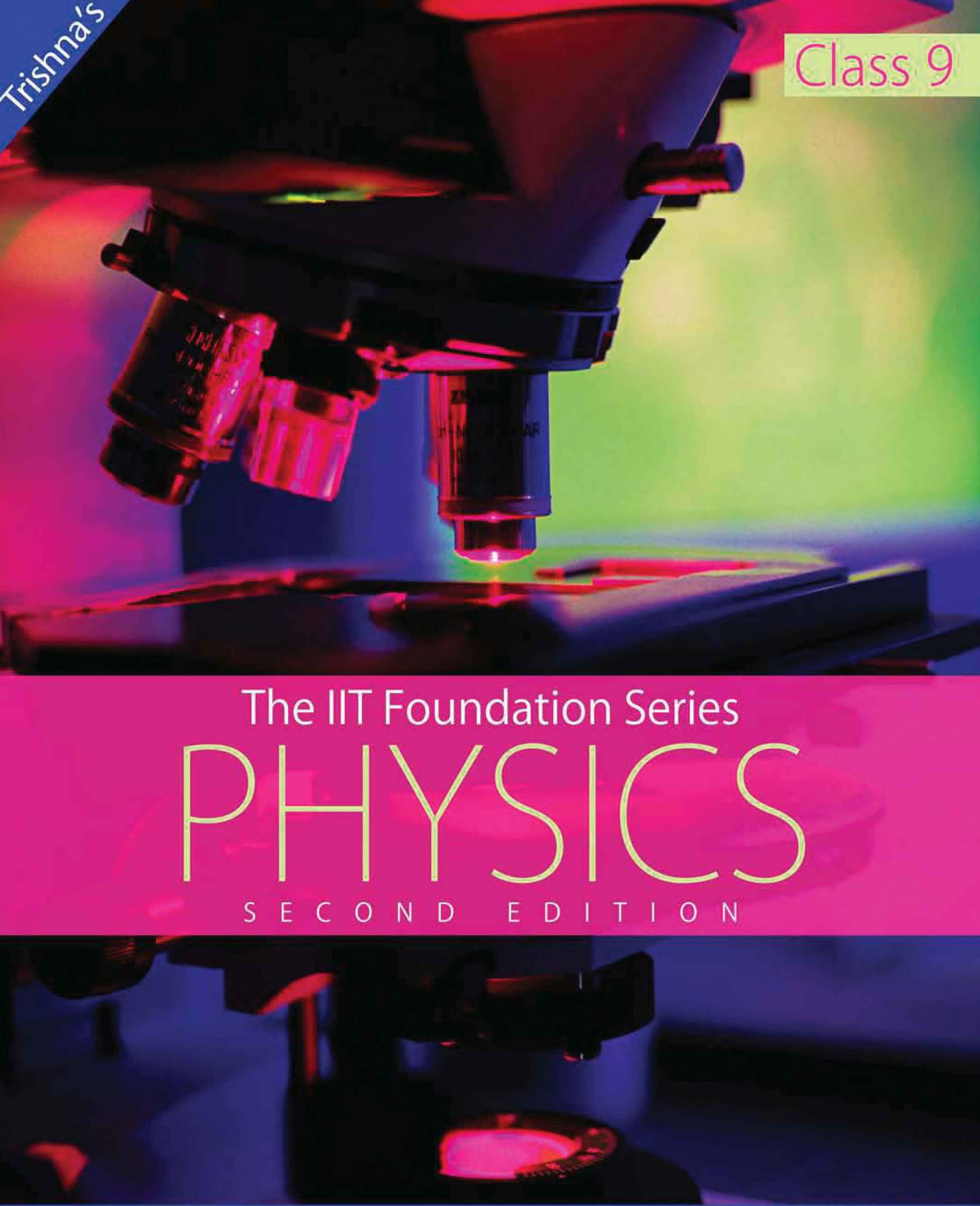
Trishna's

Class 9



The IIT Foundation Series
PHYSICS

SECOND EDITION

ALWAYS LEARNING

PEARSON

PHYSICS

CLASS **9**

The IIT Foundation Series

(Second Edition)

Trishna Knowledge Systems
A division of
Triumphant Institute of Management Education Pvt. Ltd.

PEARSON
Chandigarh • Delhi • Chennai

he aim of this publication is to supply information taken from sources believed to be valid and reliable. his is not an attempt to render any type of professional advice or analysis, nor is it to be treated as such. hile much care has been taken to ensure the veracity and currency of the information presented within, ither the publisher nor its authors bear any responsibility for any damage arising from inadvertent nissions, negligence or inaccuracies (typographical or factual) that may have found their way into this ok.

BN 9788131761878
SBN 9789332511033

ead Office: A-8(A), Sector 62, Knowledge Boulevard, 7th Floor, NOIDA 201 309, India
egistered Office: 11 Local Shopping Centre, Panchsheel Park, New Delhi 110 017, India

Detailed Contents

Class 9

Preface to the Second Edition

It is with enthusiasm that we present the second edition of the IIT Foundation series of books. The success of our first edition indicates that there exists a large group of students who wish to delve into Mathematics, Physics and Chemistry, beyond the restrictions of their school syllabus. We take this opportunity to thank all those who have contributed to the success and to reaffirm our commitment to inculcating scientific temper among the student community.

Over the last two years we have received feedback from many students and teachers who have used our books, and it has given us great satisfaction to know that they have benefitted immensely. The teachers have taught from these books and have appreciated the approach adopted in the presentation of concepts. Their feedback has encouraged us to extend the IIT-Foundation series of books to include books for students of Class 7 as well. In most school curricula, the fundamentals of Mathematics and Science that students study in Classes 8 to 10 are introduced in Class 7. While a proper understanding of these fundamentals is essential for good performance in higher classes, it is not possible for Class 7 students to develop indepth understanding of concepts unless these are presented lucidly.

With this edition, therefore, we present books for Class 7. We are confident that these will help students develop conceptual clarity at their early age, and that the student community will take full advantage of this new inclusion.

As with all our publications, the objective of this series is to provide students with a comprehensive understanding of fundamental concepts, to teach them the application of these concepts, and to help hone their problem-solving skills. We trust all our young students will find these books relevant and enlightening.

Preface

As the old adage goes, "nothing succeeds like success." The truth in this maxim cannot be overstated in today's competitive world. The present-day student is under immense pressure to thrive and emerge triumphantly in examinations. Students aspire to get into pre-eminent educational institutes to pursue the best courses–be it in engineering, medicine, arts or sciences–to enable them to prepare for careers at the global level. Their performance in entrance examinations are often the cornerstones that determine if they would be admitted into these hallowed halls of learning. With most of these exams being designed to challenge the innate talent and ingenuity of students, it is only natural that they find these tests most demanding and that they find themselves competing with the country's best minds for those few coveted seats. Only those students with a thorough understanding of the fundamental concepts and exceptional problem-solving skills pass out with flying colours in these tests.

The "IIT Foundation Series" books are designed to provide students with a comprehensive understanding of the fundamental concepts, to teach them the application of these concepts and to hone their problem-solving skills.

The objective of the IIT Foundation Series books is to ensure that students are able to delve beyond the restrictions of their regular school syllabus and get a fundamental understanding of Mathematics, Physics and Chemistry. The books are designed to kindle student interest in these subjects and to encourage them to ask questions that lead to a firm grip on the principles governing each concept.

Irrespective of the field of study that the student may choose to take up later, it is imperative that he or she develops a sound understanding of Mathematics and Science, since it forms the basis for most modern-day activities. Lack of a firm background in these subjects may not only limit the capacity of the student to solve complex problems but also lessen his or her chances to make it into top-notch institutes that provide quality education.

This book is intended to serve as the backbone of the student's preparation for a range of competitive exams, going beyond the realms of the usual school curriculum to provide that extra edge so essential in tackling a typical question paper.

A distinctive feature of this book is that it has been written by a team of well-qualified teachers experienced in imparting the fundamentals of Mathematics and Science, and their applications to active learners at T.I.M.E. (Triumphant Institute of Management Education Pvt. Ltd). They have also been instrumental in developing high-quality study material for IIT Foundation courses for Classes 7 to 10. We are sure that you will find this book, prepared by such stalwarts, to be very useful in your preparation for entrance examinations.

About the IIT Foundation Series

This book is a perfect companion not only for the students of 8th Grade, but also for higher grades. It will help them achieve the much-needed conceptual clarity in the topics which form the basis for their higher study.

Some of the important features of the book are listed below:

- Builds skills that will help students succeed in school and various competitive examinations.
- The methodology is aimed at helping students thoroughly understand the concepts in Mathematics, Physics and Chemistry.
- Helps develop a logical approach to Mathematics, Physics and Chemistry, thereby enabling more effective learning.
- Lays stress on questions asked by board/school examinations as well as application of concepts.
- The concepts are explained in a well structured and lucid manner, using simple language. This aids learning.
- A large number of examples have been included to help reinforce the concepts involved.
- Different levels of practice exercises have been provided which help students develop the necessary application and problem-solving skills.
- The exercises have been designed keeping in mind the various board/school examinations and competitive examinations, such as the NTSE, NLSTSE, Science Olympiad and Cyber Olympiad.
- The book will not only help the students in better understanding of what is taught in regular school classes (and hence enable them to do well in board examinations) but will also help in developing the acumen, resulting in a distinctive edge ovr their peers.
- Given below are a few examples that demonstrate how the course will help students in understanding the fundamentals:

How does a kingfisher catch fish?

The kingfisher flies vertically over the position of the fish, then plunges into the water at a 90° angle. The concept here is that the normally incident rays do not undergo refraction, hence the fish lies exactly where it appears to be. At any other angle, the apparent location of the fish would be different from its real location.

Why do we normally swing our arms while walking, and why not when we carry a load in our hands?

The center of gravity of a body depends on the distribution of mass in the body. As we walk, the movement of the legs tends to cause a shift in the centre of gravity. To compensate for this shift we swing our arms. When we are carrying a load in the hands, however, the effective C.G is lower, making it easier to maintain balance.

Why does salt become damp when kept exposed during the rainy season and not when kept exposed during summer?

In the rainy season humidity in the atmosphere is very high, i.e., there is a lot of moisture in the atmosphere. Thus, calcium chloride, which is the impurity present in common salt, absorbs this moisture and makes the salt damp. In summer, however, as the temperature is high, calcium chloride tends to loose moisture through the process of evaporation, and the salt is left free-flowing.

Structure of the IIT Foundation Series

The IIT Foundation Series is available in Mathematics, Physics and Chemistry. Each chapter in the book is divided into three parts, namely, theory, test your concepts and concept application.

➤ **Theory:**

The theory part deals with the various concepts in Physics/Chemistry/Mathematics, which is a part of the syllabus prescribed by major boards for Class X. The concepts are explained in a lucid manner, and diagrams have been provided, wherever necessary, to illustrate these concepts.

➤ **Test your Concepts:**

This exercise is provided at the end of the theory section of each chapter. These exercises are a collection of very short answer, short answer and essay type of descriptive questions. It is intended to provide students with model questions that they may face in the board examination.

Students are expected to prepare for these questions before they attempt any examination based on that particular chapter. Towards the end of the book, the students will find key points for selected questions of the exercise. These key points provide students with an idea of the points that should be a part of an answer for such a question.

➤ **Concept Application:**

This is a collection of exercises in four different classes: Class 7, Class 8, Class 9 and Class 10.

Class 8 consists of basic objective questions. These questions test the basic knowledge of students and enable them to gauge their understanding of concepts when they start solving this exercise. The key for this exercise is provided at the end of the respective chapter.

Classes 9 and 10 consist of descriptive questions of a higher level of difficulty. These questions help students to *apply the concepts* that they have learnt. Key points for selected questions of these exercises have been provided at the end of each chapter in order to help students solve these questions.

These books are available for 7th, 8th, 9th and 10th classes separately for Mathematics, Physics and Chemistry.

Series Content List

Class 7

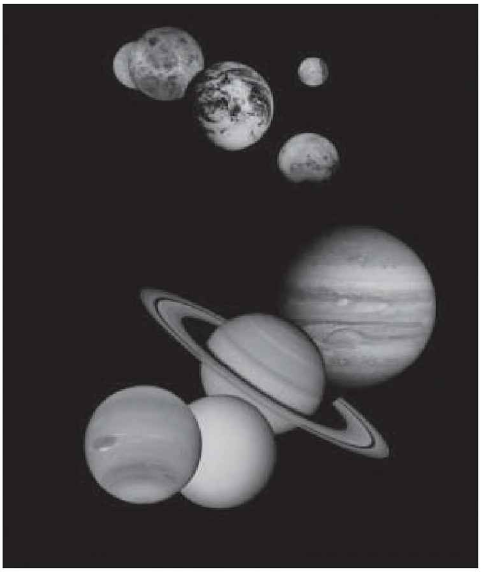
Class 8

Class 9

Class 10

1

Measurements



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 measurements of various quantities has become an inevitable part. To understand its importance let us take a few examples. Motion of a body can be changed by applying force but 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. e.g., when we say force is 12 newton, force is the physical quantity, 12 is the magnitude and newton is the unit of force.

Scalar quantities

The physical quantities which can be described completely by their magnitude only are called scalar quantities.

☛ *Example* Distance, mass, time, speed, density etc.

These quantities can be added according to ordinary algebraic rules.

Vector quantities

The physical quantities which can be described completely only by both their magnitude and direction are called vectors.

☛ *Example* Force, velocity, acceleration etc.

Addition of these quantities can be done by special methods of addition.

Fundamental, Derived quantities and their units

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 the derived quantities.

Area, volume, density, force, velocity etc. are some examples of derived quantities.

Rules to be followed in 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.

[redacted]	
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

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

(i) F.P.S. system: In this system, the units of mass, length and time are pound, foot and second respectively.

(ii) C.G.S. system: In this system, the units of mass, length and time are gram, centimetre and second respectively.

(iii) M.K.S. system: In this system, the units of mass, length and time are kilogram, metre and second respectively.

(iv) 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.

[redacted]

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

[redacted]

Force	newton	N
Work	joule	J
Frequency	hertz	Hz
Charge	coulomb	C

Definitions of units

(i) **Metre:** One metre is 1,650,763.73 times the wavelength of orange light emitted by a krypton atom at normal pressure.

(ii) **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.

(iii) **Second:** One second is the time taken by a cesium atom (Cs^{133}) to complete 9,192,631,770 vibrations.

(iv) **Ampere:** The 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 between these conductors a force equal to 2×10^{-7} newton per metre of length.

(v) **Kelvin:** Kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

(vi) **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.

(vii) **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

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.

☛ *Examples*

1. What is the dimensional formula of force?

Solution

Force = mass × acceleration

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

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

2. Write the dimensional formula of speed.

Solution

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.

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

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

Metre scale

It is graduated in cm and mm, i.e., 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 figure below:

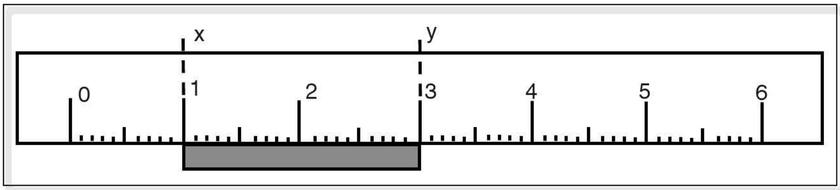


Figure 1.1

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

Length of object = y – x = 30 mm – 10 mm = 20 mm

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 figure below:

The length of 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.

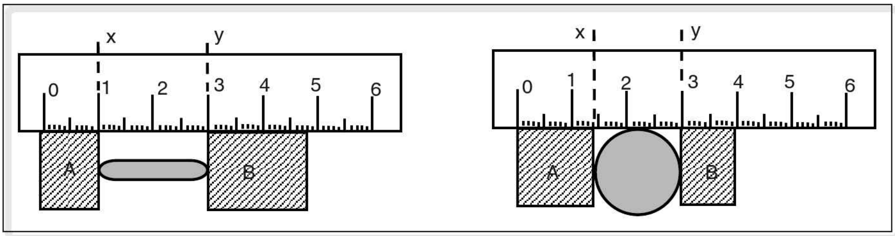


Figure 1.2

Length of rod, ℓ = y – x = 3 – 1 = 2 cm

Diameter of sphere, d = y – x = 3 – 1.4 = 1.6 cm

In the figure given below the edge B of object is not exactly coinciding with any division of scale.

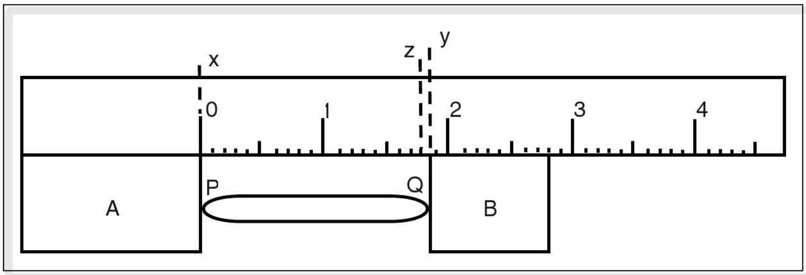


Figure 1.3

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.

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 the 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.

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 measures 9 mm.

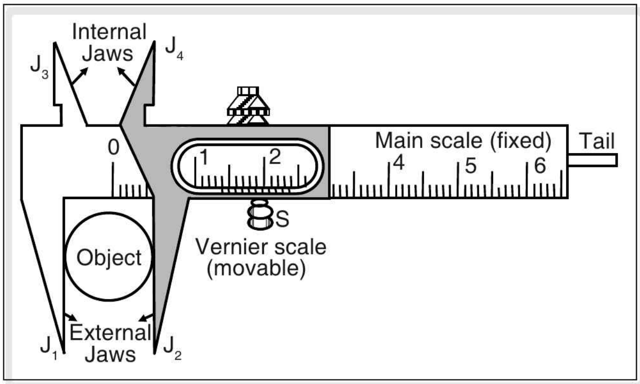


Figure 1.4

Procedure for taking a measurement using vernier callipers

1. Determine the least count of the Vernier Callipers:

   Least count (L.C.) = 1 M.S.D. – 1 V.S.D. = 1 mm – 0.9 mm = 0.1 mm = 0.01 cm

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

2. To measure the external dimensions of an object it should be held tightly between the external jaws J_1 and J_2 and to measure the inner dimensions it should be held with internal jaws J_3 and J_4.
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.C.D.) which coincides with any main scale division.
5.

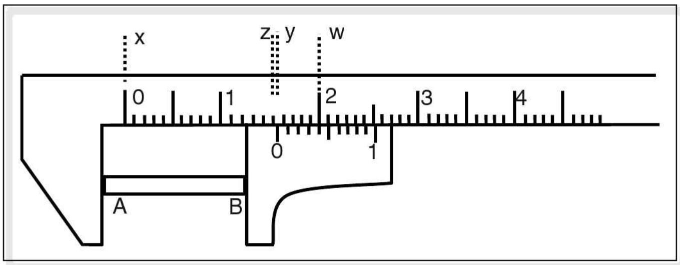


Figure 1.5

The length of rod AB = y = (z) + (y – z) = (z) + (w – z) – (w – y)

= M.S.R. + V.C.D. × M.S.D. – V.C.D. × V.S.D. = M.S.R. + V.C.D. (M.S.D. – V.S.D.)

∴ Total reading = M.S.R. + (V.C.D. × L.C.)

Example

While measuring the diameter of a sphere with a vernier callipers if M.S.R. and V.C.D. are 35 mm and 5 respectively and if the vernier scale consists 20 divisions then what is the diameter of sphere?

Solution

M.S.R. = 35 mm

V.C.D. = 5

Diameter of the sphere = M.S.R. + V.C.D. × L.C.

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

L.C. = 1 M.S.D./no. of divisions on V.S. = 1 mm/20 = 0.05 mm

Total reading = M.S.R. + n × L.C. = 35 mm + 5 × 0.05 mm = 35.25 mm

Zero error

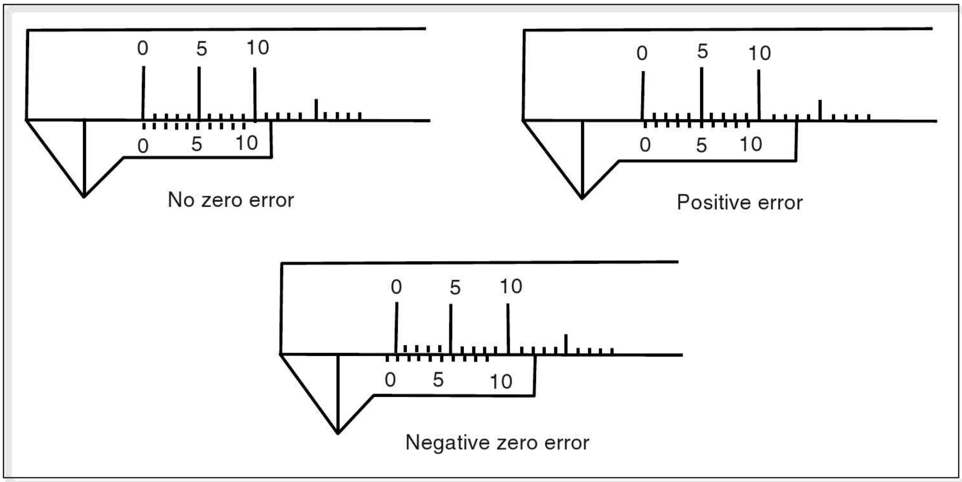
When the fixed and the movable jaws of a vernier callipers are made to come in contact, if the zeroes of both the main scale and the vernier scale are not coinciding with each other the instrument is said to have a **zero error**.

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 nth division of the vernier scale coincides with some division on the main scale, then the **zero error is (+ n × Least count)** and the **correction is (–n × Least Count)** cm.

Negative zero error

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 nth division of the vernier scale coincides with some division on the main scale, then the **zero error = – (N – n) × Least Count** and the **correction = + (N – n) × Least Count** cm, where N is the number of divisions on the



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

☛ *Example*

When the jaws of a vernier callipers are closed, the zero 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. × L.C.

= 6 × 0.1 mm = 0.6 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 the pitch of the screw.

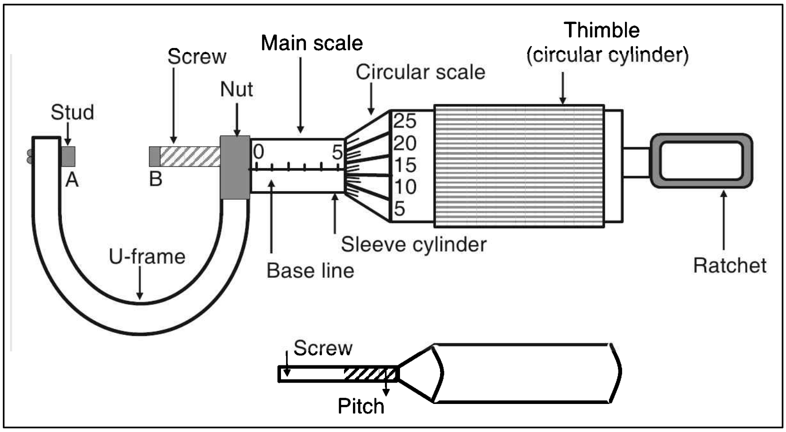


Figure 1.7

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**

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.

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

Least count of a screw gauge

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

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

Observed measurement = Main scale reading + Circular Scale Reading × 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. × 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 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 the

Zero error = + n × least count and Correction = – n × 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 the

Zero error = – (N – n) × least count and the Correction = + (N – n) × least count

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

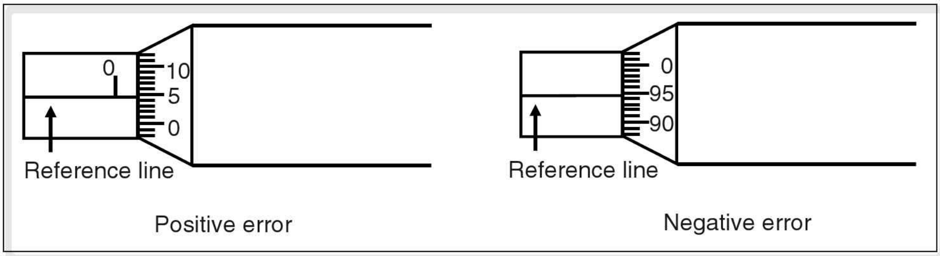


Figure 1.8

True measurement = Observed measurement + Correction for zero error

Observed measurement = (M.S.R.) + (C.S.R. × 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.

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

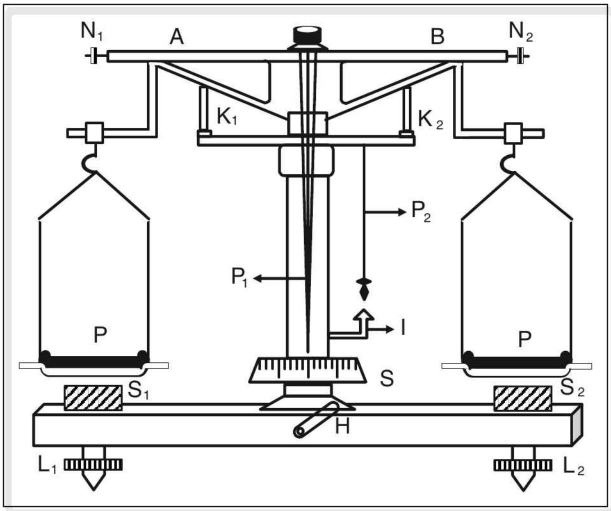


Figure 1.9 Physical Balance

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 is attached perpendicular to the beam at the centre. The free end (pointed tip) of the pointer moves over a scale 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 a 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 instrument may be set to plumb (the central pillar being vertical)

Precautions to be observed before using the balance

(i) Raising and lowering of the beam must be done gently by turning the handle without any jerks.
(ii) Arrest the beam when not in use.
(iii) Handle the weights using the forceps only and do not touch with hands.
(iv) Keep the doors of the balance box closed during weighing.
(v) 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.
(vi) Very hot or very cold substances should be avoided as they would affect the weighing due to the air currents that they would cause.

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.

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 ± P g

    If HRP is obtained; $P = \left(\frac{HRP - ZRP}{HRP - LRP}\right) \times 0.01$ g

    If LRP is obtained; $P = \left(\frac{LRP - ZRP}{LRP - HRP}\right) \times 0.01$ g

    NOTE: If RP = ZRP then mass at RP = correct mass.

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.

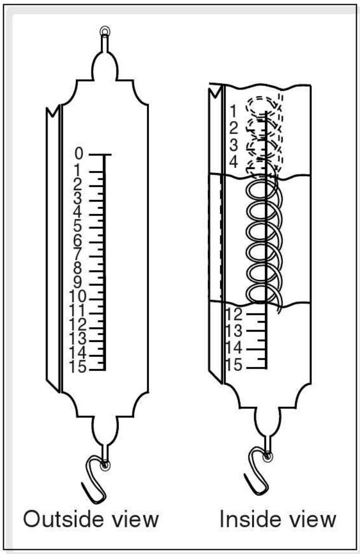


Figure 1.10

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.

Mean solar day

The average of all the solar days that occur during one full revolution of the earth around the sun.

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.

Simple pendulum

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

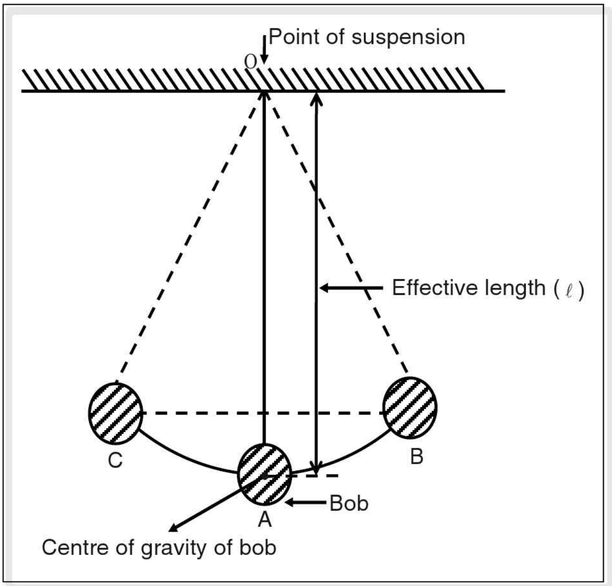


Figure 1.11 A simple pendulum

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 the end of rod.

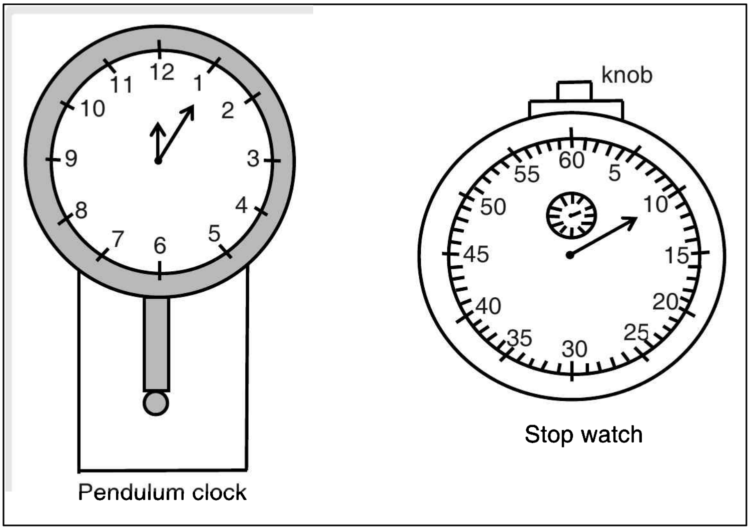


Figure 1.12

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 divided further to measure $\frac{1}{2}$ second or $\frac{1}{5}$th of a second also. Every stop watch is provided with a dual purpose knob, which is used to start and stop the watch.

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.

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

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

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

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

Volume of regular shaped bodies can be calculated from corresponding formulae after measuring the required dimensions.

Example

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

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

Volume of liquids

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

(i) **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 liquid.

(ii) **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 surface.

(iii) **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.

(iv) **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

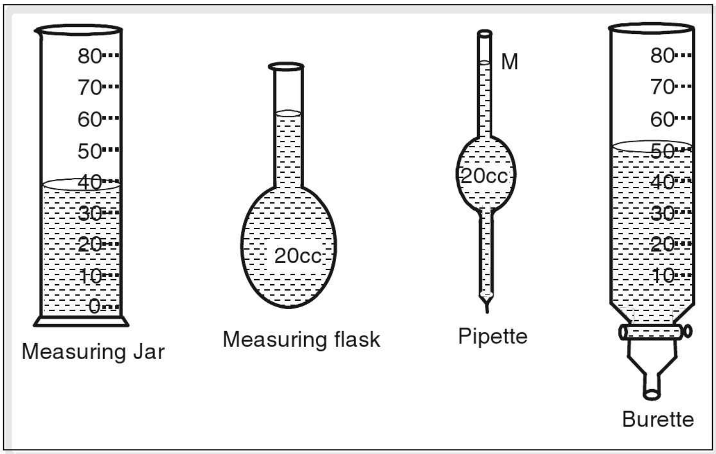


Figure 1.13

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.

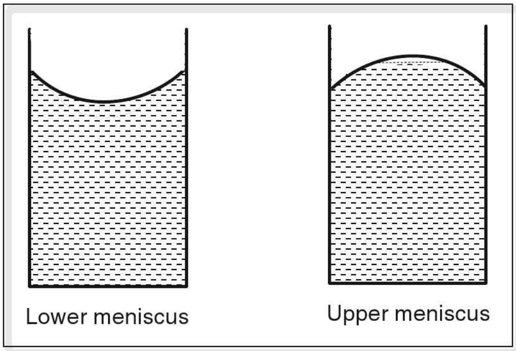


Figure 1.14

To determine the volume of irregular solids

1. Solids heavier than water and insoluble in water.

Take some water in a measuring jar and note the level of water, V_1 cm^3.

Immerse the solid whose volume is to be determined, suspended from a string and note the new level of water, V_2 cm^3.

Volume of the solid = $(V_2 - V_1)$ cm^3

2. 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 cm^3.

Tie the light solid, whose volume is to be determined, to the sinker and lower the combination into the water and note the new level of water, V_2 cm^3.

Volume of the solid = $(V_2 - V_1)$ cm^3.

3. To determine the average volume of lead shots.

Take some water in a measuring jar and note the level of water V_1 cm^3.

Drop n lead shots gently into the water and note the new level of water V_2 cm^3.

Average volume of a lead shot = $\frac{V_2 - V_1}{n}$ cm^3

4. To 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 cm^3 of the water that overflows into the measuring jar.

The volume of the solid = volume of the water displaced = V cm^3.

5. To determine the volume of a single drop of water.

Fill a clean burette clamped upright to a stand with water.

Remove any air bubbles by opening the tap for some time.

Note the level, V_1, of water in the burette.

Allow the water to trickle slowly, drop by drop, counting the number of drops (n) at the same time.

Close the tap after 20 cm^3 of water has been drained.

The average volume of a drop of water = 20/n 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 metre^3 (kg m^{-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.

Determination of the density of solids

The mass of the body is determined using a physical balance and the volume of the body is determined by displacement method.

The density of the solid is calculated using the expression

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

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 = $(m_2 - m_1)$ 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 g cm^{-3} (1.29 kg m^{-3})

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 is the origin and it always assigns with co-ordinates O (0, 0).

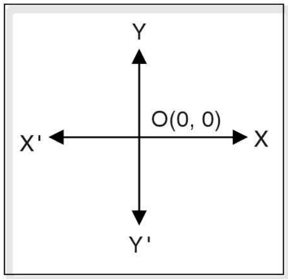


Figure 1.15

Two axes are labelled with two quantities. Generally X-axis assigned with independent quantity and Y-axis with 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 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.

t(s)	s(m)
0	0
1	5
2	10
3	15
4	20
5	25

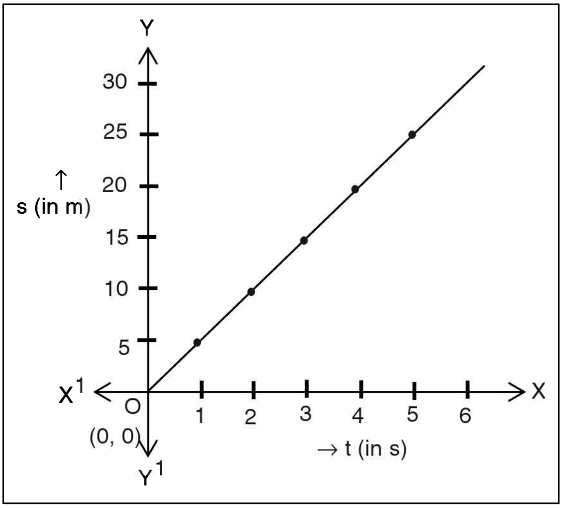


Figure 1.16

First we have to mark each data on the graph with a sharp marker. Then maximum number of marks 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 $A(x_1, y_1), B(x_2, y_2)$.

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

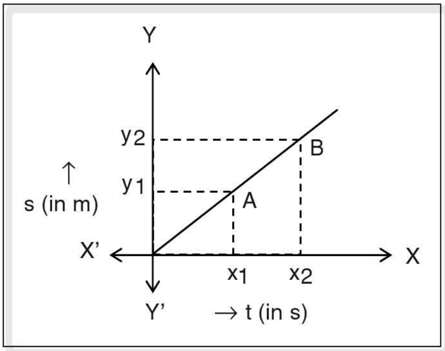


Figure 1.17

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

Example

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 two quantities.

Example

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

Scientific notation

Bigger objects like the earth, the sun and the universe constitute the macrocosm, whereas smaller objects like the atom, cell 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

10^{24}	yotto	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
10^{1}	deca-	da	10^{-24}	yocto	y

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 = True value ~ measured value.
2. relative error = $\frac{\text{Absolute error}}{\text{Actual value}}$. If the relative error is expressed in percentage it is called percentage error.

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

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, the 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 also known as the doubtful digit, is called the least significant digit.

The digit on the extreme left is called the most significant digit.

Rules for determining significant figures

All non-zero digits are significant figures. e.g., 1234 m has 4 significant figures.

All zeroes occurring between non-zero digits are significant figures. e.g., 10234 kg has 5 significant figures.

All zeroes to the right of the last non-zero digit are not significant. e.g., 1230 has only 3 significant figures.

All zeroes to the right of the decimal point and to the left of a non-zero digit are not significant. e.g., 0.00123 m has only 3 significant figures.

All zeroes to the right of a decimal point and to the right of a non-zero digit are significant. e.g., 0.2300 has 4 significant figures.

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. e.g., 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. e.g., 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.<u>3</u>5 =12.4 and it is left unchanged if the digit is even, e.g., 12.<u>8</u>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 ⇒ 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*

$\frac{2014 \times 31.5}{11.9} = 5331.1764... = 5330$, since 11.9 and 31.5 have only three significant digits each.

test your concepts ●●●

Very short answer type questions

1. Define relative density.
2. The value of G = 6.67×10^{-11} N m^2 kg^{-2} and g = 9.8 m s^{-2}.The unit of g/G in C.G.S system is ______.
3. The number of significant figures in 10.02 is __________.

4. What is the principle used in a physical balance?

5. What are the C.G.S. and S.I. units of area? Give the relationship between them.

6. The smallest measurement that can be made accurately by an instrument is called ___________.

7. A rectangular metal sheet of area 2 m^2 is rolled to form a cylinder of volume $\frac{4}{\pi}$ m^3. Then the radius of the cylinder thus formed is __________ m.

8. What is the least count of a standard screw gauge?

9. Define significant figures.

10. In a standard vernier callipers, 'N' vernier scale divisions are equal to __________ main scale divisions.

11. Name the different parts of a screw gauge.

12. If the energy of an electron in an atom is given by $E = \frac{h}{\lambda}$, 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 ________.

13. The distance between the two consecutive threads of a screw is known as the ______ of the screw.

14. What is the principle of a screw gauge?

15. Define light year.

16. The time taken by a seconds pendulum to go from one extreme end to the other is _________.

17. Define the pitch of a screw.

18. Area and volume are not _____ quantities.

19. If the length of a vernier scale having 25 divisions correspond to 23 main scale divisions, then given that 1 M.S.D. = 1 mm, the least count of the vernier calipers is _________.

20. 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?

21. Define the least count of a vernier callipers.

22. If surface tension is defined as force per unit length, then the dimensional formula of surface tension is ___________.

23. Define density.

24. Define resting point and zero resting point.

25. The time periods of two simple pendulums of different lengths is the same on two different planets. If the lengths of the two pendulums are in ratio of 1 : 9, then the ratio of the accelerations due to gravity on the two planets is

26. What is the principle of vernier callipers?

27. The diameter of a wire as measured by a screw gauge of pitch 0.5 mm is 8.3 mm. The pitch scale reading is _________.

28. Define
(a) Solar day.
(b) Mean solar day.

29. 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})

30. What is meant by degree of accuracy?

Short answer type questions

31. State the rules used for significant figures while rounding off the digits.

32. What are the precautions that should be taken while using a physical balance?

33. Discuss the zero error of a vernier callipers and how it can be corrected.

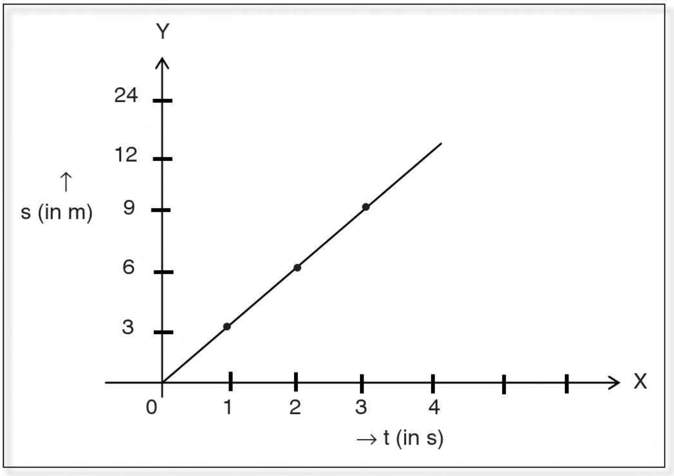
34. Describe a method to find the density of an object that is lighter than water.

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. Define least count. Describe the method to find the least count of a screw gauge.

37. 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.

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 how they are corrected?

41. The main 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 find 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 example?

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.

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. A simple pendulum can be used to determine acceleration due to gravity at a given place.

2. If the zeroth division on the vernier scale and the main scale do not concide, when the jaws are in contact then there exists an error.

3. If p is the pitch of a screw then the distance by which the screw advances when given n rotations is $\frac{p}{n}$.

4. 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 μm 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 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 m s^{-1} is ______.

11. When the jaws of a standard vernier calipers are closed, if the nth division of the vernier scale coincides with the nth 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^{+3} volume of gold is ______ kg.

Direction for question 15: Match the entries given in column A with appropriate ones from column B.

15.

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.	$[M^1L^{-3}T^o]$
J.	Least count of a screw gauge	( )	j.	$[M^1L^1T^{-1}]$

Direction for questions 16 to 30: For each of the questions, four choices have been provided. Select the correct alternative.

16. If the conductance of a conductor (G) is $\frac{I^2t}{W}$, where I is current, t is time and W is work done, then the unit of conductance expressed in terms of fundamental units is _______.

(1) $\frac{A^2s^3}{kg^2\ m}$ (2) $\frac{A^2s^3}{kg^2\ m}$ (3) $\frac{A^2s^3}{kg^2\ m}$ (4) $\frac{A^2s^3}{kg^2\ m}$

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 _______.

(1) 0.01 mm (2) 0.01 cm (3) 0.1 cm (4) 0.1 mm

18. The sensitivity of a physical balance is increased by the use of _________.

(1) knife edges (2) leveling screws (3) plumb line (4) light pans

19. The percentage errors in the measurement of g and l are α% and β% respectively, then the maximum error in measuring T will be _____.

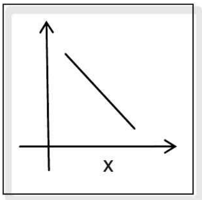
(1) $\frac{1}{2}(\alpha + \beta)\%$ (2) $\frac{1}{2}(\alpha - \beta)\%$ (3) $\frac{1}{2}(\beta - \alpha)\%$ (4) $2(\beta - \alpha)\%$

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 _________.

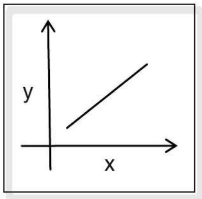
(1) +0.3 cm (2) +0.03 mm
(3) +0.12 mm (4) None of the above

21. Two variables x and y vary such that xy = constant. Then which of the following graphs represent the above relationship.

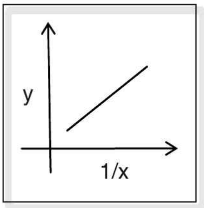
(1)



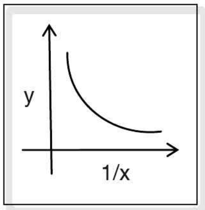
(2)



(3)



(4)



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.

(1) 47.875 (2) 47.845 (3) 47.866 (4) 47.854

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

(1) +17 (2) −17 (3) 83 (4) 34

24. Which of the following measurements is most precise?

(1) 5 cm (2) 5.00 cm (3) 5.000 cm (4) 5.00000 cm

25. The length and breadth of a rectangle were measured using an instrument and the area was determined as 28.83 cm^2. The instrument used could be ____.

(1) a vernier caliper whose least count is 0.1 mm
(2) a metre scale
(3) a vernier caliper whose least count is 0.3 mm
(4) 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 ______.

(1) 9 : 4 (2) 3 : 2 (3) 2 : 3 (4) 4 : 9

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

(1) the number of C.S.D. is 100, and the zero of the circular scale is 5 divisions above the index line.
(2) the number of C.S.D. is 100, and the zero of the circular scale is 5 divisions below the index line.
(3) the number of C.S.D. is 50, and the zero of the circular scale is 5 divisions above the index line.
(4) 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.
(1) Only (a) is true (2) Only (b) is true
(3) Both (a) and (b) are true (4) Both (a) and (b) are false

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

(1) π m s^{-2} (2) 100 π m s^{-2} (3) $\frac{1}{\pi^2}$ m s^{-2} (4) $\frac{1\text{M.S.D}}{\text{N}}$m s^{-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

(1) –8x (2) (N – 8)x (3) – (N – 8)x (4) +8x

Concept Application Level—2

31. 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.

32. 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?

33. A specific gravity bottle weights 10 g when it is empty. But weighs 100 g and 110 g when filled with an oil and water respectively. What is the relative density of oil?

34. 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.

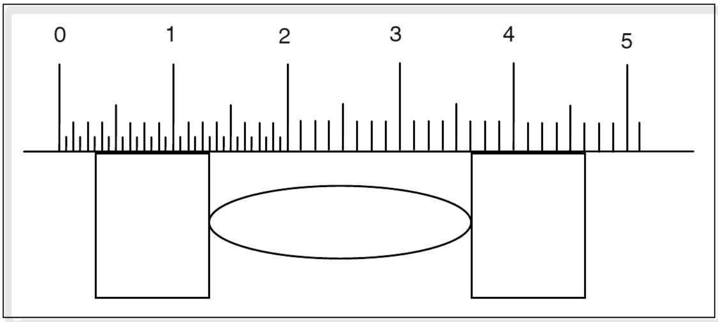
35. The fundamental frequency of a stationary wave formed in a stretched wire is $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$ where 'ℓ' is length of the vibrating wire, 'T' is the tension in the wire and 'm' is its mass per unit length. If the percentage error in measurement of ℓ, T and m are a%, b% and c% respectively, then find the maximum error in measuring 'n'.

36. 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

37. 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.

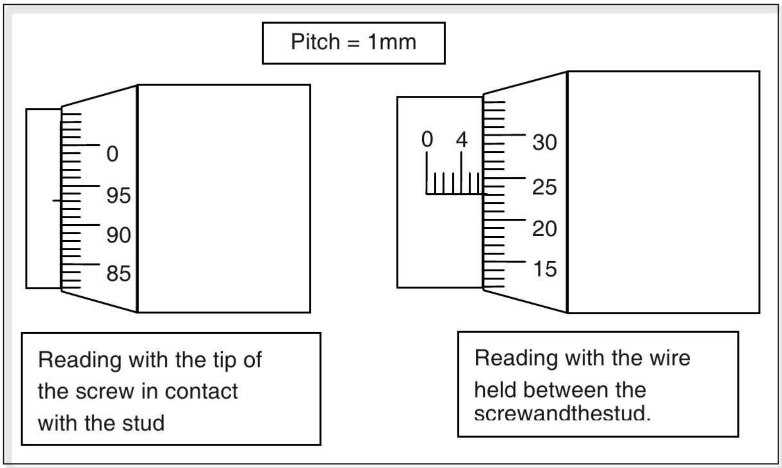
38. A simple pendulum designed on the moon as a seconds pendulum is taken to a planet where the acceleration due to gravity on the surface is twice that on the earth. If g_{earth} : g_{moon} = 6 : 1. Find the period of oscillation of the pendulum on the planet mentioned above.

39. 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.



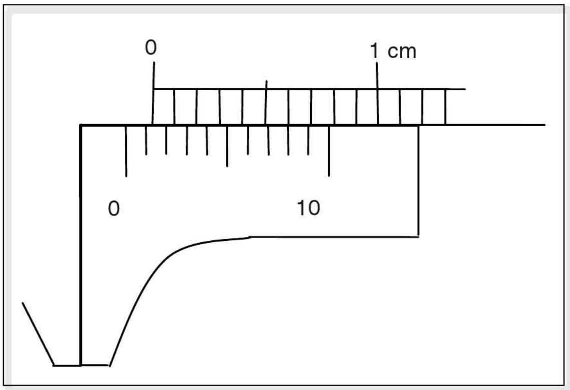
40. Find the ratio of the relative densities of two substances if their masses are equal when the volume of one is 1½ times that of the other.

41. 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.



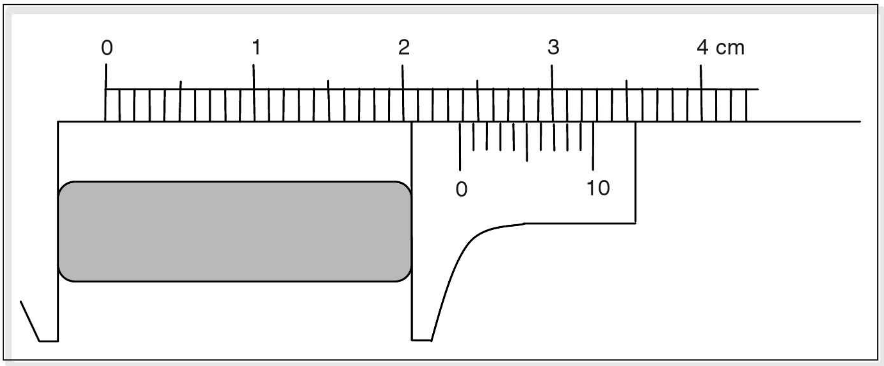
42. The working of common balance or physical balance is based on the "Principle of moments". A metre scale of uniform density is balanced at the centre. If a mass of 2 kg is suspended at an edge of the scale, then what mass should be suspended on other side at 1/4th length of the scale to maintain the horizontal position of the scale?

43. Determine the least count and the zero error of the vernier calipers shown in the figure below. What is the corresponding zero correction?



44. 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?

45. 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.

Concept Application Level—3

46. 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.

47. A simple pendulum is completely submerged under water. Discuss the variation in its time period.

48. 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?

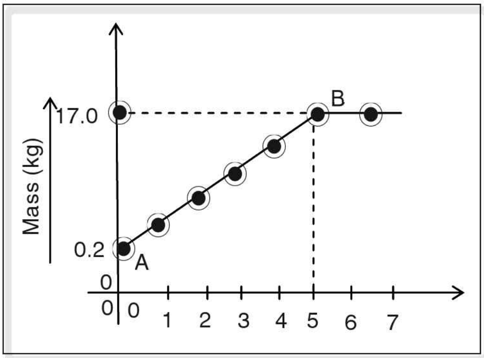
49. A liquid flows into a vessel initially empty at a steady rate of 70 $cm^3 \ s^{-1}$. The pictorial representation (graph) of the increase in the mass of the vessel with time is given below.

(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



50. 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.

key points for selected questions

Very short answer type questions

1. Ratio of density of substance to density of water at 4°C.

2. g cm^{-2}

3. 4

4. Principle of moments.

5. C.G.S. – cm^2
   S.I. – m^2
   $1 \ cm^2 = 10^{-4} \ m^2$

6. least count

7. $\frac{4}{\pi}$ m

8. 0.01 mm

9. The digits whose values are accurately known.
10. N – 1
11. Screw, nut, Main Scale, Circular scale, Thimble, Studs, U-frame.
12. J s
13. pitch
14. Screw in a nut
15. Distance travelled by light in vacuum for 1 year.
16. 1 second
17. The distance travelled by screw for one complete rotation of head.
18. fundamental
19. 0.08 mm
20. positive zero error
21. Difference between 1 M.S.D. and 1 V.S.D.
22. $[M^1L^0T^{-2}]$
23. Ratio of mass to volume.
24. Point on the scale at which the pointer comes to rest – resting point.
Resting point observed with equal empty pans is ZRP.
25. 1 : 9
26. N.V.S.D = (N – 1) M.S.D.
27. 16
28. (i) The time taken by the earth to complete one rotation about its own axis.
(ii) The average of all the solar days that occur during one full revolution of the earth around the sun.
29. 19.8 m s^{-2}
30. Extent to which one can measure a quantity without any error.

Short answer type questions

31. (i) All non-zero digits and zeros between non-zero digits are significant figures.
(ii) All zeros to the right of the last non-zero digit and zeros to the right of the decimal point and to the left of a non-zero digit are not significant.
(iii) All zeros to the right of a decimal point and to the right of a non-zero digit are significant.
33. (i) Zero of vernier–no coincidence with zero of main scale.
(ii) Vernier zero to the right of zero of main scale–positive error.
(iii) Vernier zero to the left of zero of main scale–negative error.
35. 0.6125 cm
36. (i) Smallest measurement made by an instrument accurately.
(ii) $\text{L.C.} = \frac{\text{I.M.S.D.}}{\text{N}}$.
37. 0.61 cm
38. V = 3 m s^{-1}, S = 15 m
39. $\text{Pitch} = \frac{\text{Distance moved by the thimble}}{\text{Number of rotations of the thimble}}$

$$\text{L.C.} = \frac{\text{Pitch}}{\text{Number of circular scale divisions}}$$

41. 0.5 mm, 0.0025 mm
42. (i) Measuring jar with water
(ii) Immerse the body–difference in water levels
(iii) Sinker if the body floats
45. Not possible to produce greater accuracy.

Essay type questions

46. (i) Definition of pitch of screw
(ii) Definition of least count
(iii) Definition of zero error and corresponding correction
(iv) Definition of P.S.R.

key points for selected questions

(v) Definition of H.S.R.

(vi) Observed reading = P.S.R. + H.S.R.

(vii) Corrected reading = observed reading + zero correction.

47. (i) If it is addition add the number and if it is a multiplication multiply the numbers

(ii) Check for the numbers having least number of significant digits in given numbers.

(iii) If it is the addition round off the sum to have same number of significant digits as in the number chosen in step (2)

(iv) If it is the product round off the results as per rules

48. (i) Definition of L.C.

(ii) Definition of M.S.R.

(iii) Definition of V.C.D.

(iv) Definition of error and corresponding correction

(v) Diameter of sphere = (M.S.R.) + (V.C.D.) ± (Correction)

(vi) Radius of sphere, $r = \dfrac{\text{diameter}}{2}$

(vii) Volume of sphere = $\dfrac{4}{3}\pi r^3$

49. (i) Arrest the beam and check the plumb line

(ii) Definition of ZRP

(iii) Definition of HRP and LRP

(iv) If HRP is obtained, add weight till the LRP is obtained if any LRP is obtained remove weight till the HRP is obtained.

(v) If HRP is obtained; P =

$$\left(\frac{\text{HRP}-\text{ZRP}}{\text{HRP}-\text{LRP}}\right) \times x \text{ g if LRP is obtained; P}$$

$$= \left[\frac{\text{LRP}-\text{ZRP}}{\text{LRP}-\text{HRP}}\right] \times x \text{ g where } x \text{ is weight}$$

added or removed to obtain LRP or HRP respectively

(vi) Accurate mass of the body = mass of HRP + P or mass of LRP – P

50. (i) A vertical pillar fixed on a wooden base

(ii) A horizontal beam supported on a knife edge on the pillar

(iii) Two pans should be at equal distances from centre of beam

(iv) The plumb should coincide with index

(v) The pointer oscillating on the scale fixed at the bottom of pillar

(vi) Levelling screws at the bottom of the base

KEY

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. $\frac{1\text{M.S.D.}}{\text{N}}$

10. –4

11. + n × L.C.

12. 10 μm

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. Choice (3)
17. Choice (2)
18. Choice (1)
19. Choice (1)
20. Choice (4)
21. Choice (3)
22. Choice (3)
23. Choice (1)
24. Choice (4)
25. Choice (2)
26. Choice (1)
27. Choice (4)
28. Choice (3)
29. Choice (4)
30. Choice (2)

Concept Application Level—2,3

Key points for select questions

31. (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) $1 \text{ kg m}^2 \text{s}^{-3} = 10^7 \text{ g cm}^2 \text{ s}^{-3}$

32. (i) Find the thickness of the glass plate using the formula TR = PSR + (C.S.D. × L.C.)

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

(iii) Thickness = 1.845 mm

33. (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

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

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

(iii) Measurement = 4.8 mm

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

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

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

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

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

36. (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

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

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

P.S.R. = 3

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

Correct diameter = observed reading + correction

(ii) 3.645 mm

38. (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

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

Count the number of M.S.D.'s from 2 to right block, say y

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

Lenght of the object =

$(x \times \frac{1}{16} + y \times \frac{1}{8})$ inch $= \left(\frac{x + 2y}{16}\right)$

Convert this value to cm

(iii) 5.87 cm

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

(ii) 2 : 3

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

Correct reading = observed reading + correction for zero error

Correction is positive of the error is negative

(ii) 31.19 mm^2

42. (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

43. (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

44. (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?

45. (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

46. (i) $z \propto \frac{y^2}{x}$

Dimensional formula of z

$$= \frac{(\text{dimensional formula of } y)^2}{\text{dimensional formula of } x}$$

(ii) $[M^1 L^0 T^0]$

47. (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?

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

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

49. (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}

50. (i) Calculate L.C. =

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

(ii) P.S.R. = nth division × pitch

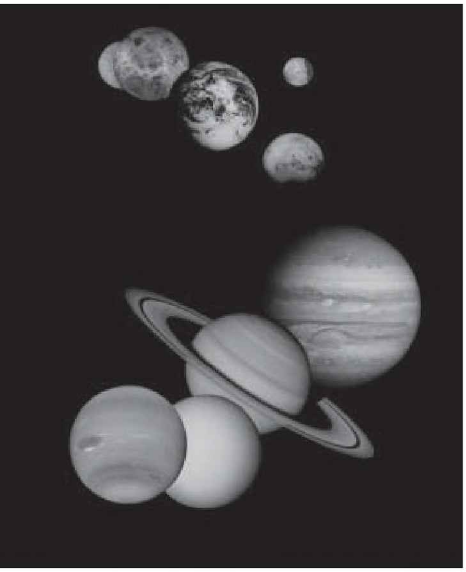
(iii) Observed reading = P.S.R + (H.S.R. × L.C.)

(iv) Zero error = – [H.S.R. + (N – n) × L.C.]

(v) Correction is positive if error is negative.

(vi) Correct measurement = observed reading + correction.

(vii) Correct measurement = 7.25 mm



2

Kinematics

NTRODUCTION

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 refers 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 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.

Types of Motion

In our every day life, we come across various types of motion, like the motion of the sun, the motion of wind etc.

Motion can be classified into

1. random motion
2. translational motion
3. rotational motion
4. oscillatory or vibratory motion

1. Random motion

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

☛ *Example*

The motion of dust particles in wind or in air.

2. 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.

3. 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*

(i) Rotation of Earth on its axis

(ii) Pulley used in drawing water.

4. Oscillatory or Vibratory motion

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

☛ *Examples*

(i) When the string of a guitar is plucked, it performs an oscillatory motion.

(ii) 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

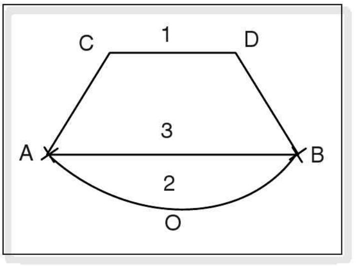


Figure 2.1

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)

Displacement

It is 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)

Displacement = $\overrightarrow{AB}$

NOTE:

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

But $\left|\overrightarrow{AB}\right| = \left|\overrightarrow{BA}\right|$

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 figure.

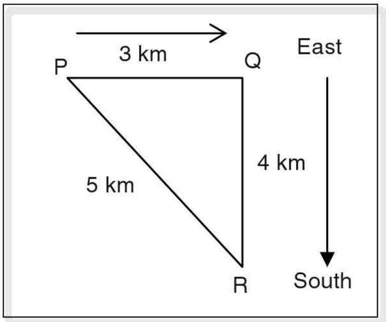


Figure 2.2

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.

Now, the total displacement $\left(\overrightarrow{PR}\right)$ 5 km along approximate south-east is obtained as the sum of the displacements 3 km along east $\left(\overrightarrow{PQ}\right)$ and 4 km along south $\overrightarrow{QR}$. Thus the two individual displacements $\overrightarrow{PQ}$ and $\overrightarrow{QR}$ are considered as the components of the displacements $\overrightarrow{PR}$. Thus the vector $\left(\overrightarrow{PR}\right)$ 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 sectors is called the 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.

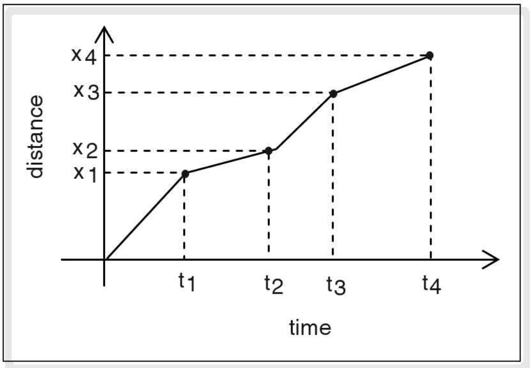


Figure 2.3

Uniform speed

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

Variable speed

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

Example

Consider the take off of an aeroplane. As it takes off, the speed of the plane increases, there after it remains constant and decreases as it approaches the destination. Thus the plane moves with variable speed.

Velocity

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

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

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 to the curve describing the path, if the body undergoes curvilinear motion.

Instantaneous velocity $\vec{V} = \dfrac{\overrightarrow{\Delta s}}{\Delta t}$

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

Instantaneous velocity: $\vec{V} = \dfrac{CB}{AC} = \dfrac{\vec{\Delta s}}{\Delta t}$

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 to the displacement time graph.

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

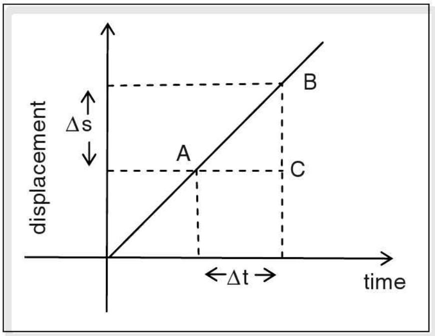


Figure 2.4 Uniform motion

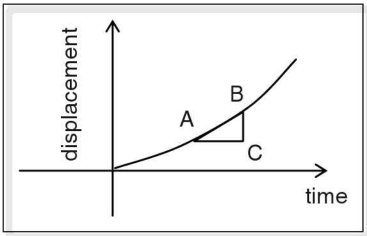


Figure 2.5 Non-uniform motion

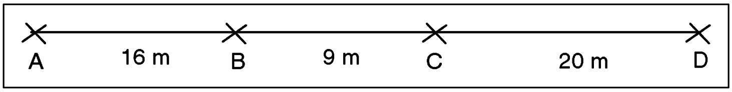
Average velocity

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.

☛ *Example*



Consider a body moving along 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

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

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 $= \dfrac{\vec{v} + \vec{u}}{2}$ 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.

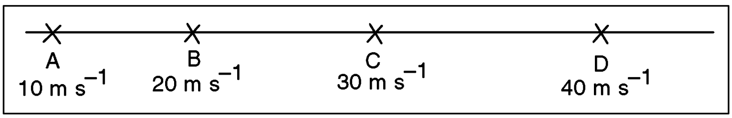
$$\text{By definition, acceleration, } \bar{a} = \frac{\text{Change in velocity}}{\text{Time}} = \frac{\bar{v} - \bar{u}}{t}$$

The direction of acceleration is along the direction in which the force causing the acceleration is acting.

Uniform acceleration

If the body changes its velocity by the equal measure in equal intervals of time, 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.

[redacted]

A	0		10		
		1		10	10
B	1		20		
		1		10	10
C	2		30		
		1		10	10
D	3		40		

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.

Plotting a graph of velocity (along y-axis) and time (along x-axis), we get a straight line as shown here. 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.

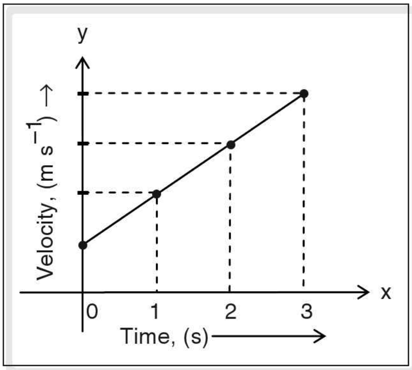


Figure 2.6

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.

Whenever the magnitude of velocity decreases, the rate of change of velocity is referred to as retardation or deceleration.

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.

1. To deduce, $v = u + at$:

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

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

   i.e., $a = \frac{v - u}{t}$

   $\mathbf{v = u + at}$

2. To derive, $s = ut + \frac{1}{2}at^2$:

Average velocity $= \frac{v+u}{2}$ ------ (1) (since acceleration is constant)

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

$\therefore$ Average velocity $= \frac{s}{t}$ -------- (2)

Comparing (1) and (2)

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

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

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

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

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

3. To derive $v^2 = u^2 + 2as$:

Average velocity $= \frac{s}{t}$ ---- (1)

Average velocity $= \frac{v+u}{2}$ ---- (2)

From (1) and (2)

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

$$s = \left(\frac{v+u}{2}\right)t\left[\text{but } v = u + at; \frac{v-u}{a} = t\right]$$

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

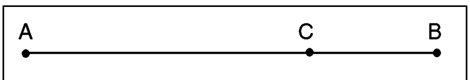
$$s = \frac{v^2-u^2}{2s}$$

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

Or

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

4. To deduce the equation for the displacement of a body in the nth 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 nth second is CB = S_n.

S_n = AB – AC --------- (1)

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

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

$AC = u (n - 1) + \frac{1}{2} a (n - 1)^2$ --------- (3)

Substituting (2) and (3) in (1), 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,

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)

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

$\therefore\ s_1 = 20 \times 1t = 20t$ km ------- (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,

$s_2 = v \times t_2 = 40 \times 3t = 120t$ km ------- (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 km h^{-1}, $t_3 = 1\,t$

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

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

s = 20 t + 120 t + 20 t

s = 160 t

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

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

Since the car is moving along a straight line,

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.

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

$\therefore$ Distance travelled $s_1 = v_1 t_1$

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

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

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

$t = 5$ seconds $s_2 = ?$

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

$v = u + at$

$v = 10 + 2 \times 5$

$v = 10 + 10$

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

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

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

$= 50 + 1 \times 25 = 50 + 25 = 75$ m

Total displacement $s = s_1 + s_2$

$s = 100 + 75 = 175$ 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.

$s_4 = 35$ m, $s_5 = 40$ m

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

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

$$\therefore 35 = u + a\left(4 - \frac{1}{2}\right) \qquad 40 = u + a\left(5 - \frac{1}{2}\right)$$

i.e., $35 = u + \frac{7}{2}a$; $\quad 40 = u + \frac{9}{2}a$

$70 = 2u + 7a$ --- (1); $\quad 80 = 2u + 9a$ --- (2)

Solving equations (1) and (2) we get

$a = \frac{10}{2} = 5\,\text{m s}^{-2}$; $u = \frac{35}{2} = 17{\cdot}5\ \text{m s}^{-1}$

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,

$$v = u + gt$$

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

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

Here

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)

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

(i) $v = u + at$

$v = gt$

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

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

(iii) $v^2 - u^2 = 2as$

$v^2 = 2gh$

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

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

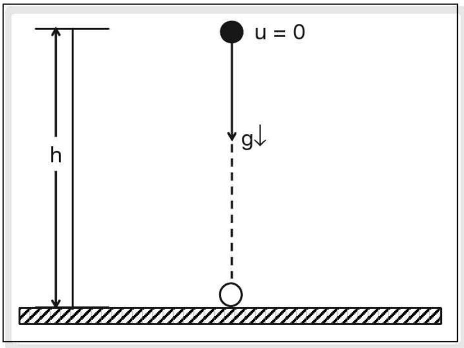


Figure 2.7

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.

Taking s = h, a = –g and v at maximum height = 0 we can write the equations of motion for such a body as follows.

(i) $v = u + at$

$v = u - gt$

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

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

(iii) $v^2 - u^2 = 2as$

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

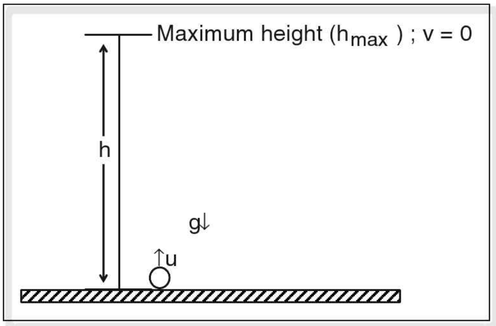


Figure 2.8

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

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

$t_a = \frac{u}{g}$ (from $v = u - gt$) Here t_a is the time of ascent.

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

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

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

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.

$$t_f = t_a + t_d = \frac{u}{g} + \frac{u}{g} = \frac{2u}{g} \qquad \text{i.e., } t_r = \frac{2u}{g}$$

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 m s^{-2})

Solution

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

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

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

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

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

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

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.

As $v^2 - u^2 = 2gh$ and $u = 0$, $v = \sqrt{2gh}$ ...... (1)

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

Comparing equations (1) and (2), 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

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 $g = 10\ m\ s^{-2}$)

Solution

Given, the initial velocity of the body $u = 0$ and $g = 10\ m\ s^{-2}$
Distance travelled by the body, $s = 45$ m

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

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

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

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)

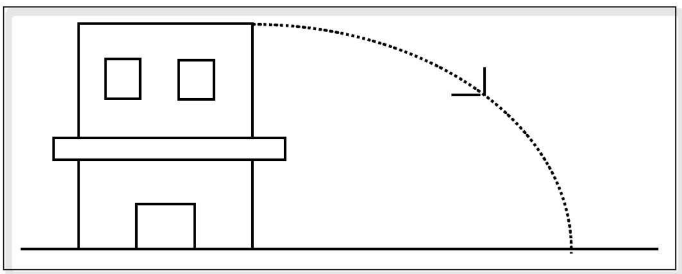
☛ *Examples*

(i) A mango falling from a tree.
(ii) A ball projected vertically upwards.

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

☛ *Example*

(i) A ball kicked horizontally from the top of a building.



(ii) A missile fired from a cannon.

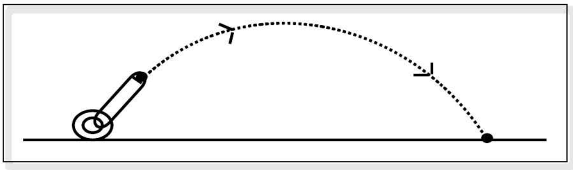


Figure 2.10

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 as 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.

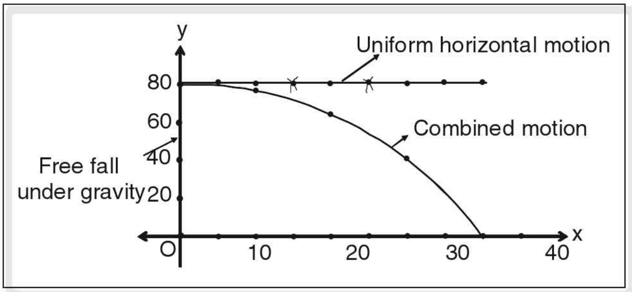


Figure 2.11

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

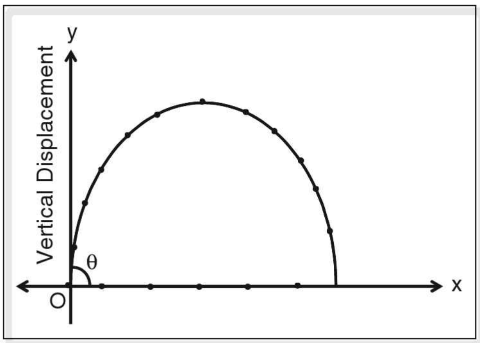


Figure 2.12

☛ *Example*

Consider a shot-put given an initial velocity making an angle 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.

This curve is called parabola. Hence the trajectory of a projectile is parabola.

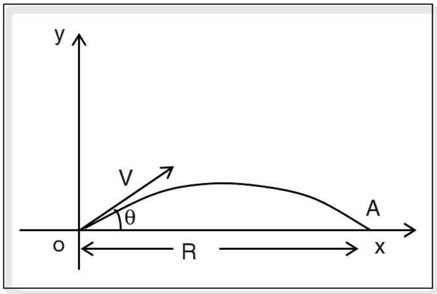


Figure 2.13

Range (R)

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

1. Range is OA in the above figure.
2. Range depends on the angle of projection.
3. Time taken for the projectile to reach the highest point from point of projection = time taken for 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, i.e., 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 cosθ' and the vertical component of velocity is 'u sinθ'. There exists no change in the horizontal component of velocity of the projectile as gravitational pull does not effect its horizontal motion. Thus, the horizontal component remains 'u cosθ' throughout the motion of the projectile. However, the vertical component of velocity i.e., 'u sinθ' 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 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 the 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 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.

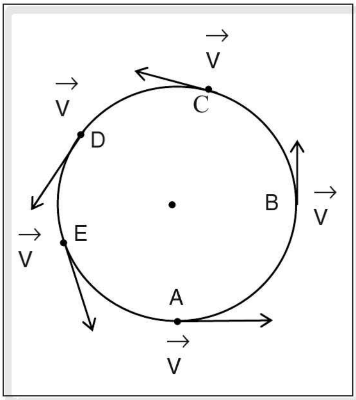


Figure 2.14

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 discussed in kinematics, namely, displacement–time graphs, velocity–time graphs and acceleration–time graphs. 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.

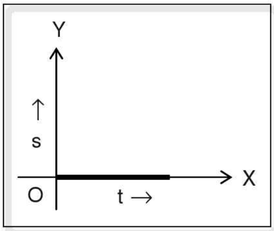
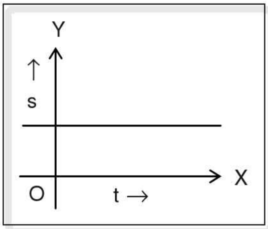


Figure 2.15

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.



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.

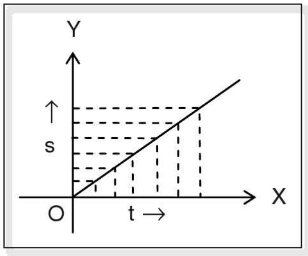


Figure 2.17

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.

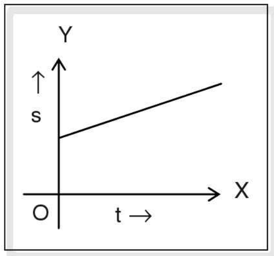


Figure 2.18

5. The s–t graph of two bodies P and Q are shown in figure (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 figure 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 $v_p = \frac{OA}{OC}$. This is the slope of OP. Similarly, magnitude of the velocity of Q is given by $v_Q = \frac{OB}{OC}$. This is the slope of OQ. As OB > OA, $v_Q > v_P$, the time considered (OC) being constant.

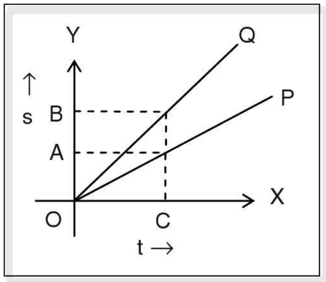


Figure 2.19

6. In figure (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 figure 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 higher than that of R.

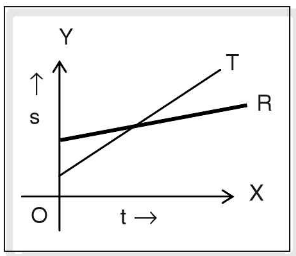


Figure 2.20

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

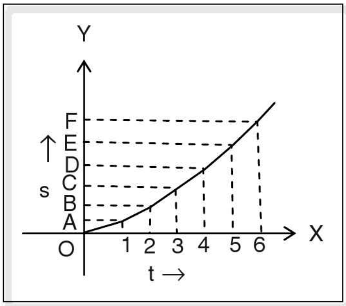


Figure 2.21

From the figure, 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.

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 figure (2.22).

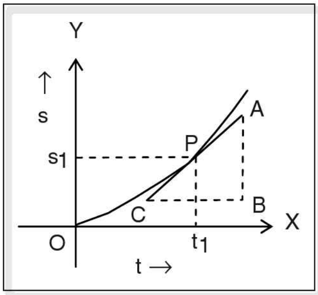


Figure 2.22

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.

8. The s–t graph of a body is as shown in figure (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 figure 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.

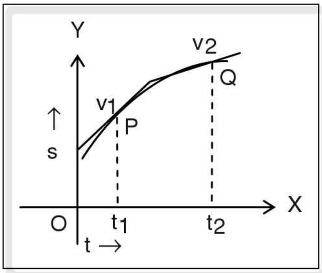


Figure 2.23

9. The s–t graph of a body is as shown in figure (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.

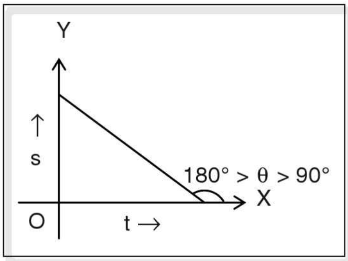


Figure 2.24

10. The s–t graph of a body is as shown in figure (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 figure. It is obvious from the figure that the slope at Q is more than that at P indicating that $v_2 > v_1$. Also, it is obvious from the figure that as time increases, displacement of the body decreases. Thus, the body is moving in opposite direction to the direction of displacement with acceleration.

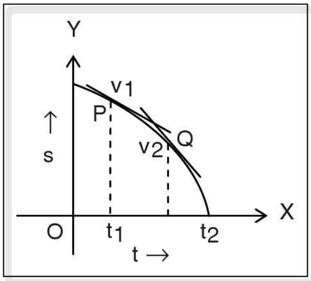


Figure 2.25

11. The s–t graph of a body as shown in the figure (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 figure 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.

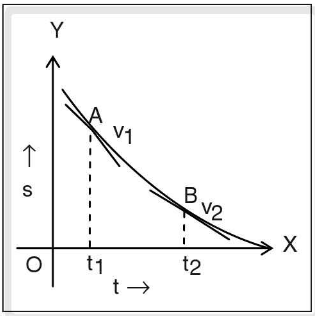


Figure 2.26

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 curve is a parabola for a uniformly accelerated motion.

Velocity–time graph

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.

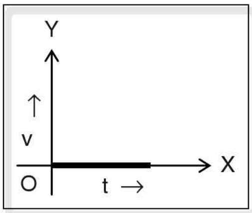
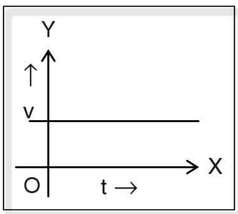


Figure 2.27

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.



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).

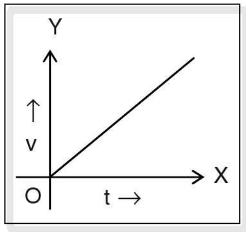


Figure 2.29

4. The v–t graph of a body is as shown in figure (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 and moves with uniform acceleration.

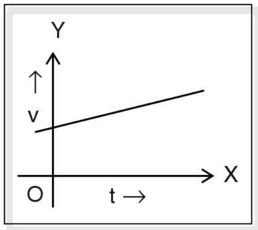


Figure 2.30

5. The v–t graph of two bodies P and Q is as shown in figure (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.

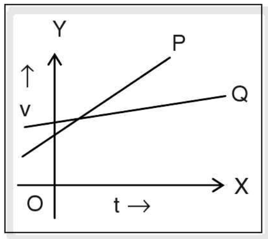


Figure 2.31

6. The v–t graph of a body is as shown in figure (2.32). The graph is a curve starting from the origin. This implies that the body has zero initial velocity 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 figure it is obvious that $a_2 > a_1$. Thus, the body moves with increasing acceleration. As the curve begins at the origin, the initial velocity of the body is zero.

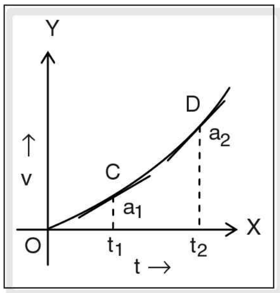
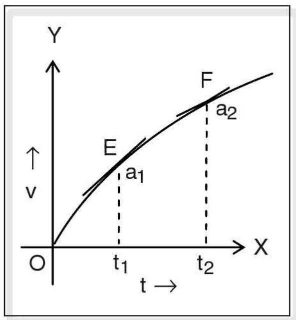


Figure 2.32

7. The v–t graph of a body is as shown in the figure (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 figure, 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.



8. The v–t graph of a body is as shown in figure (2.34). It is a straight line making an obtuse angle with the positive X-axis. There is some initial 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.

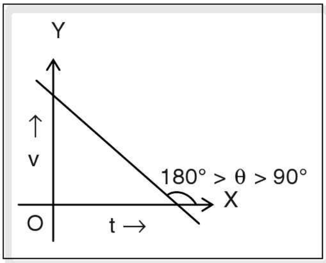


Figure 2.34

9. The v–t graph of a body is as shown in figure (2.35). The graph is not a straight line and is a curve with the velocity of the body decreasing with time. This indicates that the body moves with non-uniform retardation. The slopes of the tangents drawn to the curve at the points G and H gives the retardation of the body at the instants t_1 and t_2 respectively. As the slope at G is greater than the slope at H, the body moves with decreasing retardation.

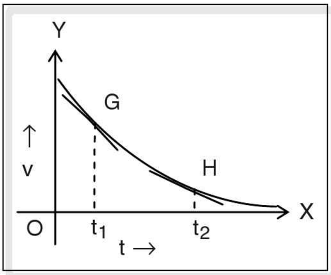


Figure 2.35

10. The v–t graph of a body is as shown in figure (2.36). It is a curve indicating decrease in velocity with time. Thus the body has variable retardation. The retardation of the body at t_1 and t_2 instants of time are given by the slopes of the tangents drawn to the curve at points I and J respectively. It is obvious from the figure that retardation increases with time. Thus the body moves with increase in retardation having some initial velocity and the final velocity being zero.

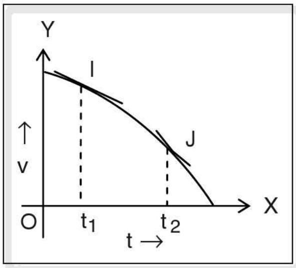


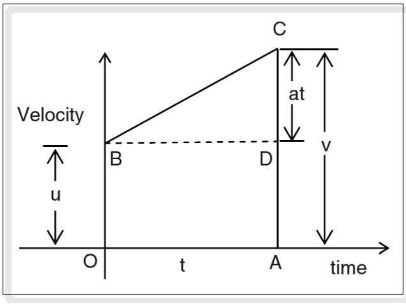
Figure 2.36

Uses

1. Nature of motion can be determined.
2. Velocity at any instant can be found out.
3. Area under the curve gives the displacement of the body.
4. Slope of the tangent to the curve gives the instantaneous acceleration.
5. Average acceleration is given by the slope of the line segment joining initial velocity and final velocity.
6. Equations of motions along straight line can be determined.

☛ *Example*

Consider a particle having initial velocity u, uniformly accelerating at the rate a, for time t and covers distance s, gaining velocity v. Graphically it can be represented by the line BC in v–t graph.



From the figure it is clear that OA = t, OB = u, AC = v, CD = at, distance travelled

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

Example

From the diagram given below which is a v–t graph of a body,

(i) find the deceleration of the body in the region BC.

(ii) find the total distance travelled by the body.

Given v is in m s^{-1} and time in s

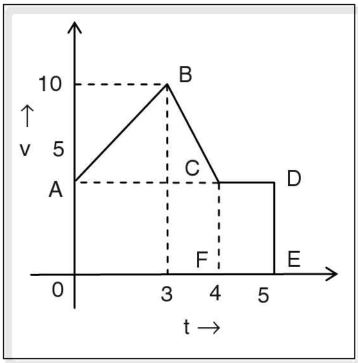


Figure 2.38

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

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

Acceleration–time graph

In this type of graph, acceleration is plotted along Y-axis and time along X-axis.

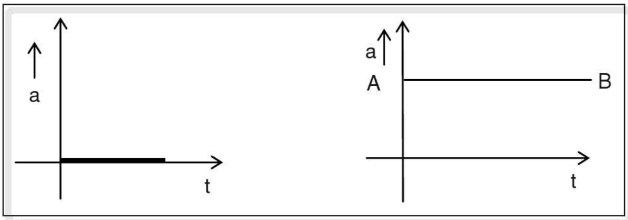


Figure 2.39

(i) a = 0, body moving with constant velocity.

(ii) 'a' is constant, body moving with uniform acceleration.

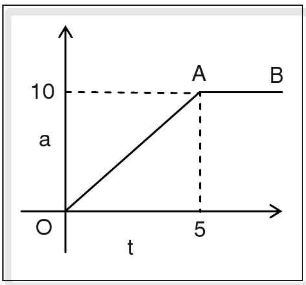
Uses of acceleration–time graph

(1) Acceleration at any intermediate time can be determined.

(2) Area under the curve gives the change in magnitude of velocity (v–u).

Example

In the graph given below, 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.

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

Graphical method–solutions made easy

Let us consider example 3 discussed earlier. The problem can be solved easily by using a v–t graph. The following figure (2.41) shows the v–t graph for the given data in the example 3.

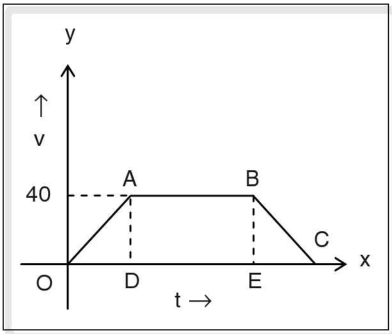


Figure 2.41

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.

$\therefore$ S = 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 km.

Total time t = x + 3x + x = 5x h.

$\therefore$ Average velocity

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

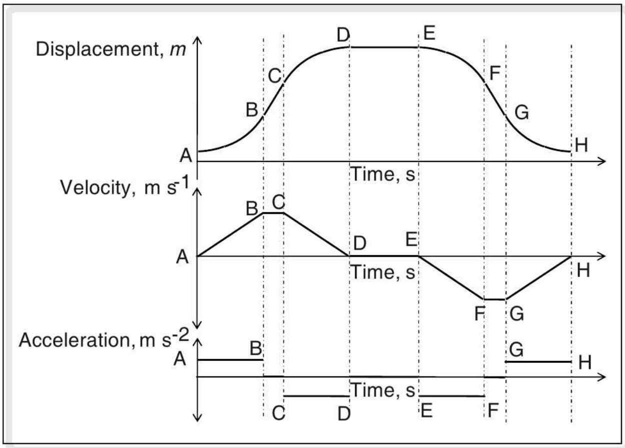


Figure 2.42

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 accelera-tion 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

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 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 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. When is a body said to be at rest and when is it said to be in motion?
10. A body projected with 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 a 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.
21. What 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. If it moves along a straight line between P and Q then its average velocity will be ______________.

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. ($g = 10\ m\ s^{-2}$)

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 an initial velocity covers 200 cm in the 2nd second and 220 cm in the 4th second. What is the initial velocity and the acceleration of the runner? (Assume the acceleration is uniform)

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.

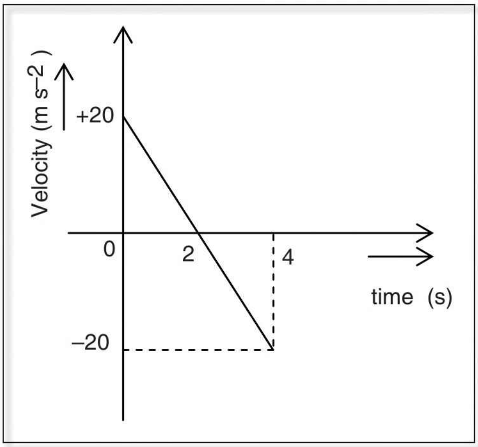
41. Give the equations of motion of a body projected vertically upwards.

42. A train travels from one station to another station at an average a 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,

(i) find the velocity of projection

(ii) maximum height attained by the body



44. Determine 'a' of the object which

(a) moves in a straight line with a constant speed of 20 m s^{-1} for 12 seconds.

(b) 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.

A. Displacement–time

B. Velocity–time

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

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

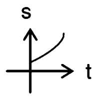
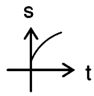
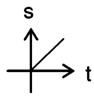
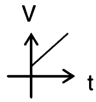
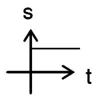
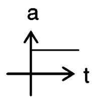
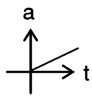
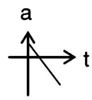
1. A body moves with retardation when it is projected vertically upwards.
2. A body is projected vertically up. On reaching maximum height, its velocity becomes zero.
3. Velocity-time graph can be used to find the displacement.
4. If a body moves with constant velocity, its displacement depends on the square of time.
5. 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.
6. Equations of motion are applicable only when a body moves with uniform velocity.
7. The distance travelled by a freely falling body in every successive second is the same.

Direction for questions 8 to 14: 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. A body projected with certain velocity making an angle other than 90° to horizontal is known as ________.
12. The ratio of magnitude of average velocity to average speed is ________.
13. The directions of both displacement and average velocity are ________.
14. ____________ is produced in a body whenever there is a change in its velocity.

Direction for question 15: Match the entries in column A with the appropriate ones in column B.

15.

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 16 to 30: For each of the questions, four choices have been provided. Select the correct option.

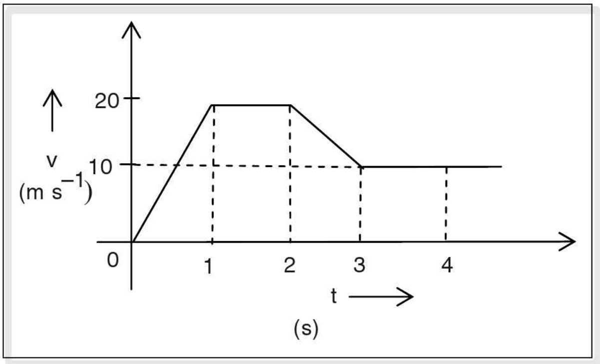
16. The ratio of magnitude of displacement to distance is always

(1) less than 1 (2) greater than 1
(3) equal to 1 (4) lesser than or equal to 1

17. The ratio of the heights from which two bodies are dropped is 3 : 5 respectively. The ratio of their final velocities is

(1) $\sqrt{5}:\sqrt{3}$ (2) $\sqrt{3}:\sqrt{5}$
(3) 9 : 25 (4) 5 : 3

18. 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.

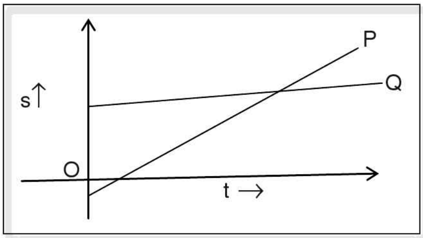


(1) 20 (2) 35 (3) 40 (4) 55

19. An ant moves from one corner of a hall to the diagonally opposite corner. If the dimensions of the hall are 8 m × 6 m, the displacement of the ant is ________ m.

(1) 14 (2) 10 (3) 28 (4) 2

20. The figure given below shows the displacement–time curve of the particles P and Q. Which of the following statements is correct?



(1) Both P and Q move with uniform equal speed.
(2) P is accelerated and Q is retarded.
(3) Both P and Q move with uniform speed, but the speed of P is more than the speed of Q.
(4) Both P and Q move with uniform speeds but the speed of Q is more than the speed of P.

21. 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}.

(1) −3 (2) 3 (3) −5 (4) 5

22. If a body starts from rest and moves with uniform acceleration, then

(1) $v \propto t$ (2) $s \propto t$ (3) $v \propto s$ (4) $s \propto \sqrt{t}$

23. If a body is projected vertically upwards then on reaching maximum height its

(1) velocity is zero and the acceleration is not zero.
(2) velocity is not zero and the acceleration is zero.
(3) both velocity and acceleration are not zero.
(4) both velocity and acceleration are zero.

24. 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 and moves linearly, the ratio of the distances of P and Q from the starting point is

(1) 4 : 1 (2) 1 : 4 (3) 2 : 3 (4) 3 : 1

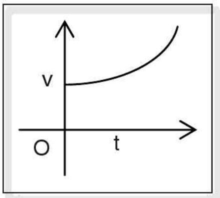
25. A body with an initial velocity of 3 m s^{-1} moves with an acceleration of 2 m s^{-2}, then the distance travelled in the 4th second is __________.

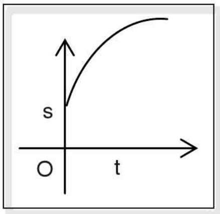
(1) 10 (2) 6 (3) 7 (4) 28

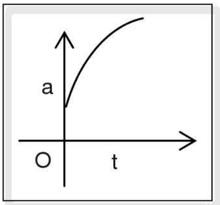
26. A bus travels the first one-third distance at a speed of 10 km h^{-1}, the next one-third distance at a speed of 20 km h^{-1} and the next one-third distance at a speed of 30 km h^{-1}. The average speed of the bus is

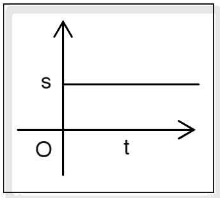
(1) 20 m s^{-1} (2) $\frac{50}{11}$ m s^{-1} (3) $\frac{180}{11}$ m s^{-1} (4) 30 m s^{-1}

27. Which of the following graphs indicates that a body is undergoing retardation?

(1)


(2)


(3)


(4)


28. The velocity of a body is given by the equation v = 6 – 0.02 t, where t is the time taken. The body is undergoing

(1) uniform retardation. (2) uniform acceleration.
(3) non-uniform acceleration. (4) zero-acceleration.

29. 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}.

(1) 10 (2) 8.7 (3) 4 (4) 6

30. Density is a __________ quantity.

(1) scalar (2) derived (3) neither (1) nor (2) (4) Both (1) and (2)

Concept Application Level—2

31. 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.

32. A ball is dropped from 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 $g = 10 \text{ m s}^{-2}$)

33. 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 will be the average speed of the journey?

34. 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 was released from the balloon. Calculate the time taken by the released body to reach the ground. Take $g = 10 \text{ m s}^{-2}$.

35. 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.

36. 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?

37. 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. Given $g_{moon} = \frac{1}{6} g_{earth}$.

38. The distance travelled by a body in the nth second is given by the expression (2 + 3n). Find the initial velocity and acceleration. Also, find the final velocity at the end of 2 seconds.

39. 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.

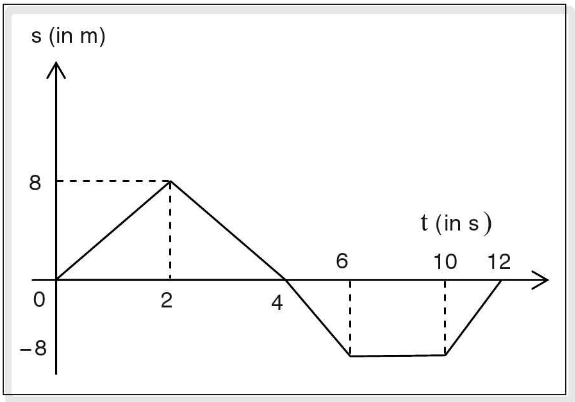
40. The ratio of distance described by a body falling freely from rest in the last second of its motion to that in last but one second of its motion is 5 : 4. Find the total time taken by the body to reach the ground.

41. 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.

42. 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?

43. A body is dropped from a certain height. Plot a displacement–time, velocity–time and acceleration – time graphs of the body.

44. Given below is the displacement–time graph of a body moving in a straight line. Find the distance covered at the end of 4 seconds. Also find the displacement of the body at the end of 12 seconds.



45. 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?

Concept Application Level—3

46. Are all physical quantities that have magnitude and direction vectors? Give example to support your answer. When is a physical quantity called a vector?

47. A body is dropped from a certain height above the ground. Its time of descent is 5 s. But at t = 3 s, the body is stopped and then released. What is the remaining time the body should travel to reach the ground?

48. 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?

49. A car starts from rest and moves with uniform acceleration of α m s^{-2} along a straight line. It then retards uniformly at a rate β m s^{-2} and stops. If 't' is the time elapsed since it starts moving and stops, find the average speed of the car.

50. A ball thrown vertically upwards with speed 'u' from the top of a tower reaches the ground in 9 seconds. Another ball thrown vertically downwards from the same position with speed 'u', takes 4 seconds to reach ground. Calculate the value of 'u'. (Take g = 10 m s^{-2})

key points for selected questions

Very short answer type questions

1. $v = u + at, S = ut + \frac{1}{2} at^2, v^2 - u^2 = 2as$
2. $u = 0$
3. 16 : 9
4. A ball kicked horizontally from a building, a missile fired from a cannon.
5. Maximum distance covered by a projectile along the horizontal.
6. A person seated in a merry-go-round.
7. Velocity
8. Time taken by a body projected vertically up to reach maximum height–time of ascent.

   Time taken by a freely falling body to reach the ground–time of descent.
9. Rest–change in position w.r.t surroundings and time.

   Motion–no change in position w.r.t surroundings and time.
10. Projectile
11. Scalar–Quantities that have only magnitude .

    Vectors–Quantities that have magnitude as well as direction.
12. No, only magnitude remain constant.
13. cm, m
14. zero
15. Sum of time of ascent and time of descent.
16. Distance does not depend on direction while displacement depends.
17. at rest
18. Motion of a body with constant angular velocity.
19. $cm\ s^{-1}, m\ s^{-1}$
20. Vector or physical
21. Time
22. Rate of change of velocity–acceleration.

    Negative acceleration–retardation.
23. Uniform acceleration
24. Uniform velocity.
25. Yes
26. zero
27. An apple falling from a tree, a ball dropped from the top of a building.
28. $\frac{v_1 + v_2}{2}$
29. zero
30. Path traced by a projectile.

Short answer type questions

31. At maximum height the velocity of the body is zero.
32. $h = \frac{1}{2} gt^2$ Ans: 1 m
33. Consider variations in velocity.
34. $v = u + at$
35. $s_n = u + a\left(n - \frac{1}{2}\right)$

    Ans: $u = 1.85\ m\ s^{-1}, a = 0.1\ m\ s^{-2}$
36. (i) $v = u + at$

    (ii) $v = 0$ for upward motion

    (iii) $u = 0$ for downward motion

    (iv) time of flight = time of ascent + time of descent
37. Definition of acceleration.
38. $v^2 = u^2 + 2as$

    Ans: 810 m, no
39. $t = \sqrt{\frac{2h}{g}}, h = \frac{u^2}{2g}$.
40. $s = ut + \frac{1}{2} at^2, a = g$

    Ans: 122.5 m
41. Acceleration of the body in vertical direction is due to gravitational force.
42. Average speed $= \frac{\text{total distance}}{\text{total time}}$

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

    Ans: $48\ km\ h^{-1}$; zero

key points for selected questions

43. Displacement = area under the v–t graph.

Ans: (i) 20 m s^{-1} (ii) 20 m

44. $a = \frac{v - u}{t}$ Ans: (a) 0 (b) $\frac{10}{7} \text{ m s}^{-2}$

45. $v = u + gt$

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

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

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

Essay type questions

46. A. (i) Body at rest ⇒ displacement (change in position) is zero.

(ii) Uniform velocity ⇒ equal displacements in equal intervals of time.

(iii) Non-uniform speed ⇒ acceleration or deceleration.

(iv) Acceleration ⇒ as time progresses, greater displacements take place in equal intervals of time.

B. (i) Body at rest ⇒ velocity = 0

(ii) Uniform motion ⇒ no change in velocity

(iii) Non-uniform motion ⇒ change in velocity

(iv) Acceleration ⇒ velocity increases with time.

C. (i) Body at rest or uniform motion ⇒ acceleration = zero

(ii) Non-uniform motion ⇒ acceleration –

(a) positive or negative

(b) constant or variable

47. S_n = distance travelled in n seconds – distance travelled in (n – 1) seconds.

48. (i) Average velocity = $\frac{s}{t} = \frac{v+u}{2}$

(ii) $v = u + at$ (iii) Eliminate 'v'

49. Displacement = Area under the velocity-time graph.

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

(ii) $v = u + at$

(iii) Eliminate 't'

KEY

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. Projectile

12. less than or equal to 1

13. same

14. Acceleration

15. Match the following

A : c

B : d

C : f

D : g

E : b

F : h

G : a

H : e

Multiple choice questions

16. Choice (4)

17. Choice (2)

18. Choice (4)

19. Choice (2)

20. Choice (3)

21. Choice (1)

22. Choice (1)

23. Choice (1)

24. Choice (2)

25. Choice (1)

26. Choice (2)

27. Choice (2)

28. Choice (1)

29. Choice (4)

30. Choice (4)

Concept Application Level—2,3

Key points for select questions

31. (i) $S_n = u - \frac{g}{2}(2n - 1)$

(ii) Using v = 0 find u and substitute in S_n formula.

(iii) 4 s

32. (i) $t = \sqrt{\frac{2h}{g}}$

(ii) Find the value of h and find t using the formula $t = \sqrt{\frac{2h}{g}}$ ----- (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.

33. (i) Average speed $= \frac{\text{total distance}}{\text{total time taken}}$

(ii) 32.73 km h^{-1}

34. (i) $s = ut + \frac{1}{2}at^2$

(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

35. (i) Displacement = 2r sinθ

Distance = Length of the arc $= \frac{\pi r\theta}{180}$

(ii) The angle made by the pendulum with the vertical is = ½ the angle made by the arc described by the pendulum.

(iii) The length of the arc = radius of the arc × 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

36. 12.5%

37. (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 = $\frac{1}{6}$ 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

38. (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}

39. (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

40. (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

41. (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) Time of flight = $\sqrt{\frac{2h}{g}}$ h = x + y

(v) 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

42. (i) $H = \frac{u^2}{2g}$

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

(ii) 576 m

43. Relate equations

44. (i) Definition of distance and displacement.

(ii) Distance = total path covered

Displacement = shortest path covered between initial and final points.

(iii) 16 m, 0

45. (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 nth and (n – 1)th second.

(iii) 40 m s^{-1}

46. (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?

47. (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

48. (i) $v = \sqrt{2gh}$

(ii) $a = \dfrac{v^2 - u^2}{2s}$

(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}

49. (i) Average speed =

$$\frac{\text{Total distance}}{\text{time}} = \frac{\text{Area under v-t graph}}{\text{time}}$$

(ii) Plot a 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 average speed = $\dfrac{\text{net displacement}}{\text{total time}}$.

Total time = $t_1 + t_2 = t$

(vi) Find the velocity using $v = u + at$ for both acceleration and retardation.

(vii) Equate the two equations.

(viii) Write t_2 in terms of t and t_1 in the equation obtained from 7.

(ix) Obtain an expression for t_1 from equation obtained from 8.

(x) Substitute the value of t_1 obtained from 9 in equation of average speed obtained from 5.

(xi) $\dfrac{\alpha\beta t}{2(\alpha + \beta)}$

50. (i) Displacement of the two balls is the same.

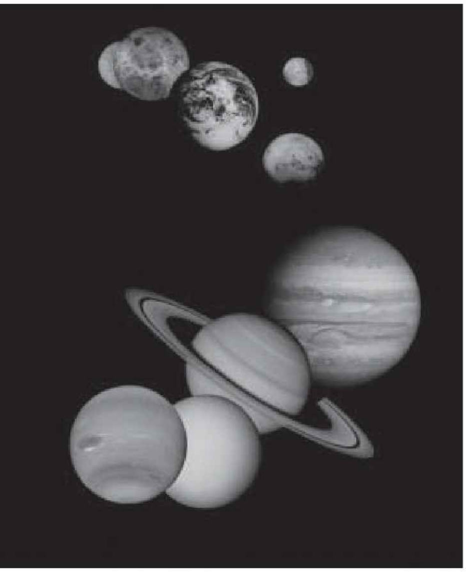
(ii) Displacement for the body dropped = displacement of the body which is projected upwards from the top of the tower.

(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}



3

Dynamics

NTRODUCTION

Dynamics is the study of motion of bodies while taking into account the cause of 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, for example, when a football is kicked, it moves with a certain speed.
2. Force is used to bring an object to rest.

   For 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 dimension.

☛ *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 and shape.

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 force in contact with 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.

☛ *Example*

Gravitational force: When a ball is thrown up into the air, it is pulled towards the earth due to earth's gravitational force.

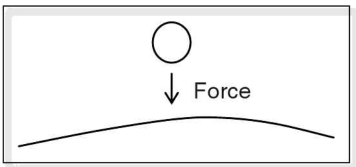


Figure 3.1

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.

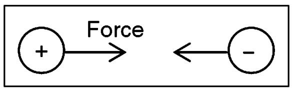


Figure 3.2

Force field

Region or space in which a non-contact force such as magnetic force, gravitational force acts is called the force field.

The region surrounding a magnet, where a magnetic substance experiences force is called the magnetic field.

The region surrounding an electric charge, where another electric charge, positive or negative, experiences a force is called the electric field.

Thus a field is a sphere of influence of a non-contact force.

Centripetal Force

When a body is moving uniformly along a circular path, the magnitude of its velocity remains constant, but the direction of velocity 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 the centripetal force, and depends on the magnitude of velocity and the radius of the circular path.

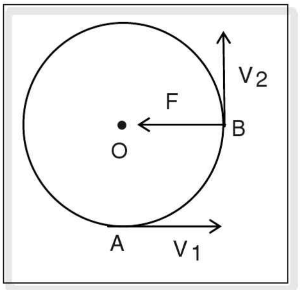


Figure 3.3

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 has a stone tied 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 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 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 defines a physical quantity called momentum.

Thus momentum is a quantity referring to the motion of a body.

Momentum = mass × velocity

$\overline{P} = m \times \overline{v}$

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 × velocity

∴ 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:

Momentum = Mass × Velocity

$= M^1L^1T^{-1}$

Example

Find the magnitude of momentum of a body of mass 10 kg moving with a velocity of 5 m s^{-1}.

Solution

Given:

mass = 10 kg velocity = 5 m s^{-1}

Momentum = Mass × Velocity

$p = mv = 10 \text{ kg} \times 5 \text{ m s}^{-1} = 50 \text{ kg m s}^{-1}$

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

Mass, $m = 5$ kg

Initial velocity, $u = 0$ m s^{-1} and

Final velocity, $v = 5$ m s^{-1}

Initial momentum (p_1)

Since the body is at rest, its initial momentum is zero.

($\therefore$ p = mass × velocity)

$p_1 = 0$

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

(i) force due to gravity acting vertically downwards, and

(ii) force exerted by the table on the book acting vertically upwards.

These two forces are equal in magnitude and opposite. Hence the resultant of these two forces acting on the book is zero.

Hold one end of a string and from the free end suspend a pan with some weights. Forces acting on the string are

(i) force due to gravity W, acting downwards, and

(ii) force exerted by the hand T, acting upwards through the string.

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.

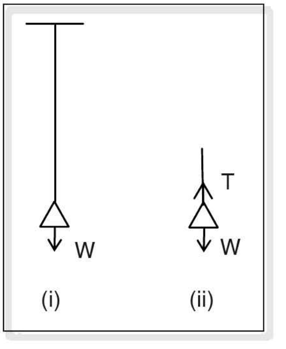


Figure 3.4

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 the velocity 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.

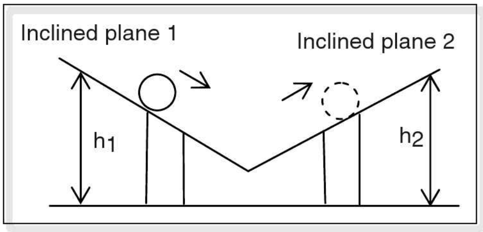


Figure 3.5

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 resistance 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 state of uniform 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 large 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 is directly proportional to the net force acting on the body and takes place in the direction of the net force."

i.e., $F \propto \dfrac{\Delta p}{\Delta t}$

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 Δt

Rate of change of momentum $= \dfrac{\vec{p_2} - \vec{p_1}}{\Delta t}$

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)

$$\therefore \text{Rate of change of momentum} = \frac{m\vec{v} - m\vec{u}}{\Delta t} = m\left(\frac{\vec{v} - \vec{u}}{\Delta t}\right) = m\frac{\vec{v}}{\Delta t}$$

Here, $\Delta\vec{v}$ is the change in velocity

$$\text{From Newton's second law of motion } F \propto \frac{m\Delta\vec{v}}{\Delta t}$$

$$\Rightarrow F \propto ma\left(\because \vec{a} = \frac{\Delta v}{\Delta t} \text{ is the acceleration of body}\right)$$

$F = k\,ma$

Unit of force is chosen in such a way that it produces unit acceleration on unit mass. Then the consonant 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.

newton (N):

It is the absolute unit of force in S.I. system.

$1\ N = 1\ kg \times 1\ m\ s^{-2}$

1 newton is that force which acts on a mass of 1 kg and produces an acceleration of $1\ m\ s^{-2}$

dyne is an absolute unit of force in C.G.S. system.

$1\ dyne = 1\ g \times 1\ cm\ s^{-2}$

Relation between newton and dyne

$1\ N = 1\ kg \times 1\ m\ s^{-2} = (1000\ g) \times (100\ cm\ s^{-2})$

Kilogram weight (kg_{wt}) or kilogram force (kg_f)

It is a gravitational unit of force in S.I. system.

$1\ kg_{wt} = 9.8\ N$

Gram weight (g_{wt}) or gram force (g_f)

It is the gravitational unit of force in C.G.S. system.

$1\ g_{wt} = 980$ dynes

Dimensional formula of force

F = mass × acceleration

$M^1 \times L^1T^{-2}$

∴ Dimensional formula of force = $M^1L^1T^{-2}$

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. Similarly when a ball is struck its moment changes in a very short interval of time.

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.

Impulse = force × time

∴ Impulse = mass × acceleration × time = m a × 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

Impulse = force × time

∴ 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

Impulse = F × t = $M^1L^1T^{-2} \times T^1 = M^1L^1T^{-1}$

☛ *Examples*

Cricket fielders lower their hands while catching a ball. If the ball is caught without lowering the hands the fielder will hurt his hands due to 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

Mass = 10 kg

$a = 0.2 \text{ m s}^{-2}$

Force = mass × acceleration ($F = ma$)

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

Thus, the magnitude of force acting on a 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 g = 0.1 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.

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

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

time $t = 0.01$ s

Impulse = change in momentum

Impulse = m (v – u)

$$= 0.1[20-(-10)]$$

$$= 0.1[20+10]$$

$$= 0.1 \times 30 \text{ kg m s}^{-1} = 3 \text{ kg m s}^{-1}$$

$$\text{Force} = \frac{\text{Change in momentum}}{\text{time}}$$

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

$$\text{Force} = \frac{0.1(20+10)}{0.01} = \frac{3}{0.01}\ 300\text{N}$$

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 km h^{-1} = $36 \times \frac{5}{18}$ = 10 m s^{-1}.

Distance traveled by the car, s = 100 m

Mass of the car, m = 400 kg

Force = mass × acceleration (from Newton's second law)

To find the acceleration, we use equation of motion $v^2 = u^2 + 2as$

0 = 100 + 200a

$$a = \frac{-100}{200} = -0.5 \text{ m s}^{-2}$$

Acceleration is negative because the final velocity (= 0) is less than the initial velocity (= 36 km h^{-1})

F = m × a

= 400 × –0.5 = –200 N

Here, the negative sign represents a retarding force

Mass and weight

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 × 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 (∴ 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 may be 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
Weight = 1 kg × 9.8 m s^{-2} = 9.8 N

Newton's Third Law of Motion

Statement

For every action there is an equal and opposite reaction.

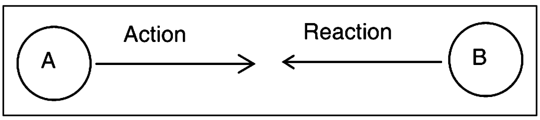


Figure 3.6

Consider two bodies A and B colliding. A exerts a force on B and this is called as an 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. It involves 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

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 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).

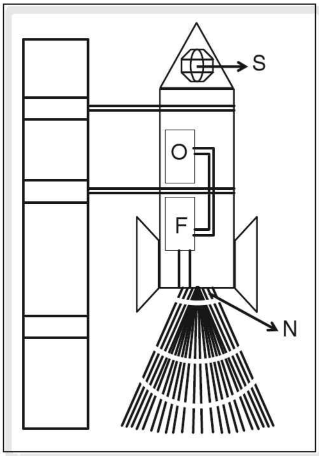


Figure 3.7 Rocket – different parts

Law of Conservation of Momentum

Newton demonstrated using the equipment shown in the figure 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.

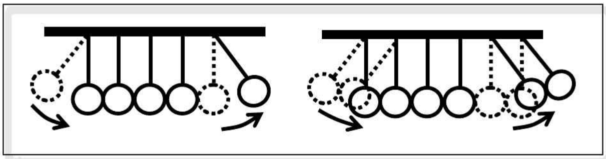


Figure 3.8

Verification of law of conservation of momentum

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.

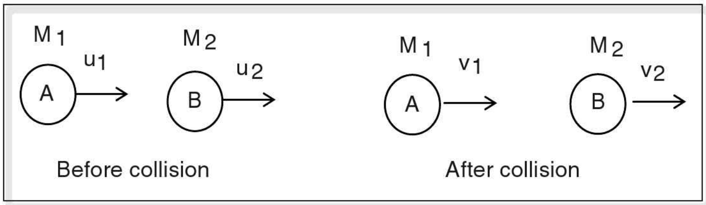


Figure 3.9

Let v_1 and v_2 be their velocities after collision. From the second law of motion, we have,

Rate of change of momentum of A, $\vec{F_A} = \dfrac{\Delta \vec{p_1}}{t}$

Rate of change of momentum of B, $\vec{F_B} = \frac{\Delta \vec{p_1}}{t}$

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.

$$\frac{\Delta \vec{p_2}}{t} = -\frac{\Delta \vec{p_1}}{t}$$

$\Delta \vec{p_1} = M_1v_1 - M_1u_1$

Similarly, $\Delta \vec{p_2} = M_2v_2 - M_2u_2$

$M_2v_2 - M_2u_2 = -(M_1v_1 - M_1u_1)$

$(M_1u_1 + M_2u_2) = (M_1v_1 + M_2v_2)$

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, $M_1 = 4$ kg

$M_2 = 2$ kg

Since the bomb is initially at rest, $u = 0$

$v_1 = 5$ m s^{-1}

$v_2 = ?$

Using the law of conservation of momentum

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$0 = 4 \times 5 + 2 \times v_2$

$20 + 2 \times v_2$

$$v_2 = \frac{-20}{2} = -10 \text{ m s}^{-1}$$

2 kg mass moves in the direction opposite to 4 kg mass. Hence v_2 is negative.

Normal force

Consider a block of wood of mass 'm' at rest on the surface of a table.

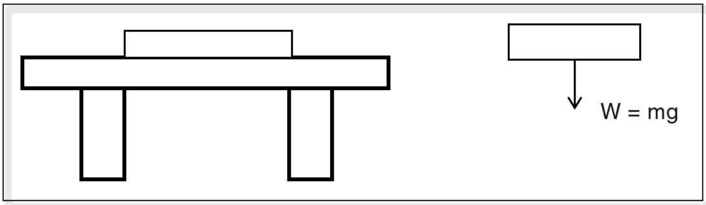


Figure 3.10

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.

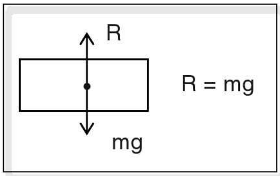


Figure 3.11

This is the force exerted by the table 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 an 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.

1. one along the plane = mg sinθ
2. one perpendicular to the plane = mg cosθ

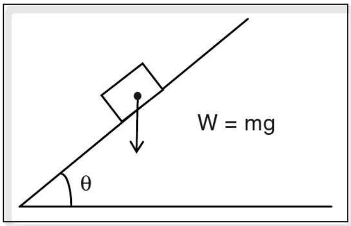


Figure 3.12

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 cosθ'

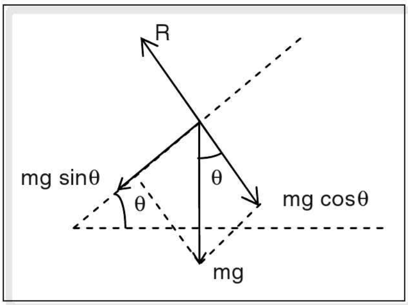


Figure 3.13

Normal reaction under the action of an applied force

Case (1)

Consider a block of wood placed on a horizontal surface. Let the block be pulled by a force 'P' as

1. Perpendicular component of P, i.e., P sinθ acts vertically upwards.
2. The weight of the block is balanced by R + P sinθ, where R is the normal reaction.

$\therefore$ R + P sinθ = mg

R = mg – P sinθ

Thus the normal reaction decreases when we pull an object.

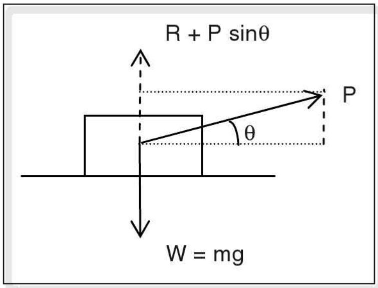


Figure 3.14

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 Sinθ), acts vertically downwards

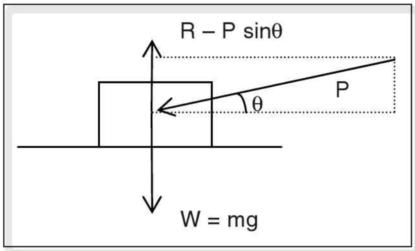


Figure 3.15

Thus the weight of the block is balanced by R-P sinθ, where R is the normal reaction.

R – P sinθ = mg

R = mg + P sinθ

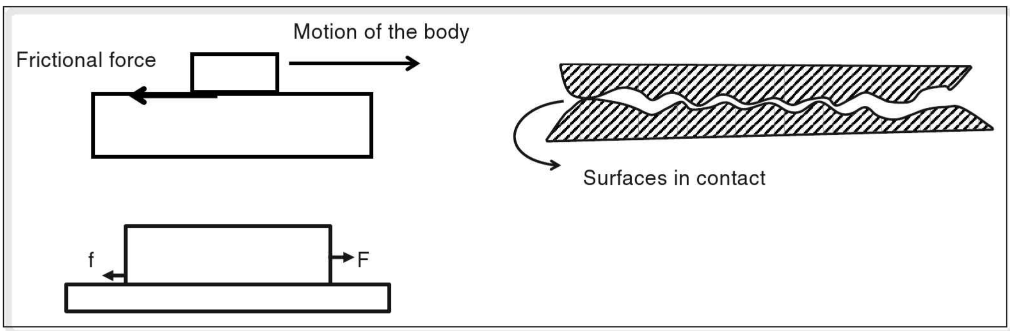
Thus the normal reaction between the contact surfaces increases when we push an object.

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.



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, greater 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

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 the body in motion. This is due to frictional force, which does not allow one body to slide over another and this is called as static friction.

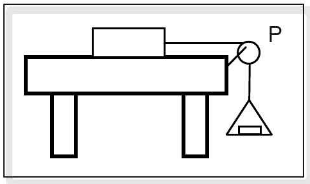


Figure 3.17

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 weights 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 the 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

$F_s \propto N$

$F_s = \mu N$

Here, F_s is the force of 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.

Verification of laws of limiting friction

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 weights were added in the two cases.

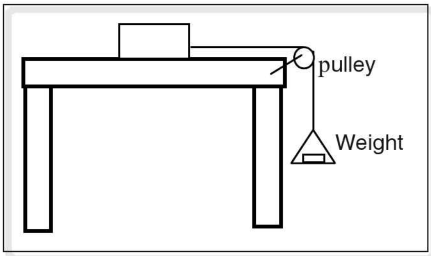


Figure 3.18

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., $\frac{\text{limiting friction}}{\text{Normal reaction}}$ = constant = μ (coefficient of friction)

Thus limiting friction is directly proportional to the normal reaction.

This implies that greater the normal reaction, greater is the friction.

2. 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 its 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.

3. 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 sliding 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 the coefficient of rolling friction.

μ_r depends on the nature of the material in contact and 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: $f_s > f_k > f_r \therefore \mu_s > \mu_k > \mu_r$

Friction in fluids

Fluids also exert friction on the bodies moving through them. But the friction of the fluids is less compared to 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.

☛ *Examples*

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)

Fish 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

Some advantages of friction:

(i) 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 will be unable to walk.

(ii) 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.

(iii) It is friction which makes it possible to hold an object in our hand.

(iv) 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.

(v) Fixing nails to walls and screws to boards is possible only due to friction.

(vi) Friction between the chain and the wheels helps us to transfer motion from one part to another part of a machine.

(vii) Writing with chalk on a board is possible only due to friction between the surfaces of the board and the chalk.

(viii) 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.

(ix) It is possible to place dishes or any object on the ground or a table due to frictional force.

Disadvantages of friction

Some of the disadvantages of friction are as follows.

(i) Friction causes the wear and tear of machine parts and this leads to the damage of certain machinery.

(ii) Friction produces heat and more energy is required to overcome it.

(iii) Friction causes loss of energy during transformation of energy from one form to another. This should be minimised.

(iv) 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 carom boards, which reduces friction between the board and the striker, caroms.

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 making modifications in arrangement. This would reduce friction.

☛ *Example*

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.

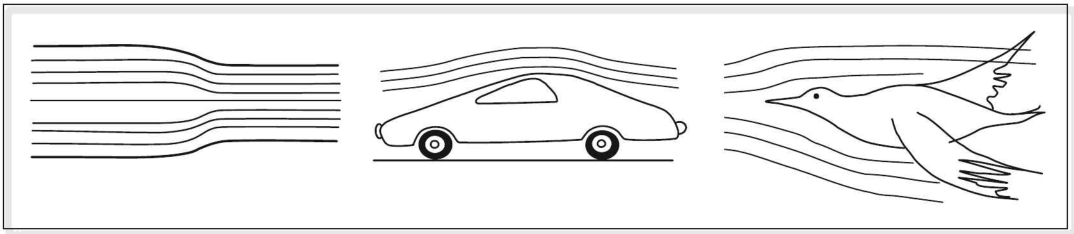


Figure 3.19

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 the above 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

$W \propto F$ and $W \propto s$

'W', 'F' and 's' are work done, applied force and displacement of the body in the direction of force respectively.

$W \propto Fs$

$W = K\ Fs$ where 'K' is a proportionality constant and the unit of force is so defined such that $K = 1$.

Hence $W = Fs$

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.

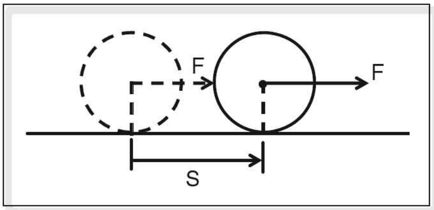


Figure 3.20

Consider a lawn roller being pulled as shown in figure (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 figure (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,

$W = (F \cos\theta)\ s$ or $W = Fs \cos\theta$

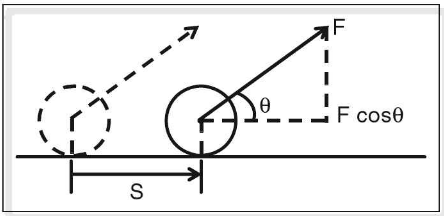


Figure 3.21

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 $\theta < 90°$

$W = Fs \cos\theta \Rightarrow$ work done is positive as $\cos\theta > 0$ when $0° < \theta < 90°$

Case (ii) If $\theta > 90 \Rightarrow$ work done is negative as $\cos\theta < 0$ when $90° < \theta < 180°$

Case (iii) If $\theta = 90° \Rightarrow$ work done is equal to zero as $\cos 90° = 0$

☛ *Example*

Work done by a centripetal force is equal to zero since centripetal force and displacement are perpendicular to each other.

NOTE:

1. If the net force is perpendicular to the displacement, the work done is always equal to zero.

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 erg = 1 dyne × 1 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 × 1 metre.

Hence joule is defined as "the work done when a net force of one newton acts on a body and displaces it through one metre in its direction".

Dimensional formula of work

Work = (Force) (displacement)

$W = F \cdot s$

$= M^1L^1T^{-2} \cdot L^1 = M^1L^2T^{-2}$

$\therefore$ 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

$$\text{Power} = \frac{\text{Work done}}{\text{time}} \left(P = \frac{W}{t} \right)$$

Since work done and time, both 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

$$P = \frac{W}{t} = \frac{Fs}{t} = F\left(\frac{s}{t}\right) = Fv$$

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)

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

$$\Rightarrow 1\ W = 1j\ s^{-1}$$

$$1\ \text{watt} = \frac{1\ \text{joule}}{1\ \text{second}}$$

Thus 1 watt is power consumed when 1 joule of work is done in 1 second. Other commonly used units of power are kilowatt and horsepower.

1. Kilowatt (kW):

   1 kW = 1000 watts

2. Horsepower (hp):

   1 hp = 746 watts = 0.746 kW

   $$\text{or } 1\ kW = \frac{1}{0.746}\ hp = 1.34\ hp$$

Dimensional formula of power

$$\text{Power} = \frac{\text{work}}{\text{time}} = \text{Force} \times \frac{\text{displacement}}{\text{time}}$$

$$= M^1L^1T^{-2} \times L^1/T^1$$

$$= M^1L^{1+1}T^{-2-1} = M^1L^2T^{-3}$$

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

Examples of energy

(i) Sound produced from an explosion can break the window panes and is capable of doing work. Hence sound is a form of energy.

(ii) 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.

(iii) 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.

(iv) 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.

(v) Electricity flowing through conductors can make the machines move and this is electrical energy.

(vi) 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.

(vii) 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.

(viii) The energy released during nuclear reactions and is capable of doing work 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 and
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 through an electric field maintained at a potential difference of one volt.

Calorie

Calorie is defined as the amount of heat energy required to raise the temperature 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 the position or motion of the body.

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.

☛ *Example of potential energy*

We have to wind the spring of a watch, in order that the watch 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 gears of the watch 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 generate 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

∴ work done on the body, W

= force (F) × displacement (h)

= (mg) × (h) = mgh

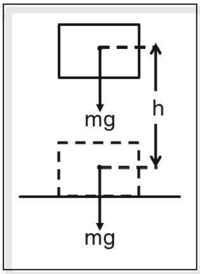


Figure 3.22

This work done on the body is stored in it in the form of gravitational potential energy.

∴ 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

To understand more about extension consider a wire of length 'ℓ' and area of cross–section 'A' fixed to a rigid support as shown.

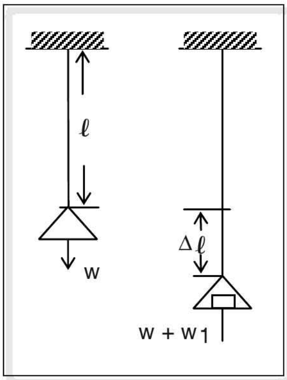


Figure 3.23

To the free end of the wire a scale pan is attached.

Increase the weights in the scale pan in steps and note down the change in the length of the wire ($\Delta \ell$)

[redacted]	
1	W
2	W + 50 g
3	W + 100 g
4	W + 150 g

The ratio of change in length to original length 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 as elastic limit. Thus Hooke's law states that "within the elastic limit the ratio of stress to strain is a constant."

$\therefore$ stress $\propto$ strain

$\frac{\text{stress}}{\text{strain}} = E$ where

E is a constant called the "modulus of elasticity".

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'.

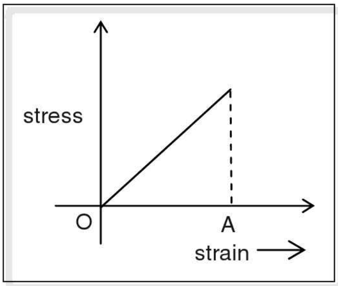


Figure 3.24

The graph of stress versus strain of an elastic body is as shown in the figure and A is the strain corresponding to the elastic limit of the body.

Derivation of expression for elastic potential energy

Consider a spring of a certain length suspended from a rigid support and a block of some mass attached to it (figure (a)). We do some work on it if we apply a force and give it an extension (figure (b)).

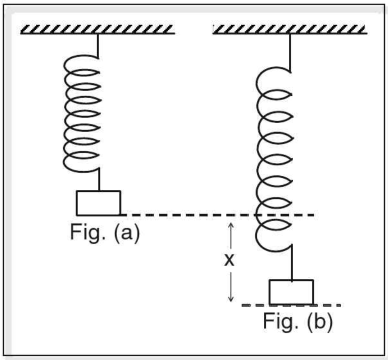


Figure 3.25

Work is done on the spring from a state where extension is zero, to a state where 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 $F_2 = k(x) = kx$

$\therefore$ Average force $F = \frac{F_1 + F_2}{2} = \frac{0 + kx}{2} = \frac{kx}{2}$

$\therefore$ work done on the spring, W = (Average force) (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' at rest' as shown in the figure. Let a constant force 'F' act on the body and displace it through a distance 'S' metre in time 't' second.

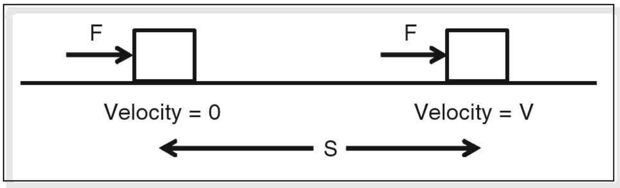


Figure 3.26

Let 'v' be the velocity of the body at the end of 't' seconds.

The acceleration produced in the body a = $\frac{\text{change in velocity}}{\text{time interval}}$

$\Rightarrow a = \frac{v - u}{t}$ (since u = 0)

$a = \frac{v}{t}$ --- (1)

$\therefore$ Force acting on the body is given by

$F = ma = m\frac{v}{t}$ --- (2) (from equation (1))

The displacement of the body is given by

s = average velocity × time

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

$$\therefore s = \left(\frac{V+0}{2}\right)t \qquad \text{--- (3)} \quad (\because u = 0)$$

Work done by the force is given by

$$W = \vec{F} \cdot \vec{S} \qquad \text{--- (4)}$$

$$= \frac{mv}{t} \cdot \frac{vt}{2} \qquad \text{(from (2) and 3)}$$

$$W = \frac{mv^2}{2}$$

Kinetic energy can be expressed as the amount of work done by the body before coming to rest.

$$\therefore \text{ kinetic energy} = \frac{1}{2}mv^2$$

$$K.E. = \frac{1}{2}mv^2$$

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

$\therefore$ work done, W = Δ 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.

Kinetic energy of the body is given by K.E. = $\frac{1}{2}$ mv^2

$$\therefore K.E. = \frac{1}{2}(mv)\,v = \frac{1}{2}pv$$

$$= \frac{1}{2}p\left(\frac{p}{m}\right) = \frac{p^2}{2m}$$

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 figure. 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.

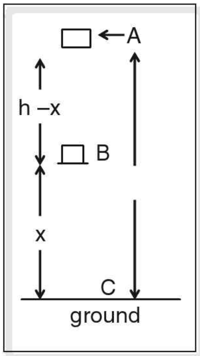


Figure 3.27

$\therefore$ potential energy at A, $P.E._A = mgh$.

Kinetic energy at A, $K.E._A = \frac{1}{2}m(0)^2 = 0$

$\therefore$ Total energy at A, $T.E._A = P.E._A + K.E._A = mgh + 0 = mgh \rightarrow (1)$

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 $v^2 = 2g(h - x)$

Now potential energy at B, $P.E._B = mgx$

Kinetic energy at B, $K.E._B = \frac{1}{2}mv^2 = \frac{1}{2}m\,2g(h - x) = mg(h - x) = mgh - mgx$

$\therefore$ the total energy at B, $T.E._B = P.E._B + K.E._B$

$T.E._B = (mg\,x) + (mgh - mgx)$

$= mgh \rightarrow (2)$

Finally at the ground, i.e., at position 'C', the height of the body is zero.

$\therefore$ Potential energy at C, $P.E._C = mg(0) = 0$

If 'v' is the velocity of the body on reaching the ground then, $v^2 = 2gh$

$\therefore$ Kinetic energy at C, $K.E._C = \frac{1}{2}mv^2 = \frac{1}{2}m(2gh) = mgh$

Thus, the total energy at C, $T.E._C = P.E._C + K.E._C$

$T.E._C = 0 + mgh = mgh \rightarrow (3)$

From equation (1), (2) and (3), 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 figure.

Position 'A' is the mean or rest 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.

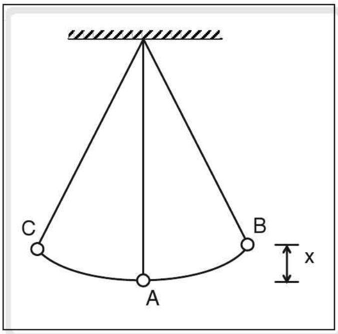


Figure 3.28

In between the mean position and the extreme positions, the energy of the bob is partly kinetic and partly potential.

Transformation of energy

According to the law of conservation of energy, energy can be neither 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, the mechanical energy is converted into 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 light 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 electrical motor transforms electrical energy into mechanical energy.
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.
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.
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 at a distance of 2 m, by applying a force of 4 N?

Solution

Work done = Force × displacement

Since the body is brought to rest, the force applied is a retarding force (F)

F = 4 N

☛ *Example*

S = 2 m

Work = force × displacement = 4 × 2 = 8 J

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. ($g = 10\ m\ s^{-2}$)

Solution

Load is lifted against gravity, hence work is done against the gravitational force.
∴ work done = mgh = potential energy

Height of one step = 0.2 m

Height of 20 steps = Total height = h = 20 × 0.2 = 4 m

m = 10 kg

work done = mgh

= 10 × 10 × 4 = 400 J

☛ *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

$$\text{Work done} = \frac{1}{2} m\left(v^2 - u^2\right)$$

m = 2 kg
u = 0
v = 20 m s^{-1}

$$\text{Work done} = \frac{1}{2} \times [20^2 - 0] = 400\ J$$

$$\text{power} = \frac{\text{work}}{\text{time}}$$

work = 400 J

time = 5 s

$$\therefore \ P = \frac{400}{5} = 80 \text{ W}$$

☛ *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 N

s = 20 m

t = 1 minute = 60 s

Work = force × displacement

∴ Work = 30 × 20 = 600 J

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{600 \text{ J}}{60} = 10 \text{ W}$$

☛ *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?

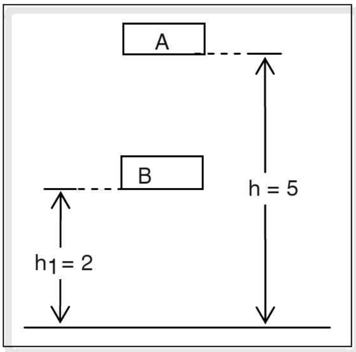


Figure 3.29

Solution

m = 2 kg

h = 5 m, h_1 = 2 m

At 'A' total energy is entirely potential energy = mgh

= 2 × 10 × 5

= 100 J

As it falls kinetic energy increases

∴ At 'B' its total energy

= potential energy + kinetic energy

Total energy at B = Total energy at A

(from law of conservation of energy)

Total energy at B = Potential energy + Kinetic energy

100 = 2 × 10 × 2 + kinetic energy

100 = 40 + kinetic energy

∴ kinetic energy at B = 100 – 40 = 60 J

Kinetic energy at the ground = potential energy at height h (from the law of conservation of energy)

Kinetic energy at the ground = 100 J

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

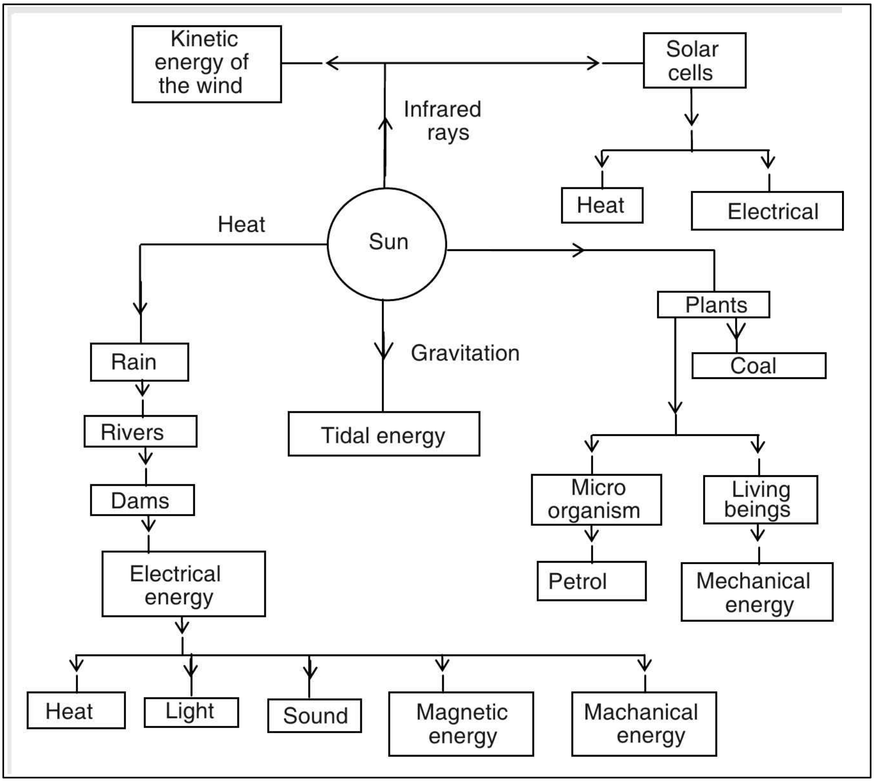


Figure 3.30

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.

Fossil fuels

Some sources of energy are obtained from fossilized substances, and hence they are called as fossil fuels. Hydrocarbons are the main constituents of fossil fuels. Traces of oxygen and other substances are found.

☛ *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.

(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, '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.

The following water of rivers and canals 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, carbondioxide, 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 heavy uranium nucleus is bombarded with a neutron it splits into two fragments with the release

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 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 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

Simple pendulum

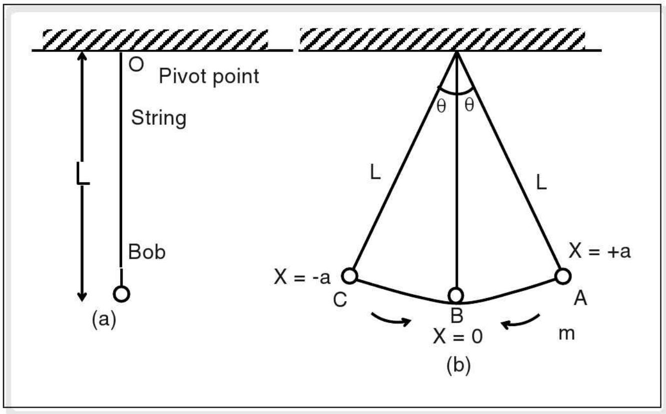


Figure 3.31

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.

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 the angular displacement.

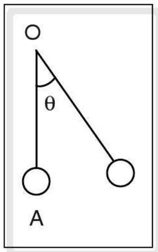


Figure 3.32

Length of the pendulum

It is the length of the string from 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 first extreme 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.

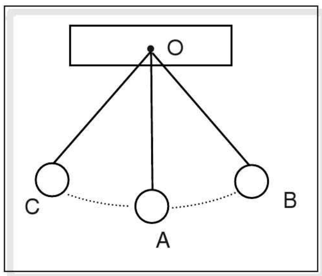


Figure 3.33

Amplitude: It is the maximum displacement of the bob from its mean position.

Period (T): It is the time taken for one complete oscillation.

Frequency (f): It is the number of oscillations made by the oscillating body in one second.

$$\text{Frequency} = \frac{1}{\text{period}}$$

$$f = \frac{1}{}$$

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 5°.
3. The period of oscillation of the pendulum varies directly as the square root of the length of the pendulum.

   $T \infty \sqrt{L}$ --- (1)
4. The period of oscillation of the pendulum varies inversely as the square root of acceleration due to gravity.

   $T \propto \frac{1}{\sqrt{g}}$ --- (2)

   Combining (1) and (2), we have,

   $$T \infty \sqrt{\frac{L}{g}}$$

   $$\therefore \; T = k\sqrt{\frac{L}{g}}$$

   k is the proportionality constant and is equal to 2π

   $$\therefore \; T = 2\pi\sqrt{\frac{L}{g}}$$

$$\therefore \; g = 4\pi^2 \frac{L}{T^2}$$

To find acceleration due to gravity using a simple pendulum

1. Adjust the length of the pendulum to a suitable length 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)

   $$T = \frac{t_{10}}{10} s$$
4. Calculate $\frac{L}{T^2}$
5. Repeat the experiment for different lengths.

   It is noted that $\frac{L}{T^2}$ is always constant
6. Calculate 'g' using the formula $g = 4\pi^2 \frac{L}{}$

S.No.	L (in m)	t_{10} (s)	$T = \frac{t_{10}}{10}$ (s)	$\frac{L}{T^2}$	$g = 4\pi^2 \frac{L}{T^2}$

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)

Then time period $T_1 = 2$ s.

When the length is doubled $L_2 = 2L$

Time period $T_2 = ?$

$$T_2 = 2\pi\sqrt{\frac{L_2}{g}} \qquad \text{——} \qquad (1)$$

$$T_2 = 2\pi\sqrt{\frac{L_2}{g}} \qquad \text{——} \qquad (2)$$

dividing (2) by (1)

$$\frac{T_2}{T_1} = \sqrt{\frac{L_2}{L_1}}$$

$$\frac{T_2}{2} = \sqrt{\frac{2L}{L}}$$

$$\frac{T_2}{2} = \sqrt{2}$$

$$T_2 = 2\sqrt{2} = 2 \times 1.41$$

$$T_2 = 2.82 \text{ seconds}$$

test your concepts

Very short answer type questions

1. State 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 are 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.
9. State Hooke's Law.
10. Name the force which is responsible for circular motion.
11. Define the S.I. unit of work.
12. A change in the state of rest or of uniform motion is produced by _____.
13. Name the force that acts outwards when the body undergoes circular motion.
14. What are lubricants?
15. 1 newton = _____ dyne.
16. Can all bodies have equal momentum?
17. What type of energy does a flying bird possess?
18. Friction always acts _____ to the surfaces in contact.
19. What is meant by unbalanced force?
20. When is the work done maximum with a given force and displacement?
21. The impulse of a body is equal to _____.
22. (i) Define inertia of motion.
    (ii) Define inertia of direction.
23. 1 kg_{wt} is equal to ________.
24. Define the S.I. unit of force.
25. What is the relation between momentum and kinetic energy?
26. The time period of a seconds pendulum _____.
27. (i) Give the dimensional formula of force
    (ii) Give the dimensional formula of momentum
    (iii) Write the dimensional formula of impulse
28. 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 ______.

29. State work energy theorem.

30. Define impulse.

Short answer type questions

31. Distinguish between renewable and non-renewable sources of energy.

32. Explain the cause of friction between two bodies in contact.

33. 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.

34. Distinguish between nuclear fission and fusion reactions.

35. Explain Newton's third law of motion with an example.

36. 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.

37. What is meant by energy crisis?

38. Derive the relation between newton and dyne.

39. 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? ($g = 10$ m s^{-2})

40. (i) Define periodic motion.

(ii) Define oscillatory motion.

41. Discuss with an example to show that inertia depends on mass.

42. 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.

43. Define simple harmonic motion.

44. State Newton's Laws of motion.

45. A body of mass 5 kg is dropped from a height of 20 m.

(i) What is 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 $g = 10$ m s^{-2}

Essay type questions

46. Describe an experiment to find 'g' using simple pendulum.

47. State and verify the law of conservation of momentum.

48. Define and derive an expression for gravitational potential energy.

49. State the law of conservation of energy and verify it in the case of a freely falling body.

50. Derive F = ma from Newton's second law of motion.

CONCEPT APPLICATION

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 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
E.	Unbalanced force	( )	e.	to reduce force of friction.
F.	Effect of 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 30: For each of the questions, four choices have been provided. Select the correct alternative.

16. The statement "friction is a self adjusting force" is ______.
(1) a false statement
(2) true in the case of static friction
(3) true in the case of rolling friction
(4) true in the case of sliding friction

17. The time period of a simple pendulum is independent of
(1) the shape of its bob.
(2) the material of the bob.
(3) the mass of the bob.
(4) 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 ________.
(1) 1 : 2
(2) 2 : 1
(3) 3 : 4
(4) 4 : 5

19. The weight of a body is 20 kg. This weight is equal to ______.
(1) 1960 N
(2) 196 J
(3) 196×10^5 dyne
(4) 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
(1) 0.025 J
(2) 0.0025 J
(3) 0.25 J
(4) 2.5 J

21. The momentum 'P' and kinetic energy 'E' of a body of mass 'm' are related as
(1) $P = \sqrt{2mE}$
(2) $P = \frac{1}{2} mE$
(3) $P = \frac{2m}{E}$
(4) $P = 2mE$

22. The force acting on a body when its momentum changes by 10 kg m s^{-1}, in 5 seconds is ______ N.
(1) 15
(2) 2
(3) 5
(4) 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
(1) 1 : 2
(2) 2 : 1
(3) 1 : 4
(4) 4 : 1

24. The change in momentum of a body
(1) is equal to the force applied on it.
(2) is equal to the product of force applied on it and the time of application of the force.
(3) Both (1) and (2) are true
(4) Both (1) and (2) are false

25. A fast moving car whose engine is switched off, comes to rest on a rough road. This is due to ______.
(1) static friction
(2) rolling friction
(3) sliding friction
(4) coefficient of rolling friction being greater than the coefficient of static friction

26. The rate of change in momentum of a body is
(1) equal to the force applied on it.
(2) proportional to the force applied on it.
(3) in the direction of applied force.
(4) All the above are true

27. Action and reaction
(1) always exist in pairs.
(2) are equal in magnitude.
(3) always act in opposite directions.
(4) All the above are true

28. Identify the false statement
(1) It is difficult to run on sand as the force of friction is small.
(2) Friction is necessary in everyday life.
(3) Friction causes wear and tear of the moving machinery parts.
(4) The coefficient 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
(1) Newton's first law of motion.
(2) Newton's second law of motion.
(3) Newton's third law of motion.
(4) All the above

30. A stone, tied to the string is whirled in a vertical circle. Then _____.
(1) the potential energy of the stone is maximum at the top most position
(2) the kinetic energy of the stone is maximum at the lowest position
(3) the potential energy is maximum at the bottom most position
(4) Both (1) and (2)

Concept Application Level—2

31. A bullet of mass 50 g moving horizontally with velocity 100 m s^{-1}, hits 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.

32. A porter carries 50 kg weight over his head. Discuss the work done in each of the following cases.
(1) Moving on horizontal road, with uniform velocity.
(2) Moving on a slope with uniform velocity.
(3) Moving on horizontal road, with acceleration.
(4) Lifting the luggage to keep it on his head.
(5) Lowering the luggage from his head, to the ground.

33. 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?

34. Explain why a car does not move when the force is applied on it by a person present inside the car?

35. 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.

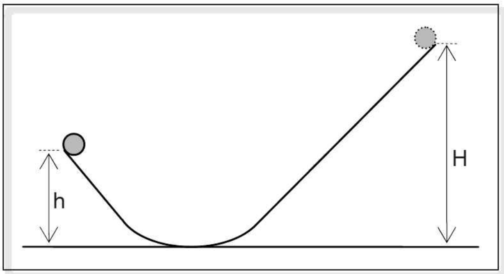
36. Discuss the conditions under which no work is done on a body.

37. A compressed spring is clamped in its compressed position and is then dissolved in an acid. Discuss what happens to its potential energy.

38. 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.

39. A log of wood is dragged up an inclined plane. Explain how the friction varies as the inclination of the plane is varied.

40. 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.

41. 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. Also, explain why the force is negative.

42. 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}.

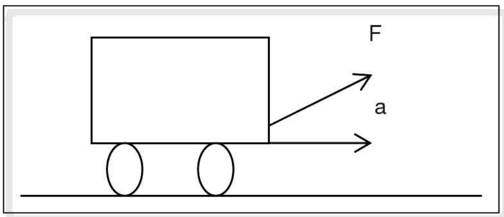
43. Consider a big cylindrical roller. Is it easy to pull it or push it? Explain.

44. 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 $g = 10$ m s^{-2}

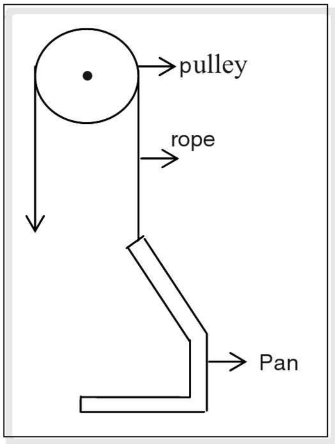
45. A person jumps onto a cement floor from a height of 1 m and comes to rest in 0.1 second. The same person on jumping from a height of 9 m into a sand pit, comes to rest in 1 second. Compare the forces exerted on him by cement floor and sand pit.

Concept Application Level—3

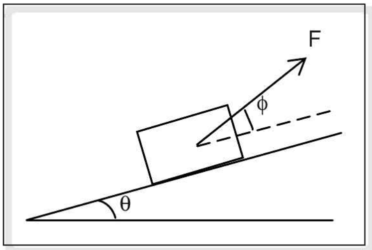
46. Are the direction of acceleration on a body and the direction of external force acting on the body always the same? If not, give an example. If the given statement is true, how do you account for it in the following situation? A toy car is tied to a string and is being pulled in a direction making an angle with the horizontal, whereas the toy car accelerates in a horizontal direction as shown in the figure.



47. 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.



48. 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 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.



49. 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.

50. 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?

key points for selected questions

Very short answer type questions

1. The total momentum before collision is equal to total momentum after collision.
2. Solar energy, Biogas
3. joule
4. Force acting perpendicular to the surface is called normal force.
5. Coal, petroleum
6. Newton's first law of motion.
7. Region in which a non contact force such as magnetic force acts is called force field.
8. The frictional force between fluid layers.
9. Within elastic limit of spring, stress in directly proportional to strain.
10. Centripetal force.
11. joule
12. Net external force.
13. Centrifugal force.
14. Materials used to make motion of a machine smoother by reducing friction.
15. 10^5
16. No
17. K.E. and P.E.
18. Tangential
19. Two or more external forces acting on a body cause the body to move.
20. Force applied and displacement are in the same direction.
21. Change in its momentum or product of force and time.
22. (a) The inability of a moving body to continue its motion unless external force acts to change its state.
    (b) The inability of a body moving in a particular direction to change its direction unless external force acts on it.
23. 9.8 N
24. Newton
25. $KE = \frac{p^2}{2m}$
26. Two second
27. (i) ML^2T^{-2}
    (ii) MLT^{-1}
    (iii) MLT^{-1}
28. $\frac{m_2}{m_1}a_2$
29. Work done by a body is equal to change in K.E. of the body.
30. Product of force and time

Short answer type questions

31. (i) Definition
    (ii) Examples
    (iii) Efficiency
    (iv) Cost-effectiveness
    (v) Advantages/Disadvantages
32. Irregulaties of surfaces.
33. Description of impulse.
    Ans: 15 kg m s^{-1}, F = 750 N
34. (i) Splitting of a heavy nuclei into fragments when bombarded with a neutron.
    (ii) Combining of lighter nuclei to form a heavy nucleus.
35. (i) Action and reaction forces.
    (ii) Force between the table and a book when placed on it.
36. The law of conservation of momentum.
    Ans: 1.875 m s^{-1}
37. Scarcity of energy resources in future.
38. (i) 1 N = 1 kg m s^{-2}
    (ii) 1 dyne = 1 g m s^{-2}

key points for selected questions

39. (i) Expression of frictional force.

(ii) Force required to accelerate + Force required to overcome friction

Ans: F = 45 N

40. (i) Repeats itself after regular intervals of time.

(ii) A periodic motion, in which body moves to and fro repeatedly.

41. Force required to push a metal ball and a plastic ball.

42. (i) Work–energy theorem

(ii) Definition of power

Ans: W = 2 j   P = 0.2 W

43. (i) Oscillatory motion

(ii) Restoring force acting on a body proportional to its displacement from mean position.

44. (i) Body remains in rest or of uniform motion unless compelled by an external force.

(ii) Rate of change of momentum directly proportional to the net force acting on a body.

(iii) Action and reaction forces.

45. (i) Potential energy at height 20 m

(ii) Conservation of energy.

Ans: (i) P.E. = 250 J, K.E = 750 J

(ii) K.E. at ground = 1 kJ

Essay type questions

46. (i) Description of equipment

(ii) Observations

(iii) Precautions

47. (i) Statement of law.

(ii) Rate of change of the momenta of two bodies.

(iii) Newton's third law.

49. (i) Statement of the law.

(ii) Initial P.E. and K.E.

(iii) P.E. and K.E. at an intermediate height.

(iv) Final P.E. and K.E.

50. (i) Statement of the law.

(ii) Definition of acceleration

KEY

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
13. potential, kinetic
14. friction

15. Match the following

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

Multiple choices

16. Choice (2)

17. Choice (4)

18. Choice (2)

19. Choice (3)

20. Choice (2)

21. Choice (1)

22. Choice (2)

23. Choice (1)

24. Choice (2)

25. Choice (2)

26. Choice (4)

27. Choice (4)

28. Choice (1)

29. Choice (1)

30. Choice (4)

Concept Application Level—2,3

Key points for select questions

31. Use

$m_1u_1 + m_2u_2 = v(m_1 + m_2)$

where v is the common velocity.

To find distance from wall at which the block falls, use $= u \times \sqrt{\frac{2h}{g}}$

where u is the horizontal velocity of the block, and h is the height of the wall.

Ans: 20 m

32. (1) $W = Fs\cos\theta$. 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

33. 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 × displacement, to find the linear distance covered by both.

34. (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.

35. Input energy = work done by effort

Output energy = work done by load.

36. Work = $Fs\cos\theta$, where F is the applied force, s the displacement and θ the angle between the two vectors.

Ans: 9 N

37. 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 reactions in an acid, when a metal dissolves in it.

38. (1) Friction is proportional to the net normal reaction force.

(2) $R = mg\cos\theta$

(3) $f \propto \cos\theta$

(4) $\cos 0° = 1$, $\cos 90° = 0$

39. 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(θ) value decreases and hence the force of friction also decreases.

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

Final State: P.E. = mgH, K.E. = 0

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

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

41. Use

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

Ans : –90N

42. 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}

43. 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?

44. 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 highest point, potential energy will be maximum.

At 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}

45. Use,

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

And find v by using

$$v = \sqrt{2gh}$$

Ans : $\frac{10 + \sqrt{5}}{3 + \sqrt{5}}$

46. 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?

47. 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?

48. 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.

Ans: $a = \frac{F_{net}}{m}$

$$= \frac{1}{m}[F\cos\varphi - \mu_k(mg\cos\theta - F\sin\varphi) - mg\sin\theta]$$

49. Use F = μmg

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

50. 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 $\frac{h_2}{2}$. ______ (v)

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)

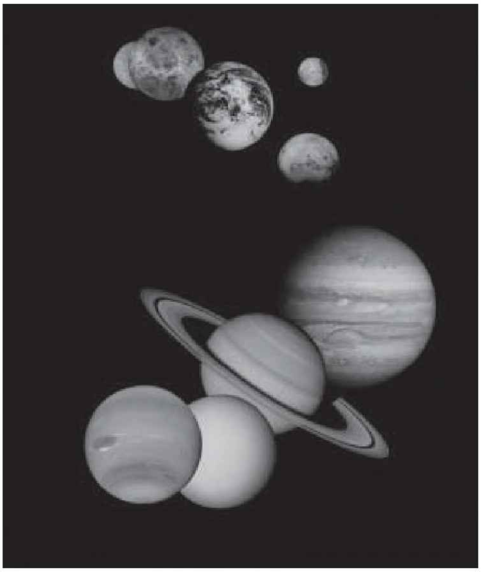
Now, find the kinetic energy of the ball in terms of its potential energy._____ (8)

By solving, (3) and (8) find the ratio of h_1 to h_2

Ans: $\frac{h_1}{h_2} = \frac{3}{2}$

4

Simple Machines



INTRODUCTION

Human beings are the most developed and the most intelligent of all species on the earth. Yet the humans are not perfect. We have quite a number of shortcomings. We do not possess the strength of the elephant or the agility of the 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

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 figure (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.

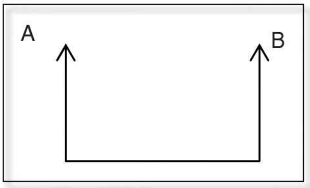


Figure 4.1

Now consider the following two forces, C and D acting at two different points as shown in the figure (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 the 'resultant' of all the forces.

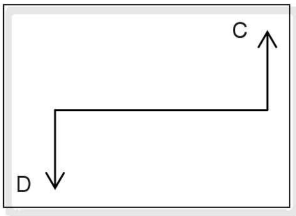


Figure 4.2

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 at the points M and N respectively as shown in the figure. The resultant of the parallel forces is R and acts at O on the rod.

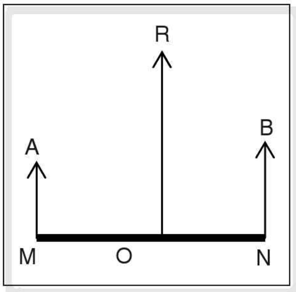


Figure 4.3

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 × MO = B × NO.

Resultant of unlike parallel forces

Unlike parallel forces acting on a horizontal rod are shown in the figure. The resultant of these forces act at point 'O' which lies outside the rod.

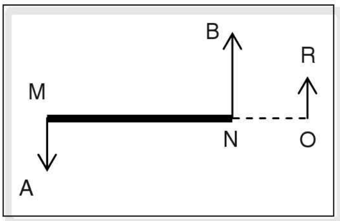


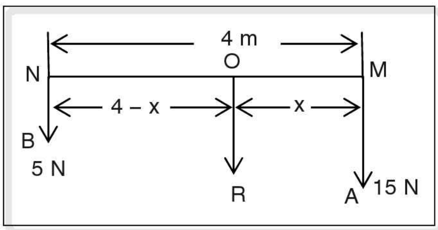
Figure 4.4

1. **Magnitude of R:** It is equal to the difference in the magnitude of the greater and the smaller forces.
   R = (A – B) or (B – A).
2. **Direction of R:** Same as the greater force (here in the direction of B).
3. **Position of O:** Outside MN on the side of the greater force such that
   A × MO = B × NO.

☛ *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

= 15 N + 5 N = 20 N.

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

A × MO = B × NO

15 × x = 5 × (4 − x)

15x = 20 − 5x

20x = 20

x = 1 m.

☛ *Example*

Find the magnitude, direction and position of the resultant, if the forces on the above problem are unlike?

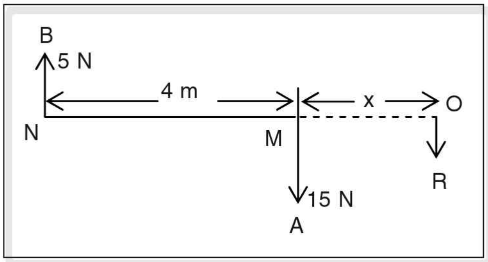


Figure 4.6

Solution

The magnitude of the resultant is

R = A − B (greater force − smaller force)

= 15 N − 5 N = 10 N

R = 10 N

Its direction is same as that of the greater force i.e., A.

Its position is outside MN on the side of A at point 'O' such that

A × MO = B × NO

15 × x = 5 × (4 + x)

15x = 20 + 5x

x = 2 m.

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 a simple machine. Although they are called simple machines, they can help us in a number of ways.

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.

☛ *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* Gears in vehicles, 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 the "mechanical advantage" of a machine.

$$\text{Mechanical advantage (M.A.)} = \frac{\text{Load (L)}}{\text{Effort (E)}}$$

$$\Rightarrow \text{M.A.} = \frac{L}{E}$$

Simple machines are tools which involve the usage of either levers or inclined planes or a combination of both.

☛ *Example*

Consider a machine with 5 as its mechanical advantage. 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 N
Given, the mechanical advantage of the machine, M.A. = 5.

Effort (E) = ?

$$\text{M.A.} = \frac{25}{E} = 5$$

$$\Rightarrow \text{Effort} = 5\text{ N}$$

Levers

Lever is a straight or 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.

1. Class I lever or levers of first order

When the fulcrum is in between the effort and load, the lever is classified as first order lever.

☛ *Examples* Scissors, seesaw, crowbar, etc.

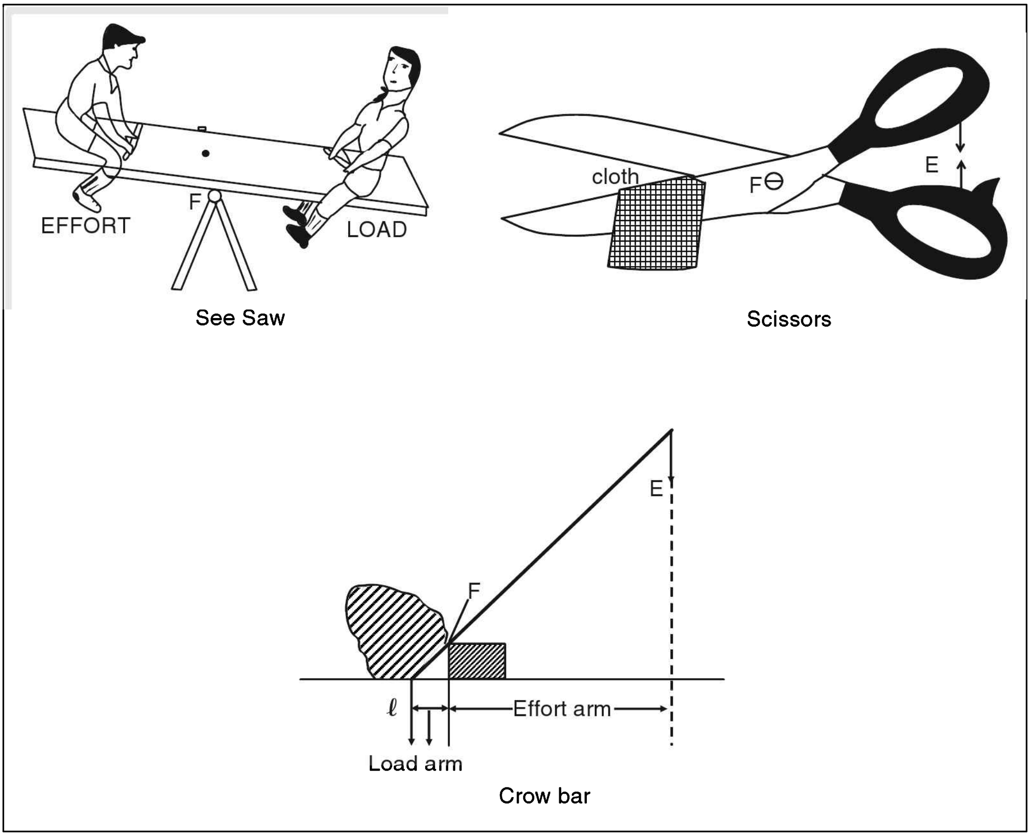


Figure 4.7

Mechanical advantage of class I lever

The following figure shows a class I lever under equilibrium. The fulcrum acts at point 'O' such that

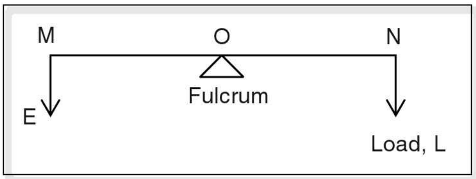


Figure 4.8

load × load arm = effort × effort arm.

$\Rightarrow L \times NO = E \times MO$

$\therefore \dfrac{L}{E} = \dfrac{MO}{NO}$. Thus the mechanical advantage of a lever of first order is,

$$M.A. = \frac{MO}{NO} = \frac{\text{effort arm}}{\text{load arm}}$$

Thus, the mechanical advantage of a lever depends on the ratio of the lengths of the effort arm to the

2. Class II lever or levers of second order

In this class of levers the load lies between effort and fulcrum.

Example

A nut cracker, wheel barrow, oar of a boat, bottle opener.

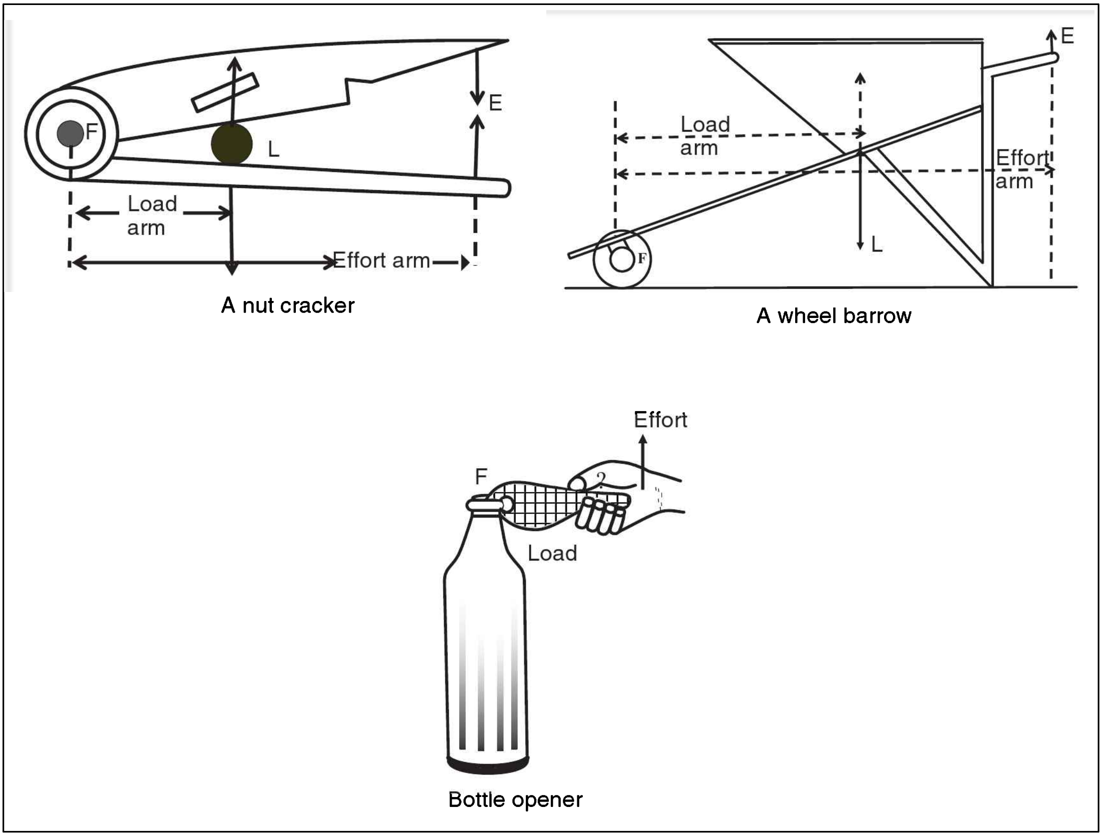


Figure 4.9

M.A. of class II lever

The following figure shows a class II lever under equilibrium.

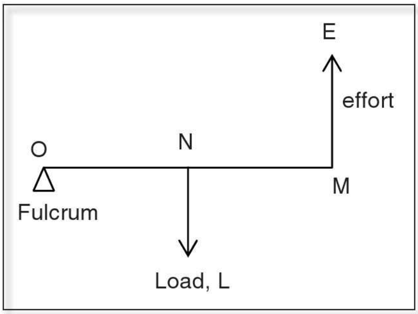


Figure 4.10

When the lever is in equilibrium
load × load arm = effort × effort arm
L × NO = E × MO. The mechanical advantage (M.A.) of the lever

$$= \frac{L}{E} = \frac{MO}{NO} = \frac{\text{effort arm}}{\text{load arm}}$$

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

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.

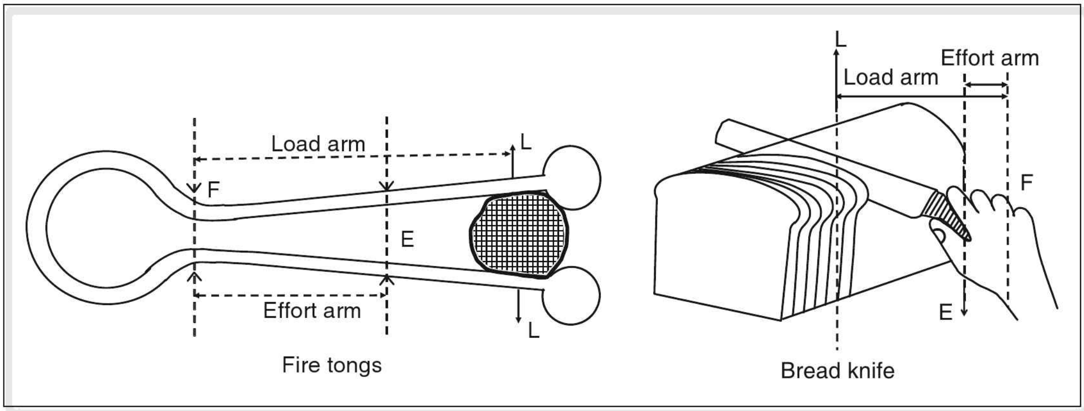


Figure 4.11

M.A. for class III levers

Consider a class III lever under equilibrium as shown in the figure below.

When the lever is in equilibrium,

load × load arm = effort × effort arm.

L × NO = E × MO. Thus the mechanical advantage of the lever,

$$(\text{M.A.}) = \frac{L}{E} = \frac{MO}{NO}$$

$$\therefore\ \text{M.A.} = \frac{MO}{NO} = \frac{\text{effort arm}}{\text{load arm}}$$

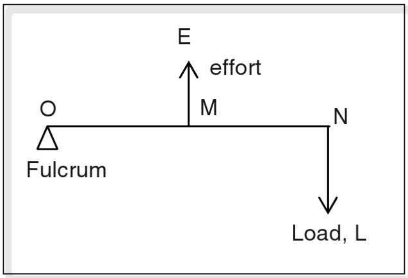


Figure 4.12

In Class III levers, the length of the load arm is always greater than that of the effort arm.

∴ 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

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) = ?

L = E × M.A.

= 10 × 5 = 50 N

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. ($g = 10\ m\ s^{-2}$)

Solution

Given:
Mass of the coal = 200 g. Thus, Load
(L) = 200 g_f
∴ L = 0.2 × 10 = 2 N. Length of the load arm = 30 cm and the length of the effort arm = 10 cm
load × load arm = effort × 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 × load arm = effort × effort arm

L × 8 cm = 32 N × 25 cm

$$L = \frac{32\text{N} \times 25\text{cm}}{8\text{cm}} = 100\text{ N}.$$

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.

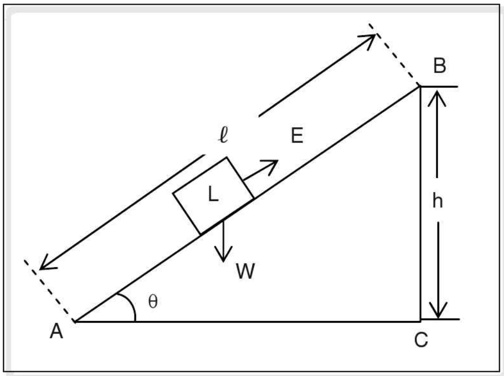


Figure 4.13

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'.

Work done by the effort = effort × displacement

$\Rightarrow E \times AB = E \, . \, \ell$

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.

Work done on the load = load × displacement

$\Rightarrow W \times BC = W. h$

Since the load is raised to the same height 'h' in both cases, work done is the same.

$$\therefore W \times h = E \times \ell \Rightarrow \frac{W}{E} = \frac{\ell}{h}.$$

The ratio of load to effort is the mechanical advantage (M.A.) of the plane.

$$\therefore \text{M.A.} = \frac{\ell}{h} = \frac{\text{length of the inclined plane}}{\text{height of the inclined plane}}$$

$$\text{M.A.} = \frac{1}{\sin\theta}\left(\because \sin\theta = \frac{h}{\ell}\right)$$

As $0° < \theta < 90°$, $\sin\theta < 1 \Rightarrow$ 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 $\ell = 4$ m.
height of the inclined plane, h = 1 m.
mechanical advantage, M.A. of the inclined plane is

$$\text{M.A.} = \frac{\ell}{h} = \frac{4\text{ m}}{1\text{ m}}$$

M.A. = 4

By definition, M.A. is equal to $= \dfrac{\text{load (L)}}{\text{effort (E)}}$

$$\Rightarrow 4 = \frac{48\text{N}}{E}$$

$$\therefore E = \frac{48\text{N}}{4}$$

E = 12 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 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 the axis of rotation. In general, a line passing through the point of rotation, such that a body rotates about this line is called the axis of rotation. The turning effect of the force on the body about the point or axis of rotation is called the 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 minimum.
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:

(i) the magnitude of the force applied and

(ii) 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 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 τ = Force × 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 N.
Distance of the point of application of force from the axis of rotation, r = 20 cm.
Hence, Torque (τ) = F × r

$$= 8 \text{ N} \times \frac{20}{100} \text{ m}$$

$$= 1.6 \text{ N m}$$

☛ *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
Torque (τ) = 5 N m

Force (F) = 10 N

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 N and the magnitude of the radius vector,

$r = 40 \text{ cm} = \frac{40}{100} \text{ m}$

Torque (τ) $= 12 \text{ N} \times \frac{40}{100} = 48 \text{ N m}$.

In the 2nd case, applied force F = 40 N and the length of the radius vector is to be found.

r = ?

$\tau = F \times r$ is the same in both the cases. Hence

$48 = 40 \times r$

$\therefore$ r = 1.2 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,

(a) the resultant of all forces on the body is zero such that its state of rest or of uniform motion do not change and

(b) 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 distances of each weight from the point of suspension. Let them be ℓ_1, ℓ_2, ℓ_3, ℓ_4, ℓ_5 and ℓ_1 respectively.

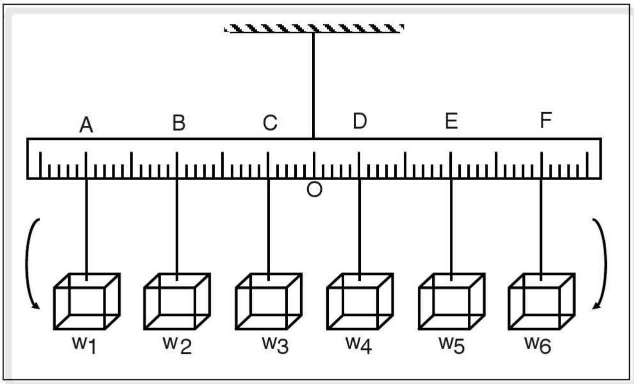


Figure 4.14

5. Total anti-clockwise moments = $W_1\ell_1 + W_2\ell_2 + W_3\ell_3$ and
   total clockwise moments = $W_4\ell_4 + W_5\ell_5 + W_6\ell_6$
6. In equilibrium, scale remains horizontal
   i.e., $W_1\ell_1 + W_2\ell_2 + W_3\ell_3 = W_4\ell_4 + W_5\ell_5 + W_6\ell_6$

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 produce a turning effect on the body is called a 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 × 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 vectorial 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 distance of 30 cm from its zero division and a load of 60 g_{wt} is tied at its zero division end 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 ($W_2 \ell_2$).

$\therefore W_1 \ell_1 = W_2 \ell_2$

W_1 = weight of the scale

ℓ_1 = distance of centre of gravity of the scale from the point of suspension

= 50 – 30 = 20 cm

W_2 = load = 60 g_{wt}

ℓ_2 = 30 cm = distance of load from the point of suspension

$\therefore W_1 \times 20 \text{ cm} = 60\ g_{wt} \times 30 \text{ cm}$

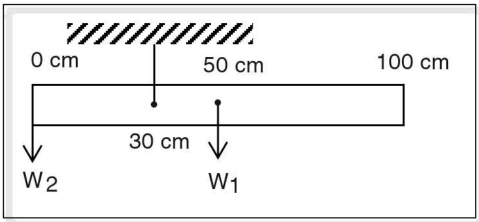


Figure 4.15

$$\therefore W_1 = \frac{60\ g_{wt} \times 30 \text{ cm}}{20 \text{ cm}} = 90\ g_{wt}$$

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

$W_1\ell_1 = W_2\ell_2$, where W_1 = 160 g_{wt}, W_2 = 240 g_{wt} and ℓ_1 = 80 cm – 50 cm

100 g wt × (80 – 50) cm = 240 $g_{wt} \times \ell_2$

$$\therefore \ell_2 = \frac{160 ´ 30}{240}$$

= 20 cm

☛ *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 m

Applied force = 4 N

∴ Moment of the couple = Force × perpendicular distance

= 4 × 0.3

= 1.2 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 and a movable rider which can be moved along the length of the beam. The beam is suspended by a hook 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'.

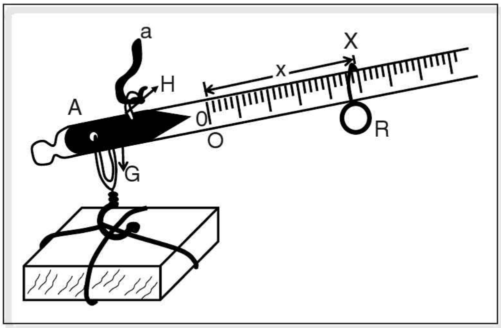


Figure 4.16 Roman steelyard

If G is the centre of gravity of the beam and W is its weight then,

W × HG = R × HO……..(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 × HA + W × HG = R × HX ----- (2)

On subtracting equation (1) from equation (2), we get

L × HA = R × OX

$$\Rightarrow L = \frac{R \times OX}{HA}$$

Since R and HA are constant for a given steelyard, L ∝ OX.

The beam is calibrated in terms of weight such that the position of the rider gives the weight

☛ *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 the axle. A wheel is attached to the axle such that they have a common axis of rotation.

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.

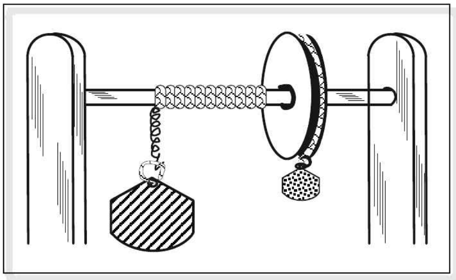


Figure 4.17 Wheel and axle

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 = $E \times 2\pi R$

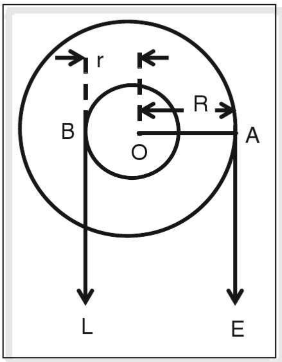


Figure 4.18

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

$$E \times 2\pi R = L \times 2\pi r$$

$$\Rightarrow E \times R = L \times r \text{ or}$$

$$\frac{L}{E} = \frac{R}{r}$$

Mechanical advantage of wheel and axle = $\frac{L}{E} = \frac{\text{Load (L)}}{\text{Effort (E)}}$

$$= \frac{\text{Radius of the wheel}}{\text{Radius of the axle}} = \frac{R}{r}$$

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,
displacement of effort = $2\pi R$
displacement of load = $2\pi r$
given $2\pi R = 5(2\pi r)$

$$\text{M.A.} = \frac{2\pi R}{2\pi r}$$

$$= \frac{5(2\pi r)}{2\pi r}$$

$$\therefore \text{M.A.} = 5$$

$$\text{Also, M.A.} = \frac{L}{E}$$

$$5 = \frac{L}{10\ \text{N}}$$

$$\therefore L = 50\ \text{N}$$

R = 35 cm; r = ?

$$5 = \frac{2\pi(35)}{2\pi r}$$

$$\therefore r = \frac{35}{5} = 7\ \text{cm.}$$

Screw jack

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 the 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.

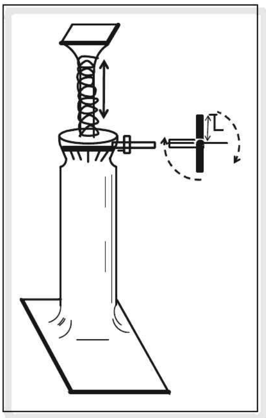


Figure 4.19

Work done by the effort = $E \times 2\pi \ell$
Where ℓ = length of the lever and
E = effort

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.

$\therefore$ 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 thew 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 the driven gear. The gear which rotates another gear is called the driving gear. The number of teeth in the driving and the driven gears decide whether speed is transferred or torque.

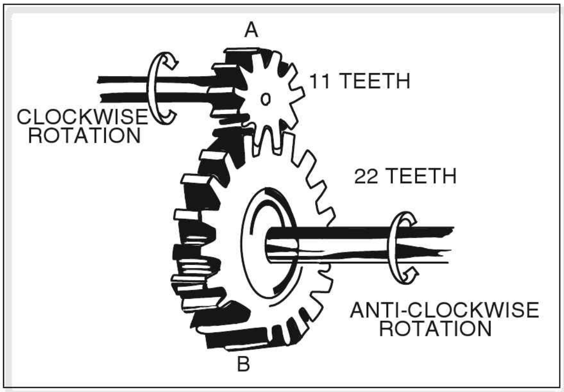


Figure 4.20 Two gear system in external contact

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

$$\text{Gain in torque} = \frac{\text{No. of teeth in the driven gear } (N_2)}{\text{No. of teeth in the driving gear } (N_1)}$$

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 a train of gears.

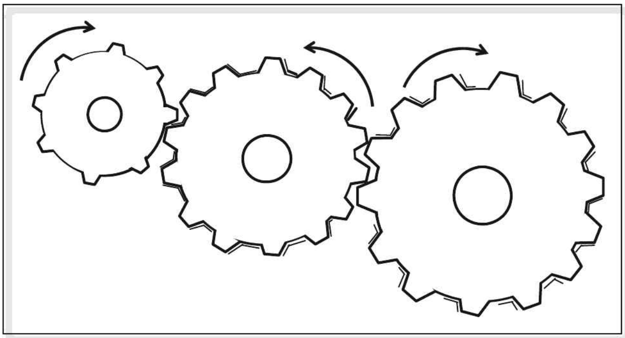


Figure 4.21

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
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 few examples of 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?

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 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 can 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 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 into a truck. The length is 3 m and the end which touches the truck is at the 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 how speed of rotation can be increased using gears with the help of an example.

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 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 one of the methods to verify the principle of moments.

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. Gears are used in vehicles to transmit motion and power.

2. An increase in the pitch of the screw increases the mechanical advantage of a screw jack

3. A wheel and axle can be treated as a modified form of a first order lever.

4. Moment of force is the product of the force applied on a body and the perpendicular distance between parallel forces, producing pure rotation.

5. The pair of forces in a couple need not always be equal in magnitude.

6. The mechanical advantage of an inclined plane increases with its slope.

7. 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.

8. Roman steelyard works on the principle of __________.

9. A pair of scissors is an example of ______ order lever.

10. ______ is the modified form of an inclined plane.

11. A set of gears is called a _______ of gears.

12. 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.

13. A road on a hill is an example of ______.

14. 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.

A.	S.I. unit of a pair of equal, unlike, parallel, coplanar forces	( )	a.	load ÷ 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

(1) increase the speed of rotation. (2) increase the torque
(3) Both (1) and (2) (4) Neither (1) nor (2)

17. If the number of teeth in the driven gear of a vehicle is less than that in its driving gear, the vehicle gains _____.

(1) speed (2) momentum
(3) Both (1) and (2) (4) None of the above

18. A simple machine

(1) acts as a force multiplier.
(2) acts as a speed multiplier.
(3) helps to change the direction of application of effort.
(4) 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

(1) 750 N (2) 500 J (3) 850 J (4) 900 J

20. In a Roman steel yard, the distance of the rider from its zero mark is proportional to the

(1) weight of the load.
(2) distance of the position of centre of gravity of the steel rod from the fulcrum.
(3) distance of point of suspension of the load from the fulcrum.
(4) All the above

21. The work done in sliding a wooden box of mass 5 kg along an inclined plane of inclination 30° and length 10 m is _______ j.($g = 10\ m\ s^{-2}$)

(1) 500 (2) 250 (3) 125 (4) 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

(1) 42 N m, anti-clockwise (2) 42 N m, clockwise
(3) 8 N m, anti-clockwise (4) 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

(1) Only A is true (2) Only B is true
(3) Both A and B are true (4) 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 g_f:1 cm. If the rider is displaced by 20 cm from its zero mark, the load attached to the steel yard is ________.

(1) 40 g_f (2) 4 kg (3) 400 g_f (4) 0.04 kg_f

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

(1) 40π (2) 20π (3) 120π (4) 80π

26. M.A. is always greater than 1 in

(1) I class levers (2) II class levers (3) III class levers (4) 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

(1) 2w (2) $\frac{\sqrt{3}w}{2}$ (3) $\frac{w}{2}$ (4) $\frac{2w}{\sqrt{3}}$

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

(1) $\frac{5}{3}$ times the initial M.A (2) $\frac{3}{2}$ times the initial M.A.

(3) $\frac{25}{9}$ times the initial MA (4) $\frac{9}{4}$ 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.

(1) 1 (2) 2 (3) 3 (4) 4

30. A wheel and axle with radii 20 cm and 5 cm respectively can be considered as

(1) a second order lever with its M.A. > 1 (2) a third order lever with its M.A. < 1

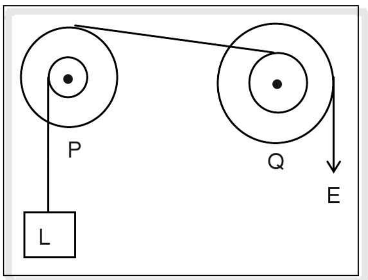
(3) a first order lever with its M.A. > 1 (4) a first order lever with its M.A. < 1

Concept Application Level—2

31. 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?

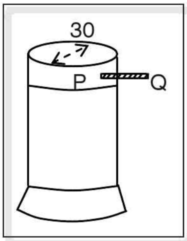
32. The efficiency of a simple machine having mechanical advantage 5 is 80%. If the displacement of the effort in lifting a load by using the machine is 20 cm, find the displacement of the load.

33.



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 kg_{wt} find E.

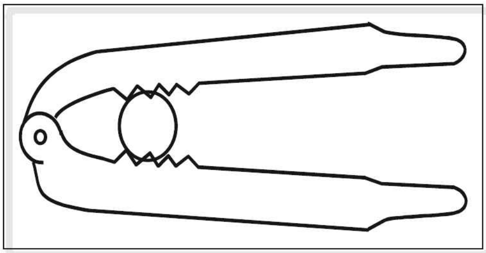
34.



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. (1 quintal = 100 kg_{wt})

35. 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.

36.



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.

37. 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_{wt} ($g = 10\ m\ s^{-2}$)

38. 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?

39. 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.

40. 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.

41. 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.

42. 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.

43. How can we obtain the resting point–indicating equilibrium, even with unequal masses in the two pans of a physical balance?

44. 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.

45. 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_{wt}. Find the magnitudes of the effort and the original load. (g = 10 m s^{-2})

Concept Application Level—3

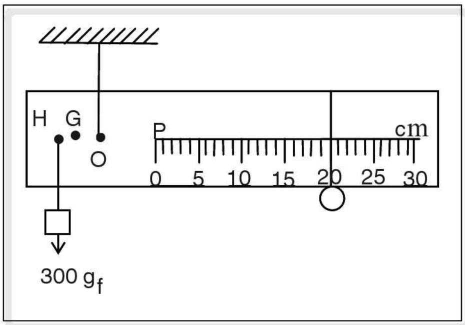
46. A scooter or a motor-cycle is a compound machine made up of several simple machines. Study the following parts of a scooter/motor cycle and identify the simple machines involved in them.

(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.

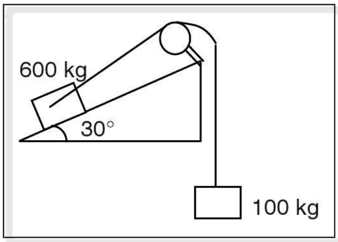
47. How can a spring balance and a rigid rod be used to weigh objects beyond the maximum reading of the balance? Explain

48.



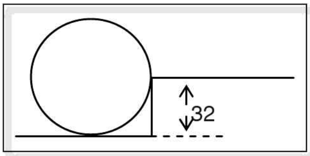
A balance similar to Roman steelyard is shown in the figure. G is the position of centre of gravity of the beam. Given OG = 3 cm, OH = 4 cm and OP = 5 cm. If the weight of the rider is 60 g_f, find the weight of the beam, least count of the balance and the maximum load that can be measured using the balance.

49. A load of 600 kg_{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?

50.



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 kg_{wt} find the minimum force that can be applied on the roller for the purpose. (take g = 10 m s^{-2})

key points for selected questions

Very short answer type questions

1. Algebraic sum of moment of forces is zero.
2. Scissors, crowbar, bottle opener, nut cracker, fire tongs, bread knife.
3. To increase mechanical advantage.
4. A rod capable of rotating about a fixed point.
5. Position of rider.
6. second class/second order
7. M.A. = 1⁄sinθ = $\frac{\text{lenght of inclined plane}}{\text{height of inclined plane}}$
8. A device which allows us to apply a force at a convenient point to overcome the force at other point.
9. The fixed point in a lever is called fulcrum.

   Distance between load and fulcrum, and distance between effort and fulcrum.
10. Work done by the effort = work done on the load. Winches, capstans.
11. Levers, pulleys, inclined plane.
12. Vector
13. Principle of moments
14. The forces whose lines of action are parallel.
15. I order, II order, III order levers
16. equal to
17. Parallel force acting in same direction and in opposite direction.
18. Principle of screw.
19. 150j
20. Turning effect of the force on a body about the axis of rotation.

    S.I. – N m, C.G.S. – dyne cm

21. I order : M.A. = 1
II order : M.A. > 1
III order : M.A. < 1

22. Increase in the length of lever.

23. Distance between the application of force and fixed point.

24. To increase mechanical advantage by increasing effort arm.

25. Two equal, coplanar unlike forces acting in the same direction.
C.G.S. – N m S.I. – dyne cm

26. Gears

27. Forces acting on a body do not cause change in the state of rest or of uniform motion of a body.

28. A smooth, rigid flat surface which is at an angle to the horizontal plane.

29. Toothed wheel that transmits the motion and power. Watches. cycle chains, flour mills.

30. Moment of forces on one side = Moment of forces on the other side.

Short answer type questions

31. (i) Fixed point
(ii) Axis of rotation

32. $\text{M.A.} = \dfrac{\text{Radius of the wheel}}{\text{Radius of the axle}}$

33. (i) Leads to pure rotation.
(ii) Can never be replaced by a single force
(iii) Resultant couple = vectorial sum of the moments of individual couples acting on it.

34. To do more work with less effort.

35. (i) Pair of equal, coplanar, and unlike parallel forces acting on a rigid body.
(ii) Lines of action of the forces are not same.
(iii) Produces turning effect.
(iv) Single force cannot produce couple.

36. Work done on load = work done by effort
Ans: 7 cm and 3.5 cm

37. (i) Force multiplier
(ii) Direction of force
(iii) Application of force
(iv) Speed

38. $\text{M.A.} = \dfrac{\ell}{h}$
Ans: 2 and 50 N

39. (i) Work done by the effort.
(ii) Work done on the load.
(iii) Work done by the effort = work done on the load
(iv) $\text{M.A.} = \dfrac{L}{E}$

40. (i) Definition
(ii) Position of R
(iii) Effect

41. (i) Cycle chains
(ii) Increase in the speed of rotation by applying less force on the pedals.

42. (L) (ℓ) = (E) (e)
Ans: 4

43. (i) Fulcrum, load, effort and
(ii) Their relative positions

44. (i) Increase or decrease the speed of rotation.
(ii) Transmit motion and power.
(iii) Produce a change in the direction of the applied force.

45. (i) Definition
(ii) Diagram
(iii) Positions of fulcrum, load and effort.

Essay type questions

46. (i) Definition
(ii) Resultant
(iii) Direction, magnitude and position of R.

key points for selected questions

47. (i) Steel yard with hole
(ii) Sliding rider
(iii) Principle of moments

48. Definition

49. (i) Common axis
(ii) Different radii
(iii) Wheel radius > axle radius
(iv) Load to axle
(v) Effort to wheel

50. (i) Suspend scale
(ii) Attach weights
(iii) Note the distances of weights from point of suspension.

KEY

Concept Application Level—1

True or 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
15. Match the following

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 Choices

16. Choice (3)
17. Choice (3)
18. Choice (4)
19. Choice (2)
20. Choice (1)
21. Choice (2)
22. Choice (2)
23. Choice (2)
24. Choice (3)
25. Choice (4)
26. Choice (2)
27. Choice (2)
28. Choice (2)

29. Choice (3)

30. Choice (3)

Concept Application Level—2, 3

Key points for select questions

31. (i) Apply the law of moments.
(ii) Let the weight of 200 g_f be suspended at distance 'x'.
(iii) moment of force = force × 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.

32. (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

33. (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 kg_f

34. (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 kg_f

35. (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 × displacement of effort = load × 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

36. (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

37. (i) Relation between length, height of the inclined plane and load, effort
(ii) Effort = 3000 N

38. (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.

39. (i) $\tau = r F \sin\theta$

(ii) Torque = 30 N m

40. (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}

41. (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.

42. (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

43. (i) Consider the adjustments made to a physical balance while determining the zero resting point.

(ii) By adjusting screws.

44. (i) Force = Impulse ÷ Time

(ii) Force on the gun = force on the bullet = $m\left(\frac{v-u}{t}\right)$, where v and u are final and initial velocities of bullets respectively and m = mass of each bullet.

(iii) Couple = force × perpendicular distance between the forces.

(iv) 30 N m

45. (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.

(vi) Effort = 10 N ; Load = 100 N

46. (i) Equations of motion, Newton's second law of motion and principle of moments.

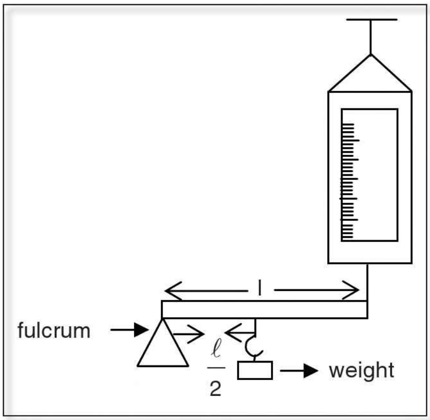
(ii) Calculate retardation using
$$a = \frac{V^2 - u^2}{2S}.$$

(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: effort = load/M.A. = F/M.A.

(v) 1.5 N

47. (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 × distance of weight from the fulcrum = reading × distance of spring balance from the fulcrum.

48. (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

49. (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.

50. (i) Anlayse 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.

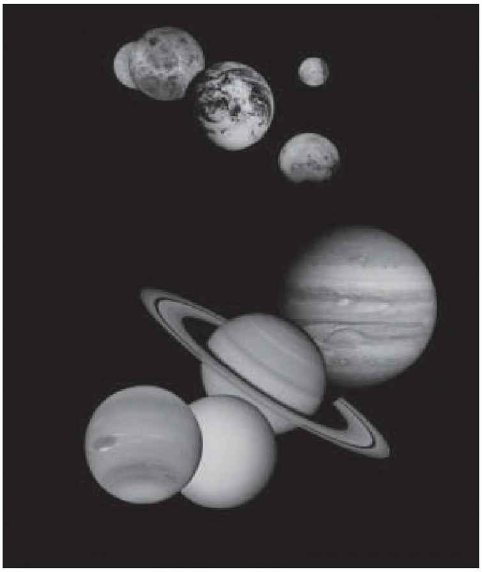
(v) For a given torque, 'F' is minimum where 'r' is maximum.

(vi) Maximum 'r' is the diameter of the roller.

(vii) E = 110 N

5

Gravitation



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 the 'Ptolemic theory' or the '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 Tyco 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

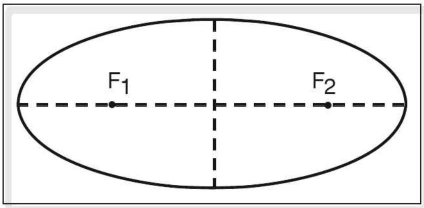


Figure 5.1 An ellipse

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 figure (5.1).

   It has two axes mutually perpendicular to each other. The longer axis is called the major axis and the shorter one is called the 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 figure (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 focii 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 figure (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"**.

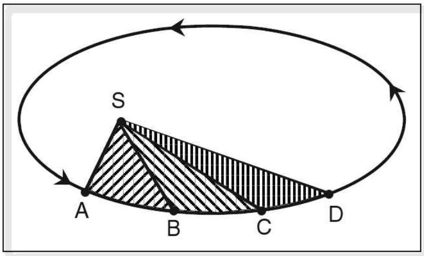


Figure 5.2

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 radius 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

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 the 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,

$F \propto m_1 m_2$ --------------(1) and

$F \propto \frac{1}{r^2}$ ------(2) as follows

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.

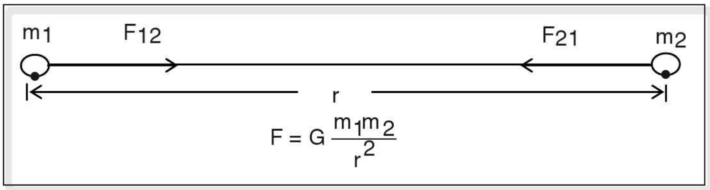


Figure 5.3 Force of gravitation between two particles. The force due to m_1 on m_2 is denoted by F_{12} and that due to m_2 on m_1 is F_{21}

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

$$F \propto \frac{m_1 m_2}{r^2}$$

$$\Rightarrow F = G\left(\frac{m_1 m_2}{r^2}\right) \text{-----(3)}$$

where 'G' is the constant of proportionality called the 'universal gravitational constant'.

Equation (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 (3) becomes,

$$F = G\left(\frac{1kg \times 1kg}{(1\,m)^2}\right)$$

$\Rightarrow$ F = G newton.

Thus the constant 'G' can be defined as "the gravitational force of attraction between two bodies of unit mass separated by unit distance".

Rewriting the equation (3) we get $G = \frac{F r^2}{m_1 m_2}$.

Thus, the S.I. unit of $'G' = \frac{(\text{unit of force}) \times (\text{unit of distance})^2}{(\text{unit of mass})^2} = N\,m^2\,kg^{-2}$.

Similarly C.G.S. unit = dyne $cm^2\,g^{-2}$

Let $m_1 = m_2 = 1$ unit

r = 1 unit

Then the equation (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 100 years later by a British scientist Henry Cavendish. Today the accepted value of G is 6.67×10^{-11} N $m^2\,kg^{-2}$.

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 then given by $F = \frac{m v^2}{r}$, where 'm' is the mass of the planet, 'v' is the velocity of the planet in its orbit called the 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 = 6.67×10^{-11} N m^{-2} kg^{-2}

∴ gravitational force of attraction, $F=\frac{G m_1 m_2}{r^2}=\frac{6.67\times10^{-11}\times600\times100}{(20)^2}=1.0005\times10^{-8}\text{ N}$.

∴ 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 comparision 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 acceleration on 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.

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 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 the 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 above figure (5.4) represents the gravitational force between two spherical bodies like the earth and the moon.

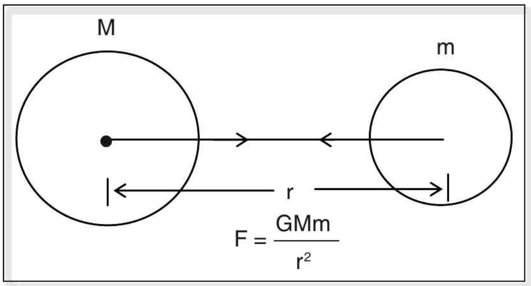
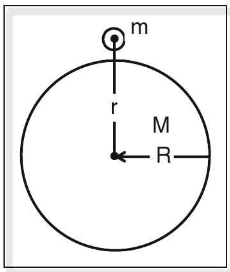


Figure 5.4

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 figure (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), As discussed earlier, weight (mg) of a body is the gravitational pull of the body towards the centre of the earth.

$$\therefore mg = \frac{GMm}{R^2} \Rightarrow g = \frac{GM}{R^2}.$$

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

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 $= 64 \times 10^{5}$ m

Universal gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Acceleration due to gravity on the surface of the earth, $g = \frac{GM}{r^2}$

$$= \frac{6.67 \times 10^{-11} \times 6 \times 20^{24}}{(64 \times 10^{5})} = 9.77 \text{ m s}^{-2}$$

☛ *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

Acceleration due to gravity on the surface of Jupiter, $g = \dfrac{GM}{R^2}$

$$= \frac{6.67 \times 10^{-11} \times 2 \times 10^{27}}{(7 \times 10^7)^2} = 27.22 \text{ m s}^{-2}$$

Acceleration due to gravity–Factors affecting it.

Unlike universal gravitational constant, the value of acceleration due to gravity is not constant at any place on 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.

1. **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 $g = \dfrac{g_o}{\left(1+\dfrac{h}{R}\right)^2}$.

When h<<R, the relation is approximated and is given by $g = g_o\left(1 - \dfrac{2h}{R}\right)$.

The following table gives an idea about the variation of 'g' with altitude.

[redacted]	
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 ms^{-2} and radius of earth, R = 6400 km).

Solution

Given, height from the surface of the earth, h = 1600 km.

Radius of the earth, R = 6400 km.

Acceleration due to gravity on the surface of the earth, g_0 = 9.8 m s^{-2}

$$g = \frac{g_0}{\left(1+\frac{h}{R}\right)^2} = \frac{9.8}{\left(1+\frac{1600}{6400}\right)^2} = \frac{9.8\times 16}{25} = 6.272\ \text{m s}^{-2}$$

☛ *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 m s^{-2} radius of the earth, R = 6400 km.

Height, h = 5 km

Here h << R, ∴ 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 at depth 'd' (g_d) and at the surface of the earth (g_o) is approximately given by the expression $g_d = g_o\left(1-\frac{d}{R}\right)$. 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.

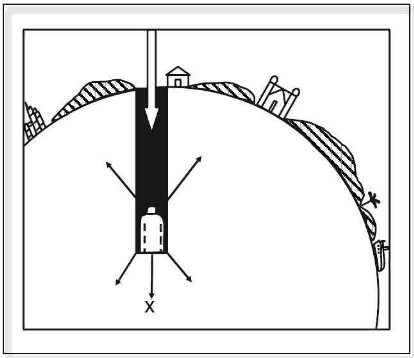


Figure 5.6

☛ *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 m s^{-2}

Radius of the earth, R = 6400 km

∴ acceleration due to gravity at the given depth, $g = g_0\left(1-\dfrac{d}{R}\right)$

$$= 9.8\ 3\left(1-\frac{1600}{6400}\right) = 9.8 \times \frac{3}{4} = 7.35 \text{ m s}^{-2}$$

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 figure (5.7).

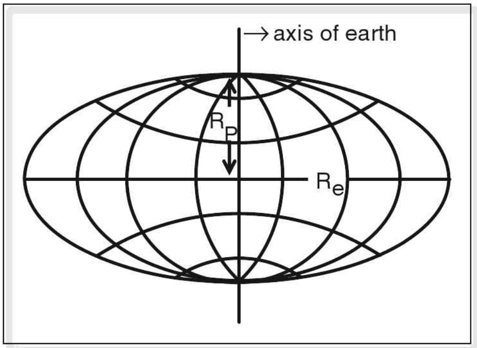


Figure 5.7

Thus, the radius of the earth measured along its equator, also called the equatorial radius (R_E); is greater than its radius measured along the poles, also called the polar radius (R_p). Since $g=\dfrac{GM}{R^2}$, 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 $g_E=\dfrac{GM}{R_E^{\,2}}$ and $g_P=\dfrac{GM}{R_P^{\,2}}$.

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

This disproved the theory put forward by Aristotle according to which a heavier body falls faster than a lighter body.

That the mass doesn't 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 weightlessness while falling down. 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.

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 figure (8).

W = w + w + w + …….w (n times)

W = nw

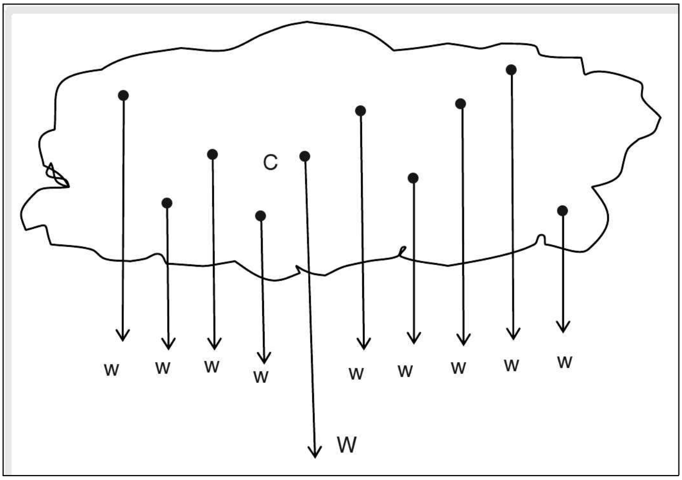


Figure 5.8

The point inside the body where this resultant weight acts is called the centre of gravity 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.

Equilibrium of bodies

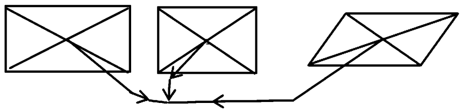
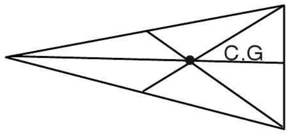
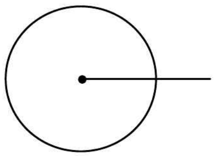
We have already seen that the centre of gravity is a point inside a body where the entire weight of the

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

Rectangle, square or parallelogram	Point of intersection of diagonals	
Triangle	Point of intersection of medians	
Sphere	Geometric centre	

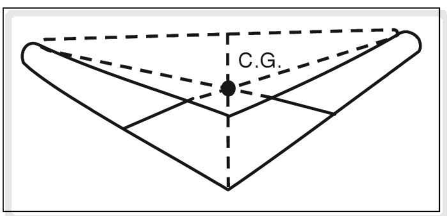
Centre of gravity of irregular bodies

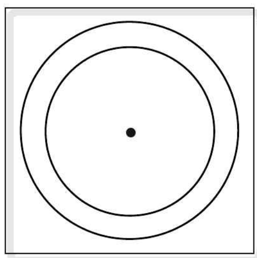
Take a piece of cardboard having irregular shape. Make three holes near any three of its sharp corners far apart and label them as 1, 2, 3.

From a nail fixed to a wall, suspend this cardboard from hole 1 such that it can oscillate about a 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





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. The resultant of all forces acting on the body should be zero so that there is no change in its state of rest or of uniform linear motion
2. 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 figure (5.11) below.

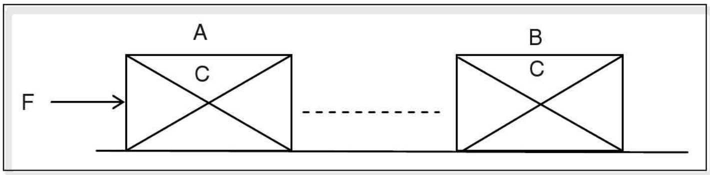


Figure 5.11

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.

In the figure (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.

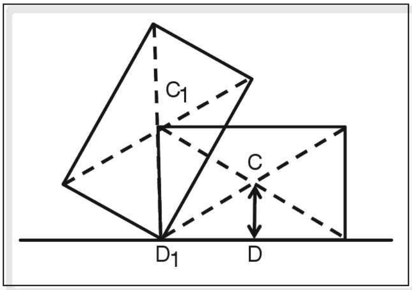


Figure 5.12

There are three types of equilibra. They are

1. stable equilibrium,
2. unstable equilibrium and
3. neutral equilibrium

Let us discuss each of them briefly.

1. 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.

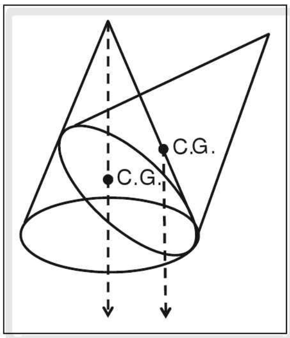


Figure 5.13 Stable

1. The straight line joining its centre of gravity and the centre of the earth (CE) should always pass through its base on the application of external force.
2. The body should have a broad base.
3. The base of the body should be heavy lowering its C.G., i.e., the centre of gravity should be as low as possible.

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.

2. 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 small
3. The top of the body is heavy. This raises its C.G.

3. 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

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.
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 rolly-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.

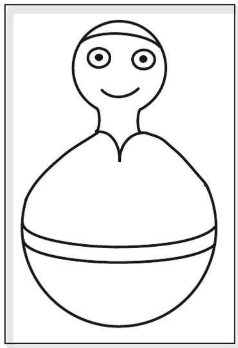


Figure 5.14 Rolly-Polly doll

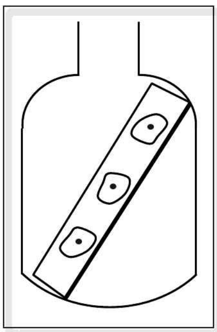
Gravitation–Applications

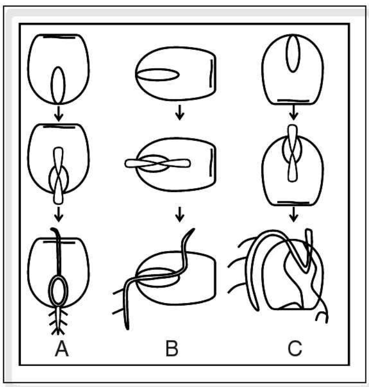
Science and technology being at its pinnacle, today it is possible for us to measure the mass of the earth, radius of the earth the value of acceleration due to gravity with the greatest precision. Newton's law of gravitation helps us to even estimate the masses of other planets and stars accurately. 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 a double star or a binary star. Newton's law of gravitation helps in determining the masses of a double star.

If the motion of a star has small irregularities, those irregularities can be detected using latest technology. One of the irregularities in the motion of stars is called a '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 laws of gravitation.

Just as 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 figure (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 figure (5.16). This phenomenon is called geotropism, which establishes the effect of gravity on plants.

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 satellite

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 come back again. 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

1. Define free fall.
2. Define an artificial satellite.
3. When does a body experience a free fall?
4. The leaning tower of PISA does not collapse inspite of being in a slanting position. Then the building is said to be in ________ equilibrium.
5. What is a geostationary satellite and what is its time period?
6. State Newton's universal law of gravitation
7. What is the effect of mass on 'g'?
8. On Mount Everest, the value of the acceleration due to gravity is __________ than its value in Kashmir valley.
9. State Newton's inverse square law.
10. Where does the C.G. of regular shaped bodies lie?
11. State S.I. and C.G.S. units of 'G' and mention its value in both the systems.
12. State Kepler's 1st law of planetary motion.
13. A spring balance measures the _____ of a body.
14. One year on a certain 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.
15. State Kepler's 2nd law of planetary motion.
16. What do you understand by the position of a body?
17. Define escape velocity of an object.
18. State Kepler's 3rd law of planetary motion.
19. Irregularity in the motion of a star is known as a __________.
20. 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 ________.
21. Define mass, weight and centre of gravity.
22. Define the following.
    (a) stable equilibrium (b) unstable equilibrium (c) neutral equilibrium
23. Define geotropism.
24. What is acceleration due to gravity?
25. Define the time period of a satellite
26. How does altitude affect 'g'?
27. The time period of a geostationary satellite is equal to ________ hours.

28. Geotropism is the phenomenon which shows the effect of __________ on plants.

29. What is the effect of latitude on 'g'?

30. What is wobble?

Short answer type questions

31. How is gravitation used to detect the presence of a binary star or a planet which is bound to a star?

32. Calculate the acceleration due to gravity on a planet of mass 2×10^{27} kg and radius 14×10^{7} m.

33. Explain how the apparent weight of a person taking a ride in a roller-coaster vary?

34. 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?

35. Compare mass and weight.

36. Weight of two bodies is 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 = 10 m s^{-2})

37. How does the centre of mass of bodies affect the force of gravitation between them?

38. A bowl with a 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?
(g_E = 9.8 m s^{-2}, g_m = 1.61 m s^{-2})

45. Give two practical examples of the equilibrium of bodies in 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.

CONCEPT APPLICATION

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 $[M^{-1}L^{3}T^{-2}]$.
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 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 air 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.

15.

	Column A			Column B
A	g_h	( )	a.	Outside the body
B	$R^3 \alpha T^2$	( )	b.	24 hours
C	Centre of mass of a hollow sphere	( )	c.	6.67×10^{-11} N $m^2 kg^{-2}$
D	G	( )	d.	Law of periods
E	Time period of a geostationary satellite	( )	e.	$g_0\left(1-\frac{2h}{R}\right)$

(Continued on the following page)

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	$g_{equator} < g_{poles}$	( )	i.	Geometrical centre
J	Orbital velocity	( )	j.	Vector

Direction for questions 16 to 30: 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, it will show (for the same body)

(1) 180 divisions. (2) 6 divisions.
(3) 150 divisions. (4) 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

(1) equator. (2) poles. (3) tropic of Cancer (4) tropic of Capricorn.

18. The centre of gravity 'G' of the bob of given simple pendulum is at position 'x' on earth. What is its new position on the surface of the moon.

(1) It remains at the same position 'x'. (2) It is above the position 'x'
(3) It is below the position 'x' (4) It shifts towards surface of the bob.

19. The weight of a body of mass 3 kg at a height of 12.8×10^6 m from the surface of the earth is ______.

(1) 9.75 N (2) 1.46 N (3) 3.26 N (4) 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 6.67×10^{-10} 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.

(1) 3.335×10^{-10} (2) 3.335×10^{-11} (3) 6.67×10^{-10} (4) 6.67×10^{-11}

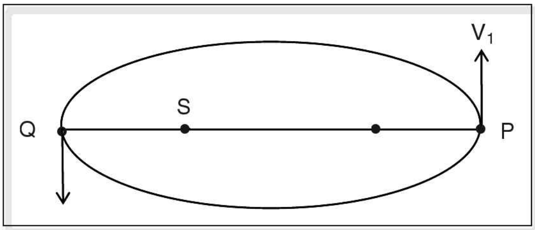
21. A circus artist rides a bicycle, on a rope tied horizontally. This is an example of _______ equilibrium.

(1) neutral (2) stable (3) unstable (4) dynamic

22. If the acceleration due to gravity on a planet is 6.67 m s^{-2} and its radius is 4×10^6 m, then the mass of the planet is ______.

(1) 16×10^{23} kg (2) 726×10^{23} kg
(3) 16×10^{24} kg (4) 26×10^{24} kg

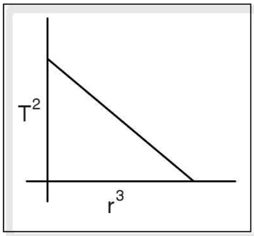
23. The figure shown below is an elliptical orbit along which a planet revolves round the sun. Let the velocity of planet at P and Q positions be V_1 and V_2 respectively. Then, the possible relationship between magnitudes of "V_1" and "V_2" is

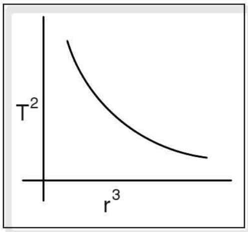


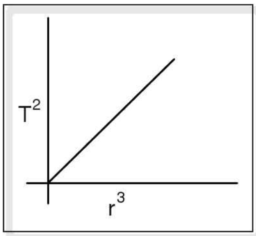
(1) $V_1 < V_2$ (2) $V_1 = V_2$ (3) $V_1 > V_2$ (4) Both 1 and 2

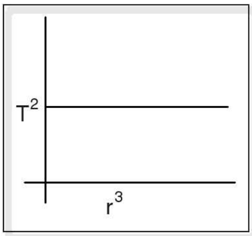
24. What is the relation between the period of rotation (R_T) and period of revolution (R_V) of moon?
(1) $R_T = R_V$ (2) $R_V > R_T$ (3) $R_V < R_T$ (4) No relation exists

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).

(1)


(2)


(3)


(4)


26. One year on a given planet is 1000 days. If the distance between the planet and the sun is made ¼th of original value. Then how many days will make one year?
(1) 180 days (2) 400 days (3) 125 days (4) 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?
(1) 5 : 3 (2) 3 : 5 (3) 3 : 2 (4) 2 : 3

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
(1) ABC (2) BCD (3) CDA (4) 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. $\left(\text{Take, } g_M = \frac{1}{6} g_E\right)$

(1) 1.66 m (2) 16.6 cm (3) 33.2 cm (4) 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 ______.

(1) 0.03335 N (2) 3.335×10^{-11} N (3) 5.558×10^{-12} N (4) 6.28×10^{-12} N

Concept Application Level—2

31. Given that d_e, d_m are densities of the earth and moon respectively and D_e, D_m are the diameters of the moon and the earth respectively. And g_e and g_m are the acceleration due to gravity on the surface the earth and moon respectively. Then find the ratio of g_m and g_e

32. 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.

33. 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.

34. 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)

35. 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 $g_E = 10 \text{ m s}^{-2}$)

36. 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.

37. 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)

38. 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 $g_o = 9.8 \text{ m s}^{-2}$).

39. 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?

40. A coke can of negligible mass is in the shape of a cylinder. Its volume is 500 ml and its base area is $\frac{100}{3}$ 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?

41. If two bodies of masses 1 kg and 4 kg respectively, 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.

42. 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 m s^{-2}).

43. 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 $\frac{1}{86400} = 1.157 \times 10^{-5}$].

44. 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 = 6.67×10^{-11} N m^2 kg^{-2}).

45. 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})

Concept Application Level—3

46. 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.

47. 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.

48. 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?

49. 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?
Mass of the sun = 2×10^{30} kg,
Mass of the moon = 7.3×10^{22} kg,
Distance between the sun and the earth = 1.5×10^{11} m
Distance between the moon and the earth = 3.84×10^8 m.
Radius of the earth = 6.4×10^6 m

50. 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?

key points for selected questions

Very short answer type questions

1. A body under the influence of gravity alone.
2. A man made object which orbits around the earth.
3. When no force acts on it.
4. stable
5. The time period of a satellite equal to 24 hrs, that satellite is called geostationary satellite.
6. 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 distance of separation between them.
7. No effect.
8. less
9. $F \alpha \frac{1}{r^2}$
10. At geometric centre
11. G – S.I. – $N\,m^2\,kg^{-2}$

    C.G.S. – dyne $cm^2\,g^{-2}$
12. Every planet revolves around the sun in elliptical orbits with sun at one of its foci.
13. weight
14. four times
15. The line joining planet to sun known as radius vector sweeps out equal areas in equal intervals of time.
16. If refers to height of C.G. above its base.
17. The velocity with which an object escapes the earth's gravitation.
18. The square of period of revolution of a planet around the sun is directly proportional to the cube of the average radius of the planet's orbit.
19. wobble
20. 1 :8
21. Quantity of matter contained in a body mass. The gravitational pull of the earth on a body – weight. The total weight acting on a body – CG
22. Body regains its position after slight displacement Body does not regains its position after application of external force – unstable equilibrium. Body remains in its original position at each new place join application of an external force – neutral equilibrium.
23. Phenomenon exhibiting downward growth of roots, on earth.
24. Uniform acceleration produced by a freely falling body.
25. Time taken by the satellite to complete one revolution around the earth.
26. g value decreases.
27. 24
28. gravity
29. g value increases as the latitude increases.
30. Irregularities in the motion of a star.

Short answer type questions

31. (i) Define binary stars
    (ii) Orbit around C.M.
    (iii) Irregularity in orbit
    (iv) Wobble
32. $g = \frac{GM}{R^2}$ Ans: 27.2 m s^{-2}
33. If roller coaster moves downwards with an acceleration "a", then will the person in it feel that his weight has decreased?
    Then find the apparent weight of the person in roller coaster. If same roller coaster moves upwards with an acceleration 'a', then will the person in it feel that his weight has increased?
    Then, find the aparent weight of the person in roller coaster?

34. $g = \frac{GM}{r^2}$ Ans: Weight of the body will decrease by 10%

35. (i) Definition
(ii) S.I. units
(iii) Scalar/vector
(iv) Constant/varying

36. (i) W = mg
(ii) $F = \frac{Gm_1m_2}{r^2}$ Ans: 8.3325×10^{-11} N

37. (i) Definition
(ii) $F = \frac{GMm}{r^2}$
(iii) r = the distance between the centre of masses of two bodies.

38. Find the centre of gravity of the given bowl having spherical base from the given data.
When this bowl tilts to the ground, with its open end facing horizontal direction.
Now, find the centre of gravity of the bowl in this position.
Does the height of "G" remain the same from the ground. Then will this form neutral equilibrium?
If the bowl is filled with water upto the centre of gravity, will the centre of gravity shift towards the base. Then, will it form stable equilibrium?

39. (i) The state of rest or uniform motion of a body does not change on application of forces.
(ii) The resultant of all forces acting on the body is zero.
(iii) The resultant of all torques acting on the body is zero.

40. $g = \frac{GM}{r^2}$ Ans: 1.61m s^{-2}

41. (i) $T^2 \propto r^3$
$$\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$
(ii) $\frac{1}{2\sqrt{2}}$ year

42. (i) Compare the distances and time periods of revolution of planets A and B separately with that of the earth.
Time period of earth = 1 year
$T^2 \propto r^3$ (From Kepler's law) ....(1)
Take the time period of revolution and the mean distance of the earth, planet A and B be T_1, r_1; T_2, r_2 and T_2 and T_3, r_3 respectively.
Then, $\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$ and $\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$ ....(2)
Here, it is given that
$r_2 = 2r_1$ and $r_3 = 4r_1$
Substitute the values of (3) in (2) and find the values of T_2 and T_3.
Find the ratio of T_2 and T_3.
(ii) $1 : \sqrt{8}$

43. (i) Line going C.G. and C.E.
(ii) Size of base
(iii) Mass of base

44. $\frac{W_1}{W_2} = \frac{m\,g_1}{m\,g_2}$ Ans: 16.1 N

45. (i) Passengers occupy the lower deck first in a double decker bus.
(ii) Heavy objects are loaded first in a ship or a truck.

Essay type questions

46. (i) Regular bodies–geometric centre
(ii) Irregular bodies–suspend body, plumb line, trace lines joining CG and CE
(iii) Point of intersection of the lines.

47. (i) Effect of gravity on animate and inanimate
(ii) Effect of gravity on plants
(iii) Experiment to study this effect
(iv) Definition of geotropism
(v) Significance of geotropism in space travel

48. (i) Planets revolve round the sun in different elliptical orbits with sun at one of the foci of the orbits.

key points for selected questions

(ii) A planet revolves round the sun such that the line joining the sun and a planet covers equal areas in equal intervals of time.

(iii) Square of the period of revolution of a planet around the sun proportional to cube of the radius of the planet's orbit.

49. (i) Natural satellite

(ii) Definition of an artificial satellite

(iii) Uses

(iv) Orbit, velocity, time period of satellite

50. (i) $F \propto \frac{1}{r^2}$ – inverse square law

(ii) Kepler's third law

(iii) Circular orbits

(iv) Centripetal force $= \frac{mv^2}{r}$

(v) $v = \frac{2\pi r}{T}$

KEY

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. Choice (4)

17. Choice (2)

18. Choice (1)

19. Choice (3)

20. Choice (3)

21. Choice (3)

22. Choice (1)

23. Choice (1)

24. Choice (1)

25. Choice (3)

26. Choice (3)

27. Choice (4)

28. Choice (1)

29. Choice (2)

30. Choice (2)

Concept Application Level—2,3

Key points for select questions

31. 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.

$$\frac{g_E}{gm} = \frac{GM_E}{R_e^2} \times \frac{R_m^2}{GM_m}$$

Here, diameters of the earth and the moon are D_E and D_m respectively.

Then $R_e = \frac{R_1}{2}$ and $R_m = \frac{R_1}{2}$

Find the relation between acceleration due to gravity on the earth and on the moon with their diameters.

32. (i) Which are the factors that effect the centre of gravity of a regular and irregular bodies?
(ii) How is the centre of gravity (G) of a body is affected, when elevator accelerates in upwards direction and downward direction?

33. 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, $T = 2\pi\sqrt{\frac{\ell}{g}}$

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?

34. (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:

Is $T^2 \propto r^3$?

Then find the ratio of the time periods of the two satellites by the formula $\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$.

(ii) $T_1 : T_2 = 1 : 8$

$g_1 : g_2 = 16 : 1$

35. (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

$KE_{max} = \frac{1}{2} Mv_{max}^2$

(ii) 500 j

36. (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) $1 : \sqrt{2}$

37. (i) The value of acceleration due to gravity at a height 'h' is given by g^1

$$= \frac{GM}{(R+h)^2} \;.......(1)$$

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 (2) equation.

(ii) 5300 km

38. (i) Consider the formula,

$$mg = \frac{GMm}{R^2} \; .... (1)$$

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}

39. (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?

40. (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 $\frac{h}{2}$.
If the mass of the can is not negligible, will this can have its own centre of gravity?
Then will the position G_2 shifts upwards?

(ii) 3 cm

41. (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,

$$F = \frac{GMm}{(R+h)^2} \; ---- (1)$$

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'.

Then, $\frac{GMm}{(R+h)^2} = \frac{GM(4m)}{(R+x)^2}$ ....(2)

Find the value of 'x' by appropriate substitutions in equation (2).

(ii) 6402 km

42. (i) Let the weight of the mine worker on the surface of earth = $w_0 = mg_o$ ....(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)

The ratio of $\frac{w_d}{w_o}=\frac{mg_d}{mg_o}=\left[1-\frac{d}{R}\right]$.....(4)

Find the ratio of w_d and w_o

Solve the 4th equation and obtain the value of "d".

(ii) 3200 m

43. (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

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

44. (i) Take the mass of the asteroid = m

Take the distance between the asteroid as = d

The attraction between the asteroid is given by,

$F=\frac{Gm^2}{d^2}$ ....(1)

The orbital velocity of each asteroid would be = v

Then, $F = \frac{mv^2}{r}$ ....(2)

Equate (1) and (2)

$F=\frac{Gm^2}{d^2} = \frac{mv^2}{r}$

Obtain the value of 'v'.

(ii) 1.29×10^3 m s^{-1}

45. (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.

$\Rightarrow V_2 = \frac{1}{8}V_1$

$\Rightarrow \frac{4}{3}\pi R_2^{\ 3} = \frac{1}{8}\left[\frac{4}{3}\pi R_1^{\ 3}\right]$

$\Rightarrow R_2 = \frac{R_1}{2}$

We know, $g = \frac{GM}{R^2}$

Where "g" is acceleration due to gravity and "M" is the mass of the earth.

$\Rightarrow g_1 = \frac{GM}{R_1^{\ 2}}$ and $g_2 = \frac{GM}{R_2^{\ 2}}$

Then, $2 = 2\pi\sqrt{\frac{\ell_1}{g_1}} = 2\pi\sqrt{\frac{\ell_1}{g_1}}$

Substitute, the value of "g_2" and obtain the value of "ℓ_2".

(ii) 3.975 m

46. The centripetal force acting on the planet revolving round the sun with orbital velocity 'v' is, $F = \frac{mv^2}{r}$ ..... (1)

Substitute, $v = \frac{2\pi r}{T}$ ....(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.

47. 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?

48. 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 $\frac{120}{1000}$ m. ...... (1)

Will the C.G. of the water tank rise by $\frac{120}{2000}$ 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.

49. (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.

50. (i) Here, the weight of the person on the surface of the earth is 'w'. Then, $w = mg = \frac{GMm}{R^2}$ .... (1)

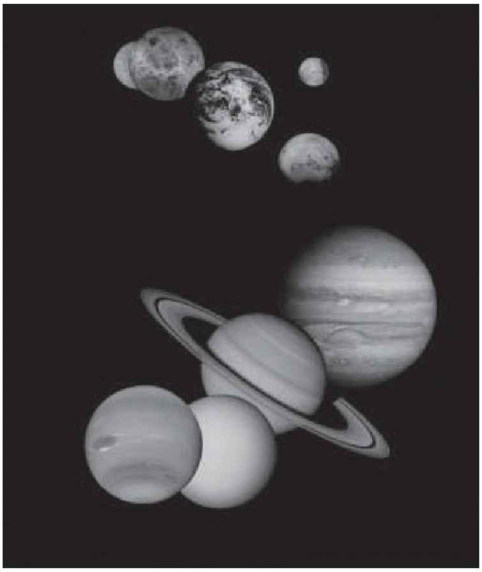
Then, the weight of the person, (i.e.,) gravitational force of attraction on the person at a height 'h' will be, $w_h = \frac{GMm}{(R+h)^2}$ - - (2)

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) $W_h = \frac{W}{4}$

6

Hydrostatics



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? 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.

Types of fluids and the differences between them

As discussed above, liquids and gases are referred to as fluids. Though they have the common property of flowing, they have certain differences too.

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.
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.
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.
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.
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.
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.

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 force acting normal to the surfaces 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). 1kg_{wt} or 1 kg_f = 9.8 N.

Similarly 1 g_{wt} or 1 g_f = 980 dyne.

Pressure

It is a common experience that, fixing blunt nails 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 Pressure (P) = $\frac{\text{Thurst (F)}}{}$

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).
1 Pa = 1 N m^{-2}
1 N m^{-2} = 10 dyne cm^{-2}
The gravitational unit of pressure is kilogram force per square metre (kg_f m^{-2}), which is approximately equal to 10 Pa.
1 kg_f m^{-2} = 10 Pa.
For meteorological purposes the unit of pressure is taken as bar.
1 bar = 10^5 Pa.

Fluid pressure

Consider a rubber balloon fixed to the bottom of a hollow glass tube as shown in figure (6.1). When water is poured into the tube, we observe that the balloon swells, as shown in figure (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 figure (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**'.

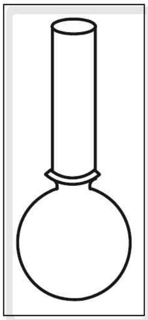


Figure 6.1

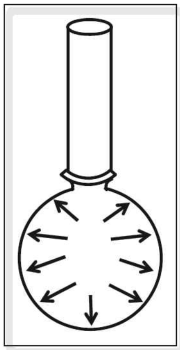


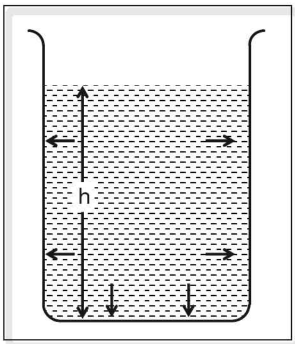
Figure 6.2

Fluids exert pressure in all possible directions. Broadly we classify fluid pressure as the pressure of the fluid acting 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 constitute 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 figure (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,



$P = \frac{\text{Force (F)}}{}$

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.

Mass (m) = (volume) (density)
= (area of cross section of beaker) (height of liquid column) (density of liquid)
= $a\,h\,\rho$

$\therefore\ w = a\,h\,\rho\,g$

$\therefore$ pressure, $P = \dfrac{ah\rho g}{a} = h\rho g$

Thus pressure exerted by a liquid at a point inside it is directly proportional to

(i) the height of the liquid column and

(ii) the density of the liquid.

Consider a big water tank with taps at different levels as shown in the figure (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 figure (6.4). This demonstrates that the pressure inside a liquid is directly proportional to the depth, and at a given depth the pressure is equal in all directions along a horizontal plane.

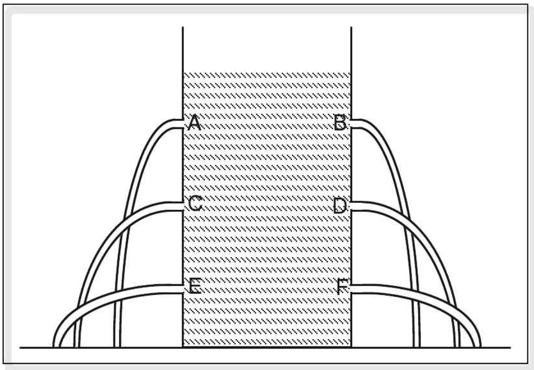


Figure 6.4

Irrespective of the shape and the size of containers, liquids seek their own level. Consider different glass tubes having different shapes and area of cross section connected through a horizontal tube at the bottom as shown in the 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.

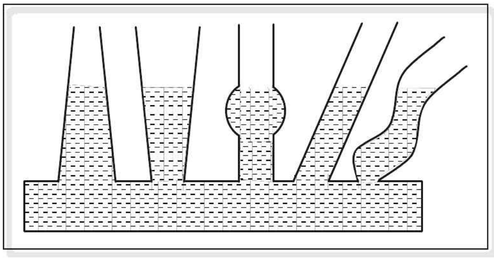


Figure 6.5

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 its surroundings and 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.

$\therefore$ 1 atm = 76 cm × 13·6 g cm^{-3} × 9·8 m s^{-2} (using '$h\rho g$' for pressure exerted by a liquid)

= 0·76 m × 13·6 × 10^3 kg m^{-3} × 9·8 m s^{-2}

= 101292·8 N m^{-2} or Pa ≈ 1·013 × 10^5 Pa.

Other units usually used in measurement of pressure are 'torr' and 'bar'

1 torr = 1 mm of Hg

1 bar = 10^5 Pa

Measurement of atmospheric pressure

The instrument used for measuring atmospheric pressure is known as barometer. Generally in the barometer a liquid is used for measuring atmospheric pressure. This liquid is known as 'barometric liquid'.

The properties of a barometric liquid

(i) A barometric liquid should have high density, so that a short column of liquid can counter-balance the atmospheric pressure.

(ii) It should have negligible vapour pressure, so that the pressure shown by the liquid column is the accurate atmospheric pressure.

(iii) The liquid should be in its pure form since any impurities present in the liquid may change its density and affect the measurement.

(iv) The liquid should be opaque so that it is easily visible and the length of column can be measured.

(v) 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. Its vapour pressure is negligible and does not affect the atmospheric pressure. It is easily available in pure form, opaque, shiny and does not stick to the walls of the container, viz glass.

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, with a narrow uniform bore is filled completely with mercury as shown in figure (6.6a). The mouth of the tube is closed with the thumb such 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 trough; and 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 the 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.

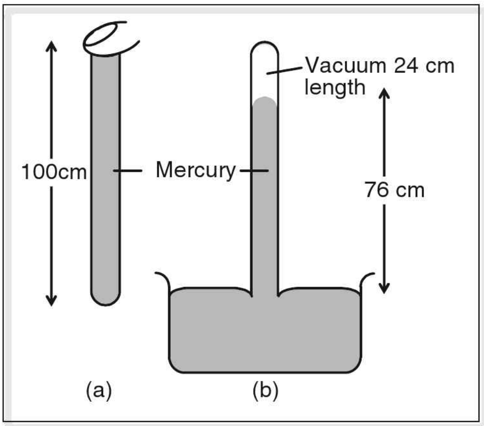


Figure 6.6 Simple barometer

The free surface of mercury present in the trough is exposed to atmosphere and 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, the pressure is equal to the pressure exerted by 76 cm length of the mercury column at the sea level. Hence we say pressure exerted by 76 cm column of mercury is equal to the atmospheric pressure at sea level 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 inaccurate readings. The pressure due to the vapour present above the mercury column in a barometer is calculated by the following expression.

   Vapour pressure = True atmospheric pressure − 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

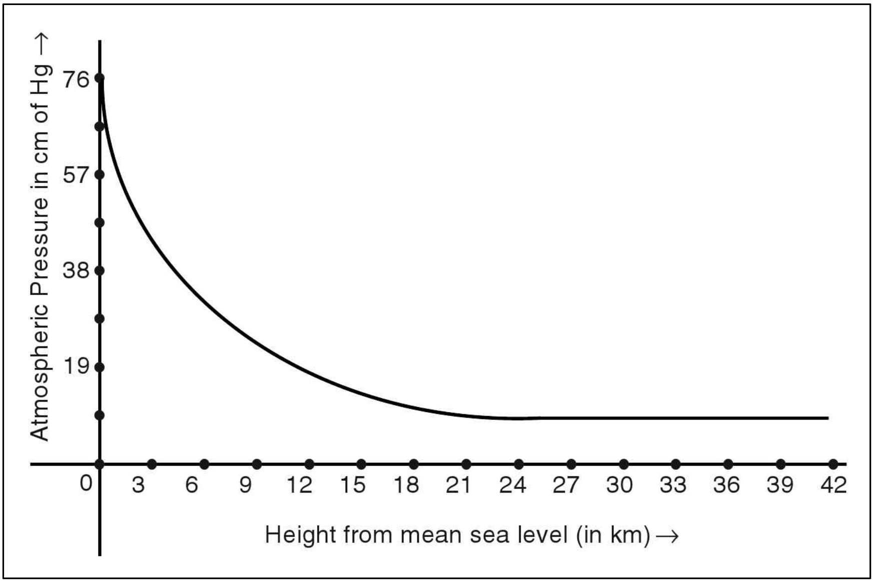


Figure 6.7 Variation of atmospheric pressure with altitude

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 the defects discussed in the case of a simple barometer, another barometer called Fortin's barometer was developed, named after the scientist who developed it. The basic structure of a Fortin's 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.

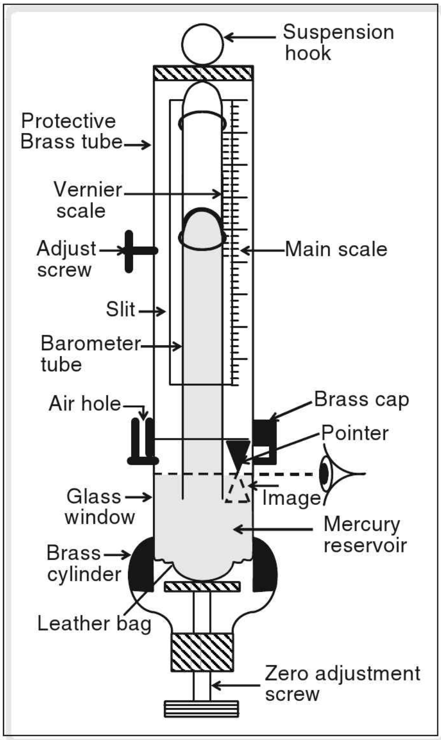


Figure 6.8 Fortin's barometer

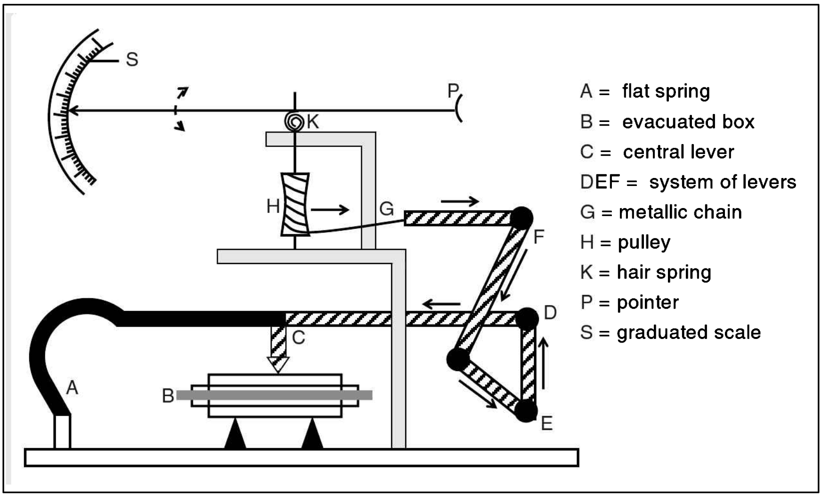
The bowl consists of a leather bag attached to a brass cylinder. To the bottom of the leather bag, a screw is arranged. By turning this screw the level of mercury in the trough is adjusted to the zero mark indicated by the ivory pointer fixed to a brass cap as shown in the figure (6.8). The glass tube 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.

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'.



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

(a) 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.

(b) 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

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_o). 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 figure 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 figure (6.10) (b), the pressure of the gas in the container (P) is less than the atmospheric pressure (P_o). Considering an equal level point 'C' in the left arm to level B in the right arm,

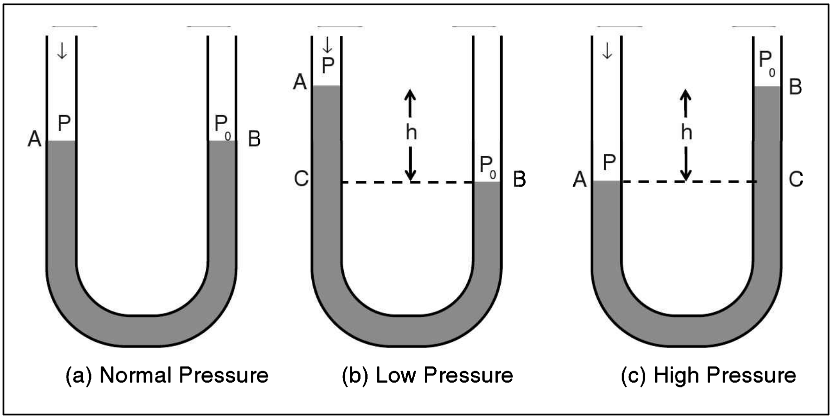


Figure 6.10 Manometer

Pressure at C = Pressure at B

$\Rightarrow P + h\rho g = P_o$ 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.

$\therefore$ Pressure of gas, $P = P_o - h\rho g$.

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 figure 6.10 (c) and the pressure of the gas is given by $P = P_o + h\,\rho g$.

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 'hρg' 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 of a given mass of a gas is inversely proportional to its pressure.

Mathematically, $P \propto \frac{1}{V}$ where 'P' and 'V' are pressure and volume of the given gas respectively.

$\Rightarrow PV = \text{constant}$.

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, $P_1V_1 = P_2V_2$.

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 an effort lesser than the load.

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 tube as shown in the figure (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 $P_1 = \frac{F_1}{a_1}$. 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 $F_2 = a_2P_2$

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.

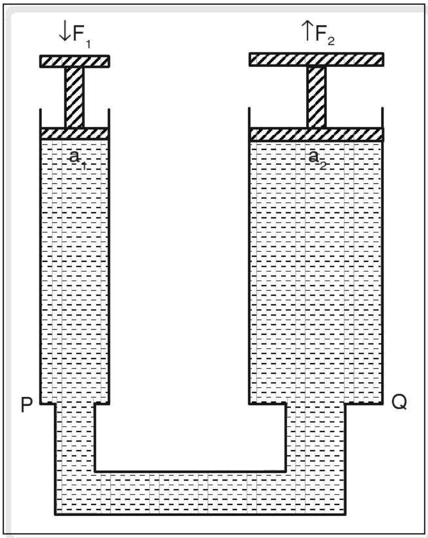


Figure 6.11 Bramahpress

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 piston of larger area of the press, what force should be applied on the piston of smaller area?

Solution

Given $a_1 = 10$ cm^2 and $a_2 = 50$ cm^2

Also given $F_2 = 100$ N, $F_1 = ?$

Pressure is equal on both the pistons $\Rightarrow P_1 = P_2$

$$\Rightarrow \frac{F_1}{a_1} = \frac{F_2}{a_2}$$

$$\Rightarrow F_1 = \left(\frac{F_2}{a_2}\right)a_1 = \left(\frac{100}{50}\right)10 \qquad 20\text{N}$$

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

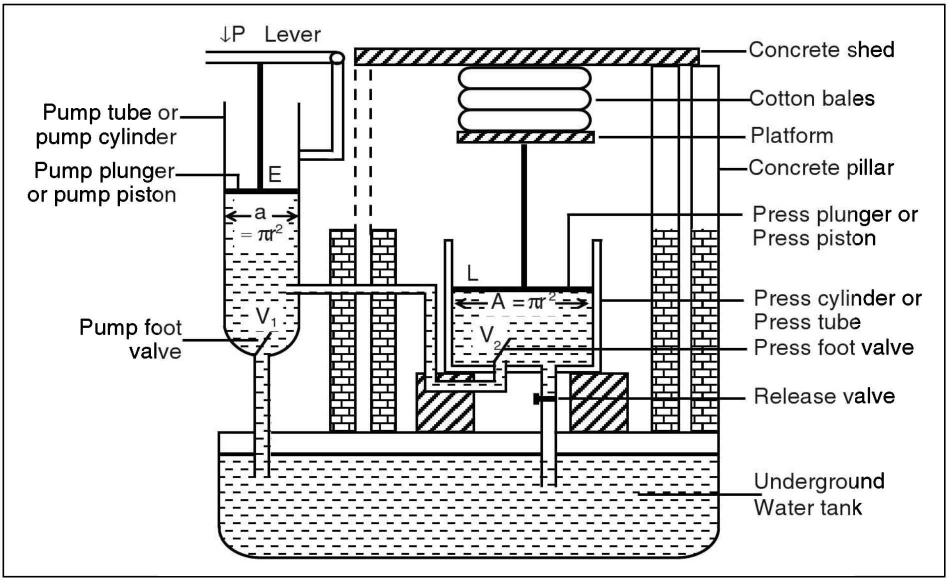


Figure 6.12 Hydraulic Press

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 ($A = \pi R^2$, where 'R' is its radius) is larger than the area of cross section of the pump cylinder ($a = \pi r^2$, where 'r' is its radius), the thrust transmitted to the piston of the press cylinder increases proportionately.

Mechanical advantage

The force exerted by the pump piston is the effort (E) and the weight lifted by the press piston is the

The pressure exerted by the pump piston on water in the pump cylinder = $\frac{\text{force}}{\text{area}} = \frac{E}{a} = \frac{E}{\pi r^2}$

$\therefore$ The pressure acting on the water in the press cylinder = $\frac{E}{a}$

$\therefore$ 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)

$$\therefore L = (A)\left(\frac{E}{a}\right) \Rightarrow \frac{\text{Load (L)}}{\text{Effort (E)}} = \frac{A}{a}$$

But $\frac{\text{Load (L)}}{\text{Effort (E)}}$ = mechanical advantage (M.A.)

$$\therefore \text{ M.A.} = \frac{\text{area of cross section of press cylinder}}{\text{area of cross section of pump cylinder}} = \frac{\pi R^2}{\pi r^2} \left(\frac{R}{r}\right)^2$$

$$= \frac{\text{square of the radius of press cylinder}}{\text{square of the radius of pump cylinder}}$$

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 automobiles in service stations is based on the principle of hydraulic press.

☛ *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 m^2. Determine the force that has to be applied on the piston of pump cylinder having an area of cross section 0·25 m^2. (Take g = 10 m s^{-2})

Solution

Given, mass of the car, m = 1400 kg
$\therefore$ weight of the car = force on the press piston = mg = 1400 × 10 = 14000 N.
area of the press piston, a_2 = 5 m^2

area of the pump piston, a_1 = 0·25 m^2

Let the force to be applied on the pump piston be 'F_1'

$$\therefore \frac{F_1}{a_1} = \frac{F_2}{a_2}$$

$$\Rightarrow F_1 = \frac{F_2}{a_2} \times a_1 = \frac{14000}{5} \times 0 \cdot 25 = 700 \text{ N.}$$

☛ *Example*

In the numerical example 2, calculate the mechanical advantage of the vehicle lifting machine.

Solution

Given area of the pump piston, a_1 = 0·25 m^2
area of the press piston, a_2 = 5 m^2
Mechanical advantage of the machine,

$$\text{M.A.} = \frac{\text{area of the press pison } (a_2)}{\text{area of the pump pison } (a_1)} = \frac{5}{0 \cdot 25} = 20$$

Hydraulic brakes

Hydraulic brakes are generally used in automobiles having large mass like cars, trucks etc. When a heavy vehicle is moving with 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 (figure 6.13) work on the principle of Pascal's law of transmission of fluid pressure.

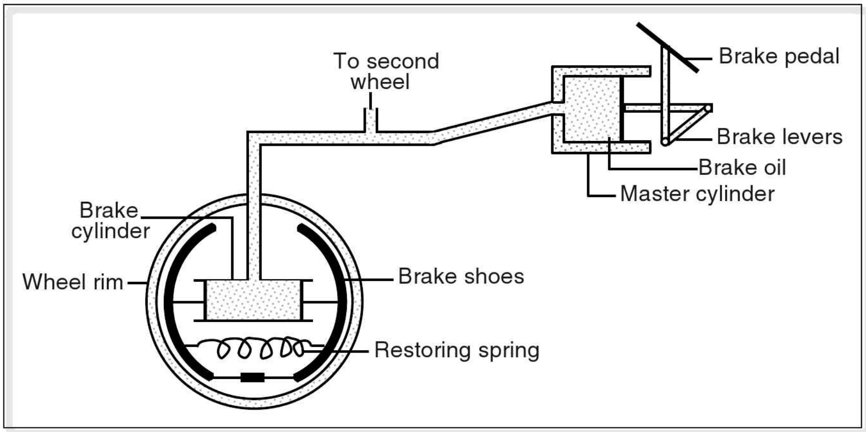


Figure 6.13 Hydraulic brakes

Hydraulic brakes system consist of a master cylinder and a brake cylinder connected by a thick metallic pipe, filled with a thick oil, generally called as 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 is connected to the two brake shoes which restore the brakes to the normal position.

In the process of applying brakes, the driver applies force on the brake pedal. This force is transmitted to the piston of master cylinder through levers. The piston of 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 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 in a fluid completely or partly, the body experiences an upward force by the fluid. 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'.

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 figure (6.14).

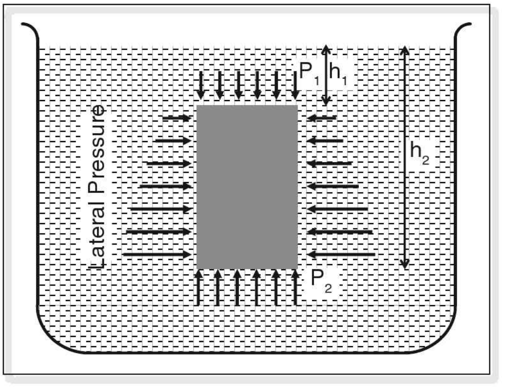


Figure 6.14 Upthrust

Pressure is exerted on the body by the liquid in all directions. Force exerted by 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 force exerted by the liquid on the top surface of the body is given by F_1 = (pressure) (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 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 = (volume of body) × (density of liquid) × (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 = (volume of liquid displaced (V)) × (density of liquid (ρ) × (acceleration due to gravity (g))
= 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 figure (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.

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', and it 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.

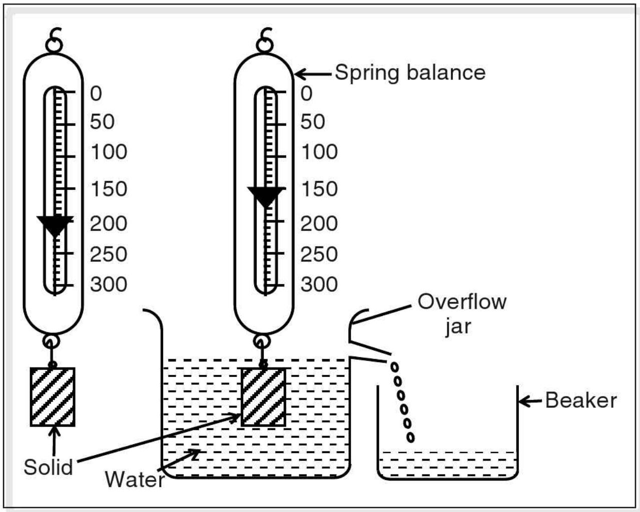


Figure 6.15 Verification of Archimedes Principle

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 g cm^{-3} = 10^3 kg m^{-3}.

Relative density

Often density of a substance is compared with the density of water at 4°C. This ratio is called the relative density. Thus "relative density of a substance is defined as ratio of density of the substance to density of water at 4°C".

Mathematically, relative density (R.D) $= \dfrac{\text{Density of substance}}{\text{Density of water at 4°C}}$

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.

As 1 g $cm^{-3} = 10^3$ kg m^{-3}, density of a substance in S.I. system = (Relative density of the substance) $\times 10^3$ kg m^{-3}

Relative density of a solid substance

$$= \frac{\text{Density of substance}}{\text{Density of water at 4°C}}$$

$$= \frac{\text{Mass of the solid}}{\text{Mass of an equal volume of water at 4°C}}$$

$$= \frac{\text{Weight of the solid in air}}{\text{Weight of water displaced by the solid}}$$

$$= \frac{\text{Weight of the solid in air}}{\text{Apparent loss of weight of the body in water}}$$

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 =

$$\frac{\text{Weight of the Solid in air}}{\text{(apparent loss of weight of the body in a liquid)}} \times \text{(relative density of the liquid)}$$

Relative density of a liquid $= \dfrac{\text{Apparent loss of weight of a body in liquid}}{\text{Apparent loss of weight of the same body in water}}$

Example

The mass of a body is 2 kg and its volume is 250 cm^3. Find its relative density.

Solutions

Given mass of the body = 2 kg = 2000 g

Volume of the body = 250 cm^3

$\therefore$ density of the body = $\dfrac{\text{mass}}{\text{volume}} = \dfrac{2000\text{ g}}{250\text{ cm}^3} = 8\text{ g cm}^{-3}$

$\therefore$ The relative density of the body is 8.

☛ *Example*

The specific gravity 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 cm^3) (19 g cm^{-3})

= 475 grams

☛ *Example*

A body weights 75 g in air, 51 g when completely immersed in a liquid and 67 g when completely immersed in water. Find the density of the liquid.

Solutions

Given, weight of the body in air, w_1 = 75 g
Weight of the body in water, w_2 = 67 g
Weight of the body in the given liquid, w_3 = 51 g

$\therefore$ Apparent loss of weight of the body in the given liquid = $w_1 - w_3$ = 75 – 51 = 24 g

Apparent loss of weight of the body in water = $w_1 - w_2$ = 75 – 67 = 8 g.

Relative density of the liquid

$= \dfrac{w_1 - w_3}{w_1 - w_2} = \dfrac{24}{8} = 3$

$\therefore$ Density of the liquid = 3 g 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 acting downwards along its centre of gravity and the upthrust 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).

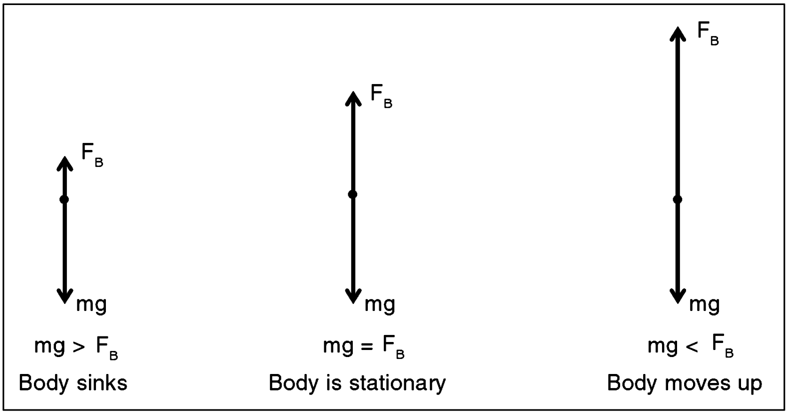


Figure 6.16

If the weight of the body is greater than the weight of the fluid displaced by it, a net downward force acts on the body and it sinks in the fluid. 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 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.

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.

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 figure (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.

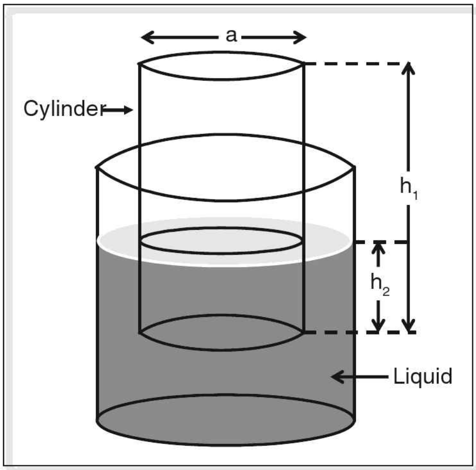


Figure 6.17

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,

$W = mg = ah_1\rho_1 g$.

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 $W^1 = ah_2\rho_2 g$.

According to the first law of floatation, $W = W^1$

$\Rightarrow ah_1\rho_1 g = ah_2\rho_2 g \Rightarrow h_1\rho_1 = h_2\rho_2$ or $V\rho_1 = V^1\rho_2$

$\Rightarrow$ (volume of the body) × (density of the body)

= (volume of the liquid displaced by the body) × (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 $\frac{\text{density of the body}}{\text{density of water}}$ = 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 cylindrical in shape and has uniform area of cross section, then relative density of the

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}

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 stationary, floating 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 in a same vertical line as shown in the figure (6.18).

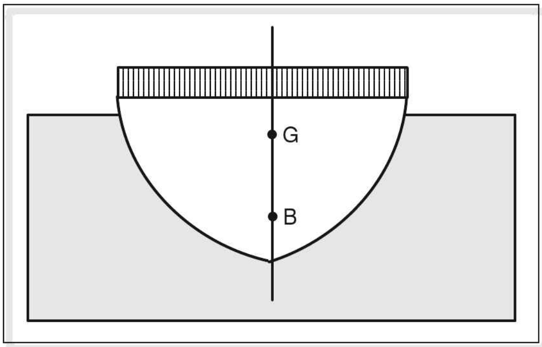


Figure 6.18

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.

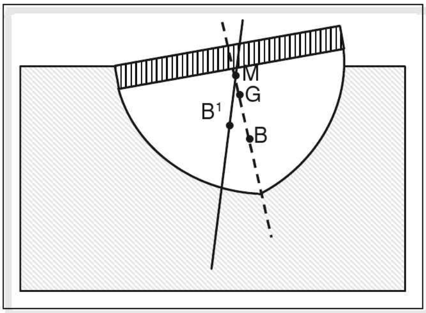


Figure 6.19

When the ship is slightly titled, say, towards left (anti clockwise direction) as shown in figure (6.19), the centre of buoyancy (B), and centre of gravity (G) of the ship do not lie in a single vertical line. But now the position of centre of buoyancy shifts to a new position (B^1).

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

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.

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 anticlock wise direction, the moment of force set by the weight of the body and up thrust acting on the body will be in clockwise direction (figure 6.20) and so the body will regain its position. Thus the body is in 'stable equilibrium'.

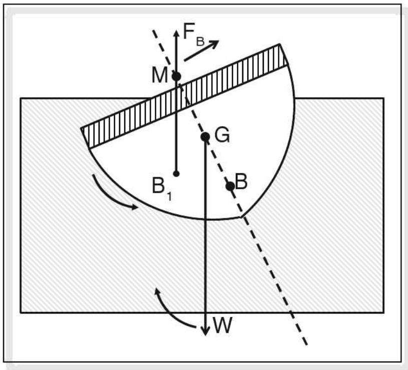


Figure 6.20

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 anticlockwise direction, the couple set up by the upthrust and the weight of the body is also in the anticlockwise direction and the body cannot regain its original position (figure 6.21). Thus the body is in an unstable equilibrium and it gets overturned.

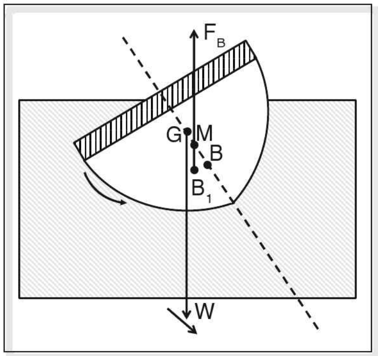


Figure 6.21

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 (figure 6.22).

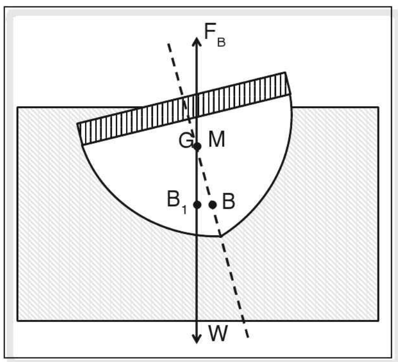


Figure 6.22

Laws of flotation—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

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 than water. 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 which is filled with a heavy substance like iron shots, or lead shots or mercury. This small bulb is called as a gravity bulb. To the upper part of the floatation bulb, a long narrow glass stem with graduations marked on it is attached (figure 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 (figure 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 flotation 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 ascending order from its top to bottom in the range about 1.0 to 1.7 (figure 6.23 c)

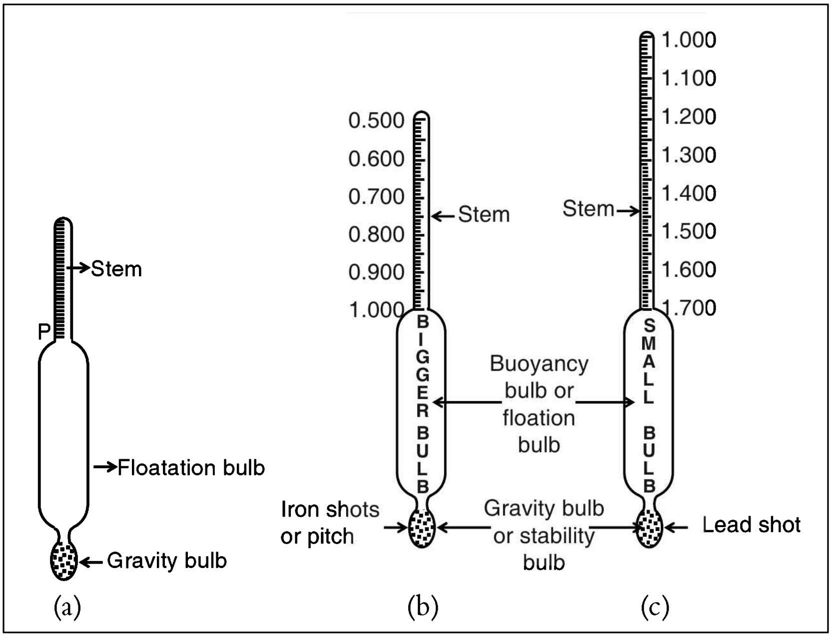


Figure 6.23

Hydrometer—Its calibration

Consider a hydrometer floating in water such that the gravity bulb and floatation bulb are inside water and the stem of the hydrometer is above water upto mark 'P' (figure 6.23 a). Let 'V cm^3' be the volume of the hydrometer upto mark 'P'. Then the volume of water displaced by hydrometer is 'V'.

$\therefore$ weight of water displaced by the hydrometer = (V $cm^3 \times 1$ g $cm^{-3} \times$ g cm s^{-2}) = Vg dyne.

Thus, according to law of floatation, weight of the hydrometer = Vg dyne --- (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 = ℓ, then volume of liquid displaced by the hydrometer = $(V + \ell a)$ 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,
weight of the hydrometer = $(V + \ell a)\,\rho g$ dyne --- (2)
From equations (1) and (2) we get
$(V + \ell a)\,\rho g = Vg$

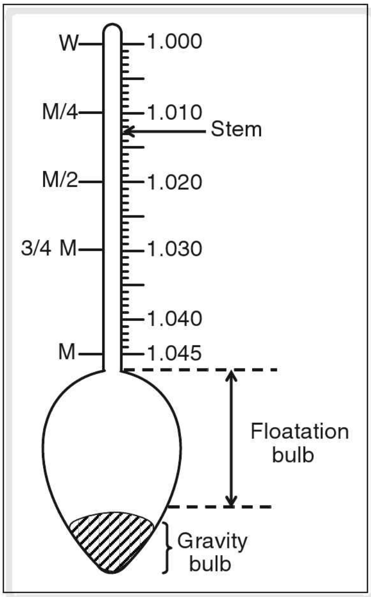
$\Rightarrow (V + \ell a)\,\rho = V$

$\Rightarrow \ell \dfrac{v(1-\rho)}{a\rho}$, Since 'V' and 'a' are cons tan t,

we get $\Rightarrow \ell = k\left(\dfrac{1}{\rho} - 1\right)$, 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.

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 (figure 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.

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.

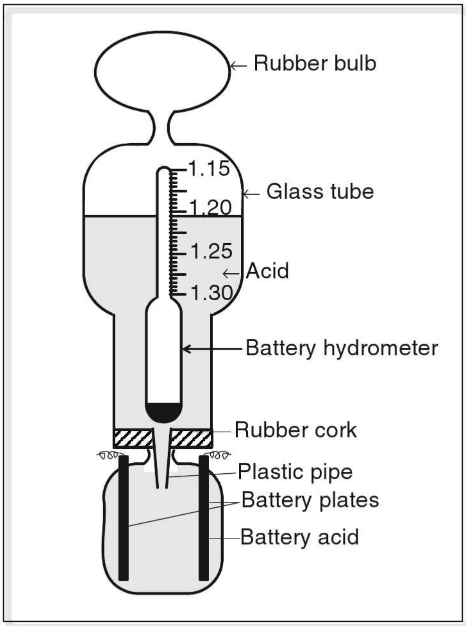


Figure 6.25 Acid battery hydrometer

Acid battery hydrometer

Sulphuric acid is the electrolyte used in the batteries employed in automobiles. The density of the acid varies about from 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 the density of 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 the required purpose. This hydrometer is known as 'acid battery hydrometer' (figure 6.25).

It consists of a big rubber bulb attached to wide glass tube at its top portion. At the bottom of the glass tube there is a nozzle. 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 into the battery.

Viscosity

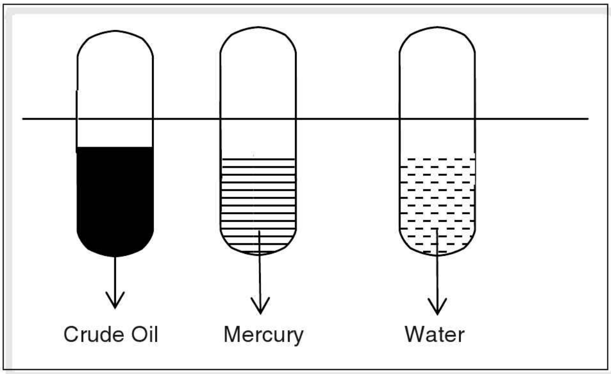


Figure 6.26

Consider the arrangement in which tubes are connected to a horizontal rod which can be rotated with the handle at one end (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 above figure, 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 time 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

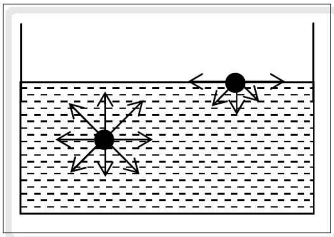


Figure 6.27

Molecules always attract each other. The force of attraction between like molecules (of the same element) is called cohesive force. The force of attraction between unlike molecules (of different type) is called adhesive force.

Consider a beaker containing a liquid (figure 6.27). A molecule 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 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, which leads to the surface behaving as a stretched membrane. This phenomenon is called surface tension. Due to surface tension, there is 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.

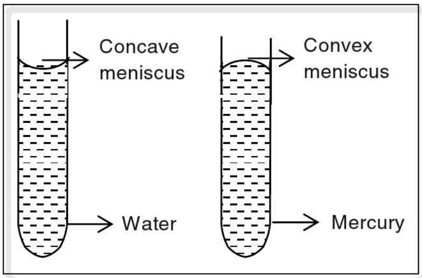


Figure 6.28

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 (figure 6.29). In mercury, the cohesive forces are very strong. Therefore, when mercury is poured in a narrow glass tube, its surface becomes convex (figure 6.30).

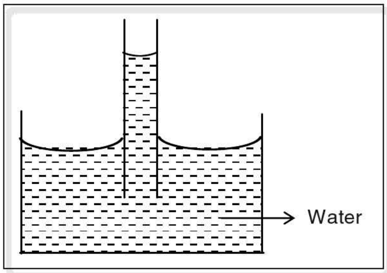


Figure 6.29

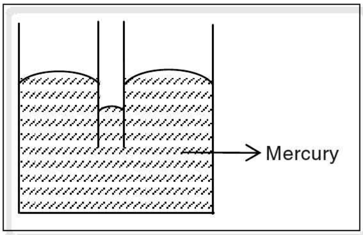


Figure 6.30

Capillarity

Consider a glass pipe of very narrow bore. When it is dipped in a beaker containing water, we find that the water rises up in the pipe so that its level in the pipe is higher than that in the beaker. Such a pipe is called a capillary tube.

If a capillary tube is dipped in mercury contained in a beaker, it can be observed that the mercury level in the tube falls below its level in the beaker thus creating a depression.

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

test your concepts

Very short answer type questions

1. State Archimedes' principle.
2. Mention a difference between a common hydrometer and a lactometer.
3. A hydrometer is used to measure ________ of liquids.
4. If relative density of a liquid is 2·3, what is its density in S.I. system?
5. State Pascal's law of transmission of fluid pressure.
6. What is a meniscus and how many types of meniscus are there, what are they?
7. What is the condition required so that a solid body sinks in a liquid and when does it just float in the liquid?
8. What is the expression for mechanical advantage of a hydraulic press?
9. Why does a liquid surface behave like a stretched membrane?
10. 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?
11. Mention two applications of Pascal's law of transmission of fluid pressure.
12. What is viscosity and what is meant by a viscous liquid?
13. Viscosity of liquids ________ with increase in temperature.
14. On what principle does the hydraulic brakes in a vehicle work?
15. Define cohesive and adhesive force.
16. Name the device used to measure the density of a liquid.
17. Define atmospheric pressure and one atmosphere.
18. 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 ________.
19. Define meta centre.
20. Which instrument is used to measure atmospheric pressure?
21. What is surface tension?
22. State the laws of floatation.
23. Which barometer is generally used in laboratories to measure atmospheric pressure quite accurately?
24. Name the instrument that can check the recharging capacity of a car battery.
25. What is the shape of liquid drops and what is the cause for their shape?
26. Which barometer does not contain any liquid?
27. What is the effect of temperature on the viscosity of liquids?
28. The force of attraction between like molecules is called ________.
29. A hydrometer used for measuring the relative density of a liquid floats to the maximum depth when immersed in water.

30. 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

31. Explain the factors that affect barometric height.
32. Derive an expression for the condition for a solid body immersed in a liquid to float in it.
33. Mention the characteristics of a floating body.
34. Define capillarity and mention few applications of it.
35. What are the disadvantages of a simple mercury barometer?
36. Explain equilibria of a floating body.
37. How does capillary action differ in water and mercury?
38. Explain the cause of upthrust on a body immersed in a liquid.
39. What is a hydrometer? Name the two categories of hydrometers and explain the principle on which its working is based.
40. Differentiate between liquids and gases.
41. Explain briefly about the verification of Archimedes' principle.
42. What are the advantages of an aneroid barometer over a simple barometer?
43. On what factors does the fluid pressure depend?
44. 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?
45. Derive an expression for fluid pressure.

Essay type questions

46. Explain capillarity in detail?
47. 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 $\frac{1}{4}$th of its volume below the liquid surface. Find the density of liquid?
(Ans: 2g cm^{-3})
48. Explain why water has concave meniscus while mercury has convex meniscus when poured in a uniformly narrow glass tube?
49. 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)
50. Explain the phenomenon of viscosity in detail?

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. Hydrometer works on the principle of 'Laws of floatation'.
2. 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.
3. 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.
4. The intermolecular forces of attraction are weaker in liquids when compared to those in solids.
5. A body remains in neutral equilibrium when meta center coincides with the center of gravity.
6. The net pressure acting at the bottom of a container filled with a liquid of density 'd' to a height of h is hdg.
7. Pressure of a gas enclosed in a container can be measured using a manometer.

Direction for questions 8 to 14: 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 _________.
9. A wooden plank immerses upto 50% in water. Then _____% of it is immersed in a liquid of density 0.5 g cm^{-3}.
10. The Mechanical Advantage of a hydraulic press is 5, the ratio of the distance travelled by the load to the effort is _________.
11. The length of water column that can exert 1 atm pressure is _________.
12. The blotting paper becomes completely wet when one end of the paper is kept in a liquid. This is an example of _____.
13. 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}.
14. An ice cube's $\frac{1}{n}$th portion sinks in water, then the density of ice is _____.

Direction for question 15: Match the entries in column A with the appropriate ones in column B.

15.

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

(Continued on the following page)

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 16 to 30: For each of the questions, four choices have been provided. Select the correct alternative.

16. Two metallic spheres of different materials immersed in water experience equal upthrust. Then both the spheres have equal

(1) weights in air (2) densities (3) volumes (4) masses

17. The pressure at a point inside a fluid is

(1) dependent on the height of the fluid column (2) dependent on the density of the fluid
(3) equal in all directions (4) All the above are true

18. When an object is made to float in two different liquids of density d_1 and d_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?

(1) $d_2 > d_1$, if $l_1 > l_2$ (2) $d_1 > d_2$, if $l_2 > l_1$
(3) $d_1 < d_2$, if $l_2 > l_1$ (4) $d_2 < d_1$, if $l_2 > l_1$

19. Kerosene lamp glows continuously until the kerosene is exhausted. This is due to the phenomenon of ________.

(1) anomalous expansion (2) capillarity
(3) thermal expansion (4) Both (1) and (2)

20. 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.

(1) 76 (2) 38 (3) 152 (4) 380

21. 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 d_A, d_B are the densities of A and B respectively which of the following statements is true?

(1) $P_A > P_B$ (2) $P_A < P_B$ (3) $P_A = P_B$ (4) $d_A > d_B$

22. The atmospheric pressure at a given place is dependent on

(1) the height of the air column (2) the temperature
(3) humidity (4) All the above

23. A spring balance shows 100 g_f reading when a metallic sphere is suspended from its hook. When the balance is lowered such that the sphere is immersed in water, the reading shown by the balance is 75 g_f. The relative density of the material of the sphere is

(1) 1 (2) 2 (3) 3 (4) 4

24. An object just floats in water. If common salt is added into the water,

(1) the volume of the object immersed in the liquid decreases.

(2) the object sinks.

(3) the object first sinks and then floats up.

(4) cannot be determined

25. A rubber balloon filled with hydrogen gas is left free in air. Then the balloon

(1) escapes into space.

(2) ascends upto a certain height in air and floats.

(3) ascends upto a certain height and then descends back to ground.

(4) ascends upto acertain height and explodes.

26. The radius of a press cylinder in a hydraulic press is double the diameter of the pump cylinder. Then

(1) mechanical advantage is 16.

(2) the work done on the load is equal to the work done by the effort.

(3) mechanical advantage is 4.

(4) both (1) and (2)

27. A substance floats in water, but sinks in coconut oil. The density of the substance

(1) is less than the density of water.

(2) is greater than the density of oil.

(3) Both (1) and (2)

(4) Cannot be decided based on the given information

28. 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.

(1) Only (i) is true (2) Only (ii) is true

(3) Both (i) and (ii) are true (4) Both (i) and (ii) are false

29. In the case of the liquids that do not wet the walls of the vessel _______.

(1) cohesive forces are larger than adhesive forces.

(2) adhesive forces are larger than cohesive forces.

(3) Both adhesive and cohesive forces are equal in magnitude.

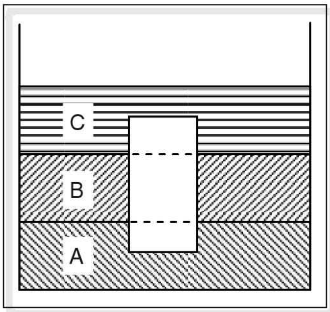
(4) None of the above

30. 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

(1) $\frac{W_2}{W_1}$ (2) $\frac{W - W_1}{W_2}$ (3) $\frac{W_2}{W - W_1}$ (4) $\frac{W - W_2}{W_1}$

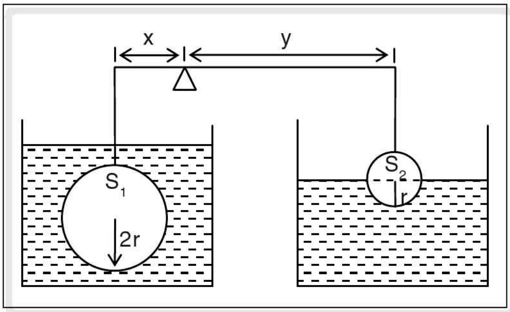
Concept Application Level—2

31. 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.



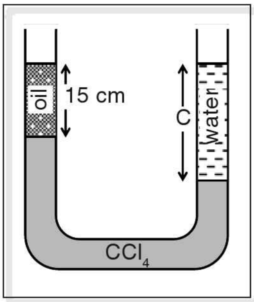
32. A hollow sphere of external and internal diameter 4 cm and 2 cm respectively floats in a liquid of density 3.5 g cm^{-3}. The level of the liquid coincides with the center of the sphere. Calculate the density of the material of the sphere.

33. Two spheres S_1 and S_2 made of same material and with 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.



34. 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?

35. 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.

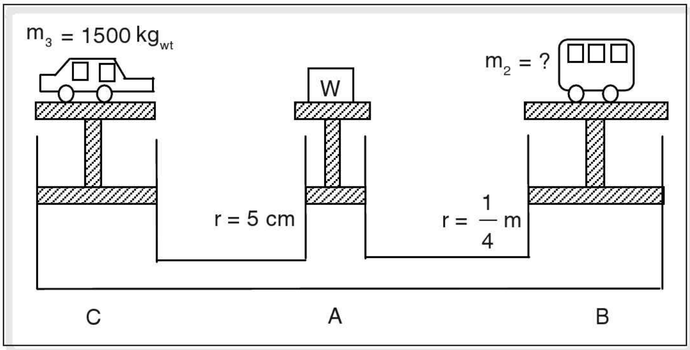


36. A metallic sphere is made of an alloy of two metals 'P' and 'Q' having specific gravities 20 and 2 respectively. The sphere weighs 120 g_{wt} in air and 90 g_{wt} in water. Find the percentage of the mass of metal 'P' in the alloy.

37. A metallic sphere is made of an alloy of two metals 'P' and 'Q' having specific gravities 20 and 2 respectively. The sphere weighs 120 g_{wt} in air and 90 g_{wt} in water. Find the percentage of mass of metal 'P' in the alloy.

38. 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 vertically in the liquids such that 1/3rd of its length is in liquid 'B' and the remaining is in liquid 'A'. Find the density of the cylindrical body.

39. In the figure shown, 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 m s^{-2}).



40. 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 test tube.

41. Two metallic spheres 'P' and 'Q' weighing 200 g_{wt} and 150 g_{wt} respectively, balance each other when immersed in water. If the relative density of 'P' is 2, find the specific gravity of 'Q'.

42. 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?

43. 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).

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.

44. 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, 3/4th 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 the hydrometer?

45. 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 m s^{-2})

Concept Application Level—3

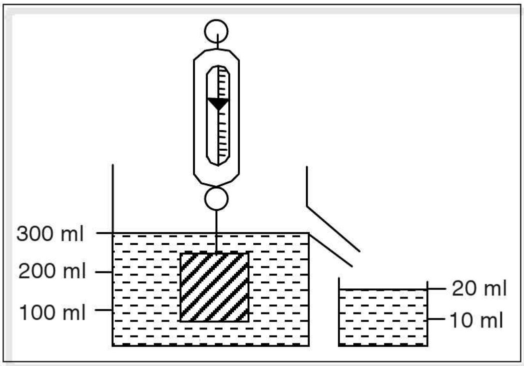
46. 'n' different liquids, which do not react chemically, are mixed to form a homogeneous mixture. If the densities of the liquids are ρ_1, ρ_2, ...ρ_n respectively then find the density of the homogeneous mixture when

(a) the masses of the liquids forming the mixture are equal
(b) the volumes of the liquids forming the mixture are equal

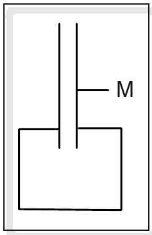
47. Why is a lactometer more sensitive than a normal hydrometer? Explain how the sensitivity of a hydrometer can be increased.

48. 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 g_{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 bottom, if the object is dropped into water?

The height of the overflow jar upto the spout is 10 cm and the area of the bottom face of the block is 4 cm^2.



49. 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).



50. 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 and a cylindrical container 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 g_{wt}. Determine the volume of water 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}.

key points for selected questions

Very short answer type questions

1. 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.

2. Common hydrometer – used to measure density of liquids.
Lactometer – A hydrometer of more sensitivity.

3. relative density

4. D = 2300 kg m^{-3}

5. 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.

6. The curved surface formed due to difference between cohesive forces and adhesive forces.

Convex, concave.

7. $D_{solid\ body} > D_{liquid}$ – body sinks
$D_{solid\ body} < D_{liquid}$ – body floats

8. M.A. = $\dfrac{\text{Area of cross section of press cylinder}}{\text{Area of cross section of pump cylinder}}$

9. Due to surface tension.

10. $D_{liquid} > D_{solid\ body}$

11. Bramah press, hydraulic press.

12. The property of a liquid to oppose the relative motion between layers is called viscosity. If the mobility of a liquid is less then that liquid is viscous liquid.

13. decreases

14. Pascal's law of transmission of fluid pressure.

15. Cohesive forces–Forces of attraction between like molecules.

Adhesive forces–Forces of attraction between unlike molecules.

16. Hydrometer

17. The pressure exerted by air.
1 atm = 76 cm of Hg.

18. 9.8×10^4 Pa

19. Due to tilt in the ship, there is a shift in centre of buoyancy, 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. This point is called meta centre(M).

20. Barometer

21. The tendency of a liquid to occupy minimum surface area.

22. (i) The weight of a floating body in a fluid is equal to the weight of fluid displaced by the body.
(ii) The centre of gravity of the floating body and the centre of buoyancy lie in the same vertical line.

23. Mercury barometer

24. Acid battery hydrometer

25. Spherical, minimum surface area

26. Aneroid Barometer

27. Viscosity of a liquid decreases as temperature increases.

28. cohesive force

29. heavier

30. 500

Short answer type questions

31. (i) Moisture in mercury
(ii) Dissolved impurities in mercury
(iii) Height from sea level

32. R.D. of solid = $\dfrac{\text{Weight of solid in air}}{\text{Apparent loss of weight of the body in water}}$

33. (i) Weight of floating body is equal to upthrust.
(ii) Apparent weight of floating body.
(iii) Net force acting on a floating body.

34. The phenomenon of rise or fall of a liquid in a capillary tube when it is dipped in a liquid. Eg: roots of plants absorb water.

35. (i) Meniscus formation
(ii) Not portable
(iii) Pollution of mercury
(iv) Difficulties to measure vertical height at any position.

36. Relative position of meta centre, centre of gravity of the floating body and the original centre of buoyancy.

37. Difference in surface tension.

38. Pressure differences of top and bottom surfaces of a body immersed in a liquid.

39. (i) Instrument–to measure the density of liquids.
(ii) Variable immersion and constant immersion.
(iii) Laws of floatation.

key points for selected questions

40. (i) Inter molecular forces of attraction.
(ii) Inter molecular spaces.

41. (i) Spring balance with a solid body attached.
(ii) Immersing the body into water.
(iii) Measuring the mass of the water displaced.

42. (i) Usage of no liquid.
(ii) Errors due to differential expansion of the liquid.
(iii) Light in weight, compact, portable.
(iv) Can be fixed in any plane.

43. (i) Height of the liquid column.
(ii) Density of the liquid.

44. Fraction inside $= \dfrac{\text{Density of floating body}}{\text{Density of liquid}}$

45. (i) $P = \dfrac{\text{Force}}{\text{Area}}$
(ii) Mass = Volume × density
(iii) P = hdg

Essay type questions

46. (i) Definition, cause, examples.
(ii) Reason for liquid to rise in a capillary.
(iii) Cause
(iv) Definition

47. (i) Ans: 2 g cm^{-3}
(ii) Laws of floatation
Ans: 2 g cm^{-3}

48. (i) Cohesive and adhesive forces.
(ii) Difference in cohesive and adhesive forces.

49. (i) Ans: 1 m^2
(ii) Pascal's law
Ans: 1 m^2

50. (i) Friction in liquid, Effect of temperature.
(ii) Force of friction between different layers.
(iii) Reason for difference in viscous forces.
(iv) Effect of temperature.

KEY

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. $\dfrac{V}{2}$
9. 100 %
10. 1 : 5
11. 10.336 m
12. capillarity
13. 500
14. $\dfrac{1}{n}$

Match the following

15. A : c
B : a
C : f
D : e
E : b

F : d
G : h
H : j
I : g
J : i

Multiple choice questions

16. Choice (3)
17. Choice (4)
18. Choice (3)
19. Choice (2)
20. Choice (2)
21. Choice (3)
22. Choice (4)
23. Choice (4)
24. Choice (1)
25. Choice (2)
26. Choice (4)
27. Choice (3)
28. Choice (4)
29. Choice (1)
30. Choice (2)

Concept Application Level—2, 3

Key points for select questions

31. 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) × (area of cross-section of the container)

$V_A = (3 \text{ cm}) \times (10 \text{ cm}^2)$

$V_A + V_B = (5 \text{ cm}) \times (10 \text{ cm}^2)$

$V_A + V_B + V_C = (8 \text{ cm}) \times (10 \text{ cm})$ = 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,

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

32. Weight of the floating body = Weight of liquid displaced.

33. 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, $F_1d_1 = F_2d_2$.

34. 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 (Pa^1) is equal to 65 cm of Hg + pressure due to air entrapped in the tube (P_2).
(i.e.,) $P_a^1 = 65 \text{ cm} + P_2$. ---- (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.
(i.e) $P_1V_1 = P_2V_2$

$$\Rightarrow P_2 = \frac{P_1V_1}{V_2} \quad ---- \quad (3)$$

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).

35. 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 $P_B = C\ell g$ ----- (1)

(Take, p = hdg)

Density of water = 1 g cm^{-3}

Height of water column = C

The pressure at point 'A' = P_A = Pressure due to oil and $CC\ell_4$ columns.

Here, $P_A = 15 \times d_{oil}g + (C - 15) \times d_{ccl} \times g$ (2)

Equate (1) and (2), and obtain the value of 'C'.

36. (i) Archimede's principle.

(ii) $R.D = \frac{W_1}{W_1 - W_2}$

(iii) Volume of the metallic sphere = volume of metal P + volume of metal Q

(iv) $\text{density} = \frac{\text{mass}}{\text{volume}}$

37. (i) Archimede's principle.

(ii) Find the weight of sphere made up of 'P' and 'Q' metals in air (w_1) and in water (w_2) from the given data.

Take masses and volumes of P and Q metals present in spheres as m_p, m_q, V_p and V_Q.

Find the densities of 'P' and 'Q' from the given information.

Find the apparent loss of weight of the sphere in water.

Find the density of the sphere using formula,

$d_s = \frac{w_1}{w_1 - w_2}$. ---- (1)

Then, density of the sphere is also equal to

$\frac{m_p + m_q}{V_p + V_q}$. ---- (2)

Is $m_p + m_Q = 120\ g_{wt}$? ---- (3)

Then, $V_p = \frac{m_p}{d_p}$ and $V_Q = \frac{m_Q}{d_Q}$. ---- (4)

Now, replace m_p by $(120\ g_{wt} - m_Q)$ and substitute in (2).

(i.e.,) $d = \frac{120}{\frac{120 - m_Q}{20} + \frac{m_Q}{2}}$. ---- (5)

Solve the equation (5) and obtain the value of m_Q

Substitute the value of "m_q" in (3) and obtain the value of "m_p".

The percentage of metal p $= \frac{m_p \times 100}{120}$

38. 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. ---- (1)

Is this equal to the volume of the displaced liquids of "A" and "B".

Now, weight of the floating body = weight of the displaced liquids = total upthrust acting on the body.

Here, weight of floating body = mg

$= Vd_sg$. ---- (2)

⇒ Then,

$V.d_sg = \frac{2}{3}V.d_Ag + \frac{1}{3}Vd_Bg$ -- (3)

Find the density of the body from equation (3)

39. 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,

$W = P \times A = P \times \pi\left(\frac{1}{4}m\right)^2$. ---- (2)

Put value of P from (1) into (2).
Here, total mechanical advantage =

$$\frac{\text{Total load}}{\text{Total effort}} \text{. ---- (3)}$$

Find the value of total mechanical advantage.

40. 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.
$\Rightarrow h.A.d_T.g = (h - 5).A.d_L.g.$ ---- (1)
Solve equation (1), to find the value of 'h'.

41. Find the weights of two given metallic spheres 'P' and 'Q' from the given data.
Find the density of the "P" from the given information.

Find the value of volume of 'P' ie., '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.
(i.e.,) $W_P - U_P = W_Q - U_Q$ (1) V_Q from (1)
where U_P and U_Q are the uptrust 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

$$d_Q = \frac{m_Q}{v_Q} = \frac{150}{v_Q}$$

42. 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?

43. Apparent weight of the sinker = extra upthrust.

44. (i) $\left(v + \frac{\ell a}{2}\right)d = w$ -------- (1)

$\left(v + \frac{3\ell a}{4}\right)d = w$ ------- (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) $d_1 = w$ -------- (3)
When the hydrometer reads maximum
$(v + \ell a)\, d_2 = w$ --------- (4)
Substitute the value of 'w' in (3) and (4) to

determine d_1 and d_2.

45. $P = h_1 dg$

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.

46. (i) Find the formula for density.
Then for given homogeneous mixture of 'n' liquids,

$$d = \frac{m_1 + m_2 + m_3 + ... + m_n}{v_1 + v_2 + ... + v_n} \quad --- \quad (1)$$

Then, for density of each liquid will be,

$d_1 = \frac{m_1}{v_1}$;

$d_2 = \frac{m_2}{v_2}$;

$d_n = \frac{m_n}{v_n}$ ----- (2)

(ii) The masses of the liquids forming the mixture are equal then,

$$d_m = \frac{m + m + m + ... + m}{v_1 + v_2 + ... + v_n}$$

$$= \frac{nm}{v_1 + v_2 + ... + v_n} \quad --- \quad (3)$$

Convert the volumes of (3) in terms of densities.

(iii) If volumes of liquids forming the mixture are equal.

(i.e.) $V_1 = V_2 = V_3 ..... = V_n$
$= V$ --- (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.

47. Find the different parts present in hydrometer. Find what happens, when the length of the stem increases and its area of cross section decreases.

48. $\text{Pressure} = \frac{\text{Thrust}}{\text{Area}}$

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.

49. Net Force = weight of the object – upthrust

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

$p = hdg$

50. Weight of the device + Weight of the lead shots = Volume of milk displaced × Density of milk

$W + w \times x = v \times d_m$ -------- (1)

$W + w \times y = v \times d_{impure\ milk}$ ------- (2)

Compare (1) and (2) and determine $d_{impure\ milk}$

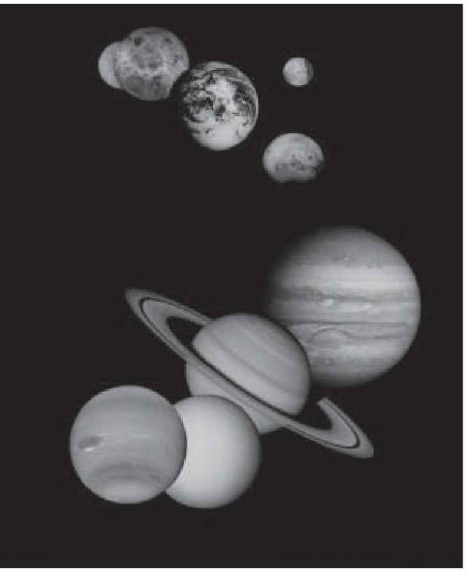
$$d_{im} = \frac{m_m + m_w}{v_m + v_w}$$

$v_w + v_m = v$

$d_w = \frac{m_w}{v_w}$ $d_m = \frac{m_m}{v_m}$

$v_w = (v - v_m)$

Substitute these values in the equation obtained by comparing (1) and (2) to determine v_w.



7

Heat

NTRODUCTION

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. A 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 from its position to another position. 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 molecules.

Units of heat

Heat energy is 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 kcal = 1000 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 is called a 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 linearly with temperature can be used to measure it. If a gas is used in thermometer, it is called a 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:

(i) The liquid should expand uniformly throughout the measuring range, so that the scale is linear.
(ii) It should be a good conductor so that the heat from the source is quickly transmitted to the liquid.
(iii) It should have low specific heat so that it can rapidly adjust itself to temperature changes without absorbing any amount of heat.
(iv) It should be opaque for clear visibility.
(v) It should not stick to the walls of the thermometer.
(vi) It should be easily available in pure form.
(vii) It should be in the liquid state throughout the range of measurement.
(viii) It should have a high boiling point and a low melting point. This helps to measure a wide range of temperatures.
(ix) It should exert a low vapour pressure.
(x) It should have a large volume coefficient of expansion so that the instrument is sensitive.

Advantages of mercury as a thermometric liquid

(i) Its expansion is uniform over a wide range of temperatures.
(ii) It is a good conductor of heat.
(iii) It has a low specific heat capacity.
(iv) It is opaque, shining and clearly visible.
(v) It does not wet the glass.
(vi) It is easily available in pure form.
(vii) It has a high boiling point and a low melting point.
(viii) 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

(i) Since the freezing point of alcohol is very low (–130°C), it can be used to record very low temperatures.

(ii) 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; has high specific heat; 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 temperature.

Water cannot be used as a thermometric liquid due to the following disadvantages.

(a) It is transparent.

(b) It sticks to the sides of glass.

(c) Its expansion is not uniform.

(d) It has a high specific heat capacity.

(e) Its freezing point is 0°C and boiling point is 100°C. So the temperature range is less.

(f) It is a bad conductor of heat.

(g) Its expansion per unit degree of rise in temperature is low.

(h) It evaporates under vacuum conditions.

(i) 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.

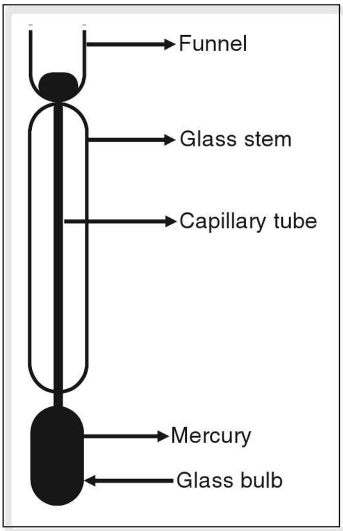


Figure 7.1

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**.

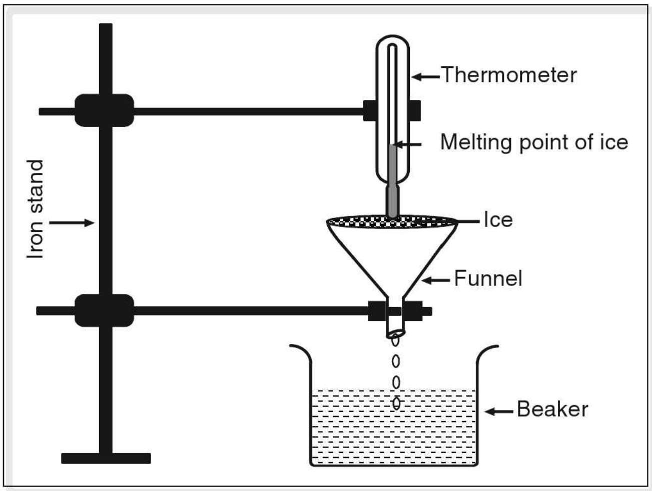


Figure 7.2

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**.

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.

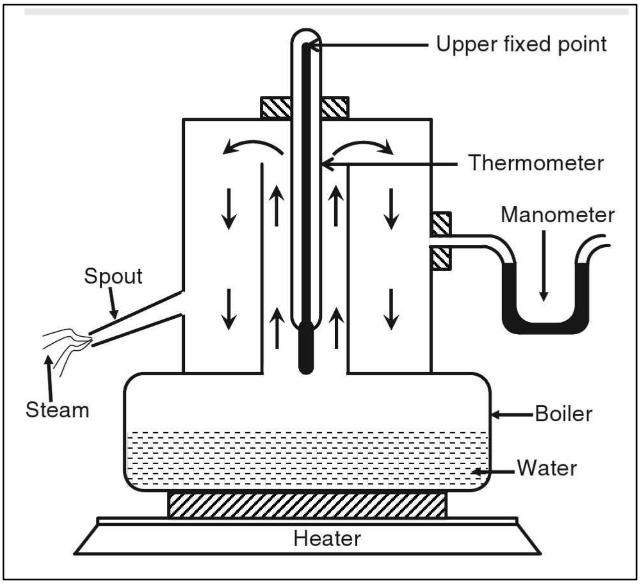


Figure 7.3 Hypsometer

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 0°C to 100°C.

Thermometric Scales

(a) Celsius scale or Centigrade scale: This scale was introduced by 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.

(b) 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

$$\frac{C - 0}{100 - 0} = \frac{F - 32}{212 - 32} \text{ or } \frac{C}{100} = \frac{F - 32}{180} \text{ or } F = \frac{9}{5}C + 32.$$

The following relation can be used to get the correct reading from a faulty thermometer:

$$\boxed{\frac{S_{faultyscale} - LFP_{faultyscale}}{UFP_{faultyscale} - LFP_{faultyscale}} = \frac{S_{correctvalue} - LFP_{correct}}{UFP_{correct} - LFP_{correct}}}$$

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 and 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 **absolute zero or Kelvin zero,** (0 K). Calculations based on experiment show that 0 K = –273°C.

Kelvin designed a scale of measurement with the lowest temperature as 0 K (–273°C). This scale is called **Kelvin scale.**

Note:

(i) No degree symbol is attached, when temperature is expressed in Kelvin.

(ii) Rise in temperature of 1°C = Rise in temperature of 1 K.

(iii) The temperature of a body can never be less than 0 K.

Relation between temperature in degree Celsius and Kelvin

We know that 0 K = –273°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.

For sterilizing, the thermometer is not placed in boiling water as the glass bulb may break. Instead sterilizing is done by using formaldehyde.

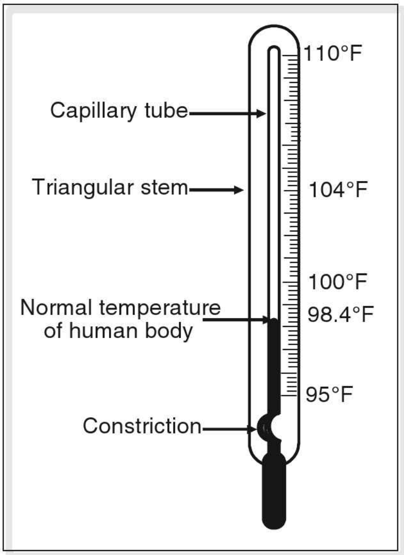


Figure 7.4

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 figure.

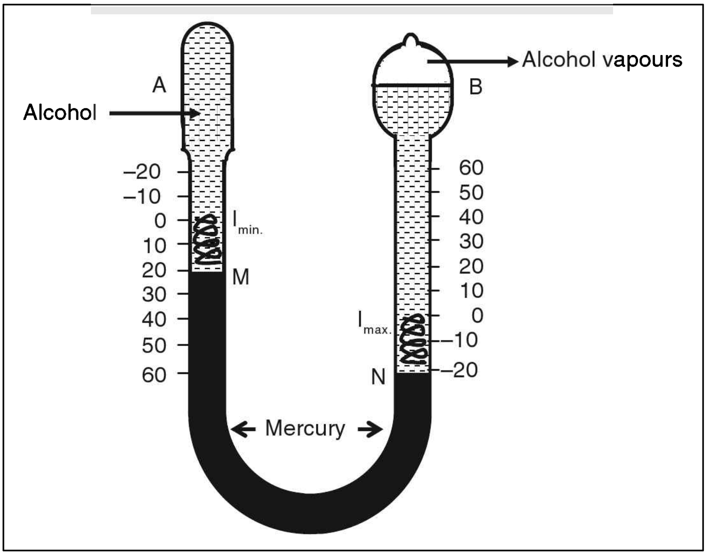


Figure 7.5

Two small light dumbell 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

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

$T = 75 + 273 = 348$ 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

$$\frac{75}{5} = \frac{F - 32}{9}$$

$$15 = \frac{F - 32}{9}$$

$F - 32 = 9 \times 15$

$F - 32 = 135$

$F = 32 + 135$

$= 167°F$

☛ *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

$$\frac{C}{5} = \frac{-40 - 32}{9}$$

$$\frac{C}{5} = \frac{-72}{9}$$

C

C = −40°C

Temperature in Kelvin scale is given by

T = C + 273

Substituting C = −40, we get

T = −40 + 273

= 233 K

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

$$c = \frac{4}{5} \times 100 = 80°C$$

To find temperature in Fahrenheit scale, use the formula

$$\frac{C}{5} = \frac{F-32}{9}$$

Substituting C = 80°C, we get

$$\frac{80}{5} = \frac{F-32}{9}$$

$\Rightarrow$ F = 32 + 16 × 9

= 32 + 144

= 176°F

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

$$\left(\frac{S-FLP}{UFP-FLP}\right)_{\text{Faulty scale}} = \left[\frac{32-(-4)}{104-(-4)}\right]$$

$$= \frac{36}{108} = \frac{1}{3} \text{ -----} \quad (1)$$

and

$$\left(\frac{S - LFP}{UFP - LFP}\right)_{\text{Correct scale}} = \frac{S - 0}{100 - 0}$$

$$= \frac{S}{100} \quad \text{-----} \quad (2)$$

Equating and solving (1) and (2), we get

$$\frac{S}{100} = \frac{1}{3}$$

$$\Rightarrow S = \frac{100}{3} = 33.33°C \ \text{(approximately)}$$

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

(i) the increase in length $(\ell_2 - \ell_1)$ is proportional to the original length ℓ_1.

(ii) the increase in length $(\ell_2 - \ell_1)$ is also proportional to the rise in temperature $(\theta_2 - \theta_1)$.

(iii) the increase in length depends upon the material.

Mathematically, $(\ell_2 - \ell_1) \propto \ell_1$ and $(\ell_2 - \ell_1) \propto (\theta_2 - \theta_1)$

$\therefore \Delta\ell = \alpha\, \ell_1 \Delta\theta$

where the proportionality constant 'α' is called **coefficient of linear expansion.**

$$\alpha = \frac{(\ell_2 - \ell_1)}{\ell_1(\theta_2 - \theta_1)} = \frac{\Delta\ell}{\ell_1 \Delta\theta}$$

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' $°C^{-1}$ or K^{-1}.

Experiment to demonstrate linear expansion in solids

Take a long aluminium rod clamped at an end as shown in the figure. 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.

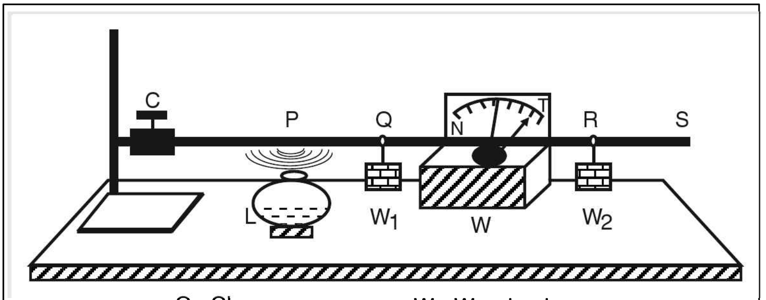


Figure 7.6

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

(i) the increase in area, $(A_2 - A_1)$ is proportional to the original area A_1.

(ii) the increase in area, $(A_2 - A_1)$ is proportional to the rise in temperature $(\theta_2 - \theta_1)$.

(iii) 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 $°C^{-1}$ 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

(i) the increase in volume $(V_2 - V_1)$ is proportional to the original volume V_1.

(ii) the increase in volume $(V_2 - V_1)$ is proportional to the rise in temperature $(\theta_2 - \theta_1)$.

(iii) 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 $°C^{-1}$ 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 $A_0 = L_0^2$.
Let the volume of the cube be V_0.
$\therefore V_0 = L_0^3$

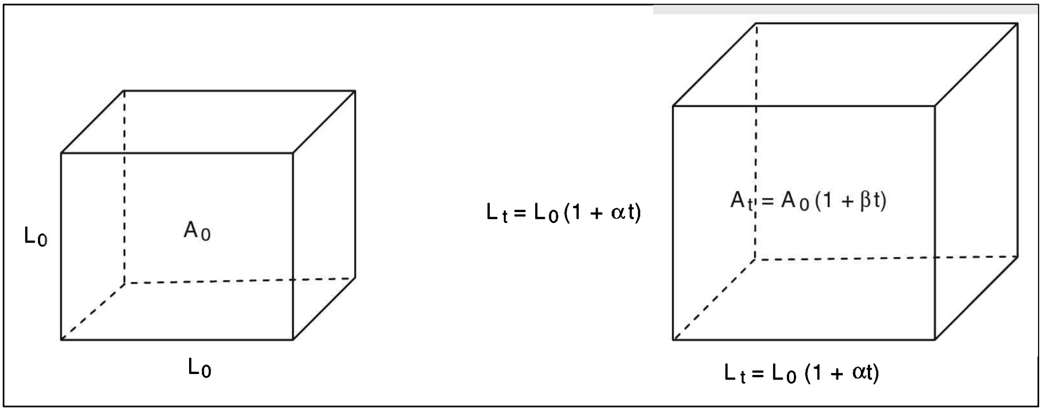


Figure 7.7

Area at 0°Celsius $A_0 = (L_0)^2$
Area at t°Celsius $A_t = (L_t)^2$
We know that length at t°Celsius is $L_t = L_0 (1 + \alpha t)$

Area at t°C is $A_t = (L_t)^2 = \{L_0 (1 + \alpha t)\}^2$
$A_t = L_0^2 (1 + 2\alpha t + \alpha^2 t^2)$
As 'α' is small 'α^2' terms can be neglected. Then $A_t = L_0^2 (1 + 2\alpha t)$
Hence, $A_t = A_0 (1 + 2\alpha t)$ (as $L_0^2 = A_0$) ----- (1)
Since we know $A_t = A_0 (1 + \beta t)$ ----- (2)
From (1) and (2) above, we get $\beta = 2\alpha$.
Similarly, we can prove that $\gamma = 3\alpha$.
Volume at 0°Celsius $V_0 = (L_0)^3$.
Volume at t°Celsius $V_t = (L_t)^3$.

We know that length at t°Celsius is $L_t = L_0 (1 + \alpha t)$

Volume at t°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 small the higher powers of α can be neglected. Then $V_t = L_0^3 (1 + 3\alpha t)$

Hence $V_t = V_0 (1 + 3\alpha t)$ (as $L_0^3 = V_0$) ----- (3)

Since we know $V_t = V_0 (1 + \gamma t)$ ----- (4)

On comparing (3) and (4) above, we get $\gamma = 3\alpha$.

$\therefore \alpha : \beta : r = 1 : 2 : 3$

Applications of expansion of solids

(i) While laying railway track a small gap is provided between two rails and connected by fish plate. This is to avoid bending of tracks in summer when the rails expand.

(ii) 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.

(iii) While laying concrete roads a small gap is left between two patches to allow for expansion.

(iv) A sag is left while laying telegraphic and electric wires, which allows them to contract during winter without breaking.

(v) A compensated pendulum is used to maintain correct time in different seasons.

(vi) Rivet lengths are made slightly less than the thickness of metal plates. They are heated and pressed on both sides. On cooling, it holds the two sheets very tightly.

(vii) 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.

(viii) Bimetallic strips work on the principle that different materials have different coefficients of expansions. 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 $19 \times 10^{-6}\ K^{-1}$. Find the increase in length of the rod if it is heated through 20°C.

Solution

Given length of the rod, $\ell = 1.5$ m.
Coefficient of linear expansion, $\alpha = 19 \times 10^{-6}\ K^{-1}$.
Increase in temperature, $\Delta\theta = 20°C$
$\therefore$ Increase in length, $\Delta\ell = \ell \times \Delta\theta$
$= (1.5) \times (19 \times 10^{-6}) \times (20) = 5.7 \times 10^{-4}$ m.

☛ *Example*

The area of a rectangular copper sheet is 0.30 m². If the sheet is heated through 10°C, its area increases by 1.02×10^{-4} m². Calculate the coefficient of areal expansion of copper.

Solution

Given area of the copper sheet, a = 0.30 m²
Increase in temperature, $\Delta\theta = 10°C$
Increase in area, $\Delta a = 1.02 \times 10^{-4}$ m².
$\Delta a = a\beta\Delta\theta$ where, β is the coefficient of a real expansion.

$$\text{Thus } \beta = \frac{\Delta a}{a \Delta \theta} = \frac{1.02\times10^{-4}}{0.3\times10} = 3.4 \times 10^{-5}\ K^{-1}.$$

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 figure.

It is seen that the level of the liquid initially falls to a mark B as shown in the figure and on further heating the level rises to the mark C.

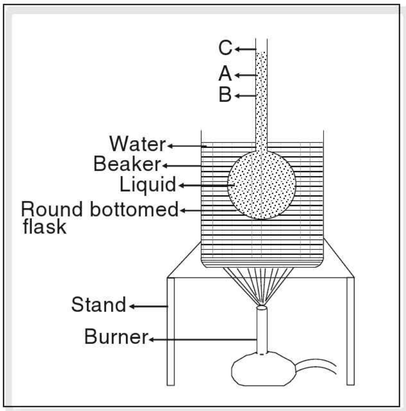


Figure 7.8

Reason for the above observation

1. When the flask containing 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 figure).
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

figure). The liquid level actually increases from B to C, when it expands and the corresponding increase in the volume of the liquid 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

(i) $\Delta V_a = \gamma_a V \Delta\theta$ and

(ii) $\Delta V_r = \gamma_r V \Delta\theta$, where '$\Delta V_a$' and '$\Delta V_r$' 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 volume per unit volume per unit rise in temperature, i.e., $\gamma_a = \dfrac{\Delta V}{V_1 \Delta t}$.

The coefficient of real expansion of a liquid is defined as the real increase in volume per unit rise in temperature, i.e., $\gamma_r = \dfrac{\Delta Vr}{V\Delta\theta}$.

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 long metallic cylinder, having a circular trough 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.

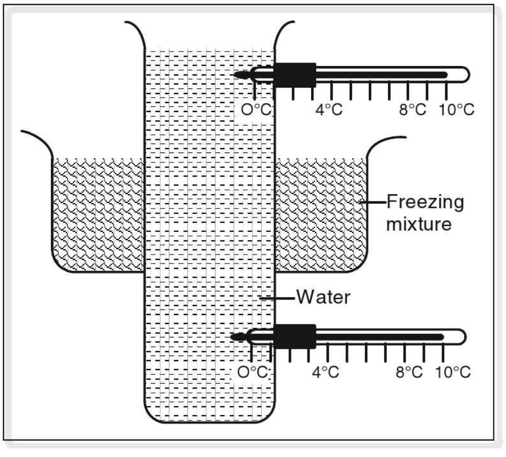


Figure 7.9 Hope's Apparatus

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.

Consequences of anomalous expansion of water

(i) 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).

(ii) In cold countries and hill stations the water pipes generally burst in winter due to the expansion of water.

(iii) 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 as shown in the figure. 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. The U-tube is filled partially 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.

Heat is absorbed by the black bulb as it is a good absorber. The shinning bulb reflects the heat, so it will not receive any radiation.

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.

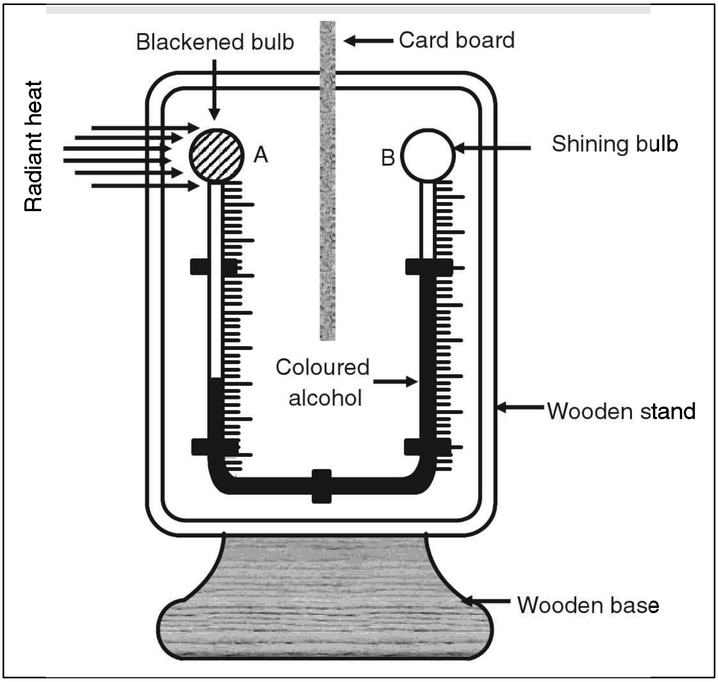


Figure 7.10

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. A molecule of a given gas is perfectly rigid and is coloured as an elastic sphere.
4. The molecules move along a straight line with different velocities, in random direction.
5. While in motion, the molecules of gas continuously collide with each other and also with the walls of the container.
6. The distance covered by a molecule between any two successive collisions with other gas molecules is called a mean 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

Boyle's Law

The relationship between volume and pressure of a gas is established by Robert Boyle, 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,

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

or $P \times V$ = 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 figure.

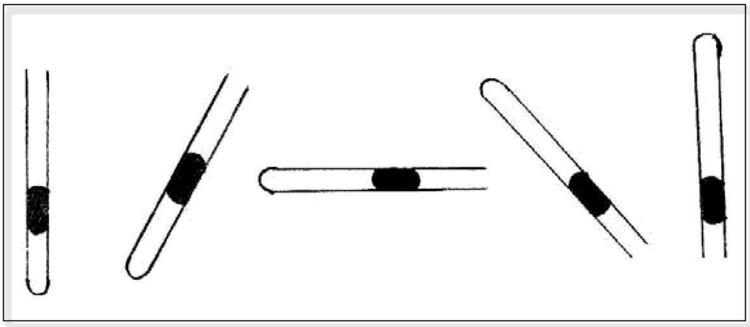


Figure 7.11 Various positions of Quill's tube

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 $(H + h) \times l$.

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)

or $\frac{V}{T}$ = 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.

$P \propto T$ (at constant volume)

or $\frac{P}{T}$ = 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 figure. This temperature is called absolute zero.

A gas whose behaviour is in accordance with Boyle's and Charle's laws is called an ideal gas.

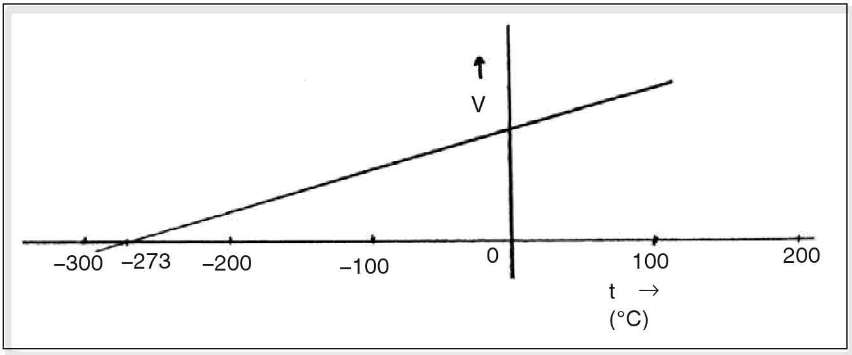


Figure 7.12 Volume versus temperature graph

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 temperature are 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,

$$P_1V_1 = P_2V^1$$

$$\Rightarrow V^1 = \frac{P_1V_1}{P_2} \quad ----- \quad (1)$$

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 the volume change from V^1 to V_2. Applying Charles' law,

$$\frac{V^1}{T_1} = \frac{V_2}{T_2}$$

$$\Rightarrow V^1 = \frac{V_2}{T_2} \times T_1 \quad ----- \quad (2)$$

Equating (1) and (2), we get

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \text{ or } \frac{PV}{T} = \text{constant}$$

the above equation is called the 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 they have 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

[redacted]			
1.	H_2	2.82	1920
2.	H_2O (vapout)	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 litre
T_1 = 273 + 27 = 300 K
V_2 = 1.5 litre
T_2 = ?
At constant pressure
$V \propto T$

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

$$\Rightarrow T_2 = \frac{V_2}{V_1} \times T_1$$

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°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 and temperature –23°C?

Solution

Given,
V_1 = 273 ml
P_1 = 76 cm of Hg
T_1 = 273 K
V_2 = ?
P_2 = 38 cm of Hg
T_2 = 273 – 23 = 250 K

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

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 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.

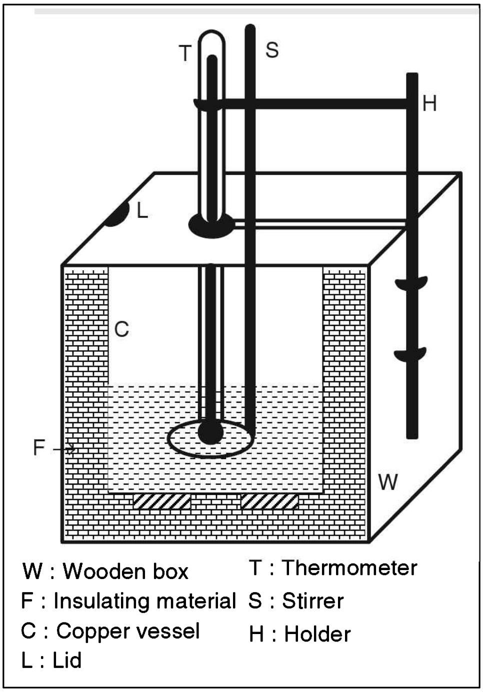


Figure 7.13

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.**

1calorie = 4.186 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 minimise 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.

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 the specific heat of the body. The value of specific heat (s) depends on the nature of the material.

As $s = \dfrac{Q}{m\Delta t}$ and for m = 1 kg and $\Delta t = 1°C$, s = Q, **specific heat** 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 (θ_1°C).

Take the solid whose specific heat is to be found and heat it in a hypsometer to a steady temperature.(θ_2°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 (θ_3°C). At the end measure the weight of the mixture (m_3 gm.).

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	$= \theta_1$°C
Let the temperature of hot solid	$= \theta_2$°C
Let the resultant temperature of mixture	$= \theta_3$°C
Mass of water	$= (m_2 - m_1)$g
Mass of solid	$= (m_3 - m_2)$g
Rise in temperature of water and calorimeter	$= (\theta_3 - \theta_1)$°C
Fall in temperature of hot solid	$= (\theta_2 - \theta_3)$°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	$= (m_3 - m_2) s_s (\theta_2 - \theta_3)$

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:

$(m_3 - m_2)\, s_s\, (\theta_2 - \theta_3) = m_1\, s_c\, (\theta_3 - \theta_1) + (m_2 - m_1)\, s_L\, (\theta_3 - \theta_1)$

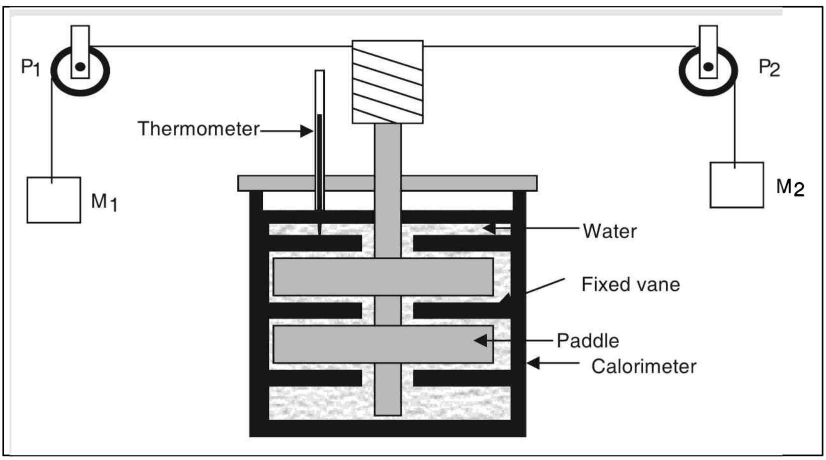
$$s_L = \frac{(m_3 - m_2)s_s(\theta_2 - \theta_3) - (m_1)s_c(\theta_3 - \theta_1)}{(m_2 - m_1)(\theta_3 - \theta_1)}$$

where s_s, s_c and s_L are respectively the specific heats of solid, calorimeter and the liquid.

Specific heat of water: Water has a specific heat of 1 cal $g^{-1}{}^{\circ}C^{-1}$. 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.



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 above. 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 = (mass of water) × (specific heat of water) × (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.

$\therefore W \propto H$ or $W = JH$

Hence, $J = \dfrac{W}{H}$

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 (cal°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

$Q = ms$ ----- (1)

Let M_1 mass of water absorb the same heat Q so that its temperature rises by 1°C. Taking specific heat

$Q = M_1 \times 1$
$Q = M_1$ ----- (2)
Equating (1) and (2),
$M_1 = m \times s$

By definition, M_1 is the water equivalent. Therefore, the water equivalent is given by the product m × 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 $[M^1L^oT^o]$. 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 × 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 vapourised 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 below.

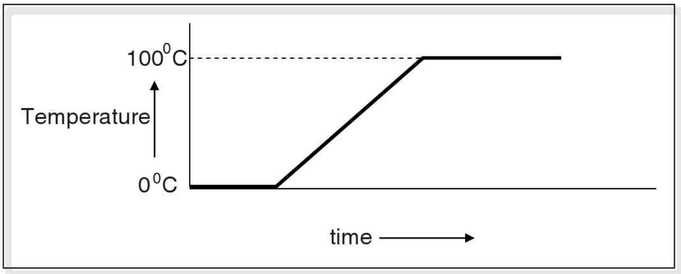


Figure 7.15

Note that the temperature remains constant at 0°C until all the ice melts. After that it increases and remains constant again at 100°C till all the water vaporizes.

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 attached to each other. This is

Evaporation

The process of vapourization of 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.

[redacted]	
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 in every region of 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 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

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)

[redacted]				
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 vapour 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 $m = 10\ g = 10^{-2}$ kg

$L = 336 \times 10^3$ J kg^{-1}

$Q_1 = 10^{-2} \times 336 \times 10^3$ J

$Q_1 = 3360$ J ----- (1)

The heat required to raise the temperature of water from 0°C to 100°C is

$Q_2 = m \times s \times \Delta\theta$

Substituting $m = 10^{-2}$ kg, $s = 4200$ J kg^{-1} K^{-1}

$\Delta\theta = 100°C$,

$Q_2 = 10^{-2} \times 4200 \times 100$

$Q_2 = 4200$ J ----- (2)

Substituting $m = 10^{-2}$ kg, $L = 2260 \times 10^3$
J kg^{-1} in

$Q_3 = m \times L = 10^{-2} \times 2260 \times 10^3$

$Q_3 = 22600\ J$ ----- (3)

where Q_3 is the heat required to convert water at 100°C to vapour.

The total heat is given by

$Q = Q_1 + Q_2 + Q_3$

$Q = 3360\ J + 4200\ J + 22600\ J$

$Q = 30160\ J$

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 m³ of saturated air, at various temperatures.

[redacted]	
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 m³ of air at a certain temperature to the mass of water vapour required to completely saturate 1 m³ 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

Solution

Relative humidity $= \frac{15}{30} \times 100 = 50\%$ at 30°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.

$$\text{Calorific value} = \frac{\text{Heat produced}}{\text{Unit mass}}$$

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 figure. 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.

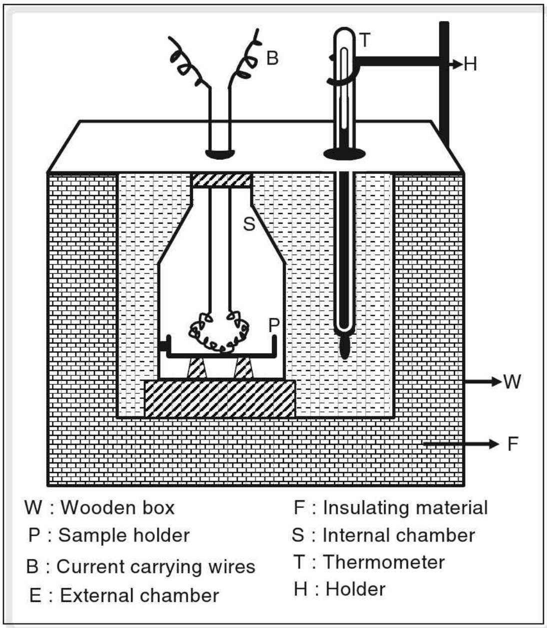


Figure 7.16

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 $mS = i^2 Rt$ or $S = \frac{i^2Rt}{m}$.

Thermal efficiency of a heating device

It is defined as the ratio of heat utilized to heat produced.

Thermal efficiency, $\eta = \frac{Q_u}{Q_T} = \frac{ms\Delta\theta}{mS}$, where 's' is the specific heat of substance and 'S' is the calorific value of fuel.

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 their 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

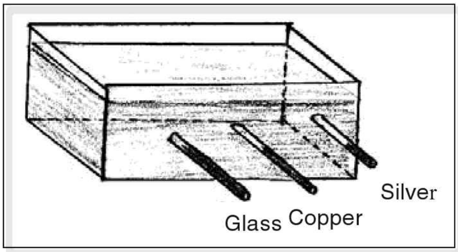
When heat energy flows easily through a given substance by conduction, it is said to be a good conductor of heat. All metals are good conductors of heat, silver being the best followed by copper and aluminum.

Among non-metals, graphite is a good conductor of heat. When a substance does not allow heat energy to pass through it easily then it is called a 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



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 solids such as silver, copper, and glass of equal length and thickness and coat them with a thin, uniform layer of wax. Now, insert them

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.

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 figure below.

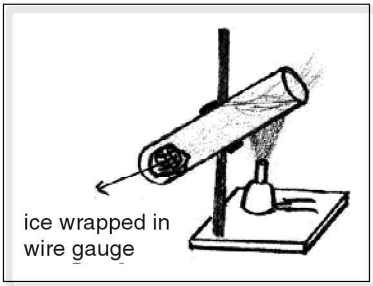


Figure 7.18 Experiment to show that water is a bad conductor of heat

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.

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 figure below.

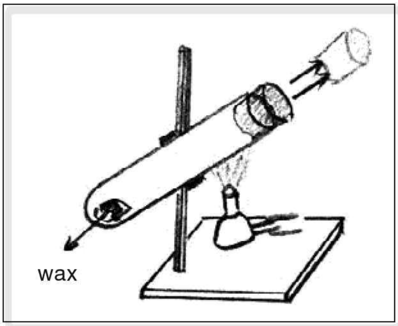


Figure 7.19 Experiment to show that gases bad conductors

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 it 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 passes 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 transmit 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.

Applications of bad conductors

Bad conductors of heat such as glass, wool, cotton, felt, asbestos, wood, etc. are used widely in various

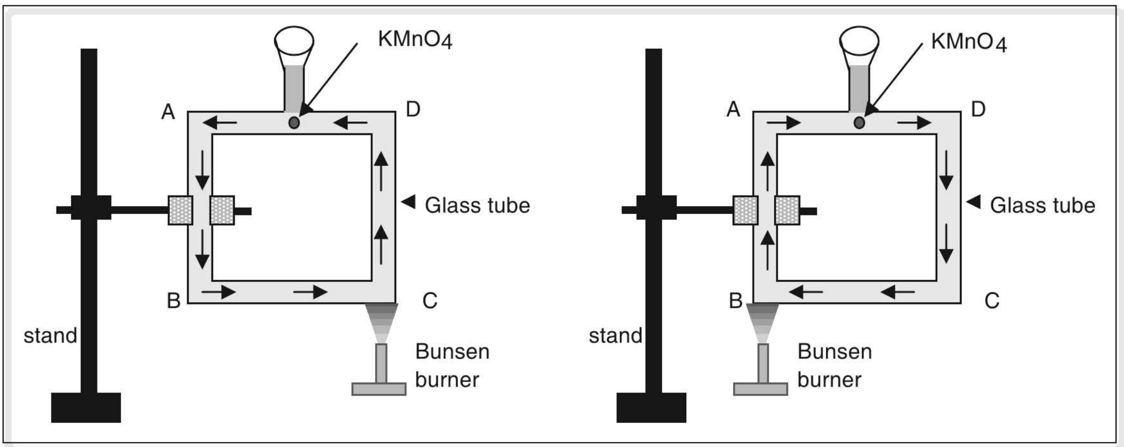
1. We wear woollen clothes and use blankets in winter as they contain large amount of trapped air which is a bad conductor of heat and therefore does not allow heat energy to flow outward from our body. Thus, our body stops losing heat and we feel warm. The fur found on the body of animals in cold countries 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.
2. 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.
3. 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.
4. The pipes carrying steam from boiler are covered with asbestos or glass wool to prevent loss of heat due to conduction.

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 figure.



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 towards C, 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

Gases are heated by convection. This can be demonstrated as follows.

Take a rectangular wooden box, provided with two glass chimneys, say A and B, and fix them on the top as shown in the figure.

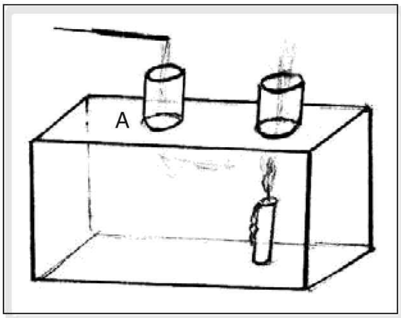


Figure 7.21

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, raises 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 the room is maintained due to formation of convection current. The rooms are provided with a top exit called ventilators through which the hot air and moisture pass. The fresh and cold air then enters the room through

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 of polar towards low pressure regions of equator. 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 figure below.

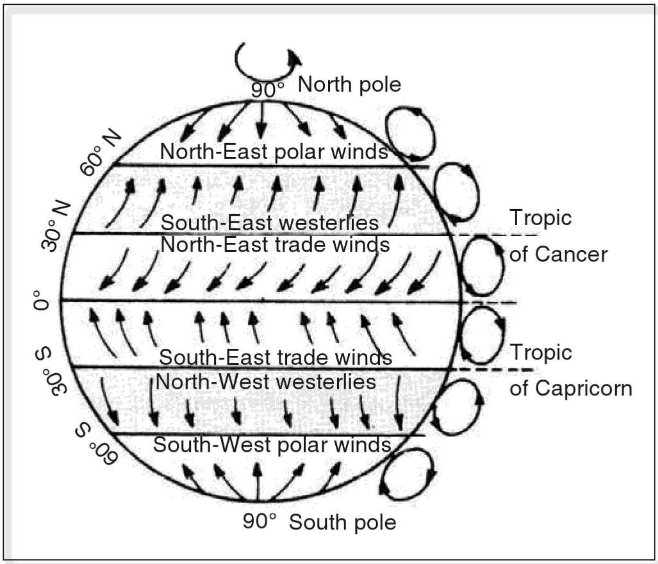


Figure 7.22

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 figure.

Radiation

In this mode of transmission of heat energy, 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 its frequency is small in comparison to visible light. In electromagnetic spectrum, the radiant heat is called infra red radiations, which are invisible. According to Planck's theory, the thermal radiations consist of small packets of energy called photons.

Every body emits thermal 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 velocity of 3×10^8 m s^{-1}
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 can 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.

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 figure below, can also be used to detect the thermal radiations.

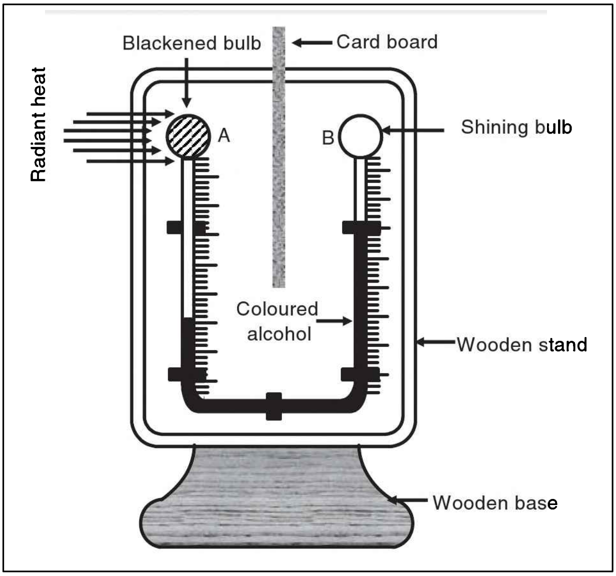


Figure 7.23

A differential air thermoscope detects the presence of thermal radiations by unequal expansion of air, when it absorbs thermal radiations. A differential air thermoscope consists of two glass bulbs connected at the end of a U – shaped tube which is partly filled with coloured alcohol. Out of the two bulbs, one is blackened with lamp black and the other 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.

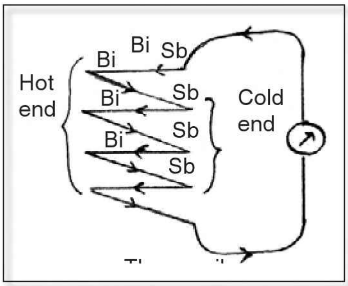


Figure 7.24 Thermopile

A thermopile, as shown in figure below, 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 figure. 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.

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

Radiation

It is a process of heat transfer from hot body to cold body without heating the intervening medium. Radiant energy does not require any material medium for its transmission. Heat radiation is a form of electromagnetic radiation like light rays and travels with a velocity of 3×10^8 m s^{-1}.

The heat radiations obey the laws of reflection and refraction, travels in all directions like light waves and can be detected by a differential air thermometer and a thermopile.

Reflecting power and absorbing power of a body

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.

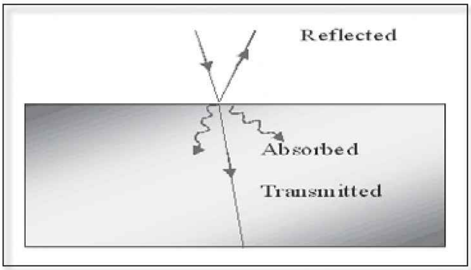


Figure 7.25

The **reflecting power** of a body is defined as the ratio of the quantity of heat energy reflected by the body to the quantity of heat energy incident on the body in one second.

Following are the factors affecting the reflecting power:

(i) Temperature of the body
(ii) Temperature of the surrounding atmosphere
(iii) Surface area of the body
(iv) Nature of the body surface such as dull, black or shinning, etc.

The **absorbing power** of a body is defined as the ratio of quantity of heat energy absorbed by the body to the quantity of heat energy incident on the body in one second.

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. The air between the two walls is evacuated and sealed. This shinning glass bulb is kept over a rubber cork on plastic or metal body. The space between the glass and 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.

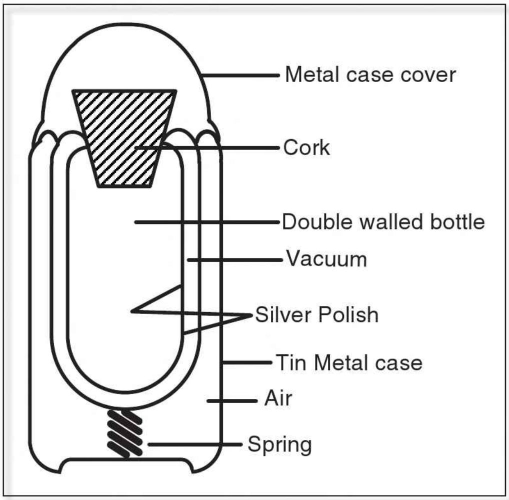


Figure 7.26

The different forms of heat loss are minimized in a thermos flask, due to the following reasons.

(i) 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.
(ii) Convection loss: Since there is a vacuum, loss due to convection is avoided.
(iii) Radiation loss: Since the glass is shinning, radiation loss is minimized.

Comparison between conduction, convection and radiation

(i) Conduction and convection do not take place, if no intervening medium is present. Radiation can

(ii) In conduction and convection, there is change in temperature of the medium, but in radiation, there is no change in temperature of the medium.

(iii) In vacuum thermal radiations travel with velocity of light, transferring heat energy at faster rate.

(iv) 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.

(v) Conduction and radiation take place in all directions. In convection, heated particles move towards cooler region.

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.

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 figure.

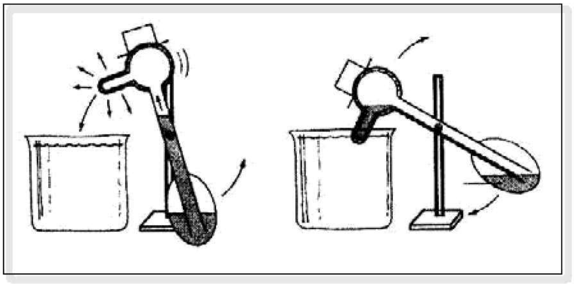


Figure 7.27 Thirsty bird – A cyclic heat engine

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.

(1) 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 figure ahead.

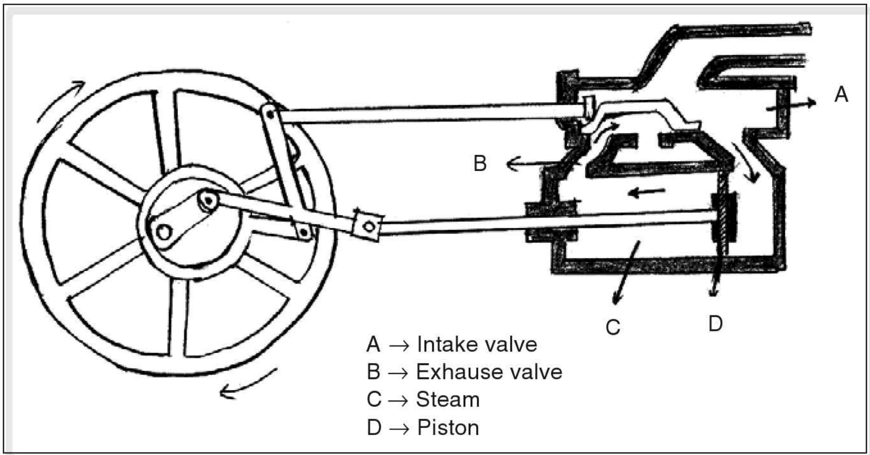


Figure 7.28 Thirsty bird – A cyclic heat engine

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.

(2) 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 figure below.

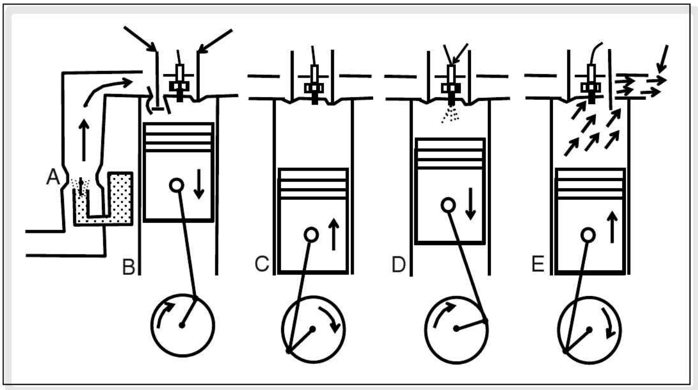


Figure 7.29 Four strokes in a petrol engine

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 iston 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

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 $= \dfrac{\text{work done}}{\text{Amount of heat supplied}} \times 100$

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

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 47×10^6 J kg^{-1}. The percentage efficiency is given by

$$= \frac{\text{Work done (W)}}{\text{Amount of heat supplied}} \times 100$$

$$Q = \frac{30 \times 47 \times 10^6}{100}$$

$$Q = \frac{30 \times 47 \times 10^6}{100}$$

$$= 131 \times 10^5 = 1{\cdot}31 \times 10^7 \text{J}$$

test your concepts

Very short answer type questions

1. Define melting and boiling points?
2. What is the water equivalent of a substance of mass 2 kg and specific heat capacity 2.4 $J\ g^{-1}\ K^{-1}$?
3. In which mode of transmission of heat is the medium not necessary?
4. 1joule = _________ calorie
5. Define specific latent heat of melting and specific latent heat of vaporization.
6. In S.I system the unit of heat energy is __________.
7. Define 1 calorie and 1 kilocalorie. What is the use of calorimeter?
8. Distinguish between internal and external combustion heat engines.
9. What is evaporation? How the rate of evaporation is related to temperature?
10. Define mechanical equivalent of heat. What is its value?
11. Give few examples of bad conductors of heat.
12. Among petrol and diesel engines, which is more efficient?
13. Define heat capacity and specific heat capacity. State their SI units.
14. What is a cyclic process?
15. Does calorific value of fuel depend upon its mass?
16. 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?
17. In which mode of transmission do the particles of a medium move from one place to another place?
18. Why does not a diesel engine have a spark plug?
19. What is minimum possible temperature? Given its value in Kelvin and Celsius scale?
20. Heat travels through vacuum as _________.
21. Define relative humidity. State its SI unit.
22. According to kinetic theory of gases, what is the cause of gas pressure?
23. What is the use of a thermopile?
24. State Boyle's and Charles' laws.
25. Why are burns due to steam more harmful than those due to boiling water?
26. The S.I. unit of specific latent heat of vapourization is _________.
27. Define coefficients of linear, superficial and cubical expansions.
28. Heat energy flows from a body at __________ temperature to a body at __________ temperature.

29. What are the values of specific latent heat of melting of ice and specific latent heat of vaporization of water?

30. Define coefficient of apparent and real expansion of a liquid.

Short answer type questions

31. Give some advantages of high specific heat capacity of water.

32. Differentiate between evaporation and boiling.

33. 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 kcal$°C^{-1}$, 25 kg)

34. Derive the relation between the coefficients of thermal expansion, α, β and γ of a solid.

35. What is a thermopile? Explain its working.

36. 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: 12.6×10^3 J kg^{-1} K^{-1})

37. Explain how land and sea breeze occur.

38. 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 $1{\cdot}8 \times 10^{-4}$ $°C^{-1}$.
(Ans: 13.127 g cm^{-3})

39. On what factors does the radiating power of a hot body depend?

40. Why do pendulum clocks made of ordinary metal go slow in summer?

41. 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 = 12×10^{-6} $°C^{-1}$ and that of brass = 18×10^{-6} $°C^{-1}$, find length of the two rods at 0°C.
(Ans: brass rod = 10 cm iron rod = 15 cm)

42. Find the quantity of water vapour at 100°C required just to melt 1 kg of ice at 0°C.
(Ans: 148 g)

43. Define apparent and real expansion of a liquid and derive a relation between them.

44. Explain why metals are good conductors of heat?

45. Distinguish between heat and temperature.

Essay type questions

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.

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. Heat engines convert mechanical energy into heat energy.
2. As pressure increases, the melting point of ice decreases.
3. Temperature determines the direction of flow of heat energy.
4. Conduction process can be explained on the basis of both atomic model and kinetic model.
5. Liquids have two types of volumetric expansion.
6. Gas thermometers are more sensitive than liquid thermometers.
7. Water has high specific heat capacity.

Direction for questions 8 to 14: Fill in the blanks.

8. Specific heat capacity of water is ________ J kg^{-1} K^{-1}.
9. At constant volume the pressure of a given mass of a gas is directly proportional to its __________.
10. 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 ___________.
11. A temperature of 50°C on Celsius thermometer corresponds to _____ on Fahrenheit thermometer.
12. The relative humidity is expressed as __________.
13. The quantity of heat produced when a unit mass of a substance is completely burnt is called its ___.
14. 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.

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.	cal g^{-1} $^0C^{-1}$

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

(1) it is reflected
(2) it is absorbed
(3) it is transmitted through it
(4) 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

(1) reflecting power of the body
(2) radiating power of the body
(3) transmitting power of the body
(4) absorbing power of the body

18. Among the following __________ represents the smallest temperature change

(1) 1 K
(2) 1°C
(3) 1°F
(4) 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

(1) the sample becomes supersaturate
(2) the sample remains saturated
(3) the sample becomes moist air
(4) the sample becomes unsaturated

20. Temperature of a body is the measure of

(1) sum total of kinetic and potential energy of the molecules of the given body.
(2) amount of heat energy present inside the given body.
(3) mechanical vibrations of the body.
(4) 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 _________.

(1) 80°C
(2) 82.5°C
(3) 85°C
(4) 77.5°C

22. In a thermos flask, heat loss by conduction and convection can be avoided by

(1) providing vacuum between the two walls of the flask.
(2) filling the space between the two walls of the flask with cork which is a bad conductor of heat.
(3) providing a shining glass.
(4) All the above

23. When ice water is heated, its density

(1) decreases
(2) increases
(3) first increases, then decreases
(4) 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 __________.

(1) $0.0005\ K^{-1}$
(2) $0.05\ K^{-1}$
(3) $0.05\ K^{-1}$
(4) $0.00\overline{5}\ K^{-1}$

25. The unit for volume coefficient of expansion is

(1) $°C^{-1}$
(2) K^{-1}
(3) $°F^{-1}$
(4) All of these

26. The water equivalent of a body, whose mass is 'm' g and specific heat is 's' cal $g^{-1}°C^{-1}$ is given by __________.

(1) m + s
(2) $\frac{m}{s}$
(3) $\frac{s}{m}$
(4) ms

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 kJ $kg^{-1°}$ C^{-1}, specific heat of water = 4.2 J $g^{-1}°C^{-1}$
specific latent heat of fusion of ice = 336 J g^{-1})
(1) 398.95 kJ (2) 387.75 kJ
(3) 337.75 kJ (4) 357.75 kJ

28. Efficiency of a heat engine is defined as the
(1) product of the work done by the heat engine and amount of heat supplied to it.
(2) ratio of the amount of heat supplied to it and work done by the heat engine.
(3) ratio of the work done by the heat engine and amount of heat supplied to it.
(4) 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
(1) mass (2) heat energy (3) temperature (4) specific heats

30. The Quill's tube with its open end upwards is fixed in slanting position making 45^0 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 ____________.

(1) H + h (2) H – h (3) $H + \frac{h}{\sqrt{2}}$ (4) $H - \frac{h}{\sqrt{2}}$

Concept Application Level—2

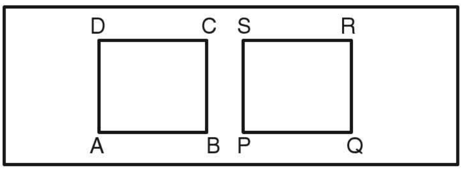
31. Two metallic tins made of copper and steel are stuck together with the copper tin inside the steel tin. Explain a method to separate the tins.

32. As an air bubble rises from the bottom of a large water storage tank to free surface of water, the radius of the air bubble increases from 6 mm to 10 mm. The temperature of the water at the surface is 42°C and its bottom is 27°C. Find the depth of the water tank.
(Take density of water = 1 g cm^{-3}, g = 10 ms^{-2}, 1 atmospheric pressure = 760 mm of Hg; density of mercury =13.6 g cm^{-3})

33. The ratio of densities two metallic spheres X and Y is 1 : 2. Their ratio of radii is 2 : 1. If the ratio of heat supplied to given metallic spheres is 2 : 3. Calculate the ratio of specific heat capacity of X and Y, if they experience an equal rise in temperature.

34. A vessel contains ice and is in thermal equilibrium at –10°C and is supplied heat energy at the rate of 20 cal s^{-1} for 450 seconds. If the mass of ice is 0.1 kg and due to supply of heat energy, the whole ice just melts find the water equivalent of the vessel. (Take specific heat of ice = 0.5 cal $g^{-1}°C^{-1}$ and specific heat of the vessel is = 0.1 cal $g^{-1}°C^{-1}$. Latent heat of fusion = 80 cal g^{-1} and assume that no heat is transferred to the surroundings)

35. From a rectangular sheet of metal two small square shaped pieces, as shown in the figure, are cut off. The rectangular metal sheet is then heated. What happens to the area of the squares? Also explain what happens to (i) the distance between the points C and D? and (ii) the distance between point C and S?



36. Two copper spheres of equal mass, one solid and the other hollow, are heated through an equal rise in temperature. What is the ratio of the time taken to heat them, if the ratio of the rate at which heat is supplied to the solid sphere to hollow sphere is 1 : 2?

37. A faulty mercury thermometer has a stem of uniform cross section marked in mm. If this reads 83 mm instead of 80 mm at LFP and 229 mm instead of 220 mm at UFP. Find the difference in the length of the mercury thread in both the faulty and correct thermometers at 250 ^{0}C (Take LFP = 0°C and UFP = 100°C)

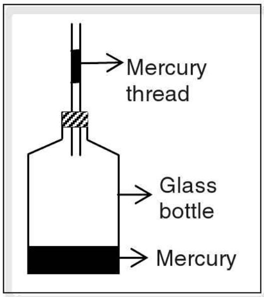
38. Find the water equivalent of paraffin oil, if 100 kg of paraffin oil absorbs 4180×10^3 J to raise its temperature from 300 K to 320 K. (Take specific heat of water as 4.18 J g^{-1}°C^{-1})

39. Why does the temperature of the surrounding start falling when the ice of a frozen lake starts melting?

40. Why do the fish plates of railway tracks have oval shaped holes?

41. Is it possible to heat (boil) fluids by convection process in weightlessness condition,

42. A constant volume air thermometer is as shown in the figure. 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 glass and mercury are 1.8×10^{-4} K^{-1} and 6×10^{-5} K^{-1} respectively.



43. Two metal cylinders 'A' and 'B' of same material 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.

44. 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 cal g^{-1}°C^{-1}, the specific heat of copper = 0.1 cal g^{-1}°C^{-1} and latent heat of fusion of ice = 80 cal g^{-1}.

45. 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 J kg^{-1} K^{-1}
Specific latent heat of fusion of ice = 336000 J kg^{-1}

Concept Application Level—3

46. 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.

47. A hollow sphere is heated. Explain the type of change produced in its
(i) internal radius (ii) external radius (iii) volume
(iv) mass (v) density

48. A metallic solid body of weight 'W_1' is immersed in a liquid, whose temperature is t_1°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°C, the apparent weight of the body is 'W_3'. If the density of this liquid at t_1°C and t_2°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°C and t_2°C.

49. 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.

50. As the altitude from the surface of the earth increases, the atmospheric temperature falls. Explain.

key points for selected questions

Very short answer type questions

1. Temperature at which solid changes to liquid is melting point.
   Temperature at which liquid changes to gas is boiling point.

2. $Q = 2 \times 2.4 \times 10^3$ J kg^{-1} K^{-1}
   $= 4.8 \times 10^3$ J kg^{-1} K^{-1}

3. Radiation

4. 0.24

5. Amount of heat required to change unit mass of solid to liquid completely is called specific latent heat of melting.
   Amount of heat required to change unit mass of liquid to vapour completely is called specific latent heat of vaporization.

6. Joule

7. 1 calorie of heat is produced if 4.2 joule of work is done.
   1 kilo calorie = 1000 calorie
   Measurement of heat energy.

8. Position of burning fuel in an engine chamber.

9. (1) Vaporisation of liquid.
   (2) Rate of evaporation ∝ temperature.

10. $J = \frac{W}{H}$
    $J = 4.2$ J cal^{-1}

11. Glass, wool, gases

12. Diesel engine

13. Heat capacity is the amount of heat energy required to raise the temperature of a body through 1°C or 1K.
    It is the heat required to raise the temperature of a body of a unit mass by 1°C.

14. Repetition of same process again and again.

15. $\text{Calorific value} = \frac{\text{Heat produced}}{\text{Unit mass}}$

16. Yes

17. Convection

18. The air is compressed to $\frac{1}{16}$th of its initial volume and it is hot enough to ignite diesel.

19. 0 K = −273°C

20. Radiation

21. Ratio of mass of water vapour 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. No units.

22. No. of collisions of gas molecules.

23. Used to detect thermal radiations.

24. Boyle's law $V \propto \frac{1}{P}$ (T = Constant)

Charles Law $V \propto P$ (P = Constant)

25. Latent heat of vaporization.

26. J kg^{-1}

27. $\alpha = \frac{\Delta\ell}{\ell_1 \Delta\theta}$

$\beta = \frac{\Delta A}{A_1 \Delta\theta}$

$\gamma = \frac{\Delta V}{V_1 \Delta t}$

28. Higher, lower

29. 80 cal g^{-1}

540 cal g^{-1}

Short answer type questions

31. (1) Coolant

(2) Land breeze and sea breeze

32. Evaporation: (1) Takes place at all temperatures.

(2) Temperature changes during the process.

(3) Surface phenomenon.

(4) Depends on free surface area of the liquid.

Boiling: (1) Takes places at definite temperature.

(2) Temperature does not change.

(3) Takes in every region of liquid.

(4) Independent of surface area of the liquid.

33. (1) C = ms

(2) Definition of water equivalent.

Ans: Thermal capacity is 25 kcal°C^{-1}

Water equivalent = 25 kg.

34. $\alpha = \frac{\Delta\ell}{\ell_0(\Delta\theta)}$;

$\beta = \frac{\Delta A}{A_0(\Delta\theta)}$;

$\gamma = \frac{\Delta V}{V_0(\Delta\theta)}$

$\alpha : \beta : \gamma = 1 : 2 : 3.$

35. (1) Sensitive device to detect thermal radiations.

(2) Number of rods of antimony and bismuth connected in series.

(3) Form junctions

(4) Thermal radiations are incident, temperature difference is developed.

(5) Flow of current is detected by galvanometer.

36. $Q = ms\Delta\theta$

Ans: 12.6×10^3 J kg^{-1} K^{-1}

37. (1) Day time, land heated to high temperature due to difference in specific heat capacities of water and land.

(2) Difference in pressure in the upper and lower layers.

(3) Hence, a sea breeze.

(4) Night time, land cools faster.

(5) Difference in pressure

(6) Hence, a land breeze

38. $\Delta V = V \gamma \Delta \theta$;

Ans: 13.127 g cm^{-3}

39. (1) Reflecting power

(2) Absorbing power

40. Linear expansion of solids

41. $\alpha_1 \ell_1 = \alpha_2 \ell_2$ or $\Delta\ell_1 = \Delta\ell_2$

Ans: length of brass rod = 10 cm

length of iron rod = 15 cm

42. Principle of calorimetry

Ans: 148 g (approximately)

43. Real expansion of a liquid = apparent expansion

key points for selected questions

of the liquid + volume expansion of the container

44. (1) Metals contain large number of free electrons.

(2) Receive heat energy, gain K.E. and start moving away from source of heat.

45. Heat: (1) A cause

(2) Calorimeter

(3) Unit – joule

(4) Sum of PE and KE

Temperature: (1) A effect

(2) Thermometer

(3) Kelvin

(4) Average KE of molecules

Essay type questions

46. (1) Conduction: Heat energy flows from one molecule to another molecule of a solid without their actual movement.

(2) Convection: molecules of a fluid are free to move within the mass of a fluid.

(3) Radiation: For transmission of heat energy, material medium may or may not be present.

47. (1) Wooden box

(2) Copper vessel

(3) Insulating material

(4) Pan in the vessel

(5) Connecting wires

48. (1) Electromagnetic waves

(2) Travel with velocity of 3×10^8 m s^{-1}

(3) Travel through vacuum

(4) Travel in straight lines

(5) Can be reflected and refracted

(6) Travel in all directions

49. (1) Gap between double walls of an ice box is filled with glass, wool to prevent the heat from flowing in so that ice does not melt.

(2) Handles of appliances like pressure cooker, electric iron, ovens.

(3) Pipes carrying steam from boiler.

50. (1) Hot water bath

(2) Heating the given solid

(3) Calorimeter with water, their mass and temperature

(4) Mixing of solid with water in calorimeter

(5) Stirring and final temperature

(6) Principle of calorimetry

KEY

Concept Application Level—1

True or false

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. Choice (4)
17. Choice (4)
18. Choice (3)
19. Choice (4)
20. Choice (4)
21. Choice (2)
22. Choice (1)
23. Choice (3)
24. Choice (4)
25. Choice (4)
26. Choice (4)
27. Choice (1)
28. Choice (3)
29. Choice (3)
30. Choice (3)

Concept Application Level—2, 3

Key points for select questions

31. 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?

32. (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 atm = 10.336 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) 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) 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 = ($P_2 - P_1$) m

 (ii) 35.273 m

33. (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

34. (i) The amount of heat absorbed by the ice at -10^0 C to just melt = Q
 $\Rightarrow Q_1 = m_i S_i \Delta t + m_i L_F$ – (1)
 The actual amount of heat energy supplied = Q = R × t – (2)
 Q = 20 × 450 cal
 Then find the amount of heat absorbed by vessel = Q_2 Q –
 Q_1 – (3)
 $Q_2 = m_V S_V (\Delta T)$ – (4)
 Find the value m_V from (4)
 Now water equivalent = M = $m_V S_V$

 (ii) 50 g

35. 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.

36. (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)

$$= \frac{\text{Heat supplied (Q)}}{\text{time (t)}}$$

$\Rightarrow Q = Kt \quad \rightarrow \quad (1)$

Also $Q = ms\Delta\theta \rightarrow \quad (2)$

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

37. (i) The relation comparing two scales is given by:

$$\left(\frac{S-LFP}{UFP-LFP}\right)_{correct} = \left(\frac{X-LFP}{UFP-LFP}\right)_{Faulty} \quad -(1)$$

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 $\ell_2 - \ell_1$

(ii) 18 mm

38. (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

39. Does ice absorb or liberate heat while melting?

How does this affect the heat content in the surroundings of the ice?

40. (i) If the fish plates have circular – shaped holes instead of oval – shaped ones, do the railway tracks have scope for horizontal thermal expansion?

(ii) 24°C

42. (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 $\Delta V_{mercury} = \Delta V_{bottle}$?

Use $\Delta V = V\gamma\Delta\theta$

Is $\Delta\theta$ the same for the bottle and the mercury in it?

(ii) $\frac{3}{1}$

43. (i) Given the two metal cylinders are of the same material,

$\Rightarrow$ 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

44. (i) Heat is absorbed by both the calorimeter and the contents in it.

Calculate the total heat supplied in the given time, using Q = (rate of heat supplied) × time.

Initial temperature of the calorimeter and the contents in it is the same.

Use Q = mL and Q = msΔθ as required.

(ii) 61.4°C

45. (i) Use Q = mL and Q = msΔθ according to the situation.

Use principle of calorimetery.

Total heat produced = (mass of the substance) × (calorific value of the substance).

(ii) 5.46 MJ kg^{-1}

46 (i) → Find the total amount heat required to convert 1 kg of ice at 0°C to water at 100°C

→ $Q_1 = m_i L_F + m_i S_W (\Delta T) = mL_F + mS_W (100)$ – (1)

→ Find the amount of steam that gets condensed into water 100°C

→ Consider the efficiency of the calorimeter as 90%

⇒ Then, $\frac{90}{100}(m_S L_V) = Q_1$ - (2)

Find the value of m_S from (2)

Find the ratio of $\frac{m_s}{m_W}$

Heat last to the surrounding is = $\frac{1}{10} m_s L_V$

(ii) 0.49, 84 kJ

47. 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.

48. (i) Take volumes of the body at t_1°C and t_2°C be V_1 and V_2 respectively. Take the densities of the liquid at t_1°C and t_2°C as d_1 and d_2 respectively. Find the apparent loss in weight of the body in liquid at t_1°C and t_2°C

Then, $W_1 - W_2 = V_1 d_1 g$

and $W_1 - W_3 = V_2 d_2 g$

The volume coefficient of the solid body =

$$\gamma = \frac{\Delta V}{V_0 \Delta T} = \frac{V_2 - V_1}{V_1 (t_2 - t_1)} \, {}^0C^{-1}$$

Convent 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) $\frac{d_1(w_1 - w_3) - d_2(w_1 - w_2)}{d_2(t_2 - t_1)(w_1 - w_2)}$ °C^{-1}

49. When the thermally insulated can containing a liquid is shaken, there is some work done on it.

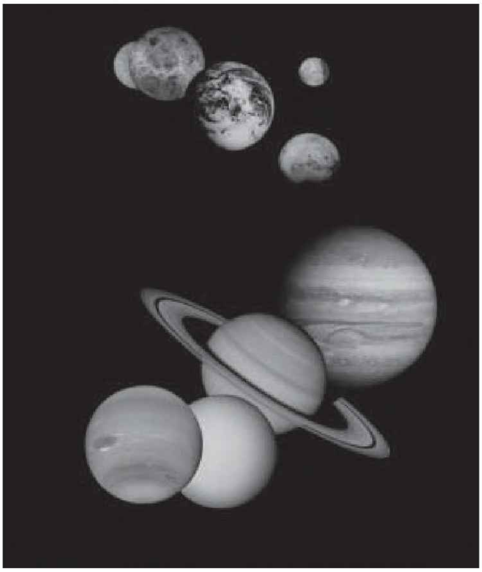
The work done is transformed into energy.

Into what form of energy is the work done transformed?

50. Does the atmosphere get heated by absorbing the radiation that passes through it in the process of incidence on land?

Or, does the atmosphere get heated by the radiation that is reflected from the land?

As the distance from a radiating body (source of radiation) increases, how does the intensity of radiation vary?



8

Wave Motion and Sound

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, and
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 suspended by means of a thread from a rigid support and allowed to vibrate in a vertical plane as shown in figure (8.1). 'O' is the rest position or 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.

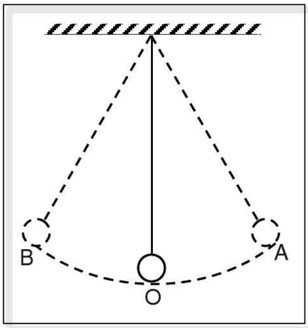


Figure 8.1

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 figure (8.2).

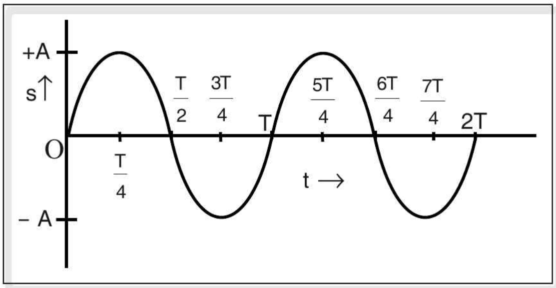


Figure 8.2

As the time increases, displacement increases to the maximum of 'A' at $t = \frac{T}{4}$ and then the bob comes to mean position at $t = \frac{T}{2}$ and so displacement is zero. It continues to move towards negative side, and when the time $t = \frac{3T}{4}$ its displacement is equal to amplitude. When t = T, it comes back to mean position completing one full vibration.

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 $n = \frac{1}{T}$.

Here, we find that the graph 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.

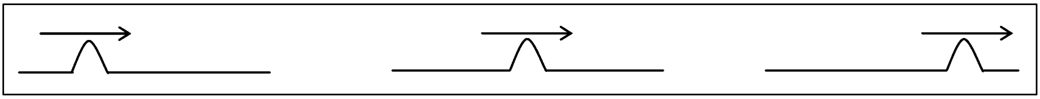


Figure 8.3

A **wave** on the other hand is a sustained disturbance lasting for a longer duration, like waves on the surface of water.

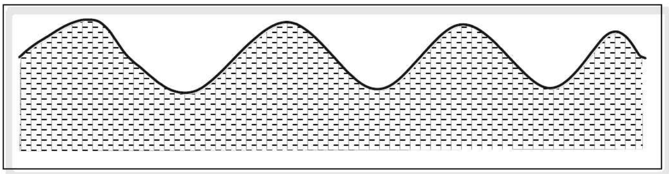


Figure 8.4

Before we proceed to study wave motion in greater detail let us first review the terms and physical quantities associated with wave motion.

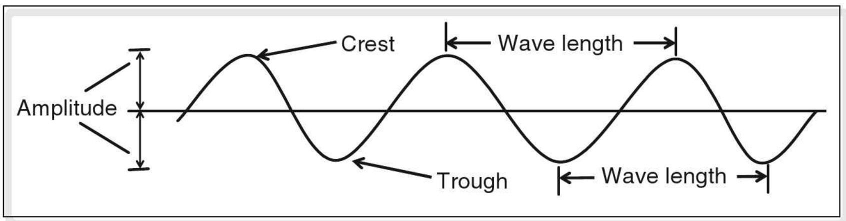


Figure 8.5

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.

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 hertz = 1 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 any given 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

Thus we see that 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:

A. 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, 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 an elastic medium for their propagation. They can propagate through material media as well as vacuum. Light waves are an example of electromagnetic waves.

B. 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, such a wave is called a 'longitudinal wave' and if it is perpendicular to the direction of wave motion such a wave is called a '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 figure (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 figure (8.7).

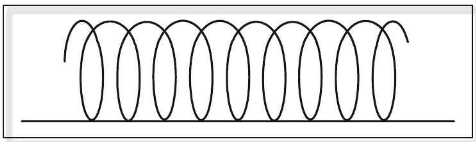


Figure 8.6

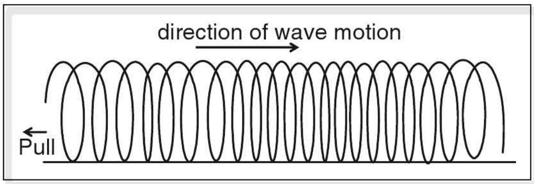


Figure 8.7 Longitudinal waves

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

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 in the string as shown in figure (8.8). The original position of the string is shown by a dotted line. It is also called as mean or rest position. Here the wave moves in the horizontal direction whereas the particles of the string vibrate in the perpendicular direction (vertical).

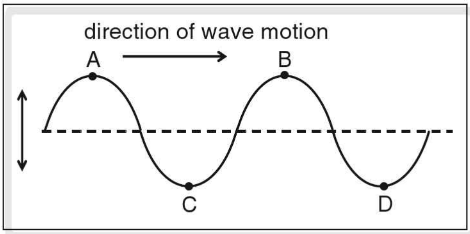


Figure 8.8 Transverse wave

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.

Consider the cross section of water surface when waves are propagating through its surface as shown in the figure (8.9).

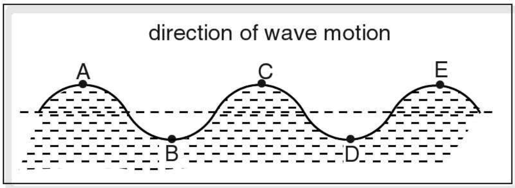


Figure 8.9

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 $v = \frac{\lambda}{T}$.

As $\frac{1}{T} = n$, (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 figure (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 figure (8.10).

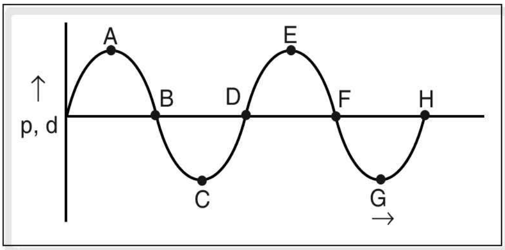


Figure 8.10 Distance of element of gas from source of sound

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.

Comparative study of transverse and longitudinal waves

[redacted]	
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.

C. 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'.

Consider a progressive transverse water wave moving from left (point P) to right and striking a hard surface at 'Q' as shown in figure 8.11(a). It then gets reflected at 'Q', and travels towards 'P'. Thus the two waves, one going from 'P' to 'Q' and the other going from 'Q' to 'P' 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 figure 8.11) and points, where the displacement of the vibrating particles is maximum are called 'antinodes' (shown as A in figure 8.11).

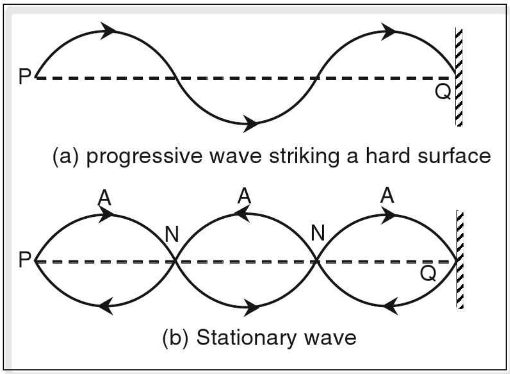


Figure 8.11

On the whole, the wave appears to be standing or stationary, contained between two positions 'P' and 'Q' and so called as '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 combination of two similar progressive waves traveling in opposite directions'.

Comparative study of progressive and 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.

Sound

Sound is a form of energy. It causes sensation in our ears. It is produced by bodies which vibrate.

Consider a tuning fork 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 suspended from a rigid support by means of a thread, the ball is flicked by the fork (figure 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.

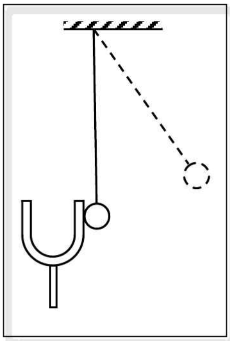


Figure 8.12

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 (figure 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 figure), the bell rings and the sound is heard.

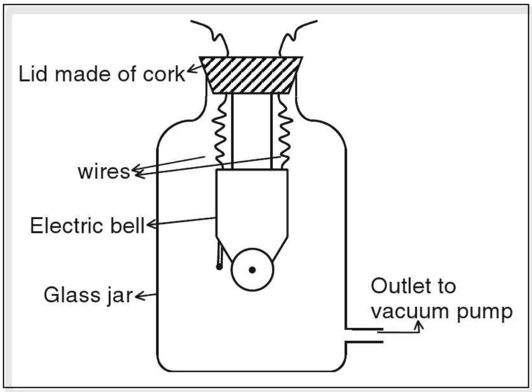


Figure 8.13 Bell-jar experiment

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 will be 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

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 bodies that vibrate.
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 3×10^8 m s^{-1}.	6. The value of velocity of sound in air at normal temperature and pressure is 330 m s^{-1}.

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 then 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 largest in solids, less in liquids and least in gases and so the decreasing order of velocity of sound is $v_s > v_\ell > v_g$ 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 given medium was derived by Newton as $v = \sqrt{\frac{P}{d}}$; where 'P' and 'd' are pressure and density of a given gas and 'v' is velocity of sound in the 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 the 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 '$\gamma$' 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 found to be 'adiabatic' (changes that take place without any transfer of heat). The value of velocity of sound in air calculated using the Laplace correction was coinciding with the observed value obtained by experimentation.

Factors on which the velocity of sound in a gas depends

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.

   If v_1 and v_2 are the velocities of sound in a gas at absolute temperatures T_1 and T_2 respectively then $v_1 \propto \sqrt{T_1}$ and $v_2 \propto \sqrt{T_2}$.

So $\frac{v_1}{v_2} = \sqrt{\frac{d_2}{d_1}}$

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 respectively 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 T_1 and T_2 temperatures, then $\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$.

   On simplification, we get $v_t = v_0\left(1 + \frac{t}{546}\right)$; where v_o and v_t are the velocities of sound in air at 0°C and at t°C respectively. Thus the velocity of sound in air increases by approximately 0.61 m s^{-1} for 1°C rise in 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' respectively, 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 in given by $v = \sqrt{\frac{\gamma P}{d}}$; where '$\gamma$' is a constant, 'P' is the pressure and 'd' is the density. When the pressure of a gas is changed, its density also changes such that the ratio $\frac{'P'}{d}$ is always a constant. Hence, the variation of pressure of a gas does not affect the velocity of sound in it.

4. 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.

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 figure (8.14).

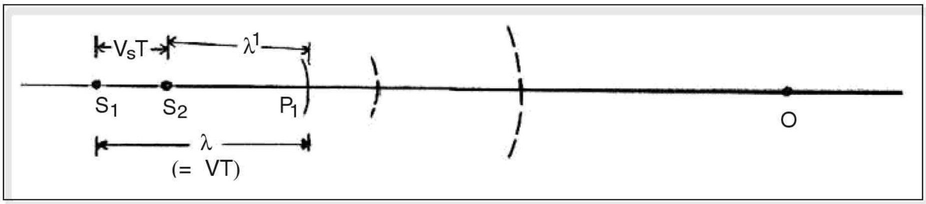


Figure 8.14

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_ST). Thus the next wave would be generated at S_2 instead at S_1 and the apparent wavelength would be S_2P_1 (λ^1).

$\therefore$ Apparent wavelength, $\lambda^1 = S_2P_1$

$= S_1P_1 - S_1S_2$

$= vT - v_ST$

$= T(v - v_S)$

$= \dfrac{v - v_s}{n}$ where 'n' is the real frequency which is the reciprocal of the time period.

But the velocity of sound v remains constant.

$$\therefore\ v = n\lambda = n^1\lambda^1$$

$$\lambda^1 = \frac{v}{n^1}$$

$$\therefore\ \frac{v}{n^1} = \frac{v - v_S}{n}$$

$$n^1 = n\left(\frac{v}{v - v_s}\right)$$

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 each other.

[redacted]			
$+ v_S$	zero	$n\left[\dfrac{V}{V + V_S}\right]$	Source moving towards the stationary observer
$- v_S$	zero	$n\left[\dfrac{V}{V + V_S}\right]$	Source moving away from the stationary observer
Zero	$+ v_O$	$n\left[\dfrac{v + v_O}{v}\right]$	Observer moving towards the stationary source
Zero	$- v_O$	$n\left[\dfrac{v - v_O}{v}\right]$	Observer moving away from the stationary source

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 the Mach number in honour of an Austrian physicist Ernst Mach.

$$\text{Mach number, M} = \frac{\text{Velocity of the object}}{\text{Velocity of sound in the surrounding medium}}$$

Consider a stationary source A (Mach number, M = 0). The sound waves produced would be concentric spheres as shown in figure (8.15).

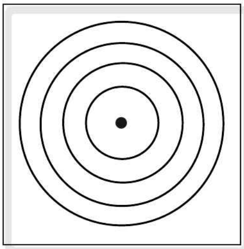


Figure 8.15

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. (figure 8.16)

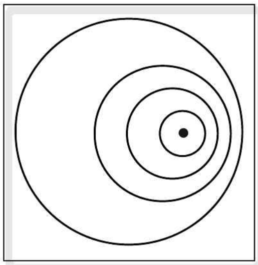


Figure 8.16

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 figure (8.17).

In this case the sound waves would reach the observer alongwith the source. Thus the sound cannot be heard until the source reaches him.

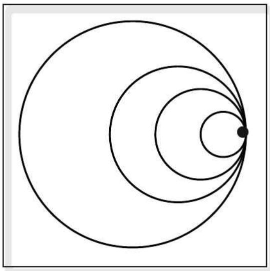


Figure 8.17

If the source travels at a speed greater than the speed of sound, when the corresponding Mach number, M is greater than l, the source precedes the sound produced by it, and the wavefronts lagging behind the source would form a cone as shown in figure (8.18). Thus as the source has passed the observer, wavefronts (compressions) coming from opposite directions would produce an intense thumping sound.

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.

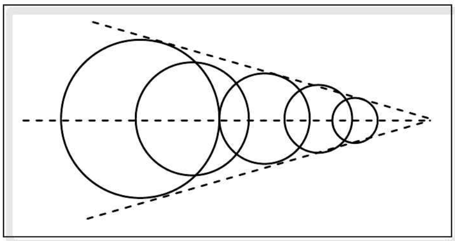


Figure 8.18

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 certain 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. These type of vibrations are called forced vibrations.

☛ *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 object is equal to that of the applied force.

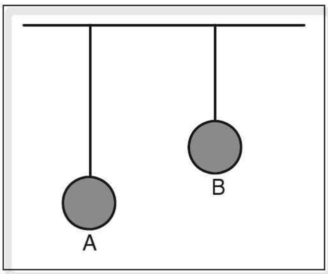


Figure 8.19

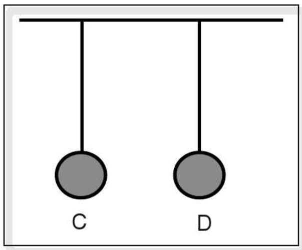


Figure 8.20

☛ *Example*

Consider two arrangements of a pair of pendulums as shown in figures (8.19) and (8.20). In figure (8.19) the two pendulums A and B have different lengths and thus their natural frequencies are different. In figure (8.20) the two pendulums C and D possess same natural frequencies.

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 figure (8.21). Place two tuning forks on the sound boxes. 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.

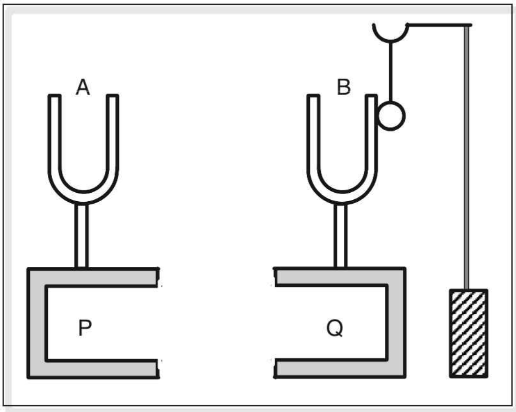


Figure 8.21 Resonance in sound boxes

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 oncoming wave. This leads to a zero displacement in the particles close to the rigid wall. At rigid end a node is always formed. Thus at rigid boundary a compressions reflected back as a compression and rarefaction is reflected as 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.

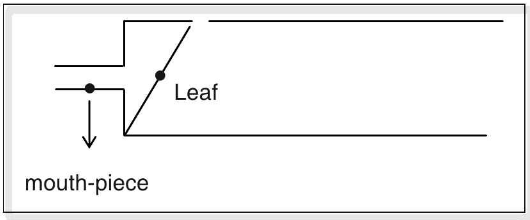


Figure 8.22

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.

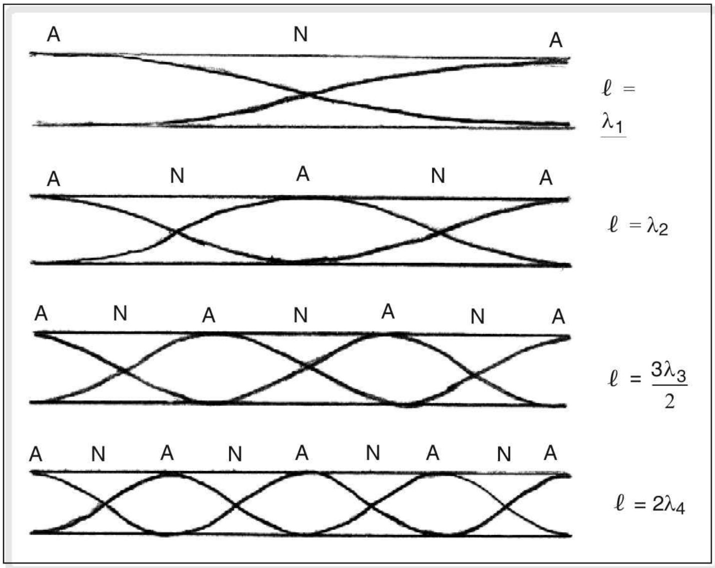


Figure 8.23 Modes of Vibrations in Open Pipe

1st harmonic

$$\frac{\lambda_1}{2} = \ell$$

$$\lambda = 2\,\ell$$

2nd harmonic

$$\lambda_2 = \ell$$

3rd harmonic

$$\frac{3\lambda_3}{2} = \ell$$

$$\Rightarrow \lambda_3 = \frac{2\ell}{3}$$

4th harmonic

$$2\lambda_4 = \ell$$

$$\Rightarrow \lambda_4 = \frac{\ell}{2}$$

Frequency of fundamental mode

In fundamental mode of vibration

$\lambda_1 = 2\,\ell$ units

Let 'v' be the velocity of wave. Then frequency n_1 is given by

$$n_1 = \frac{v}{\lambda_1} = \frac{v}{2\ell}$$

First overtone (or) second harmonic

Wavelength, $\lambda_2 = \ell$

⇒ frequency of first overtone

$$n_2 = \frac{v}{\ell}$$

$$\Rightarrow n_2 = 2\left(\frac{v}{2\ell}\right) 2n_1$$

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 pth harmonic (or) (p – 1)th overtone is, $n_p = pn_1$

$$n_p = p\left(\frac{v}{2\ell}\right)$$

In an open pipe

$n_1 : n_2 : n_3 : n_4 \ldots.. = 1 : 2 : 3 : 4 : \ldots..$

Stationary waves formed in closed end organ pipe

Organ pipe

The vibrations produced in the air column reflects back without change in phase and always a node forms at this end, but at the open end an antinode forms.

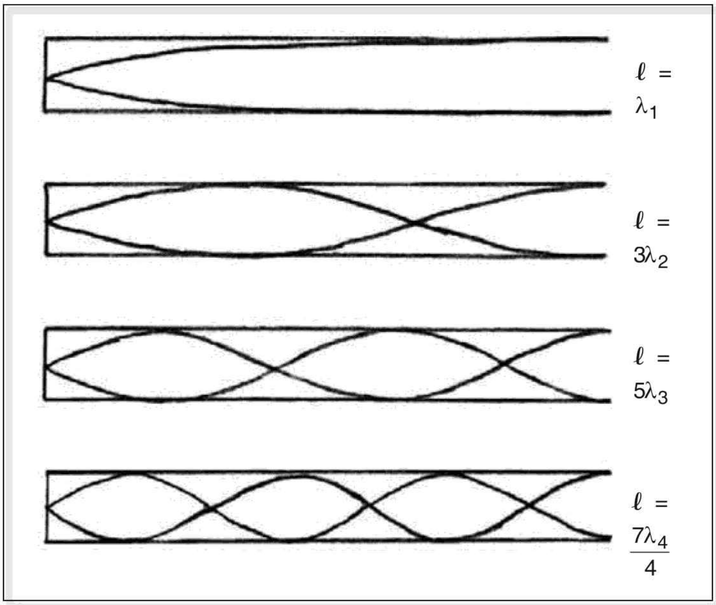


Figure 8.24 Modes of Vibrations in closed Pipes

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, $\lambda_2 = \dfrac{4\ell}{3}$

Frequency, $n_2 = \dfrac{3v}{4\ell} = 3\left(\dfrac{v}{4\ell}\right) = 3n_1 \Rightarrow n_2 = 3n_1$

Second overtone or third harmonic

Wavelength, $\lambda_3 = \dfrac{4\ell}{5}$

Frequency, $n_3 = \dfrac{5v}{4\ell} = 5\left(\dfrac{v}{4\ell}\right) = 5n_1 \Rightarrow n_3 = 5n_1$

Similarly, frequency of the pth 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 $\ell_1 = \dfrac{\lambda}{4}$

The second resonating length, $\ell_2 = \dfrac{3\lambda}{4}$

$$\ell_2 - \ell_1 = \frac{3\lambda}{4} - \frac{\lambda}{4} = \frac{2\lambda}{4} = \frac{\lambda}{2}$$

$\Rightarrow \lambda = 2(\ell_2 - \ell_1)$

$\therefore\ v = n\lambda$

$\Rightarrow v = n \times 2(\ell_2 - \ell_1)$

$\Rightarrow v = 2n(\ell_2 - \ell_1)\ \text{m s}^{-1}$

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.

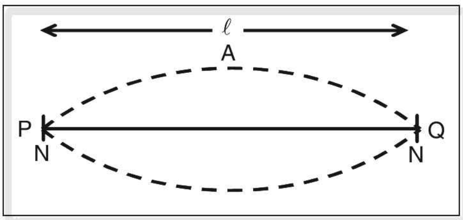


Figure 8.25 Stationary waves in strings; string vibrating in fundamental mode

When the string is plucked at the centre it vibrates with one loop as shown in figure (8.25). When it is plucked at one fourth of its length it vibrates with two loops (figure 8.26) and when it is plucked at one-sixth of its length it vibrates with three loops as shown in figure (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 the fundamental mode of vibration. The frequency of all the other possible modes are integral multiples of the fundamental frequency. These are called overtones.

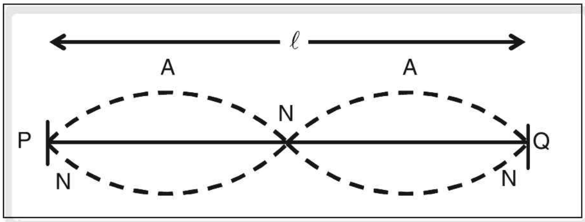


Figure 8.26 String vibrating in second harmonic

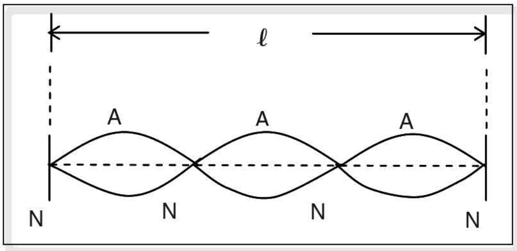


Figure 8.27

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.

$\lambda = 2\ell$

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,

$\lambda_2 = \ell$

$n_2 = \frac{v}{\lambda} = 2\frac{v}{2\ell}$

$= 2n_1$

$n_2 = 2n_1$

Third harmonic (or) second overtone

In this mode of vibration string vibrates with three loops, where

$$\lambda_3 = \frac{2\ell}{3}$$

$$n_3 = \frac{3v}{2\ell} = 3n_1$$

$$n_3 = 3n_1$$

Thus in general, the frequency of the pth harmonic can be written as $n_p = pn_1 = p\left(\frac{v}{2\ell}\right)$

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 Strings

Law of tension

The fundamental frequency of a stretched string varies in proportion to the square root of tension in it, while its length and linear mass densities are kept constant.

$$n_1 \propto \sqrt{T}$$

Law of linear mass density

The fundamental frequency of a stretched string varies in proportion to the reciprocal of the square root of the linear mass density (m) of the string, while its length and tension are maintained constant

$$n_1 \propto \frac{1}{\sqrt{m}}$$

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.

$$n_1 \propto \frac{1}{\ell}$$

Thus $n_1 \propto \sqrt{T}$

$$\propto \frac{1}{m}$$

$$\propto \frac{1}{\ell}$$

$\Rightarrow$ 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 with holes on its lateral sides. Through these air can flow freely. At one of its end a peg is arranged to which a string is tied. The other end of the string passes over a frictionless pulley. Two knife edges are used to change the vibrating length of the string.

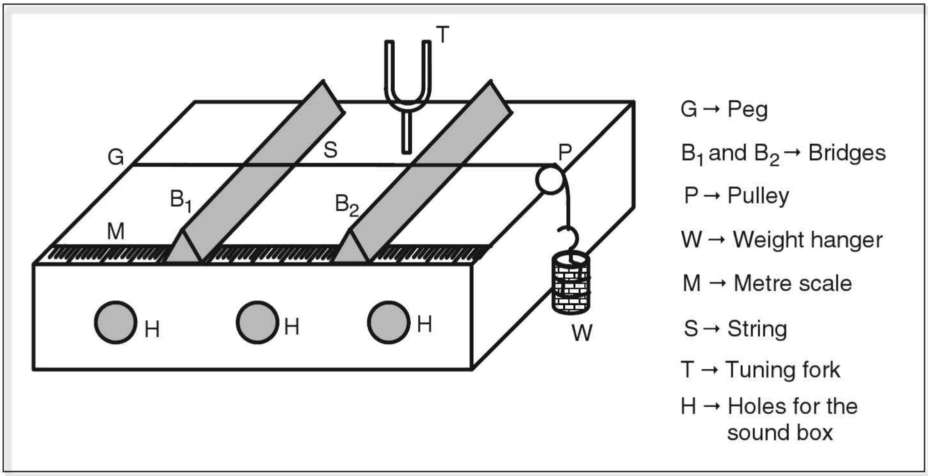


Figure 8.28 Sonometer

The string 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 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 the string.

Verification of laws of vibrations of 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 each case.

Thus $n\ell$ = constant

$$\Rightarrow n \propto \frac{1}{\ell}$$

[redacted]

Law of tension

We have $n \propto \frac{1}{\ell}\sqrt{\frac{T}{m}}$

If n and m are maintained constant, $\frac{\sqrt{T}}{\ell}$ will be a constant.

Thus the law of tension can be proved by proving $\frac{\sqrt{T}}{\ell}$ 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.

[redacted]

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 = constant

frequency, n = constant

as $n = \frac{1}{2\ell}\sqrt{\frac{T}{m}}$, it implies that

$\ell\sqrt{m}$ = constant

[redacted]

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.

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 figure (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.

(a) Angle of incidence is equal to the angle of reflection.

(b) The incident wave SN and the reflected wave NL are on the same plane.

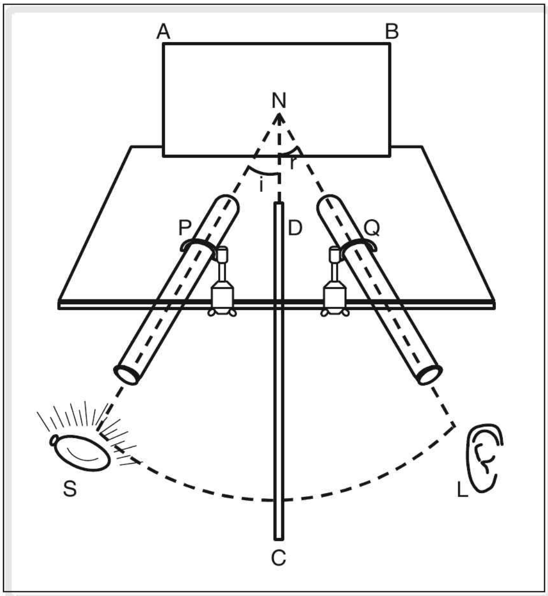


Figure 8.29 Reflection in Sound

Some practical applications of reflection of sound

Mega phone, 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.

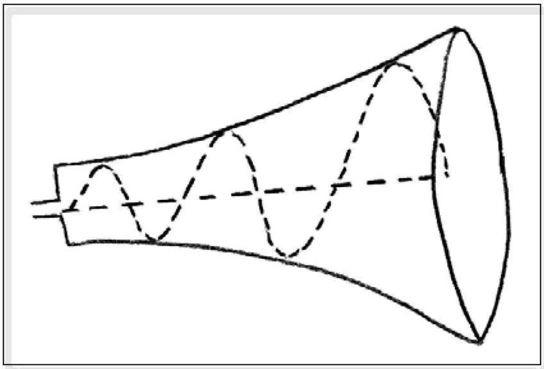


Figure 8.30 Mega phone

Hearing aid

The hearing aid used by the persons who are hard of hearing is also called ear trumpet. The sound enter 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 audiotoria 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.

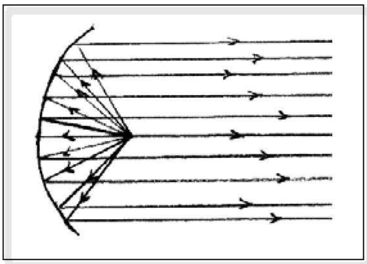


Figure 8.31 Sound board

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 one for the detection of the reflected ultrasonics from the ocean bed are fixed as shown in figure (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 $d = \frac{vt}{2}$.

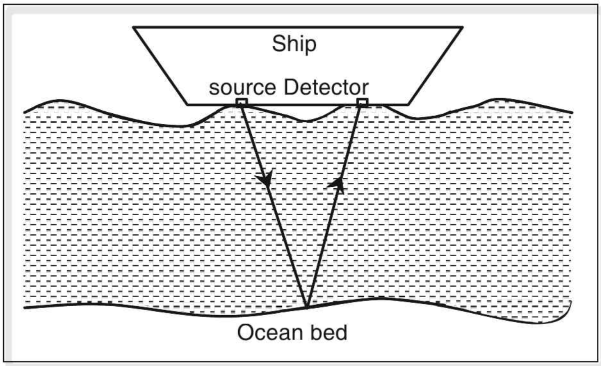


Figure 8.32 Working of sonar

Echo

When a sound wave strikes a smooth, hard surface it is reflected back to the listener and the repetition of sound a short time after it is produced is called an '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 surface. In order to distinguish between these two sounds a time gap of atleast 0.1 second (which is known as **persistence of hearing**) is required. 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 (figure 8.33), the time taken to hear the echo is 't' seconds, then from figure (8.33),

we get $v = \frac{2d}{t}$ or $d = \frac{vt}{2}$

If $t = 0{\cdot}1$ second, then $d = \frac{v \times 0.1}{2} = \frac{v}{20}$

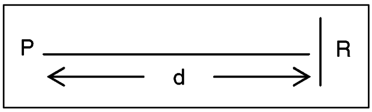


Figure 8.33 Echo

Thus, the minimum distance required to hear an echo is $\frac{1}{20}$th 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 (figure 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 figure (8.34), we have, $v = \frac{2(d + x)}{t_1}$ and $v = \frac{2x}{t_2}$

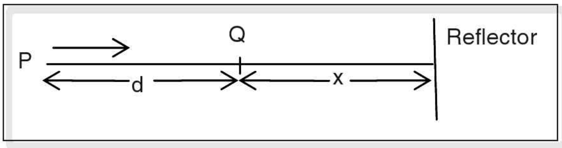


Figure 8.34

$\therefore\ 2(d + x) = vt_1$ 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 figure (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.

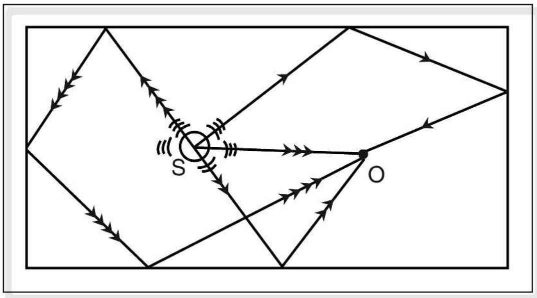


Figure 8.35 Reverberation

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 optimised 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 figure (8.36).

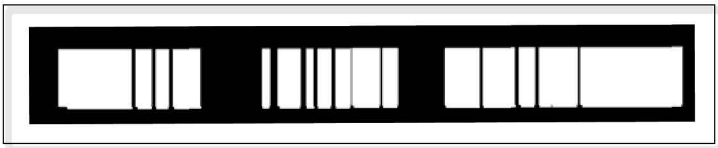


Figure 8.36

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 figure (8.37).

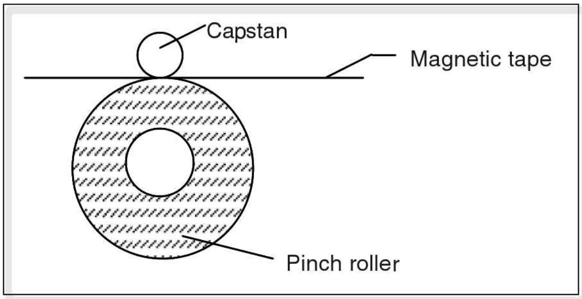


Figure 8.37

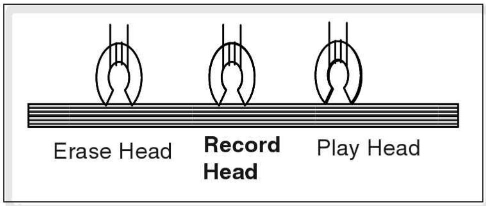


Figure 8.38

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 as shown in the figure (8.38).

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.

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.

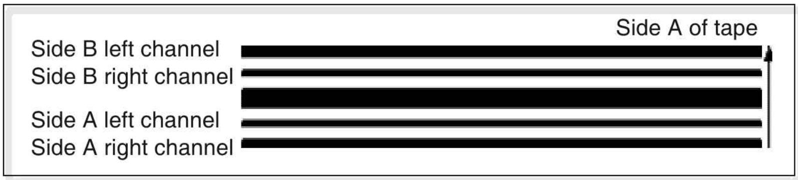


Figure 8.39

Recording of sound on motion picture films

In the early 20th century the technology of recording sound on film along with the optical images revolutionalised 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.

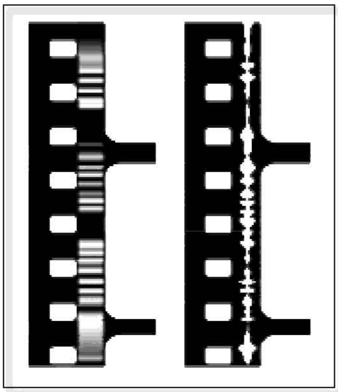


Figure 8.40

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 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 figure (41) here is divided into three parts—the outer ear, the middle ear and the inner ear.

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.

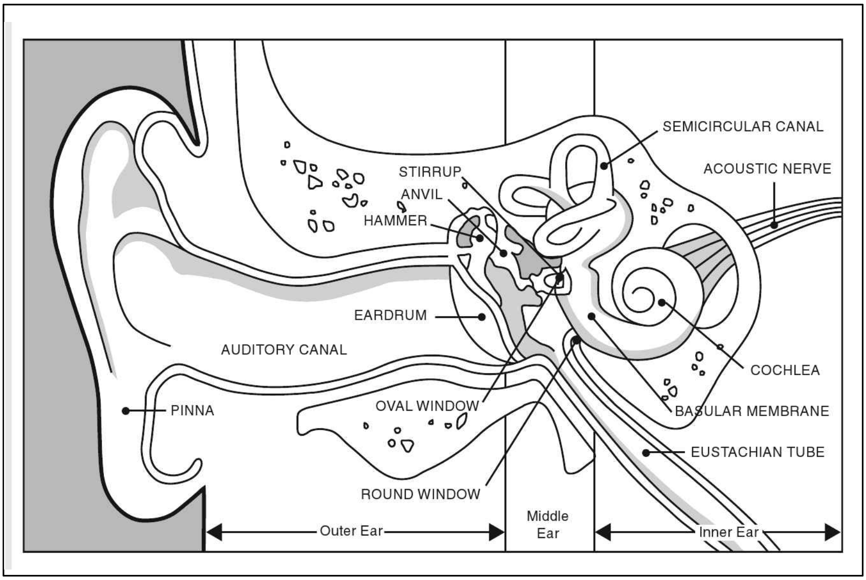


Figure 8.41

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 the 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 the 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.

☛ *Examples*

1. 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 m s^{-1}

Frequency of the wave, $n = \frac{320}{2} = 160$ hertz

Velocity of wave, $v = n\lambda$

Wave length, $\lambda = \frac{v}{n} = \frac{240}{160} = 1.5$ m

2. 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, $\lambda = 0.75$ m × 2
= 1.5 m
Velocity of the wave = 300 m s^{-1}

frequency, $n = \frac{v}{\lambda} = \frac{300}{1.5} = 200$ hertz

3. A source of sound 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

Velocity of sound = 320 m s^{-1}
Velocity of source = 100 m s^{-1}
Frequency of sound = 200 Hz

Apparent frequency of sound $= \dfrac{vn}{v - v_s}$

$$= \frac{320 \times 200}{320 - 100} = \frac{320 \times 320}{220} = \frac{6400}{22} \cong 290\text{Hz}.$$

4. A source of sound and a listener are moving towards each other. The velocity of 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

Apparent frequency, $n = \left(\dfrac{v + v_0}{v - v_1}\right) n = \left(\dfrac{340 + 15}{340 - 20}\right) 640 = 710 \text{ Hz}$

5. 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

Fundamental frequency, $n = \dfrac{v}{2\ell}$

$v = 100 \text{ m s}^{-1}$

Length of string, $\ell = \dfrac{v}{2n} = \dfrac{100}{2 \times 50} = 1 \text{ m}.$

6. A string of 2 m length is fixed at both the ends. The transverse wave created in it propogates with a speed of 50 m s^{-1}. If the string is made to vibrate with three loops then find the frequency of the wave produced.

Solution

Fundamental frequency, $n = \dfrac{v}{2\ell}$

$$= \frac{50 \text{ m s}^{-1}}{2 \times 2 \text{ m}} = \frac{50}{4} = 12.5 \text{ Hz}$$

The frequency of third harmonic = 3n

$= 3 \times 12.5 = 37.5$ Hz.

7. 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 kg × 10 = 20 N

frequency = 100 Hz

length of string = 50 cm = 0.5 m

fundamental frequency, $n = \frac{1}{2\ell}\sqrt{\frac{T}{m}}$

$$\Rightarrow m = \frac{T}{4l^2n^2} = \frac{20}{4 \times \frac{1}{4} \times (100)^2}$$

$= 2 \times 10^{-3}$ kg m^{-1}

8. 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

$$= \frac{v}{2\ell}$$

$$\Rightarrow 30 \text{ Hz} = \frac{300 \text{ m s}^{-1}}{2\,\ell \text{ m}}$$

$$\Rightarrow \ell = \frac{300}{2 \times 30} = 5 \text{ m}$$

Frequency of the third overtone = $4 \times n$, = 4×30 = 120 Hz

9. 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 = 3×30 = 90 cm

Velocity of sound = $2n(\ell_2 - \ell_1)$

= 500×60 = 30000 cm s^{-1} = 300 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 then what is the frequency of vibration. If the length of string is 3 m then what is the frequency 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 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 $v = n\lambda$

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, then 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 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?

Essay type questions

46. Describe an experiment to demonstrate the laws of reflection of sound waves.

47. Describe the reasonating 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 the experiment to prove the laws of transverse waves along stretched string.

50. State and explain ‘sonic boom’ and ‘reverberation’.

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. There is no phase difference between the particles in a stationary wave, within a loop.

2. During resonance, the body undergoing forced vibrations vibrates with a larger amplitude.

3. The velocity of sound in a gas is directly proportional to the square root of the temperature of the gas taken in degree celsius.

4. The frequencies of stationary waves formed in closed-end organ pipes are in the ratio 1:3:5:7……

5. Light waves are transverse in nature.

6. In simple harmonic motion, the acceleration of the body is inversely proportional to its displacement from the mean position.

7. The velocity of sound is affected by the density of the solid.

Direction for questions 8 to 14: Fill in the blanks.

8. The fundamental frequency of a stretched string is directly proportional to $\frac{1}{\sqrt{m}}$, where 'm' is the ________ of the string.

9. Jet planes which move with speeds greater than the speed of sound are called ________.

10. If the motion of an object repeats itself at regular intervals of time, it is called __________ motion.

11. The velocity of sound is ________ when the density of a gas is quadrupled with the pressure remaining constant.

12. In a stationary wave, the phase difference between the particles in a given loop is ________.

13. The audible frequency range of the sound for human beings is ________.

14. 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.	$n \propto \sqrt{\frac{T}{m}}$

(Continued on the following page)

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 ocean	( )	j.	Mach number > 1.

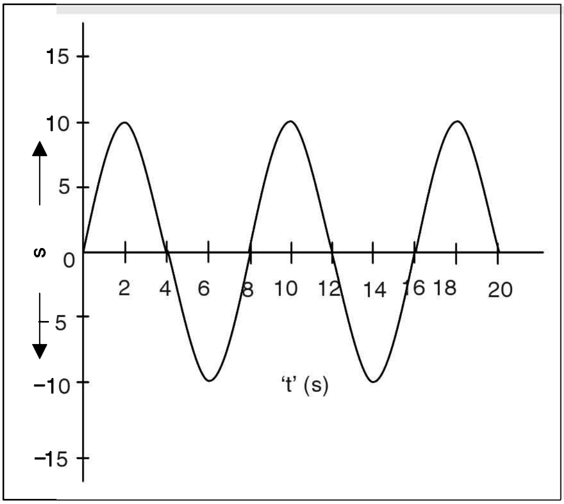
Direction for questions 16 to 30: For each of the questions, four choices have been provided. Select the correct alternative.

16. The fundamental frequency of a stretched string is given by ________.
(ℓ,T,m have their usual meaning)

(1) $n = \ell\sqrt{\frac{T}{m}}$ (2) $n = \ell^2\sqrt{\frac{T}{m}}$ (3) $n = \frac{1}{2\ell}\sqrt{\frac{T}{m}}$ (4) $n = \frac{1}{2\ell^2}\sqrt{\frac{T}{m}}$

17. The special technique used in ships to calculate the depth of ocean beds is
(1) LASER (2) SONAR (3) sonic boom (4) 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



(1) 4 s, 5 cm (2) 8 s, 10 cm (3) 4 s, 10 cm (4) 8 s, 5 cm

19. The minimum distance between the particles in a medium vibrating with the same phase of a wave is known as
(1) amplitude (2) wavelength (3) frequency (4) 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_____.

(1) 21 km (2) 10.5 km (3) 105 m (4) 1500 m

21. The tuning of a radio transistor is based on the principle of _________.

(1) beats (2) resonance (3) echo (4) reverberation

22. If the fundamental frequency of a wave in an open pipe is 540 Hz, the frequency of the (p−1)th harmonic is ___________ Hz.

(1) (p−1)540 (2) p (540) (3) (p+1)540 (4) 0

23. The minimum distance to hear an echo is (taking the velocity of sound in air to be 330 m s^{-1})

(1) 1/20 m (2) 16.5 m
(3) 20 m (4) Cannot be determined

24. A medium should possess the property of ________ for the propagation of mechanical waves.

(1) permeability (2) inertia (3) elasticity (4) both (2) and (3)

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?

(1) 20 m s^{-1} (2) 30 m s^{-1} (3) $20\sqrt{3}$ m s^{-1} (4) 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

(1) transverse wave (2) longitudinal wave
(3) electromagnetic wave (4) All the above

27. Which of the following is false regarding progressive waves?

(1) They carry energy and momentum from one place to another.
(2) The energy possessed by these waves is kinetic in nature.
(3) There is no phase difference between the particles in a wave.
(4) 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

(1) the density of the gas also changes.
(2) the ratio of the pressure to the density remains unaffected.
(3) the velocity of the sound remains unaffected.
(4) All the above

29. A body travelling with a speed of more than the velocity of sound in air is said to travel with

(1) supersonic speed (2) hypersonic speed
(3) ultrasonic speed (4) infrasonic speed

30. The correct statement among the following is

(1) sounds with frequency greater than 20 kHz are known as ultra-sonics.
(2) Dogs can hear ultrasonic sounds.
(3) In SONAR, ultra-sonics are used.
(4) All the above

Concept Application Level—2

31. 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}).

32. 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})

33. 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}.

34. How does a stethoscope help a doctor to hear the sound of a patient's heart-beat?

35. 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})

36. Do the velocity, frequency and wavelength of a sound wave increase, decrease or remain constant, when it is reflected from an obstacle? Explain.

37. 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 $T_1 + T_2$.

38. 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.

39. 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?

40. 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}

41. 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?

42. Why cannot transverse waves be produced in air?

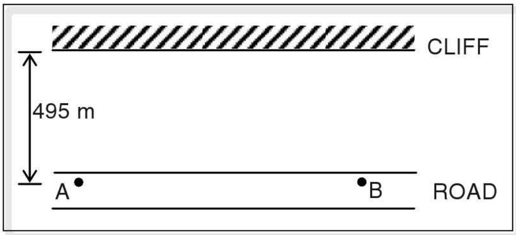
43. The driver of a car approaching a cliff with a uniform velocity of 15 m s^{-1} sounds the horn and the echo is heard by the driver after 3 seconds. If the velocity of sound is 330 m s^{-1}, calculate the distance between the cliff and the point where the horn was sounded? Also calculate the distance between the cliff and the point where the echo is heard?

44. 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.

45. 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.

Concept Application Level—3

46. 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.



47. Why are sirens of mills heard upto longer distances in the rainy season as compared to the summer season?

48. 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.

49. 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.

50. Why are the ultrasonic sounds preferred to audible and infrasonic sounds in detecting the tumors in a physical body.

key points for selected questions

Very short answer type questions

1. Regions where the particles are very close to each other.
2. Distance between any two successive crests or troughs or between any two compressions or rarefactions.
3. Regions where the particles are far apart.
4. $T = \frac{1}{20}$ s, $\frac{1}{20} \times 10^{-3}$ s
5. Point in a stationary wave, where the displacement of the particle is zero.
6. Solid, liquid, gas.
7. A disturbance created in a medium.
8. Mechanical wave.
9. Direction of vibration of the particles of the medium is perpendicular to the direction of motion of wave.
10. Sound Navigation and Ranging

11. Direction of vibration of the particles of the medium is parallel to the direction of wave motion.

12. Transverse waves can be set in a medium which opposes change in shape. Liquids and gases have no definite shape.

13. Requirement of medium for propagation.

14. Number of oscillations made by a particle in one second.

15. Do not require elastic medium for their propagation.

16. antinodes

17. Propagates in the medium and never returns back.

18. Frequency which ranges from 20 Hz to 20 kHz

19. Wave which propagates between two fixed points.

20. Time taken by a particle to complete one oscillation

21. A point of maximum displacement of a particle in upward direction.

22. Sounds with frequency less than 20 Hz.

23. A point of maximum displacement of a particle in downward direction.

24. Point in a stationary wave, where the displacement of the particle is maximum.

25. Sounds with frequency greater than 20 kHz.

26. Measured in terms of direction of motion and displacement from the mean position of the particles.

27. hertz

28. Particles whose direction of motion and displacement from the mean position are equal.

29. Temperature, density, humidity, wind.

30. Particles whose direction of motion and displacement from the mean position are not equal.

Short answer type questions

31. (1) Definitions of waves.
(2) Propagation of energy.
(3) Production of waves.
(4) Variation in phase of media particles.
(5) Nodes and antinodes.

32. 7 nodes → 6 loops → 6th harmonic
$n_6 = 6n_1$
$n_4 = 4n_1$
(Ans : 150 Hz, 100 Hz)

33. (1) Definition of S.H.M.
(2) Description of simple pendulum.
(3) Nature of oscillations of simple pendulum.
(4) The factors affecting its time period.

34. $v = 2n(\ell_2 - \ell_1)$
(Ans: 500 Hz)

35. (1) Define velocity, frequency and wavelength of sound.
(2) The distance travelled by the wave in one second, $V = \frac{\lambda}{T}$.
(3) $n = \frac{1}{T}$

36. $n_1 = \frac{v}{4\ell}$

(Ans: 330 m s^{-1})

37. (1) Full form of SONAR.
(2) Purpose of it.
(3) Its working

38. (1) Based on necessity of the medium.
(2) Elastic waves/Mechanical waves
(3) Electromagnetic waves
(4) Based on direction of vibration of particles with respect to the direction of wave motion – Transverse and longitudinal waves.

39. $n \propto \frac{1}{\ell}$
(Ans: 40 cm)

key points for selected questions

40. (1) Dependence of sound on temperature, density, molecular weight etc.

41. (1) Definitions of mechanical and e.m. waves.
(2) Requirement of media

42. Amplitude, frequency, wavelength, pressure.

43. $n^1 = \left(\frac{V \pm V_O}{V \pm V_S}\right)n$

(Ans: 171 Hz)

44. (1) Definitions of waves (longitudinal and transverse)
(2) Direction of vibrations of media particles with respect to direction of propagation.
(3) Variation in density, shape of media.
(4) The media through which the waves can propagate.
(5) Definition of wavelength in both the cases

45. (1) Audible range of sound.
(2) Infrasonics, ultrasonics.
(3) SONAR, RADAR etc.
(4) Ability of bats to produce and recognize the ultrasonics.

Essay type questions

46. (1) Reflection of sound.
(2) Laws of reflection.
(3) Experimental arrangement to produce sound and to receive the reflected sound.

47. (1) Description of experimental arrangement.
(2) Formation of stationary waves in closed end organ pipe.
(3) Definition of resonating air columns.
(4) Expression for velocity of sound in terms of first and second resonating lengths and frequency of tuning fork used.

48. (1) Nature of sound wave.
(2) Arrangement of a bell in a jar.
(3) Connecting the jar to a vacuum pump.
(4) Variation in the intensity of sound as gas is removing from it.

49. (1) Description of sonometer.
(2) The three laws of transverse waves along the stretched string.
(3) Verification of law of length.
(4) Verification of law of tension.
(5) Verification of law of mass.

50. (1) Supersonics.
(2) Production of sonic boom by the supersonics.
(3) Reflection of sound.
(4) Multiple reflections of sound in a closed room.
(5) definition of reverberation.

KEY

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. Choice (3)

17. Choice (2)

18. Choice (2)

19. Choice (2)

20. Choice (2)

21. Choice (2)

22. Choice (1)

23. Choice (2)

24. Choice (4)

25. Choice (3)

26. Choice (2)

27. Choice (3)

28. Choice (4)

29. Choice (1)

30. Choice (4)

Concept Application Level—2,3

Key points for select questions

31. (i) $v = n\lambda$, $s = vt$

(ii) Hz

32. (i) Doppler effect,

$$n^1 = n\left(\frac{v}{v - v_s}\right); n^{11}$$

$$= n^1\left(\frac{v + v_0}{v}\right)$$

(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

33. (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

34. 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?

35. (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

36. Velocity of sound in a given medium

37. (i) Relation between frequency and tension of a stretched string.

(ii) $n \propto \sqrt{T}$

(iii) 17 Hz

38. (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

39. (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

40. (i) $n^1 = n\left(\frac{v - v_0}{v + v_s}\right); n^1\ n\left(\frac{v - v_0}{v + v_s}\right)$

(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

41. (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'

42. (i) Advantages of ultra sounds

(ii) Changes that take place in the medium when transverse waves propagate.

43. (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.

44. (i) $v = \sqrt{\frac{T}{m}}$

(ii) 250 g

45. (i) Dependence of velocity of sound on density of a gas.

(ii) $V \alpha \frac{1}{\sqrt{d}}, d = \frac{m}{V}$

(iii) gas B, $V_A = 1.3 V_B$

46. (i) Equation of echo, Pythagoras theorem

(ii) $v = \frac{2d}{t_1}$

$$v = \frac{\text{(distance covered by sound waves)} + \text{(distance between driver and person)}}{t_2}$$

Pythagoras theorem

(iii) 412 m

47. (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?

48. How does the intensity of sound vary with distance of the point of observation from the source of sound?

49. (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 ……

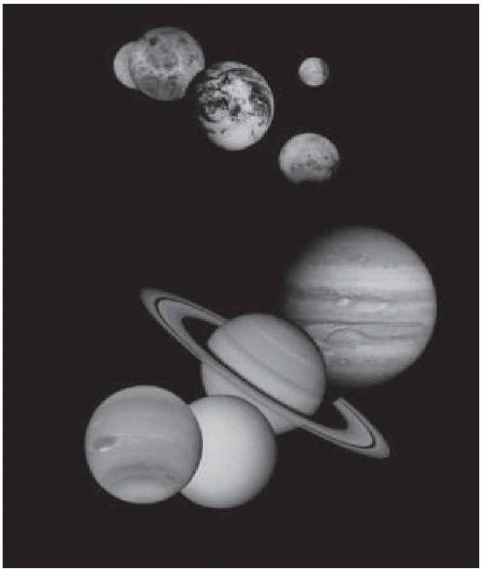
50. (i) Directionality of ultrasonics, applications of ultrasonics, imaging on internal organ

(ii) Is the wavelength of ultrasonics larger or shorter when compared with that of audible and infrasonic sounds?

When are the waves reflected sharply at the boundaries of an obstacle? Is it possible when their wavelength is shorter or longer?

9

Light



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, the stars etc. In an incandescent bulb, the filament is heated to a high temperature and thus the real 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 hetrogenous.

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 hetrogenous media.

Media like glass, or a thin layer of water, 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 medium is called translucent medium.

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 small is called a point source of light. Light coming out from a pin hole in a closed enclosure is practically 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 extended source.

Example a bulb, a candle etc.

In a homogenous medium, light travels along a straight line. The straight line path of light is called a ray.

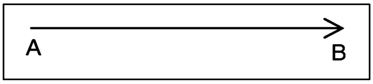


Figure 9.1

The arrow mark gives the direction in which the light ray travels.

A bundle of light rays is called a beam of light.

If the light rays in a beam of light travel so that they are parallel to each other, such a collection of rays is called a parallel beam.

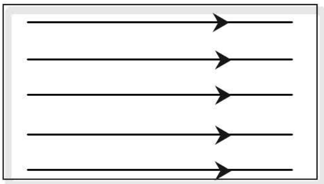
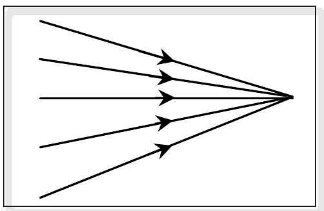


Figure 9.2 Parallel Beam

If the rays converge and meet at a point then the beam of light is called a convergent beam.



If two or more rays appear to spread out from a point, then such a collection of rays is called a divergent beam.

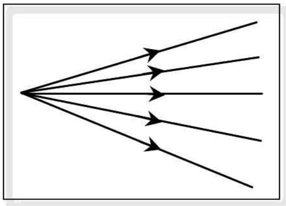


Figure 9.4 Divergent beam

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 always travel in a straight path is called rectilinear propagation of light.

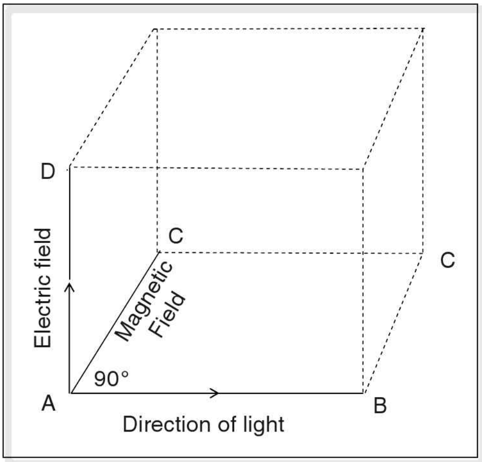


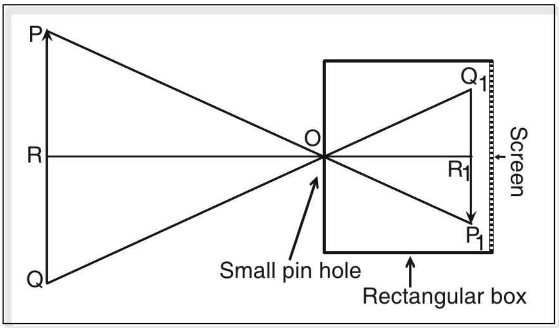
Figure 9.5

☛ *Examples of 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.

Experiment to prove rectilinear propagation of light

Take three cardboards A, B and C, of the same size and make a pin hole in 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 that order. Place a luminous source like a candle near cardboard A and look through the hole in the cardboard C. The light passing through the holes A, B and C would be visible at the far end. When one of the cardboards is slightly displaced, light would not be visible. This proves the rectilinear propagation of light.



Pinhole camera

A pinhole camera (figure 9.6) is a device which can be used to take photographs of objects. It is based on the

The pinhole camera consists of a rectangular card-board 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 gets projected 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 **magnification**.

$$\therefore \text{Magnification} = \frac{\text{Size of image}}{\text{Size of object}} = \frac{\text{Distance of image from the pinhole}}{\text{Distance of object from the pinhole}}$$

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, due to an increase in the intensity of the light from the object.
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 due to the spreading of light over a small area.

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 lot.

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 lens.

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. 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 the umbra region. If the distance between the screen and the opaque object decreases, the size of the umbra region decreases.

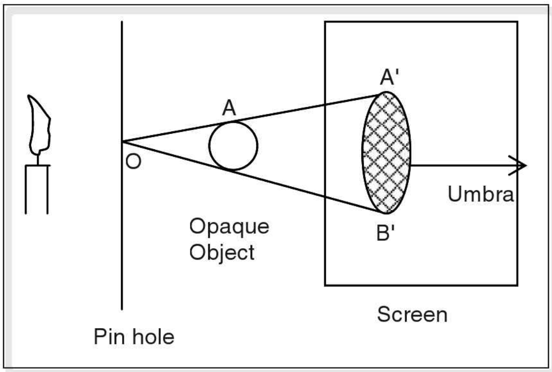


Figure 9.7

By varying the distance between the opaque object and the screen, the size of the umbra region can be varied.

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. $A_1 B_2$ is the shadow of AB due to point source S_1. Similarly the rays starting from S_2 meet the screen beyond A_2 or B_1. Thus, A_2B_1 is the shadow of AB due to point source S_2.

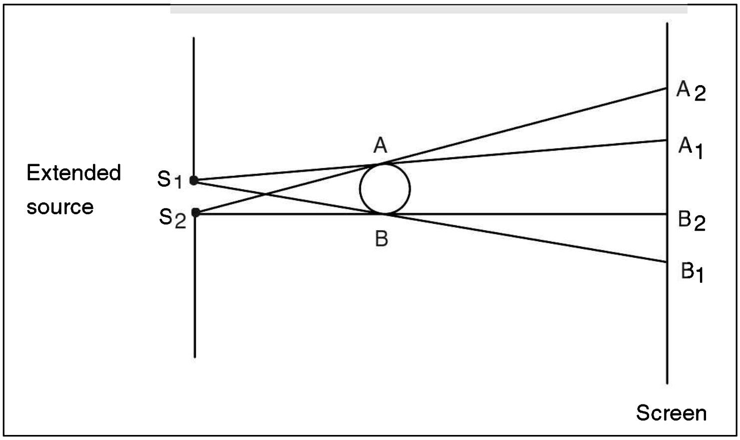


Figure 9.8

From the screen, the region A_1B_1 does not receive any light and hence the region is umbra. But the region A_1A_2 receives light from the extended source except from the point S_2. Thus the A_1A_2 is a penumbra.

Similarly, the region B_1B_2 receives light from the extended source except from S_1, hence the region BB^1 is a penumbra.

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 then 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 incandencent 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 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 of regular reflection—glass, glycerine.

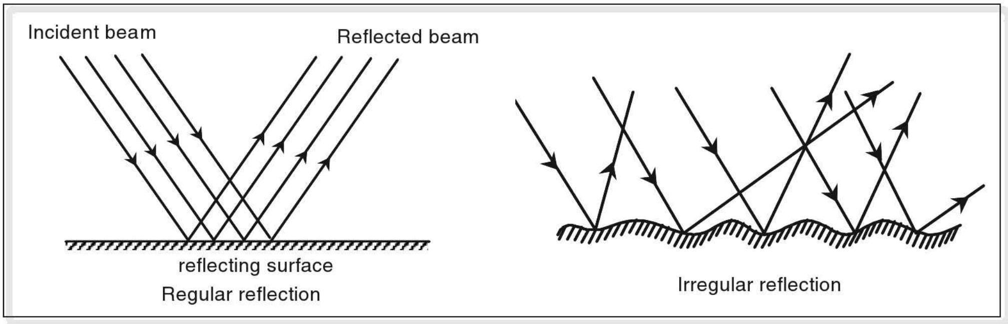


Figure 9.9

☛ *Examples of 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 a **'real image'** and if it is not possible to obtain the image on a screen it is called a **'virtual image'**.

Difference between virtual and real 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 reflections

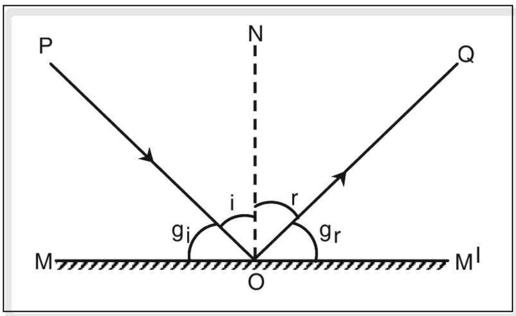
Consider an object at a point P, let MM^1 be a highly polished plane surface of a mirror.

(i) The ray PO from the object, travelling towards the mirror is called the **incident ray**.

(ii) The point 'O' at which the incident ray meets the mirror is called the **point of incidence**.

(iii) The ray OQ which bounces off the surface of the mirror after reflection is called the **reflected ray**.

(iv) The perpendicular (ON) drawn to the surface of the mirror at the point of incidence is called the



(v) The angle between the incident ray (PO) and the normal (ON) is called the **'angle of incidence'** and is denoted by 'i'.

(vi) The angle between the reflected ray (OQ) and the normal (ON) is called the **'angle of reflection'** and is denoted by 'r'.

(vii) The angle between the incident ray (PO) and the reflecting surface (MM^1) is called the **'glancing angle of incidence'**.

(viii) The angle between the reflecting surface (MM^1) and the reflected ray (OQ) is called the **'glancing angle of reflection'**.

Laws of Reflection

Light rays, on reflection at any point, obey 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.

Mirror

It is a smooth polished surface from which regular reflection takes place.

(i) 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 position from where the two divergent reflected rays appear to originate is the position of the image.

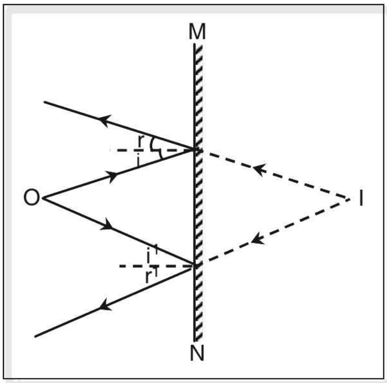
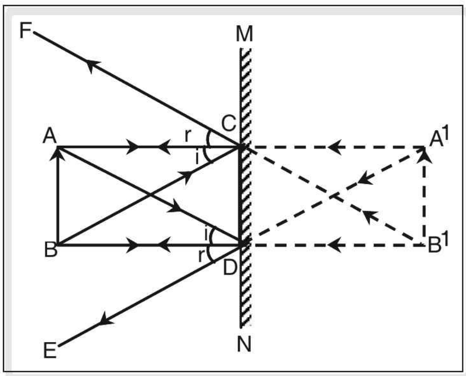


Figure 9.11 Reflection of a point object in a plane mirror

(ii) 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 'A''.



The image of point 'A' of the object is formed at 'A''. Similarly

Figure 9.12 Reflection of an extended 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 'B^1'. Thus, the total image of the object 'AB' is formed as 'A^1 B^1'. 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.

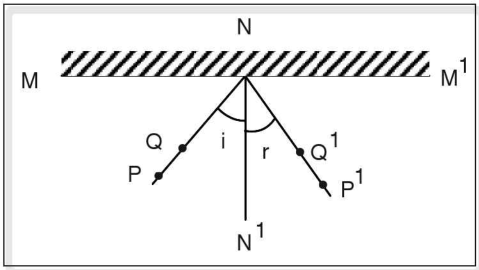


Figure 9.13

Procedure

Fix a white sheet on a drawing board. Draw a line MM^1 and a normal NN^1 to the line.

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′ and Q′ 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 P^1N 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.

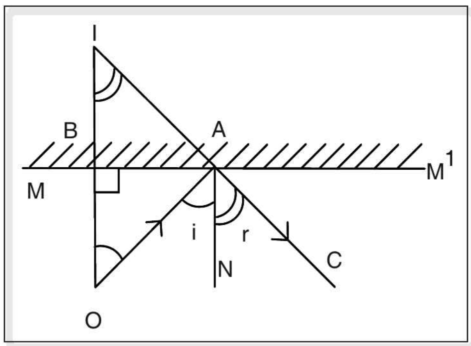
[redacted]

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 a plane 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 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,

$\angle i = \angle r$ ----- (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.

In the figure,

$\angle BOA = \angle i$ ----- (2) (alternate angles)

$\angle BIA = \angle r$ ----- (3) (corresponding angles)

from equation (1), (2) and (3)

$\angle BOA = \angle BIA$ ---- (4)

In triangles BOA and BIA.

$\angle BOA = \angle BIA$

$\angle ABI = \angle ABO$ (right angle)

AB is common to both the triangles.

$\therefore \Delta BOA \cong \Delta BIA$.

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

Consider a plane mirror 'AB' as shown in the figure (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.

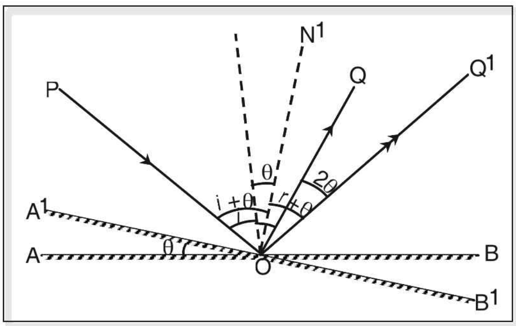


Figure 9.15 Effect of rotation of a plane mirror

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′.

$$\angle QOQ^1 = \angle POQ^1 - \angle POQ = [\angle PON^1 + \angle N^1OQ^1] - \angle POQ = [(i + \theta) + (r + \theta)] - [i + r]$$

$$\text{Since } i = r,\ \angle QOQ^1 = [(i + \theta) + (i + \theta)] - [i + i] = (2i + 2\theta) - 2i = 2\theta$$

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

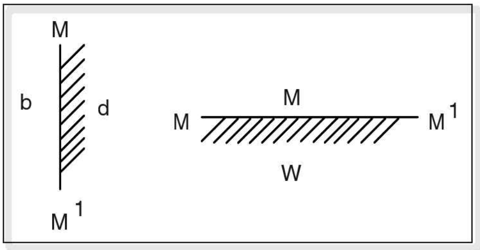


Figure 9.16

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.

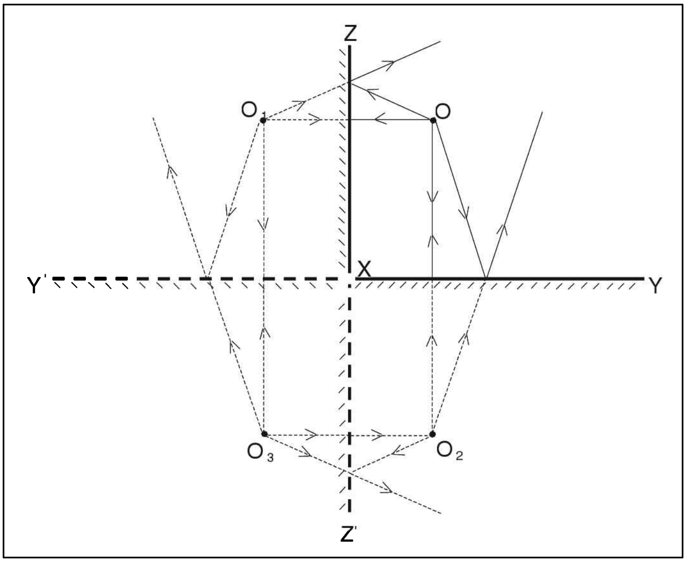


Figure 9.17

2. When two mirror are kept parallel to each other.

Consider two mirrors MN and XY placed parallel to each other, as shown in the figure. Let A be an object placed in between them.

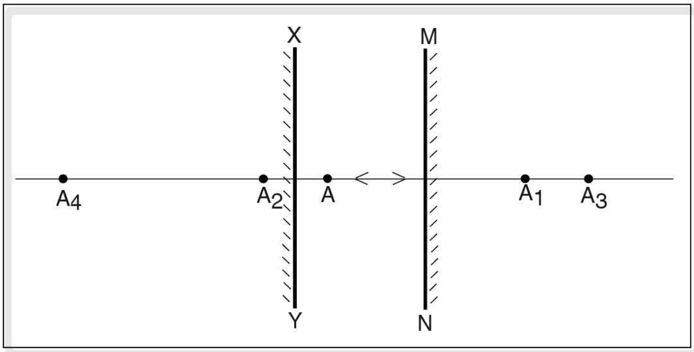


Figure 9.18

A_1 is the image of an object formed by the mirror MN (by normal incidence) A_1 acts as a virtual object to 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. (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 figure (9.20).

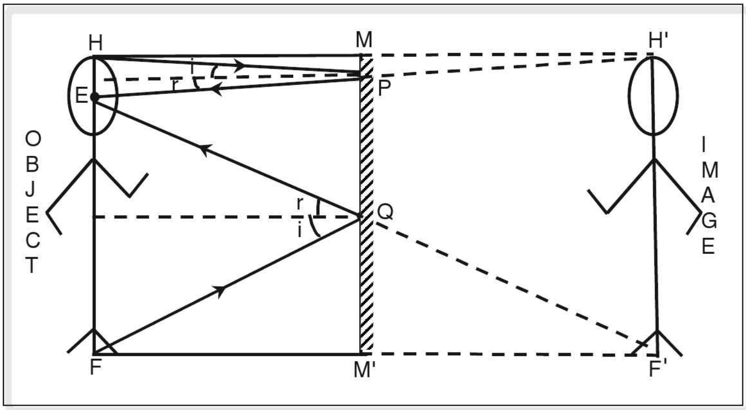


Figure 9.19

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),

$$HR = RE = \frac{HE}{2} \text{ - - - - - (1)}$$

$$SF = ES = \frac{EF}{} \text{ - - - - - - (2)}$$

Now, PQ = RS

$= RE + ES = \frac{HE}{2} + \frac{EF}{2}$ (from equation 1 and 2)

$= \frac{HE + EF}{2} = \frac{HF}{2} = \frac{1}{2}$ (The height of the person viewing his image)

Also, $QM' = SF = \frac{1}{2}EF$ (The eye level from the ground)

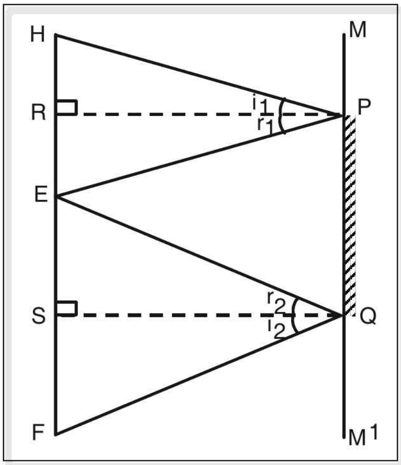


Figure 9.20

We can conclude the following about the image formed by a plane mirror:

(i) Same size as that of the object.

(ii) At same distance behind the mirror as the object is in front of the mirror.

(iii) Erect but laterally inverted.

(iv) Virtual.

(v) Keeping the incident ray constant, if the mirror is rotated by an angle 'θ', the reflected ray is rotated by an angle '2θ'.

(vi) 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

(i) Plane mirrors are primarily used as looking glasses.

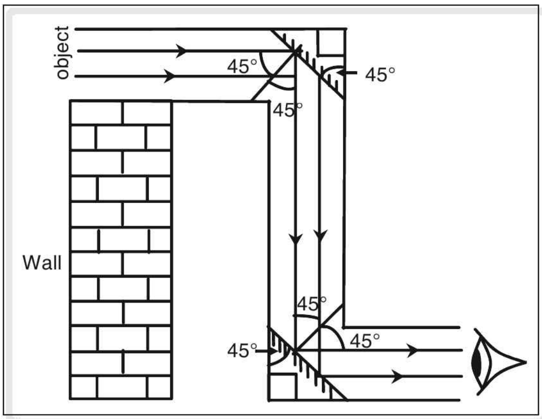
(ii) Since a combination of mirrors can produce multiple images, they are used to provide false dimensions in showrooms.

(iii) They are also used as reflectors in solar cookers.

(iv) 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. The inner sides of the tube is blackened to prevent reflection. Two plane mirrors 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 in the upper tube and the reflected rays from this mirror are incident on the second mirror 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



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 and 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.

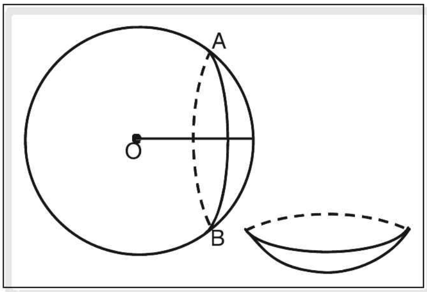


Figure 9.22 Hollow glass sphere and a section of it

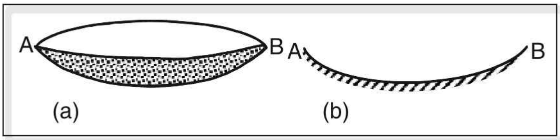


Figure 9.23 (a) Concave mirror formed by silver coating the outer side (b) Symbolic representation of a concave mirror

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 mirror.

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

Principal axis: The line passing through the pole and the centre of curvature is called the 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 portion is made is called the radius of curvature. CN is the radius of curvature.

CN = CP = (where R is the radius of curvature).

Principal focus

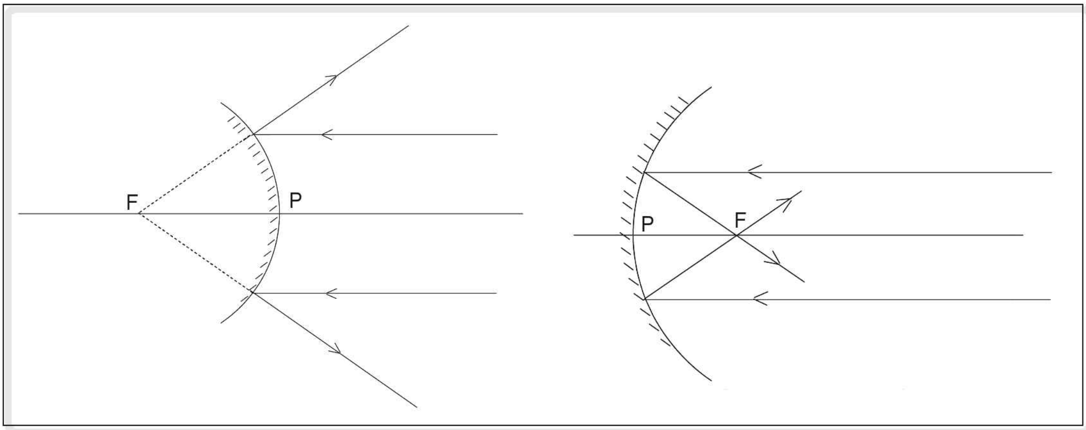


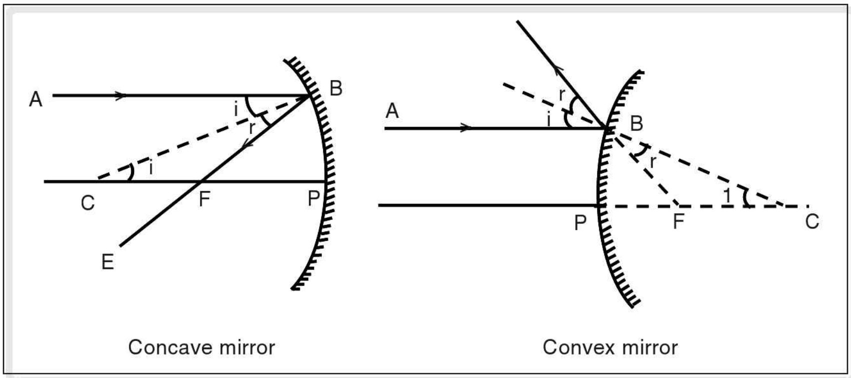
Figure 9.24

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

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 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

$\angle i = \angle r$ ----- (1)

From the figure

$\angle i = \angle 1$ ----- (2) (alternate angles in figure of concave mirror and corresponding angles in figure of concave mirror).

comparing equation (1) and (2)

$\angle r = \angle 1$

$\therefore$ BF = FC ----- (3)

For small apertures, i.e., for rays close to the principal axis,

$\therefore$ BF is nearly equal to PF ----- (4)

$\therefore$ from equation (3) and (4)

PF = FC ----- (5)

The radius of curvature

PC = PF + FC

PC = PF + PF ($\because$ from (5) FC = PF)

$\therefore$ R = 2PF

R = 2f

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 placed in front of a spherical mirror, any two of the following light rays coming from a point on the object are drawn.

(i) 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.

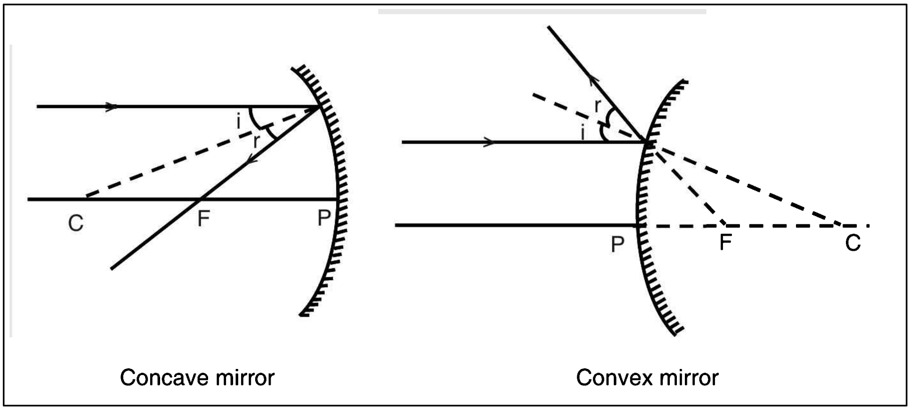


Figure 9.26

(ii) 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.

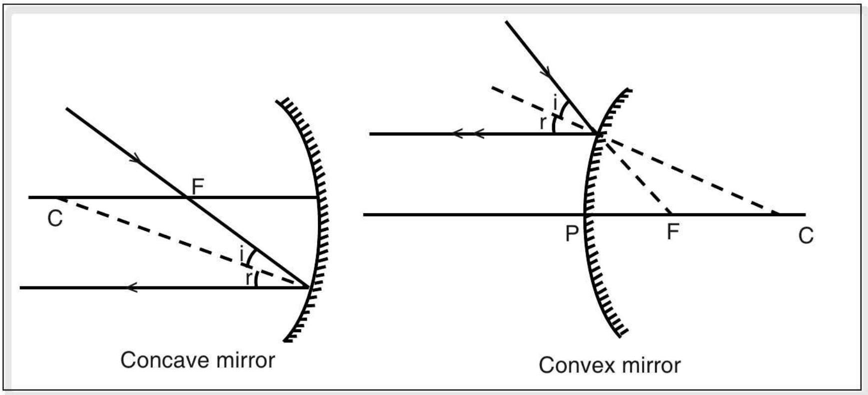


Figure 9.27

(iii) 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.

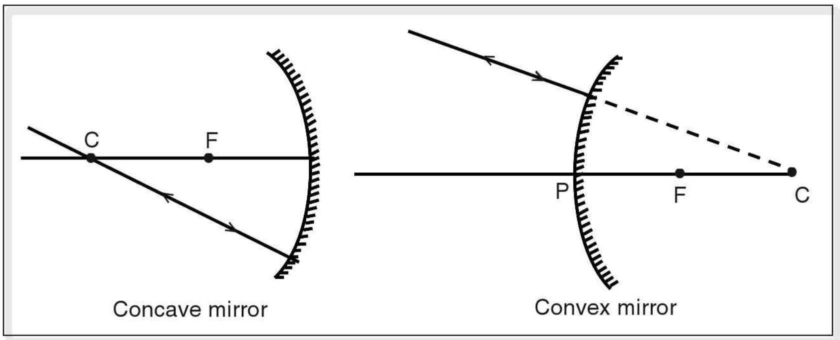


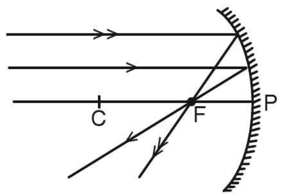
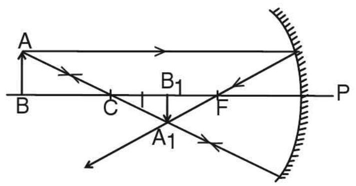
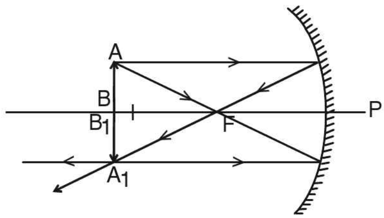
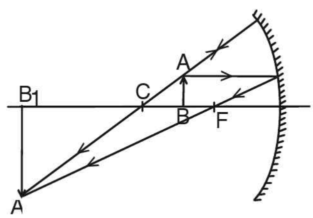
Figure 9.28

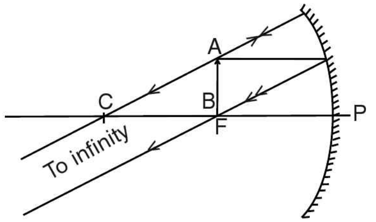
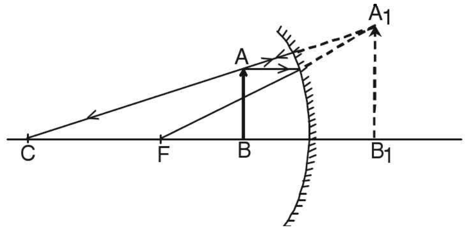
Geometrical construction of the formation of an image in a spherical mirror

Draw the object (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

$u = \infty$		Real, inverted and highly diminished, $v = f$
$R < u < \infty$		Real, inverted and diminished, $f < v < R$
$u = R$		Real, inverted and of equal size as that of object, $v = R$
$f < u < R$		Real, inverted and magnified, $v > R$

u = f		Real, inverted and highly magnified, $v = \infty$
u < f		Virtual, erect and magnified, and formed on the opposite side of the mirror as that of the object.

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 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 figures.

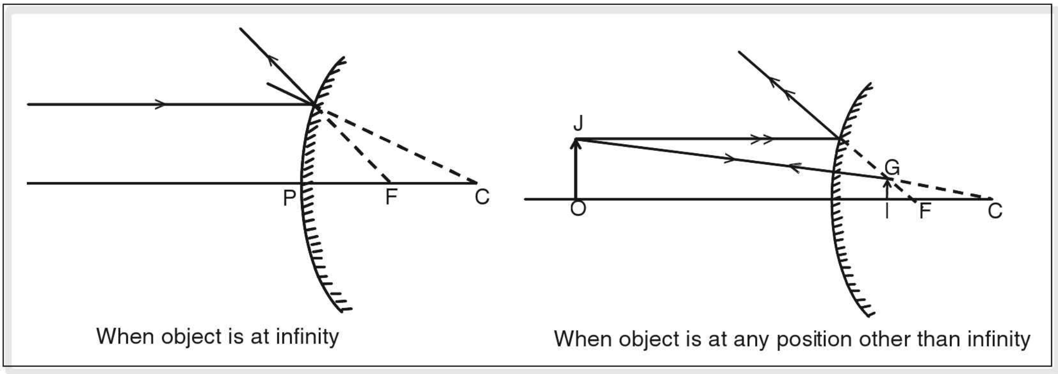


Figure 9.29

Mirror formula and Cartesian sign convention

The mirror formula is given 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.
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.

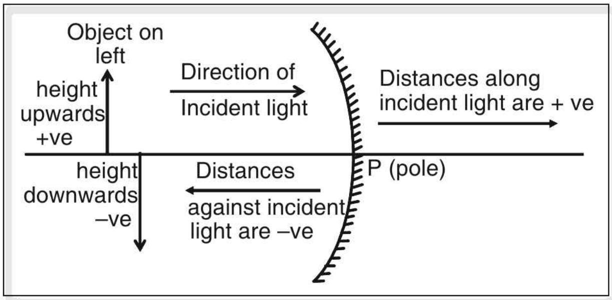


Figure 9.30 Cartesian sign convention

Relation between object distance, image distance, and focal length of a spherical mirror

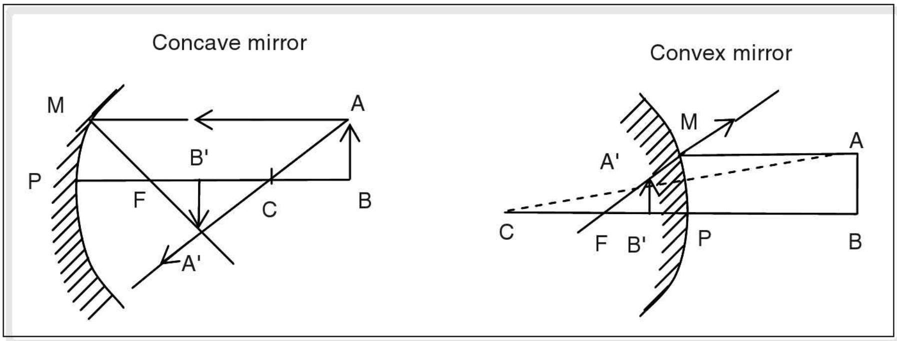


Figure 9.31

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

$$\frac{AB}{A'B'} = \frac{BC}{B'C} \qquad \text{-----} \qquad (1)$$

From similar triangles A′B′F and PMF

$$\frac{PM}{A'B'} = \frac{PF}{B'F} \qquad \text{-----} \qquad (2)$$

But PM ≅ AB (for small apertures, and when incident rays are close to the principal axis)

∴ equation (2) can be written as

$$\frac{AB}{A'B'} = \frac{PF}{B'F} \qquad \text{-----} \qquad (3)$$

comparing equation (1) and (3)

$$\frac{PF}{B'F} = \frac{BC}{B'C} \qquad \text{-----} \qquad (4)$$

PF = focal length = f

PC = R

PB = u

PB′ = v

[redacted]

$$\frac{PF}{PB' - PF} = \frac{PB - PC}{PC - PB'}$$

using sign convention

$$\frac{-f}{-v - (-f)} = \frac{-u - (-R)}{-R + v}$$

$$\frac{-f}{-v + f} = \frac{-u + R}{-R + v}$$

$$fR - fv = + uv - vR - uf + fR$$

$$fv = uv - vR - vR - uf \text{ or}$$

$$- uv + vR - vf + uf = 0$$

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

$$\frac{-1}{f} + \frac{1}{u} + \frac{1}{v} = 0 \text{ or } \frac{1}{f} + \frac{1}{u} + \frac{1}{v}$$

–

$$\frac{PF}{PF - PB'} = \frac{PB + PC}{PC - PB'}$$

using sign convention

$$\frac{f}{f - v} = \frac{-(u) + R}{R - v}$$

v

$$\frac{f}{f - v} = \frac{-u + R}{R - v}$$

$$fR - fv = - uf + uv + fR - vR \text{ or}$$

$$- fv = - uf + uv - vR$$

But R = 2f

$$\therefore - fv = - uf + uv - v(2f) \text{ or}$$

$$uf - uv + 2vf - vf = 0$$

$$uf - uv + vf = 0$$

Dividing throughout by uvf

$$\frac{1}{v} - \frac{1}{f} + \frac{1}{u} = 0 \text{ or } \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ is called the 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.

$\therefore$ 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.
3. 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.

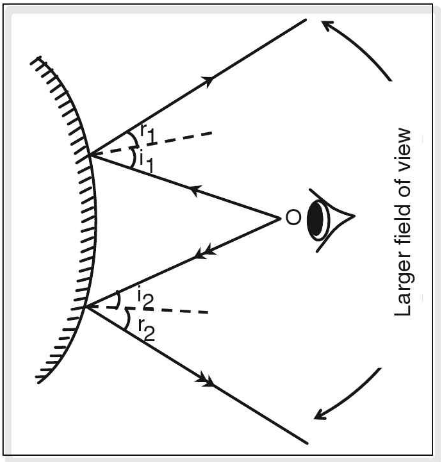


Figure 9.32

4. Concave mirrors are used to produce magnified virtual images. So these can be used as shaving mirrors.
5. 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.
6. 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.
7. Concave mirrors are used in solar devices to reflect light rays.

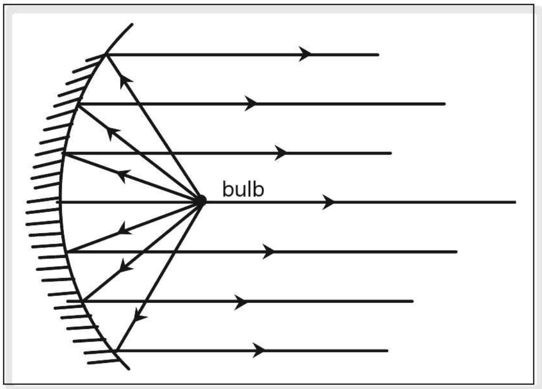


Figure 9.33

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.

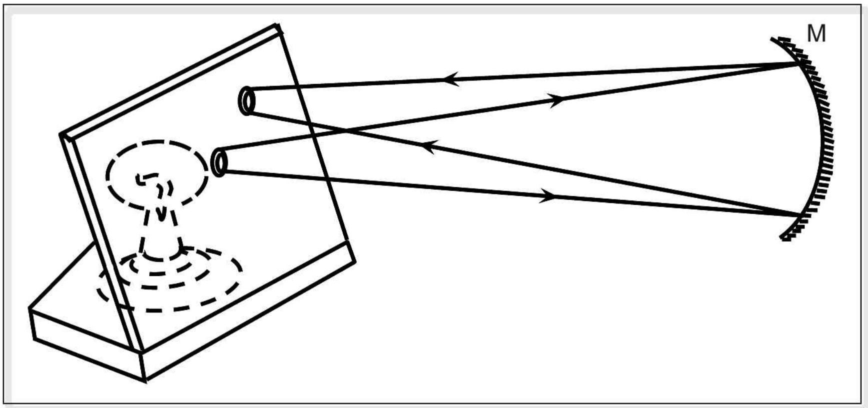


Figure 9.34 Radius of curvature of a concave mirror

Procedure

1. Mount the given concave mirror on the mirror stand.
2. Place the mirror in front of an illuminated wire mesh or a candle.
3. 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.
4. Measure the distance between the object and the concave mirror. This gives the radius of curvature of the given mirror.

To determine the focal length of a concave mirror.

1. By distant object method.

Apparatus required: Concave mirror, mirror stand, screen and a measuring scale.

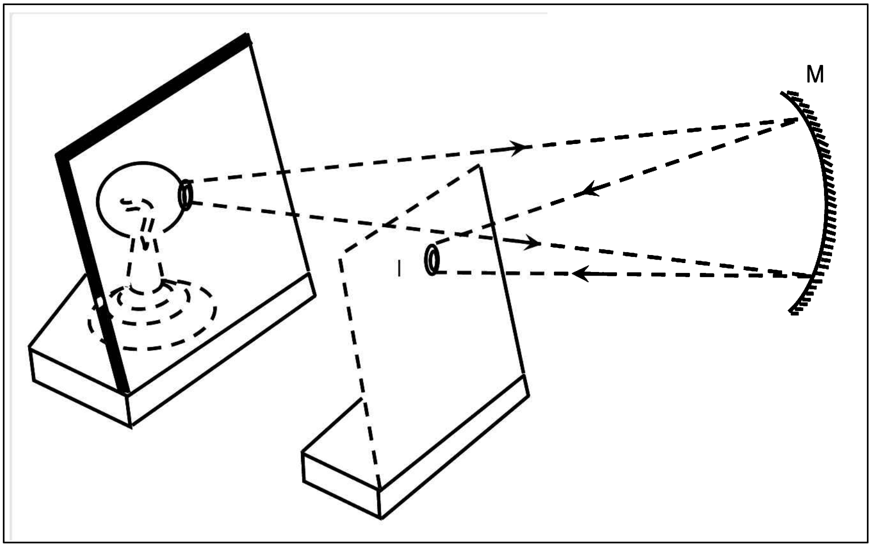


Figure 9.35

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.
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 measuring 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 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

$$f = \frac{vu}{v+u} \left[\begin{array}{l} \because \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \\ \frac{1}{f} = \frac{v+u}{uv} \end{array} \right]$$

8. Repeat the experiment for different object distances and note down the image distance and find its focal length. Tabulate the result.

[redacted]

The focal length of a given concave mirror can be calculated graphically too.

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.

Draw a straight line OP from the origin making an angle of 45° with X-axis and intersecting the curve at P. Drop perpendiculars from P to the X and Y-axes meeting them at A and B respectively.

Measure the distance OA and OB.

It will be found that OA and OB are equal to each other and equal to the radius of curvature of the concave mirror.

$$\text{Focal length} = \frac{\text{Radius of curvature}}{2}$$

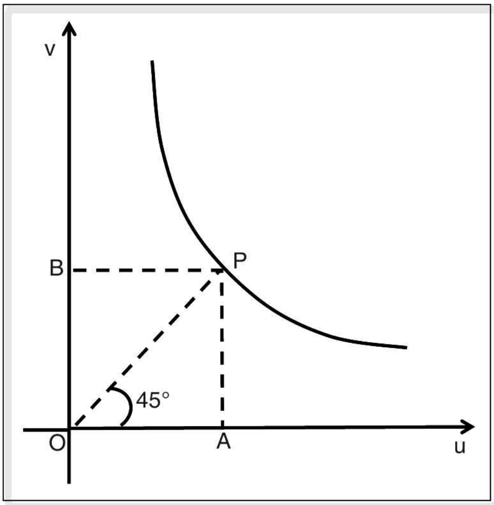


Figure 9.36 Focal length of a concave mirror –uv method

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

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{f} = \frac{-1}{20} - \frac{-1}{60}$$

$$\frac{1}{f} = \frac{-(60+20)}{60 \times 20} = \frac{-80}{1200}$$

$$f = \frac{-1200}{80} = -15 \text{ cm}$$

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)

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{15} - \frac{1}{-10}$$

$$v = \frac{150}{25} = 6 \text{ cm.}$$

Positive sign indicates that the image is virtual.

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.

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.

$$m = \frac{-v}{u}$$

$$\therefore m = \frac{v}{} = 2$$

v = 2u

focal length of a concave mirror = – 8 cm.
(using sign convention)
From mirror formula,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{-8} = \frac{1}{u} + \frac{1}{2u}$$

$$\frac{1}{-8} = \frac{3u}{2u^2}$$

$$-8 = \frac{2u}{3}$$

$$2u = 3 \times (-8)$$

$$u = \frac{3 \times -8}{2} = 3 \times (-4) = 12 \text{ cm}$$

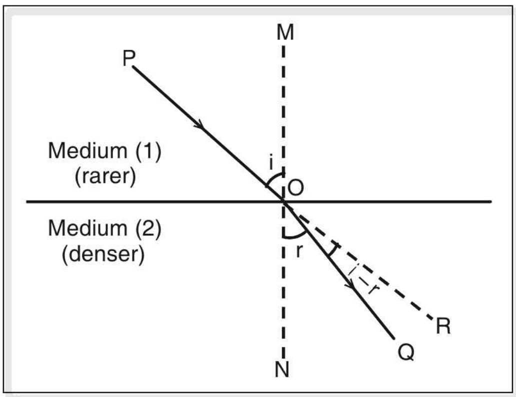
The object is placed at a distance of 12 cm from the pole of the concave mirror.
Image distance v = 2u
v = 2 × (–12)
v = – 24 cm.
The image is formed at a distance of 24 cm from the pole, and is formed on the same side of the mirror where the object is kept.

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

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 an imaginary line drawn at the point of incidence, perpendicular to the boundary separating the two media and is called the '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 $(i \sim r)$.

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.

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 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

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 1st medium, which is rarer and the 2nd medium, which is denser, respectively, then the refractive index of the 2nd medium with reference to the 1st medium is given by,

$$\mu_{21} = \frac{\mu_2}{\mu_1}$$

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

$$\mu_1 = \frac{c}{v_2}$$

Similarly refractive index of the 2nd medium is given by

$$\mu_2 = \frac{c}{v_2}.$$

But, $\mu_{21} = \frac{v_1}{v_2}$;

$$\Rightarrow \mu_{21} = \frac{\left(\frac{c}{\mu_1}\right)}{\left(\frac{c}{\mu_2}\right)}$$

$$\therefore \mu_{21} = \frac{\mu_2}{\mu_1}$$

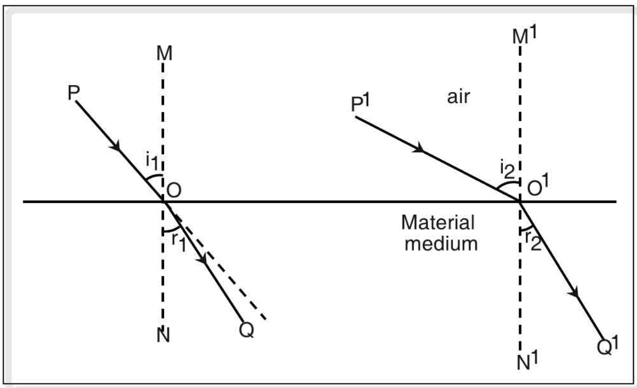
Sometimes μ_{21} is also represented as ${}_1\mu_2$ or ${}^1\mu_2$.

NOTE

1. Optical density is the property of a 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 velocity, it does not have any units.

Snell's law

As 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', incident on the plane surface of a transparent material, travelling

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'.

But in both the cases, the ratio of sine of the 'angle of incidence' to sine of the 'angle of refraction' is 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:

(i) The incident ray, the refracted ray, and the normal to the interface at the point of incidence–all lie in the same plane.

(ii) 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.

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 a change in the altitude of the sun. Thus the sun appears at a higher position than it actually is (fig 39). Moreover, when the sun is at the

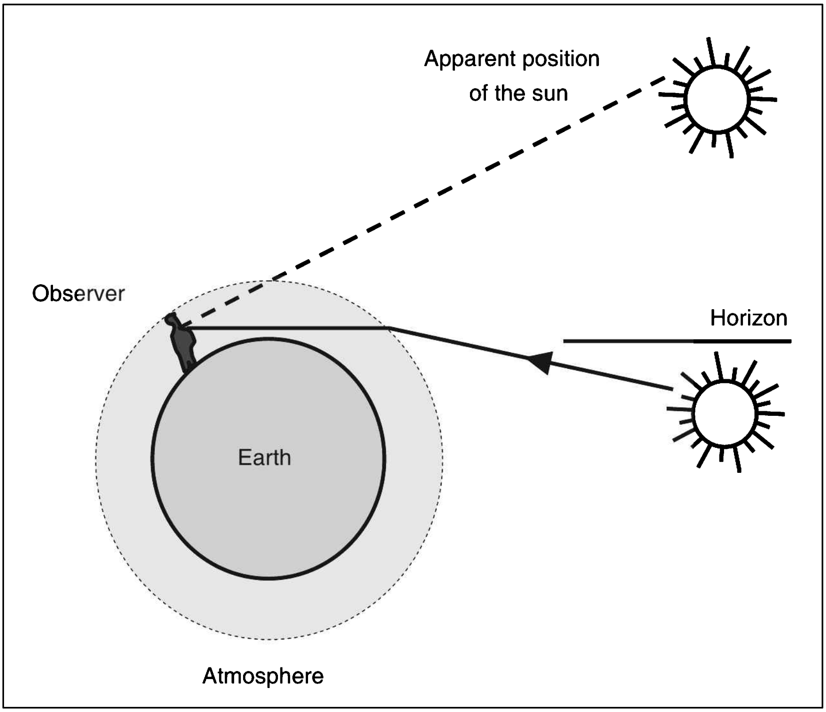


Figure 9.39 Atmospheric refraction effects at sunrise and sunset

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).

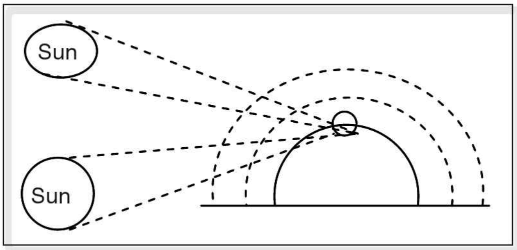


Figure 9.40

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 denser medium, the angle of refraction in the rarer medium is 90°, as shown in the figure (9.41).

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).

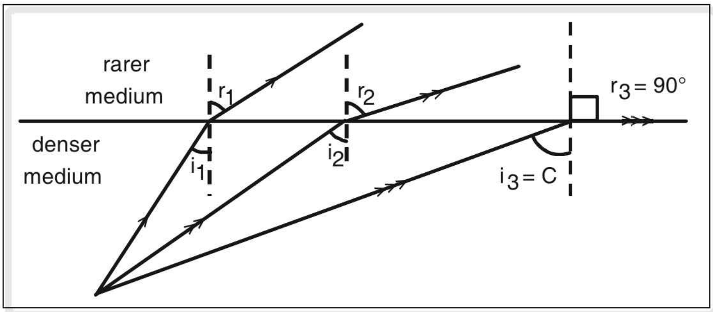


Figure 9.41 Critical anglea

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

$$\mu_{21} = \frac{\sin r_1}{\sin i_1} = \frac{\sin r_2}{\sin i_2} = \frac{\sin r_3}{\sin i_3}, \text{ since } r_3 = 90°$$

$$\mu_{21} = \frac{\sin r_3}{\sin i_3} = \frac{\sin 90°}{\sin C} \therefore \mu_{21} = \frac{1}{\sin C}$$

Here, 'C' is the critical angle of the given denser medium with respect to the given rarer medium and can also be written as 'C_{21}' or '${}_1C_2$'.

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 goes along the boundary separating 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.

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.).

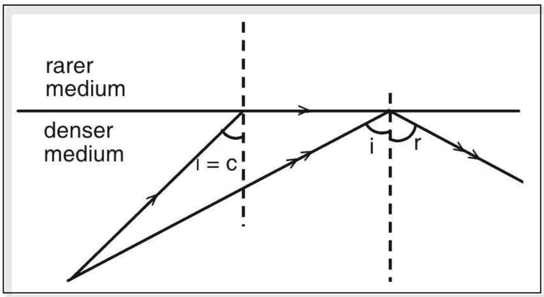


Figure 9.42 Total internal reflection

Condition required for total internal reflection to occur

1. The light rays should travel from denser medium to rarer medium.

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, as shown in the figure, due to total internal reflection.
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.

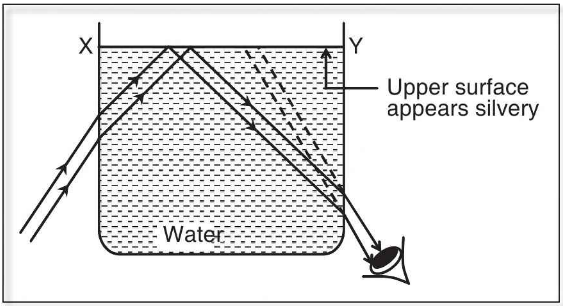


Figure 9.43

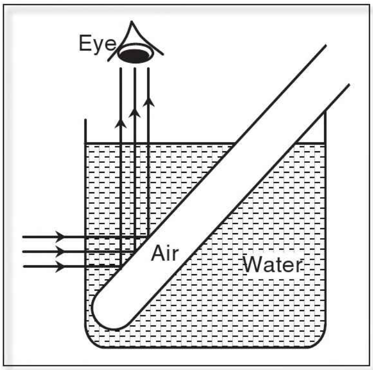


Figure 9.44

4. Mirages

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 one 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.

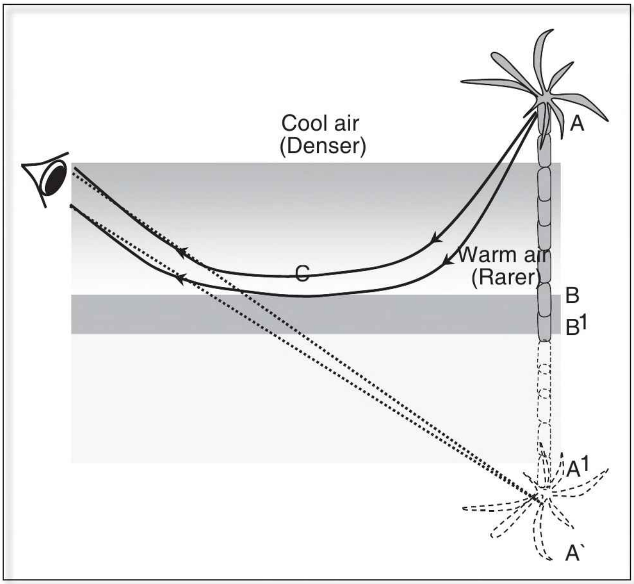


Figure 9.45

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.

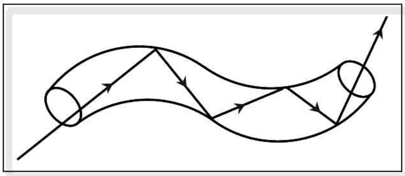


Figure 9.46 Optical fibre

8. Formation of rainbow is due to total internal reflection, and dispersion of light.

Refraction through a prism

A prism is a solid with five faces, three rectangular and two triangular, as shown in the figure.

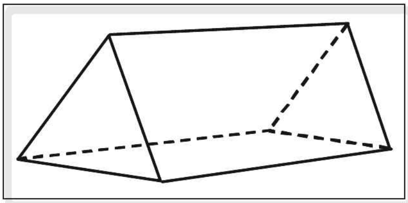


Figure 9.47 A prism

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 adjoining figure.

In the given (fig 9.48) 'PQ' is the 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.

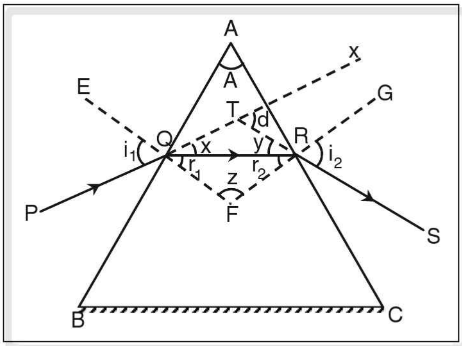


Figure 9.48

'EF' and 'FG' are the normals on 'AB' and 'AC' at points 'Q' and 'R' respectively. 'AB' and 'AC' are known as the refracting faces of the prism and hence the angle between these two refracting faces (A) is known as the **'angle of the prism'**. The face 'BC' of the prism is known as its base. In the absence of the prism, the incident light ray would have travelled along the path 'PQT', but due to the prism it refracts at the two faces of the prism 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).

As 'AQFR' is a quadrilateral,

$\angle A + \angle AQF + \angle z + \angle ARF = 360°$

But $\angle AQF = \angle ARF = 90°$

$\therefore \angle A + \angle z + 180 = 360°$

$\Rightarrow \angle A + \angle z = 180°$ ----- (1)

As 'QFR' is a triangle,

$\angle r_1 + \angle r_2 + \angle z = 180°$ ----- (2)

From equations (1) and (2)

$\angle A + \angle z = \angle r_1 + \angle r_2 + \angle z$

$\Rightarrow \angle A = \angle r_1 + \angle r_2$

or $A = r_1 + r_2$ ---- (3)

As $x = i_1 - r_1$, $y = i_2 - r_2$ and $x + y = d$,

$i_1 - r_1 + i_2 - r_2 = d$

or $i_1 + i_2 - r_1 - r_2 = d$

$\Rightarrow i_1 + i_2 - (r_1 + r_2) = d$

$\Rightarrow i_1 + i_2 - A = d$ (from eq 3)

or $i_1 + i_2 = A + d$ ----- (4)

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 parabola, as shown in the given figure.

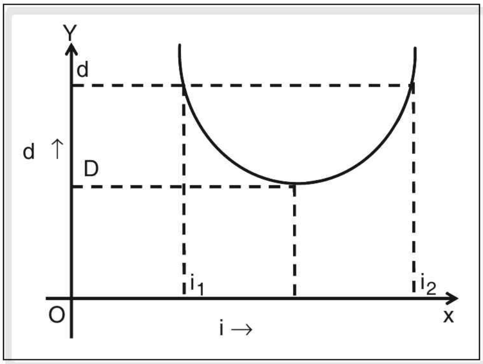


Figure 9.49 'i' Vs 'd' graph

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 given figure), both the angles of incidence and emergence will be 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.

Then we have $r_1 = r_2$

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 (3) and (4) reduce to

$r + r = A \Rightarrow 2r = A$, or $\Rightarrow r = \frac{A}{2}$ ----- (5)

and $i + i = A + D \Rightarrow 2i = A + D; \Rightarrow i = \frac{A + D}{2}$ ----- (6)

From Snell's law we have,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

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.

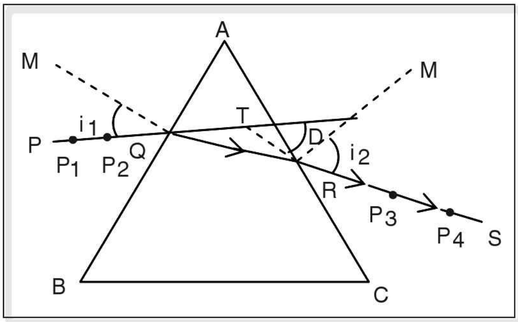


Figure 9.50

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 principal cross section. 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 to the surface on the line AB. (QM is the normal to AB).
6. Draw a line PQ such that it makes an acute angle with the normal QM.
7. The line PQ will be the incident ray.
8. Replace the prism exactly on the boundary marked on the paper.
9. Fix two pins P_1 and P_2 on the line PQ. Such that they are perpendicular to the plane of the paper.
10. Looking through the second refracting face of the prism that lies on the line AC 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 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 the angle with a protractor.
17. Repeat the experiment for different angles of incidence.

18. Tabulate the result in the tabular column.

[redacted]

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 point where $i_1 = i_2$).
22. Calculate the refractive index of the material of the prism using the formula

$$\mu = \frac{\text{Sin}\left(\frac{A+D}{2}\right)}{\text{Sin}\left(\frac{A}{2}\right)}$$

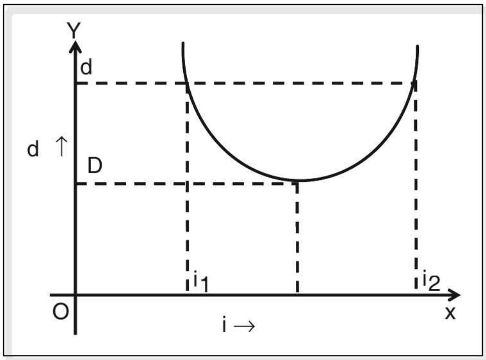


Figure 9.51 'i' vs 'd' graph

Note: The emergent ray always bends towards the base of the prism.

Dispersion of white light by a glass prism

When a narrow beam of sunlight falls on one of the faces of an equilateral prism placed in a dark room, it is found that a band of colours resembling those of a rainbow are observed on a white screen placed on the other side of the prism.

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.

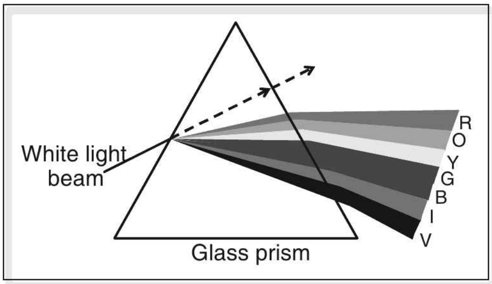


Figure 9.52 Spectrum of white light

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 a **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 such a spectrum is called an **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 figure. 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.

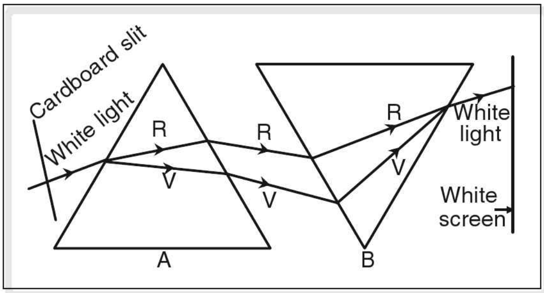


Figure 9.53

Conclusion

The second prism combines the different colours incident on it into white light. Each of the colours entering the second prism were bent towards the base in accordance with the laws of refraction and they rejoined 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 droplets it undergoes refraction and splits into seven colours. These seven colours undergo total internal reflection before emerging out from the lower half of the droplet. Thus light undergoes refraction twice and total internal reflection once. The white light is split into seven colours.

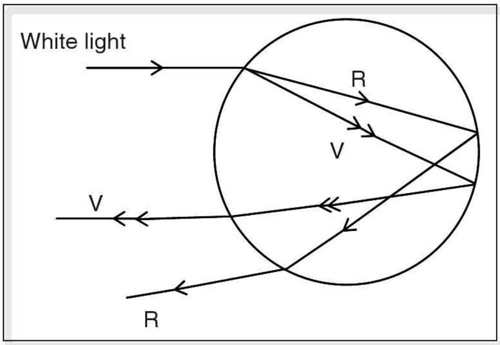


Figure 9.54

Colours

The brain has the ability to distinguish the electromagnetic radiations of different wavelengths in the

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 green coloured surface like a leaf, all the radiations corresponding to the red colour would be absorbed and the surface would appear black.

Primary colours of light

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.

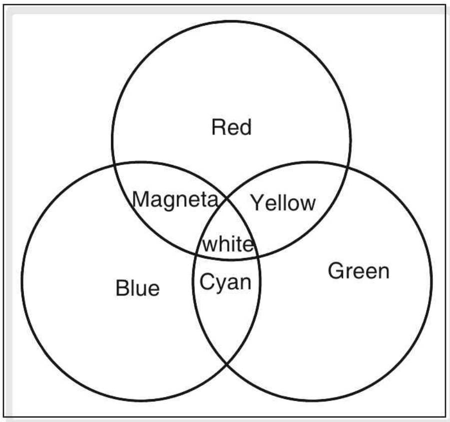


Figure 9.55

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 are called complementary colours.

Red + Cyan = White

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 a red coloured object would appear black, and a yellow coloured object would appear green when seen through a green filter.

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

They 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. e.g., 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.

Magneta, 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.

Cyan, yellow and magenta are called the 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

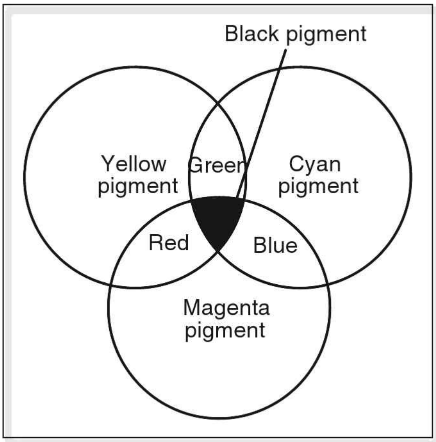


Figure 9.56

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 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 3×10^8 m s^{-1} in vacuum. The following table gives the classification of the electromagnetic waves based on their wavelength.

[redacted]	
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)

Infrared radiations which are absorbed by bodies lead to their getting heated up. 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 from the sun to the earth is transferred 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 used in RADAR (radio detection and ranging) for tracking the position of enemy planes in warfare.
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. 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 mm 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 as 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 shines in dark. This is due to fluorescence.

Certain materials or substances absorb short 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.

The figures depict the different types of lenses. They are

a. Plano-convex lens
b. Plano-concave lens
c. Bi-concave or concave lens
d. Bi-convex or convex lens
e. Convexo-concave lens
f. Concavo–convex lens

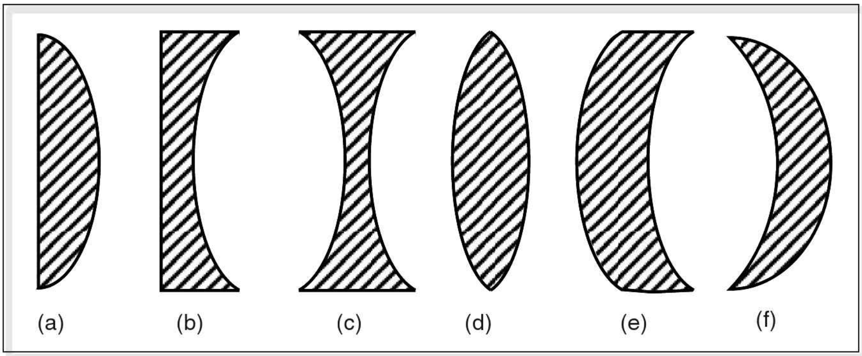


Figure 9.57

Refraction through 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.

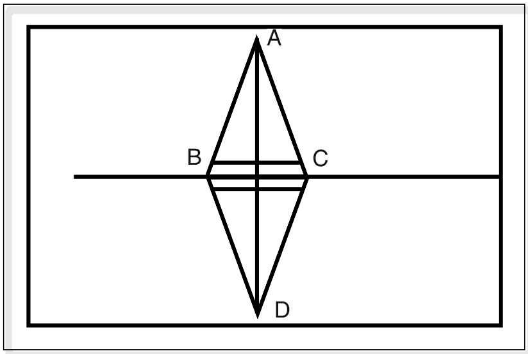


Figure 9.58 ABC and DBC: prisms

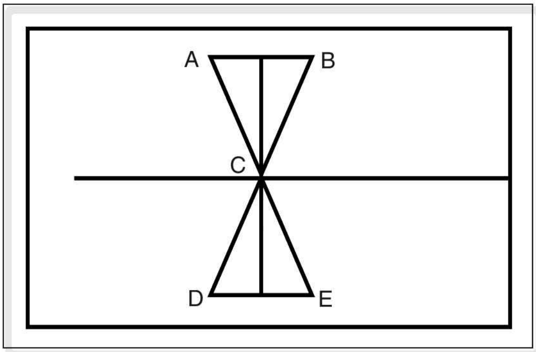


Figure 9.59 ABC and CDE: prism

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 prism meet at the vertex. Hence this lens is thinner at the centre.

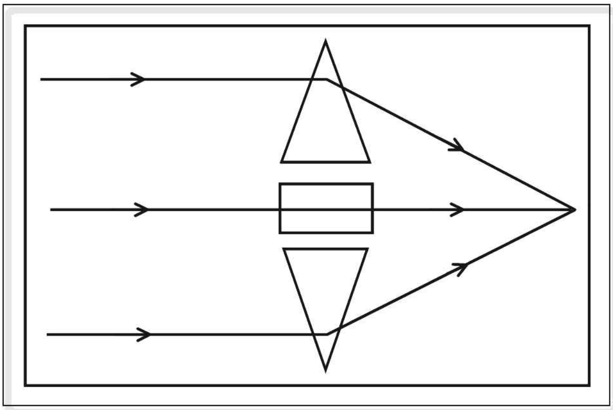


Figure 9.60

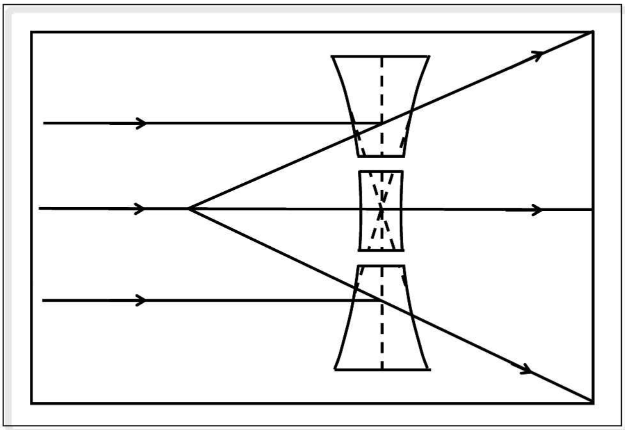


Figure 9.61

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 as a divergent beam. Hence a concave lens is a diverging lens.

General terms related to a spherical lens

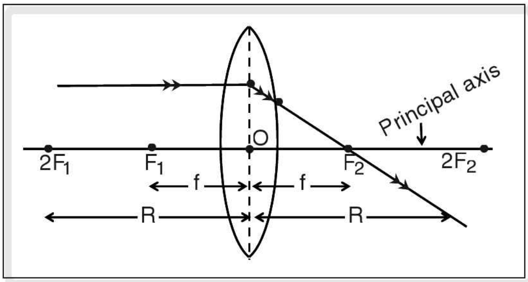


Figure 9.62

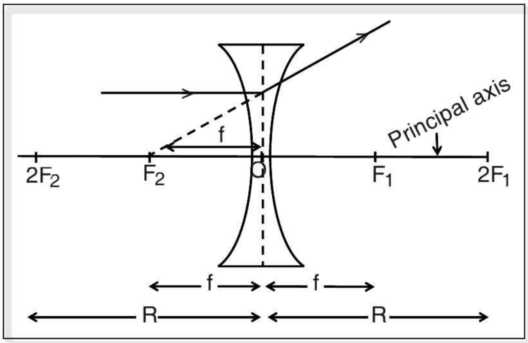


Figure 9.63

1. **Optic centre:** The geometric centre of a lens is known as its optic centre. In the figure, '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 figures (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 focii for a bi-convex or bi-concave lens. In the figures (9.62 and 9.63) 'F_1' and 'F_2' are the principal focii.

5. **Radius of curvature (R):** The radius of the imaginary 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.

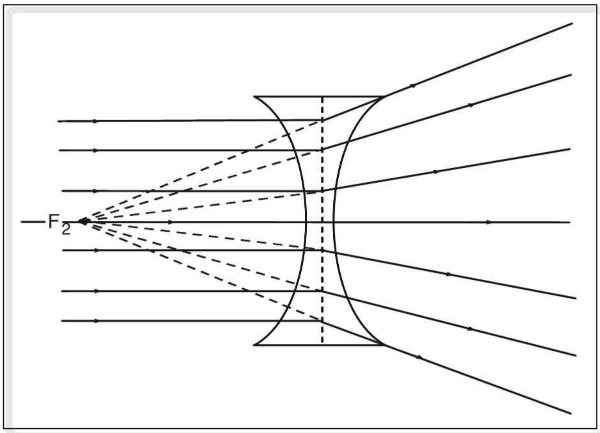


Figure 9.64

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 the lens, emerges without any deviation after refraction at the two surfaces of the lens.

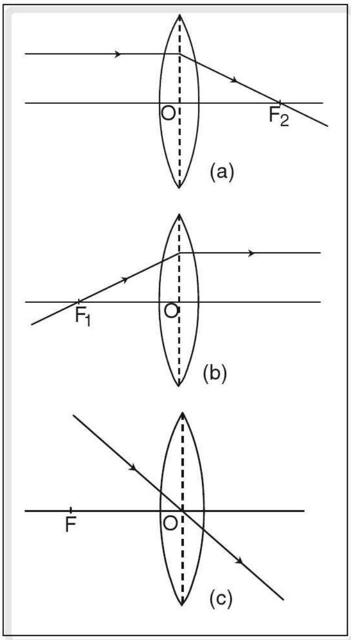


Figure 9.65

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

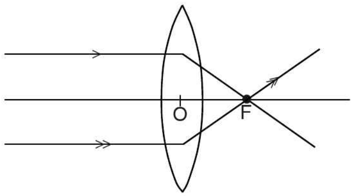
When the object is at infinite distance from the lens, the image is formed on the other side of the lens, highly diminished, real and inverted.

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

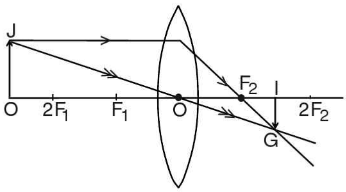
[redacted]

At infinity
i.e., $u = \infty$



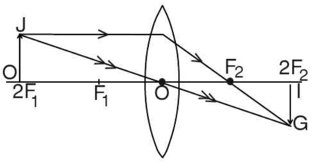
Real, inverted and highly diminished and formed at the principal focus
$\Rightarrow$ i.e., $v = f$.

Beyond the centre of curvature
i.e., $u > 2f$



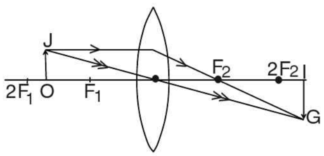
Real, inverted and diminished. Formed between F_2 and $2F_2$ i.e., $f < v < 2f$

At the centre of curvature.
i.e., $u = 2f$



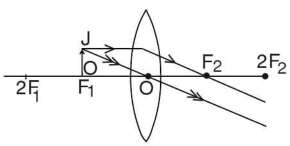
Real, inverted and of equal size as the object, formed at the centre of curvature i.e., $v = 2f$

Between F_1 and $2F_1$
i.e.,
$f < u < 2f$



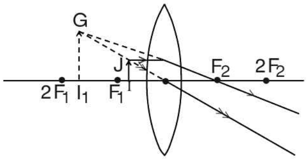
Real, inverted and magnified, and formed beyond $2F_2$ i.e., $v > 2f$

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., $u < f$

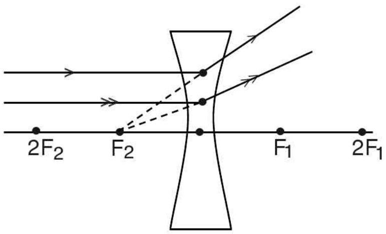
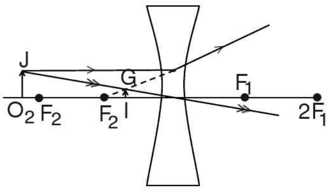


Virtual, erect and magnified. Formed on the same side of the lens as the object.

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 slight 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

At infinity i.e., u = ∞		Erect, virtual and highly diminished. Formed at the focus. i.e., v = f
At any position other than infinity.		Erect, virtual and dimished; 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.

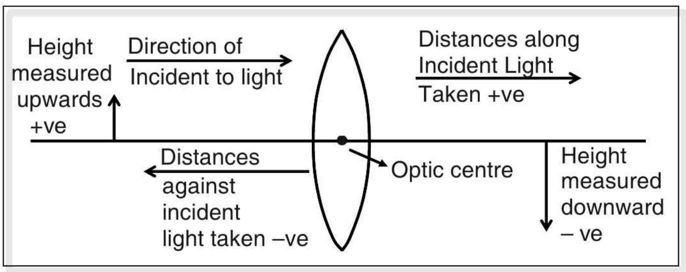


Figure 9.66 Sign convention in lenses

Difference between convex and concave lens

Incident rays parallel to the principal axis after refraction at the two surfaces meet at a specific point called the 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 the 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.

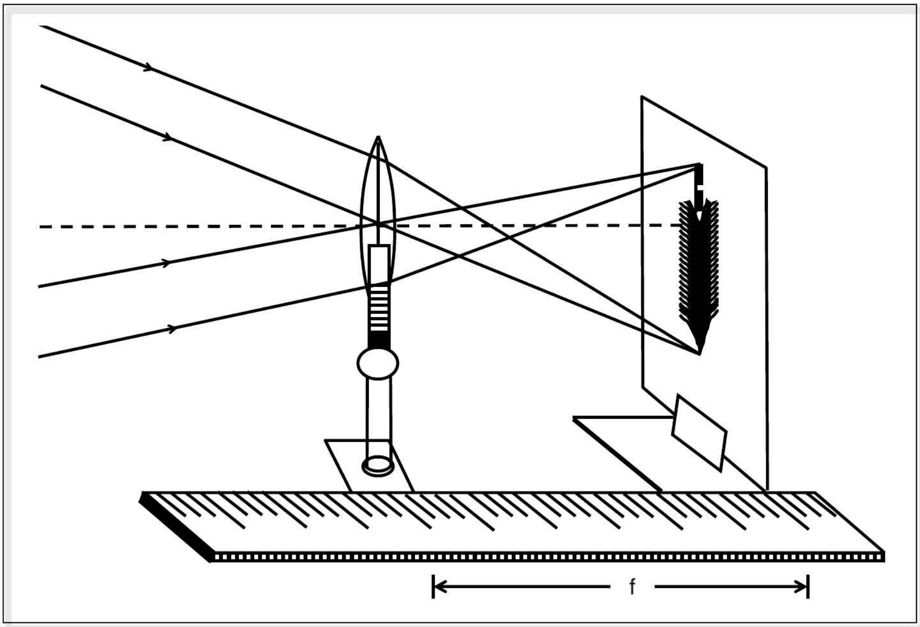


Figure 9.67 Distant object method

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.

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.

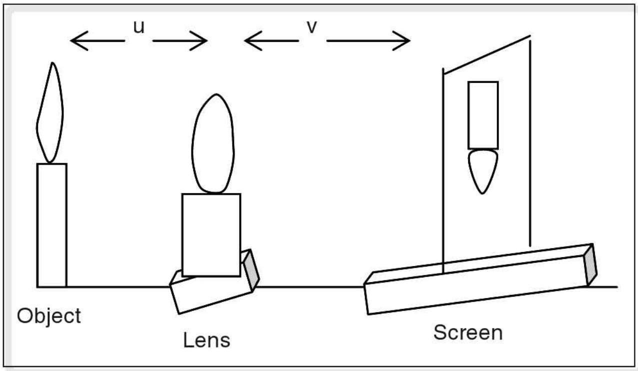


Figure 9.68

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

$$f = \frac{uv}{u + v}$$

Note: The sign convention should be used while substituting the values for u and v.

7. Repeat the experiment for different object distance and tabulate them.
8. Determine the focal length in each case and also note down the nature of the image.

[redacted]

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 of diameter nearly 2.5 cm. Image of an object is obtained when the incident light is refracted by a cystalline 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 the choroid. This adjustment of the eye lens to form sharp images of objects at different distances is known as accommodation.

The central opening or aperture, called the 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 the iris.

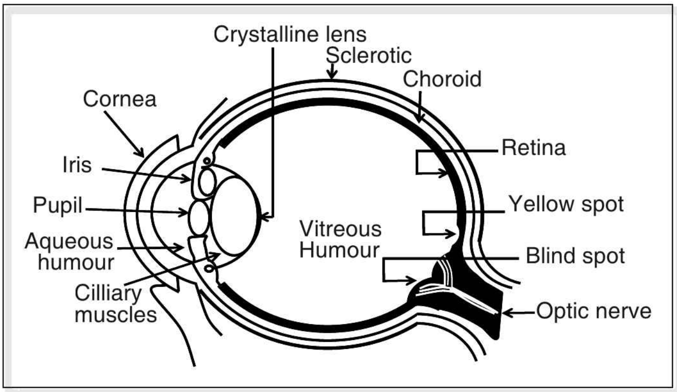


Figure 9.69 The Structure of the Eye

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 are

1. Myopia or short-sightedness
2. Hypermetropia 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 image of a distant object on the retina but focuses the

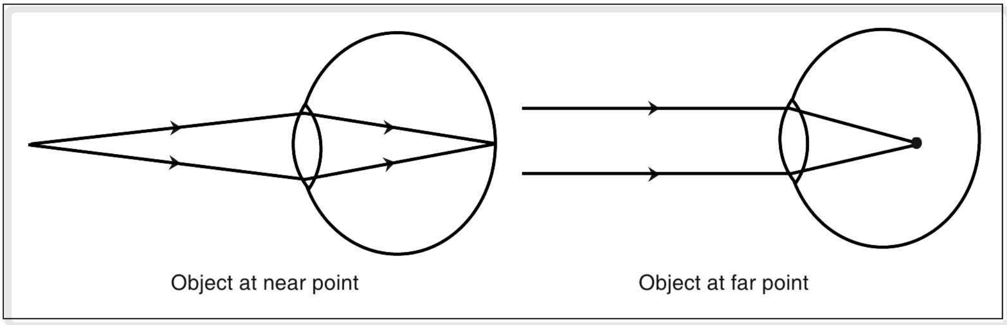


Figure 9.70 Image formation in person having myopia

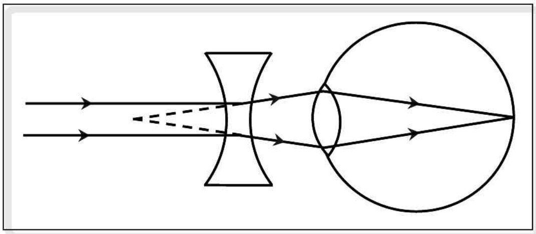


Figure 9.71 Correction of myopia

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.

Hypermetropia

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 image behind the retina.

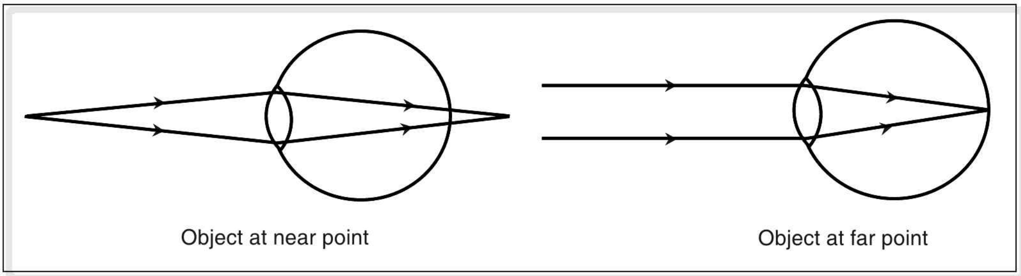
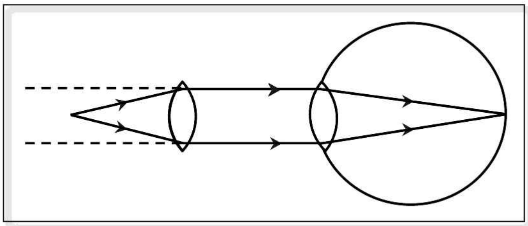


Figure 9.72 Image formation in a person having hypermetropia



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 the 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 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.

$P = P_1 + P_2 + P_3 + \ldots..$

Camera

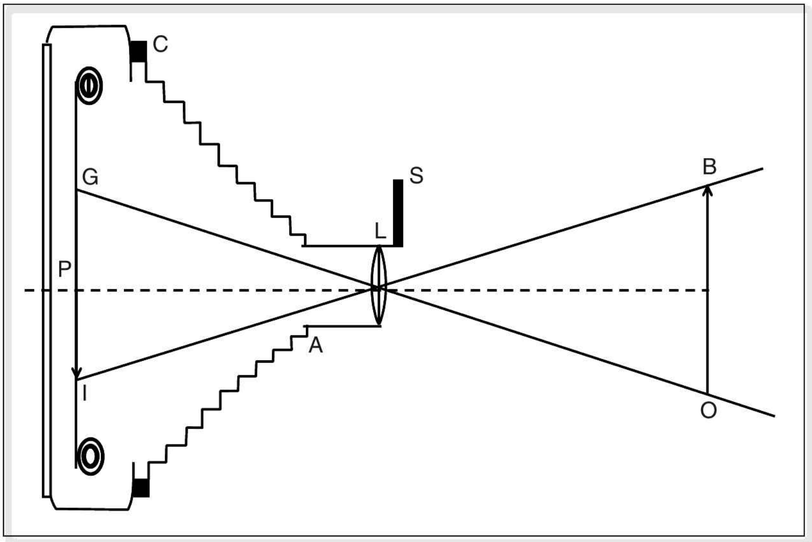


Figure 9.74 Box Camera

OB = Object S = Shutter L = Convex lens A = Adjustable frame C = Light proof box IG = Image 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.

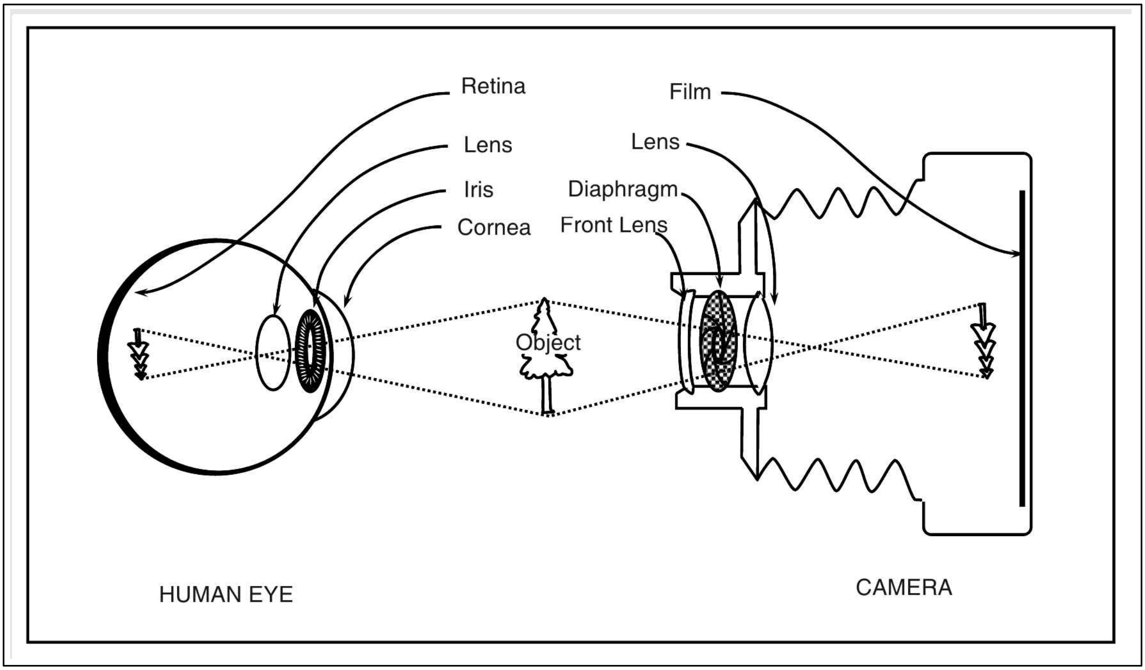


Figure 9.75 Human eye and camera – A comparison

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 instrument like microscopes are used as magnifying devices.

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.

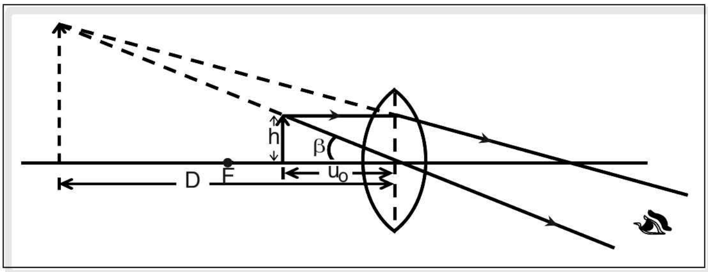


Figure 9.76 Simple Microscope

An erected virtual and magnified image of the object is obtained.

$$M = \frac{\text{height of image}}{\text{height of object}} = \frac{v}{u}$$

Uses

1. A single microscope (also called as a 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 compound microscope.

Compound microscope

A compound microscope consists of two convex lenses. The lens with the shorter focal length is placed towards the object and this lens is called the objective. The other lens with larger focal length and larger aperture is used for viewing the object and is called the 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.

An object AA_1 to be viewed is placed between F_1 and $2F_1$ (closer to F_1) of the objective. The image BB_1 is formed beyond the $2F_2$, on the other side of the objective. The image BB_1 serves as an object for the eye piece.

The distance between the eye piece and the objective 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.

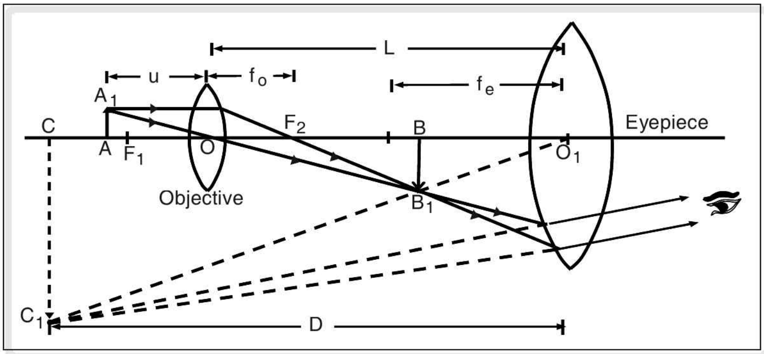
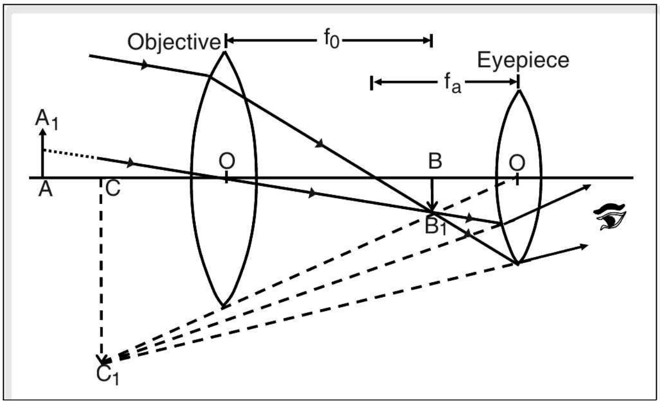


Figure 9.77 Compound microscope

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 large focal length is placed towards the distant object and is called the objective. The objective refracts light from the distant object AA_1 and forms a real, inverted and diminished image BB_1 of the object. 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.



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.

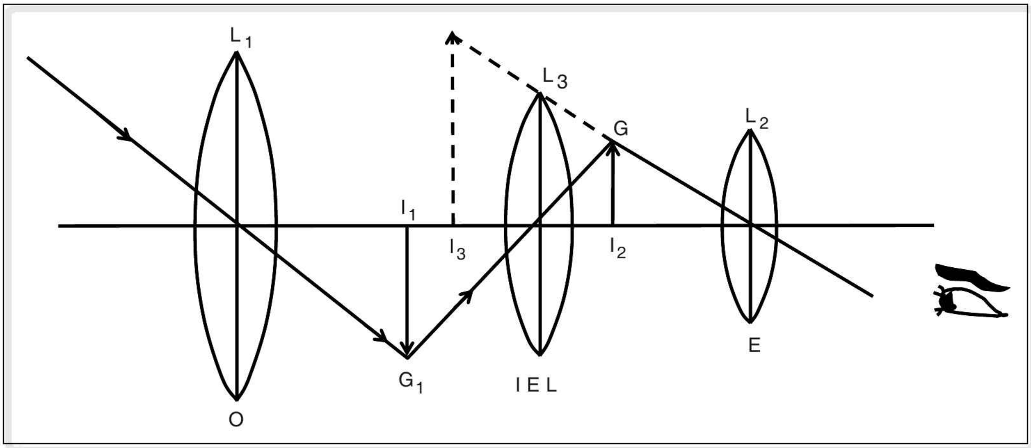


Figure 9.79 Terrestrial telescope

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

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{20} = \frac{1}{v} - \frac{-1}{-30}$$

$$\frac{1}{20} = \frac{1}{v} + \frac{1}{30}$$

$$\frac{1}{} = \frac{1}{} - \frac{1}{}$$

$$\frac{1}{f} = \frac{30 - 20}{30 \times 20} = \frac{10}{600}$$

$$v = \frac{600}{10} = 60 \text{ cm.}$$

$$\text{Magnification } m = \frac{\text{height of the image}}{\text{height of the object}} = \frac{v}{u}$$

$$M = \frac{60}{-30} = -2.$$

Negative sign indicates the image is inverted and m is greater than one, hence 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 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., $h_i = \frac{1}{2}$ho.

Magnification of the lens $m = \frac{v}{u} = \frac{h_i}{h_o}$
v is the image distance
u is the object distance.

$$m = \frac{h_i}{h_o} = \frac{1}{2}\frac{h_o}{h_o} = \frac{1}{2}$$

$$m = \frac{v}{u}$$

$$\frac{1}{2} = \frac{v}{u}$$

$$\Rightarrow v = \frac{u}{2}$$

From lens formula.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{-12} = \frac{1}{\frac{u}{2}} - \frac{1}{u}$$

$$\frac{1}{} = \frac{2}{} - \frac{1}{}$$

$$\frac{1}{-12} = \frac{2-1}{u}$$

$$\frac{1}{-12} = \frac{-1}{u}$$

u = 12 cm.

The object is placed at a distance of 12 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)

$\therefore f = 2.5$ cm $= 2.5 \times 10^{-2}$ m.

Power of the lens $P = \frac{1}{f}$ Dioptre (D)

$$P = \frac{1}{2.5 \times 10^{-2}} = \frac{10^2}{2.5} = 40 \text{ D.}$$

2. The near point of a normal eye is 25 cm

= object distance

= –25 cm = u

(from sign convention)

v = 2.5 cm

= distance of the eye lens from the retina (i.e., the focus)

$$\frac{1}{f} = \frac{1}{2.5 \times 10^{-2}} - \frac{1}{-25 \times 10^{-2}}$$

$$\frac{1}{f} = \frac{100}{2.5} + \frac{100}{25}$$

$$\frac{1}{f} = 40 + 4$$

$$\frac{1}{f} = 44$$

$$\text{Power} = \frac{1}{f} = 44 \text{ D.}$$

test your concepts

Very short answer type questions

1. Is the virtual image formed by a concave mirror always magnified?
2. State Snell's law.
3. Define dispersion.
4. Under what conditions is it possible to obtain a virtual image with the help of a convex lens?
5. Define primary colours.
6. How are shadows cast?
7. What is a mirror formula?
8. Mention two uses of IR rays.
9. Red and cyan are called _________ colours.
10. What is umbra and penumbra?
11. What is total internal reflection?
12. What is fluoroscence?
13. What is a lens formula?
14. What is a spherical mirror?
15. Define optic centre of a lens.
16. Define critical angle?
17. What is a pigment?
18. Define refraction of light.
19. 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°?
20. Among the different colours of light the colour which undergoes the maximum scattering is ___________.
21. Define spectrum.
22. Define refractive index.
23. What is irregular reflection?
24. Why is a concave mirror is called a converging mirror?
25. What is meant by scattering of light?
26. Give two uses of uv rays.

27. What is a rainbow?

28. Define focal length of a lens.

29. A light ray travels from oil to water medium. Does it bend towards the normal or away from the normal?

30. When the object is placed at infinite distance from a concave mirror, where does the image formation take place?

Short answer type questions

31. Explain the formation of rainbow.

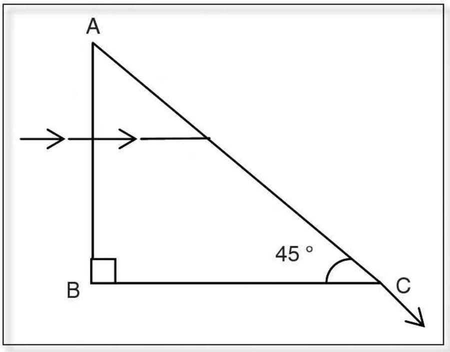
32. A concave mirror is made from a hollow sphere of radius of curvature 30 cm. If an object 2 cm high is placed at 10 cm from the pole of the mirror, determine (1) the position, (2) nature and (3) size of the image.

33. Why does the sun appear red in colour at sun rise and sun set.

34. 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 continuous to pass through the hole in the wall?

35. State and explain sign conventions used in spherical mirrors.

36. 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?

39. Define power of a lens and write its unit?

40. Write any two advantages and two disadvantages of a pin hole camera.

41. What are the difference between microscope and telescope.

42. 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?

43. What is lateral inversion of images? Explain with example.

44. 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?

45. Prove that focal length of a spherical mirror is equal to half the radius of its curvature.

Essay type questions

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?

CONCEPT APPLICATION

Concept Application Level—1

Direction for question 1 to 7: State whether the given statements are true or false.

1. Red, green and blue pigments are primary pigments.
2. When an object is placed between two plane mirrors which are inclined at right angle, the number of images formed is four.
3. The power of a rectangular glass slab is zero.
4. Virtual image produced by convex mirror is always smaller in size and located between focus and the pole.
5. Rainbow is an impure spectrum caused by sunlight.
6. The rays passing through the optic centre of a thin lens suffers no lateral displacement.
7. 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.

8. 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, when expressed in metres.

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 to 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.

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 30: Select the correct alternative from the given choices.

16. V_v, V_R, V_G are the velocities of a violet, red and green light respectively passing through a prism after the dispersion of white light. Which among the following is a correct relation?

(1) $V_V = V_R = V_G$ (2) $V_V > V_R > V_G$ (3) $V_V < V_G < V_R$ (4) $V_V < V_R < V_G$

17. As an object moves towards a convex mirror, the image

(1) magnification increases (2) moves towards the mirror

(3) Neither (1) nor (2) happens (4) Both (1) and (2) happens

18. When a light ray passes from an optically denser medium into an optically rarer medium

(1) its velocity in increases (2) frequency remains same

(3) wavelength increases (4) All the above

19. Time taken for the sunlight to pass through a window glass of 5 mm thickness is _______ s. (μ_{glass} = 1.5)

(1) 2.5×10^{-11} (2) 0.4×10^{-8} (3) 4×10^{-8} (4) 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 _____.

(1) vertically upwards

(2) at an angle to the vertical which is less than the critical angle.

(3) at an angle to vertical which is equal to the critical angle.

(4) at an angle to the vertical which is greater than critical angle.

21. Choose the correct statement.

(1) The final image formed by a terrestrial telescope is inverted.

(2) The final image formed by an astronomical telescope is erect.

(3) The final image of an astronomical telescope is magnified.

(4) Both (1) and (2)

22. Light appears to travel in a straight line because

(1) it passes by the atmosphere

(2) its wavelength is very small

(3) its velocity is very large

(4) it is a form of energy

23. Choose the correct statement

(1) The combination of a convex lens and a concave lens is a concave lens if the focal length of convex lens is less than that of concave lens.

(2) The power of the combination of a concave lens and convex lens is more than the power of individual lenses.

(3) The combination of a convex lens and concave lens of equal focal length behaves as a glass slab.

(4) All the above

24. The power of two lenses are + 6D and – 4D, the power of the combination two lenses is

(1) 6D (2) 4D (3) 2D (4) 3D

25. The angle which the incident ray makes with the mirror is called

(1) angle of incidence (2) angle of reflection

(3) right angle (4) glancing angle of incidence

26. A magenta pigment absorbs _________ colours

(1) red (2) blue (3) green (4) 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

(1) rotates in clockwise direction (2) rotates in anti-clockwise direction

(3) is inverted (4) 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?

(1) The rays incident on the first mirror and the rays reflected from the second mirror are always parallel.

(2) The rays incident on the first mirror and the rays reflected from the second mirror are perpendicular.

(3) The angle of deviation lies between 90° and 180°.

(4) None of the above

29. Which of the statements is true if a planet is observed with the help of an astronomical telescope?

(1) The image of the planet is errect.

(2) The objective is larger than the eye piece.

(3) Eye piece has greater focal length than the objective.

(4) 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.

(1) between the lens and its focus.

(2) on the focus of the lens.

(3) between f and 2f.

(4) at infinity

Concept Application Level—2

31. 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?

32. 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 indecent ray on the first mirror, determine the angle between two plane mirrors.

33. Explain why shadows cast by lower part of the skyscrapers or vertical poles is sharper than the shadows of upper portion of the same object.

34. Why do clouds appear white?

35. 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.

36. An object is placed between two identical convex mirrors X and Y of focal length 15 cm at the mid point on their common principle 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.

37. A rod of length $\frac{f}{2}$ 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.

38. 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.

39. 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.

40. 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.

41. 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.

42. 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 appears to be at a height of 4 cm from the bottom. Determine the refractive index of the second glass cube.

43. 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

44. Which radiation is used to photograph in smoke or fog? Explain why?

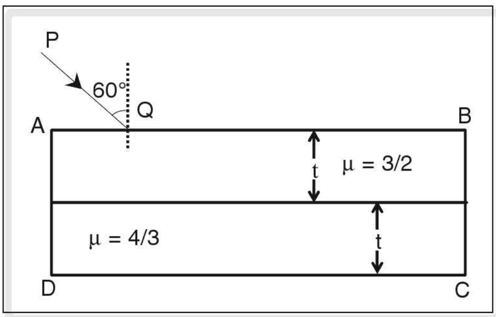
45.

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.

Concept Application Level—3

46. 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.

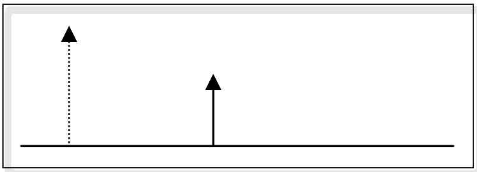


47. The base of a rectangular glass slab of thickness 10 cm and refractive index 1.5 is silvered. A coloured spot inside the glass slab at a distance of 8 cm from the base. Determine the position of the image formed by the mirror as observed from the top.

48. 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.

49. 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?

50. 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 the ratio u : v : f. What is the type of the lens used? Draw the ray diagram to show the position of the lens and the principal focii.



key points for selected questions

Very short answer type questions

1. Yes
2. $\mu = \frac{\text{Sini}}{\text{Sinr}}$
3. Splitting of light into its component colours.
4. Object placed between focus and optic centre.
5. Red, blue and green–cannot be obtained by mixing any two or more colours.
6. Obstruction of path of sunlight.
7. $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

   Where f – focal length.
   u – object distance
   v – image distance of the mirror.
8. (i) Physiotherapy to treat swollen joints, muscles etc.
   (ii) Take photographs in foggy weather.
9. Complimentary colours.
10. Region of total darkness – Umbra

    Region of partial darkness – penumbra
11. (i) Light travels from denser to rarer medium.
    (ii) Angle of incidence greater then critical angle of the medium.
    (iii) Light rays get reflected back into the same medium.
    (iv) Variation of refractive index of air.
    (v) Optical illusions.
12. Materials absorb short wavelengths of light and emit light in the longer wavelength region.
13. $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

    Where f – focal length
    u – object distance
    v – image distance
14. Part of hollow glass spheres.
15. Geometric centre of a lens.
16. Angle of incidence of the light ray in the given denser medium, for which the angle of refraction is 90°.
17. Optically active substances, which absorb most of the colours of white light, selectively reflect one or more colours.

key points for selected questions

18. Bending of light when it travels from one transparent medium to another medium.

19. $n = \frac{360}{\theta} - 1$

20. violet

21. Band of colours obtained on the screen, when white light splits into its component colours.

22. Ratio of the velocity of light in one medium to that of the other.

23. Reflected light rays are not parallel.

24. Reflected light rays converge at a point.

25. Irregular or diffused reflection of light when it travels through a medium.

26. (1) Detect fake currency notes.

(2) Distinguish original diamonds from fake ones.

27. Dispersion of light through rain drops.

28. Distance of the principal focus from the optic centre of the lens.

29. Away from the normal.

30. At the focus.

Short answer type questions

31. (i) Rain drops acts as prism.
(ii) Sunlight passes through them.
(iii) Total internal reflection.
(iv) Dispersion of light.

32. (i) R = 2f
(ii) $\frac{1}{v} + \frac{1}{u} = \frac{I}{f}$
Ans:
(iii) 30 cm behind the mirror
(iv) virtual and erect
(v) 6 cm

33. Light of shorter wavelength is scattered more.

34. i = r
Ans = 5°

35. (i) Distances parallel to the principal axis measured from the pole of the mirror
(ii) Distances measured in the direction of incident light are taken as positive.
(iii) Distances measured in a direction opposite to the direction of incident light are taken as negative.
(iv) Heights measured above principal axis – positive.
(v) Heights measured below principal axis – negative.

36. $\mu = \frac{1}{\text{SinC}}$; Ans = $\sqrt{2} = 1.414$

37. (i) Light ray incident parallel to the principal axis.
(ii) Light ray passing through centre of curvature.
(iii) Point where the reflected rays extended backwards meet.

38. (i) $P = P_1 + P_2$
(ii) $P = \frac{1}{f}$ Ans: 2.5 D

39. $P = \frac{1}{f}$, f is in meters.
Unit – dioptre

40. Adv: (i) Easy to construct and operate.
(ii) Not expensive
Disadv: (i) Cannot take images of moving objects
(ii) Time required to take photographs is more.

41. (i) Difference in the focal length of the objective lens and eye lens.
(ii) Difference in the position of the object.

42. $n = \frac{360°}{\theta} - 1$ Ans: 80°

43. (i) Left hand side appears as right hand side and vice versa.
(ii) Image rotates around 180° about the vertical axis.

key points for selected questions

(iii) Man standing in front of plane mirror.

44. (i) For a convex mirror, $v = \frac{uf}{u - f}$

(ii) for a plane mirror, $v = u$

(iii) $u_1 + v_1 = u_2 + v_2$

Ans: 20 cm from the object.

45. (i) Ray diagram

(ii) Laws of reflection

(iii) Similar triangles.

Essay type questions

46. (i) Apparatus

(ii) Adjustments

(iii) $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

(iv) Sign convention

(v) Observations

47. (i) Tracing the prism on white paper.

(ii) For different angles of incidence, finding angles of emergence in each case.

(iii) Tracing them to find angle of deviation in each case.

(iv) Plotting graph for ∠i vs ∠d in each case to find angle of minimum deviation.

48. (i) Ray diagram

(ii) Positions of object and image

(iii) Similar triangles

(iv) Sign conventions

49. (i) Ray diagram

(ii) Focal lengths of objective and eye-piece

(iii) Position of the images.

(iv) Nature of image.

50. (i) Variation of refractive index of air.

(ii) Optical illusions.

KEY

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. 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. Choice (3)

17. Choice (4)

18. Choice (4)

19. Choice (1)

20. Choice (3)

21. Choice (3)

22. Choice (2)

23. Choice (3)

24. Choice (3)

25. Choice (4)

26. Choice (3)

27. Choice (4)

28. Choice (1)

29. Choice (2)

30. Choice (1)

Concept Application Level—2,3

Key points for select questions

31. (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?

$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ substitute f = 10 cm and v = ∞ to obtain 'u'.

(ii) $u_1 = 7.14$ cm
$u_2 = 10$ cm

32. (i) Angle of incidence = angle of reflection
Sum of the three angles of a triangle = 180^0
Draw the ray diagram and determine the sum of the angle
of incidences and angle of reflections

(ii) 45°

34. 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.

35. (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

36. (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'.
∴ 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

37. (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,

∴ 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

38. (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, μ_w

$$= \frac{\text{Real depth}}{\text{apparent depth}}$$

How do the above formula change if the person observes the object in air from water?

(ii) Shift = $h(\mu_w - 1)$

39. (i) When mirror is rotated through θ the reflected ray is rotated through 2θ

The initial angle of incidence i_1

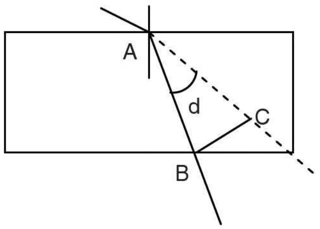
$= i_2 + r_2$

When i_2 and r_2 are the angle of incidence and angle of reflection after rotating the mirror.

(ii) 60°

40. $\sqrt{3}$

41. (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

42. 2.25

43. (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)

∴ The distance between objective and eye piece = $v_1 + u_2$

(ii) 106.89 cm

44. 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?

45. (i) The magnification $m = \frac{v}{u}$

$\therefore v = mu$ ----- (1)

The distance between object and the image

$= v + u$ ----- (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

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad ----- \quad (3)$$

(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

46. (i) Apprent 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) $\mu = \frac{24}{17}$

47. (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

48. (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.

∴ Refractive index

$$\frac{\text{Real depth}}{\text{Apprent depth}} = \frac{d}{d-(u_1 - u_2)}$$

(ii) $\mu = 1.66$ or $\frac{5}{3}$

49. (i) Let h_1 and h_2^1 be the real and apparent height of the stone at t = 0 s.

Let h_2 and h_2^1 be the real and apparent height of the stone at t = 1 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}

50. (i) Magnification $m = \frac{v}{u}$ ----- (1)

$v = u + d$

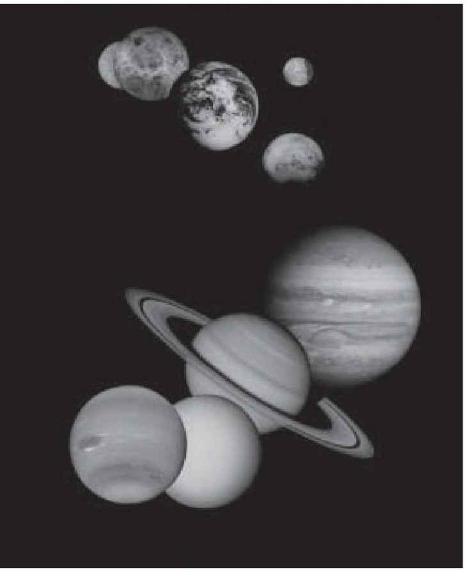
where 'd' is the distance between the image and the object.

Substitute the value of v in (1) and determine the value 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.

(ii) 2 : 6 : 3



10

Electricity

NTRODUCTION

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: Two kinds

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. Dr 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, Dr 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 $[M^{\circ}\ L^{\circ}\ A'\ T']$

Properties of charges

The following are the properties of electric charges.

1. There are two types of charges, namely, positive and negative.
2. 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.
3. A neutral body becomes positively charged on losing electrons and not because of gaining protons.
4. A neutral body becomes negatively charged, when it gains electrons.
5. 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. If 'q' is the magnitude of charge on any body then, q = ne where 'n' is any natural number and 'e' is the charge of an electron and is approximately equal to 1.6×10^{-19} C. This is known as 'quantization of electric charge'.

6. 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.
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 and then 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. Thus, the charge is said to be 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. (Figure 10.1)

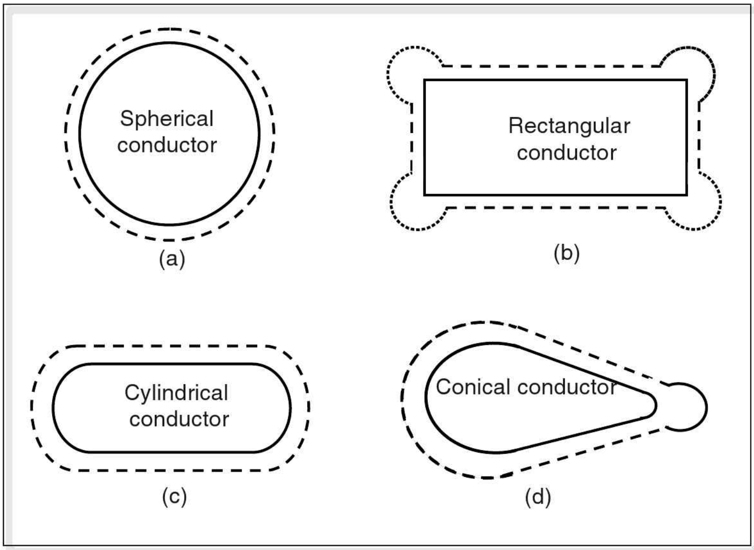


Figure 10.1 Distribution of charge on various conductors

11. The charge supplied to an insulator (also called a dielectric) is not distributed over its entire surface and remains at the supplied position on the insulator.
12. 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.

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

☛ *Examples* All metals, graphite, acid and alkali solution in water, 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

Charging by conduction

When a charged body is brought in contact with an uncharged conductor, transfer of charge takes place from the charged body to the conductor. This type of charging is known as 'charging by conduction'.

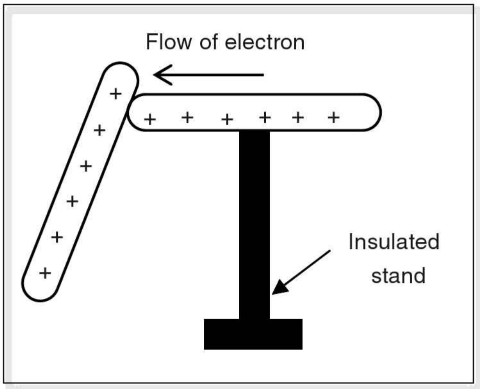


Figure 10.2

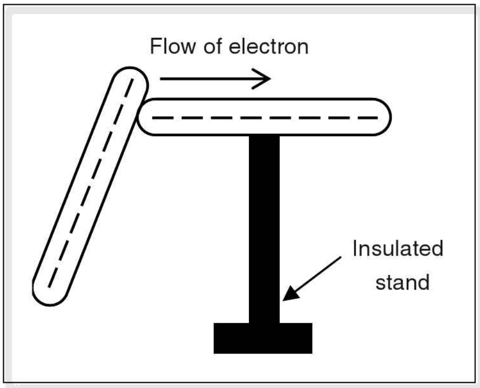


Figure 10.3

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 figure, 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 other side of it.

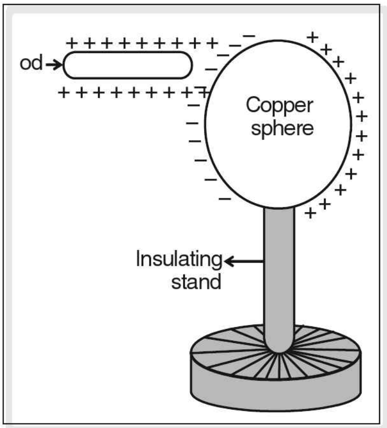


Figure 10.4

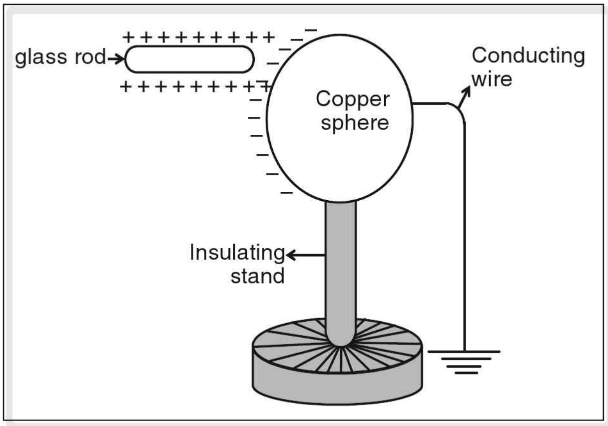


Figure 10.5

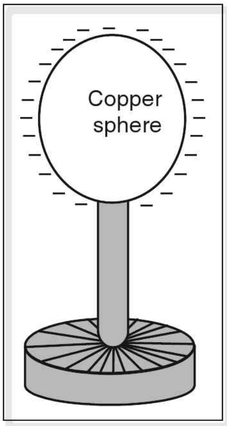


Figure 10.6

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) (figure (10.5)). 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 (figure (10.6)). 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 figure (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 electroscope and a gold leaf electroscope are the basic models.

Pith ball electroscope

A pith ball electroscope 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 figure 10.7 (a).

If a glass rod rubbed with a silk cloth (charged positively) is brought into contact with the pith ball, the ball gets attracted to the rod initially (figure 10.7 (b)). Once the rod touches the ball, the ball acquires the positive charge and gets repelled by the rod in the next moment (figure (10.7c)). 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.

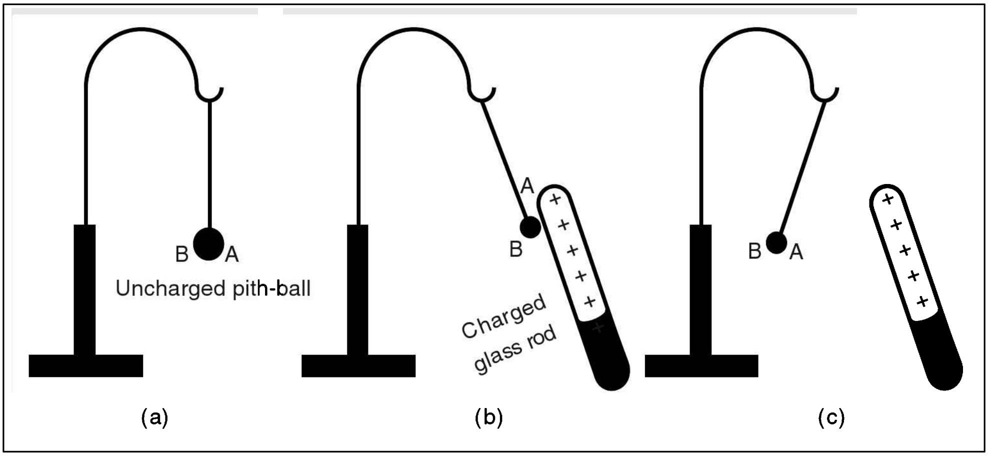


Figure 10.7 Pith Ball electroscope

Gold leaf electroscope

A gold leaf electroscope consists of a glass jar placed on a non-conducting surface like wood. 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.

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 is provided at the upper end of the brass rod.

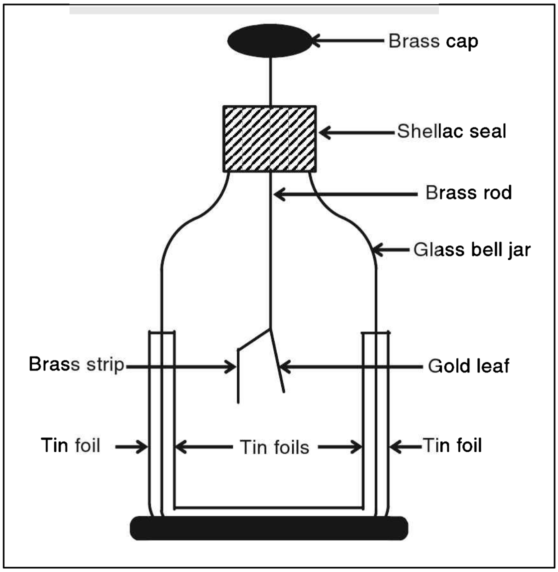


Figure 10.8 Gold leaf electroscope

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.

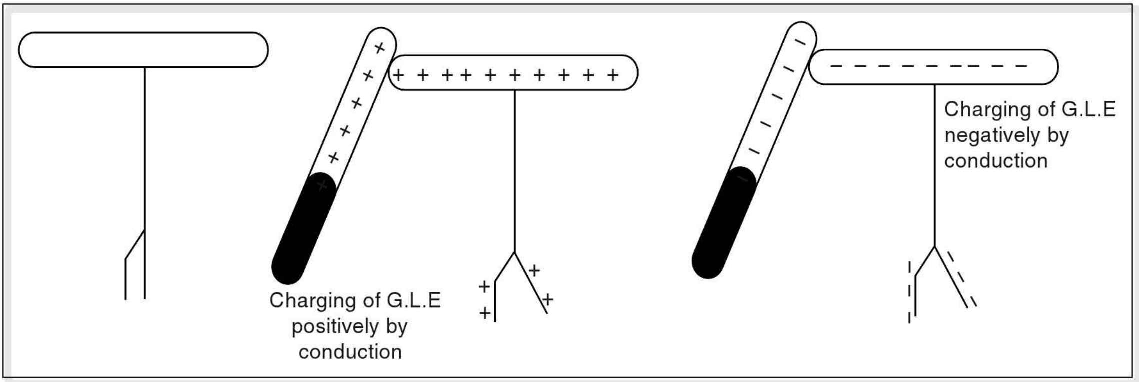


Figure 10.9 Charging by conduction

Proof plane

If the size of a body to be tested is very large, we use an instrument, which makes it easier to carry the charge from the body to an electroscope. Such an instrument is a 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 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.

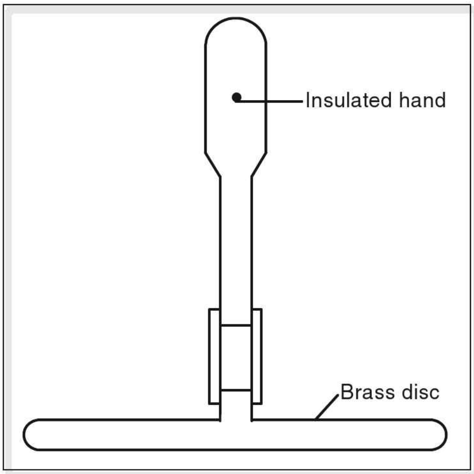


Figure 10.10 Proof Plane

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.

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.

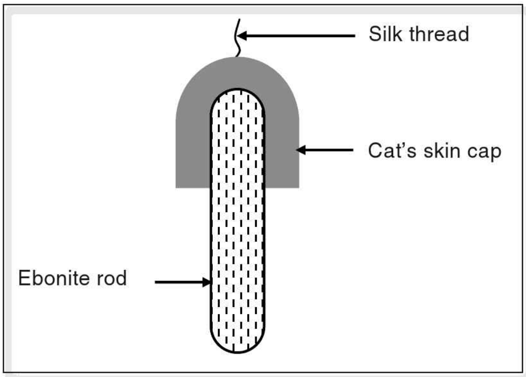


Figure 10.11

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 A 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 (figure (10.12)) 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'.

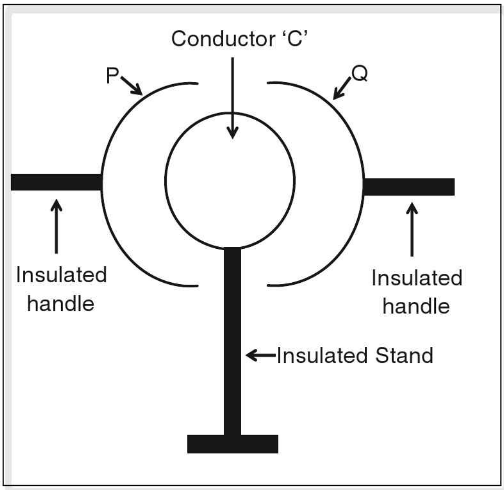


Figure 10.12

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.

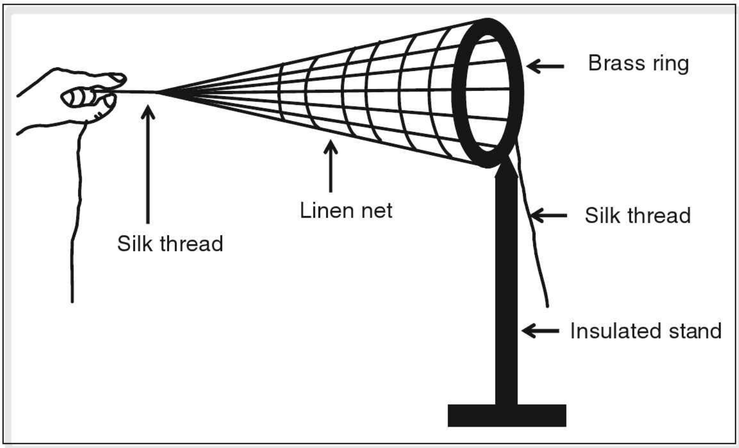


Figure 10.13

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.

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. And 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 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 charged bodies is directly proportional to the product of the magnitude of the charge on the bodies.

If 'q_1' and 'q_2' are the charges on two bodies and the force between them is 'F', then $F \propto q_1 q_2$ ———— (1).

The force of attraction or repulsion between two charged bodies 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 charged bodies having charges 'q_1' and 'q_2' and the force between them is 'F', then

$$F \propto \frac{1}{r^2} \text{ ———— (2)}$$

Combining proportionalities (1) and (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 two charged 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 charged bodies are present. In SI system, if air is the medium or the charges are in vacuum, then the constant is $\frac{1}{4\pi\varepsilon_0}$ where 'ε_0' is called 'permittivity of vacuum or of air'. If the medium surrounding the charged bodies is other than vacuum or air, then the constant is $\frac{1}{4\pi\varepsilon}$, where 'ε' is the 'permittivity of the medium. Thus we have $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$ when the medium

Similarly, $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$ 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, $\frac{1}{4\pi\varepsilon_0}$ 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 45×10^{-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 μC, 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) = 45×10^{-3} N

$q_2 = ?$

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ N\ m^2\ C^{-2}$$

$$\therefore\ 45 \times 10^{-3} = 9 \times 10^9 \times \frac{8\times10^{-6}\times q_2}{(4)^2} \Rightarrow q_2 = 10\ \mu C$$

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

$$\therefore \text{ Force } F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$$

$$= \frac{9\times10^9\times3\times10^{-6}\times4\times10^{-6}}{(2)^2}$$

$$= \frac{9\times10^9\times3\times10^{-6}\times4\times10^{-6}}{4} = 27\times10^{-3}\,N = 27\text{ mN}$$

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 $[MLT^{-3}A^{-1}]$.

☛ *Example*

Find the magnitude of a charge whose electric field strength is 18×10^3 N C^{-1} at a distance of 5 min air.

Solution

Given

Electric field strength (E) = 18×10^3 N C^{-1}

Distance (r) = 5 m

Charge (q) = ?

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$$

$$18 \times 10^3 = 9 \times 10^9 \times \frac{q}{(5)^2}$$

q = 50 μC

☛ *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 nC = 32×10^{-9} C

r = 3 m

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2} = 9 \times 10^9 \times \frac{32 \times 10^{-9}}{(3)^2} = 32 \text{ N C}^{-1}$$

☛ *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 C, F = 9 N

∴ 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 50 μC of charge at a point 30 m away from it in air.

Solution

Given, Q = 5 μC = 5×10^{-9} C

r = 30 m

∴ 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 the point.

Solution

Given, electric field strength E = 30 N C^{-1}
Charge, q = 20 C
∴ The force on the charge F = Eq = (30)(20) = 600 N

Electric Potential

Consider a positive charge 'Q' placed in air. The electric field strength due to the charge at a distance 'r' from it 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 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). "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 $[ML^2T^{-3}A^{-1}]$.

☛ *Example*

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.

Solution

Given q = 10 C and w = 200 J

∴ Electric potential, $V = \frac{w}{q} = \frac{200\ J}{10\ C} = 20\ J\ C^{-1}$ or 20 V

Example

The work done in bringing 5 C of charge from infinity to a point near a charged body is 20 J. Find the potential at that point.

Solution

Given, charge, q = 5 C

Work done, w = 20 J

$\therefore$ The electric potential, $V = \frac{w}{q} = \frac{20\ J}{5\ C} = 4\ V$

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 V

Given, charge, q = 5 C

Work done, w = 20 J

$\therefore$ The electric potential $V = \frac{w}{q} = \frac{20\ J}{5\ C} = 4\ V$

The electric charge q = 12 C

$\therefore$ Work done $w = V\ q = 6 \times 12 = 72\ J$

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 V

Work done, W = 600 J.

We know, W = V q

$\therefore\ q = \frac{W}{V} = \frac{600}{20} = 30\ C.$

Potential difference

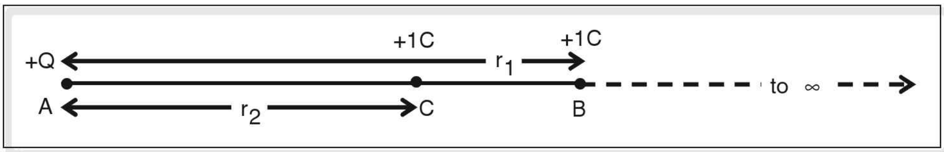


Figure 10.14

Consider a charge '+Q' placed at a point 'A' in air as shown in figure 14. 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 = 10 J

And charge q = 5 C

∴ The potential difference between the points

$$\Delta V = \frac{w}{q} = \frac{20\ J}{5\ C} = 4\ \text{volt}.$$

☛ *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

∴ The total charge, $q = ne = 500 \times 10^{18} \times 1.6 \times 10^{-19} = 80$ C

The potential difference between the two points,

$\Delta V = 1$ millivolt $= 10^{-3}$ V

∴ 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). Thus one farad is the capacitance of a conductor, whose potential increases by one volt on addition of one coulomb of charge to it. 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.

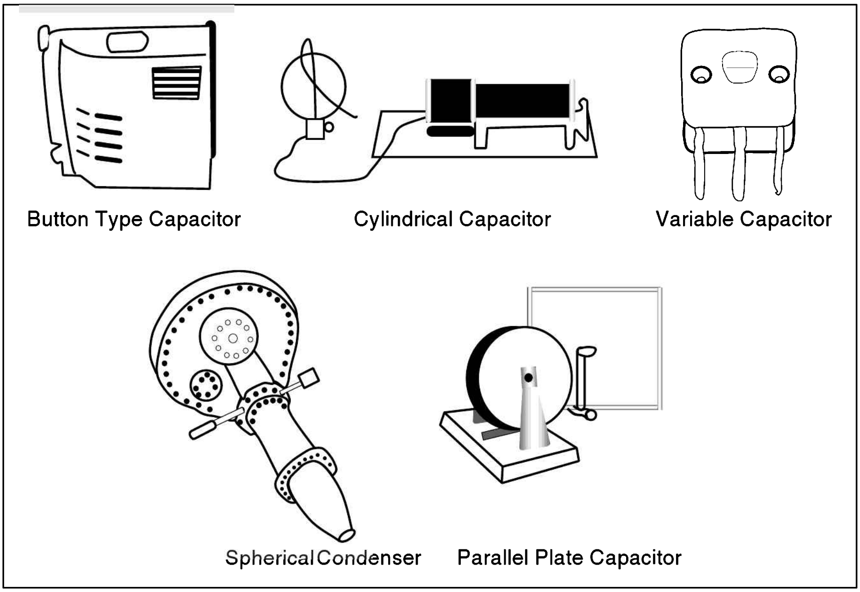


Figure 10.15 Different types of capacitors

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 C of charge at a potential of 5 V. Calculate its capacitance.

Solution

Given, charge on the conductor q = 25 C
Potential of the conductor V = 5 V

$\therefore$ Capacitance of the conductor $C = \frac{q}{V} = \frac{25\,C}{5\,V} = 5$ F

☛ *Example*

The capacitance of a capacitor is 3 μF. If a charge of 108 μC exists on it, calculate its potential.

Solution

Given, capacitance of the capacitor, C = 3 μF.
Charge on the capacitor, q = 108 μC.

$\therefore$ Potential of the capacitor, $V = \frac{q}{C} = \frac{108\,\mu C}{3\,\mu F} = 36\,V.$

Electric current

Consider two water tanks 'A' and 'B' having different cross sectional areas, at the same level as shown in figure 10.16. 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 close, 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'.

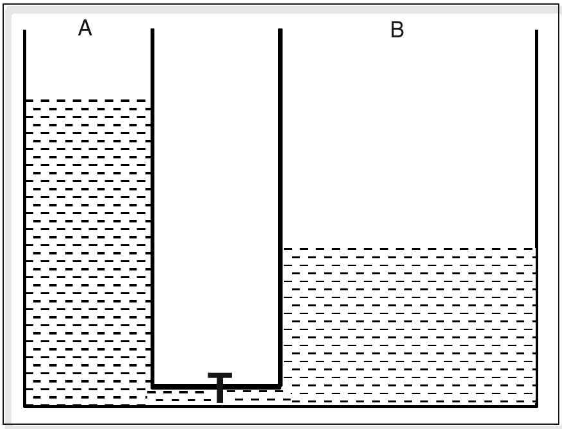


Figure 10.16

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 from the body at the higher potential to the body at the 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 $V_P = \frac{2\,C}{0.5\,F} = 4\,V$ and the potential of 'Q' is $V_Q = \frac{5\,C}{2\,F} = 2.5\,V$. 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 potential through a conducting material constitute 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 constitute 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 (figure 10.17 a). 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 (figure 10.17 b). 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

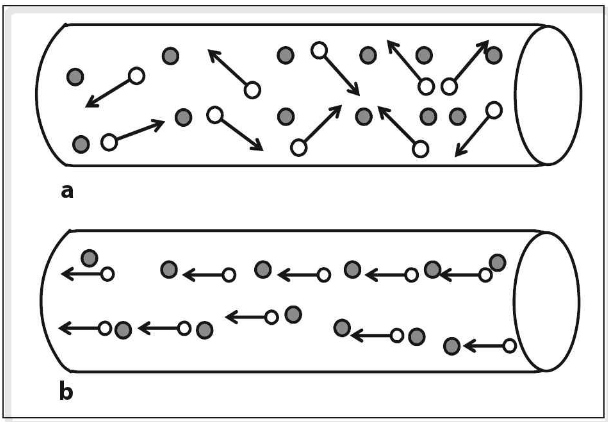


Figure 10.17 (a) Free electrons in a conducting wire (b) Conduction in a

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.

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.

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, $1\text{A} = 1\ \text{C s}^{-1}$. Hence one ampere is defined as the electric current established in a conductor when one coulomb charge flows through a given cross section of the conductor in one second.

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 milliseconds.

Solution

Given charge, q = 10 C

Time, t = 2 milli second = 2×10^{-3} s

$\therefore$ The electric current, $i = \frac{q}{t} = \frac{10\ \text{C}}{2\times10^{-3}\ \text{s}} = 5000\ \text{A}$

☛ *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 μs.

The charge of an electron, $e = 1.6 \times 10^{-19}$ C.

Solution

Given, i = 5 A, t = 1μs = 10^{-6} s

$$i = \frac{ne}{t}$$

$$\therefore\ n = \frac{it}{e} = \frac{5\times10^{-6}}{1.6\times10^{-19}} = 3.125\times10^{13}$$

Electric cell

It is obvious that the water flows from tank 'A' to tank 'B' in the example quoted earlier (refer to figure (10.16)) 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.

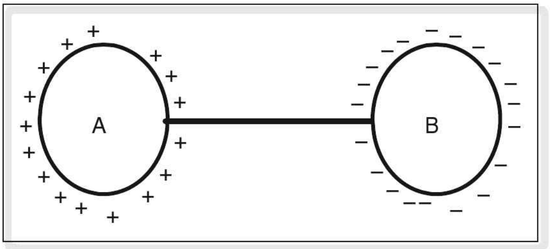


Figure 10.18

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 figure (10.18). 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 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.

Let us now consider the construction and working of a simple Voltaic cell. A Voltaic cell consists of a glass made of copper dipped in the acid in the beaker. These two plates or rods are called 'electrodes' and the sulphuric acid is called an 'electrolyte'.

At the zinc electrode, zinc atoms are converted into ions (Zn^{2+}) giving out two electrons to the conducting wire ($Zn \rightarrow Zn^{2+} + 2e^-$). Thus, zinc electrode is negatively charged and is called a cathode, and is at a lower potential. The dissociated positive hydrogen ions (H^+) from the sulphuric acid ($H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$) reach the copper electrode and absorb two electrons to form hydrogen gas that is evolved at the copper electrode ($2H^+ + 2e^- \rightarrow H_2\uparrow$). Since positive ions are accumulated on the copper electrode, it is called 'anode' and is at a higher potential.

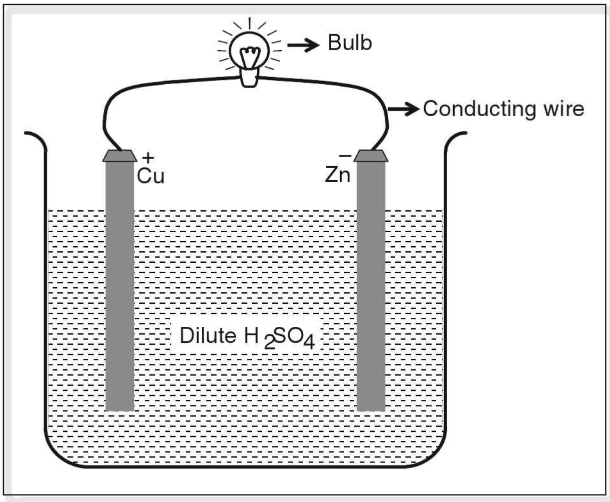


Figure 10.19 Voltaic cell

Thus, positive charges flow from 'anode' to 'cathode' in the external conducting wire and it is the conventional electric current. Electrons move from cathode to anode in the external conducting wire and it is the actual electronic current. So, as discussed earlier, the direction of conventional and electronic currents are opposite to each other. In driving the charges through the external conducting wire connected to the two terminals of the cell, work is done and so energy is spent at the cost of chemical energy of the cell. This energy spent by the cell in driving the charges through the external conducting wire is called 'electromotive force' or 'emf' and so the cell is also called an emf device. Emf is the energy spent in driving a unit positive charge through the external conducting wire connected across the terminals of the cell and thus it is measured in 'volt'.

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. Once the chemicals are used up, 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.

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.
Chemical reactions are irreversible.	Chemical reactions are reversible.
These cells cannot be recharged.	These cells can be recharged.
The large amount of current cannot be drawn from these cells.	These cells can be used to draw a large amount of current.
The restriction to the flow of charges through these	The restriction to the flow of charges through these

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).

$$\Rightarrow R \propto \ell \text{ or } \frac{R}{\ell} = \text{constant for a conductor.}$$

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),

$$R \propto \frac{1}{a} \text{ or } Ra = \text{constant for a conductor.}$$

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 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 considerable resistance is called a '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 figure 10.20(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 a series combination (figure 10.20(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 a parallel combination (figure 10.20(c)).

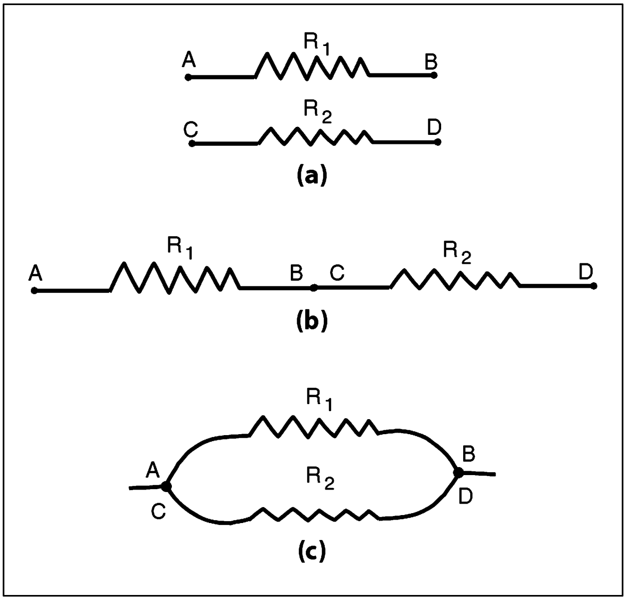


Figure 10.20 (b) Series combination (c) Parallel combination

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 $R_{net} = R_1 + R_2$. This is true for 'n' number of resistors connected in series combination. Thus, we have $R_{net} = R_1 + R_2 + R_3 + \ldots\ldots R_n$, where $R_1, R_2, R_3, \ldots, R_n$ 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 $\frac{1}{R_{net}} = \frac{1}{R_1} + \frac{1}{R_2}$. If there are 'n' number of resistors with different resistances connected in parallel, then we have

$$\frac{1}{R_{net}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$$

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.

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, $I \propto V$ 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.

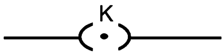
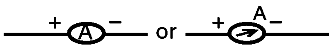
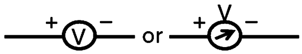
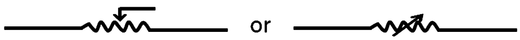
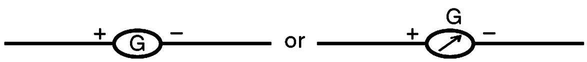
Thus, $R = \frac{V}{I}$.

So, $1 \text{ ohm}(W) = \frac{1 \text{ volt (V)}}{1 \text{ ampere(I)}}$.

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".

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.

A cell	
A battery	
Alternating current source	
Plug key	
Switch	
Tapping Key	
Conducting 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 (figure 10.21). 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 the ends of 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 figures 10.22 and 10.23 show an ammeter and a voltmeter connected in the circuit in open and closed conditions respectively.

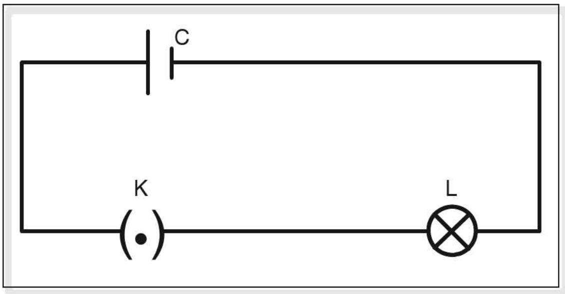


Figure 10.21 A Simple circuit

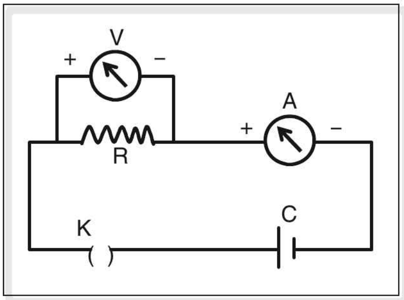


Figure 10.22 An open circuit

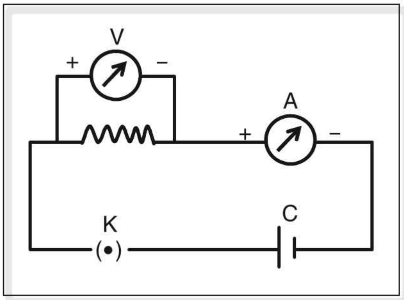


Figure 10.23 A Closed circuit

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 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 enter the circuit is called open circuit.

Electrical power

When 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

$q = It \qquad \left(\because I = \frac{q}{t}\right)$

$\therefore W = V \times I \times t$

$$\therefore\ P = \frac{W}{t} = \frac{V \times I \times t}{t}$$

$P = VI$

$$\therefore\ P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$$

☛ *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) = ?

$$P = \frac{E}{t} = \frac{2400}{60}$$

$\therefore\ P = 40\ W$

☛ *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 × 60 = 3600 s
Energy consumed (E) = ?

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

$\therefore\ E = Pt$

$E = 1000 \times 3600 \quad = 3600000\ J$

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.

Electrical energy = Power × 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)

As we have seen already

1kW h = 3·6 MJ = 1 unit

Example

Calculate the electrical energy consumed in units when a 60 W bulb is used for 10 hours

Solution

Electric power (P) = 60 W = $\frac{60}{1000}$ = 0·06 kW

time = (t) = 10 hrs

Electric energy = Pt

= 0·06 × 10 = 0·6 kW h = 0·6 unit

Example

Calculate the units of electricity consumed in the month of November for the following details. One 60 W bulb used for 5 hours daily

One 100 W bulb used for 3 hours daily.

One 1 kW electric heater used for 2 hour daily.

Also calculate the monthly bill at the rate of Rs 2·50 per unit.

Solution

Electric energy = electric power × time

E = Pt

1. Electric bulb

   E_b = 60 W × 5 h

   = 0·06 × 5 = 0·3 kW h bulb consumes 0·3 units daily

   There are 30 days in the month of November

   ∴ Energy consumed by the bulb for 30 days is 0·3 × 30 = 9 kW h or 9 units.

2. Electric bulb

   E = 100 W × 3 h

   = 0.1 × 3 = 0.3 kW h = 0.3 units daily

   For 30 days E_r = 0.3 × 30 = 9 kW h = 9 units.

3. Electric heater

   E_h = 1000 W × 2 h = 2 kW h = 2 units daily

   For 30 days, E_h = 2 × 30 = 60 units

   Total energy consumed in the month of November is $E_h + E_r + E_h$

   = 9 + 9 + 60 = 78 units

   The cost of electricity is Rs 2·50 per unit

Energy consumed is 78 units

$\therefore$ Monthly bill for November = 78 × 2·50 = Rs 195

☛ *Example*

An electric heater has a rating of 3 kW, 220 V. Calculate the following

1. current,
2. resistance offered by the heater and
3. cost of running the heater for 10 hours at the rate of Rs 3·50 per unit.

Solution

Given

Electric power (P) = 3 kW

= 3000 W

Potential difference (V) = 220 V

P = VI

where I = electric current

$$I = \frac{P}{V} = \frac{3000}{220} = 13.63\ \text{A}$$

$$\text{Electric resistance (R)} = \frac{V}{I}$$

$$= \frac{220}{13 \times 63} = 16.14\ \Omega$$

Electric energy (E) = Power × Time

= 3 kW× 10 h

= 30 kW h

= 30 units

$\therefore$ Cost of 30 units of energy = 30 × 3.50

= Rs 105

☛ *Example*

Calculate the resistance offered by 3 HP water pump which runs on 220 V supply.

Solution

Electric power (P) = 3 HP = 3 × 746 W

= 2238 W

P = VI

$$\therefore\ I = \frac{P}{V}$$

Substituting P = 2238 W, V = 220 V,

$$I = \frac{2238}{220} = 10.17\ \text{A}$$

Electric resistance (R)

$$= \frac{V}{I} = \frac{220}{10{\cdot}17} = 21{\cdot}63\ \Omega$$

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. 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 connected to zero potential. The earth wire is connected to the body of kW h meter 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 of high rating of about 50 A is installed in series with the live wire.

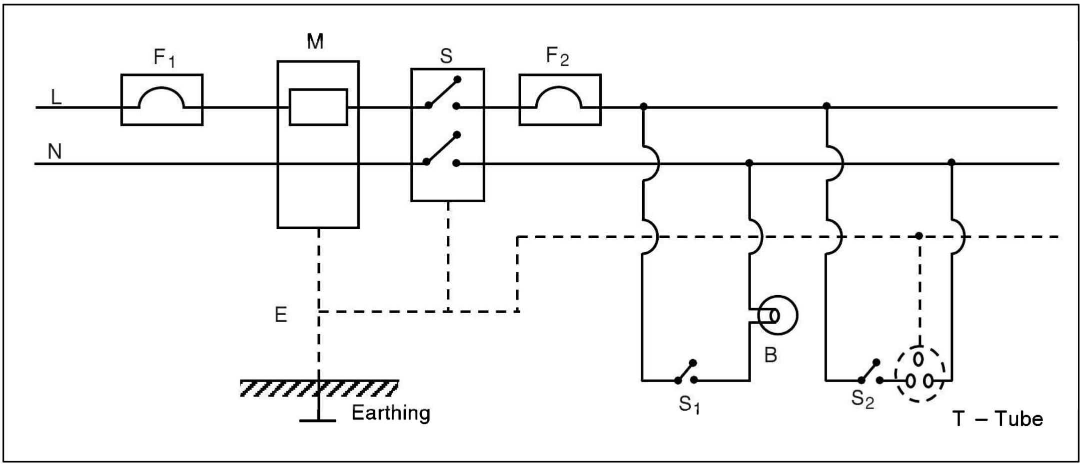


Figure 10.24 Domestic wiring

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. 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 it 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

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. The presence of electric current cannot be detected just by looking at a wire.
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 electric shock. This may prove fatal.
3. Electricity is one of the major cause 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 accidently 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 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 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. Explain 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 actual electric current.

37. Explain Biot's experiment.

38. Show that $1 \text{kW h} = 3 \cdot 6 \text{ MJ}$

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.

CONCEPT APPLICATION

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. Within the cell, conventional current flows from its negative to the positive terminal.
2. Only when an electric field is set up in a conductor, the electrons in it start moving.
3. The magnitude of the charge on 6250×10^{15} number of electrons is equal to 1 coulomb.
4. When a few billion electrons are added to the earth, its potential rises.
5. The charge supplied to a glass rod at one of its ends stays at the same place.
6. Two conductors of the same size, shape and material have the same capacitance.
7. 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.

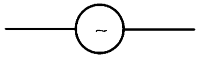
8. A body charged positively is considered to be at a _____ potential and a body that is charged negatively is considered to be at a _____ potential.
9. If 100 billion electrons are added to earth, then the potential of the earth _______.
10. _____ is defined as the rate at which the charges move across any cross section of a conductor.
11. The dimensional formula of capacitance is _____.
12. The purpose of _____ is to prevent electric shocks.
13. The obstruction offered to the passage of electric current by a material is called __________.
14. 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.

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.	$8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$	( )	e.	to transfer charge from a charged body

(Continued on the following page)

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 30: 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.
(1) 8 (2) 72 (3) 24 (4) 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 ______.
(1) 4 : 1 (2) 1 : 4 (3) 1 : 2 (4) 2 : 1

18. A gold leaf electroscope is used for
(1) measuring the charge present on charged bodies.
(2) detecting the current flowing between two charged bodies.
(3) measuring the potential of charged bodies.
(4) detecting the nature of the charge present on charged bodies.

19. A unit positive charge is moved along the circumference of a circle with a −100 C charge at the centre of the circle. Then the work done in the process is ________.
(1) negative work of 100 J (2) positive work of 100 J
(3) zero (4) $\dfrac{Q.1}{4\pi\in_0 .r}$

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 1.6×10^{-19} C)
(1) 1.6×10^{-19} (2) 1.25×10^{19} (3) 6.25×10^{8} (4) 3.2×10^{18}

21. The force of attraction between two charged bodies depends on
(1) the quantity of charge present on each charged body
(2) distance between the charged bodies
(3) the medium separating the charged bodies
(4) All the above

22. A device that measures current through a circuit is
(1) ammeter and is always connected parallel to the circuit
(2) ammeter and is always connected in series in the circuit

(3) voltmeter and is always connected parallel to the circuit
(4) 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 volts is ______ farad.

(1) 50 (2) 200 (3) 5×10^{-3} (4) 0.5

24. The resistance of a current carrying wire depends on

(1) the area of cross-section of the conducting wire.
(2) the length of conducting wire.
(3) the material of the wire.
(4) All the above factors

25. A dielectric is

(1) a bad conductor of electricity (2) a good conductor of electricity
(3) also called a capacitor (4) 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 ______.

(1) nR (2) $\frac{n}{R}$ (3) $\frac{R}{n}$ (4) $nR-\frac{n}{R}$

27. An electric device which converts mechanical energy into electrical energy is __________.

(1) a D.C. generator (2) an A.C. generator
(3) an electric cell (4) Both (1) and (2)

28. Two charged bodies with a distance 'd' between them are placed in water and then in air, then the new force between them ________. (dielectric constant of water is more than one)

(1) increases (2) decreases
(3) remains the same (4) first decreases then increases

29. On increasing the number of resistances connected in series, the total resistance of the series combination _________

(1) increases (2) decreases (3) remains the same (4) 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 ________.

(1) is doubled (2) is quadrupled
(3) becomes half (4) decreases to $\frac{1}{4}$th of their original force

Concept Application Level—2

31. 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 J $kg^{-1}K^{-1}$.

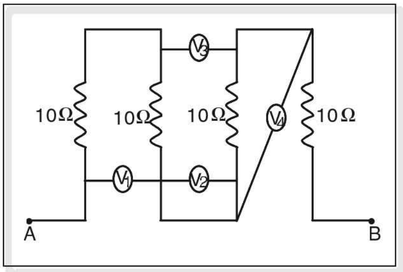
32. A circle is constructed of a uniform wire of resistance of 2 ohm per cm and is connected in a circuit such that it offers maximum resistance. Find the maximum resistance. (Take radius of the circle as 7 cm).

33. 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.

34. A potential difference of 300 V is maintained between the two plates of a parallel plate capacitor with air between the plates. The potential difference between the plates decreases to 100 V when a block of mica is inserted between the plates. Find the dielectric constant of mica, assuming that the space between the plates is completely filled by mica.

35. 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 height of 10 m, find the quantity of water lifted by the pump (take $g = 10\ m\ s^{-2}$).

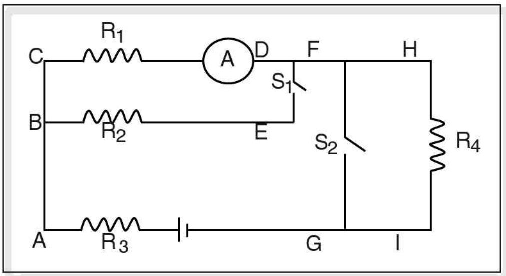
36. In the following diagram, if the P.D. across AB is 10V what is the reading shown by V_2? How are the readings of V_1 and V_3 related? Between V_1 and V_4, which reading is higher? Explain your answer.



37. Two α particles are separated by a distance of 4 fermi (in air). Find the coloumb force between the α particles.

38. An electric current of 8 A is made to flow through a room heater of resistance 30 Ω. Calculate
(1) the PD across the heater.
(2) the power supplied to the heater.
(3) the amount of heat energy liberated from it in one minute.
(4) if heater is used for 10 hours daily in the month of December then find the number of units consumed by it.

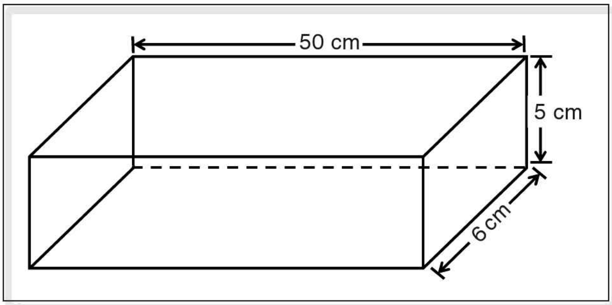
39. The resistors R_1, R_2, R_3 and R_4 are connected as shown in the figure. S_1 and S_2 are two switches. Discuss the flow of current through the resistors when
(1) S_1 and S_2 both are closed.
(2) S_1 and S_2 both are open.
(3) S_1 is closed and S_2 is open.



40. Two wires of equal length and diameter, one made of copper and the other 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.

41. Calculate the excess number of electrons that must be placed on each of two similar uncharged spheres that are located 5 cm apart (in air), such that the force of repulsion between them is 36×10^{-19}N.

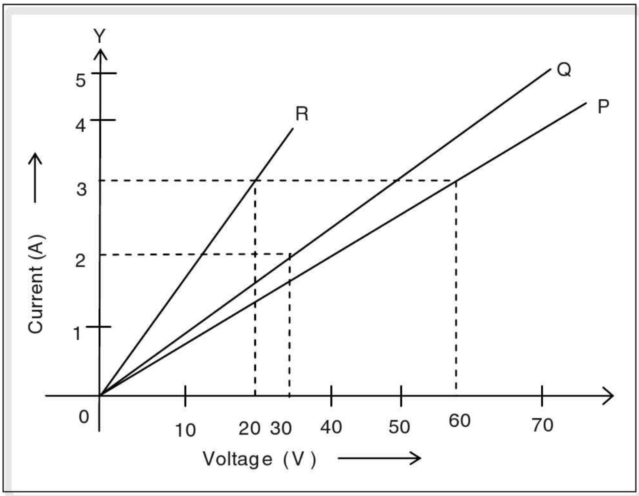
42. For the block shown in the figure below, find the ratio of maximum to minimum resistance, that the block can offer when connected in a circuit.



43. 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 5V find the number of electrons that pass across the conductor in one second. (The charge on an electron is 1.6×10^{-19} C).

44. 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 μC, find the charge present on each body.

45. The graph of current versus voltage drop across the three resistors P, Q, R is as shown above. Find the ratio of their resistances.



Concept Application Level—3

46. Two conducting wires A and B made of same material of lengths 1 m, 2 m and area of cross sections 1 cm^2, 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 5 Ω, then find the resistance of the new wire of length 5 m formed by melting A and B.

47. Two conducting spheres are charged individually to potentials 160 V and 50 V respectively. Then they are connected in such a way that the total charge of the combination is the sum of the individual charges with common voltage across the capacitors being 140 V. Find the ratio of their capacitances.

48. The metallic bob of a simple pendulum of mass 0.5 kg carries a positive charge of $\frac{1}{4}$ C. If the pendulum is suspended in an electric field of strength 15 N C^{-1} directed from east to west, analyse the forces acting on the bob and derive the condition for equilibrium and also the angle subtended at the equilibrium. (Take, g = 10 m s^{-2})

49. 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 PD between A and B is 1 volt, find the gain in KE of the electron.

50. A charge "Q" is divided into two parts 'A' and 'B' and the two parts are separated by a certain distance (is constant). Find for what charges on A and B would the force between them is maximum and comment when the force is minimum.

key points for selected questions

Very short answer type questions

1. Capacitance of a conductor is defined as the ratio of charge on a conductor to its potential.
2. The opposition to electric current through a conductor is called "electric resistance".
3. SI unit of capacitance is 'farad'. One farad is the capacitance of a conductor, whose potential increases by one volt on addition of one coulomb of charge to it.
4. Live or phase wire is connected to high potential. Neutral wire is connected to zero potential.
5. 1.6×10^{-19} C
6. The substances which have fairly large number of free electrons which can be made to drift rapidly are called electric conductors.
   Ex: All metals, graphite, 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 of electricity
   Ex: All gases, glass, etc.
7. electromotive force or emf.
8. When electrons are gained.
9. Potential difference between two points in an electric field is defined as the work done in moving a unit positive charge from one point to other.

key points for selected questions

10. In an electric circuit, resistors can be combined in two different ways.
   (i) Series combination
   (ii) Parallel combination

11. Branch of electricity which deals with study of charges at rest.

12. When current flows, work is done in moving charges across the circuit against the resistance offered by the circuit. This is the electrical energy. SI unit of electrical energy is Joule. Watt-hour, kilowatt hour are useful units of electrical energy.
   Rate at which electrical energy is utilized is called electrical power.
   $$\text{Electrical power} = \frac{\text{electircal work}}{\text{time}}$$
   SI unit is watt

13. repulsion

14. Charge present on a body is always an integral multiple of the charge of an electron.
   $q = ne$, n = integer,
   e = charge of an electron.

15. The arrangement of all the electrical components and their connections is called an electric circuit.

16. Live wire – Red colour
   Neutral wire – Black
   Earth wire – Green

17. An instrument used to detect and also to find the nature of charge on a body.

18. Electric current is defined as the rate at which electric charge move across a given cross-section.
   $i = q/t$.

19. Kilo watt hour

20. The process of inducing charge on a body by bringing another charged body near to it.

21. good conductors

22. Conventionally, the direction in which positive charge carriers move is treated as direction of conventional current for a conductor the charge carriers are electrons which are negatively charged particles. Actual electric current consists of flow of electrons in a conductor.

23. The streak of light due to electric discharge among charged clouds.

24. The region surrounding a charged body where its effect is felt by another charged body is known as an "electric field".

25. Electric cell is a device that provides 'emf' in the circuit by shifting charge carriers (if negative) from lower potential to higher potential by consuming chemical energy.

26. The strength of the electric current through a conductor is directly proportional to the potential difference across its ends.
   $I \propto V$.

27. The electrostatic force between two charged 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.
   $F \propto q_1 q_2$ and $F \propto 1/r^2$

28. decreases

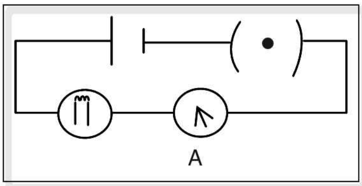
29. When current is not draw from a cell, the potential difference that exists between the terminals of the cell is called emf of the cell.

30. Electric potential at a point in electric field is defined as the work done on unit positive charge to move it from infinite distance to that point.

Short answer type questions

31. Silk kite, silk thread, iron key, flying kite on a raining day.

32.



33. Lightning conductors are conducting rods with pointed tips provided at the top of buildings and connected to a copper plate buried in earth at the basement of the building. When clouds pass near by, they induce high charge densities on the conducting rod, which helps the lightning to strike the lightning rod.

34. A body acquires charge either by losing electrons or by gaining electrons. As such the amount of charge on a body is always expressed as an integral multiple of the charge on an electron
$q = ne$, n – integer
e – charge on an electron

35. Measured in units
1 unit = 1 kilowatt hour

36. Electric current due to the motion of positive charge is treated as conventional electric current. Electric current due to the motion of electrons in treated as actual electric current.

37. Metallic sphere, insulated stand, two metallic hemispherical shells with insulate handles; supply of charge to the sphere.

38. 1 kilowatt hour
= 1000 × 60 × 60 Joules
= 3.6×10^6 Joules
= 3.6 MJ

39. Glass trough, sulphuric acid, Zn and Cu plates, connecting wires, a small bulb.

40. Charged glass rod, uncharged copper sphere. place them close to each other, charge is induced in uncharged copper sphere. When other side of the copper sphere is connected to the ground, there will be net charge left on copper sphere.

41. Electric resistance of a conductor depends on
(i) length of the conductor,
(ii) cross-sectional area of the conductor and
(iii) nature of the material.

42. Electric power

$$= \frac{W}{t} = V \times I = I^2 R = \frac{V^2}{R}$$

43. Pith ball electroscope consists of a pith ball suspended from a copper hook by means of a silk thread.
Charged pith ball can be used to identify the presence of charge on a body and also the nature of the charge.

44. In primary cell, chemical are used up in transforming chemical energy into electrical energy and the original composition of the chemicals is not retained.

45. A proof plane consists of a brass disc with an insulated handle at its centre. Proof plane gets charged when it is brought into contact with charge body. Charged proof plane can be brought near a gold left electroscope to detect the charge on its surface.

Essay type questions

46. Fit a cat's skin cap over an ebonite rod. Rub the rod with the cap so that both are charged. When we verify for charge on both cat's skin and ebonite, the total charge is proved as zero. By removing ebonite rod from cat's skin and check for the presence of charge on either bodies, it is proved that both got oppositely charged and the magnitudes of charge on both are equal.

47. (i) Presence of electric current cannot be detected just by looking at a wire.
(ii) If any one comes in contact with live wire, it may prove fatal.
(iii) Fire outbreak may occur due to short-circuit.
(iv) Damaged electric appliance may cause fire accidents.

48. Gold leaf electroscope consists of a glass jar, brass cap, brass rod, shellac seal, gold leaf tin foil. Initially is given some known charge. When a body is brought in contact to the brass cap, depending on the increase or decrease of divergence of gold leaf, we can detect and also identify the nature of the charge on the body.

key points for selected questions

49. (i) Three insulated thick copper wires

L – live wire, N – neutral wire E – earth wire.

(ii) Fuse wire of high rating is installed in series with the live wire before the live and neutral wires enter the kWh meter.

(iii) Two different circuits – lighting circuit and heating circuit each with separate fuse wire of rating 5 A and 15 A.

(iv) Colour coding-live wire – Red colour
Neutral – Black
Earth – green

(v) Earth wire to conduct leakage current.

(vi) All appliance are connected in parallel across the live wire.

50. (i) Two charges – positive and negative.

(ii) Charge is conserved.

(iii) Charge is quantized.

(iv) Net charge always reside on the outer surface of a conductor.

(v) Charge density is more on the surface of a conductor at parts of higher curvature.

KEY

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. $[M^{-1}L^{-2}T^{4}A^{2}]$
12. earthing
13. resistance.
14. $[M^{1}L^{2}T^{-3}A^{-1}]$

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. Choice (1)
17. Choice (1)
18. Choice (4)
19. Choice (3)
20. Choice (2)
21. Choice (4)
22. Choice (2)

23. Choice (3)

24. Choice (4)

25. Choice (1)

26. Choice (3)

27. Choice (4)

28. Choice (1)

29. Choice (1)

30. Choice (2)

Concept Application Level—2,3

Key points for select questions

31. (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 $Q = ms\Delta\partial$.

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

32. (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 resistnace.

(iv) $\frac{1}{R_{effective}} = \frac{1}{R_1} + \frac{1}{R_2}$

(v) Take $R_1 = R_2 = (2 \text{ ohm cm}^{-1}) \times \frac{44 \text{ cm}}{2}$

(vi) Find R_{eff} from (2).

(vii) 22 Ω

33. (i) Given the force of attraction between two point charges q_1 and q_2 is $= F_1$

$$= \frac{1}{4\pi k \in_0} \frac{q_1 q_2}{d^2} = 1000 \text{ N}$$

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

$$= F_2 = \frac{1}{4\pi k \in_0} \frac{\frac{125}{100} q_1 \frac{75}{100} q_2}{\left(\frac{75}{100} d\right)^2}$$

Find the value of F_2 in terms of F_1 and get the value in newtons.

(ii) 1666.67 N

34. (i) $q = CV = C_1 V_1$

(ii) 3

35. (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

36. 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.

37. (i) An α particle consists of two protons and two neutrons.

Determine the charge of each α particle as
$q = n \times \overline{e}$
where n is the number of protons and $\overline{e}$ 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

38. (i) 1. V = iR

2. P = V × I

3. Q = V × i × t

4. Q = P × t

5. 1 kW h = 1 unit

(ii) 240 V; 1.92 kW; 115.2 kJ; 595.2 units

39. 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.

40. 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?

41. (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 $\frac{1}{4\pi}$ determines the value of q_1 q_2.

But $q_1 = q_2 = ne$
Where n is the number of electrons and $\overline{e}$ is the charge on each electron.
($\overline{e} = 1.602 \times 10^{-19}$C)
Find out the value of n from the above relation.

(ii) n = 6250

42. (i) Recall the laws of resistance

$R \propto l$

$R \propto \frac{1}{A}$

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.

(ii) $\frac{R_{max}}{R_{min}} = \frac{100}{1}$

43. (i) Use the formula, P.D, $V = \frac{W}{q}$

$V = \frac{KE}{ne}$ (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) 4×10^4 electrons

44. (i) Let q_1, q_2 be the charge of each particle.
$q_1 + q_2 = 30\ \mu C$.

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.
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) $q_1 = 10 \times 10^{-6}$ C; $q_2 = 20 \times 10^{-6}$ C
$q_1 = 20 \times 10^{-6}$ C; $q_2 = 10 \times 10^{-6}$ C

45. (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.

$$R_P = \frac{V_R}{i_R}$$

$$R_Q = \frac{V_R}{i_R}$$

$$R_R = \frac{V_R}{i_R}$$

Find the ratio of $R_P : R_Q : R_R$

(ii) $R_P : R_Q : R_R = 20:15:\frac{20}{3}$ (or) $12 : 9 : 4$

46. (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.

47. (i) When the spheres are connected in parallel, the total charge is the sum of the charges of the individual spheres, i.e., $Q = Q_1 + Q_2$.

The effective capacitance in parallel combination is $C = C_1 + C_2$.
But $C = QV$,
$C_1 = Q_1V_1$
$C_2 = Q_2V_2$
(ii) $C_1 : C_2 = 9 : 2$

48. (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) $\theta = \tan^{-1} (0.75)$

49. (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.

Electric potential $V = \frac{w}{q}$

where w is the work done.
q is the charge on the electron.
(ii) $1.6 \times 10^{-19}5$

50. (i) $F = \frac{1}{4\pi\epsilon_0 k} \frac{Q_1Q_2}{d^2}$

Then, $\frac{1}{4\pi\epsilon_0 k} \frac{1}{d^2}$ are constant.

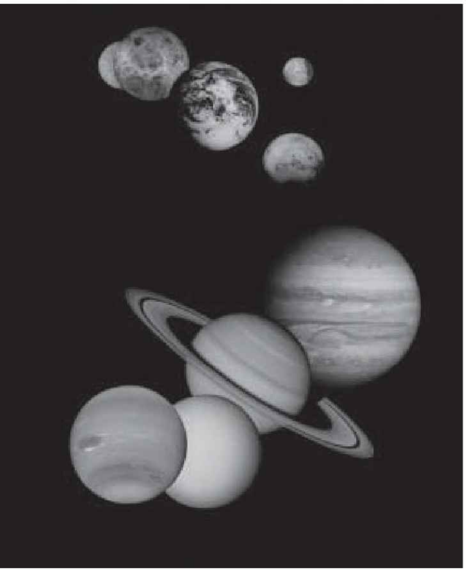
$\Rightarrow F \propto Q_1 . Q_2$

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.



11

Magnetism

NTRODUCTION

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 bar magnet which has two magnetic poles (N pole and S pole) of equal magnetic strength. The line joining the North Pole and the South Pole of the bar magnet is known as magnetic axis. The line perpendicular to the axis and passing through the centre of the axis is termed as equatorial line. The magnetic poles cannot be isolated, i.e., single poles do not exist.

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. The magnetic force of attraction is maximum in small regions near the ends of the magnet. These are called the 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 pair. All magnets have a north and 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. E.g.,- 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 varying 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 rectangular bar.

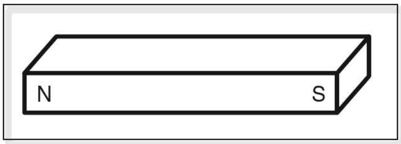


Figure 11.1 Bar magnet

2. **Magnetic needle**

   It is a magnet tapered towards both ends and pivoted at the centre. It is used to check the direction of a magnetic field and to map the lines of force of other magnets.

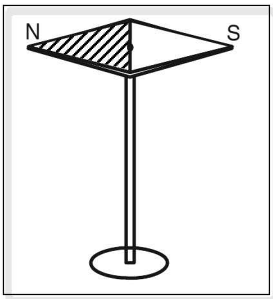


Figure 11.2 Magnetic needle

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.

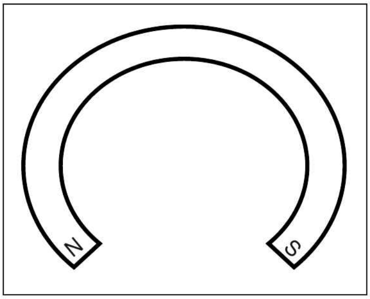


Figure 11.3 Horse-shoe magnet

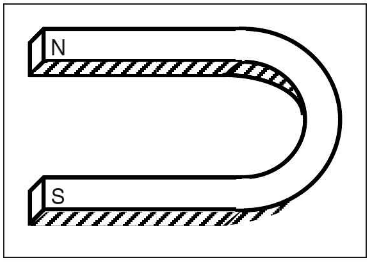


Figure 11.4 Horse-shoe magnet

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 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.

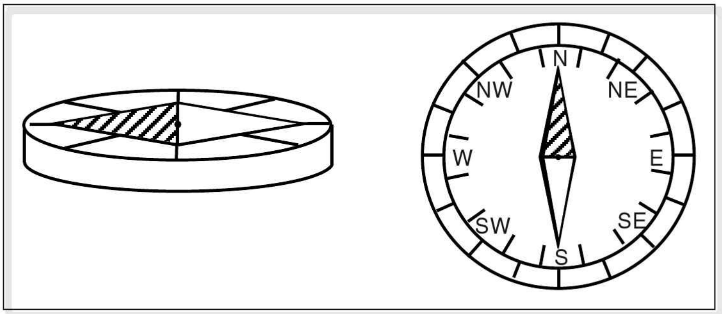


Figure 11.5 Magnetic compass

Bar magnet

Given below are few important terms associated with a bar magnet.

(i) The geometric ends (A and B) of a bar magnet are called its **geometric poles.**

(ii) The property of a magnet to attract small pieces of iron seems to be 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.

(iii) 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.

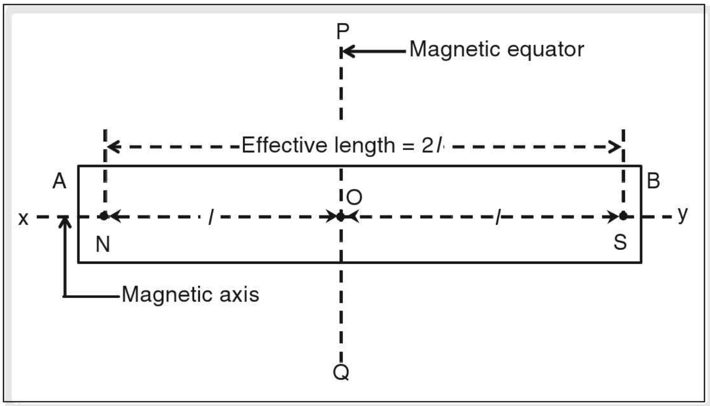


Figure 11.6 Bar Magnet

(iv) The line joining the north pole and the south pole of a magnet is called the **axis of the magnet.**

(v) The distance (ℓ) between any one of the magnetic poles and the centre of the magnet is called the **length of the magnet.**

(vi) The distance between the north pole and the south pole of the magnet is called the **effective length** of the magnet. This is slightly less than the physical length of the magnet and is taken to be equal to 2ℓ.

(vii) The product of the pole strength and the length of the magnet is called the **magnetic moment.**

(viii) A vertical plane passing through the magnetic axis of a freely suspended magnet is called its **magnetic meridian.**

(ix) An imaginary line passing through the centre of the magnet and perpendicular to the magnetic axis is called the **magnetic equator.**

(x) 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.

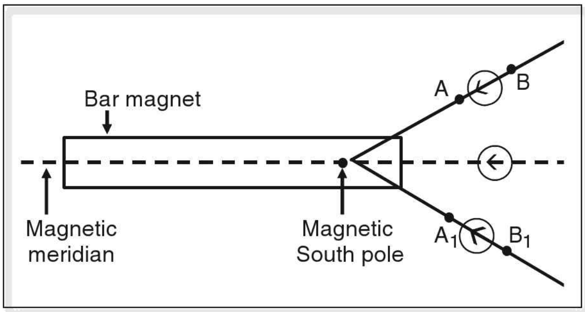


Figure 11.7

Remove the needle and place a bar magnet axially on the line. Trace its outline and 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.

(i) Single touch method

(a) Keep the steel bar to be magnetized on a wooden table.

(b) 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 figure.

(c) Once reached the other end, lift the magnet gently away from the steel bar and again bring it to the starting end.

(d) Repeat this process several times.

(e) Now the steel bar will be magnetized with the starting end as the north pole and the other end as the south pole.

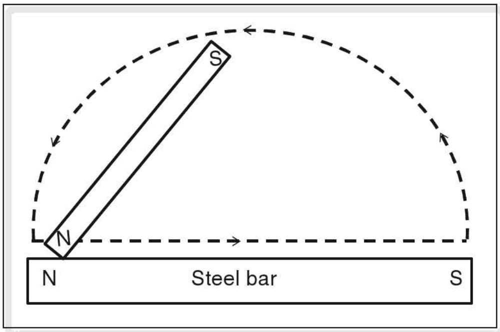


Figure 11.8

(f) 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.

(ii) Divided double touch method

(a) Keep the steel bar to be magnetized (as shown in the figure) on the top of two permanent magnets.

(b) Bring two permanent magnets with opposite poles and touch the middle of the steel bar and rub and move as shown in the figure.

(c) Repeat this several times.

(d) The end of the steel bar at which south pole of the magnet leaves become the north pole. The end of the steel bar at which the north pole of the magnet leaves becomes the south pole.

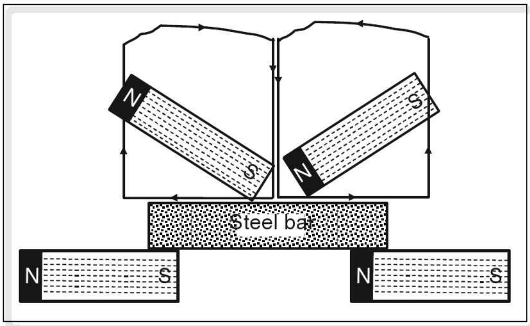


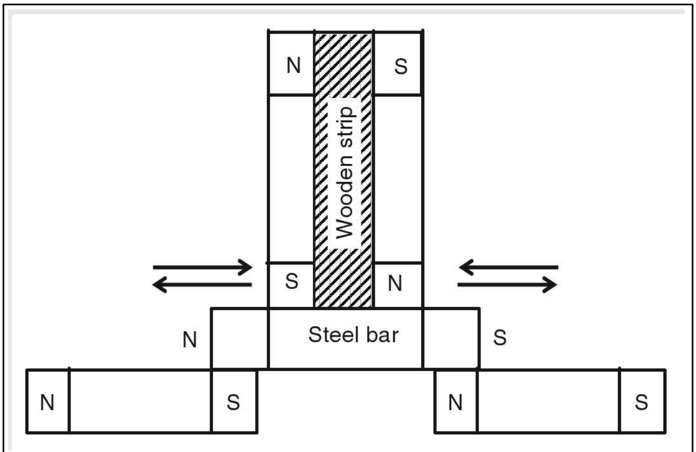
Figure 11.9

(iii) Double touch method

(a) Two permanent magnets separated by a piece of wood or cork are held together such that their opposite poles are together.

(b) This combination is placed on a piece of soft iron or steel in the centre and moved to and fro form one end to the other end without lifting.

(c) The polarities of the magnetised bar is



(d) For better and stronger magnetisation, the piece to be magnetised may be placed over two permanent magnets as shown.

(iv) Electrical method

(a) Keep the steel bar to be magnetized inside a long coil of insulated copper wire.

(b) Pass strong direct current through the coil for some time.

(c) The specimen of the steel bar will get magnetized.

(d) The end at which current enters in an anticlockwise direction will become the north pole and the other end becomes the south pole.

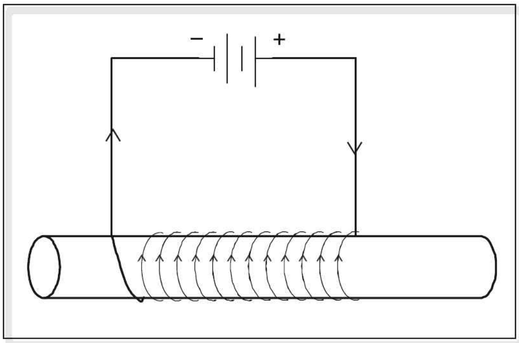


Figure 11.11

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. This type of magnet is known as 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:

(i) By rough handling

(ii) Heating the magnet and allowing it to cool while it is lying in east–west direction

(iii) By passing high frequency electric current

(iv) A magnet may lose its magnetism by self-induction.

1. **Electrical method:** If alternating current of a high frequency is passed through an insulated copper wire wound over a magnet, 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.

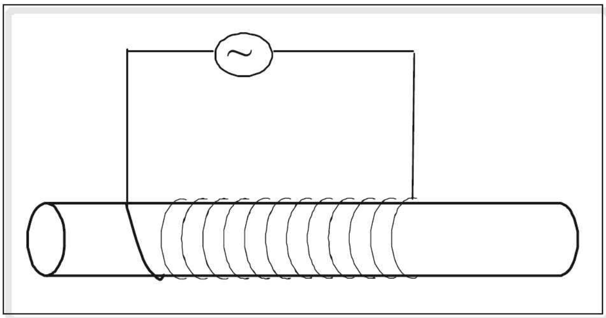


Figure 11.12

2. **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.

5. **By self induction:** A single magnet left on its own also loses magnetism due to induction between its molecules. Thus it is called self induction.

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). Place a bar of soft iron between the two as shown in figure (11.14).

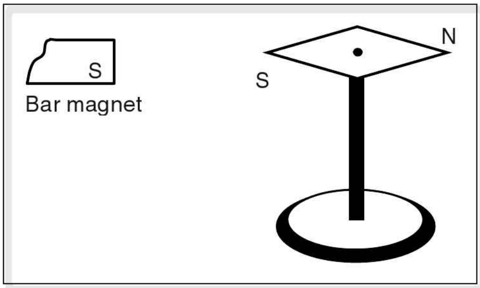


Figure 11.13

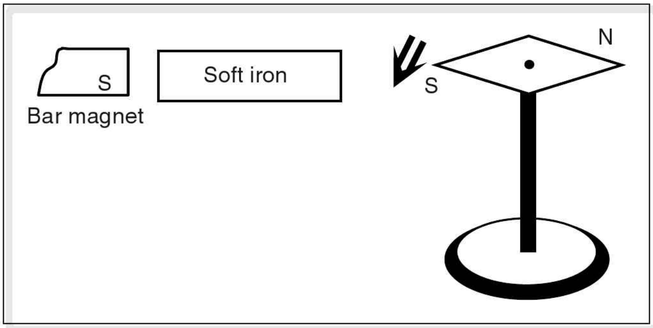


Figure 11.14

Then the south pole of the needle gets deflected again. Remove either the soft iron bar or 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.

(i) **Ferromagnetic substances:** The substances which are strongly attracted by a magnet are called ferromagnetic substances. These substances can be easily magnetised to make strong magnets.
E.g., (a) iron, nickel and cobalt
(b) alloys like steel and alnico (Al + Ni + Co + Fe)

(ii) **Paramagnetic substances:** The substances which are feebly attracted by a magnet are called paramagnetic substances.
E.g.,- aluminium, manganese, zinc and platinum

(iii) **Diamagnetic substances:** The substances which are feebly repelled by a magnet are called diamagnetic substances.
E.g.,- bismuth, copper, antimony and water.

Ewing's molecular theory of magnetism

If we break a bar magnet, each of the pieces formed act 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 magnetised substances (fig 11.15(b)) 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. 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 neutralise the magnetic effect of each other.

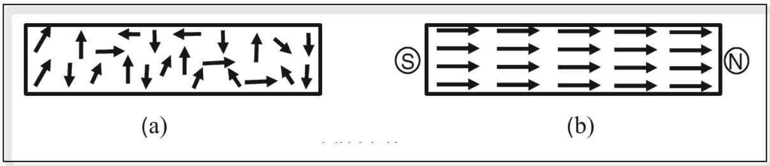


Figure 11.15

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 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 a 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 the 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 a **line of force.** Hence, the magnetic lines of force act as pictorial representation of a magnetic field.

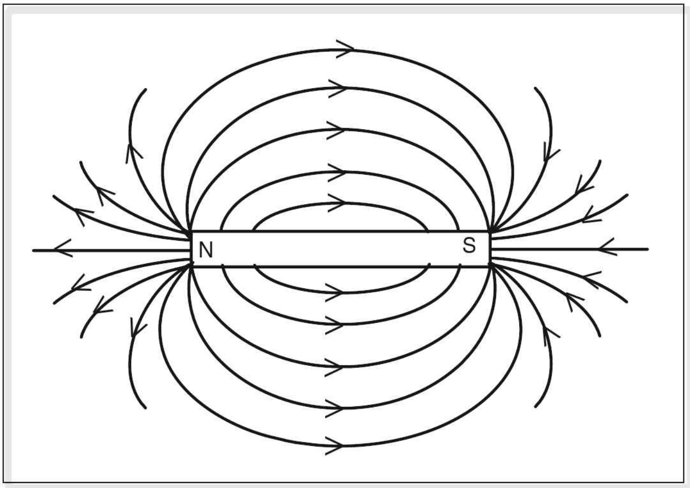


Figure 11.16

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 of which 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 uniformly over the cardboard, now slightly tap the board. 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.

(a) Pattern formed by single bar magnet

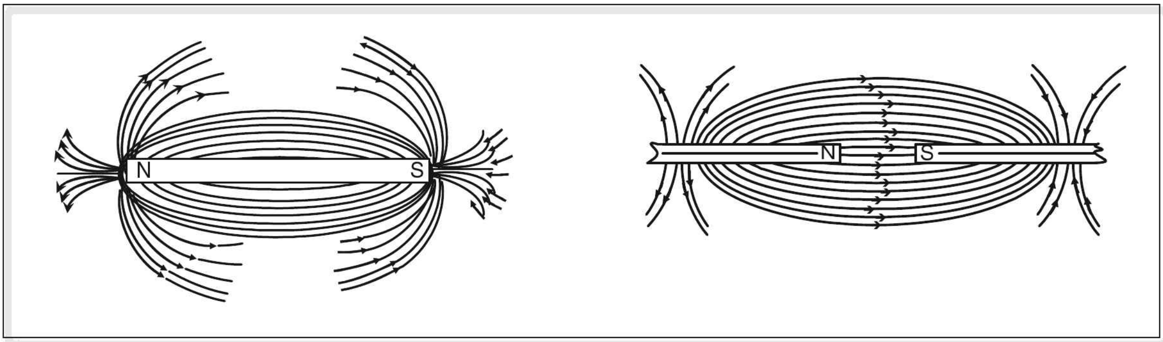


Figure 11.17

(c) Pattern formed by two bar magnets with similar poles facing each other.

(d) Pattern formed by a horse-shoe magnet

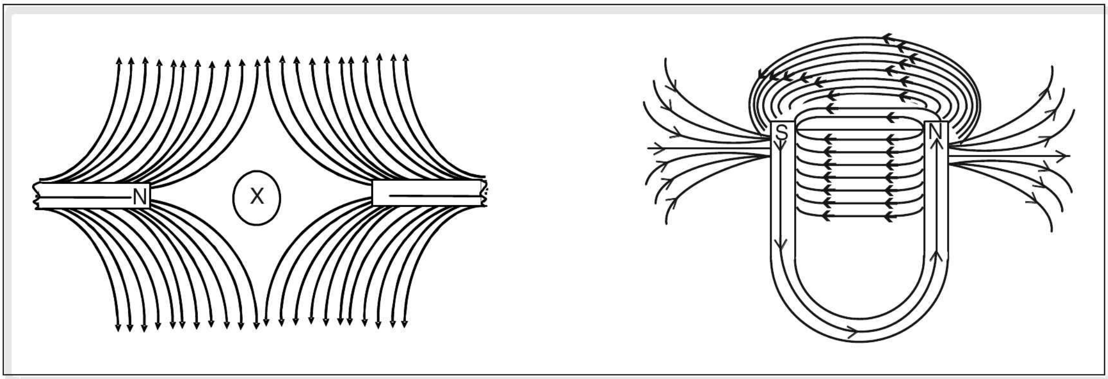
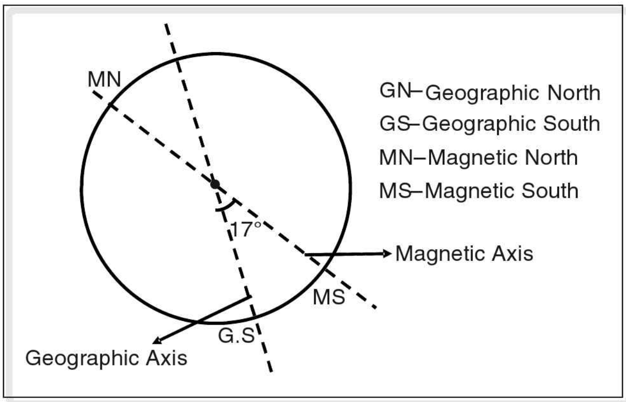


Figure 11.18 Patterns of magnetic field lines

A neutral point (X) is obtained between the two like poles.

The space between two opposing magnetic fields, where the resulting magnetic effect is zero is called a 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 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

(i) 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.

In the figure (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 and the 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.

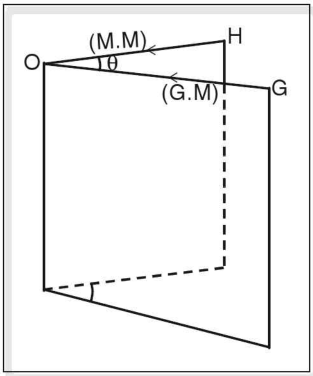
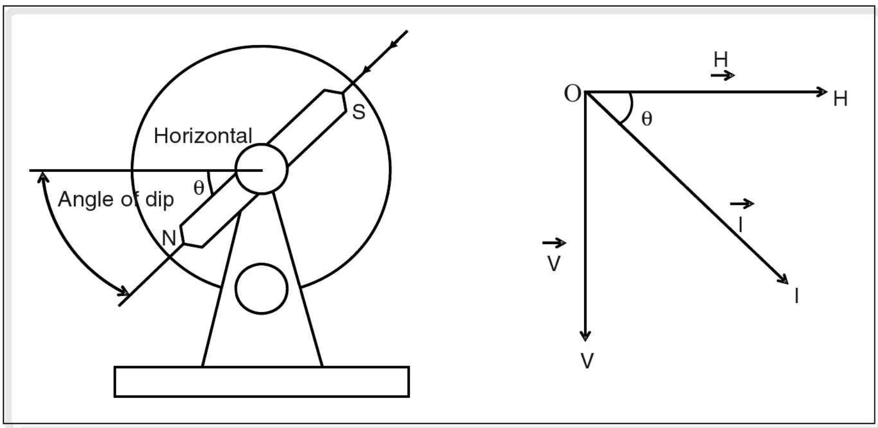


Figure 11.20

(ii) 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 the angle of dip.



Angle of dip can also be

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.

(a) The angle of dip is zero at the magnetic equator and 90° at the magnetic poles.

(b) The angle of dip increases as the magnetic needle is moved towards the north or the south pole.

(c) In the northern hemisphere the north pole of the magnetic needle dips whereas in the southern hemisphere, its south pole dips.

(d) Dip at a place is determined by an instrument called dip circle.

(iii) Horizontal component (I) of the earth's magnetic field

As shown in the figure below, 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 α is the angle of dip.

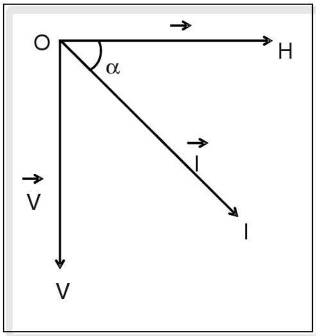


Figure 11.22

From the figure,

$H = I\cos\alpha$ --- (i)

$V = I\sin\alpha$ --- (ii)

Dividing (ii) by (i), we get

$$\tan\alpha = \frac{V}{H} \quad \text{---(iii)}$$

Squaring and adding equations (i) and (ii) give

$I^2 = H^2 + V^2$ --- (iv)

At the 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

(i) Isoclinic line is a line joining all the places on the globe having the same angle of dip or inclination is called isoclinic line.

(ii) A clinic line or magnetic equator is a line joining all the places having zero angle of dip or inclination.

(iii) Isogonic line is a line which joins all the places on the earth having the same angle of declination.

Magnetic field due to a bar magnet in the earth's magnetic field

(i) **South pole pointing towards geographical north**
Place a bar magnet on a white paper 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 (figure 11.23).

At the null point, denoted by X in the figure, the field due to the bar magnet is equal and opposite to the field due to earth.

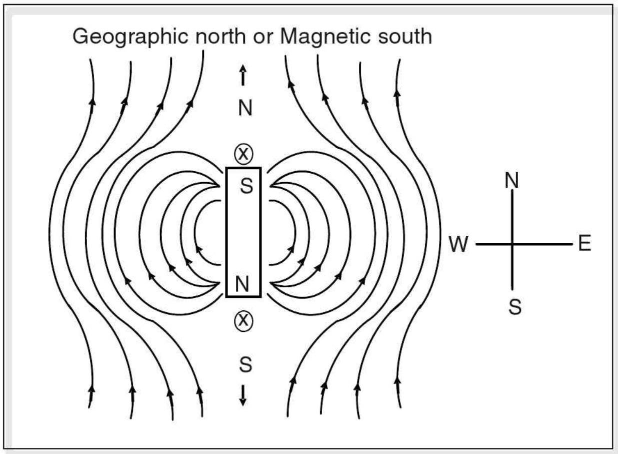
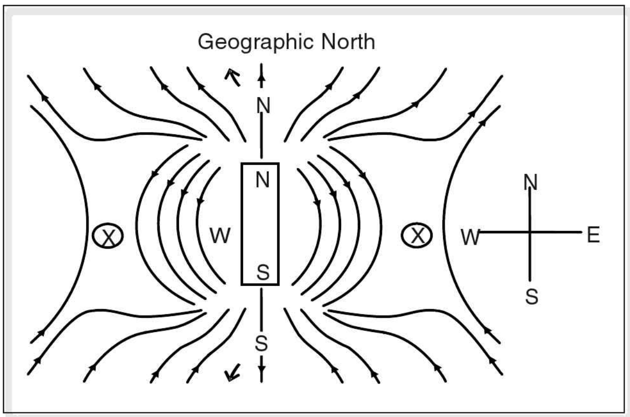


Figure 11.23 Magnetic north or Geographic south

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 null points denoted by X are obtained on the equatorial line (figure 11.24).



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 electric current, i.e., a stream of electrons, create magnetic field surrounding them. Since magnetic field is a vector quantity, it has both magnitude and direction. 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.

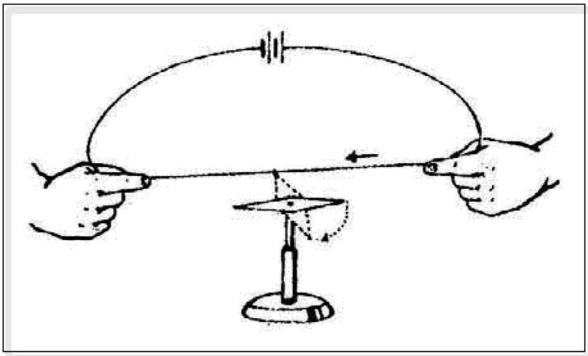


Figure 11.25

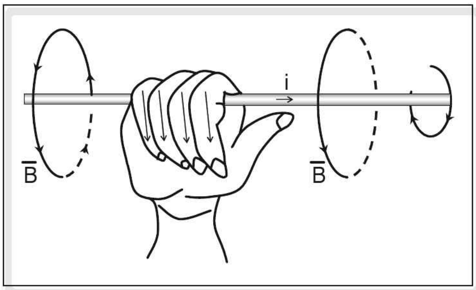
As the current is increased, the deflection in the needle also increases. If the direction of the current is reversed, the north pole of the needle deflects to the east. If the needle is kept above the copper wire, the needle deflects in directions opposite to that in above two cases. This experiment 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

Hold a linear object like a wire or a rod as a grip in your right hand. If the direction of pointing a 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.



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. Make a small hole at its centre so as to allow an insulated wire 'PQ' to pass through the hole; such that the length of the wire is perpendicular to the plane of the cardboard figure (11.27). Connect the wire to a plug key and a cell as shown in figure (11.27).

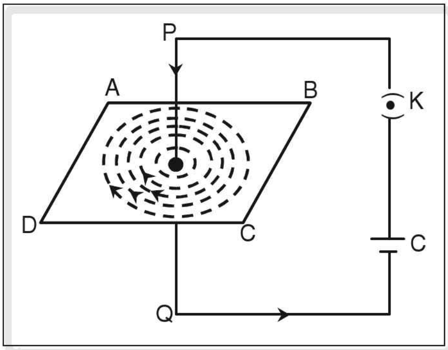


Figure 11.27

Sprinkle some iron filings on the cardboard, and insert the plug in the key to give electric connection to the conductor PQ. We observe that the iron filings are arranged in concentric circles with the centre at the hole on the cardboard as shown in figure (11.28). The concentric circles indicate the direction of magnetic field around the current carrying conductor.

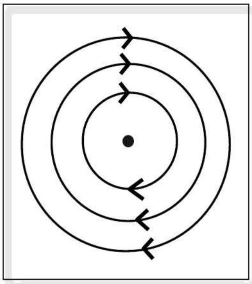


Figure 11.28

Magnetic field around a circular conductor

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 figure (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.

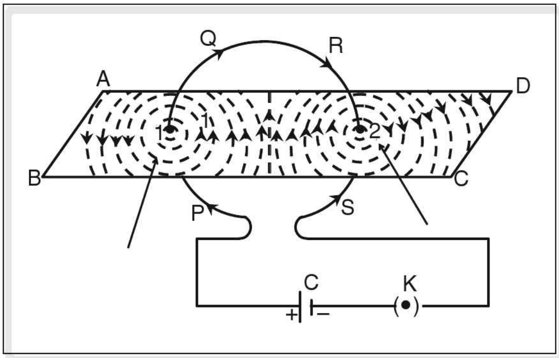


Figure 11.29

Galvanoscope

We have seen the nature of the magnetic field due to circular coil carrying 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 figure (11.30). Inside the box, a small magnetic needle is pivoted which rotates in a horizontal plane.

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.

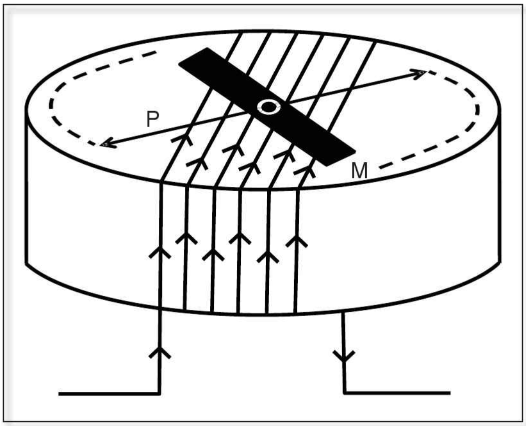


Figure 11.30 Galvanoscope
M – Magnetic needle P – Pointer

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.

Ammeter and galvanometer are devices used to measure 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 electromotive force (emf) of an electric cell.

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 figure (11.31), the current is in anticlockwise 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 in the core of the solenoid, the magnetic field intensity increases. Such an arrangement is called an electromagnet.

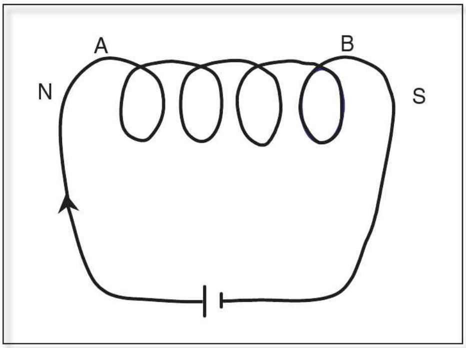


Figure 11.31 Solenoid

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 falls down.

An electric bell

The circuit diagram of an electric bell is as shown in figure (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.

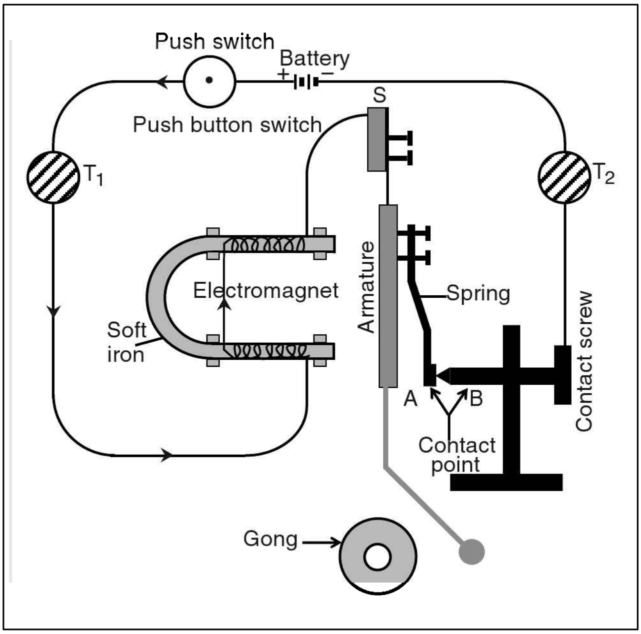


Figure 11.32 An electric bell

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 and placed near the switch which has to be controlled. When the relay is switched on, the electromagnet is magnetized and attracts the switch 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.

An electromagnetic relay which itself works on low voltage is used to control electric circuit operating at high voltage.

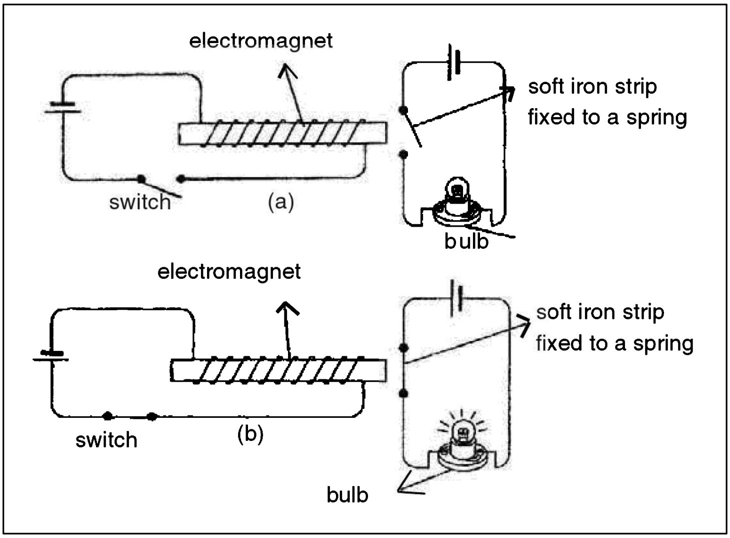


Figure 11.33

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.

The car key itself acts as a switch. When it is on, current flows through an electromagnet. The soft iron core attached to a spring 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 thick and short wire.

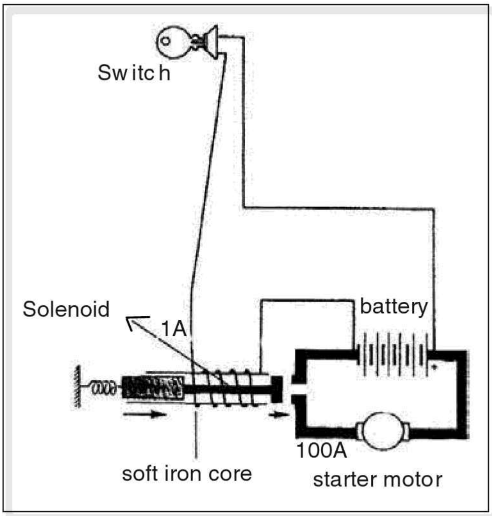


Figure 11.34

test your concepts

Very short answer type questions

1. Define: (1) magnetic field (2) magnetic field lines.
2. State Maxwell's right hand grip rule.
3. The line which joins all the places having zero angle of declination is called an ________.
4. Define: (1) ferromagnetic (2) paramagnetic (3) diamagnetic substances.
5. Cobalt is a ________ substance.
6. A straight conductor carrying current from north to south deflects magnetic needle placed parallel and above it towards _______.
7. Define terrestrial magnetism.
8. State the nature of lines of force due to a circular coil carrying current.
9. Magnetism is concentrated at the ___________ of a magnet.
10. Define natural and artificial magnets.
11. Define neutral point and state the locations of neutral points. When the north pole of a bar magnet points towards the geographic north.
12. Define neutral point and side the locations of neutral points. When the north pole of a bar magnet points towards the geographic south.
13. What is the use of a galvanoscope?
14. Define pole, axis, equator and magnetic meridian of a bar magnet
15. Define solenoid
16. The angle between resultant intensity of the earth's magnetic field and its horizontal component at a given place is called ___________ at that place.
17. The branch of physics which deals with the study of magnets is called as ___________.
18. Define magnetic and non magnetic substances.
19. Define electromagnet
20. The direction of magnetic field due to a current carrying conductor can be determined by Ampere's ___________ rule.
21. A solenoid with an iron core acts as __________.
22. What is magnetic induction?
23. Define E.M. relay
24. Define angle of dip,
25. Define angle of declination and
26. Define geographic and magnetic meridian of the earth.

27. The effective length of a bar magnet is equal to __________.

28. What is electromagnetism?

29. What is the angle of dip when both vertical and horizontal components of the earth's magnetic field are equal?

30. What is the nature of lines of force due to a straight current carrying conductor?

Short answer type questions

31. Magnetic induction precedes attraction–explain.

32. Explain isogonic and agonic lines.

33. State the factors which affect the strength of magnetic field around a circular current carrying coil.

34. What are the different types of artificial magnets?

35. Repulsion is the sure test for magnetism–explain.

36. What is horizontal component of the earth's magnetic field?

37. Explain galvanoscope.

38. State various methods of magnetization.

39. Explain the cause for variations in the angle of dip.

40. Explain 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 diagrams explain how will you locate the neutral points due to a bar magnet when
(1) its north pole points towards geographic north and
(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) electric bell and (2) relay switch for car starte

50. With the help of a diagram explain:
(1) single touch method (2) divided double touch method
(3) double touch method (4) electrical method of magnetization.

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false

1. A steel bar can be magnetised by passing alternating current through a coil wound on the steel bar.
2. The angle of dip increases as we move from the earth's magnetic equator to its magnetic poles.
3. Both the poles of a magnet have the same strength.
4. The angle of declination cannot be equal to zero.
5. Diamagnetic substances are feebly attracted by magnets.
6. 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.
7. Magnetic lines of force around a current carrying conductor are circular.

Direction for questions 8 to 14: Fill in the blanks.

8. The intensity of magnetic field due to a short bar magnet at a given point on its axis is inversely proportional to ___________.
9. Tangent galvanometer is used to measure ___________.
10. The product of pole strength and the magnetic length of a magnet is called ____________.
11. Earth's geographic north pole is very close to its magnetic ______________.
12. During magnetization the kinetic energy of the molecular magnets is converted to ______ energy.
13. The point at which the resultant magnetic effect is zero is called a ___________.
14. A freely suspended magnet lies in the horizontal plane at _____________.

Direction for question 15: Match the entries in column A with the appropriate ones in column B.

15.

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

(Continued on the following page)

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 16 to 30: For each of the questions, four choices have been provided. Select the correct alternative.

16. The magnetic field due to a bar magnet _______.
(1) has the same direction at any point
(2) is uniform
(3) is non uniform
(4) Both (1) and (3)

17. At the null point _______.
(1) horizontal component of earth's magnetic field is zero
(2) horizontal component of earth's magnetic field is equal to the magnetic field of the bar magnet
(3) intensity of earth's magnetic field is zero
(4) intensity of earth's magnetic field is equal to the magnetic field of bar magnet

18. Which of the following is a property shown by a magnet?
(1) Attractive property
(2) Directive property
(3) Induction
(4) All the above

19. The strength of a magnetic field increases as ________.
(1) the number of magnetic lines of force passing through a given area increases
(2) strength of the magnetic poles increases
(3) distance between the magnetic poles increases
(4) Both (1) and (2)

20. A conducting wire can give magnetic poles when it is _______.
(1) bent into the form of a circular ring
(2) placed in an external magnetic field
(3) suspended freely in air
(4) All the above

21. Which of the following is an artificial magnet?
(1) Bar magnet
(2) Horse-shoe magnet
(3) Magnetic needle
(4) All the above

22. The magnetic field near the centre of a current carrying coil is uniform and _________.
(1) parallel to the plane of coil
(2) perpendicular to the plane of coil
(3) circular
(4) Both (2) and (3)

23. Which of the following statements is false of a place closer to the north pole?
(1) $V > H$
(2) V is nearly equal to I
(3) H is nearly equal to I
(4) $V = \sqrt{I^2 - H^2}$

24. The torque acting on a current carrying loop placed in an external uniform magnetic field does not depend on the __________.
(1) shape of the loop
(2) strength of current through it
(3) strength of the magnetic field
(4) area of the loop

25. The ability of a galvanoscope to detect weak current increases with __________.
(1) decrease in number of turns (2) increase in its diameter
(3) decrease in its diameter (4) Both (1) and (3)

26. Consider the following two statements A and B, and select the correct choice.
A: Repulsion is a sure test of magnetism.
B: Magnetic induction precedes attraction.
(1) Only A is true (2) Only B is true (3) Both are true (4) Both are false

27. Retentivity is high in the case of ______.
(1) steel (2) copper (3) soft iron (4) aluminium

28. A solenoid is __________.
(1) an electromagnet (2) a temporary magnet
(3) a permanent magnet (4) Both (1) and (2)

29. Consider the two given statements A and B and select the correct choice.
A: an EM relay operates on high voltage.
B: an EM relay controls high voltage circuit.
(1) Only A is true (2) Only A is false (3) Both are true (4) Both are false

30. When a magnet is bent into the form of 'L' its magnetic moment _______.
(1) increases (2) decreases
(3) remains same (4) Cannot be determined

Concept Application Level—2

31. In spite of deflecting a magnetic needle kept near it, a straight current carrying wire doesn't possess magnetic poles. Explain

32. Why is it not possible to magnetise an iron bar beyond the saturation point?

33. A current carrying wire can deflect a magnetic needle. What is its effect on another current carrying wire kept near it?

34. Explain the nature of force between two adjacent turns of a solenoid. How does this force affect its length?

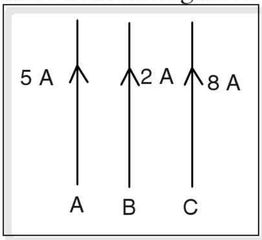
35. A magnet is cut into two parts by cutting it along its length. Is the crowding of the magnetic lines of force at the poles of the new magnet the same as it was in the old magnet? Explain your answer.

36. 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.

A	4×10^{-5}	3×10^{-5}	--
B	8×10^{-5}	--	10×10^{-5}
C	--	5×10^{-5}	13×10^{-5}

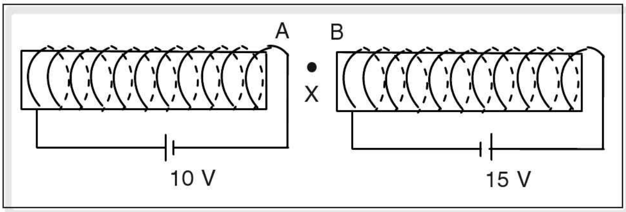
37. What is the working principle of a galvanoscope? How can its sensitivity can be increased?

38. Three straight wires A, B and C are placed in a plane parallel to each other and separated by equal distance, carrying current as shown in the figure. Determine the direction of force on B.



39. 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?

40. 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.

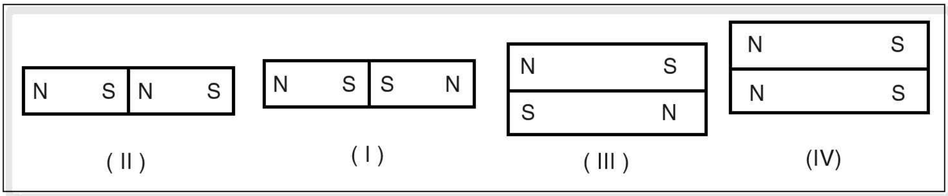


41. Which among the following dimensions of a bar magnet affect its pole strength and the magnetic moment? Explain.

(1) Length (2) Breadth (3) Thickness

42. 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?

43. 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?



44. Will the angle of dip in Russia be greater or lesser than that in India? Explain.

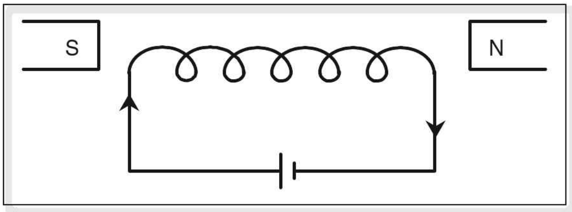
45. If a magnetic compass and a dip circle are taken to the magnetic poles of the earth, what would be the directions of their needles? Explain giving reasons.

Concept Application Level—3

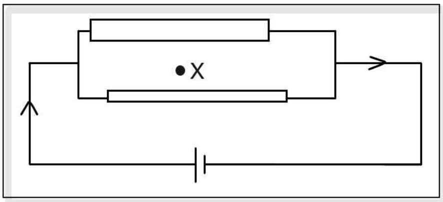
46. Can the combination of a current carrying wire and a solenoid produce neutral points?

47. 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.

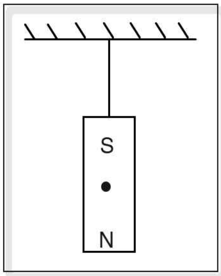
If the magnets do not move, will there be any change in the length of the coil? What will happen on reversing the direction of current?



48. Two wires of equal length and different areas of cross section are parallel to each other and are connected across 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?



49. 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?



50. 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.

key points for selected questions

Very short answer type questions

1. (i) Magnetic field: The space surrounding the magnet within which the magnetic effect is felt.

(ii) Magnetic field lines: The path along which a free north pole moves in a magnetic field.

2. When a linear object like a rod is held as a grip in the right hand, the direction of pointing a thumb indicates the direction of current through the conductor, then the direction of other four fingers curled around the rod indicates the direction of the magnetic field produced by the current through the conductor.

3. Agonic line

4. (i) The substance which is strongly attracted by a magnet.

(ii) The substance which is feebly attracted by a magnet.

(iii) The substance which is feebly repelled by a magnet.

5. Ferromagnetic

6. West

7. The branch of physics that deals with the study of the earth's magnetic field.

8. Concentric circles, and straight at the centre of the loop.

9. Poles

10. (i) Naturally occurring substance that can attract pieces of iron kept near by is called natural magnet.
(ii) Magnets made artificially in different shapes and sizes is called artificial magnet.

11. The point where the magnetic field due to the bar magnet is equal and opposite to the magnetic field due to the earth-Neutral point.
(i) Equatorial line of the bar magnet.

12. Axial line of the bar magnet.

13. To detect weak current.

14. Pole:
(i) The geometric ends of a bar magnet are its geometric poles.
(ii) The regions where the attractive property of a magnet is high, are called magnetic poles.
Axis:
The line joining the north pole and south pole of a bar magnet.
Equator:
An imaginary line passing through the centre of the magnet and perpendicular to the magnetic axis.
Magnetic meridian:
A vertical plane passing through the magnetic axis of a freely suspended magnet.

15. A conducting wire of spiral shape, which produces magnetic field when electricity is passed thought it.

16. angle of dip

17. magnetism

18. (i) Substances which are attracted by magnets–Magnetic substances.
(ii) Substances which are not attracted by magnets–Non-magnetic substances.

19. Solenoid with an iron core inside it.

20. right hand grip

21. electromagnet

22. The process in which a magnetic substance becomes a magnet when kept near a strong permanent magnet.

23. Used to control the working of a switch in some other circuit whose working is based on electromagnet.

24. The angle through which the north pole dips down with respect to the horizontal.

25. The angle between geographic meridian and the magnetic meridian.

26. An imaginary plane passing through the geographic north and south poles of the earth–Geographic meridian.

An imaginary plane passing through the magnetic north and south poles of the earth Magnetic meridian.

27. The distance between its two poles.

28. The magnetic effects of electricity.

29. 45°

30. Concentric circles.

Short answer type questions

31. When an iron bar is brought near a magnet it gets attracted by the magnet. Before attraction, poles are induced on the iron bar. The end of the iron bar facing the magnet, acquires opposite pole to that of the magnet and the far end of the iron bar acquires the same pole. Hence, iron bar gets attracted by the magnet.

32. (i) Definition of isogonic and agonic lines.
(ii) A line joining all the places having the same angle of declination–Isogonic line.
(iii) A line joining all the places having zero angle of declination–Agonic line.

33. (i) Strength of the current in the coil.
(ii) Number of turns in the coil.

34. Bar magnet, magnetic needle, horse-shoe magnet, magnetic compass.

35. Attractive and repulsive property of a magnet; attractive property of a magnetic material

36. The resultant intensity (I) of the earth's magnetic field can be resolved into two components, viz., horizontal component (H) and vertical component (V) of the earth's magnetic field.

37. Brass box, coil, and magnetic needle.

38. Single touch method, divided double touch method, double touch method, electrical method.

39. Is the magnetic field of earth uniform throughout the earth?

40. (i) Solenoid with an soft iron core inside it acts as an electromagnet.
(ii) Behaves like a magnet as long as current flows through it.
(iii) Loses magnetism once the current is stopped.

41. A magnetic needle or a magnetic compass.

42. Electrical method, heating, rough handling, induction, self-induction.

43. (i) Definition of isoclinic and aclinic lines.
(ii) A line joining all the places on the globe having the same angle of dip-Isoclinic line.
(iii) A line joining all the places having zero angle of dip-Aclinic line

44. Direction of current.

45. (i) Always form closed curves.
(ii) Leave the north pole and enter the south pole externally
(iii) Move from south to north pole internally.
(iv) No two lines intersect each other.

Essay type questions

46. Domain, molecular magnet, alignment in external magnetic field/on magnetisation.

47. (i) Equatorial line, the field due to the bar magnet is equal and opposite to the field due to the earth.
(ii) Axial line: the field due to the bar magnet is equal and opposite to the field due to the earth.

48. (i) Attractive property.
(ii) Directive property.
(iii) Pair property and
(iv) Law of magnetic poles.

49. (i) Electromagnet, armature, contact points, gong.
(ii) EM relay operating on low voltage.

50. (1) (i) Steel bar to be magnetised placed on a wooden table.
(ii) Steel bar rubbed with a strong permanent magnet in only one direction.
(iii) Starting end of the steel bar gets magnetized with same pole as that of the permanent magnet and the other end as the opposite pole.

(2) (i) Steel bar placed on two permanent magnets.
(ii) Two permanent magnets with opposite poles facing each other.
(iii) Rub in opposite directions starting from middle.
(iv) The end where the magnet leaves, acquires opposite pole as that of the magnet.

(3) (i) Two permanent magnets separated by a piece of wood held together with opposite poles facing each other.
(ii) This is placed on a steel bar in the centre and moved to and fro to other end without lifting.
(iii) Polarities are opposite to those of nearest stroking magnets.

(4) (i) Steel bar to be magnetised is wound with an insulated copper wire.
(ii) Strong current is passed through the coil.
(iii) Direction of current in anti-clockwise direction – North pole, clockwise direction – South pole

KEY

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. electric current
10. magnetic moment
11. south pole
12. magnetic energy
13. neutral point
14. magnetic equator

Match the following

15.

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

Multiple choice questions

16. Choice (3)
17. Choice (2)
18. Choice (4)
19. Choice (4)
20. Choice (1)
21. Choice (4)
22. Choice (2)
23. Choice (3)
24. Choice (1)
25. Choice (3)
26. Choice (3)
27. Choice (1)
28. Choice (4)
29. Choice (2)
30. Choice (2)

Concept Application Level—2, 3

Key points for select questions

31. Recall the definition of magnetic poles. Is there any point in a wire conducting electricity where all the magnetic lines of force are concentrated?

32. 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?

33. A current carrying wire produces a magnetic field around it.

34. 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?

35. 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?

36. A $\rightarrow$ 5×10^{-5}
    B $\rightarrow$ 6×10^{-5}
    C $\rightarrow$ 12×10^{-5}
    $\theta_A = \theta_B > \theta_C$

37. 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.

38. 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.

39. 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?

40. The magnetic field of the electromagnet.
Resultant magnetic field.
Identification of magnetic poles of an electromagnet.

41. Pole strength of a magnet depends upon number of ferromagnetic poles at the ends.

42. The direction of force on a wire conducting electric current placed in an external magnetic field.The formation of couple due to force.

43. 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?

44. (i) What does a dip circle indicate?
(ii) What is the direction of the earth's magnetic field?

45. 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?

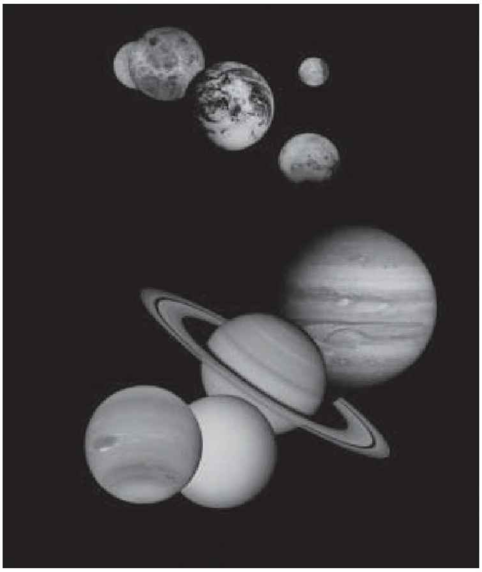
46. The null points are obtained due to the cancellation of two magnetic fields equal in magnitude and opposite in direction.
Current carrying conductor can produce a magnetic field around it.

48. 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.

49. The magnetic field around a magnet is three dimensional and the strength of the magnetic field at certain distance around the magnet is equal.

12

Modern Physics



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 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 in classical 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

The chemists and physicists 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.

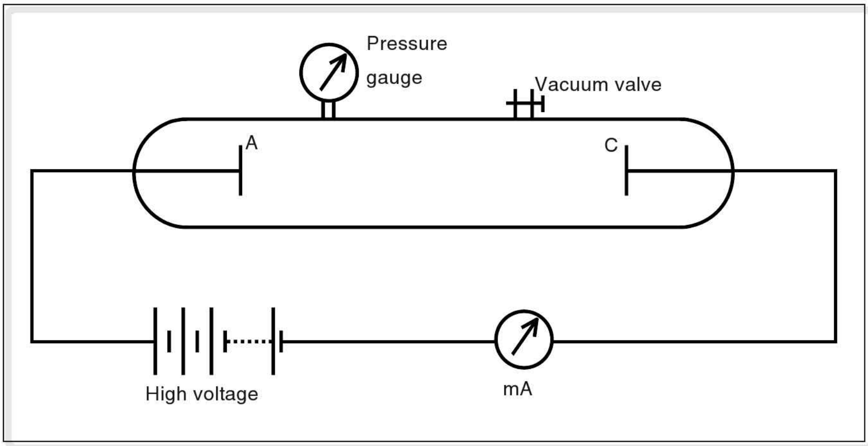
5. The mass of a subatomic particle is generally expressed in 'atomic mass units' (u), and one atomic mass unit is defined as 1/12th the mass of a C-12 atom.
6. The protons and neutrons are held together in the nucleus by nuclear force.
7. The atomic number (Z) is the number of protons in a nucleus.
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 energy levels.
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, eg. Hydrogen ($_1H^1$) and Deuterium ($_1H^2$).
13. The charge to mass ratio of an electron (e/m ratio) is given as 1.76×10^{11} C kg^{-1}.
14. The magnitude of charge of an electron is 1.6×10^{-19} C.
15. The mass of an electron is nearly 9.1×10^{-31} 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 electric potential 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 figure (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.



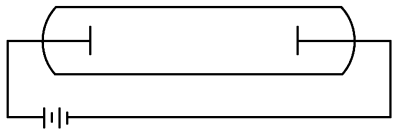
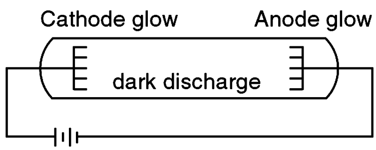
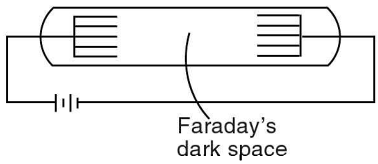
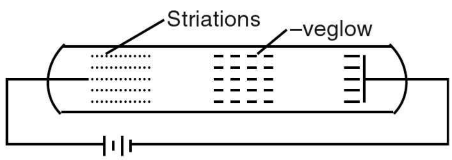
On reducing the pressure to about 10 mm of Hg, a luminous discharge with crackling sound is observed between the two electrodes. On further reduction of the pressure, the entire space between the electrodes is filled with a nearly uniform luminous glow. The colour of the glow depends on the gas present in the tube. When the tube is filled with air, magenta–red glow is

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 at the region behind the cathode. The fluorescence is caused by the rays emitted from the cathode, and are 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.

[redacted]

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 the 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 figure (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.

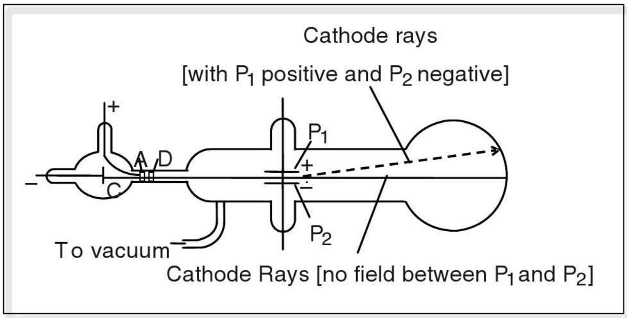


Figure12.2

The modern television picture tube, glow signs, domestic fluorescent tube lights, cathode ray oscilloscopes are all modified discharge tubes.

Millikan's experiment

Robert Millikan 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 1.6×10^{-19}C. Combining this value with the e/m ratio determined by Thomson, the mass of the cathode ray particle (electron) was calculated.

$$m = \frac{e}{e/m} = \frac{1.6\times10^{-19}}{1.76\times10^{11}} = 9.1\times10^{-31}\text{kg}$$

Goldstein's experiment

Goldestein'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.

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

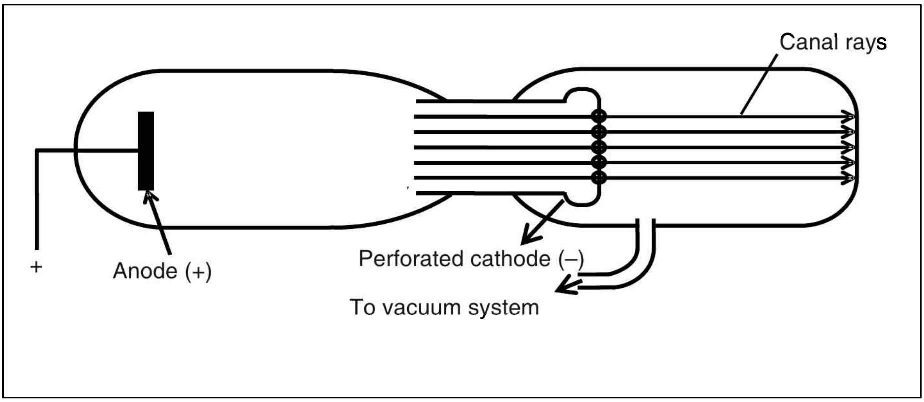


Figure 12.3 Goldstein's experiment

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)

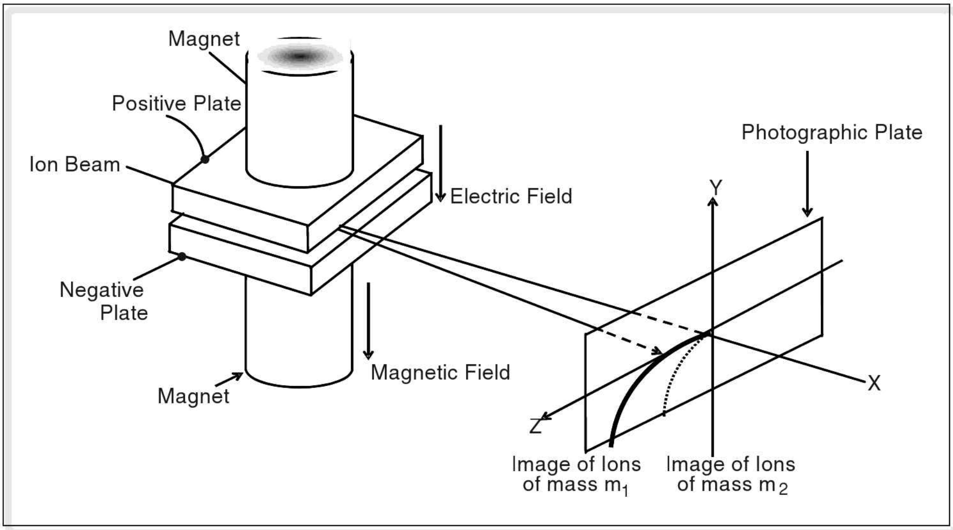


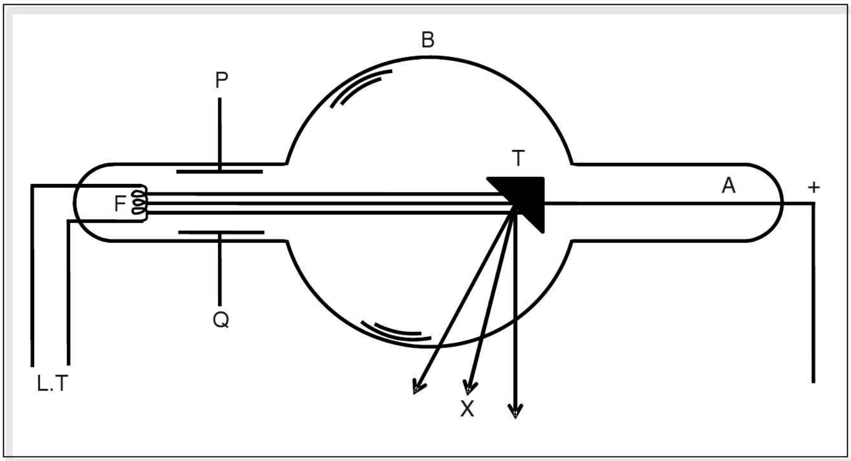
Figure 12.4

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. Roentgen 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.

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 1 A° to 100 A°. Like all other electromagnetic radiations they travel in straight lines with a speed of 3×10^8 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 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 the 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 Prof. 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, ϒ radiations

Analysis of the ionizing rays (radiations) emitted by the radioactive substances revealed that these

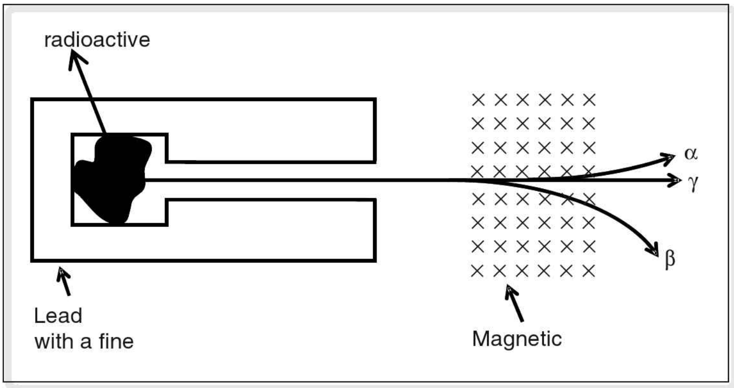


Figure 12.6

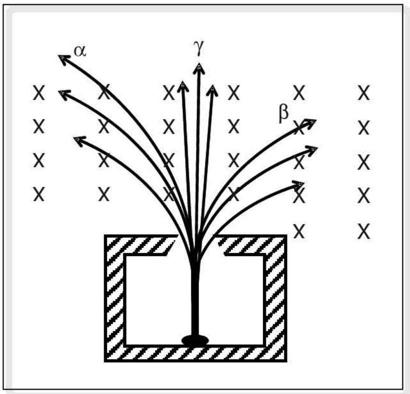


Figure 12.7 Deflection in Magnetic field

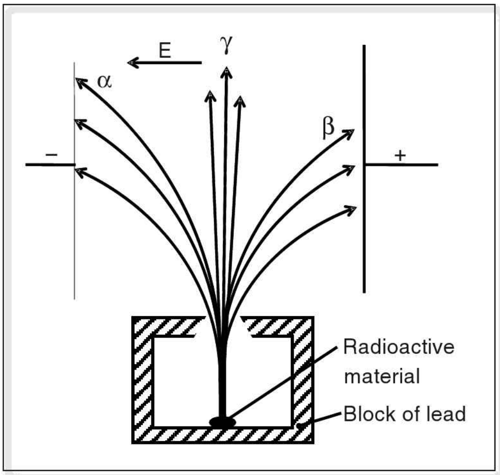


Figure 12.8 Deflection in Electric field

Properties of α, β, ϒ rays

(i) **α-rays (alpha rays)**

(a) Ionized helium atoms.

(b) Positively charged particles.

(c) Deflect towards the negative plate when passing through an applied electric field.

(d) Deflect in magnetic field, in accordance with Fleming's left-hand rule.

(ii) **β-rays (Beta rays)**

(a) Highly energized electrons.

(b) Negatively charged particles.

(c) Deflect towards the positive plate when passing through an electric field.

(d) Deflect in magnetic field, in accordance with Fleming's left-hand rule.

(iii) **γ-rays (gamma rays)**

(a) High energy electromagnetic radiation.

(b) Electrically neutral.

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 particles of 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.

Concept Application Level—1

Direction for questions 1 to 7: State whether the following statements are true or false.

1. X-rays are electromagnetic radiations of wavelength greater than that of visible light.

2. $\frac{e}{m}$ of cathode rays differ at different temperatures.

3. α, β and γ radiations have the same velocity as light.

4. All gases at normal temperature and pressure are good conductors of electricity.

5. Alpha rays are highly-energized electrons.

6. 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.

7. Canal rays are positively charged.

Direction for questions 8 to 14: Fill in the blanks.

8. Alpha particles are _________ charged.

9. X-rays travel at a speed of ______ m s^{-1}.

10. β rays are emitted from the ________.

11. ______ rays are highly energized electrons.

12. The accelerated positive ions in a discharge tube collide with ______ to eject electrons.

13. ______ photographs are used to detect fracture of bones.

14. 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.

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.	1.76×10^{11} C kg^{-1}
G.	Study of cathode rays	( )	g.	emitted from anode
H.	Discovery of X-rays	( )	h.	discovery of radioactivity
I.	Marie curie	( )	i.	William Roentgen
J.	Henri Bequerel	( )	j.	Medical diagonostics

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 sample emits radiation at time t minutes then the next nuclei emits radiation after _____.

(1) 2t minutes (2) 2t seconds (3) 2t hours (4) any time

17. The rays that are unaffected by a magnetic field are _____.

(1) canal rays (2) γ-rays (3) cahode rays (4) All the above

18. The rate of emission of radiation, when a radioactive sample is placed in water, _____.

(1) increases (2) decreases (3) remains the same (4) Cannot be determined

19. X-rays are produced by impinging _____ on a target.

(1) α particles (2) protons (3) electrons (4) X-rays

20. X - rays are produced in _____.

(1) high vacuum tubes

(2) in tubes having inert gases at low pressure

(3) in tubes having inert gases at high pressure

(4) in tubes having any gases at very low pressures.

21. The emission of 'weak X-rays' from uranium salts discovered by Becquerel could _____.

(1) ionize gases (2) affect photographic plates

(3) penetrate through matter (4) All the above

22. The conditions for the discharge of electricity through gases in a discharge tube is _____.

(1) high potential and high pressure. (2) high potential and low pressure.

(3) low potential and high pressure. (4) low potential and low pressure.

23. A modified discharge tube is used as _____.

(1) cathode ray oscilloscope (2) fluorescent tube

(3) X-ray tube (4) All the above

24. In a Coolidge tube, an electric field is applied _____.

(1) to increase the charge on the cathode rays.

(2) to accelerate the cathode rays.

(3) to produce fluorescence.

(4) Both 1 and 2

25. The fluorescence of the glass (discharge) tube at very low pressure is characteristic of _____.

(1) the phosphors in the material of the glass (2) the gas used in the tube

(3) the cathode (4) All the above

26. The false statement about X-rays is _____.

(1) X-rays are not particles

(2) X-rays are uncharged

(3) X-rays can penetrate through all bodies

(4) X-rays cause fluorescence when they are incident on cadmium sulphide

27. X-rays are deflected by _____.

(1) electric field (2) magnetic field (3) gravitational field (4) None of these

28. A light paddle wheel placed in the path of _____ will rotate.

(1) cathode rays (2) α-rays (3) β-rays (4) All the above

29. The electric field applied in vertical direction to the cathode rays moving horizontally deflect them in _____.

(1) horizontal direction (2) vertical direction

(3) Both (1) and (2) (4) None of these

30. Becquerel rays can _____.

(1) affect photographic plate (2) penetrate through matter

(3) ionize gases (4) All the above

Concept Application Level—2

31. If an α-ray and a β-ray has 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 8.88×10^{-18}C. Why can't such a quantity of charge be present on the oil drop? Explain. (Charge on an electron is 1.6×10^{-19}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 $\frac{e}{m}$ of singly-ionized atoms of the same element can have different values? Explain.

35. If the entire mass of the body is assumed to be made up of electrons, how many electrons are present in the body if the mass of the body is 45.5 kg and that of an electron is 9.1×10^{-31} 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 C moves through a potential difference of y V the gain in kinetic energy is equal to xy 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 the mass 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 8.4×10^7 m s^{-1}. What is the percentage increase in the kinetic energy of electrons?

(Take $c = 3 \times 10^8$ 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 ${}_ZX^A$ 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.

Concept Application 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.

($\frac{e}{m}$ of electron is 1.76×10^{11} C kg^{-1})

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?

key points for selected questions

Very short answer type questions

1. Negative electrode
2. fluorescence
3. A device that is used to study flow of charges through gases.
4. cathode
5. 1.76×10^{11} C kg^{-1}
6. 10^{-4} mm of Hg
7. High electric potential, low pressures.
8. Light
9. Special rays emitted by uranium salts.
10. Coolidge tube.
11. At a particular pressure, rays emitted from cathode are called cathode rays.
    Specific charge = 1.76×10^{11} C kg^{-1}.
    Charge of electron = 1.6×10^{-19} C.
12. 1.65 mm of Hg

key points for selected questions

13. Filament voltage, voltage applied across the electrodes.
14. Becquerel
15. 0.1 mm of Hg
16. X – rays
17. 1 A° to 100 A°
18. unaffected
19. 0.02 mm of Hg
20. γ-rays
21. (i) Photography of internal organs.
    (ii) Scanning luggage for security.
22. Cathode rays or γ - rays or uv rays
23. Deflect towards the positive plate.
24. X-rays
25. Millikan's experiment
26. The property of self-disintegration and spontaneous emission of radiations by some unstable nuclei of certain elements.
27. $\frac{1}{1840}$
28. Mass spectroscopy.
29. γ
30. Anode rays.

Short answer type questions

31. Scanning the internal organs.
    Treatment of cancer.
32. (i) Deflects towards the positive plate, when electric field is applied.
    (ii) Charge to mass ratio of the cathode rays $e/m = 1.76 \times 10^{11}$ C kg^{-1}.
33. High speed cathode rays are suddenly stopped.
34. (i) Electromagnetic radiations.
    (ii) Travel in straight line with a speed of 3×10^8 m s^{-1}.
    (iii) Wavelength ranges from 1 A° to 100 A°.
35. (i) Compare the cathodes.
    (ii) Compare the anodes.
    (iii) How are X-rays produced.
    (iv) Compare the speed of the electron rays.
36. (i) Deflection of cathode rays.
    (ii) Charge to mass ratio.
38. Goldstein's experiment: Two chambers separated by perforated cathode, application of high potential difference between cathode and anode, discharge of rays by anode.
40. Oil droplets, atomizer, electric field.
41. Recall the properties of electromagnetic waves. Recall the nature of electromagnetic waves.
42. Coolidge tube – Filament connected to low voltage supply which acts as a cathode anode connected to target. High speed cathode rays strike the target and emit X-rays.
43. Negatively charged, positively charged.
44. Definition, production and properties of canal rays.
45. (i) Spontaneous emission or self-disintegration by unstable nuclei of some elements.
    (ii) Repulsive force between protons.

Essay type questions

46. (i) Modified discharge tube.
    (ii) Deflection of cathode rays.
    (iii) Charge to mass ratio of cathode rays.
47. (i) Modified double chamber of Goldstein.
    (ii) Single hole in the centre of the cathode.
    (iii) Applying electric field perpendicular to the axis of the second chamber.
    (iv) Deflection of the canal rays.
48. Table for discharge phenomenon in gases.
49. (i) Two chambers separated by a perforated cathode.
    (ii) Application of high potential difference between the anode and cathode.
    (iii) Cathode ray discharge accompanied by simultaneous discharge in the chamber behind the cathode–canal rays.
50. ∝-rays:
    (i) Ionized Helium atoms.
    (ii) Positively charged particles.
    (iii) Deflect in electric and magnetic fields.

key points for selected questions

β-rays:

(i) Highly energized electrons.

(ii) Negatively charged particles.

(iii) Deflect in electric and magnetic fields.

γ-rays:

(i) High energy electromagnetic radiation.

(ii) Electrically neutral.

(iii) Emerges in deflected when passing through electric and magnetic fields.

KEY

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. 3×10^8 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. Choice (4)
17. Choice (2)
18. Choice (3)
19. Choice (3)
20. Choice (1)
21. Choice (4)
22. Choice (2)
23. Choice (4)
24. Choice (2)
25. Choice (1)
26. Choice (3)
27. Choice (4)
28. Choice (4)
29. Choice (2)
30. Choice (4)

Concept Application Level—2, 3

Key points for select questions

32. Is it possible for a body to have charge less than 1.6×10^{-19}C as it is the charge of a fundamental particle. Is 8.88×10^{-18}C an integral multiple of 1.602×10^{-19}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 × mass of each electron.

    (ii) – 0.55 mg

34. Recall the definition of isotopes.

Is there any difference between the masses of $^1_1H^+$ and $^2_1H^+$

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

$$\frac{m_1}{m_2} = \frac{1}{7200}$$

$$\frac{x_1}{x_2} = \frac{1}{2} \text{ and } y_1 = y_2$$

Total energy gained (xy) = change in kinetic energy

$$\left(\frac{1}{2}m(v^2 - u^2)\right)$$

$$u_1 = u_2 = 0$$

$$\therefore \frac{v_1^2}{v^2} = \frac{m_2 x_1 y_1}{m_1 x_2 y_2}$$

(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) 3.52×10^{12} 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. What are the different kinds of forces present inside a nucleus?

What is the nature of force?

Compare the mass of a nature with the mass of all the constituents of the nucleus.

How do you account for the difference in their mass?

What is the relation between mass and energy?