a charged body in a potential difference. Relate the electric work done with the definition of work. That is, $w = Fs = mas = Vq$.
(ii) $3.52 \times 10^{12} \text{ m s}^{-2}$
49. Recall the nature of X-rays.
All electromagnetic radiations consist of energy.
What are the other forms of energy produced along with X-rays in a discharge tube?
50. A strong nuclear force which is the cause of nuclear formation is stronger than the electrostatic repulsive force between two protons. So, the existance of more than one proton inside the nuclears is possible.



Notes

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