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Physics

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Trishna Knowledge Systems

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Action or Working of a Transistor	11.19	<i>Practice Questions</i>	11.29
Amplifier	11.20	<i>Hints and Explanation</i>	11.37
Transistor as an Amplifier	11.20		

Preface

Pearson IIT Foundation Series has developed into a trusted resource for scores of students who have aspired to be a part of the elite undergraduate institutions of India. As a result it has become one of the best selling series, providing authentic and class tested content for effective preparation.

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

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

To ensure high level of accuracy and practicality this series has been authored by a team of highly qualified and experienced faculties involved in grooming the young minds. That said, we believe that there is always scope for doing things in a better manner and hence invite you to provide us with your candid feedback and suggestions on how we can make this series more superior.

Chapter Insights

Remember

Before beginning this chapter, you should be able to:

- Make clear distinction between heat and temperature, measurement of temperature with the help of thermometers
- Know good and bad conductors of heat, different

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

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

Key Ideas

After completing this chapter, you should be able to:

- Understand the various factors affecting the heat absorbed by a body and to deduce an expression for heat energy

Units of Specific Heat Capacity

From the above equation, we get $s = \frac{Q}{m\Delta\theta}$.

Thus, unit of $s = \frac{\text{Unit of } Q}{(\text{Unit of } m) (\text{Unit of } \Delta\theta)}$

S.I. unit of specific heat capacity is $\frac{\text{joule}}{\text{kilogram} \times \text{kelvin}} = \text{J kg}^{-1} \text{K}^{-1}$.

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

Note boxes are some add-on information of related topics

NOTE

The intensity level of sound is measured in units of decibels (dB).

EXAMPLE

The velocity of sound in oxygen is at STP 100 m s^{-1} . Find the velocity of sound in hydrogen.

SOLUTION

Velocity of sound in a gas,

$$V \propto \frac{1}{\sqrt{\text{Molecular weight } M}}$$

$$\frac{V_1}{V_2} = \sqrt{\frac{M_2}{M_1}}$$

$$\frac{V_{H_2}}{V_{O_2}} = \sqrt{\frac{M_{O_2}}{M_{H_2}}} = \sqrt{\frac{32}{2}} = \sqrt{16} = 4.$$

$$V_{H_2} = 4 \times V_{O_2}$$

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

Illustrative examples solved in a logical and step-wise manner

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Motion of an aeroplane is an example of _____ dimensional motion.
2. Define maximum height.
3. A particle is projected up with a velocity of $\sqrt{29} \text{ m s}^{-1}$ from the top of a tower of height 10 m. Its velocity on reaching the ground is _____ m s^{-1} .
4. In a velocity time graph, the negative slope indicates _____.
5. Define time of ascent and time of descent.
6. A body is falling freely under gravity. The distances covered by it in the first, second and third seconds of its motion are in the ratio of _____.
7. The equations of motion are applicable only when _____.
11. What is acceleration due to gravity?
12. A stone is dropped from the top of tower and it reaches the ground after 3 s. Then the height of that tower is _____ $\text{g} = 10 \text{ m s}^{-2}$.
13. Two balls are dropped from heights h_1 and h_2 , respectively. The ratio of their velocities on reaching the ground is _____.
14. What is the acceleration of a body when it is projected vertically upwards?
15. Two bodies of different masses m_1 and m_2 are dropped from two different heights h_1 and h_2 . The ratio of the times taken by the two to reach the ground is _____.

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

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

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

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Define artificial transmutation.
2. Energy released in a nuclear reaction is given by _____.
3. What is a chain reaction?
4. _____ are used to absorb the neutrons in a nuclear reactor.
5. In a discharge tube, at what pressure cathode rays are produced?
6. Thorium series is also called _____.
7. If the half-life period of a radioactive substance is _____.
16. What is a fusion reaction?
17. How are X-rays produced?
18. In artificial transmutation, the bombarding particles are called _____.
19. What forces are responsible for keeping the nucleons together in a nucleus?
20. Why are nuclear fusion reactions also known as thermo-nuclear reactions?
21. Which rays among α , β and γ are deflected most in a magnetic field? Which rays remain undeflected?

Explanation for questions 31 and 40:

$$31. S_n = ? , u = 20 \text{ ms}^{-1}, a = 2 \text{ ms}^{-2}, n = 8$$

$$S_n = u(1s) + a\left(n - \frac{1}{2}\right) = 20 + 2\left(8 - \frac{1}{2}\right) (1s)$$

$$= 20 + (16 - 1) = 20 + 15 = 35$$

$$32. v^2 - u^2 = 2as$$

$$v^2 - 0 = 2 \times 2 \times 10 = 40 \Rightarrow v = \sqrt{40} \text{ ms}^{-1}$$

$$33. u = 5 \text{ m s}^{-1}, v = 25 \text{ m s}^{-1}, t = 5 \text{ s}$$

$$a = \frac{v - u}{t} = \frac{25 - 5}{5} = 20 / 5 = 4 \text{ ms}^{-2}$$

$$34. s = ?, u = 0, a = 1 \text{ m s}^{-2}, t = 5 \text{ s}$$

$$s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times 1 \times 25 = 12.5 \text{ m}$$

$$35. u = 0$$

$$h \propto t^2$$

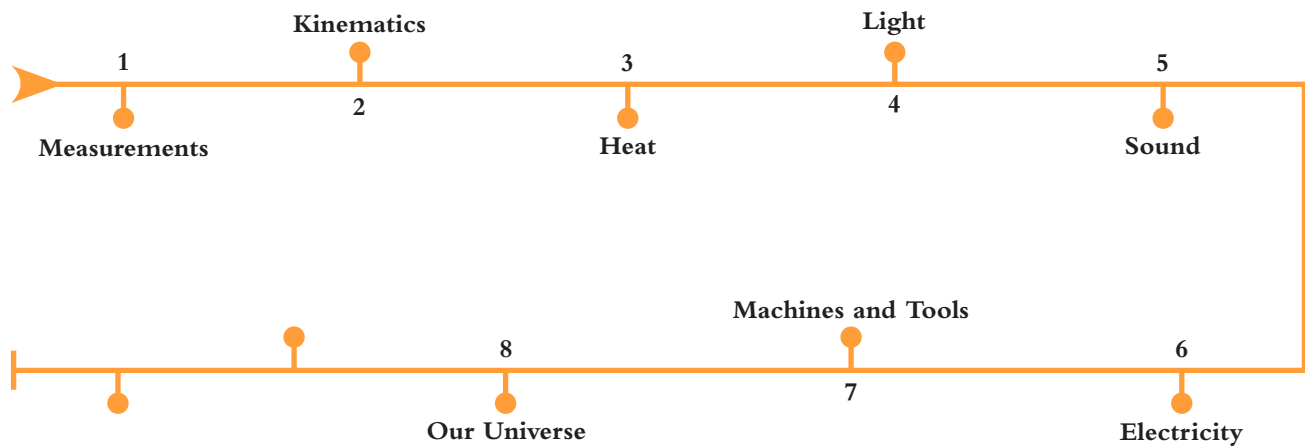
$$\therefore \sqrt{\frac{h_1}{h_2}} = \frac{t_1}{t_2}$$

$$t_1 : t_2 = 1 : 2$$

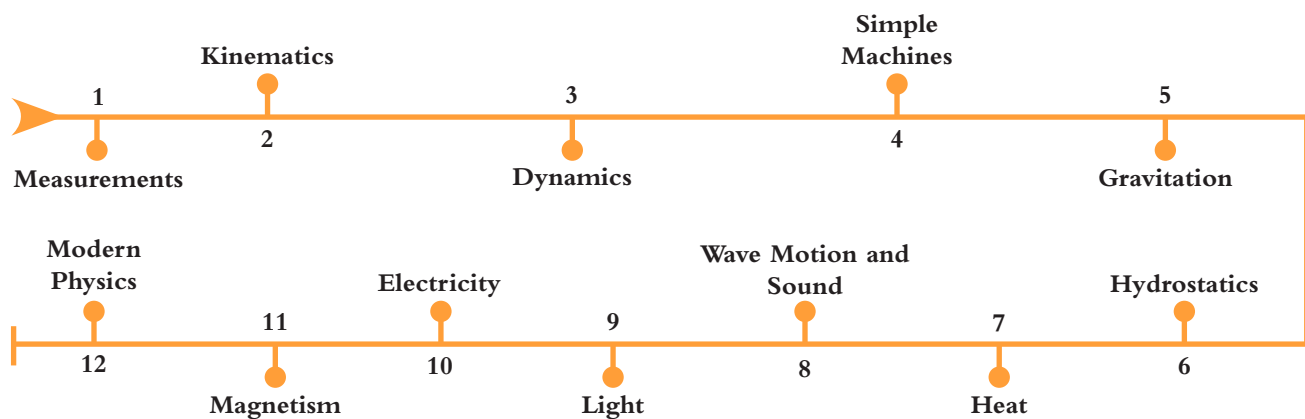
Hints and Explanation for key questions along with highlights on the common mistakes that students usually make in the examinations

Series Chapter Flow

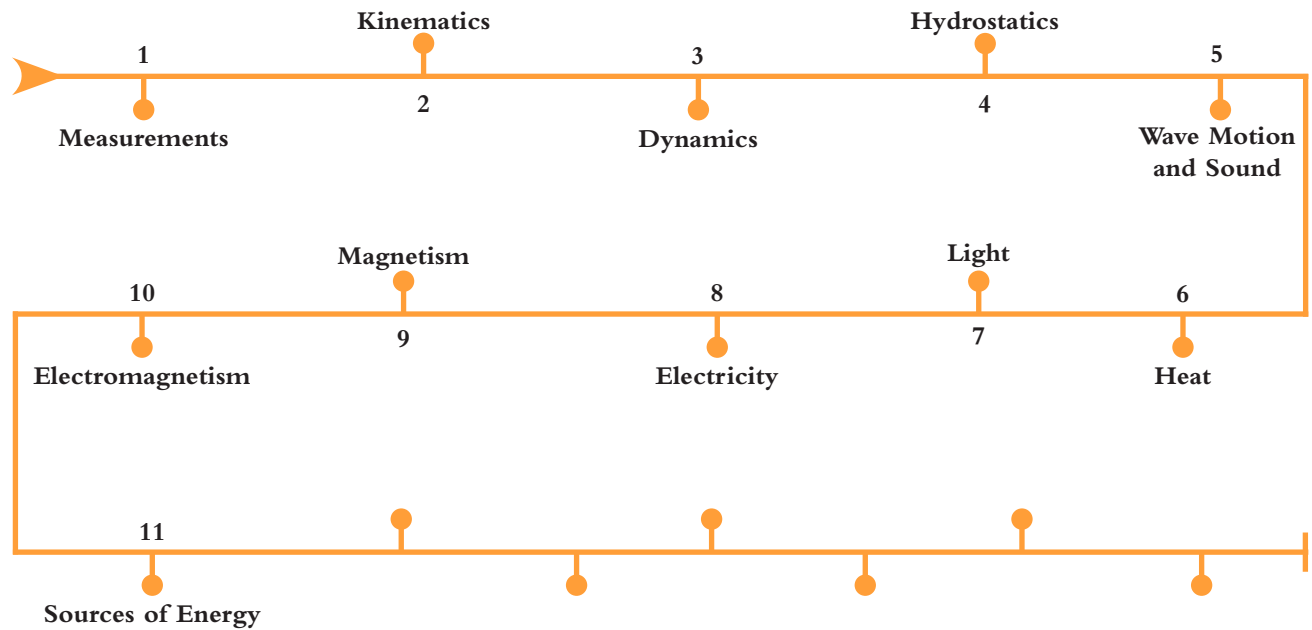
Class 7



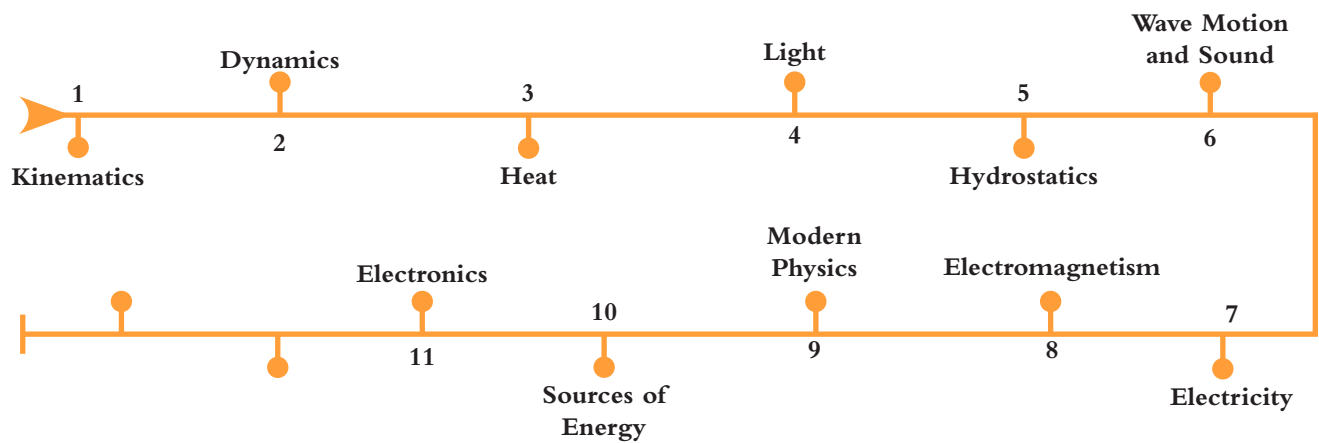
Class 9



Class 8



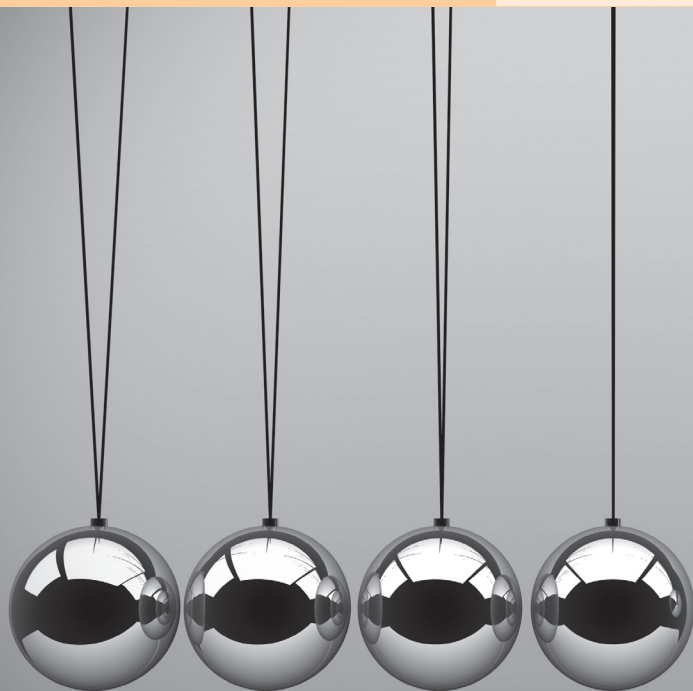
Class 10



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Chapter 1

Kinematics



Remember

Before beginning this chapter, you should be able to:

- Learn the importance of classifying motion into different groups
- Define the scalar and vector quantities and to classify the different quantities into scalar and vectors
- Understand the terms and to determine the equations of motions relating to these terms

Key Ideas

After completing this chapter you should be able to:

- Understand the different physical quantities and different systems of units
- Recognize the importance of accuracy of measurements and to understand how vernier callipers is used to measure the length more accurately
- Study the methods of determining physical quantities like area, volume, mass and density
- Find the relation between various physical quantities

INTRODUCTION

One can study the motion of a body in a given time interval if its initial velocity, final velocity, acceleration, and displacement are known.

The relation between $\vec{v}$, $\vec{u}$, $\vec{a}$, t and $\vec{s}$ for a body moving with uniform acceleration in a straight path are well known to us. Equations which relate these quantities are known as equations of motion.

The equations of motion are:

1. $v = u + at$
2. $s = ut + \frac{1}{2} at^2$
3. $v^2 = u^2 + 2as$
4. $s_n = u + a (n - 1/2)$

Do the above equations hold good for a body which is dropped from a height, or projected vertically upwards?

Answer to the above can be found out by the example given below.

Example: Drop two stones, of masses 1 kg and 5 kg, respectively simultaneously, from the same height. Note the time taken by the two stones to reach the ground. Which stone reaches the ground first? We observe that both the stones reach the ground in approximately the same time.

The above fact was proved experimentally by Galileo. He dropped a heavy iron ball and a light wooden ball simultaneously from the leaning tower of Pisa. Both the balls reached the ground at the same time though their masses were different.

Further experiments proved that wherever air resistance is negligible, all bodies, irrespective of their masses would take the same time to reach the ground when dropped from the same height. In fact, a body dropped from a height would accelerate as it travels downwards, i.e., its velocity increases as it moves down. On the other hand, the velocity of a body projected vertically upwards would decrease as it moves up. Since this acceleration is due to the gravitational force exerted by the earth, it is generally referred to as ‘acceleration due to gravity’ and is denoted by the letter ‘g’.

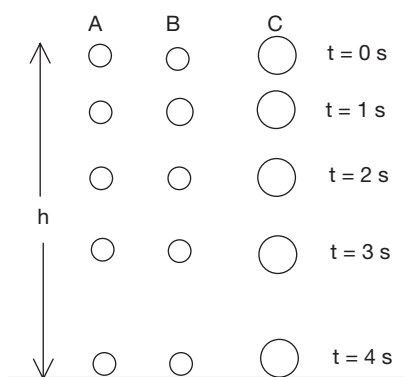


FIGURE 1.1 Objects A, B and C dropped from a height ‘h’

The value of this ‘g’ at mean sea level is approximately 9.8 m s^{-2} or 10 m s^{-2} .

For obvious reasons, the acceleration due to gravity acts downwards and would take a '+' sign or '-' sign depending on the sign convention chosen. And as a body moves along a straight line path either when dropped from a height or when projected vertically up, the same equations of motion may be used in both the cases by taking appropriate signs for 'g'. Thus, the equations of motion for a body moving vertically under the influence of gravity are

1. $v = u \pm gt$
2. $s = ut \pm \frac{1}{2} gt^2$
3. $v^2 = u^2 \pm 2gs$
4. $s_n = u \pm g(n - \frac{1}{2})$

The value of 'g' at mean sea level is taken as 9.8 m s^{-2} or 10 m s^{-2} approximately.

FREELY FALLING BODY

When an apple drops from a tree, the initial velocity of the apple is zero due to inertia of rest. The apple moves towards the earth under the influence of gravity. Though the motion is opposed by friction of air, the resistance of air may be considered negligible in comparison to the weight of the body. Such a motion which takes place under the influence of only gravity is called free-fall.

Equations of Motion for a Freely Falling Body

Let us consider a special case of a freely falling body released from rest (i.e., dropped) which means the initial velocity 'u' is equal to zero. The body moves towards the earth due to the gravitational force of the earth.

Considering the downward direction as positive (you can also take it as negative) the equations of motion of a freely falling body, dropped from a height 'h' from the ground, are obtained by substituting zero for u, h for s, and g for a in the equations of motion. Then, we get

1. $v = gt$
2. $h = \frac{1}{2} gt^2$
3. $v^2 = 2gh$
4. $s_n = g (n - \frac{1}{2})$

Equations of Motion for a Body Thrown Vertically Upwards

Let a ball be thrown vertically upwards. What do we observe?

The following facts are observed:

1. The impulsive force given to the ball provides an initial velocity to the ball for it to move upwards.
2. The ball reaches a certain maximum height where it stops (i.e., $v = 0$) and then returns to the ground.

Conclusions

1. It is impossible for a body to move away from the earth on its own due to the earth's gravitational pull. Hence, an initial velocity should be given to the body.
2. At low speeds, a body cannot keep going up indefinitely but will return to the ground after reaching a certain height.

Here, the acceleration due to gravity acts in a direction opposite to the direction of initial velocity.

Considering the upward direction as positive, the equations of motion for a body projected vertically upwards are obtained by substituting h for s and $-g$ for a as follows.

1. $v = u - gt$
2. $h = ut - \frac{1}{2}gt^2$
3. $v^2 = u^2 - 2gh$
4. $s_n = u - g(n - \frac{1}{2})$

EXAMPLE

A ball is dropped from the top of a building 19.6 m high. Find the time taken by the ball to reach the ground.

SOLUTION

This is a case of a freely falling body. Since the ball is dropped, its initial velocity is zero. Thus, we have

$$u = 0$$

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

$$a = +g = +9.8 \text{ m s}^{-2} \text{ ('+' sign since the body is moving downwards).}$$

Using the second equation of motion, $s = ut + \frac{1}{2}at^2$

$$19.6 \text{ m} = 0 + \frac{1}{2} \times (9.8 \text{ m s}^{-2}) \times (t)^2$$

$$t^2 = \frac{19.6 \times 2}{9.8} = 4$$

$$\therefore t = 2 \text{ s.}$$

EXAMPLE

A Diwali rocket, when ignited at the ground level, rises vertically upwards to the level of a window 10 m from the ground. Find the magnitude of velocity of the rocket at the time of its take off.

SOLUTION

Since the body is moving up, the acceleration due to gravity 'g' is taken with a '-' sign in the equations of motion. The body rises up to a height of 10 m, i.e., its velocity at this height is zero, substituting these values in the 3rd equation of motion, $v^2 = u^2 + 2as$, we get

$$0 = u^2 - 2(9.8 \text{ m s}^{-2})(10 \text{ m})$$

$$\therefore u^2 = 196$$

$$u = 14 \text{ m s}^{-1}$$

EXAMPLE

A stone is released from a hot-air balloon which is rising steadily with a velocity of 4 m s^{-1} . Find the velocity of the stone at the end of 3 s after it is released.

SOLUTION

Let the downward direction be positive. As the stone was moving with the balloon, the initial velocity of the stone is the same as that of the balloon, i.e., 4 m s^{-1} upwards directions. Thus, we have

($\because$ Initial velocity of the stone is opposite to displacement of stone)

$$u = -4 \text{ m s}^{-1}$$

$$a = +9.8 \text{ m s}^{-2}$$

$$t = 3 \text{ s}$$

Considering the first equation of motion,

$v = u + at$, and substituting the values of u , a and t

$$v = -4 + 9.8 \times 3$$

$$v = -4 + 29.4$$

$$v = 25.4 \text{ m s}^{-1}$$

EXAMPLE

A stone is dropped by a person from the top of a building, which is 200 m tall. At the same time, another stone is thrown upwards, with a velocity of 50 m s^{-1} by a person standing at the foot of the building. Find the time after which the two stones meet.

SOLUTION

Let the two stones meet at a distance of $x \text{ m}$ from the top of the building, and ' t ' be the time taken.

Let us assume the downward direction as positive,

For the stone, that is dropped, its initial velocity $u = 0 \text{ m s}^{-1}$; displacement $s = x$ and acceleration = acceleration due to gravity (g).

$$\text{Using } s = ut + \frac{1}{2}at^2, \text{ a } x = (0)t + \frac{1}{2}gt^2 \quad (1)$$

For the stone that is projected vertically upwards, its initial velocity, $u = -50 \text{ m s}^{-1}$; displacement $s = -(200 - x)$ and

acceleration $a = g$. Using $s = ut + \frac{1}{2}at^2$,

we get

$$\begin{aligned} -(200 - x) &= -50 \times t + \frac{1}{2}gt^2 \\ 200 &= 50t - \frac{1}{2}gt^2 + x \end{aligned} \quad (2)$$

From the equations (1) and (2), we have

$$200 = 50t - \frac{1}{2}gt^2 + \frac{1}{2}gt^2$$

$$200 = 50t$$

$$\therefore t = 4 \text{ s}$$

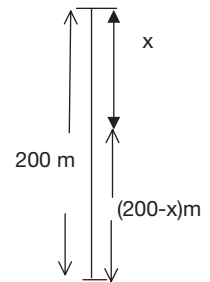


FIGURE 1.2 A 200 m tall building

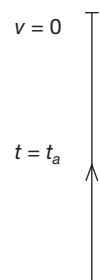
Maximum Height Reached by a Body Projected Vertically Upwards

Consider two balls A and B , and let A be thrown upwards with a higher initial velocity than B . Observe which reaches greater height. Ball A reaches a greater height than ball B .

Thus, the maximum height reached by a body depends on its initial velocity and is independent of its mass.

When a body is thrown upwards, the velocity of the body decreases continuously and finally becomes zero at a certain height. This height where the final velocity of the body is zero is called the maximum height. (denoted by $h_{\max}$ or H).

At the maximum height, $v = 0$



$\therefore$ From $v^2 = u^2 - 2gh$, we get

$$0 = u^2 - 2g h_{\max}$$

$$\Rightarrow h_{\max} \text{ or } H = \frac{u^2}{2g}$$

Here, $h_{\max}$ refers to the maximum height attained by the body thrown vertically upwards. From this expression it is evident that the maximum height depends on the velocity of projection.

Time of Ascent (t_a)

It is the time taken by a body, projected vertically upwards, to reach the maximum height.

At maximum height, the final velocity of the body $v = 0$.

From the equation,

$$v = u + at, \text{ we get}$$

$$\Rightarrow 0 = u - gt_a$$

$$\Rightarrow t_a = \frac{u}{g}$$

Thus, the time of ascent of a body, projected vertically upwards, depends on the velocity of projection. Hence, greater the initial velocity, greater will be the maximum height attained by a body and its time of ascent.

Time of Descent (t_d)

It is the time taken by a body, projected vertically upwards, to return to/come back the point of projection from its position of maximum height.

Let t_d be the time of descent of a body projected vertically upwards. Let ' u ' be the velocity of projection of the body and $h_{\max}$ be its maximum height. In the return journey of the body from its position of maximum height, its initial velocity is zero. Hence, using

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

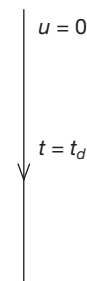
we get

$$h_{\max} = 0 + \frac{1}{2}g t_d^2 \Rightarrow t_d = \sqrt{\frac{h_{\max} \times 2}{g}}$$

$$\text{As } h_{\max} = \frac{u^2}{2g},$$

we get

$$t_d = \sqrt{\frac{u^2}{2g} \times \frac{2}{g}} \Rightarrow t_d = \sqrt{\frac{u^2}{g^2}} \Rightarrow t_d = \frac{u}{g}$$



Thus, we find that the time of ascent is always equal to the time of descent.

Time of Flight (T)

It is the total time taken by a body projected vertically upwards to reach the position of maximum height and then return to the point of projection. It is denoted by T . It is the total time for which the body remains in the air, and is equal to the sum of the time of ascent and the time of descent.

$$\text{Time of flight} = t_a + t_d$$

$$\Rightarrow T = u/g + u/g \Rightarrow T = \frac{2u}{g}$$

Velocity on Reaching the Ground

For a freely falling body dropped from certain height ' h ', the initial velocity is zero.

From $v^2 = u^2 + 2as$, substituting $u = 0$, $a = g$ and $s = h$, we get

$$v^2 = 2gh$$

$$\therefore v = \sqrt{2gh} \quad (1.1)$$

Here, v is the final velocity on reaching the ground and h is the height from which the body is dropped. When a body is projected vertically upwards with initial velocity u , then at the maximum height, $v = 0$

$$0 = u^2 - 2gh \text{ (From the equation } v^2 = u^2 + 2as)$$

$$u^2 = 2gh$$

$$u = \sqrt{2gh} \quad (1.2)$$

From equations (1.1) and (1.2) it is seen that on reaching the ground, the velocity of the body dropped from a certain height is equal to the velocity with which it is projected vertically upwards.

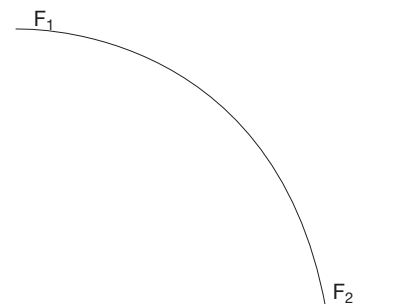
TWO-DIMENSIONAL MOTION

EXAMPLE

An aeroplane is flying horizontally at a height of 500 m with a velocity of 72 km h^{-1} over a flood affected area. Food packets are to be dropped for the people standing at a particular place on the ground. At what horizontal distance from that place should the food packets be released from the plane, so as to reach the intended place?

SOLUTION

When a food packet is released from an aeroplane moving horizontally, due to inertia the food packets would have an initial velocity equal the velocity of the plane, i.e., 72 km h^{-1} in the horizontal direction, while the initial velocity in the vertical direction



would be zero. Thus, the motion of the body is in two dimensions – vertical, under the influence of gravity (acceleration = $+g \text{ m s}^{-2}$) and horizontal due to its initial velocity as shown in figure.

Furthermore, let us neglect the effects of wind and air drag. Considering the vertical motion alone, the time taken by a packet to reach the ground is, time of descent,

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 500}{10}} = \sqrt{100} = 10 \text{ s}$$

Simultaneously, the packet is also moving horizontally. Packet travels with uniform velocity

$$u = 72 \text{ km h}^{-1} = 72 \times \frac{5}{18} \text{ m s}^{-1} = 20 \text{ m s}^{-1},$$

in the horizontal direction is not any force acting in the horizontal direction.

Let x be the horizontal distance travelled by the packet in the time of descent.

$$\begin{aligned} \text{Using } s &= ut + \frac{1}{2}at^2 \text{ in the horizontal direction, } \because a = 0, \text{ we get } x = (20 \text{ m s}^{-1}) \times (10 \text{ s}) \\ &= 200 \text{ m. } (\because a_n = 0) \end{aligned}$$

Thus, the food packets should be dropped from the plane at a horizontal distance of 200 m from the intended place for the people to be able to receive them.

SIGN CONVENTION

While solving numerical questions, it would be convenient to adopt one single sign convention rather than remembering two sets of equations of motion for bodies moving along a vertical path under the influence of gravity, whether freely falling bodies or those projected vertically upwards.

According to this sign convention, displacement velocity and acceleration, being vector quantities are taken as positive quantities when directed upwards and as negative quantities when directed downwards.

According to this sign convention, displacement, velocity and acceleration, being vector quantities, are taken as positive quantities when directed upwards and as negative quantities when directed downwards.

Quantity	Body projected downwards (Freefall)	Body projected upwards
Initial velocity	$-u$	$+u$
Final velocity	$-v$	$+v$
Acceleration	$-g$	$-g$
Displacement	$-h$	$+h$
$V = u + at$	$-v = -u - gt$ $\Rightarrow v = u + gt$	$V = u - gt$

Quantity	Body projected downwards (Freefall)	Body projected upwards
$V^2 - u^2 = 2as$	$v^2 - u^2 = 2(-g)(-h)$ $\Rightarrow v^2 - u^2 = 2gh$	$v^2 - u^2 = 2(-g)(+h)$ $\Rightarrow v^2 - u^2 = -2gh$
$s = ut + \frac{1}{2}at^2$	$-h = -ut - \frac{1}{2}gt^2$ $\Rightarrow h = ut + \frac{1}{2}gt^2$	$+h = ut + \frac{1}{2}(-g)(t^2)$ $\Rightarrow h = ut - \frac{1}{2}gt^2$
$S_n = u + a/2 (2n - 1)$	$-Hn = -u + (-g)/2 (2n - 1)$ $\Rightarrow Hn = u + g/2 (2n - 1)$	$+Hn = u + (-g)/2 (2n - 1)$ $\Rightarrow Hn = u - g/2 (2n - 1)$

EXAMPLE

A body at rest falls from a height and covers 34.3 m in the last second of its fall. Find the height from which the body is dropped.

SOLUTION

Let the body take ' n ' seconds to reach the ground. Thus, n th second is its last second of fall. Initial velocity of the body, $u = 0 \text{ m s}^{-1}$. The distance covered by the body in its n th second $s_n = 34.3 \text{ m}$. Using $s_n = u + g(n - \frac{1}{2})$, we get $34.3 = 0 + 9.8 \left(n - \frac{1}{2}\right) \Rightarrow n = 4$

Thus, the duration of the fall for the body is $t = 4$ seconds.

$\therefore$ The height from which the body is dropped, $h = \frac{1}{2}gt^2 = \frac{1}{2}(9.8)(4)^2 = 78.4 \text{ m}$.

EXAMPLE

A stone is dropped from the top of a tower and it reaches the ground in 8 s. How much time will it take to cover the first quarter of the distance from the top?

SOLUTION

Let the height from which the stone is dropped be x . Since the stone is dropped its initial velocity, $u = 0 \text{ m s}^{-1}$, $s = -x$, $a = -g$

Time of descent of the stone, $t = 8 \text{ s}$

$\therefore$ From the equation $s = ut + \frac{1}{2}at^2$, we have

$$x = \frac{1}{2}g \times 8^2$$

$$x = 32g \quad (1)$$

Let t_1 be the time taken to cover first quarter of the distance

$$\therefore \frac{1}{2} = \frac{1}{2} g t_1^2$$

$$\therefore x/4 = \frac{1}{2} g t_1^2$$

$$\Rightarrow \frac{32g}{4} = \frac{1}{2} g t_1^2$$

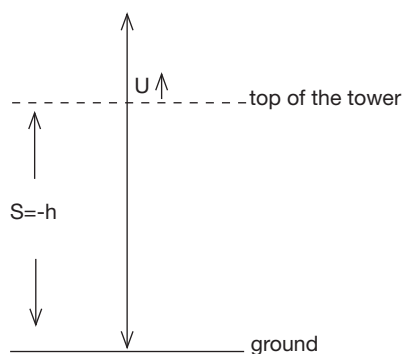
$$\Rightarrow t_1^2 = 16$$

$$\Rightarrow t_1 = 4 \text{ s}$$

EXAMPLE

A ball is thrown vertically upwards from the top of a tower with a velocity 10 m s^{-1} . The ball reaches the ground with a velocity of 30 m s^{-1} . What is the height of the tower?

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



SOLUTION

According to the sign convention, taking the vectors in the upward direction as positive

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

Final velocity, $v = -30 \text{ m s}^{-1}$

Displacement, $s = -h$, where h is the height of the tower and acceleration, $a = -10 \text{ m s}^{-2}$.

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

we get

$$(-30)^2 = (10)^2 + 2(-10)(-h)$$

$$\therefore h = \frac{(-30)^2 - 10^2}{2 \times 10} = \frac{900 - 100}{20} = 40 \text{ m}$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Motion of an aeroplane is an example of _____ dimensional motion.
2. Define maximum height.
3. A particle is projected up with a velocity of $\sqrt{29}$ m s⁻¹ from the top of a tower of height 10 m. Its velocity on reaching the ground is _____ m s⁻¹
4. In a velocity time graph, the negative slope indicates _____.
5. Define time of ascent and time of descent.
6. A body is falling freely under gravity. The distances covered by it in the first, second and third seconds of its motion are in the ratio of _____.
7. The equations of motion are applicable only when the body moves with _____.
8. A hollow iron ball and a solid iron ball are dropped from the same height. Which ball reaches the ground first?
9. Show that for a body, the magnitude of velocity of projection in the upward direction is the same as the magnitude of velocity of the body on reaching the point of projection in its downward motion.
10. The sum of the time of ascent and the time of descent is called _____.
11. What is acceleration due to gravity?
12. A stone is dropped from the top of tower and it reaches the ground after 3 s. Then the height of that tower is _____ g = 10 m s⁻².
13. Two balls are dropped from heights h_1 and h_2 , respectively. The ratio of their velocities on reaching the ground is _____.
14. What is the acceleration of a body when it is projected vertically upwards?
15. Two bodies of different masses m_1 and m_2 are dropped from two different heights h_1 and h_2 . The ratio of the times taken by the two to reach the ground is _____.
16. If an object is thrown vertically up with a velocity of 19.6 m s⁻¹, it strikes the ground after _____ s.
17. Write the equations of motion for a body projected vertically downwards.
18. If a body is projected horizontally from top of a building. In 2 second, it falls vertically through a distance of _____ m. ($g = 10$ m s⁻²)
19. What is time of flight?
20. If two balls are thrown vertically upwards with the same velocity, what is the difference in the maximum height gained by them?

Short Answer Type Questions

21. Deduce an expression for the maximum height reached by a body.
22. Obtain an expression for time of flight.
23. Why does the velocity decrease when the body is projected upwards?
24. Show that the time of ascent is equal to time of descent for a body projected vertically upward.
25. Derive an expression for the velocity when a body dropped from a height reaches the ground.

Essay Type Questions

26. Two kids standing on different floors of an apartment block drop balls from the balconies. The second kid standing at a lower level drops the ball 2 seconds after the first kid does. Both the balls reach the ground simultaneously, 5 seconds from the time the first ball was dropped. What is the difference between the heights of the two balconies? (Take $g = 10$ m s⁻²)
27. A ball is dropped from a certain height. If it takes 0.2 s to cross the last 6.2 m before hitting the ground, find the height from which it was dropped. (Take $g = 10$ m s⁻²)
28. A ball is thrown vertically upwards with a speed of 30 m s⁻¹. Draw a graph showing the velocity of the ball as a function of time. (Take $g = 10$ m s⁻²)
29. A man standing at a distance of 6 m from a building 21.6 m high observes a kid slipping from the top floor. With what speed should he run to catch the kid at a height of 2 m from the ground? (Assume speed of the person to be uniform; $g = 10$ m s⁻²)
30. A stone is dropped from a height of 45 m. What will be the distance travelled by it during the last second of its motion? (Take $g = 10$ m s⁻²)



CONCEPT APPLICATION

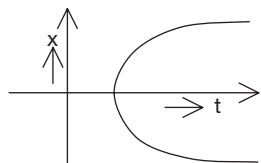
Level 1

Directions for questions 1 to 7:

State whether the following statements are true or false.

- The area under acceleration time graph gives change in velocity.
- A particle cannot have its displacement (x) versus time (t) graph, as shown in the figure below.

Graph



- The direction of acceleration due to gravity depends on the direction of motion of a body.
- A projectile has constant speed in horizontal direction.
- The displacement of a body has the same direction as that of its average velocity.
- A body can have constant velocity and still have varying speed.
- The velocity of a body can change even if its acceleration is zero.

Directions for questions 8 to 14:

Fill in the blanks.

- For a projectile, the magnitude of acceleration in the horizontal direction is _____ and that in the vertical direction is _____.
- If a particle moves from A to B along a straight line with velocity v_1 and then B to A with velocity v_2 , its average velocity is _____.
- The time taken by a body which is projected horizontally from a height ' h ' from the ground to reach the ground is _____.
- Two balls are dropped from heights h_1 and h_2 , respectively. The ratio of their time of descents is _____.

- A body is projected vertically upward with velocity u m s^{-1} . When it returns to the point of projection, its velocity is _____.
- The _____ of motion changes during the motion of a projectile.
- During upward motion of a body projected vertically upward, the angle between velocity and ' g ' is _____.

Directions for questions 15:

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

15. (a)

Column A	Column B
Constant speed	Body on
A. with varying () (a)	reaching point of
velocity	projection.
B. Zero displacement () (b)	Uniform circular
and finite distance.	motion
Final velocity	At any
C. (v) = 0, finite () (c)	intermediate
acceleration	point of a body
	dropped from
	certain height
Zero vertical	At highest point
D. velocity and non- () (d)	of body projected
zero acceleration	vertically up.

(b)

Column A	Column B
Vertical	A body dropped
P. component of () (p)	from a certain
velocity is zero.	height
Q. Non-uniform () (q)	At maximum
velocity	height of a body
	under projectile
	motion.
R. Zero initial () (r)	Parachute
velocity	descending
	down from an
	aeroplane.
S. Retarded motion () (s)	Motion of a car
	on a busy road.



Directions for questions 16 to 40:

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

16. A body projected vertically up has displacement of 16 m in the first n seconds while it was moving up. Its magnitude of displacement in the last n second while falling down is

(a) 8 m (b) 4 m
(c) 16 m (d) 2 m

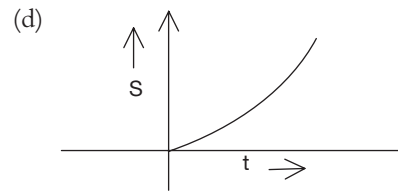
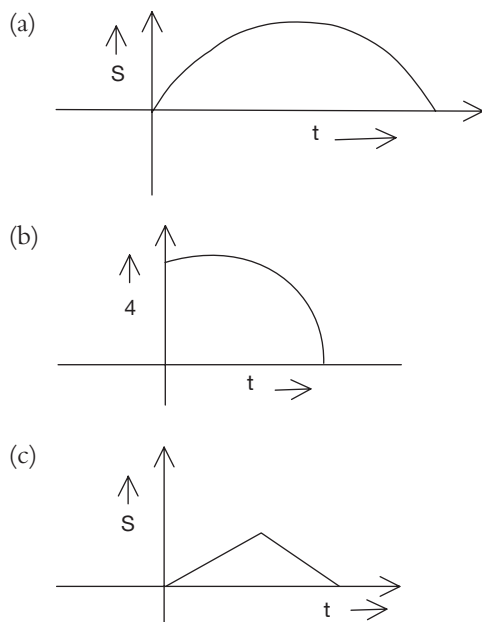
17. The acceleration of a moving body can be found out from

(a) slope of velocity time graph.
(b) area under velocity time graph.
(c) slope of distance time graph.
(d) area under distance time graph.

18. Two bodies are projected from the ground with the same speed. If the angles of their projection from the ground are 45° and 15° , respectively, the ratio of their ranges is

(a) 1 : 2 (b) 2 : 1
(c) $\sqrt{3} : 2$ (d) $1 : \sqrt{2}$

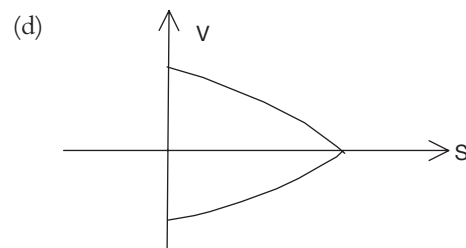
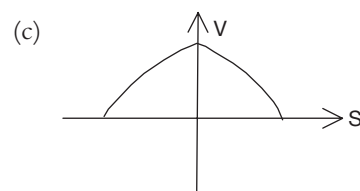
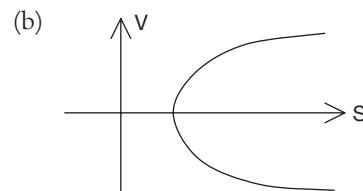
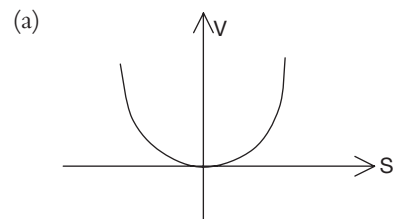
19. The displacement–time, graph for a body thrown vertically up and falling back to the point of projection, is _____.



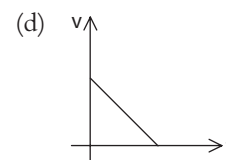
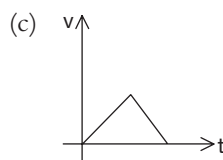
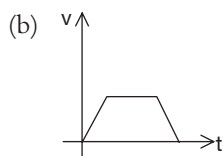
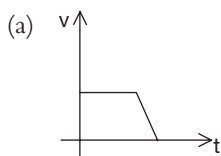
20. A stone dropped from the top of a tower travels 4.9 m in the last second, then the velocity of the stone on reaching the ground is

(a) 19.6 m s^{-1} (b) 9.8 m s^{-1}
(c) 4.9 m s^{-1} (d) 29.4 m s^{-1}

21. The graph of velocity versus displacement of a body which is thrown vertically up and falling back to the point of projection is _____.



22. A body is projected vertically up from the ground with certain velocity. Its velocity is reduced to $\frac{1}{4}$ th of its initial velocity at 75 m height. Then the maximum height reached by the body is
 (a) 75m (b) 80m
 (c) 100m (d) 40m
23. If a body is projected with certain velocity making an angle 30° with the horizontal, then
 (a) its horizontal velocity remains constant.
 (b) its vertical velocity changes.
 (c) on falling to the ground, its vertical displacement is zero.
 (d) All of the above
24. A freely falling body from rest acquires velocity V in falling through a distance h . If here after the body falls through a further distance h , velocity acquired by it is
 (a) $2V$ (b) V
 (c) $\sqrt{2}V$ (d) $4V$
25. Two cars A and B move such that car A moving with a uniform velocity of 15 m s^{-1} overtakes car B moving from rest with an acceleration of 3 m s^{-2} . The time, after which, they meet again, is
 (a) 5 s (b) 15 s
 (c) $\sqrt{3}s$ (d) 10 s
26. A stone dropped from the top of a tower travels 15 m in the last second of its motion. If $g = 10 \text{ m s}^{-2}$, then the time of fall is
 (a) 2 s (b) 2.5 s
 (c) 5 s (d) 3 s
27. A body is projected vertically upward with certain velocity. The magnitude of its displacement in the last second of its upward motion is _____.
 (a) $2g$ (b) $\frac{g}{3}$
 (c) $\frac{g}{2}$ (d) $\frac{3g}{2}$
28. In the following $v-t$ graphs, identify the graph that represents a body moving initially with uniform velocity and then with uniform retardation until it stops.



29. Three bodies A, B and C are thrown simultaneously with the same speed from the top of a building. A is thrown vertically upward, B horizontally and C, vertically downward. All the three, on reaching the ground,
 (a) have equal velocities.
 (b) have equal vertical displacements.
 (c) take equal time to reach the ground.
 (d) Both (a) and (b)
30. An ant moves along the sides of a square room ABCD of length 4 m starting from A, it reaches the opposite corner C by travelling from A to B and from B to C. If the time taken is 2 s , the average velocity of the ant is
 (a) 4 m s^{-1} (b) $2\sqrt{2} \text{ m s}^{-1}$
 (c) 2 m s^{-1} (d) $4\sqrt{2} \text{ m s}^{-1}$
31. A body started with a velocity of 20 m s^{-1} and moving with an acceleration of 2 m s^{-2} . The distance travelled by the body in the 8th second is _____ m.
 (a) 35 (b) 20
 (c) 120 (d) 10
32. A body starts from rest and moving with an acceleration 2 m s^{-2} and covering a distance of 10 m . The final velocity of the body is _____ m s^{-1} .
 (a) $\sqrt{98}$ (b) $\sqrt{40}$
 (c) $\sqrt{20}$ (d) $\sqrt{12}$
33. A body initially moving with a velocity of 5 m s^{-1} , attains a velocity of 25 m s^{-1} . The acceleration of the body in 5s is _____ m s^{-2} .
 (a) 8 (b) 7
 (c) 4 (d) 3
34. A body starts from rest, and moving with an acceleration of 1 m s^{-2} . The displacement of the body in 5 seconds is _____ m.
 (a) 12.5 (b) 25
 (c) 7.5 (d) 15



35. Two bodies of different masses are dropped from heights of 2 m and 8 m, respectively, then the ratio of the time taken by them is _____ m.

- (a) 1 : 4 (b) 1 : 1
(c) 1 : 2 (d) 1 : 3

36. An object is thrown vertically upward with a velocity of 10 m s^{-1} . It strikes the ground after _____ seconds. (Take $g = 10 \text{ m s}^{-2}$)

- (a) 10 (b) 2
(c) 5 (d) 1

37. An object is released from a balloon rising up with a constant speed of 2 m s^{-1} . Its magnitude of velocity after 1 s is _____ m s^{-1} .

- (a) 5.3 (b) 7.8
(c) 2.8 (d) 6.4

38. A ball is projected vertically up with a velocity of 20 m s^{-1} . Its velocity when it reaches 15 m height is _____ m s^{-1} . (Take $g = 10 \text{ m s}^{-2}$)

- (a) 10 (b) 15
(c) -10 (d) Both (a) and (c).

39. Two balls are projected horizontally from the top of a building simultaneously with velocities 15 m s^{-1} and 20 m s^{-1} , respectively. The ratio of times taken by them to reach the ground _____ is.

- (a) 2 : 3 (b) 3 : 4
(c) 1 : 1 (d) 4 : 9

40. A body 'A' is dropped from a height h and the other body B is thrown horizontally with a velocity of 10 m s^{-1} from the same height simultaneously. If the time taken by the body A to reach the ground is 3 s, arrange the following steps in a proper sequence to find the velocity of the body 'B', in vertical direction when it is at a vertical height of 20 m above the ground.

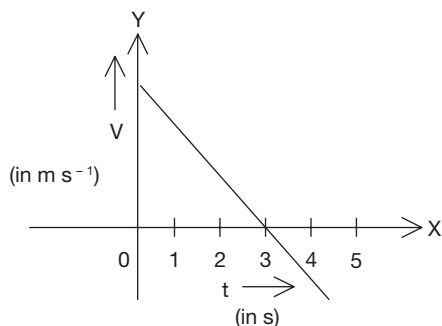
- (a) Find the displacement covered by the body B when it is at a height of 20 m.
(b) Calculate of the vertical height from the ground through which both the bodies are falling.
(c) Write the required equation of motion and calculate the velocity at the given point.
(d) Analyse the relation between the motions of two bodies.
- (a) d c a b (b) d b a c
(c) a b c d (d) d b c a

Level 2

41. A lift ascends from rest with uniform acceleration of 4 m s^{-2} . Then it moves with uniform velocity and finally comes to rest with a uniform retardation of 4 m s^{-2} . If the total distance covered during ascending is 28 m and the total time for ascending 8 s, respectively, then find the time for in which the lift moves with uniform velocity. Also find its uniform velocity.

42. The following graph represents the velocity-time graph of a body projected vertically upward under gravity.

Find the maximum height attained by the body. (Take $g = 10 \text{ m s}^{-2}$)



43. A body moves with a uniform speed in a circular path of radius r . What is the displacement of the body on covering $(1/4)$ th of the revolution?

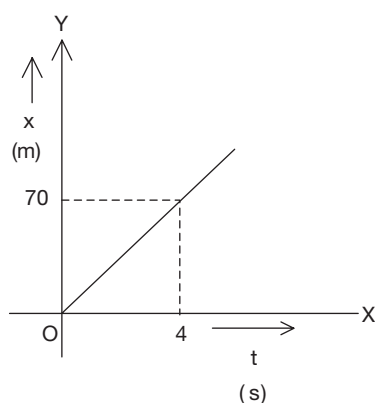
44. A body is projected vertically upward. Show that the

- (i) distance covered by it in the first ' n ' seconds of ascent is equal to the distance covered by it in the first ' n ' seconds of its descent.
(ii) the distance covered by it in the last ' n ' seconds of ascent is equal to the distance covered by it in the first ' n ' seconds of its descent.

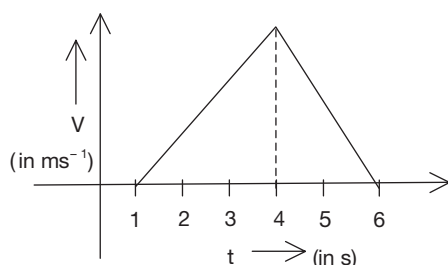
45. A missile is launched from the ground making 45° with the horizontal to hit a target at a horizontal distance of 300 km. If it is required to hit a target at a horizontal distance of 675 km launched at same angle with horizontal, find the percentage change in its velocity of projection.



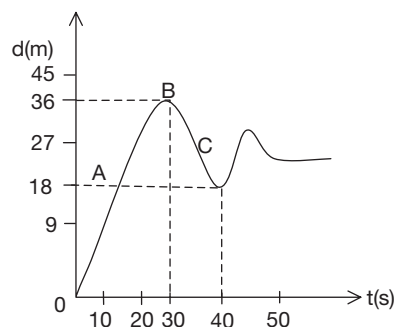
46. A freely falling body acquires a velocity ' v ' m s^{-1} in falling through a distance of 80 m. How much further distance should it fall, so as to acquire a velocity of ' $2v$ ' m s^{-1} ? (Take $g = 10 \text{ m s}^{-2}$)
47. A body is dropped from certain height H . If the ratio of the distances traveled by it in $(n - 3)$ seconds to $(n - 3)$ rd second is $4 : 3$, find H . (Take $g = 10 \text{ m s}^{-2}$)
48. The variation of horizontal displacement (x) of a projectile with time (t) is as shown in the figure below. If the angle of projection is 60° , find the velocity of projection.



49. A juggler sets 4 balls in motion in succession to a height of 19.6 m from his hand. What is the velocity of projection of each ball? Once set in motion, what are the displacements of the other three balls when the 2nd ball just leaves his hand?
50. A person watching through the window of an apartment sees a ball that rises vertically up and then vertically down for a total time of 0.5 s. If the height of the window is 2 m, find the maximum height above the window reached by the ball. ($g = 10 \text{ m s}^{-2}$).
51. A freely falling body crosses points P , Q and R with velocities V , $2V$ and $3V$, respectively. Find the ratio of the distances PQ to QR .
52. The velocity-time graph of a car is as shown in the figure below. Find the acceleration and deceleration of the car if its total displacement is 90 m.



53. In the displacement versus time graph below find the average velocity in the time interval of 0 to 30 second. Comment on the signs of velocities at points A , B and C .



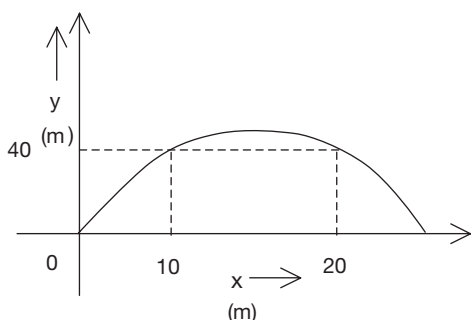
54. Are the equations of motion applicable to bodies projected vertically up with any velocity, say 8 km s^{-1} , for determining the maximum height?
55. A stone is thrown horizontally from a tower with certain velocity and at the same time, another stone is dropped freely from the same height. Which stone reaches earlier? Explain.
56. In the 2008 Olympics held in Beijing, Usain Bolt of Jamaica set a new world record in 100 meter race, He completed the 100 meter run in 9.69 s.
- Determine his average speed in km h^{-1} .
 - If he has travelled 90 m in 8.69 s, calculate his average velocity in the last second.
 - If he has maintained a uniform acceleration for the first 8.69 s, calculate the acceleration and the velocity at the end of 8.69 s.
57. Drag racing is a competition in which the vehicles compete to be the first to cross the finishing point along a straight path. In July 2009 Schumacher set a record by completing 400 m in 4.428 s in the drag racing competition.
- Determine the average velocity of his car.
 - If he maintained a uniform velocity for the last 50 m and he covered that distance in 1 s determine the velocity at the end of 350 m.
 - Determine the acceleration if he maintained a uniform acceleration in the first second and the distance travelled is 37.5 m. The velocity at the end of first second is 75 m s^{-1} .



58. What is the condition for which the average velocity and average speed of a body are equal?
59. Two bodies are projected from the ground with the same speed. If the angles of their projection from the ground are 30° and 60° , respectively, what is the ratio of their horizontal displacements after 2 s?
60. Compare the motion of a body dropped to that of a horizontal projectile, both falling from the same height.

Level 3

61. The displacement (x) variation of a particle with time (t) is given by expression $x = -15t^2 + 20t + 30$ find the position of the body at $t = 0$ s and $t = 6$ s. Is this particle moving with uniform acceleration? Explain.
62. The horizontal range of a bullet fired with angle of projection 45° to the horizontal is 360 m. If it is fired from a lorry moving in the direction of bullet with the uniform velocity 18 km hr^{-1} and with same elevation, what is the new range horizontal distance traveled by the bullet? (Take $g = 10 \text{ m s}^{-2}$).
63. The graph of vertical displacement (y) versus horizontal displacement (x) of a projectile is as shown below.



From the values given in the graph, find the time at which the projectile has the displacements, as indicated in the graph.

64. A body moving linearly with uniform acceleration covers distances p , q , r and s after successive intervals of time, t s. Find the ratio of $\frac{(s-p)}{(r-q)}$
65. A small steel ball is dropped from a height of 2.5 m into a tall glycerin jar. It hits the surface of glycerin with certain velocity and sinks to the bottom by losing 20% of its velocity at the surface. If the time taken to reach the bottom after it is dropped is 2 s and velocity in glycerin is lost at constant rate, then find the average velocity of the ball over the whole journey.
66. A person travels two parts of the total distance in the ratio 2 : 1 with constant speeds of 30 km h^{-1} and 40 km h^{-1} , respectively. What is the average speed of the journey?
67. An automobile traveling with a speed of 72 km h^{-1} , can be stopped within a distance of 30 m, by applying brakes. What will be the stopping distance, if the automobile speed is increased to $\sqrt{3}$ times and the same breaking force is applied?
68. A body takes ' t ' seconds to reach a maximum height ' H ' m, when projected vertically upward from the ground. Find the position of the body after $\frac{t}{2}$ seconds from the ground in terms of H .
69. A hot air balloon, released from ground, moves up with a constant acceleration of 5 m s^{-2} . A stone is released from it at the end of 8 seconds. Find the height of the stone from the ground at the end of 8 seconds after it is released from the balloon. (Take $g = 10 \text{ m s}^{-2}$)
70. A stone thrown from the ground just crosses a wall of height 5 m in 2 s. If the wall is at a horizontal distance 25 m, from the point of projection of the stone, find at what distance the stone falls behind the wall. (Take $g = 10 \text{ m s}^{-2}$).



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. zero, g 9. 0 10. $\sqrt{\frac{2h}{g}}$ 11. $\sqrt{h_1} : \sqrt{h_2}$ 12. $-u \text{ m s}^{-1}$ 13. direction 14. 180°

Match the following

15. (a) A : b B : a C : d D : c
(b) P : q Q : s R : p S : r

Multiple choice questions

16. (c) 17. (a) 18. (b) 19. (a) 20. (b) 21. (d) 22. (b) 23. (d) 24. (c) 25. (d)
26. (a) 27. (c) 28. (a) 29. (b) 30. (b) 31. (a) 32. (b) 33. (c) 34. (a) 35. (c)
36. (b) 37. (b) 38. (d) 39. (c) 40. (b)

Explanation for questions 31 and 40:

31. $S_n = ?$, $u = 20 \text{ m s}^{-1}$, $a = 2 \text{ m s}^{-2}$, $n = 8$

$$S_n = u(1s) + a\left(n - \frac{1}{2}\right) = 20 + 2\left(8 - \frac{1}{2}\right) (1s)$$

$$= 20 + (16 - 1) = 20 + 15 = 35$$

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

$$v^2 - 0 = 2 \times 2 \times 10 = 40 \Rightarrow v = \sqrt{40} \text{ m s}^{-1}$$

33. $u = 5 \text{ m s}^{-1}$, $v = 25 \text{ m s}^{-1}$, $t = 5 \text{ s}$

$$a = \frac{v - u}{t} = \frac{25 - 5}{5} = 20 / 5 = 4 \text{ m s}^{-2}$$

34. $s = ?$, $u = 0$, $a = 1 \text{ m s}^{-2}$, $t = 5 \text{ s}$

$$s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times 1 \times 25 = 12.5 \text{ m}$$

35. $u = 0$

$$h \propto t^2$$

$$\therefore \sqrt{\frac{h_1}{h_2}} = \frac{t_1}{t_2}$$

$$t_1 : t_2 = 1 : 2$$

36. $u = 10 \text{ m s}^{-1}$; $t = 2u/g = 2 \times 10/10 = 2 \text{ s}$

37. $u = -2 \text{ m s}^{-1}$; $t = 1 \text{ s}$

$$v = u + at = -2 - 9.8 \times 1 = -7.8$$

38. $u = 20 \text{ m s}^{-1}$

$$s = 15 \text{ m},$$

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

$$v^2 - (20)^2 = 2 \times 10 \times -15$$

$$v^2 = 100 \Rightarrow v = +10 \text{ m s}^{-1}$$

39. As the initial vertical velocity is zero in both the cases they take the same time to reach the ground.

40. (i) The vertical motion of a horizontal projectile is same as that of a freely falling body.

$\therefore$ The time taken to reach the ground for the horizontal projectile, $t = 3 \text{ s}$.

- (ii) $\therefore$ The vertical height from the ground,

$$h = \frac{1}{2}gt^2 = \frac{1}{2} \times 10 \times 3^2 = 45 \text{ m}$$

- (iii) The displacement covered by 'B' when it is at a height of 20 m from the ground, $h_1 = 45 - 20 = 25 \text{ m}$.

- (iv) $\therefore v^2 = u^2 + 2g h_1$

$$v^2 = 2 \times 10 \times 25 = 500$$

$$v^2 = \sqrt{500} = 10\sqrt{5} \text{ m s}^{-1}$$



Level 2

41. (i) Find the time for acceleration, retardation and uniform velocity by using equations of motion.
 (ii) Find the time during it is moving with uniform velocity.
 (iii) Find the uniform velocity time?
 (iv) 4 m s^{-1}
42. (i) Find the velocity at $t = 3 \text{ s}$. This gives the velocity v .
 (ii) From $v = u - gt$, find the value of u by substituting the value of v , g and t .
 (iii) Find the maximum height by substituting the values of u , v and g in equation $v^2 = u^2 - 2gh$.
 (iv) 45 m
43. (i) Find the relation between the number of revolutions and the corresponding angle described.
 (ii) Using the definition of displacement, identify the initial and final points
 (iii) Using trigonometric ratios find the displacement for $\frac{1}{4}$ th of the revolution.
 (iv) $\sqrt{2}$
44. (i) Find the velocity v_1 of a body projected upwards after $t = (t_1 - n)$ seconds $t_1 = \text{time of ascent} = (u_1/g)$ using equation $v_1 = u_1 - gt$
 (ii) v_1 is the initial velocity in the beginning of last n seconds
 (iii) Find s_1 by substituting $v = 0$ and $u = v_1$ in equation $v^2 = u^2 - 2gs_1$
 (iv) Find the displacement s_2 for the body falling from rest for n seconds using equation $s = ut + \frac{1}{2}gt^2$
 (v) Compare s_1 and s_2 .
45. (i) Consider the relation between the horizontal distance and the initial velocity.
 (ii) 50% increase
46. (i) Let h_1 be the displacement during which the velocity changes from v to $2v$. Find h_1 by substituting $u = v$, $v = 2v$ in equation $v^2 = u^2 + 2gh_1$
 (ii) Find v^2 for a body dropped from a height of 80 m from the equation $v^2 = u^2 + 2gh$
 (iii) Substitute the value of v^2 in equation obtained in 1 and find h_1
 (iv) 240 m
47. (i) Obtain the equation for the distance travelled in $(n - 3)$ seconds using equation $s_1 = \frac{1}{2}gt^2$
 (ii) Obtain equation for the distance travelled in $(n - 3)$ rd second using equation $s_n = u + \frac{g}{2}(2n - 1)$
 (iii) Divide equation obtained from 1 by equation obtained in 2
 (iv) Equate the ratio to $4 : 3$
 (v) Find the value of n
 (vi) Substitute the value of n in equation $s = \frac{1}{2}gt^2$ ($t = n$) and find s which gives the value of H .
 (vii) 125 m
48. (i) Find the value of x and t in the graph
 (ii) Find the value of velocity of projection, u , using the equation $x = u \cos \theta \cdot t$
 (iii) 35 m s^{-1}
49. (i) Find h for all the balls using u and t .
 (ii) $14.7 \uparrow, 19.6, 14.7 \downarrow$
50. (i) Let h be height above the window by which the ball rises and t_1 be the time.
 (ii) The height of the ball from its fall is given by, $h = \frac{1}{2}gt_1^2$.
 (iii) Time taken for the ball to cross the window = $(t_1 + \frac{1}{4})$ seconds and distance covered to cross the window = $h + 2$.
 (iv) Substitute $s = h + 2$, $u = 0$ and time $t = t_1 + \frac{1}{4}$ in the equation $s = ut + \frac{1}{2}gt^2$.
 (v) Equate R.H.S. of 2 and 4 and find t .
 (vi) Substitute the value of t in 2 and find h .
 (vii) 160 m
51. (i) Consider the equation of motion $v^2 = u^2 + 2gs$ for a freely falling body.
 (ii) Velocity at P is the initial velocity and velocity at Q is the final velocity for the displacement PQ .
 (iii) Substitute initial and final velocity in equation given in 1 and find S_1 .



- (iv) Similarly velocity at Q and velocity at R are initial and final velocity for the displacement $QR = S_2$.
- (v) Substitute the initial velocity and final velocity for displacement QR in equation as given in 1 and then find S_2 .
- (vi) Find the ratio S_1 and S_2 .
- (vii) 3 : 5
52. (i) Area under $v - t$ graph gives the total displacement.
- (ii) Area of triangle = $\frac{1}{2} \times \text{base} \times \text{height}$
- (iii) Substitute the base and area of the triangle and find the height of the triangle.
- (iv) The height of the triangle gives the maximum velocity attained by the car.
- (v) Find the time taken to attain maximum velocity, t_1 and the time taken to come to rest, t_2 from maximum velocity from the graph.
- (vi) Find acceleration using equation $v = at_1$ and deceleration using equation $v = u + at_2$ ($v = 0$ and substitute u , the maximum velocity of the car from iv)
- (vii) Acceleration = 12 m s^{-2}
Deceleration = 18 m s^{-2}
53. (i) Average velocity = $\frac{\text{Total displacement}}{\text{total time}}$
- (ii) 1.2 m s^{-1}
54. (i) When can the equations of motion be applied?
- (ii) As the height of the body above the earth's surface increases, does acceleration due to gravity remain constant?
55. As the vertied initial velocity of two stones are zero, they will reach the ground in the same time.
56. Given data:-
Distance travelled, (s) = 100 m
Time taken, (t) = 9.69 s
- (a) Average speed = $\frac{\text{total distance}}{\text{total time}}$

$$= \frac{100}{9.69} \text{ m s}^{-2} = \frac{100 \times 3600}{9.69 \times 1000} \text{ km h}^{-1}$$

$$= \frac{360}{9.69} = \frac{36000}{969} = 37.15 \text{ km h}^{-1}$$

- (b) Average velocity in the last second

$$= \frac{\text{total displacement in the last second}}{1 \text{ s}}$$

$$= \frac{(100 - 90)}{1} = \frac{10}{1}$$

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

$$= 2 \times 18 = 36 \text{ km h}^{-1}$$

- (c) $u = 0$, $v = ?$ $a = ?$ $t = 8.69 \text{ s}$, $s = 90 \text{ m}$

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

$$90 = 0 + \frac{1}{2} \times a \times (8.69)^2$$

$$a = \frac{90 \times 2}{(8.69)^2} = \frac{180}{75.52} = 2.38 \text{ m s}^{-2}$$

$$v = u + at = 0 + 2.38 \times 8.69 = 20.68 \text{ m s}^{-1}$$

57. (a) $S = 400 \text{ m}$, $t = 4.42 \text{ s}$

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

$$= \frac{400}{4.42} = \frac{40,00}{442} = 90.5 \text{ ms s}^{-1}$$

- (b) As he maintained the uniform velocity for the last 50 m, and the initial velocity at the beginning of 50 m is equal to the final velocity at the end of 350 m.

$$\therefore \text{velocity} = \frac{50}{1} = 50 \text{ m s}^{-1}$$

- (c) $u = 75 \text{ m s}^{-1}$, $s = 37.5 \text{ m}$, $t = 1 \text{ s}$; $a = ?$

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

$$37.5 = 0 \times 1 + \frac{1}{2} a \times 1^2$$

$$a = 37.5 \times 2 = 75 \text{ m s}^{-2}$$



58. The average velocity is the ratio of total displacement and time. The average speed is the ratio of total distance and time. Therefore, the average speed and average velocity are equal if the total displacement is equal to the total distance. That is if the body travels along a straight line without changing the direction.

59. $S_H = u_H \times t$

$$\therefore S_1 : S_2 = u \cos 30 \times 2 : u \cos 60 \times 2$$

$$= \sqrt{\frac{3}{2}} : \frac{1}{2} = \sqrt{3} : 1$$

Level 3

61. (i) Change in position is displacement
(ii) Change in displacement in 1s and is velocity
(iii) Change in velocity in 1s and is acceleration.

62. (i) Using the formula for horizontal distance calculate the initial velocity to find the time of flight. Using this time of flight calculate the additional the horizontal distance traveled by bullet fired from the lorry due to the motion of the lorry.

(ii) 402.42 m

63. (i) Find the value of t_1 in terms of u by substituting $x = 10$ in the equation $x = u \cos \theta \cdot t_1$
(ii) Similarly, find the value of t_2 by substituting $x = 20$ m in the above equation
(iii) Divide 1 and 2 to obtain the ratio t_1 and t_2 .
(iv) Divide vertical displacement, $y = u \sin \theta \times t - \frac{1}{2}gt^2$ by $g/2$.
(v) Write the above equation in a quadratic form with variable t , i.e., in the form of $At^2 + Bt + C = 0$
(vi) The roots of the above equation are t_1 and t_2 .
(vii) The product of roots, ie $t_1 t_2 = C/A$.
(viii) Substitute the values of C and A and find $t_1 t_2$.
(ix) Solve equation obtained from 3 and 8 which gives the value of t_1 and t_2 , given $y = 40$ m corresponding to $x = 10$ m and $x = 20$ m.

(x) 2 s and 4 s

64. (i) Find p, q, r, s using $s = ut + \frac{1}{2}at^2$

(ii) Finding the ratio of $\frac{(s-p)}{(r-q)}$

(iii) 3 : 1

60. (i) When the two bodies fall from the same height, the time taken by them to reach the ground is the same.
(ii) The two bodies will have the same vertical displacement at any instant of time.
(iii) When the body is projected horizontally, it has an initial velocity in the horizontal direction, but the velocity in the vertical direction is zero. The velocity increases in the vertical direction, as it reaches the ground. The vertical motion of a horizontal projectile is similar to that of body dropped from the same height.

65. (i) Find the velocity with which the ball moves in glycerine. Then find time for which it travels.
(ii) Find the distance traveled in glycerin.
(iii) Find average velocity.
(iv) 5.3 m s^{-1}

66. Let distances travelled be $2x$ and x .

$$\text{Time taken to travel } 2x \text{ distance} = \frac{2x}{30}$$

$$\text{Time taken to travel } x \text{ distance} = \frac{x}{40}$$

$$\text{Total time} = \frac{2x}{30} + \frac{x}{40}$$

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time taken}} = \frac{3x}{\frac{2x}{30} + \frac{x}{40}}$$

$$= \frac{3x}{\frac{8x+3x}{120}} = \frac{3x \times 120}{11x} = \frac{360}{11} = 32.7 \text{ km h}^{-1}$$

67. Given,

$$a = 72 \frac{\text{km}}{\text{h}} = 72 \times \frac{5}{18} = 20 \text{ ms}^{-1}$$

$$s = 30 \text{ m}$$

$$v = 0$$

$$\therefore \frac{30}{s} = \frac{u^2}{2a}$$



Since a is same, $s \propto a^2$

$$\frac{30}{s} = \frac{u^2}{(\sqrt{3}u)^2} \quad (\because u \text{ is increased to } \sqrt{3} \text{ times})$$

$$\frac{30}{s} = \frac{u^2}{3u^2}$$

$$s = 90\text{m}$$

68. Let ' h ' be the height attained by the body in $(t/2)$ second

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

$$\text{Substituting } s = h, t = \frac{1}{2}$$

$$h = u \times \frac{t}{2} - \frac{1}{2}g\left(\frac{t^2}{4}\right) \quad (1)$$

$$H = \frac{u^2}{2g} \Rightarrow u = \sqrt{2gH} \quad (2)$$

$$t = \frac{u}{g} = \frac{\sqrt{2gH}}{g} \quad (2)$$

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

$$h = \sqrt{2gH} \times \frac{\sqrt{2gH}}{2g} - \frac{g}{2} \times \frac{2gH}{4g^2}$$

$$\frac{2gH}{2g} - \frac{H}{4} = H - \frac{H}{4} = \frac{3}{4}H$$

69. The velocity of the stone, when it is released from the balloon is given by, $v = u + at$ and is equal to the velocity of the balloon. Consider downward direction as positive and substitute, $v = ?$, $u = 0$, $a = -5 \text{ m s}^{-2}$, $t = 8$

$$v = -5 \times 8 = -40 \text{ m s}^{-1} \quad (1)$$

The displacement of the stone after 8 s is

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

Substituting $s = h$, $u = -40 \text{ m s}^{-1}$,

$$t = 8\text{s}, g = 10 \text{ m s}^{-2}$$

$$h = -40 \times 8 + \frac{1}{2} \times 10 \times 8^2$$

$$h = -320 + 320 \quad h = 0.$$

The stone returns back to the position from where it was released, i.e., the height of the balloon from the ground at the end of 8 seconds.

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

Substitute, $u = 0$,

$$a = -5 \text{ m s}^{-2}, t = 8\text{s}$$

$$s = -\frac{1}{2} \times 5 \times 8 \times 8 = -5 \times 4 \times 8$$

$$s = -160 \text{ m}$$

$\therefore$ The height of the balloon from the ground is 160 m.

70. The horizontal component of the initial velocity

$$= \frac{25\text{m}}{2\text{s}} = 12.5 \text{ m s}^{-1}$$

Let the vertical component of the initial velocity be u .

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

$$5 = 2u - \frac{1}{2} \times 10 \times 4$$

$$u = \frac{25}{2} = 12.5 \text{ m s}^{-1}$$

$$\therefore \text{ Time of light} = \frac{2u \sin \theta}{g} = \frac{2 \times 12.5}{10} = 2.5\text{s}$$

$$\therefore \text{ Horizontal range} = (12.5 \text{ m s}^{-1}) \times (2.5 \text{ s})$$

$$= 31.25\text{m}.$$

Thus, the distance behind the wall

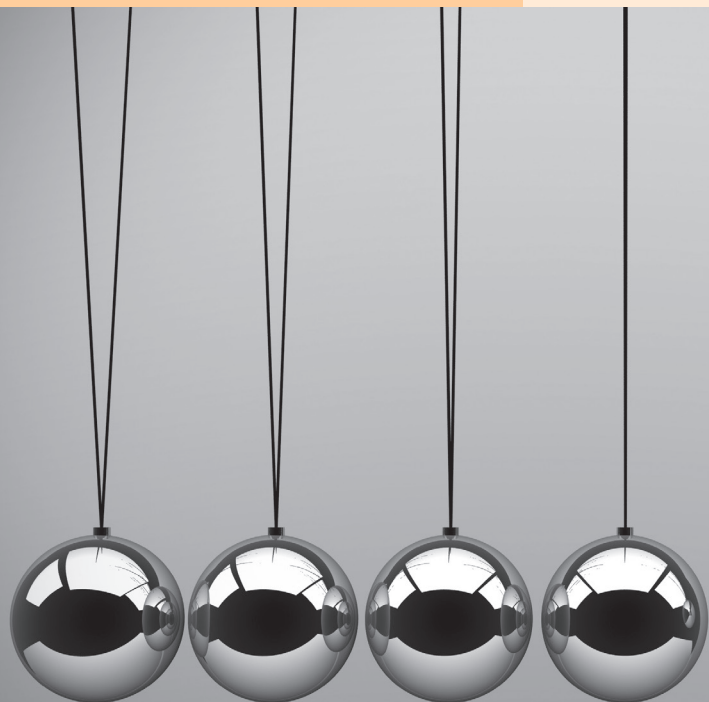
$$= 31.25 - 25 = 6.25 \text{ m}.$$



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Chapter 2

Dynamics



Remember

Before beginning this chapter, you should be able to:

- State Newton's three laws of motion
- Understand the different factors that affect the friction, the advantages and disadvantages of friction
- Study how energy is conserved and to understand the term power
- Learn the terms associated with a simple pendulum and to verify the laws of simple pendulum

Key Ideas

After completing this chapter, you should be able to:

- Learn laws of motion and their application in mechanics
- Understand the terms work, energy and power and to learn the different factors affecting them
- State some laws such as Law of conservation of momentum, Newton's universal law of gravitation, Principle of moments, Principle of orbiting satellite, etc.
- Study the different terms associated with the working of simple machines and to understand their working.
- Find differences between centripetal force and centrifugal force and study its applications on everyday life
- Understand the different terms related to circular motion and study circular motions

INTRODUCTION

Dynamics is an important branch of physics which deals with the effect of forces on bodies. Newton's laws of motion which are of great importance relate the type of motion of the body that results from the action of the forces. To understand Newton's laws, we need to define and understand the importance of a physical quantity called momentum.

LINEAR MOMENTUM

Activity 1: Drop a cricket ball on the pan of a beam balance from a certain height. Note down how far the needle swings. Now remove the cricket ball and drop a tennis ball on to the pan from the same height as that in the case of the cricket ball and note how far the needle swings in this case. It is found that the needle swings to a greater extent when the cricket ball is dropped on the pan of the balance.

Activity 2: Similar to activity 1, drop a cricket ball on the pan of the beam balance from different heights separately and note down the extent of swings of the needle of the balance in each case.

It is found that the swing of the needle is greater when the cricket ball falls from a greater height. Greater the height of the ball from which it is dropped, higher is its velocity on hitting the pan of the balance and greater is the swing of the needle.

Thus, from the above activity, it is found that greater the mass or velocity, greater is the impact of the ball on the pan of the balance.

This combined effect of mass and velocity gives rise to a physical quantity known as linear momentum. Linear momentum of a particle is denoted by ' p ' and that of a system of particles is denoted by P . It is defined as a product of its mass (m) and velocity (v). So, linear momentum can be written as linear momentum = mass $\times$ velocity $\Rightarrow P = m \times v$

Since the product of a scalar and vector is always a vector, momentum is a vector quantity and the direction of linear momentum is the same as that of velocity.

Units of Momentum

Unit of momentum = (unit of mass) (unit of velocity)

$\Rightarrow$ S.I. unit of $P = \text{kg m s}^{-1}$ or N s and

C.G.S. unit of $P = \text{g cm s}^{-1}$ or dyne second

Dimensional Formula

$P = m \times v \Rightarrow$ dimensional formula of $P = (\text{dimensional formula of mass}) \times (\text{dimensional formula of velocity}) = [M L T^{-1}]$

Thus, dimensional formula of P is $[M^1 L^1 T^{-1}]$.

Change of Linear Momentum

Linear momentum of a body changes in two cases. They are as follows.

1. When there is a change in the velocity of the body, and mass remaining constant:

Change in linear momentum $\Delta P = m \Delta v$, where Δv being the change in velocity

The above equation is valid only if $v \ll c$ or v is less than 10^6 m s^{-1} , where c is the velocity of light in vacuum.

- 2. When there is a change in mass with constant velocity:** When a truck is moving with constant velocity, and if the object in it are falling down through a hole, its mass decrease and then its momentum also decrease. It is represented by $\Delta p = \Delta m (v)$.

EXAMPLE

Calculate the velocity of a body of a mass 2 kg whose linear momentum is 5 N s.

SOLUTION

Linear momentum of the body = $P = \text{mass} \times \text{velocity}$

Mass, $m = 2 \text{ kg}$

Momentum, $P = 5 \text{ N s}$

Velocity, $v = ?$

$$P = mv$$

$$5 = 2 \times v$$

$$v = \frac{5}{2} = 2.5 \text{ ms}^{-1}$$

EXAMPLE

A car of mass 1000 kg is moving uniformly at 10 m s^{-1} . If the engine of the car develops an extra linear momentum of 1000 kg m s^{-1} , calculate the new velocity with which the car runs.

SOLUTION

Initial momentum of the car, $P_1 = m \times v_1$

$$P_1 = 1000 \times 10$$

$$P_1 = 10,000 \text{ N s or kg m s}^{-1}$$

Increase in momentum of the car = 1000 N s

Thus, new momentum of the car, $P_2 = P_1 + \text{increase in momentum}$

$$P_2 = 10,000 + 1000$$

$$P_2 = 11000 \text{ N s}$$

$$P_2 = m \times v_2, \text{ where } v_2 \text{ is the new velocity of the car.}$$

$$\therefore 11000 = 1000 \times v_2$$

$$v_2 = \frac{11000}{1000} = 11 \text{ ms}^{-1}$$

$$v_2 = 11 \text{ m s}^{-1}$$

NEWTON'S FIRST LAW OF MOTION

Statement

Every body remains in a state of rest or of uniform motion along a straight line unless it is acted upon by an external force.

Thus, from the above statement, acceleration is zero if the net force acting on the body is zero $\Rightarrow \vec{a} = 0$ if $\vec{F} = 0$.

This law states that every body resists the change in its state of rest or that of uniform motion. This property is known as inertia. Thus, Newton's first law is also called the law of inertia. If no force acts on a body, there always exists a reference frame in which the body has no acceleration. Such a reference frame is called an inertial reference frame.

NEWTON'S SECOND LAW OF MOTION

Statement

Rate of change of linear momentum is directly proportional to the net force acting on the body and takes place in the direction of the force.

Derivation

Consider a body of mass ' m ' moving with initial velocity ' u '. Let a force F act on it for ' t ' seconds, so that the velocity changes to v .

$$\text{Initial linear momentum of the body} \quad P_1 = mu$$

$$\text{Final linear momentum of the body} \quad P_2 = mv$$

$$\begin{aligned} \text{Change in linear momentum in } t \text{ second} &= P_2 - P_1 \\ &= mv - mu \end{aligned}$$

$$\text{Rate of change of linear momentum} = \frac{mv - mu}{t}$$

$$\text{According to Newton's second law of motion } F \propto \frac{mv - mu}{t}$$

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

From equations of motion $\frac{v - u}{t} = a$, the acceleration of the body

$$\therefore F \propto ma \Rightarrow F = kma$$

where k is constant of proportionality

If a force acting on a body of unit mass produces in it a unit acceleration, then the force acting on the body is one unit.

$$\text{Thus, } F = kma \Rightarrow (\text{unit force}) = k (\text{unit mass}) (\text{unit acceleration})$$

$$1 = k \times 1 \times 1$$

$$\therefore k = 1$$

$$\text{Thus, } F = ma$$

Alternate Method

Let ΔP be the change in the linear momentum of a body of mass ' m ' due to a force F acting on the body for a small interval of time Δt .

Then, rate change of linear momentum = $\frac{\Delta P}{\Delta T}$

$$\frac{\Delta P}{\Delta t} = \frac{\Delta(mv)}{\Delta t} \quad (\because P = mv) \quad (2.1)$$

or

$$\frac{\Delta P}{\Delta t} = m \frac{\Delta v}{\Delta t} \quad (2.2)$$

Equation 2.2 provided the mass of the body is constant.

From the second law of motion, we get $F \propto \frac{\Delta v}{\Delta t}$ or $F \propto m \frac{\Delta v}{\Delta t}$

But $\frac{\Delta v}{\Delta t}$ is the rate of change of velocity which is equal to acceleration

$$\therefore F \propto ma, \text{ i.e., } F = kma$$

Unit force is that force which acting on a body of unit mass produces in it a unit acceleration. Then k would be equal to 1, i.e., $k = 1$

Thus, $F = ma$.

Thus, the net force acting on a body produces an acceleration in it.

This law is the fundamental law of nature. Mathematically force is the product of mass and acceleration.

Impulse of a Force

When we hammer a nail to a wall, we apply a large force in a short interval of time. Thus, there is a change in the momentum of the hammer. This change in momentum is equal to the product of force and time for which the force is applied. This product is called impulse.

Thus,

$$\text{impulse} = \text{force} \times \text{time}$$

Unit of impulse is N s or kg m s⁻¹

Dimensional formula of impulse = [Force] $\times$ [time]

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

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

According to Newton's second law, acceleration produced in a given mass varies directly with the force applied. $a \propto F$ if mass is constant.

Thus, the graph of acceleration versus force is a straight line.

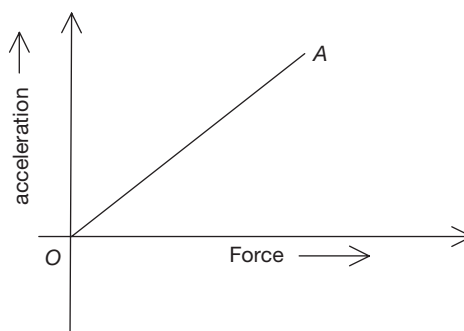


FIGURE 2.1 Acceleration-Force graph

From the second law, acceleration produced by a given force is inversely proportional to the mass $a \propto (1/m)$ provided force is constant.

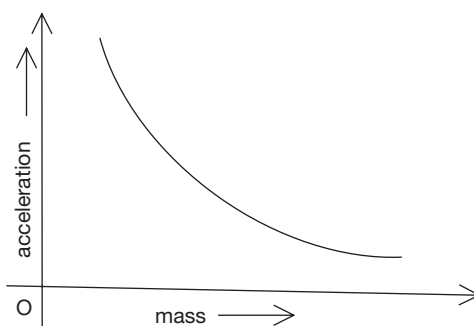


FIGURE 2.2 Acceleration-Mass graph

S.I. Unit of Force

Definition of newton (N): If a force acting on a body of mass 1 kg produces in it an acceleration of 1 m s^{-2} , then the force is said to be 1 newton. The S.I. unit of force is newton (N).

$$\therefore 1 \text{ newton} = 1 \text{ kg} \times 1 \text{ m s}^{-2}.$$

C.G.S. Unit of Force

Definition of dyne: One dyne is the force that acts on a body of mass 1 g and produces in it an acceleration of 1 cm s^{-2} . The C.G.S. unit of force is dyne.

$$\therefore 1 \text{ dyne} = 1 \text{ gram} \times 1 \text{ cm s}^{-2}.$$

Relation between Newton and Dyne

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

$$1 \text{ newton} = 1000 \text{ g} \times 100 \text{ cm s}^{-2}$$

$$1 \text{ newton} = 10^3 \times 10^2 \text{ g cm s}^{-2}$$

$$\text{Therefore, } 1 \text{ newton} = 10^5 \text{ dynes (1 dyne} = 1 \text{ g cm s}^{-2}\text{)}$$

Gravitational Unit of Force

If a force acts on a body of unit mass and produces in it an acceleration equal to the acceleration due to gravity of earth, then the force is said to be gravitational unit of force. In S.I. system, gravitational unit of force is kilogram force, represented by kg_f .

$$1 \text{ kg}_f = 1 \text{ kg} \times 9.8 \text{ m s}^{-2} = 9.8 \text{ N}$$

In C.G.S. system one gravitational unit of force is gram-force, represented by g_f .

$$1 \text{ g}_f = 1 \text{ g} \times 980 \text{ cm s}^{-2} = 980 \text{ dynes.}$$

NEWTON'S THIRD LAW OF MOTION

Statement

For every action, there is an equal and opposite reaction. If a body A exerts a force $-\vec{F}$ on body B, then B exerts a force $-\vec{F}$ on A.

EXAMPLE

A force of 500 N acts on a body of mass 1000 kg and the body is brought to rest within a distance of 64 m. Find the initial velocity and the time taken by the body to come to rest.

SOLUTION

Force, $= F = 500 \text{ N}$

Mass of the body, $m = 1000 \text{ kg}$

From Newton's second law of motion,

$F = ma$, where F , m and a are the force, mass and acceleration, respectively,

$$\therefore a = \frac{F}{m} = \frac{500}{1000} = 0.5 \text{ ms}^{-2}$$

To find initial velocity, consider the equation of motion $v^2 = u^2 + 2as$

Since the body is retarding, $a = -0.5 \text{ m s}^{-2}$ and since it comes to rest, $v = 0$

$$\therefore 0 = u^2 + (2 \times (-0.5) \times 64)$$

$$0 = u^2 - (1 \times 64)$$

$$\Rightarrow u^2 = 64 \Rightarrow u = \sqrt{64} = 8 \text{ m s}^{-1}$$

To find the time taken, consider the equation of motion

$$v = u + at$$

$$0 = 8 - 0.5 \times t$$

$$t = \frac{8}{0.5} = 16 \text{ s}$$

$$\therefore u = 8 \text{ m s}^{-1}, t = 16 \text{ s and } a = -0.5 \text{ m s}^{-2}$$

EXAMPLE

A ball of mass 50 g at rest is hit by a bat and the ball covers 400 m in 2 s. If the ball was in contact with the bat for 0.1 s, find the magnitude of force applied on it. Assume that no other force acts on the ball after it is hit by the bat.

SOLUTION

We are given that the distance covered by ball is 400 m

$$\therefore s = 400 \text{ m}$$

And, time in which the ball covers a distance of 400 m = 2 s

$$\therefore \text{Final velocity of the ball} = \frac{400}{2} = 200 \text{ ms}^{-1}$$

This is the velocity of the ball after being hit. Initial velocity of the ball, i.e., the velocity of the ball before being hit by the bat = 0

Time for which the force acts = 0.1 s

From equation of motion,

$$v = u + at$$

$$200 = 0 + a \times 0.1$$

$$a = \frac{200}{0.1} = 2000 \text{ ms}^{-2}$$

From Newton's second law, $F = ma$.

Mass of the ball, $m = 50 \times 10^{-3} \text{ kg}$

$$\Rightarrow F = 50 \times 10^{-3} \times 2000 = 100 \text{ N}$$

Force acting on the ball = 100 N

WORK

When a force acts on a body causing the body to be displaced, then work is said to be done by the force.

When we try to push a wall, the wall does not move even a bit, i.e., there is no displacement and no work is done. Thus, work is done only if a force acts on a body and if the body is displaced. Hence, work done in a body is a product of force applied on it and displacement of the body in the direction of force.

Mathematical Expression for Work

Work done is directly proportional to the force applied on the body.

$$W \propto \vec{F} \quad (2.3)$$

Work done is directly proportional to displacement of the body.

$$W \propto \vec{s} \quad (2.4)$$

From equations (2.3) and (2.4), and keeping in mind that work is a scalar quantity.

$$W \propto \vec{F} \times \vec{s}$$

$$W = k \vec{F} \times \vec{s}$$

where k is proportionality constant. By defining the unit of work, k is taken as one.

Unit Work

When a unit force acting on a body displaces it through one unit, then the work done is one unit. Thus, $k = 1$. If $F = 1$ unit and $s = 1$ unit, then $W = 1$ unit and $k = 1$.

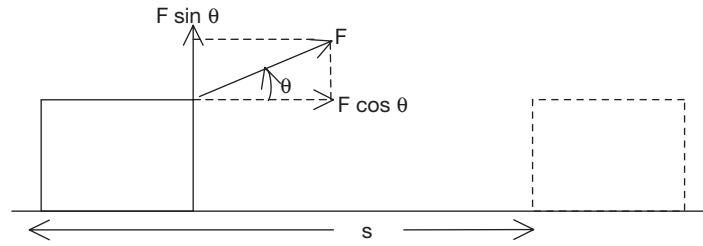


FIGURE 2.3 Force applied on a body at an angle θ

If the direction of applied force on a body makes an angle θ with the direction of its displacement, then the component of the force along the direction of displacement is $F \cos \theta$, and the work done is

$$W = F \cos \theta \times s \text{ or}$$

$$W = F \times s \cos \theta$$

Thus, the work is said to be done when a force or its component acting on a body displaces it in its direction.

$$W = F \times s \cos \theta$$

or

$$W = \vec{F} \times \vec{s}$$

where $\vec{F} \times \vec{s} = Fs \cos \theta$.

Thus, work is the dot product of force and displacement since work is a scalar quantity. Dot product of two vectors is a scalar.

Special Cases

Case (i)

If the displacement is in the direction of force, then $\theta = 0^\circ$ and $\cos 0^\circ = 1$

$$W = Fs \cos \theta$$

$$W = Fs$$

Example: In a horse pulling a cart Force exerted by the horse on the cart and the displacement of the cart are in the same direction.

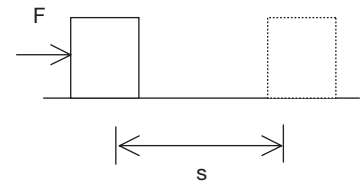


FIGURE 2.4

Case (ii)

If the displacement vector is at right angles to the applied force, then $\theta = 90^\circ$.

$$W = Fs \cos 90^\circ$$

$$W = 0 \text{ (zero)}$$

$$\therefore \cos 90^\circ = 0$$

Example: A porter walking with a load on his head. Work done by the porter is equal to zero.

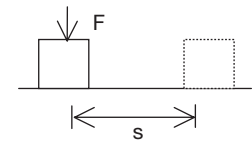


FIGURE 2.5

Case (iii)

If the displacement is along a direction opposite to that of the force, then $\theta = 180^\circ$.

$$W = Fs \cos 180^\circ$$

$$W = -Fs$$

$$(\because \cos 180^\circ = -1)$$

Work done by the force is negative in this case. This is the case where the force opposes the motion, e.g., the truck driver applies brakes to his moving vehicle.

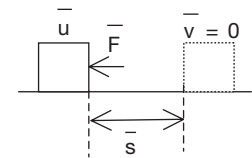


FIGURE 2.6

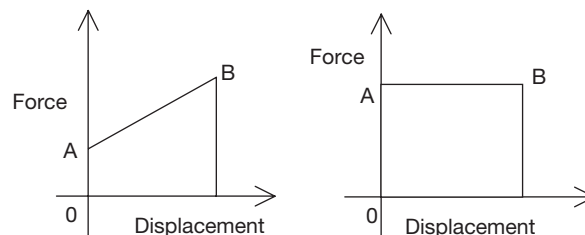


FIGURE 2.7 Graphs of work done

If the force varies with displacement, then the work done is obtained by plotting a graph. Force is plotted along the Y-axis and displacement along the X-axis. The area enclosed by the curve gives the work done. If a constant force acts on the body, then the graph is a straight line parallel to X-axis. Work done by constant force is equal to the area of rectangle formed in the F - s graph.

Work Done by the Force of Gravity

All bodies are attracted towards the centre of earth due to force of gravity. If a body moves short distance horizontally over the surface of the earth or in a circular path around the earth, like satellites, work done by the force of gravity is zero because the displacement of the body at any instant is perpendicular to the direction of force of gravity. If a body of mass ' m ' falls vertically down through a height h , then the work done will be equal to mgh , i.e., the change in the gravitational potential energy.

$\therefore$ Force due to gravity on the body

$$F = mg \text{ and } \theta = 0^\circ$$

$$\therefore \cos\theta = 1$$

If h is the displacement, i.e., the height through which the body falls,

$$W = Fs \cos\theta$$

$$W = (mg) (h) (\cos\theta) = mgh$$

This can also be obtained from work-energy theorem, work done = change in potential energy = mgh .

NOTE

- (i) No work is done when $\theta = 90^\circ$ ($\cos 90^\circ = 0$), i.e., when force and displacement are perpendicular to each other.
- (ii) No work is done when a body undergoes circular motion.

Units of Work

Work = Force $\times$ displacement

$$1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$$

S.I. unit of work is joule (J).

DEFINITION OF JOULE

One joule of work is said to be done when a force of 1 newton acting on a body displaces it through 1m in its direction. C.G.S. unit of work is erg; $1 \text{ erg} = 1 \text{ dyne} \times 1 \text{ cm}$.

If a force of 1 dyne acting on a body displaces it through 1 cm in its direction, then the work done is said to be one erg.

Dimensional Formula for Work

Work = Force $\times$ displacement. Thus, $[\text{work}] = [\text{force}] [\text{displacement}]$

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

$$= [M^1 L^2 T^{-2}]$$

Relation between Joule and Erg

$$1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$$

$$1 \text{ J} = 10^5 \text{ dyne} \times 10^2 \text{ cm}$$

$$1 \text{ J} = 10^7 \text{ dyne cm}$$

$$\text{But } 1 \text{ dyne} \times 1 \text{ cm} = 1 \text{ erg}$$

$$\therefore 1 \text{ J} = 10^7 \text{ erg}$$

POWER

Work done does not depend on time. For example, If a person A lifts 10 kg load through 5 m in 2 minutes and person B lifts the same load through the same height in 1 minute, the work done by both the persons is the same, but the rate at which the work is done is not the same. We say that the second person is stronger and has more power. Thus, power is defined as the rate at which work is done.

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

$$\text{Power} = \frac{\text{force} \times \text{displacement}}{\text{time}}$$

$$\because \text{Work} = \text{force} \times \text{displacement}$$

$$P = \frac{F \times s}{t}$$

$$\left(\frac{s}{t} = \text{average velocity} \right)$$

$$P = F \times v$$

If the displacement makes an angle ' θ ' with the force, then the power

$$P = F \times v \cos \theta = \vec{F} \cdot \vec{v}$$

$$P = \vec{F} \cdot \vec{v}$$

Thus, power is a dot product of force and velocity, and a scalar quantity.

Unit of Power

S.I. unit of power is watt or J s^{-1} . Watt is denoted by W.

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

$$1 \text{ W} = \frac{1 \text{ J}}{1 \text{ s}}$$

Definition of Watt

If one joule of work is done in one second, then the power is said to be one watt.

$$1\text{W} = \frac{1\text{J}}{1\text{s}} = \frac{1\text{N} \times 1\text{m}}{1\text{s}} = \frac{1\text{kg} \times 1\text{m s}^{-2} \times 1\text{m}}{1\text{s}} = \text{kg m}^2\text{s}^{-3}$$

$$\begin{aligned}\text{C.G.S. unit of power is erg per second } \frac{1 \text{ erg}}{1 \text{ second}} &= \frac{1 \text{ dyne} \times 1\text{cm}}{1 \text{ second}} \\ &= \frac{1\text{g} \times \text{cm s}^{-2} \times \text{cm}}{\text{s}} \\ &= 1 \text{ g cm}^2 \text{ s}^{-3}\end{aligned}$$

Multiple units or bigger units of power are

1. kW – kilo watt = 10^3 W
2. MW – mega watt = 10^6 W
3. GW – giga watt = 10^9 W
4. hp – Horse power = 746 W

Dimensional formula for power

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

$$\text{Hence, } [\text{power}] = \frac{[\text{work}]}{[\text{time}]}$$

$$= \frac{[\text{M}^1\text{L}^2\text{T}^{-2}]}{[\text{T}]} = [\text{M}^1\text{L}^2\text{T}^{-3}]$$

ENERGY

A body which is capable of doing work possesses energy. Thus, energy is the ability or the capacity of a body to do work.

Unit of Energy

The unit of energy is the same as that of work. Thus, S.I. unit of energy is joule (J) and its C.G.S. unit is erg. Energy appears in various forms namely, heat, light, sound, electricity, etc.

Heat Energy

It is the energy which causes a sensation of hotness or coldness.

Example: Energy obtained by burning wood. Heat energy is measured in calories or kilo calories.

Calorie: It is amount of heat energy required to raise the temperature of one gram of water through 1°C . It is denoted by 'cal'.

$$1 \text{ calorie} = 4.2 \text{ J}$$

Kilo calorie: It is the amount of heat energy required to raise the temperature of one kilogram of water through 1°C .

$$1 \text{ kilo calorie} = 4.2 \text{ kJ}$$

Electrical Energy

Energy possessed by charge particles in motion is referred to as electrical energy.

Units of electrical energy: It is the energy spent/used in 1 hour at the rate of 1W.

- 1. watt hour (W h):** It is the electric energy used in 1 hour at the rate of 1W.

$$1 \text{ W h} = 1 \text{ watt} \times 1 \text{ hour} \quad (\because \text{Energy} = \text{power} \times \text{time})$$

$$= \frac{1\text{J}}{1\text{s}} \times 3600 \text{ s}$$

$$\text{Thus, } 1 \text{ W h} = 3600 \text{ J}$$

Kilowatt hour is a multiple of Wh and is a bigger unit of energy.

$$\begin{aligned} 1 \text{ kilo watts hour} &= 10^3 \text{ watt hour} \\ &= 3600 \times 10^3 \text{ J} \\ &= 3.6 \text{ MJ} \end{aligned}$$

- 2. Body Electron volt:** It is the work required to move an electron or a proton (in an electric field) through a potential difference of exactly one volt. It is denoted by eV.

$$\begin{aligned} 1 \text{ electron volt} &= \text{charge of 1 electron} \times 1 \text{ volt} \\ &= 1.6 \times 10^{-19} \text{ C} \times 1 \text{ V} \\ &= 1.6 \times 10^{-19} \text{ J} \end{aligned}$$

Light Energy

It is the energy which causes sensation of sight.

Example: Light energy emitted by sun.

Sound Energy

It is the energy which produces sensation of hearing.

Example: The ringing of a bell.

Magnetic Energy

Energy possessed by a magnet is called magnetic energy.

Example: Energy possessed by motors.

Chemical Energy

Energy released or absorbed by atoms or molecules during chemical reaction is called chemical energy.

Example: Energy released during combustion.

Nuclear Energy

Energy released during fission or fusion of nucleus is called nuclear energy. In nuclear fusion or fission nuclear mass is converted to energy ($E = mc^2$ where m is the mass, c is velocity of light in air).

Example: Atom bomb and hydrogen bomb release energy in the form of heat and radiation. Nuclear energy is used in nuclear reactor to generate electric power.

Mechanical Energy

Energy possessed by a body due to its position or motion is known as mechanical energy. Mechanical energy is classified into potential energy and kinetic energy.

Potential Energy

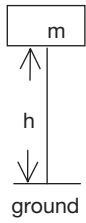
It is the energy possessed by a body due to its position or configuration.

Example: Wound spring of a clock possesses potential energy. When the spring unwinds, it uses this energy for the movement or rotation of the hands of the clock. Stretched bow, stretched elastic band and compressed gas molecules possess elastic potential energy.

Elastic Potential Energy

Elastic potential energy is the potential energy possessed by an elastic body in a deformed state, i.e., it is the amount of work done in deforming the body within its limit of elasticity and is stored in the body as elastic potential energy. This potential energy possessed by the spring is called elastic potential energy. This potential energy possessed by the spring is called elastic potential energy.

Water stored at a height possesses potential energy due to its position. This energy is used to rotate a turbine which in turn generates electric energy. Energy possessed by water stored at height is called gravitational potential energy. Thus, gravitational potential energy is the amount of work done in lifting the body against gravity.



Expression for Gravitational Potential Energy

When a body of mass m is lifted to a height ' h ', work is done against gravity. This work done is stored as gravitational potential energy in the body.

Work done in lifting a body = Force $\times$ displacement

$W = \text{mass} \times \text{acceleration due to gravity} \times \text{displacement}$

$W = mgh$

Thus, gravitational potential energy = mgh

NOTE

Surface of the earth is taken as reference for height in calculations of gravitational potential energy. By this assumption, gravitational potential energy of a body on the surface of the earth at mean sea level is considered to be zero.

Kinetic Energy

Energy possessed by a body due to its motion or a body is called kinetic energy.

Example: Wind possesses kinetic energy and this energy is used to rotate the blades of a wind mill. For a body of mass m and velocity v , kinetic energy is given by,

$$KE = \frac{1}{2}mv^2$$

Kinetic energy of a body increases if the velocity or speed of the body increases. To increase the kinetic energy of a body, net force has to be applied. Thus, the work done by this force is equal to the change in the kinetic energy of the body. This is known as work-energy theorem.

WORK-ENERGY THEOREM

The work done on a body by a force is equal to the change in its kinetic or potential energy when change in speed of the body is the effect of the force on the body.

Consider a body of mass m moving with a velocity ' v '. Let a retarding force ' F ' be applied on it causing it to come to rest after a distance ' s '.

From equation of motion, we get

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

$$0 = v^2 - 2as$$

(negative sign is used because the body is retarding)

$$v^2 = 2as$$

or

$$\frac{v^2}{2} = as \quad (2.5)$$

Work done by the body before coming to rest = Force $\times$ displacement

$$= ma \times s$$

$$= mas \quad (2.6)$$

Substituting equation (2.5) in equation (2.6), we get

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

Kinetic energy = Work done by the retarding force

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

If 'u' is the initial velocity of the body and 'v' is the final velocity, then the change in kinetic energy,

$$K_f - K_i = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$= \frac{1}{2}m(v^2 - u^2) = \frac{1}{2}m2as \quad (v^2 - u^2 = 2as)$$

$$= (ma)s = (\text{force}) \times (\text{displacement}) = \text{work done}$$

Thus, change in Kinetic energy of the body = work done on the force

This is the mathematical expression of work – energy theorem.

Different Forms of Kinetic Energy

The three types of motion that a body may display are:

1. Translatory motion
2. Rotatory motion
3. Vibrational motion

1. **Translational kinetic energy:** It is the kinetic energy possessed by a body moving along a straight line.

Example: Energy possessed by a freely falling body.

2. **Rotational kinetic energy:** It is the kinetic energy possessed by a rotating body.

Example: Wheels of a car in motion have rotational kinetic energy along with translational kinetic energy whereas the blades of a rotating fan have rotational kinetic energy only.

3. **Vibrational kinetic energy:** It is the energy possessed by a body, which executes to and fro motion about its mean position.

Example:

1. Energy possessed by an oscillating pendulum.
2. Energy possessed by a vibrating stretched string.

Relationship between Kinetic Energy and Momentum

$$\text{Kinetic energy of a body,} \quad K = \frac{1}{2}mv^2 \quad (2.7)$$

$$\text{Momentum,} \quad p = mv \quad (2.8)$$

From (2.7) and (2.8)

$$K = \frac{1}{2} \frac{p^2}{m}$$

$$p^2 = 2m.K$$

where K is the kinetic energy

$$\therefore p = \sqrt{2mk} \text{ or } K = \frac{p^2}{2m}$$

LAW OF CONSERVATION OF ENERGY

Statement: Energy can neither be created nor destroyed but it can be transformed from one form to another form, i.e., the total energy of a system remains constant.

Examples of interconversion of energy:

1. In solar cells, light energy is converted into electrical energy.
2. In fans, electrical energy is converted in to mechanical energy.
3. In plants, light energy is converted into chemical energy.
4. In burning fuel like wood, etc., chemical energy is converted into light and heat energy.
5. In microphone, sound energy is converted into electrical energy.

CONSERVATION OF MECHANICAL ENERGY

Statement

Total mechanical energy of an isolated system always remains constant.

Mechanical energy is the sum of potential energy and kinetic energy. According to law of conservation of energy, if potential energy of a body increases, its kinetic energy decreases and vice versa such that the total mechanical energy always remains constant.

NOTE

It is always the kinetic energy which is converted into other forms, i.e., during the conversion of mechanical energy into other forms.

Application of Law of Conservation of Energy

1. In the case of a freely falling body.

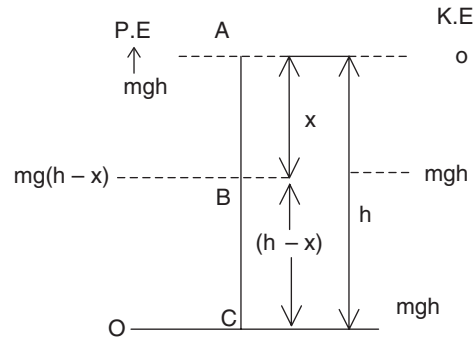


FIGURE 2.8

Consider a body of mass m at A falling freely under gravity dropped from A at height h . At the point ' A ', energy of the body is purely potential because it is momentarily at rest.

$\therefore$ Total energy at A = potential energy + kinetic energy

$$\text{Total energy at } A = mgh + 0 \quad (2.9)$$

As the body falls through a distance x , its potential energy decreases because its height from the ground decreases but the kinetic energy increases as its velocity increases.

$$\therefore \text{Total energy at } B = \text{potential energy} + \text{kinetic energy} = mg(h-x) + \frac{1}{2}mv_B^2 \quad (2.10)$$

where v_B is the velocity at B .

Substituting $u = 0$, $v = v_B$, $a = g$ and $s = x$ in the equation of motion $v^2 = u^2 + 2as$, we get

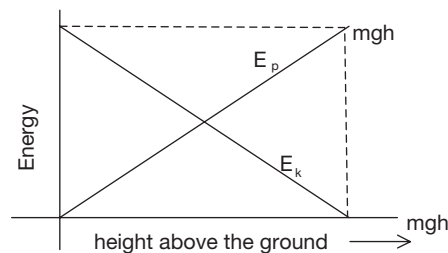


FIGURE 2.9 Energy graph of the object at a certain height

$$v_B^2 = 2gx \quad (2.11)$$

Substituting equation (2.11) in (2.10), we get

$$\text{Total energy at } B = mg(h-x) + \frac{1}{2}m2gx$$

$$= mgh - mgx + mgx$$

$$\therefore \text{total energy at } B = mgh \quad (2.12)$$

At the instant when the body strikes the ground, entire energy of the body is kinetic. Potential energy is equal to zero at the ground.

$\therefore$ Total energy at C = potential energy + kinetic energy

$$\text{Total energy at C} = 0 + \frac{1}{2}mv_C^2 \text{ where } v_C \text{ is the velocity at point C} \quad (2.13)$$

From equations,

$$v_C^2 = u^2 + 2as$$

$$v_C^2 = 0 + 2gh$$

$$\text{Equation (2.13) can be written as total energy at C} = \frac{1}{2}mv_C^2 = mgh$$

Thus, the kinetic energy of the body is equal to initial potential energy. The total energy remains constant and is independent of height of fall.

NOTE

Resistance of air is neglected in verifying the above law.

2. Conservation of energy in the case of a simple pendulum

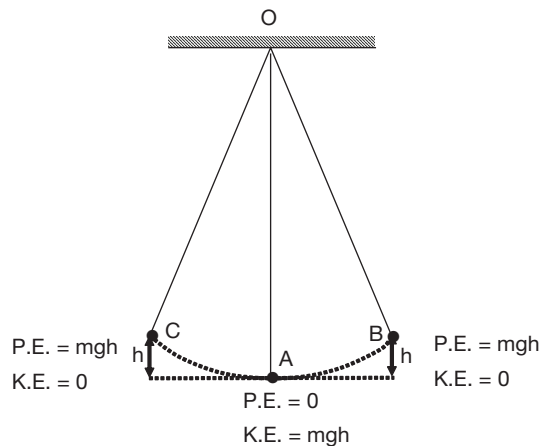


FIGURE 2.10 Motion of a simple pendulum

O is the point of suspension of the simple pendulum. When the pendulum is made to swing, it reaches equal heights on either side of the mean position A, B and C are called the extreme positions of the pendulum.

At an extreme position, the bob of the pendulum is momentarily at rest, hence, its energy is entirely potential

$$\therefore \text{Total energy at extreme position} = \text{P.E.} + \text{K.E.} = mgh \quad (2.14)$$

As it swings from extreme position to mean position, potential energy decreases and its kinetic energy increases such that the total energy remains constant. At the mean position, energy of the bob is purely kinetic.

Total energy at mean position = P.E + K.E.

$$= 0 + \frac{1}{2}mv^2 \quad (2.15)$$

$$\text{But } v^2 = u^2 + 2as \text{ (} u = 0, s = h, a = g \text{)} \quad v^2 = 0 + 2gh$$

$$\begin{aligned} \therefore \text{Total energy at mean position} &= 0 + \frac{1}{2}mv^2 \\ &= mgh \end{aligned} \quad (2.16)$$

Thus, K.E. at the mean position is equal to initial potential energy at the extreme position. As it moves from mean position to the other extreme position, its kinetic energy decreases but potential energy increases as the height increases.

Hence, at extreme position, energy of the bob is entirely potential and at any intermediate position, total energy of the bob is the sum of potential energy and kinetic energy.

Thus, total energy of the bob remains constant throughout the swing.

NOTE

Air friction is neglected in the above discussion.

EXAMPLE

What is the work done by a force of 2 N in displacing a body by 2 m in the direction of the force?

SOLUTION

$$\text{Work done} = \vec{F} \cdot \vec{s}$$

$$= Fs \cos \theta$$

where F is the force, s is the displacement and θ is the angle between F and s .

In the given example,

$$\theta = 0^\circ, F = 2 \text{ N}, s = 2 \text{ m}$$

$$\Rightarrow \text{Work done} = 2 \times 2 \times \cos 0^\circ$$

$$= 2 \times 2 \times 1 = 4 \text{ J}$$

EXAMPLE

What is the work done in lifting a mass of 10 kg through a height of 5 m from the ground? ($g = 10 \text{ m s}^{-2}$)

SOLUTION

Work done against the force of gravity $= F \times S = mg \times h$

where m is the mass, g is acceleration due to gravity and ' h ' is the height from the ground level.

Thus, work done $= mgh = 10 \times 10 \times 5 = 500 \text{ J}$

EXAMPLE

A bullet of mass 0.02 kg moving with a velocity of 30 m s^{-1} is brought to rest by a wooden plank. Calculate the work done on the bullet before it comes to rest.

SOLUTION

According to work energy theorem,

Work done = change in kinetic energy

$\Rightarrow W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ where m is the mass, v is the final velocity and u is the initial velocity of the body.

Since $v = 0$ ($\because$ bullet comes to rest)

$$\begin{aligned} W &= \frac{-1}{2}mu^2 \\ &= \frac{-1}{2} \times 0.02 \times (30)^2 \\ &= -9 \text{ J} \end{aligned}$$

The negative sign indicates that the force acting on the bullet and its displacement are opposite to each other.

EXAMPLE

What is the work done by a porter in carrying a load of 50 kg?

- (i) While walking along the platform
- (ii) While climbing up a slope of height 10 m ($g = 10 \text{ m s}^{-2}$)?

SOLUTION

While carrying a load the porter applies a force equal to mg vertically upwards.

(i) Work done by a porter along the horizontal

$$W \propto \vec{F} \cdot \vec{s} = Fs \cos \theta$$

Where F is the force, s is displacement and θ is angle between F and s .

Since $\theta = 90^\circ$, work done $W = F \cdot s \cos 90^\circ = 0$ (zero).

$\therefore$ Work done when the porter walks along the platform = 0

(ii) Work done when the porter walks along the slope

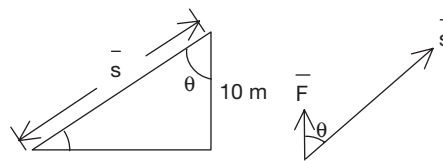


FIGURE 2.11

$$W = \vec{F} \cdot \vec{s} = Fs \cos \theta$$

Work is done by force of gravity, $F = mg$ and $s \cos \theta = h$

$$\therefore W = mgh$$

$$\therefore W = 50 \times 10 \times 10 = 5000 \text{ J} = 5 \text{ kJ}.$$

EXAMPLE

What is the power developed by an engine in lifting 3000 litre of water from, a well 20 m deep, in one minute (1 litre water = 10^3 kg; $g = 10 \text{ m s}^{-2}$)?

Assume that there is no loss of energy in the conversion of energy.

SOLUTION

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

Work = force $\times$ displacement

$$W = \vec{F} \cdot \vec{s}, \text{ work is done by the force of gravity} = Fs \cos \theta$$

$$\therefore F = mg, s = h \text{ and } \theta = 0^\circ$$

$$W = mgh \cos 0$$

$$= 3 \times 10^3 \times 10 \times 20 = 6 \times 10^5 \text{ joules}$$

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

Time = 1 minute = 60 seconds

$$\therefore \text{Power} = \frac{6 \times 10^5}{60} = 10^4 \text{ W} = 10,000 \text{ W}$$

The power of the engine is 10 kW.

EXAMPLE

In a hydroelectric power station, water is allowed to fall at the rate of 2000 kg per second on a turbine kept 100 m below the water level.

- (i) Calculate the potential energy of water falling every one second.
- (ii) Find kinetic energy of this water when it falls through a height of 25 m.
- (iii) If 80% of initial potential energy is converted in to electrical energy, calculate the power output in 1 second ($g = 10 \text{ m s}^{-2}$).

SOLUTION

- (i) From definition of potential energy (P.E)

$$\text{P.E} = mgh$$

$$\text{P.E} = 2000 \times 10 \times 100$$

$$= 2 \times 10^6 \text{ J.}$$

From law of conservation of energy

Total energy at the highest point

$E_1 = \text{potential energy} + \text{kinetic energy}$

$$E_1 = mgh + 0 \text{ (K.E at the highest point} = 0)$$

$$\Rightarrow E_1 = 2 \times 10^6 \text{ J}$$

- (ii) When water falls through a height of 25 m, its velocity (v) is given by:

$$v^2 = u^2 + 2g_s$$

$$v^2 = 0 + 2 \times 10 \times 25$$

$$v^2 = 500$$

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

$$\text{KE} = \frac{1}{2} \times 2000 \times 500$$

$$\text{KE} = 5 \times 10^5 \text{ J}$$

(iii) 80% of initial potential energy is converted into electrical energy

$$80\% \text{ of } E_1 = \frac{80}{100} \times 2 \times 10^6$$

$= 16 \times 10^5 \text{ J}$ is converted in to electrical energy

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

$$= \frac{16 \times 10^5}{1} = 16 \times 10^5 \text{ W}$$

Thus, the power output is $16 \times 10^5 \text{ W} = 1.6 \text{ MW}$.

Parallel Forces

A 5 N force acting along east can be represented by a ray 5 cm long with the arrow pointing towards east.



FIGURE 2.12 Force denoted by ray OA.

1. The point of application of the force is represented by the point O.
2. The length of line OA is proportional to the magnitude of the force.
3. The direction of the arrow indicates the direction of the force. Thus, a force can be represented graphically.

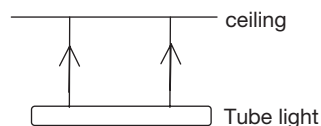


FIGURE 2.13 A tube-light fixed with ceiling

When a tube light fixture is suspended from two points symmetrical about its centre from the ceiling of a room as shown, two equal forces act along the strings by which the fixture is suspended. These two forces act along the parallel lines are called as parallel forces.

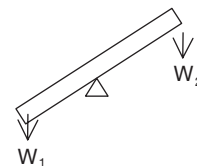


FIGURE 2.14 See-saw

When two lads sit on either side of a see-saw, the weights of the lads act vertically downwards along the parallel lines. These parallel forces are called like parallel forces.

In the Fig. 2.15 (i), A and B represent a set of like parallel forces. Similarly in Fig. 2.15 (ii), C and D also represent another set of like parallel forces. Thus, the forces acting along parallel lines in the same direction are called like parallel forces.

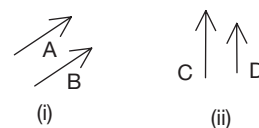


FIGURE 2.15

When we want to lift a load using a wooden plank as shown, the weight of the load acts vertically downwards and the force exerted acts vertically upwards. These two forces act along the parallel lines in opposite direction. These types of parallel forces are called unlike parallel forces.

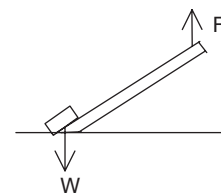


FIGURE 2.16

In the adjacent Fig. 2.17 (iii), E and F represent a set of unlike parallel forces. Similarly in Fig. 2.17 (iv), G and H also represent another set of unlike parallel forces. Thus, unlike parallel forces are forces acting along parallel lines in opposite directions.

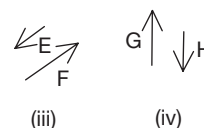
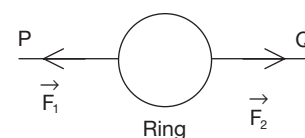


FIGURE 2.17

Therefore, parallel forces are classified into like parallel forces and unlike parallel forces.

Consider a ring pulled by two persons P and Q in two diametrically opposite directions with forces F_1 and F_2 , respectively.

The ring moves in the direction of F_2 when F_2 is greater than F_1 . Then, the resultant of the forces of F_1 and F_2 is $F_2 - F_1$ and acts in the direction of F_2 .

FIGURE 2.18 A ring pulled by P and Q

If the magnitude of F_2 is equal to F_1 then the body does not move, then the resultant of the two forces is zero. Therefore, **resultant** of two or more (parallel) forces is that single force whose effect is the same as that of the combination of all forces.

When unequal weights F_1 and F_2 are placed on the pans of a balance, the resultant of the weights acts along R . If the balance is suspended by a string, the tension in the string F_3 is equal in magnitude and opposite in direction to that of the resultant. This force F_3 is called equilibrant.

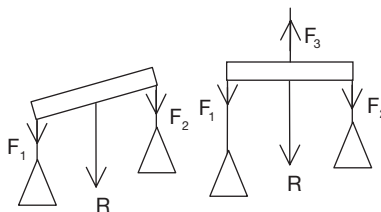


FIGURE 2.19

When $20g_{wt}$ and $10g_{wt}$ are suspended to a beam or a rod, the two forces act along the parallel lines vertically downwards. The resultant of these two forces is equal to $20 + 10 = 30 g_{wt}$ and it acts vertically downwards near the greater force such that the point of action of the resultant divides the line joining the point of action of the two forces internally in the inverse ratio of the forces.

Thus, the magnitude of the resultant of two parallel forces is equal to the sum of individual forces, i.e., $R = P + Q$. The direction of the resultant is the same as the direction of either force. The resultant force R divides the line joining the point of action of P and Q in the inverse ratio of the forces.

$$\Rightarrow P \times AC = Q \times BC, \text{ i.e., } \frac{P}{Q} = \frac{BC}{AC}$$

When a body is lifted by a wooden plank by applying a force F at B , which acts vertically upwards, half the weight of the body W , acts vertically downwards on the plank at A . These two forces constitute unlike parallel forces and the resultant of these forces acts in the direction of the greater force. Its magnitude is equal to $(W/2) \sim (F)$.

The point of action of the resultant divides the line joining the point of action of the two forces externally in an inverse ratio of the forces.

Thus, the magnitude of the resultant of the two unlike parallel forces is equal to difference of the magnitudes of the individual forces. Direction of the resultant is in the direction of the greater force and the point of action of the resultant divides the line joining the point of action of the two forces externally in the inverse ratio of the forces.

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

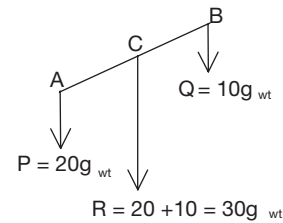


FIGURE 2.20 Two forces A & B suspended to a beam

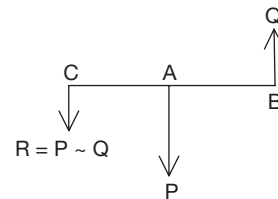


FIGURE 2.21 Unlike parallel forces A & B

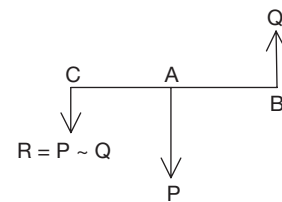


FIGURE 2.22 Direction of resultant of two unlike parallel forces

MOMENT OF A FORCE

When a force is applied on a door handle, it tends to turn (open or close) the door about the hinges.

This rotating or turning effect of a force about a fixed point or fixed axis is called moment of the force about that point. This moment of the force, i.e., the turning effect is maximum if the applied force is perpendicular to the plane of the door and the point of application is farthest from the hinges.

Therefore, the moment of force is measured by the product of the magnitude of the force and the perpendicular distance between the fixed point or the fixed axis and the line of action of the force.

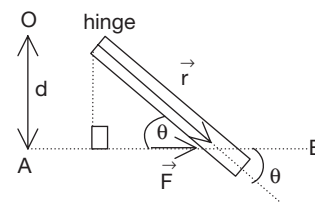


FIGURE 2.23 Moment of a force

This moment of force, also called torque, is a vector quantity and is given as a cross product of the force vector, $\vec{F}$ and the radius vector, $\vec{r}$ as,

$$\vec{\tau} = \vec{r} \times \vec{F} \text{ and the magnitude of torque is given by,}$$

$$\begin{aligned}\tau &= rF \sin\theta \\ &= (F) (r \sin\theta) \\ &= F \cdot d\end{aligned}$$

The direction of the torque is perpendicular to the plane containing the vectors $\vec{r}$ and $\vec{F}$. Thus, if O is the fixed point and AB is the line of action of the force and d is the perpendicular distance between O and line AB , the magnitude of the moment of force $= F \times d$.

If the perpendicular distance between the line of action of the applied force and the fixed point is greater, greater will be the turning effect.

Example: Door handles are provided far away from the hinges so that less force is required to obtain greater turning effect.

EXAMPLE

Find the turning effect if a force 2 N is applied on a door, perpendicular to its plane at a distance of 40 cm from its hinge.

SOLUTION

Moment of force = force $\times$ perpendicular distance from fixed axis

Perpendicular distance, $d = 40 \text{ cm} = 0.4 \text{ m}$

Thus, moment of force $= 2 \times 40 \times 10^{-2}$
 $= 0.8 \text{ N m}$

Similarly, it is easier to tighten or unwind a screw using a long spanner or a screw driver with a bigger handle. By convention, moment of force is taken as positive if it rotates the body in an anti-clockwise direction and negative if it rotates the body in a clockwise direction.

NOTE

Turning effect is zero when forces are applied on the fixed point or on the fixed axis.

Unit of Moment of Force

Moment of force = force $\times$ perpendicular distance

Hence, unit of torque = (unit of force) (unit of distance)

Thus, the S.I. unit of moment of force is N m and in C.G.S. system it is dyne cm.

Dimension Formula of Moment of Force

Moment of force = force $\times$ perpendicular distance

$$\begin{aligned}\text{Thus, [torque]} &= [\text{Force}] [\text{distance}] \\ &= [M^1 L^1 T^{-2}] \times [L] \\ &= [M^1 L^2 T^{-2}]\end{aligned}$$

NOTE

The dimensional formula of torque is the same as that of work.

PRINCIPLE OF MOMENTS OR THEOREM OF MOMENTS

Statement

When a number of parallel forces act on a rigid body and the body is in equilibrium, then the algebraic sum of the moments of the individual forces about any point is equal to zero, i.e., sum of anti-clockwise moments is equal to sum of clockwise moments.

If $\vec{F}_1, \vec{F}_2$ are $\vec{F}_3$ three parallel forces acting about O under which the body is in equilibrium, then according to the principle of moments, $F_1 d_1 + F_3 d_3 = F_2 d_2$ or $F_1 d_1 + F_3 d_3 - F_2 d_2 = 0$

Consider a wooden plank of length 4 m supported at its ends by two supports whose tensions are 40 kg_{wt} and 30 kg_{wt}. Weight of 50 kg is suspended at the centre of the plank and 20 kg_{wt} is suspended at a distance 1 m from the end.

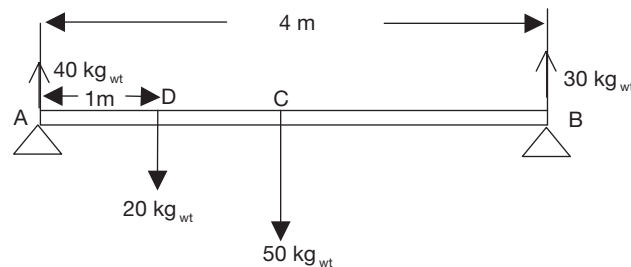


FIGURE 2.25 A wooden plank by two supports

If the plank is in equilibrium, then algebraic sum of the moment about any point should be equal to zero. Taking moments about A, we get

$$(40 \times 0) - (20 \times 1) - (50 \times 2) + (30 \times 4) = -20 - 100 + 120 = 0$$

Experiment to Verify the Principle of Moments

1. Metre scale is supported at its centre by a knife edge so that the scale remains horizontal.
2. Slotted weights W_1 and W_2 are added to the weight hangers, which are suspended to the scale, such that the scale remains in equilibrium.

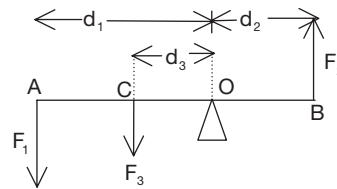


FIGURE 2.24 Three parallel forces in equilibrium

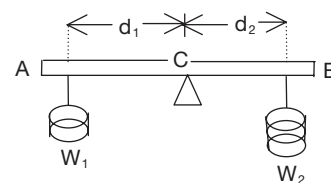


FIGURE 2.26 Weights suspended to a scale

- Distances between slotted weights and the centre of the scale are measured. Let the distances from the knife edge to the weights W_1 and W_2 be d_1 and d_2 , respectively.
- Moment of the force is calculated using the formula.

Moment of force = Force $\times$ distance

Clockwise moment = $W_2 \times d_2$

Anti-clockwise moment = $W_1 \times d_1$

Trial No	W_1 kg $_{wt}$	W_2 kg $_{wt}$	d_1 m	d_2 m	Anti-clockwise moment ($W_1 \times d_1$)	Clockwise moment ($W_2 \times d_2$)

- Experiment is repeated for different weights and different distances and the result is tabulated.

Observation

In all the cases, it is found that the anticlockwise moment is equal to the clockwise moment.

NOTE

Experiment can be conducted by having more than two weights. In all the cases it can be verified that the sum of anticlockwise moments is equal to sum of clockwise moments.

Experiment to Find the Weight of a Body Using the Principle of Moments

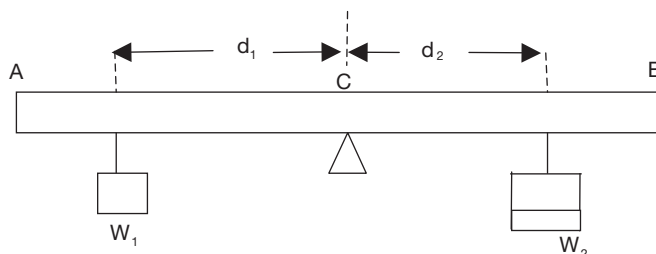


FIGURE 2.27 W_1 & W_2 suspended to a scale AB

- Metre scale is supported at its centre by a knife edge, so that the scale is horizontal
- The unknown weight (W_1) is suspended on one side of the scale as shown and known weight (W_2) is suspended on the other side.

3. The two weights are adjusted and positioned on the scale, until the scale remains horizontal (equilibrium position).
4. Distance d_1 between unknown weight and the centre of the scale is noted down. Similarly, distance d_2 between the known weight and the centre of the scale is also noted down.
5. From the principle of moments $W_1 \times d_1 = W_2 \times d_2$ or $W_1 = \frac{W_2 \times d_2}{d_1}$

Therefore, the weight of the unknown body is determined.

COUPLE

Two equal and unlike parallel forces constitute a couple. A couple does not produce translatory motion since the resultant of the forces is zero. Rotating effect of the couple is known as moment of couple.

Example: Couple is applied in turning (opening or closing) a tap and winding or unwinding a screw, etc.

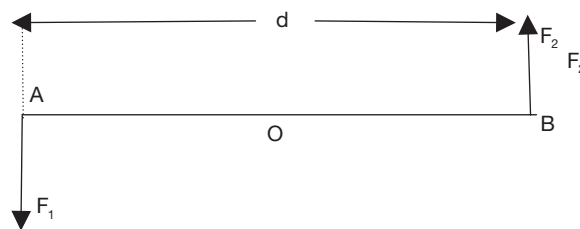


FIGURE 2.28 2 Equal and unlike parallel forces

Moment of couple is measured by product of either force and the perpendicular distance between the two forces (arm of couple).

In the Fig. 2.28, F_1 and F_2 would constitute a couple if $F_1 = F_2 = F$ (say)

$$\begin{aligned}\therefore \text{Moment of couple} &= F \times AB \\ &= F \times d\end{aligned}$$

Moment of couple is taken as positive if the couple rotates the body in an anticlockwise direction and negative if it rotates the body in a clockwise direction. Unit of moment of couple is N m in S.I. system and dyne cm in C.G.S. system.

NOTE

A couple cannot be balanced by a single force, it has to be balanced by another couple.

EXAMPLE

AB is a rigid rod of uniform cross section and length 6 m. Two forces, $P = 5 \text{ N}$ and $Q = 3 \text{ N}$ act at the ends A and B of the rod. Find the magnitude, direction and point of application of the resultant if the

- (i) two forces are like parallel forces.
- (ii) two forces are unlike parallel forces.

SOLUTION

- (i) For like parallel forces

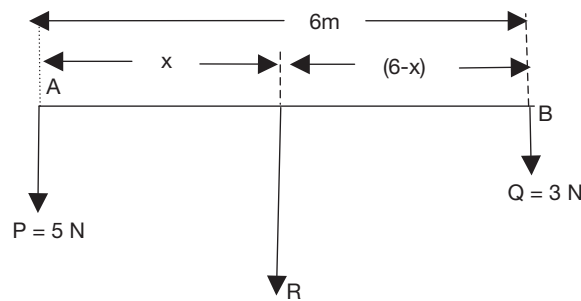


FIGURE 2.29 Two parallel forces

Magnitude of the resultant, $R = P + Q$

$$R = 5 + 3 = 8 \text{ N}$$

Direction of the resultant is in the direction of P and Q (i.e., downwards)

Let the resultant act at a distance x from 5 N, then

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

$$5 \times x = 3 (6 - x)$$

$$\Rightarrow 5x = 18 - 3x \Rightarrow 5x + 3x = 18$$

$$\Rightarrow 8x = 18 \text{ or } x = 2.25 \text{ m}$$

$\therefore$ The resultant acts at a distance 2.25 m from 5 N.

- (ii) Unlike parallel forces

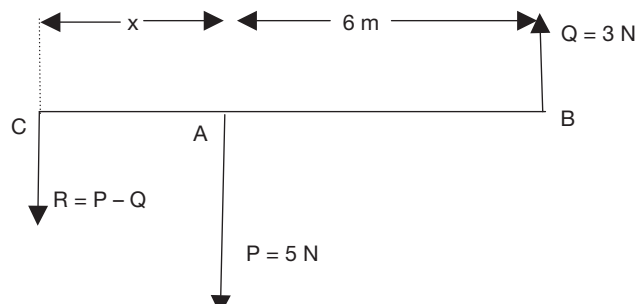


FIGURE 2.30 Two unlike parallel forces

Magnitude of the resultant of two unlike parallel forces is

$$R = P \sim Q$$

$$\Rightarrow R = 5 - 3 = 2 \text{ N}$$

Direction of the resultant is along the greater force.

$\Rightarrow$ direction of the resultant R is in the direction of P .

If the resultant acts at a distance x from 5 N, then

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

$$5 \times x = 3 (6 + x)$$

$$5x = 18 + 3x$$

$$5x - 3x = 18$$

$$2x = 18 \Rightarrow x = 9 \text{ m}$$

i.e., resultant acts at a distance 9 m from 5 N.

EXAMPLE

Two lads of $40 \text{ kg}_{\text{wt}}$ and $60 \text{ kg}_{\text{wt}}$ sit on either side of a see-saw of length 3 m which is supported at its centre. Where should a third lad of $30 \text{ kg}_{\text{wt}}$ sit so as to balance the see-saw?

SOLUTION

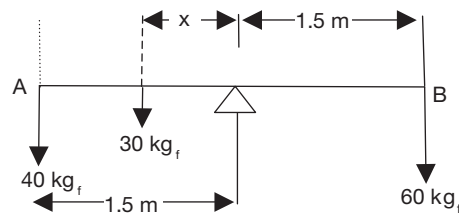


FIGURE 2.31 A see-saw

Let the third lad sit at a distance ' x ' from the support to balance the see-saw. From the principle of moments the sum of anticlockwise moments is equal to the sum of clockwise moments. (moment = force $\times$ perpendicular distance) Anti-clockwise moment is taken as positive

$$(40 \times 1.5) + (30 \times x) - (60 \times 1.5) = 0$$

$$60 + 30x - 90 = 0$$

$$30x - 30 = 0$$

$$30x = 30 \Rightarrow x = 1 \text{ m}$$

EXAMPLE

A painter of $50 \text{ kg}_{\text{wt}}$ stands on a wooden plank of length 5 m and negligible mass. The plank is suspended at its ends by ropes. The painter stands at a distance 2 m from one end of the plank. Find the tensions (force) in the ropes.

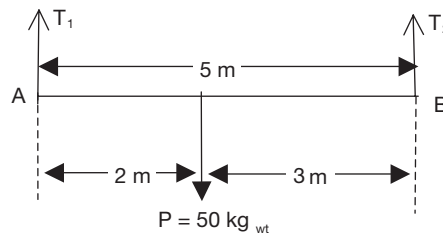
SOLUTION

FIGURE 2.32 A wooden plank of length AB

- (i) Let T_1 and T_2 be the tensions in the ropes. Painter P stands at a distance 2 m from the end A. From the principle of moments the algebraic sum of the moments about any point is equal to zero. Anti-clockwise moment is taken positive. Applying theorem of moments about point A, we get

$$(T_1 \times 0) - (50 \times 2) + (T_2 \times 5) = 0$$

$$-100 + 5T_2 = 0$$

$$5T_2 = 100 \Rightarrow T_2 = 20 \text{ kg}_{\text{wt}}$$

- (ii) For equilibrium of the plank, condition is upward force = downward force

$$\therefore T_1 + T_2 = P$$

$$\Rightarrow T_1 + 20 = 50$$

$$\Rightarrow T_1 = 50 - 20 = 30 \text{ kg}_{\text{wt}}$$

Alternately, applying principle of moments about B;

$$(T_1 \times 5) - (50 \times 3) + (T_2 \times 0) = 0$$

$$5T_1 - 150 = 0$$

$$\Rightarrow T_1 = 30 \text{ kg}_{\text{wt}}$$

Static Equilibrium

A body is said to be in equilibrium if it does not change its state of rest or uniform motion. If the body does not possess translatory motion and rotatory motion, then the body is said to be in static equilibrium. Hence, the conditions for a body to be in equilibrium are

1. the algebraic sum of the forces acting on the body should be equal to zero,

2. the algebraic sum of the moments of forces about any point should be equal to zero, and
3. all forces must be coplanar forces.

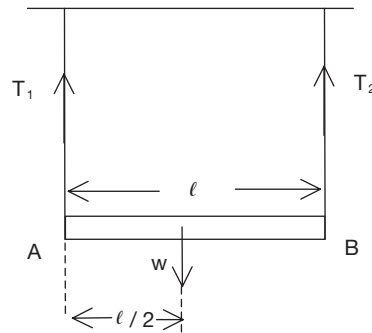


FIGURE 2.33 A wooden plank suspended by 2 ropes

Consider a wooden plank suspended by two parallel ropes at its ends A and B as shown. The wooden plank is in equilibrium under the action of forces. The upward forces acting on the plank are T_1 and T_2 , where T_1 and T_2 are the tensions in the ropes. The weight of the plank W acts vertically downwards. The plank is in equilibrium because.

$$T_1 + T_2 = W \quad (2.17)$$

$$T_1 + T_2 - W = 0$$

Thus, the upward force = downward force

The plank does not possess any rotatory motion. Therefore, the algebraic sum of moment of the forces about $A = 0$.

$$\text{i.e.,} \quad T_1 \times 0 - W \times \frac{\ell}{2} - T_2 \times \ell = 0$$

Where ℓ is the length of the plank

$$W \times \frac{\ell}{2} - T_2 \times \ell = 0$$

$$\therefore T_2 = \frac{W}{2} \quad (2.18)$$

By (2.17) and (2.18) equation

$$T_1 = \frac{W}{2}$$

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

Centre of Gravity

Consider a rigid body. It consists of a number of particles and these particles are attracted towards the earth due to gravity. The forces acting on the particle are F_1, F_2, F_3 , etc. These forces act downwards along parallel lines. These are called like parallel forces. These like parallel forces can be replaced by a single force whose effect is the same as the combination. This is called as the resultant. The resultant force acts at a particular point. This point can be

assumed as the point where the whole weight, W of the body acts. This point is known as centre of gravity (C.G)

Thus,

$$\vec{W} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots\dots\dots$$

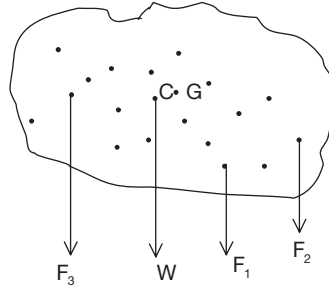


FIGURE 2.34 A rigid body consisting of many particles

Example: Consider a foot ball. The whole weight of the ball acts through the centre of the ball. This point is the centre of gravity of the ball. Therefore, in general, centre of gravity (C.G) may lie inside or outside a body.

While studying the state of equilibrium of a body, we often refer to the position of C.G. of the body to specify the position of a body. Therefore, when we say the position of the body is changed, we mean that the position of the C.G. is changed.

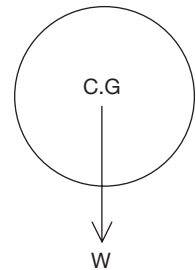


FIGURE 2.35

A funnel is placed on a table top with its base in contact with the horizontal surface because the tip of the funnel has smaller area of cross-section and when the funnel is made to stand on the tip it topples down. Thus, for the funnel to be stable it should be rested with its broader base in contact with the horizontal surface.

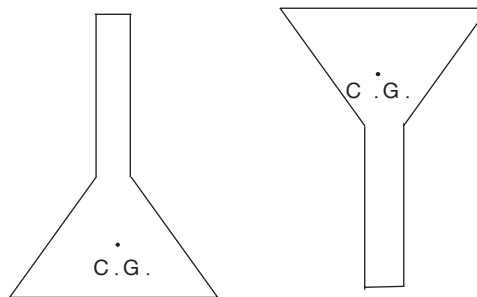


FIGURE 2.36 Funnel

Formula race cars are shorter in height and have broader and heavier base. Thus, the height of their centre of gravity from their base is lesser. Even if the car tilts due to high speed, it can regain its original position because the vertical line from the centre of gravity falls within the base and the centre of gravity of the car is almost at the base.

The height of centre of gravity of an empty bottle from its base is higher when compared to the height of centre of gravity in the case when the bottle is half filled with a liquid. Hence, the stability of the bottle is more when it is half filled compared to that when it is empty.

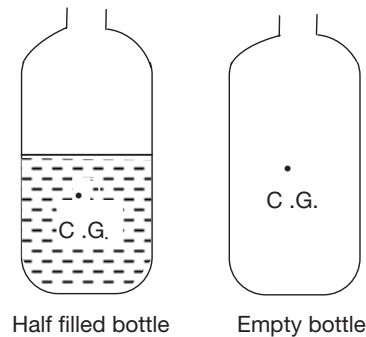


FIGURE 2.37

The famous leaning tower of Pisa is stable even though it is slightly tilted from the vertical, as the line joining its centre of gravity and the centre of the earth falls within its base.

Thus, for a body to be stable,

1. it should have a broader base,
2. the height of the centre of gravity should be lowered (C.G can be lowered by having heavy base), and
3. the vertical line drawn from the centre of gravity of the body to the centre of the earth should fall within the base of the body.

Stable Equilibrium

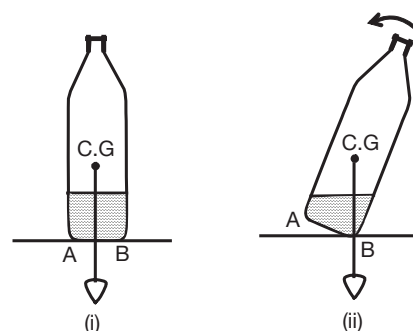


FIGURE 2.38 A bottle placed straight and tilted

When the base of a water bottle is in contact with the horizontal surface, the centre of gravity of the bottle falls within the base. If the bottle is tilted slightly, centre of gravity of the bottle is raised. As a result the stability of the bottle decreases. If the vertical line drawn from the centre of gravity to the centre of the earth passes between A and B, the moment of weight restores the bottle its initial position, then the bottle is said to be in stable equilibrium.

Thus, a body is said to be in stable equilibrium if the body returns to its original state after the external force causing the change of position of the body is withdrawn.

Unstable Equilibrium

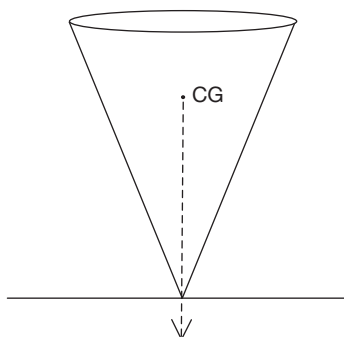


FIGURE 2.39 A cone placed upside down on its tip

A cone resting on its apex would topple when the slightest of disturbances causes the vertical line drawn from the C.G. to centre of the earth to fall outside the base.

Thus, the cone cannot regain its original position. This is known as unstable equilibrium. Therefore, a body is said to be in unstable equilibrium if the body does not return to its initial position after the removal of the external force causing a change in its position.

In the example of the bottle, if the bottle is tilted such that the vertical line from the C.G. passes to the right of B, the moment of weight turns the bottle clockwise and the bottle topples.

Neutral Equilibrium

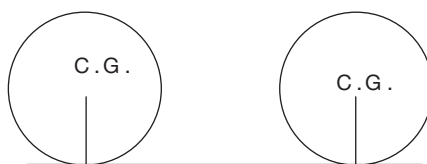


FIGURE 2.40 Change of position of ball on a horizontal surface when rolled

When a ball is rolled on a horizontal surface, it takes a new position but the position of centre of gravity remains intact. This state of the ball is known as neutral equilibrium.

Thus, a body is said to be in neutral equilibrium if it takes a new position without the change in its position of centre of gravity.

Example: Center of Gravity:

1. Kids or infants stand with their legs apart, so that the centre of gravity falls between the legs. This gives them the stability.
2. Vessels like jugs, mugs, water bottles, candles, candle stand, etc., have a broad base to prevent toppling.
3. The base of the ships, pedestal fans and formula cars are made heavy in order to lower centre of gravity which gives them stability.

NOTE

The position of centre of gravity remains unchanged, whether the body is at rest or in motion.

SIMPLE MACHINE

In order to cut paper or cloth, we make use of scissors. To squeeze lemon, we use a squeezer. Slopes or inclined planes connecting higher floors to the lower floors are usually seen in tall buildings or hospitals. These slopes are used to carry load easily. These devices make our work easier and convenient.

In all these devices, we apply a small force at some convenient point and a greater force acts on the body at another point in desired direction. These devices are known as simple machines.

Nut cracker on its own cannot crack a nut. Energy or the force has to be applied to the nut cracker to crack the nuts. This force applied the machine to overcome resistance is called effort or power, which is denoted by P .

In the above case of nut cracker, the force exerted on the machine or the cracker to overcome resistance is called the effort and the force required to crack the nut is called the load.

For any machine, the effort applied or the energy supplied to the machine is used to move machine parts, is partly to overcome friction and the remaining part of the energy is used to do useful work. Thus, all the energy supplied to the machine is not used in doing useful work. Hence, the useful work done by the machine is always less than the actual work done on the machine.

The machine whose parts are weightless and frictionless is called as an, 'ideal' machine. In an ideal machine, the output energy is equal to the input energy or in other words all the work done on the machine is used in overcoming resistance or the load.

Thus, in an ideal machine or perfect machine, output is equal to input.

$$\text{Work done by the machine} = \text{Work done on the machine.}$$

This is known as the principle of a machine. Ideal machine cannot be realised in practice because it is impossible to have a machine whose parts are weightless and frictionless.

Mechanical Advantage (M.A)

The ratio of load to effort is known as mechanical advantage.

$$\therefore \text{Mechanical advantage (M.A)} = \frac{\text{Load (} W \text{)}}{\text{Effort (} P \text{)}}$$

If a large load is lifted with small effort, then the mechanical advantage is greater than one. The effort applied on the machine is used to run the machine parts, to overcome friction and to do useful work. Thus, the total load is the sum of the force to overcome the moveable parts, load due to friction and the useful load.

This ratio of total load to effort is called ideal mechanical advantage (I.M.A.)

$$\text{Therefore,} \quad \text{I.M.A.} = \frac{\text{Total load}}{\text{effort}}$$

The ratio of useful load to effort is called actual mechanical advantage (A.M.A.)

$$\text{Therefore,} \quad \text{A.M.A.} = \frac{\text{Useful load}}{\text{effort}}$$

Velocity Ratio

Consider a load W lifted using a crow bar as shown in the Fig. 2.41. The effort P moves a certain distance ' x ', then the load moves through a distance ' y ' in the same interval of time in which the effort moves. The ratio of displacement of effort to the displacement of load is called velocity ratio (V.R.).

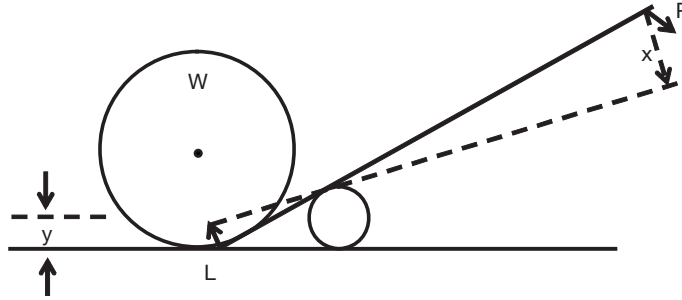


FIGURE 2.41 A load W lifted using a crow bar

$$\text{V.R.} = \frac{\text{displacement of the effort}}{\text{displacement of the load}} \Rightarrow \text{V.R.} = \frac{x}{y}$$

Dividing the displacement of effort and load by time, we get $\text{V.R.} = (x/t) \div (y/t)$ where t is time in which the load or the effort moves.

$$\therefore \text{Velocity Ratio} = \frac{\text{velocity of the effort}}{\text{velocity of the load}}$$

Efficiency (η)

It has already been pointed out that the actual work done by a machine is always less than the work done on the machine. The ratio of useful work done by the machine to the work done on the machine is known as efficiency.

$$\text{Efficiency} = \frac{\text{Useful work done by the machine}}{\text{Work done on the machine}}$$

Useful work done by the machine is the work done to overcome useful load (the output) and the work done on the machine is called the input.

$$\therefore \text{efficiency} = \eta = \frac{\text{output}}{\text{input}}$$

In practice, since the output is less than input, efficiency of a machine is always less than one or 100%. For ideal machines output is equal to input. Hence, the efficiency of an ideal machine is 100%.

$$\eta = \frac{\text{Work done in overcoming load}}{\text{Work done on the machine}}$$

If P is the effort which displaces through x in overcoming a load W , and y is the displacement of the load, then output = $W \times y$ and input = $P \times x$.

Hence,

$$\text{Efficiency, } \eta = \frac{W \times y}{P \times x}$$

($\because$ work = force $\times$ displacement)

$$\eta = \frac{W/P}{x/y}$$

$$\eta = \frac{\left(\frac{\text{load}}{\text{effort}} \right)}{\left(\frac{\text{displacement of effort}}{\text{displacement of the load}} \right)} \Rightarrow \eta = \frac{\text{mechanical advantage (M.A)}}{\text{velocity ratio (V.R.)}}$$

This gives the relation between efficiency, mechanical advantage and velocity ratio.

If W_1 is the useful load and R is the resistance due to moveable parts and the friction, then the total load $W = W_1 + R$.

In the case of a machine having friction and weight, work done in overcoming the total load is equal to work done by the effort.

$$\Rightarrow (W_1 + R) \times y = P \times x$$

$$\Rightarrow \frac{W_1}{P} + \frac{R}{P} = \frac{x}{y}$$

$$\Rightarrow \frac{R}{P} = \frac{x}{y} - \frac{W_1}{P} \Rightarrow R = P \left(\frac{x}{y} - \frac{W_1}{P} \right)$$

$$\Rightarrow R = \text{effort (V.R. - A.M.A.)}$$

A simple machine can be a straight or a bent rigid bar called lever capable of rotating about a fixed point, or it might be a rigid flat surface inclined at an angle called an inclined plane. Thus, simple machines can be classified into levers and inclined planes.

Pulley and wheel-and-axle are modifications of lever. Inclined plane is modified into wedge and screw.

Levers

It is a rigid bar, straight or bent rigid body. The fixed point about which the lever rotates is called fulcrum (F).

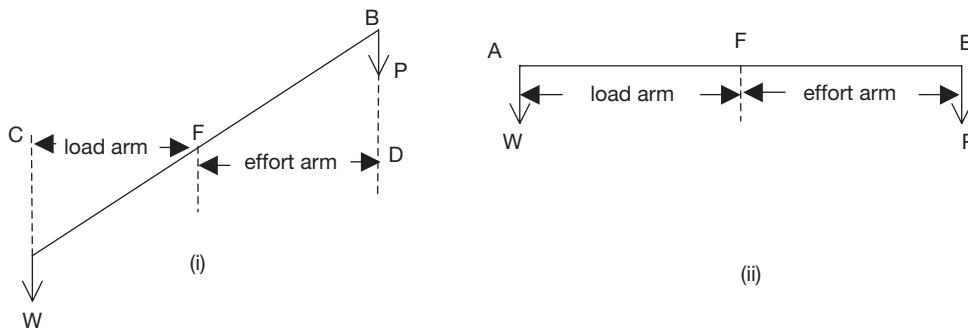


FIGURE 2.42 A See-Saw

In a see-saw, the load is applied at the end A and the effort P to lift the load is applied at B. The perpendicular distance between the load and the fulcrum is called the load arm and the perpendicular distance between the effort and the fulcrum is called effort arm. Thus, in the above diagram (ii) load arm is CE, the effort arm is DE.

In the above example, for the see-saw to be in equilibrium the algebraic sum of the moment of forces about the fulcrum should be equal to zero.

$$\Rightarrow W \times AF - P \times BF = 0 \text{ or } W \times AF = P \times BF$$

Thus, $\text{load} \times \text{load arm} = \text{effort} \times \text{effort arm}$

This is called the principle of lever. From principle of lever,

$$\text{load} \times \text{load arm} = \text{effort} \times \text{effort arm}$$

$$\Rightarrow \frac{\text{load}}{\text{effort}} = \frac{\text{effort arm}}{\text{load arm}}$$

But $\text{load/effort} = \text{mechanical advantage (M.A.)}$

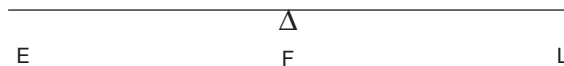
$$\therefore \text{M.A} = \frac{\text{effort arm}}{\text{load arm}}$$

Thus, mechanical advantage of a lever increases with increase in the length of its effort arm. In the case of cutting pliers or a nut cracker, the length of the effort arm is greater than that of the load arm so less effort is used to cut a wire or crack a nut.

Depending upon the relative positions of load, effort and fulcrum, levers are classified into first order, second order and third order levers.

First-order Lever

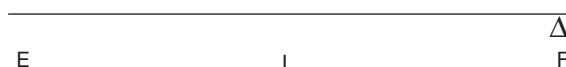
In the case of a see-saw, cutters, crowbar, pliers, scissors, etc., fulcrum lies between the effort and the load. This type of lever is known as a first order lever. It is shown in figure given below.



Usually in a first order lever the length of the effort arm is greater than that of the load arm. Thus, the mechanical advantage of a first order lever, in general, is greater than or equal to one. But in scissors the effort arm is shorter than the load arm, and the mechanical advantage is less than one.

Second-order Levers

In nutcracker, squeezer, hinges, etc., load lies between effort and fulcrum. These type of levers are called second order levers. In a second order lever, the effort arm is greater than the load arm. Hence, the mechanical advantage of second order lever is always greater than one. It is shown in figure given below.



Third-order Lever

In forceps, tongs, knife or when a person swims the effort lies between load and the fulcrum. This type of lever is called third order lever. In third order lever the load arm is longer than the effort arm. Thus, the mechanical advantage of the third order lever is always less than one. First and second order levers are force multipliers and the third order levers are speed multipliers. It is shown in figure given below.

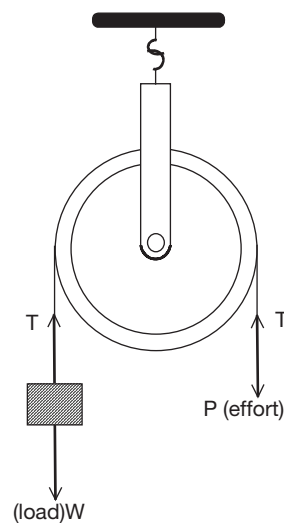


Pulley

It is a wheel or a flat disc which has a grooved edge or a rim. A pulley rotates about a fixed axis which passes through the centre of the pulley. The axle is fixed to a frame or a block. If the block is clamped, the pulley is called fixed pulley and if the block is not clamped, the pulley is called moveable pulley.

Single Fixed Pulley

It is a single pulley which is usually used to draw water from a well. The frame of the pulley is clamped.



Single fixed pulley

FIGURE 2.43 Single fixed pulley

A rope is passed through the groove. To one end of the rope a load is tied and effort is applied at the other end. The effort is applied in the downward direction. The tension ' T ' of the rope acts on both the sides of the rope upward.

If the pulley is not rotating and the load due to friction and moveable parts is neglected, then both the load and the effort are equal to the tension in the string.

Thus,

$$W = P = T$$

$$\text{Mechanical advantage} = \frac{\text{load}}{\text{efforts}} = \frac{W}{P} = \frac{T}{T} = 1$$

In practice, the effort applied is greater than load due to friction in the moveable parts of the pulley.

If the effort moves through a distance 'x', load is lifted through the same distance also.

$$\text{Hence, velocity ratio (V.R.)} = \frac{\text{distance moved by the effort}}{\text{distance moved by the load}} = 1$$

Thus, there is no gain in mechanical advantage or in velocity ratio of the pulley. It is used only to change the direction of effort. It is easier to exert effort in the downward direction, i.e., in the direction of gravity which makes lifting of loads convenient.

Efficiency of an Ideal Pulley

$$\eta = \frac{\text{mechanical advantage (I.M.A)}}{\text{velocity ratio}}$$

$$\text{M.A} = 1 \text{ and V.R} = 1$$

$$\eta = 1 \text{ or } 100\%$$

Thus, the efficiency of an ideal pulley is 100%.

In practice, the effort applied is used to lift useful loads, to overcome loads due to friction and load due to moveable parts. But the total load is equal to effort. If the useful load is W_1 and R is the load due to friction and moveable parts, then total load = $W_1 + R$.

$$\Rightarrow W_1 + R = P$$

$$\Rightarrow \frac{W_1 + R}{P} = 1 \Rightarrow \frac{W_1}{P} + \frac{R}{P} = 1$$

$$\Rightarrow \frac{W_1 + R}{P} = 1 - \frac{R}{P} .$$

$$\text{But } \frac{W_1}{P} = \frac{\text{useful load}}{\text{effort}} = \text{Actual Mechanical Advantage (A.M.A)}$$

$$\therefore \text{A.M.A.} = 1 - \frac{R}{P}$$

Single Moveable Pulley

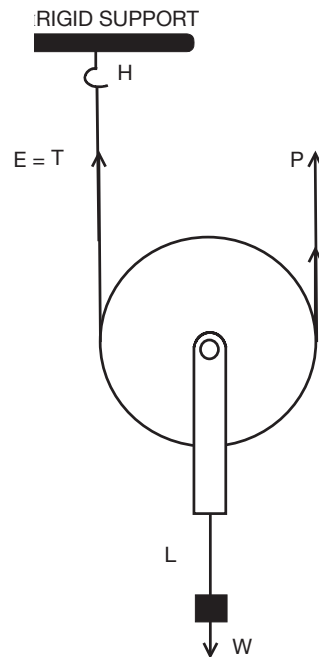


FIGURE 2.44 Single moveable pulley

If the block of the pulley is not clamped, it is called moveable pulley. In this case, the pulley moves as the effort pulls the rope. One end of a rope is fixed to a hook. The rope passes through the rim of the pulley and the effort is applied in the upward direction at the other end of rope. The moveable pulley divides the rope into two segments. Tension ' T ' acts in an upward direction along the two segments of the rope. If P is the effort applied to overcome total load, then $P = T$ and it is obvious from the Fig. 2.44 that $W = T + T = 2T$, where W is the total load.

$$\text{Thus, mechanical advantage} = \frac{\text{load}}{\text{effort}} = \frac{W}{P} = \frac{2T}{T} = 2$$

Thus, the effort applied is equal to half the load. Hence, a single moveable pulley acts as a force multiplier. If the effort moves through a distance ' x ', the load is lifted through a distance $\frac{x}{2}$.

Thus, velocity ratio of the single moveable pulley

$$\text{V.R.} = \frac{\text{displacement of the effort}}{\text{displacement of the load}}$$

$$\text{V.R.} = \frac{x}{\frac{x}{2}} = \frac{2x}{x} = 2.$$

The efficiency of a single moveable pulley

$$\eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{2}{2} \text{ or } 100\%$$

If W_1 is the useful load and R is load due to friction and moveable parts of the machine,

$$\text{Mechanical advantage} = \frac{\text{total load}}{\text{efforts}} \Rightarrow \text{M.A.} = \frac{W_1 + R}{P}$$

Since
$$\text{M.A.} = \frac{\text{Total load}}{\text{effort}} = \frac{W}{P} = 2, \text{ we get}$$

$$\frac{W_1}{P} + \frac{R}{P} = 2 \text{ or } \frac{W_1}{P} = 2 - \frac{R}{P}$$

where $\frac{W_1}{P}$ is the actual mechanical advantage (A.M.A.).

Hence,
$$\text{A.M.A.} = 2 - \frac{R}{P}$$

Since the ratio of R to P is a positive quantity, A.M.A. of a single moveable pulley is always less than 2.

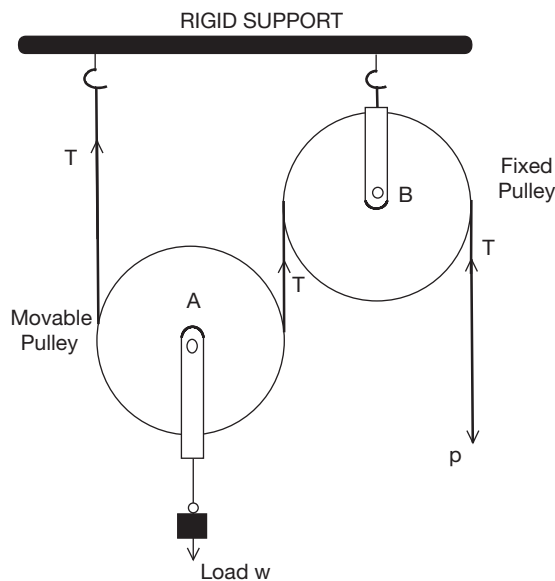


FIGURE 2.45 Single movable pulley with a fixed pulley

Since it is not convenient to apply effort in the upward direction, a single moveable pulley is combined with a fixed pulley to give the same M.A. and V.R. and it is easier to apply the effort using the combination of the fixed pulley and moveable pulley because the effort is applied in the downward direction. It consists of two pulleys. One pulley (B) is fixed and this pulley helps to change the direction of effort. The other pulley (A) moves along with the rope. The load is attached to the moveable pulley.

So one end of rope is fixed to a hook and the rope passes through the moveable pulley and the fixed pulley. The moveable pulley moves along the two segments of the rope. If the effort moves through a distance x , each length of the segment of rope is decreased by an amount equal to $(x/2)$.

Sheath Pulley System or Block and Tackle System

It consists of two sets of pulleys. One set of pulleys is attached to a rigid support at the top and is called the block. The lower set of pulleys carries a load and is called tackle.

One end of the string or rope is fixed to a hook of the tackle. The rope passes round the rim of all the pulleys and the effort is applied at the free end of the rope in the downward direction, as shown in the Fig. 2.46.

Tackle is supported by ' n ' segments of the rope, where ' n ' is the number of pulleys in the system. Tension on each segment of the rope is T and it acts vertically upwards.

If P is the effort used to overcome load W , then $W = nT$ and $P = T$. Thus, the ideal mechanical advantage of the pulley system, $= \frac{W}{P} = \frac{nT}{T} = n$

Thus, the I.M.A. of a pulley system is equal to number of pulleys in the system. The effort required to lift the load is (W/n) . Thus, the system of pulleys acts as a force multiplier and it also changes the direction of force.

Thus, larger the number of pulleys, lesser is the effort. If the effort moves through a distance x , then length of each segment of the rope is decreased by (W/n) .

Thus, the velocity ratio of the pulley system (V.R.)

$$= \frac{\text{displacement of the effort}}{\text{displacement of the load}} \Rightarrow \text{V.R.} = \frac{x}{\left(\frac{x}{n}\right)} = n$$

NOTE

Since M.A. = n , there is no gain in energy.

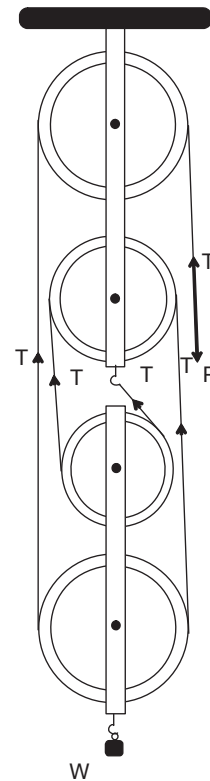


FIGURE 2.46 Block and tackle for four

The efficiency of system of pulleys

$$\eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{n}{n} = 1 \text{ or } 100\%$$

η is 100% only in an ideal system of pulleys. If W_1 is the useful load to overcome by the effort, then M.A. = (W/P) , where W is the total load. But $W = W_1 + R$ where R is the load due to friction and moveable parts of the system.

$$\text{Then} \quad \text{M.A.} = \frac{W_1 + R}{P}$$

$$\text{Since} \quad \text{M.A.} = n,$$

we get

$$\frac{W_1 + R}{P} = n$$

$$\frac{W_1}{P} + \frac{R}{P} = n$$

But (W_1/P) is the actual mechanical advantage of the pulley system A.M.A.

$$\Rightarrow \quad \text{A.M.A.} + \frac{R}{P} = n$$

$$\text{Hence,} \quad \text{A.M.A.} = n - \frac{R}{P}$$

Since (R/P) is positive, A.M.A. of the pulley system is always less than n .

Effect of Weight of Pulleys in Tackle

If W_2 is the weight of the pulleys in the tackle, then the load and weight is balanced by nT , where n is the number of pulleys and T is the tension on each part of the rope. Thus,

$$W + W_2 = nT = nP \quad (\because T = P)$$

where P is the effort

$$\Rightarrow W + W_2 = nP$$

$$\Rightarrow \frac{W}{P} = \frac{W_2}{P} = n \Rightarrow \frac{W}{P} = n - \frac{W_2}{P}$$

$$\text{Hence,} \quad \text{M.A.} = n - \frac{W_2}{P} \quad \left(\because \frac{W}{P} = \text{M.A.} \right)$$

The efficiency of the system of pulleys,

$$\eta = \frac{\text{M.A.}}{\text{V.R.}}$$

$$\Rightarrow \eta = \frac{n - \frac{W_2}{P}}{n} \quad (\because \text{V.R} = n)$$

$$\Rightarrow \eta = 1 - \frac{W_2}{nP}$$

Therefore, to achieve higher efficiency in the system of pulley, the weights of the pulleys in the tackle should be lesser.

Wheel and Axle

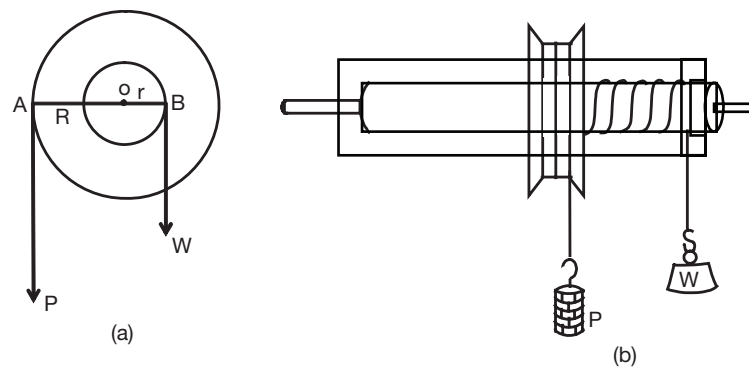


FIGURE 2.47 Wheel and axle

A wheel is fixed to a strong cylindrical axle such that they have a common axis. The radius of the wheel (R) is greater than the radius of the cylindrical axle (r). A string is wound around the cylinder. Load is attached to the free end of this string. Effort is applied to the free end of the string which is wound round the wheel. The windings of the rope on the wheel is in the opposite direction to that of the windings on the axle. The rotating effect of the wheel is equal to the rotating effect of the cylinder.

$\Rightarrow$ Moment of the wheel about the axis = Moment of the axle about the axis

$\Rightarrow P \times R = W \times r$, where P is the effort and W is the load.

$$\Rightarrow \frac{W}{P} = \frac{R}{r}$$

But (W/P) is the mechanical advantage (M.A.).

$$\text{M.A.} = \frac{R}{r}$$

$$\text{M.A.} = \frac{\text{Radius of the wheel}}{\text{radius of the axle}}$$

Screw Jack

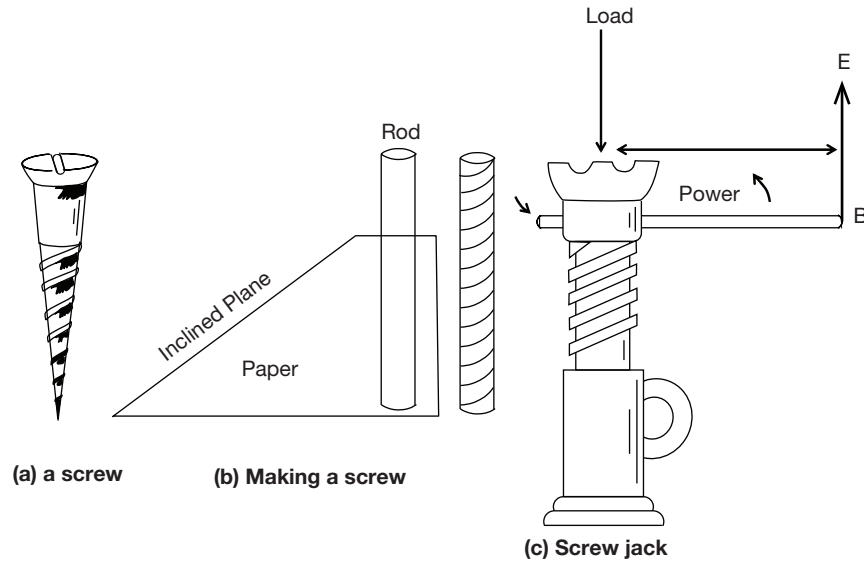


FIGURE 2.48 (a), (b), (c) The screw jack

When a tyre of a car or a heavy vehicle is punctured, the vehicle should be lifted up so as to remove or replace the tyres. These vehicles are lifted up easily using a device known as screw jack.

A screw jack consists of a screw which works through a base which is at rest or stationary. The screw jack is placed under the vehicle or the load to be lifted and the effort is applied through a horizontal bar. The effort E applied gives a turning effect to the bar and the bar in turn rotates the screw. When the bar undergoes one complete rotation, the screw is raised by a height which is called pitch of the screw. Pitch is the distance between two consecutive threads of the screw.

For an ideal screw jack, work done by the effort is equal to work done on the load. If P is the effort applied to the horizontal bar and W is the load which is lifted through height h , then work done by the effort is $2\pi\ell \times P$ where ℓ is the length of the bar from the axis of the screw. $2\pi\ell$ is the distance moved by the effort of the horizontal bar.

Work done on the load = $W \times h$, where ' h ' is the pitch of the screw.

Work done by effort = work done on the load.

$$\Rightarrow 2\pi\ell \times P = W \times h$$

$$\Rightarrow \frac{W}{P} = \frac{2\pi\ell}{h}$$

Ratio of load to effort (W/P) is the mechanical advantage (M.A.) of the screw jack.

$$\text{Thus, M.A. of the screw jack} = \frac{2\pi\ell}{h}$$

Inclined Plane

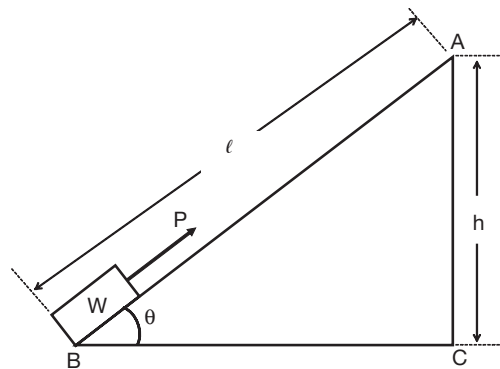


FIGURE 2.49 Inclined plane

In order to climb up a hill or top of a building, we make use of slopes or a ladder or a staircase. We make use of slopes to take vehicles in and out of the house, garage or parking slots at higher level. Flyovers are constructed with slopes. Thus, by using the slopes, we can easily move the load against gravity, to a higher location. Inclined plane is a smooth rigid plane inclined to the horizontal.

Mechanical Advantage of an Inclined Plane When Efforts Acts Parallel to the Plane

Consider an inclined plane AB inclined to the horizontal at an angle θ . Let W be the load to be moved along the plane AB by applying effort P .

If the surface of the plane is considered to be frictionless, then the output work is equal to the input work, i.e., work done by the effort is equal to work done on the load.

$$\Rightarrow P \times AB = W \times AC$$

$$\frac{W}{P} = \frac{AB}{AC}$$

$$\frac{W}{P} = \frac{\text{Length of the plane } (\ell)}{\text{height of the plane } (h)}$$

From Fig. 2.49, $\frac{AC}{AB} = \sin \theta$

$$\therefore \frac{W}{P} = \frac{l}{\sin \theta} = \frac{\ell}{h}$$

But (W/P) is the mechanical advantage (M.A.) of the inclined plane.

$$\therefore \text{M.A.} = \frac{W}{P} = \frac{\ell}{H} = \frac{1}{\sin \theta}$$

From the above expression, it is obvious that lesser the inclination of the slope, lesser is the effort to raise a given load along the inclined plane. Thus, greater effort is required to climb a steep hill.

Experiment to Determine Mechanical Advantage of an Inclined Plane

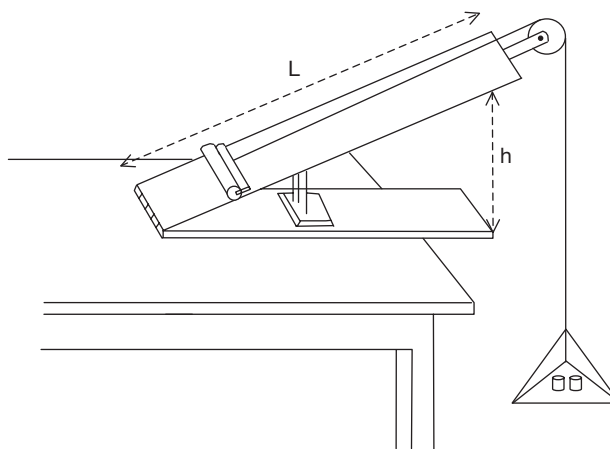


FIGURE 2.50 Inclined plane

Apparatus required: Inclined plane, meter scale, physical balance, scale pan, roller and weights.

Procedure

1. Inclined plane is inclined at a suitable angle or a spring balance.
2. Weight of the roller ' W ' is found using a physical balance or a spring balance.
3. The roller is attached to one end of the string and the string is passed over a pulley. To the free end of the string, is attached a scale pan whose mass (S) is known.
4. The length ' L ' of the plane and the height ' H ' is measured using a metre scale.
5. Suitable weights are added in the scale pan, so that the roller just ascends the plane. The weight W_1 , in the scale pan is noted down.
6. The weights in the scale pan are gradually decreased until the roller just descends. The weight W_2 in the scale pan is noted down.
7. Experiment is repeated for different heights of the plane and the results are tabulated.

Observation

Weight of the roller, $W = \text{_____ g}_{\text{wt}}$

Weight of the scale pan, $S = \text{_____ g}_{\text{wt}}$

Length of the plane, $L = \text{_____ cm}$

Trial No.	W_1 (g)	W_2 (g)	L (m)	$P = S + \left(\frac{W_1 + W_2}{2} \right)$	L/H	$\frac{W}{P}$
1						
2						
3						
4						
5						

$$P \text{ is the effort} = S + \left(\frac{W_1 + W_2}{2} \right) \text{ kg}_{\text{wt}}.$$

Result: It is found that $\frac{W}{P} \approx \frac{L}{H}$ and M.A. = $\frac{W}{P}$.

EXAMPLE

A machine is used to displace a load of 400 N through 50 cm by an effort of 100 N. If the efficiency of the machine is 80%,

- (i) find its mechanical advantage and velocity ratio.
- (ii) find the distance moved by the effort.
- (iii) find the resistance due to the moveable parts of the machine and friction.

SOLUTION

(i) In the given problem

Load, $W = 400$ N.

Distance moved by the load = $y = 50$ cm = 0.5 m.

Effort, $P = 100$ N.

Efficiency = $\eta = 80\%$.

$$\text{M.A.} = \frac{\text{load}}{\text{effort}} = \frac{W}{P} = \frac{400}{100} = 4$$

Thus, the M.A. of the machine is 4.

To find V.R., we can use the relation,

$$\eta = \frac{\text{M.A.}}{\text{V.R.}}$$

$$\Rightarrow \frac{80}{100} = \frac{4}{\text{V.R.}}$$

$$\therefore \text{V.R.} = \frac{4 \times 100}{8}$$

$$\text{V.R.} = 5.$$

V.R. of the machine is 5.

(ii) To find the distance moved by the effort, we use the relation

$$\text{V.R.} = \frac{\text{distance moved by the effort}}{\text{distance moved by the load}} = \frac{x}{y}$$

where x is the distance moved by the effort, and y is the distance moved by the load

$$\Rightarrow 5 = \frac{x}{0.5}$$

$$\therefore x = 0.5 \times 5 = 2.5 \text{ m}$$

Hence, distance moved by the effort = 2.5 m.

(iii) Resistance due to moveable parts of the machine and friction.

$$R = P (\text{V.R.} - \text{A.M.A.})$$

where R is the resistance due to moveable parts and friction.

A.M.A. is the actual mechanical advantage

$$\text{A.M.A.} = \frac{\text{useful load}}{\text{effort}}$$

$$\text{Useful load} = 400 \text{ N}$$

$$\therefore \text{A.M.A.} = \frac{400}{100} = 4$$

$$\therefore R = 100 (5 - 4) = 100 \text{ N.}$$

Thus, the load due to moveable parts and friction is 100 N.

EXAMPLE

Calculate the resistance offered by a lemon when an effort of 0.06 N is applied. The effort arm of the squeezer is 10 cm and the load arm is 3 cm. In length, assume that the effort is applied at the end of the effort arm.

SOLUTION

In the given problem

Effort, $P = 0.06 \text{ N}$

Effort arm = 10 cm = 0.1 m

Load arm = 3 cm = 0.03 m

According to the principle of a simple machine,

Load $\times$ load arm = effort $\times$ effort arm

$$\Rightarrow W = \frac{0.06 \times 0.1}{0.03} = 0.2 \text{ N}$$

Hence, resistance offered by the lemon = 0.2 N

EXAMPLE

A person draws 10 kg water from a well at a depth of 5 m using a single fixed pulley by applying an effort of 120 N. Find the mechanical advantage, velocity ratio and efficiency of the machine. ($g = 10 \text{ m s}^{-2}$)

SOLUTION

In the given problem

$$\text{Load} = W = 10 \times 10 = 100 \text{ N}$$

$$\text{Effort} = P = 120 \text{ N}$$

$$\therefore \text{M.A.} = \frac{W}{P} = \frac{100}{120} = 0.833$$

$$\text{V.R.} = \frac{\text{distance moved by the effort}}{\text{distance moved by the load}}$$

In a single fixed pulley the distance moved by the effort = distance moved by the load.

$$\therefore \text{V.R.} = 1$$

$$\text{efficiency} = \eta = \frac{\text{M.A.}}{\text{V.R.}}$$

$$\eta = \frac{0.833}{1} = 0.83 \text{ or } 83\%$$

EXAMPLE

A block and tackle system of pulleys consists of 8 pulleys. A load of 1000 kg_f is lifted by an effort of 250 kg_f. Find the mechanical advantage, velocity ratio and efficiency.

SOLUTION

In the given problem

$$\text{Number of pulleys, } n = 8$$

$$\text{Load} = W = 1000 \text{ kg}_f$$

$$\text{Effort, } P = 250 \text{ kg}_f$$

$$\therefore \text{M.A.} = \frac{\text{load}}{\text{efforts}} = \frac{1000}{250} = 4$$

If the effort moves through a distance 'x', then the load moves through a distance x/n .

$$\text{V.R.} = \frac{\text{distance moved by the effort}}{\text{distance moved by the load}} = \frac{x}{x/n} = n = 8$$

$$\text{Efficiency, } \eta = \frac{\text{M.A.}}{\text{V.R.}} = \frac{4}{8} = 0.5 = 50\%$$

Thus, the efficiency of the given system of pulleys is 50%.

EXAMPLE

A screw jack is used to lift a vehicle of weight 10000 N through a height of 0.25 m from the ground. If the length of the rod is 0.3 m, find the effort and mechanical advantage used to lift the load. (Assume the jack to be ideal)

SOLUTION

Given, load, $W = 10,000$ N

Height through which the load is lifted, $(h) = 0.25$ m

Length of the rod = 0.3 m

For an ideal machine work done on the load is equal to work done by the effort.

$\Rightarrow W \times h = 2\pi\lambda \times P$, where P is the effort.

$$\begin{aligned}\therefore P &= \frac{W \times h}{2 \lambda} \\ &= \frac{10,000 \times 0.25}{2 \lambda \times 0.3} = \frac{25000}{6\pi} = 1326.29 \text{ N}\end{aligned}$$

$$\text{M.A.} = \frac{\text{load}}{\text{effort}} = \frac{10,000}{1326.29} = 7.539$$

Thus, the M.A. = 7.539

CIRCULAR MOTION

When we open or close a door, the door rotates about a fixed axis (hinges). Each particle or point on the door describes an arc with its centre at the foot of the perpendicular line drawn from the particle to the axis of rotation. Thus, the particles of the door undergo a circular motion.

Hence, a body is said to be in circular motion if every particle in it moves along a circular path and the centre of all these circles lies on the axis of rotation.

If a particle moves along a circle with uniform speed, then the motion of the particle is called as uniform circular motion.

Examples:

1. Motion of a person in a giant wheel or a merry-go-round.
2. Motion of the moon round the earth.

Consider a particle in a rigid body undergoing uniform circular motion along a circle of radius r . In uniform circular motion, though the speed of the particle is constant, its linear velocity is not constant. The magnitude of linear velocity is constant but its direction is along the tangent to the circumference of the circular

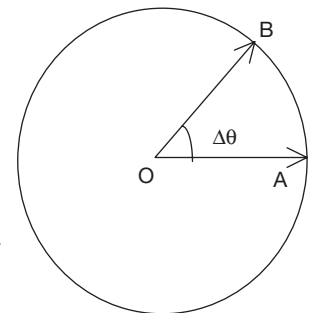


FIGURE 2.51 A particle in uniform circular motion

path. Thus, the direction of the linear velocity changes continuously. According to Newton's first law, the particle should move along the tangent due to inertia of direction. Instead the particle changes its direction and moves along a circular path due to a net external force acting on it. Thus, the particle undergoes displacement along the curve.

Thus, the radius vector $\vec{OA}$ drawn from the centre of circular path to the particle rotates. The angle through which the radius vector turns is known as 'angular displacement'. The angular displacement, $\Delta\theta = \angle AOB$. Its value can be found out using $\Delta\theta = \frac{\lambda}{r}$ = length of arc AB/radius r . Its unit is radian. (2π radian = 360°)

Let the particle be at point 'A' at time t_1 . Due to the net external force acting on it, the particle undergoes uniform circular motion and let the particle after time t_2 be at B. Let $\Delta\theta$ be the angular displacement of the radius vector,

The rate of angular displacement is called angular velocity. It is represented by ω .

$$\omega = \frac{\Delta\theta}{t_2 - t_1} = \frac{\Delta\theta}{\Delta t},$$

where Δt is small interval of time.

Hence,

$$\omega = \frac{\text{change in angular position}}{\text{time}} = \frac{\text{angular displacement}}{\text{time}}$$

Angular displacement is measured in radian and time in second. Hence, the S.I. unit of angular velocity is radian per second. When the time interval Δt tends to zero, then the ratio of $\Delta\theta$ to Δt is called instantaneous angular velocity.

Instantaneous angular velocity,

$$\omega = \lim_{\Delta t \rightarrow 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt}$$

Relation between v , r and ω

Consider a particle moving with constant speed v along a circular path of radius r . Let θ be angular displacement in time interval t , then the angular velocity,

$$\omega = \frac{\theta}{t}, \quad s = \text{APB} = \text{length of the minor arc.}$$

$$\text{But } \theta = \frac{s}{r}$$

$$\therefore \omega = \frac{s}{rt}$$

But displacement/time = linear velocity, v

$$\Rightarrow \omega = \frac{v}{r} \text{ or } v = \omega r$$

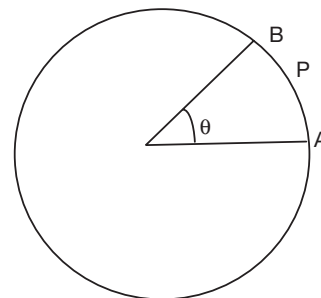


FIGURE 2.52 A particle moving along a circular path

Alternative Method

Consider a particle moving in a circular path of radius r with uniform speed ' v '. Let $\Delta\theta$ be an extremely small angular displacement of the radius vector $\overline{OA}$ in time interval Δt .

$$\text{Length of the arc AB} = s = r\Delta\theta$$

$$\text{Linear velocity of the particle} = \frac{\text{arc length}}{\Delta t} = \frac{r\Delta\theta}{\Delta t}$$

$$\text{But } \frac{\Delta\theta}{\Delta t} = \text{angular velocity} = \omega$$

$$\therefore v = r\omega$$

Thus, the above equation gives the relation between linear velocity and angular velocity.

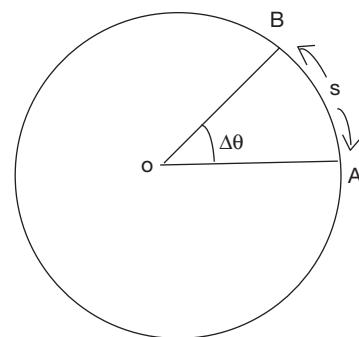


FIGURE 2.53 A particle moving along a circular path

Angular Momentum

Momentum gained by the body due to rotation is angular momentum. The angular momentum is defined as $\vec{L} = \vec{r} \times \vec{p}$, where $\vec{p}$ is the linear momentum and $\vec{r}$ and $\vec{p}$ are perpendicular to each other, where r is radius of rotation.

$$L = mvr$$

$$\text{Thus, angular momentum} = mvr$$

$$\therefore v = \omega r$$

$$L = mr^2\omega$$

S.I. unit of $L = \text{Kgm}^2 \text{s}^{-1}$ or Js and CGS unit is $\text{g cm}^2 \text{s}^{-1}$.

Period

The time taken by a body to complete one revolution is called its time period of revolution. It is denoted by T .

We know $\omega = \frac{\Delta\theta}{t}$ and $\Delta\theta = 2\pi$ radians is its time period

$$\therefore \text{Period} = \frac{2\pi}{\text{angular velocity}}$$

$$T = \frac{2\pi}{\omega} \text{ or } \omega = \frac{2\pi}{T}$$

NOTE

2π radians = 360°

From the earlier discussion, we know that when a particle undergoes a circular motion, the magnitude of the velocity remains the same but the direction of the velocity changes at every point. The direction of velocity is along the tangent to the circumference of the circle. Thus, the particle is continuously accelerated. This acceleration acts in the direction of the force. This force is always perpendicular to the tangent to the circle. Thus, the force is directed towards the centre of the circle. Hence, the acceleration is directed towards the centre of the circular path and this acceleration is called 'centripetal acceleration' or normal acceleration or 'radial acceleration'.

Centripetal acceleration 'a' is given by, $a = \frac{v^2}{r}$ where v is the magnitude of linear velocity and r is the radius of the circular path.

Also, since $v = r\omega$, $a = \omega^2 r$

Centripetal Force

It is seen that when a particle undergoes uniform circular motion, a force is required to make the particle change its direction of motion continuously to move along the circular path with a constant speed. This force is always directed towards the centre of the circular path. This force is called as centripetal force or radial force (inward force).

Thus, centripetal force is the force which is always directed towards the centre of the circle (i.e., along the radius vector) when the body undergoes uniform circular motion.

Centripetal force, $F = \text{mass of body} \times \text{centripetal acceleration}$

$$\therefore F = m \frac{v^2}{r} = m\omega^2 r \quad (\because v = \omega r)$$

Centripetal force is provided by an external agency.

Examples:

1. The centripetal force required for a planet to go round the sun is provided by the gravitational force applied by the sun on that planet.
2. The centripetal force required for electrons to move round the nucleus is provided by electrostatic force of attraction between the nucleus and the electron.

Centrifugal Force

In kinematics, we have studied that rest or motion is defined depending on a reference. For example, a bird flying is said to be in motion when the reference frame is attached to the ground. But for another bird flying alongside, the first bird appears to be at rest.

Thus, we find that Newton's first law can be applied depending on the reference frame. Hence, whenever no net force acts on a body producing a change of rest or of uniform motion, then there always exists a reference frame in which a body has no acceleration. Such a reference frame is called inertial reference frame or inertial frame.

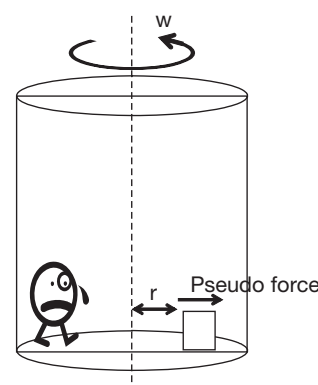


FIGURE 2.54

Example: A car moving with uniform velocity can be considered as an inertial frame, since no force acts on any body placed in the car.

However, traveling in a train accelerating forwards, you would observe objects like a box placed on the floor of the coach sliding backward as if a force is acting on them. Thus, a reference frame attached to an accelerating train is a non-inertial reference frame, and the force which appears to be acting on the box is referred to as a pseudo force or a fictitious force. (The force which exists without any external agent is called pseudo force)

Example: Standing passengers in a bus are thrown forward when the driver suddenly applies brakes.

Similarly, standing on the rotating platform of a merry-go-round, the hanging seats along the circumference appear to be pushed outward as if a radially outward force acts on them. This pseudo force arising from a circular motion or rotatory motion is referred to as centrifugal force.

Example: Consider a man sitting in a circular chamber rotating about a central vertical axis at a uniform angular velocity, ω rad s^{-1} .

Let a box be resting on the floor at a distance of r from the centre.

As the chamber continues to rotate at uniform angular velocity, the man would observe that the box would slide and move towards the wall of the chamber. The box would remain at rest only after it comes into contact with the wall.

Similarly, every particle of the chamber also experiences such a force directed radically outwards.

The centripetal force and centrifugal force are equal in magnitude but opposite in direction.

$$\text{Centrifugal force} = \frac{mv^2}{r} = m\omega^2 r$$

Thus, the magnitude of the centrifugal force is given by the expression.

Centripetal force	Centrifugal force
It is always directed towards the centre.	It is directed away from the centre.
It is a real force.	It is a pseudo force.
It is always associated with an external agent, e.g., tension in the string, etc.	Being a pseudo force, it is not associated with any external agent.
It is the cause of a circular motion.	It is the effect of circular motion.
It is the pull on the body towards the centre of the circle.	It is a tendency to move away from the centre of the circle.

Similarities between Centripetal Force and Centripetal Acceleration

1. Magnitude of both the forces is given by the expression $\frac{mv^2}{r}$ or $m\omega^2 r$
2. In uniform circular motion, their magnitude is constant.
3. The magnitude of each force depends on the mass and the speed of rotation.

NOTE

Centripetal force and centrifugal force are not action – reaction pair since both are acting on the same body.

Application of Centrifugal Force

Centrifuge

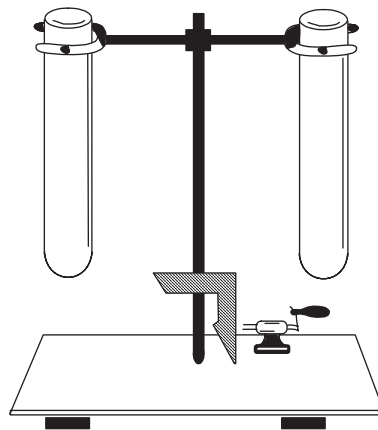


FIGURE 2.55 Centrifuge

Centrifuge is a device used to separate minute particles of varying densities which cannot be separated by sedimentation. Its working is similar to the butter churn used to churn curds. It consists of a number of vials suspended to a horizontal frame which is supported by a vertical stand. The vials are filled with solid liquid mixture from which solid particles are to be separated and the vials are rotated in a horizontal plane at a very high speed by an electric motor. Higher density particles move towards the bottom of the vials (small lubes) because centrifugal force for heavier particles is greater than the lighter particles. Thus, the lighter particles move towards the axis and can be easily skimmed off. Thus, particles of different densities are separated.

Centrifuge is used to separate cream from milk, to separate hormones, viuses proteins, etc. from blood.

Laundry Drier or Washing Machine Dryer

It consists of a perforated cylindrical vessel which can rotate about its axis at a very high speed. The clothes to be dried are placed in the cylinder and are rotated with high speed. The adhesive force between water and the cloth is less compared to the centrifugal force acting on the water molecules.

This centrifugal force, forces the water molecules to escape through the holes of the cylindrical vessel. Thus, the wet clothes get dried.

Centrifugal Governor

It works on the principle of a centrifugal force. This device was applied to a steam engine by James Watt. It is a special governor that controls the speed of an engine by regulating the fuel intake into it, irrespective of load or fuel supply conditions, and thus, maintains a near constant speed.

Centrifugal Pump

This device is used to transfer liquids or gases from low pressure regions. This device works on the principle of centrifugal force. Exhaust fans and blowers are centrifugal pumps.

Banking

The centripetal force that helps a vehicle to negotiate a curve is the frictional force between the tyres and the road. Since the vertical displacement of the vehicle moving along a circular path is zero, the frictional force involved is only static frictional force, which is limited by $\mu_s N$.

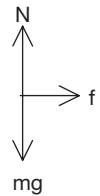
$$\text{Since } N = mg,$$

$$f \leq \mu_s mg$$

$$\text{Equating } f \text{ to centripetal force, } \frac{mv^2}{R},$$

$$\text{we get } \frac{mv^2}{R} \leq \mu_s mg$$

$$\frac{v^2}{R} \leq \mu_s g$$



Thus, both the speed of the vehicle and the radius of curvature are limited to the extent that the ratio $\frac{v^2}{R}$ must be less than $\mu_s g$.

If either the speed increases or the curve to be negotiated is sharper, then frictional force alone would not be sufficient to produce the corresponding centripetal acceleration and a component of the normal force is utilized.

This is the reason a cyclist negotiating a curve would tend to bend in the direction of the curve; and roads are provided with banking.

Banking of Roads

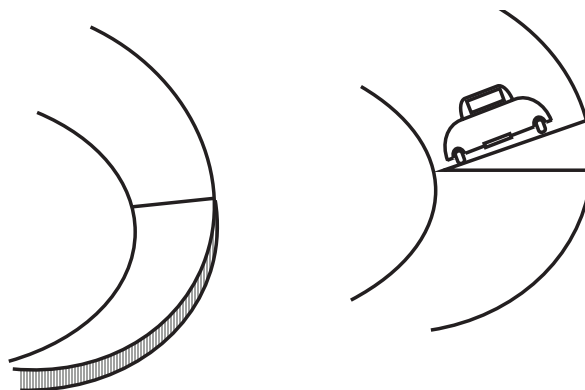


FIGURE 2.56 Centrifuge

Banking is the inclination given to roads and rail tracks at turnings or along curved paths, by raising the outer edge of the path slightly above the inner edge towards the centre of the curvature.

Consider a body moving along a horizontal circular path, where no banking is provided.

A car moving on a road (or a train moving on the rails) requires a centripetal force while taking a turn. To some extent, this centripetal force is provided by the friction between the road and tyre. When the vehicles are heavy, the required centripetal force may not be provided by the frictional force, as it is limited.

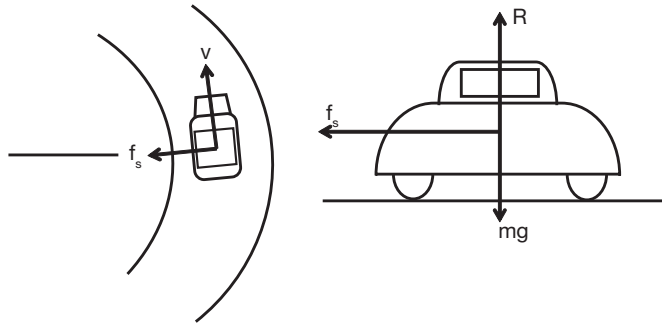


FIGURE 2.57 A car moving on a road while taking a turn

As the magnitude of f_s cannot exceed $\mu_s R$, where μ_s is the coefficient of static friction,

$$\begin{aligned} \therefore f_s &\leq \mu_s R \\ f_s &\leq \mu_s mg, \text{ i.e., } \frac{mv^2}{r} \leq \mu_s mg \\ \mu_s &\geq \frac{v^2}{rg} \end{aligned}$$

If this condition is not satisfied, the car or train would skid outwards.

Now, consider a curved road with banking. The angle made by the road with the horizontal line is called the 'angle of banking'.

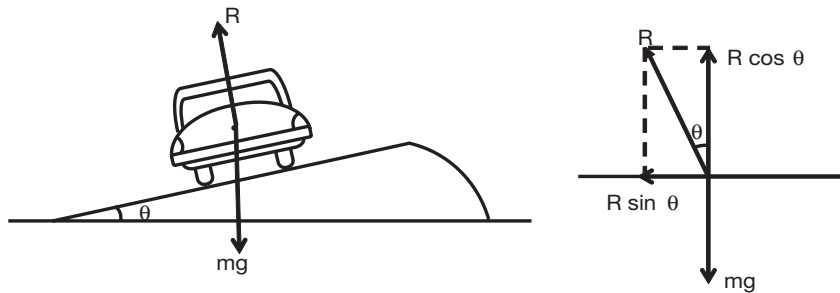


FIGURE 2.58 A curved road with banking

Let the angle of banking be θ . On resolving, the normal reaction ' R ' into components, we can say that normal reaction is equal to the weight of the car.

$$\text{i.e., } R \cos \theta = mg \quad (2.19)$$

and $R \sin \theta$ acts as centripetal force acting on the car.

$$\text{i.e.,} \quad R \sin \theta = \frac{mv^2}{r} \quad (2.20)$$

By Eq. (2.19) and (2.20)

$$\begin{aligned} \text{Thus, we have} \quad \tan \theta &= \frac{v^2}{rg} \\ \Rightarrow v &= \sqrt{rg \tan \theta} \end{aligned}$$

Above formula is used to find expected speed at a curve.

The roads are banked, i.e., the angle of banking is provided for the average expected speed of the vehicles. If the speed of the vehicle v is less, then the average expected speed (v_0) for a given banking, the vehicle would skid towards the centre. If $v > v_0$, the car would skid outwards.

Centrifugal Reaction

Take a stone and tie it to a string and whirl the stone with the other end of the string tied to the forefinger so that it describes a horizontal circle. The string exerts a force on the stone towards the centre. This force is centripetal force. At the same time, the string exerts an outward force on the finger and this force is known as centrifugal reaction.

Thus, centrifugal reaction is a reaction force which acts on an agent, which makes the body to move along a curve or a circular path.

It is important to note that centrifugal reaction is not centrifugal force. Centrifugal reaction is a reaction force according to Newton's third law of motion, whereas centrifugal force is a pseudo force in a non-inertial frame.

EXAMPLE

A car takes a turn along a curved road of radius 40 m and the angle of banking of the road is 45° . At what maximum speed, can the car be driven so that it may not skid ($g = 10 \text{ m s}^{-2}$)?

SOLUTION

The maximum speed for the car is given by v .

$$\tan \theta = \frac{v^2}{rg}$$

where r is the radius of the road, g is the acceleration due to gravity and θ is the angle of banking = 45° .

$$r = 40 \text{ m}$$

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

$$\tan \theta = \frac{v^2}{rg}$$

$$\tan 45^\circ = \frac{v^2}{40 \times 20} \Rightarrow (\because \tan 45 = 1)$$

$$v^2 = 400$$

$$v = \sqrt{400} = 20$$

The maximum speed of the vehicle = 20 m s^{-1}

EXAMPLE

A record player makes 60 rpm (revolution per minute). Find its angular velocity and its period.

SOLUTION

In the above problem, the number of revolutions per minute, $n = 60$. Hence, the number of revolutions in one second, $n = \frac{60}{60} \text{ rps} = 1$

$$\begin{aligned} \therefore \text{Angular velocity} &= \omega = 2\pi \times n \\ &= 2\pi \times 1 \\ &= 2\pi \text{ radians s}^{-1} \end{aligned}$$

EXAMPLE

A figure skater spins on her toes with her arms stretched out. If the length of each arm is 60 cm and if she spins at a uniform linear speed of 4 m s^{-1} , measured at the tip of the arm, find the

- (i) angular velocity.
- (ii) period.

(Consider length of arm = distance from tip of the arm to the axis of rotation)

SOLUTION

- (i) In the above problem, since the ballet dancer spins on her toe, the length of the arm = radius = r .
 $r = 60 \text{ cm} = 0.6 \text{ m}$
 Linear speed = $v = 4 \text{ m s}^{-1}$

Angular velocity, $\omega = \frac{v}{r} \text{ rad s}^{-1}$

$$\omega = \frac{4}{0.6} = \frac{40}{6} = 6.66 \text{ rad s}^{-1}$$

(ii) period, that is time taken for one revolution,

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{6.66} = 0.9425 \text{ s}$$

EXAMPLE

A block of mass 150 g moves with a uniform speed in a circular groove of radius 30 cm. Find its centripetal acceleration and centripetal force acting on the block if the linear speed of the block is 0.8 m s^{-1} .

SOLUTION

In the given problem

Mass, $m = 150 \text{ g} = 0.150 \text{ kg}$

Radius, $r = 30 \text{ cm} = 0.3 \text{ m}$

Linear speed, $v = 0.8 \text{ m s}^{-1}$

Hence, centripetal acceleration, $a = \frac{v^2}{r}$

$$\therefore a = \frac{(0.8)^2}{(0.3)} = \frac{0.64}{0.3} = \frac{6.4}{3} = 2.13 \text{ ms}^{-2}$$

$$\text{Centripetal force } F = \frac{mv^2}{r} = m\omega^2 r \text{ or}$$

$$F = m \cdot a$$

$$= 0.15 \times 2.13 = 0.195 \text{ N}$$

EXAMPLE

A bucket containing water is fastened to a rope and is whirled in a vertical circle of radius 50 cm. Find the minimum speed at the highest point, so that the water does not spill.

SOLUTION

The bucket should be rotated such that the weight of the bucket and the water in it are balanced by the centrifugal force.

Let the mass of the bucket filled with water be $= m$

$$\therefore \text{weight} = mg$$

weight = centrifugal reaction acting on the bucket filled with water

$$\Rightarrow mg = \frac{mv^2}{r}$$

$$(\because \text{centrifugal reaction} = \frac{mv^2}{r})$$

where r is radius or the length of the rope = 500 cm = 0.5 m

$$\therefore v^2 = rg$$

$$v = \sqrt{rg}$$

$$V = \sqrt{0.5 \times 9.8} = \sqrt{4.90}$$

$$v = 2.214 \text{ m s}^{-1}$$

PLANETARY MOTION

Motion of the planets, moon, sun, etc., puzzled many scientists. It was Ptolemy in the second century A.D. who put forward a theory known as geo-centric theory. According to his theory, Sun along with the other planets revolves round the stationary earth, which is the centre of the universe.

Geo-centric theory is also known as Ptolemaic theory. Geo-centric theory was accepted until Copernicus, a Polish monk proposed a theory known as 'helio centric theory'. According to helio-centric theory, earth along with other planets revolves round the sun in a circular orbit. Helio-centric theory was accepted for many years. It was Kepler, assistant of Tycho Brahe who analysed the observations of Brahe and supported the helio-centric theory and put forward his results in the form of laws called as Kepler's laws.

FIRST LAW OF KEPLER

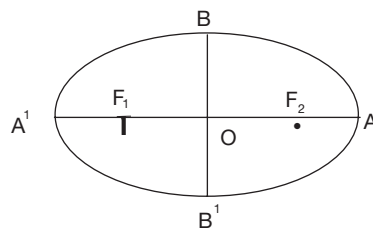


FIGURE 2.59 Ellipse

First law of Kepler states that all planets revolve round the sun in an elliptical orbit of different radii with the sun at one of their focal points.

Ellipse consists of two axes, longer axis ($A A^1$) is called the major axis and the shorter axis ($B B^1$) is called the minor axis. Two points F_1 and F_2 which are at fixed positions on the major axis are called as focii.

Kepler's first law is also called law of orbits.

SECOND LAW OF KEPLER

According to the second law of Kepler, an imaginary line drawn from sun to the planet, also called radius vector, sweeps out equal areas in equal intervals of time.

Consider a planet orbiting around the sun as shown in the Fig. 2.60. Let P_1 and P_2 be the positions of the planet at the beginning and end of a given time interval, say a month. After a certain duration, let P_3 and P_4 be the positions of the planet at the beginning and end of a month duration. Then according to Kepler's second law, the area SP_1P_2 is equal to the area SP_3P_4 .

This law is called law of areas.

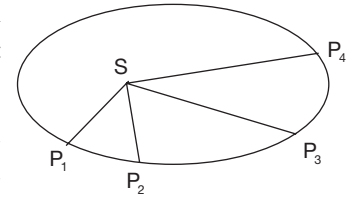


FIGURE 2.60 A planet orbiting around the sun with varying positions

THIRD LAW OF KEPLER

Statement: Square of the time period of revolution of a planet is directly proportional to cube of mean distance of that planet from the sun.

If T is period of revolution of the planet and d is the mean distance of the planet from the sun, then $T^2 \propto d^3$.

If T_1 and T_2 are periods of revolutions of two planets, and d_1 and d_2 are the mean distances of the planets from the sun, respectively, then according to Kepler's third law,

$$\frac{T_1^2}{T_2^2} = \frac{d_1^3}{d_2^3}$$

NEWTON'S UNIVERSAL LAW OF GRAVITATION

Newton was investigating the nature of force that makes the moon go round the earth. His observation of an apple falling towards the earth led him to conclude that earth attracts all bodies towards it and he found that the force of attraction is not limited only to terrestrial bodies, but to all bodies in the universe. Force between the bodies is known as gravitational force. Newton made use of Kepler's second law in stating the universal law of gravitation.

Statement

Every body in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

If m_1 and m_2 are masses of two bodies separated by a distance d , then according to universal law of gravitation, the gravitational force between them, F is given by,

$$F \propto m_1 m_2 \quad (2.21)$$

and

$$F \propto \frac{1}{d^2} \quad (2.22)$$

Combining (2.21) and (2.22), we get

$$F \propto \frac{m_1 m_2}{d^2}$$

$$\Rightarrow F = G \frac{m_1 m_2}{d^2}$$

where G is the universal gravitational constant.

S.I. unit of G :

$$G = \frac{F \times d^2}{m_1 m_2}$$

$$\text{Unit of } G = \frac{\text{unit of } F \times (\text{units of distance})^2}{(\text{unit of mass}) \times (\text{unit of mass})} = \frac{N \times m^2}{kg \times kg}$$

Thus, the unit of G in S.I. system is $N \, m^2 \, kg^{-2}$ and the value of $G = 6.67 \times 10^{-11} \, N \, m^2 \, kg^{-2}$.

Dimensional Formula of G

Dimensional formula of G ,

$$\begin{aligned} &= \frac{[\text{Force}] \times [\text{distance}]^2}{[\text{mass}]^2} = \frac{[M^1 L^1 T^{-2}] \times [L^2]}{[M^1] \times [M^1]} \\ &= [M^{-1} L^3 T^{-2}] \end{aligned}$$

Hence, the dimensional formula of G is $[M^{-1} L^3 T^{-2}]$

$G = F$ when $m_1 = m_2 = 1$ unit and the distance between the two bodies is one.

$$G = \frac{F \times 1^2}{1 \times 1} = F$$

Thus, universal gravitational constant is equal to the gravitational force acting between two bodies each of unit mass and separated by a unit distance.

When a ball or any object is thrown up, it is pulled towards the earth due to earth's gravitational force. As a result, the velocity of the body increases by $9.8 \, m \, s^{-1}$ for every second at sea level near the equator of the earth. Thus, the body is uniformly accelerated.

This uniform acceleration of a freely falling body due to earth's gravitational force is known as acceleration due to gravity. Acceleration due to gravity is denoted by ' g '.

NOTE

Acceleration due to gravity is the same for all bodies irrespective of their mass, shape and size.

Relation between G and g

Consider an apple of mass m falling from a tree. The apple is acted upon by gravitational force due to earth, and hence, it is attracted towards the earth. From Newton's law of gravitation, the gravitational force acting on the apple is given by,

$$F = \frac{GMm}{R^2} \quad (2.23)$$

Where M is the mass of the earth and R is the radius of the earth.

From Newton's second law, the apple is accelerated towards centre of the earth due to gravitational force.

$$\therefore F = mg \quad (2.24)$$

From equations (2.23) and (2.24), we get

$$mg = \frac{GMm}{R^2} \text{ or } g = \frac{GM}{R^2}$$

This equation shows the relation between g and G and it shows that g is independent of mass of the body, i.e., all bodies irrelevant of their masses are accelerated to the same extent. Thus, when we drop a wooden ball and a solid iron ball of different masses simultaneously from the same height, both reach the earth at the same time.

From the relation $g = \frac{GM}{R^2}$, the value of g can be found out.

Mass of the earth = 6×10^{24} kg

Radius of the earth = 6.4×10^3 km = 6.4×10^6 m.

$$\therefore g = \frac{GM}{R^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^6)^2} = 9.77 \text{ m s}^{-2}$$

The value of ' g ' calculated above is near the equator at sea level. The value of ' g ' varies with height, depth and latitude.

Variation of ' g ' with Height

Consider a body of mass ' m ' at a height ' h ' above the surface of the earth. If M and R are mass and radius of the earth, respectively, then acceleration due to gravity at height ' h ' is given by,

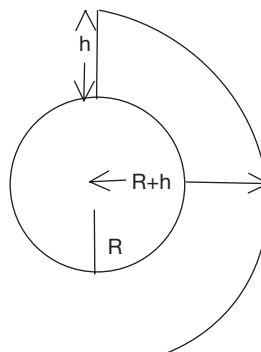


FIGURE 2.61 A body of mass ' m ' at a height ' h ' above the surface of the earth

$$g_h = \frac{GM}{(R+h)^2} \quad (2.25)$$

On the surface of the earth

$$g = \frac{GM}{R^2} \quad (2.26)$$

From equation (2.25) and (2.26), we get

$$\begin{aligned} \frac{g_h}{g} &= \frac{R^2}{(R+h)^2} \\ \frac{g_h}{g} &= \frac{R^2}{R^2 \left(1 + \frac{h}{R}\right)^2} \\ g_h &= \frac{g}{\left(1 + \frac{h}{R}\right)^2} \end{aligned}$$

Expanding $\left(1 + \frac{h}{R}\right)^{-2}$ using binomial theorem and neglecting the higher powers.

When $h \ll R$, i.e., close to the earth's surface,

$$\text{we get} \quad \left(1 + \frac{h}{R}\right)^{-2} \quad \left(\therefore 1 - \frac{2h}{R}\right)$$

$$\Rightarrow \quad g_h = g \left(1 - \frac{2h}{R}\right)$$

Thus, acceleration due to gravity decreases with height.

Variation of 'g' with Depth

As we go deep into the earth, the effective mass of the earth decreases. Effective mass of the earth at a depth 'h' is given by,

$$M_d = \frac{4}{3} \pi (R-h)^3 \rho,$$

where ρ is the average density of the earth.

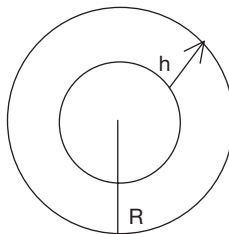


FIGURE 2.62 The earth at a depth 'h'

Thus, acceleration due to gravity decreases with depth and the acceleration at depth ' h ' is given by,

$$g_d = g \left(1 - \frac{h}{R} \right)$$

At the centre of the earth, depth, $h = R$. Therefore, $g_d = 0$.

Variation of ' g ' with Latitude

Earth is not exactly spherical in shape, but is ellipsoidal. Its polar diameter is lesser by 40 km approximately than the equatorial diameter. Since $g \propto (1/R^2)$ acceleration due to gravity is greater or maximum at the poles and minimum at the equator.

Earth is not uniformly dense. There are a variety of mineral deposits, water, oil, etc., inside the earth and on the surface there are massive land formations like mountains, etc. Hence, the value of g is affected by all these factors. Small variations in g is measured by a device known as gravity meter.

MASS AND WEIGHT

The force exerted by the earth on a body is called weight. Thus, the weight of a body (w) is equal to mg where ' m ' is the mass of the body and ' g ' is acceleration due to gravity. From earlier discussion, it is seen that g varies from place to place, hence, the weight of the body also varies from place to place and is different on different planets since ' g ' is different on different planets, whereas the mass is the amount of matter contained in the body, and thus, mass of a body remains constant everywhere.

Suppose we measure the mass and the weight of a body using a common balance and a spring balance, respectively, at two places, say Kanyakumari and Mount Everest, we observe that mass of the body at the two places is same but its weight on Mount Everest is less than that at Kanyakumari.

Mass	Weight
It is the amount of matter contained in the body.	It is the force exerted by the earth on the body, i.e., $W = mg$.
Mass remains same anywhere in the universe.	Weight changes or varies from place to place.
S.I. unit of mass is kilogram.	S.I. unit of weight is newton and gravitational unit is kg_f or kg_{wt} .
Mass is measured by a common balance or physical balance.	Weight is measured by spring balance.

Measurement of Weight–Spring Balance

The weight of a body (mg), as discussed earlier, can be determined using a spring balance. Before we proceed to know about how the measurement of weight is done by using a spring balance, we need to know about the balance and the principle behind it.

A spring balance consists of a spring and a pointer attached to the spring sliding over a scale as shown in the Fig. 2.63. There is a hook attached to the lower end of the spring so as to enable us to attach the given load to the balance.

Working Principle of a Spring Balance

If a load is attached to the hook of a spring balance, there is an extension in the length of the spring due to the attached load. Thus, there is a downward force acting on the spring all along its length. The force acting per unit area of cross-section of the spring is called stress. If ' F ' is the downward force acting on the spring and ' A ' is the area of cross section of the spring, then stress (F/A). Due to this stress, there is an extension ($\Delta\ell$) in the length of the spring. This extension or elongation of the spring takes place throughout its length (ℓ). The ratio of elongation to its original length or elongation per unit length is called 'strain'. Thus, strain = ($\Delta\ell/\ell$).

The amount of strain produced in the spring is directly proportional to the stress applied on it. This proportionality is applicable to the spring within the elastic limit (the condition in which the spring tends to lose its elastic property) only. Thus, within the elastic limit, for an elastic body, stress is proportional to the strain. This is known as Hooke's law.

Thus, according to Hooke's law

$$\text{stress} \propto \text{strain} \Rightarrow \frac{\text{stress}}{\text{strain}} = \text{constant}$$

$$\therefore \frac{F/A}{\Delta\ell/\ell} = \text{constant}$$

$$\Rightarrow \frac{F}{A} \times \frac{\ell}{\Delta\ell} = \text{constant}$$

$$\Rightarrow \frac{F}{\Delta\ell} \times \frac{\ell}{A} = \text{constant}$$

As ' ℓ ' the initial length of the spring and ' A ' the area of cross-section of the spring are constant, we have $(F/\Delta\ell) = \text{constant}$. The downward force ' F ' acting on the spring is the weight of the load ' w ' and so $(W/\Delta\ell) = \text{constant}$.

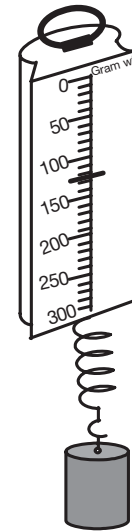


FIGURE 2.63
Spring balance

Experiment to Determine Weight of a Body using a Spring

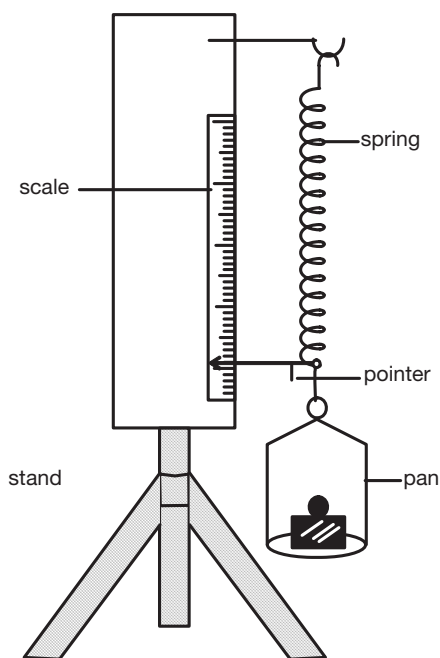


FIGURE 2.64 Spring balance

Consider a spring of considerable length suspended from a rigid support as shown in the Fig. 2.64. Let ' ℓ ' be its length, when no load is attached to the free lower end of the spring. When a load is attached at the lower end of the spring, it has an extension $\Delta\ell$. According to Hooke's law, within the elastic limit, the weight of the load attached at the bottom of the spring (w) is directly proportional to the extension ($\Delta\ell$). Thus, $w \propto \Delta\ell$ and so $(w/\Delta\ell)$ constant. This is the principle used in measuring the weight of a substance.

Attach a pan of negligible weight at the bottom of the spring. Let ' ℓ_o ' be the length of the spring shown by the pointer on the scale. Now place 10 g weight in the pan, and note the pointer reading. Let it be ' ℓ_1 '.

Then the extension in the spring $\Delta\ell = \ell_1 - \ell_o$. Now increase the weight in the pan in steps of 10 g and in each case note the pointer reading ' ℓ_1 ', so that the extension $\Delta\ell$ in each case can be calculated. The procedure is repeated till the weight in the pan is around 100 g. Now gradually decrease the weight in the pan in steps of 10 g and again note the pointer reading ' ℓ_2 ' in each case. Calculate the mean of the pointer readings while loading and un-loading the

pan so that extension $\Delta\ell$ is calculated accurately. In each case, calculate $\frac{\Delta\ell}{\text{weight}}$.

The observations are tabulated as below.

Sl. No.	Weight in the pan (w) (g)	Pointer positions While loading ℓ_1 (cm)	While unloading ℓ_2 (cm)	Mean position $\ell = \frac{\ell_1 + \ell_2}{2}$ (cm)	Extension $\Delta\ell = \ell - \ell_0$ (cm)	$\frac{\Delta\ell}{w}$ (cm g^{-1})
1	10					
2	20					
3	30					
4	40					
5	50					
6	60					
7	70					
8	80					
9	90					
10	100					

A graph is plotted between w (in g_{wt}) along the X -axis and $\Delta\ell$ (in cm) along the Y -axis. The graph obtained is a straight line making a positive angle with the X -axis and passing through the origin, as shown in the Fig. 2.65.

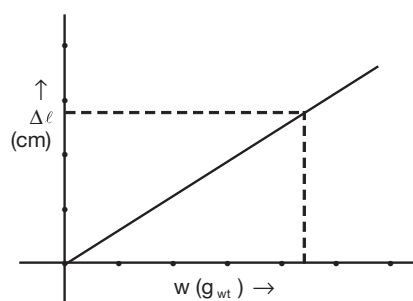


FIGURE 2.65 w versus $\Delta\ell$ graph

To determine the weight of a body, the body is kept in the pan; then the extension in the spring is measured. From the graph of weight versus extension, the weight of the body is determined.

Rockets

Rockets are vehicles which are used to carry objects having heavy mass like space craft, satellite, etc. The mass of rocket plays an important role in accelerating the rocket. Rocket works on the principle of conservation of linear momentum which states that when net external force acting on the system is zero, the total momentum of the system remains constant.

During the launching of a rocket fuels are burnt and the gases escape with a high speed. These gases are ejected through a nozzle present at the rear end of the rocket. The rocket acquires the same momentum as that of the ejected or exhaust gases but in the opposite direction.

Unlike other vehicles, rockets carry their own oxidant which provides oxygen for combustion of the fuel. Hence, rockets can operate in space. Rocket carries payload or space-craft, which is usually placed in the front portion of the rocket.

The mass of the rocket not only includes the mass of the space craft but also mass of the fuels and oxidants called rocket propellant. The mass of the rocket has an effect in its acceleration.

The product of rate of the fuel consumption and its escape velocity gives the force or thrust exerted on the rocket. If R is the rate of fuel combustion and V_{ex} is the exhaust velocity of the fuel, then

$$RV_{ex} = \text{force exerted on the rocket.}$$

$$RV_{ex} = \text{mass of rocket} \times \text{acceleration of the rocket.}$$

Thus, greater the mass of the rocket, lesser is its acceleration. But as the rocket consumes fuel, the mass of the rocket keeps on decreasing. Further, acceleration due to gravity decreases as the rocket goes higher and the resistance of air also decreases as it ascends. The ratio of mass of pay load (M) to mass of propellant (m) is called 'pay load ratio'. Thus, pay load ratio = M/m .

The propellants, i.e., fuel and oxidant are kept in different chambers and they are supplied in controlled quantities to the engine and the combustion of the fuel takes place in the engine. The exhausted gases come out through the nozzle present at the rear end.

Multi-stage Rockets

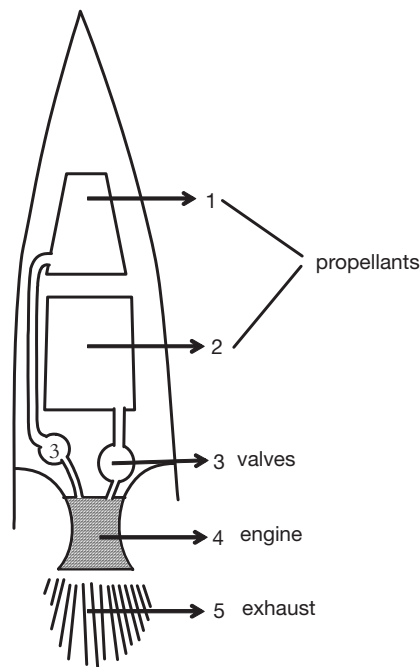


FIGURE 2.66 Rocket

In order to carry heavy load, multi-stage rockets are used. A multi-stage rocket consists of a number of parts of a rocket which are placed (joined) one above the other. As the rocket ascends to a height say about 100 km, it discards the chambers of propellants which have been used. Thus, the mass of the rocket is reduced. This is the first stage. The second stage carries the rocket to a still greater height and at a certain height the chambers of the propellant get detached from the rocket. The next stage takes over and the process continues. Thus, the fuel consumed is reduced. This increases the efficiency of the rocket.

Rockets which are used to launch space vehicles or scientific instruments are multistage rockets and generally have massive first booster stage and two smaller stages.

Rockets are used to launch space-craft or satellites and missiles. Rockets are equipped with radio transmitters which help in transmission of data collected back to the earth.

Satellite

Moon is the natural satellite of the earth. INSAT, Aryabhata, Sputnik, etc., are artificial satellites. Thus, satellites are celestial or artificial objects which revolve round a body of larger mass.

Artificial satellites are man-made satellites and these are launched using multi stage rockets. A rocket takes a satellite to the desired height and places the satellite in an orbit by giving sufficient horizontal velocity.

PRINCIPLE OF ORBITING SATELLITE

When an object is dropped, it reaches the earth along the vertical line in the absence of air resistance (free fall). If the object is thrown horizontally with the same initial velocity, it takes a curved path, but still it reaches the earth.

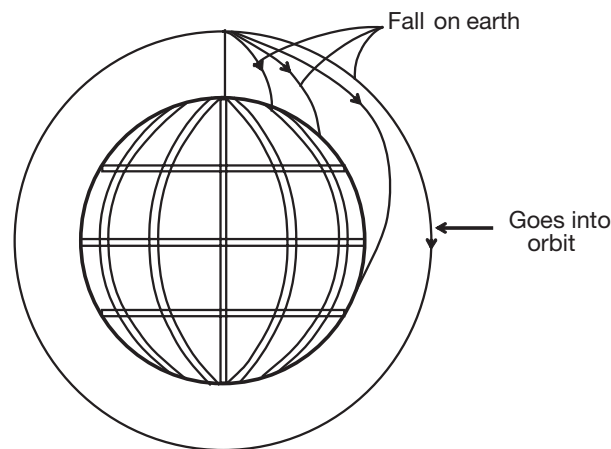


FIGURE 2.67 An object moving around the earth in an orbit

If the initial horizontal velocity is further increased, the object takes a less curved path and the object would fall on the earth at a farther point or the range increases. Thus, as the initial velocity increases, greater is the radius of the curved path.

If the object is given an initial horizontal velocity such that the radius of the curved path described by the object is equal or greater than the radius of the earth, the object will never return to earth. Instead it orbits round the earth and the object becomes an artificial satellite. The value of initial velocity of the object is less than the required value the object falls to earth.

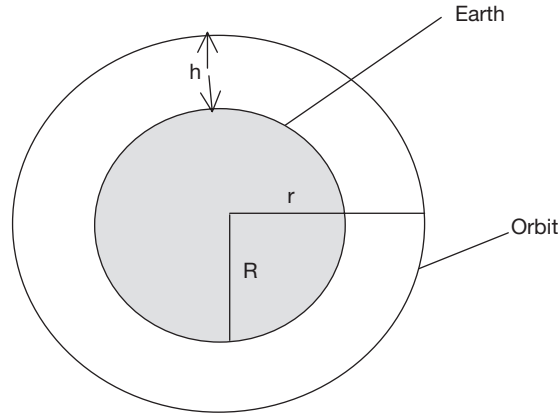
Orbital Velocity (v_0)

FIGURE 2.68 Satellites moving in an orbit around the earth

Satellites are taken to a required height and are given required horizontal velocity such that it revolves round the planet. This horizontal velocity with which the satellite revolves round the planet is called as orbital velocity.

For any satellite to go around the planet, it requires a centripetal force. The centripetal force required for the satellite is provided by gravitational force of attraction between the satellite and the planet.

$\therefore$ Centripetal force = gravitational force between satellite and the planet.

$$\frac{mv_0^2}{r} = \frac{GMm}{r^2} \quad (2.25)$$

where M is the mass of the planet,

r is the radius of the orbit,

m is the mass of the satellite,

G is universal gravitational constant and

v_0 is the orbital velocity of the satellite.

$$\Rightarrow v_0^2 = \frac{GM}{r}$$

But

$$r = R + h,$$

where R is the radius of the planet and h is the height of the satellite from the surface of the planet.

$$\therefore V_0 = \sqrt{\frac{GM}{R+h}}$$

If $h \ll R$, then

$$v_o = \sqrt{\frac{GM}{R}}$$

$$\text{or } v_0 = \sqrt{gR} \left(\because g = \frac{GM}{R^2} \right) \approx 87 \text{ km s}^{-1}$$

Thus, the orbital velocity is independent of the mass of the satellite.

Example: Orbit velocity on the earth is 7.6 Kms^{-1}

Escape Velocity (v_e)

It is the minimum velocity required for a satellite or any body to escape from the earth's gravitational pull. For any satellite to escape from earth's gravitational pull, work has to be done against gravitational force. This work done appears as kinetic energy of the satellite. Thus, kinetic energy given to the satellite is equal to work done on the satellite against gravitational force.

(Here $\frac{GMm}{R^2} \times 12$ and so equal to P.E of the body w.r.t earth centre)

$$\therefore \frac{1}{2} m v_e^2 = \frac{GMm}{R^2} \times R \quad (\text{work} = \text{force} \times \text{displacement})$$

where v_e is the escape velocity M is the mass of the planet and R is the radius of the planet.

$$\therefore v_o = \sqrt{\frac{GM}{R}}$$

or

$$v_e = \sqrt{2gR} \quad \left(\because g = \frac{GM}{R^2} \right)$$

where g is acceleration due to gravity on the surface of the planet. Thus, the escape velocity is same for all bodies because it is independent of mass of the body.

Substituting the value of $g = 9.8 \text{ m s}^{-2}$ and radius of the earth, $R = 6400 \text{ km}$, it is found that the escape velocity of a body on the earth is $11.2 \text{ km per second}$. That is, in order to escape from Earth's gravitational pull, an object should possess a minimum speed of 11.2 kms^{-1} .

$$\therefore V_e \text{ on the earth surface} = 11.2 \text{ Kms}^{-1}$$

Relation between Orbital Velocity and Escape Velocity

Orbital velocity of a satellite orbiting close to earth's surface is given by,

$$v_o = \sqrt{gR} \quad (2.26)$$

Escape velocity of a body on the surface of the earth is given by,

$$v_e = \sqrt{2gR} \quad (2.27)$$

where R is the radius of the earth.

From equation (2.26) and (2.27),

$$v_o = \sqrt{2} v_e \text{ or } v_e = \frac{1}{\sqrt{2}} v_o$$

Uses of Artificial Satellites

1. **Communication satellite:** Satellites are used for global communication, telephone communication, fax messages, TV transmission and internet. Communication satellites are geo-stationary satellites.

A geo-stationary satellite appears to be at rest in space at a certain height above the equator. This satellite has the same period of revolution as that of the earth, hence, this satellite appears to be at rest with respect to earth. By placing three satellites in proper positions, the whole globe can be linked.

INSAT series of satellites are geo-stationary satellites. Latest geo-stationary satellite launched by India is INSAT-3E. This was launched on 28th September 2003.

2. **Weather forecasting:** These satellites are used to give information about weather changes, about cyclones, hurricanes, floods, etc.
3. **Remote sensing satellites:** These satellites are used to identify underground water resources, mineral resources, etc., to find the areas of ocean, forest, deserts, etc., to monitor air, water, sound and thermal pollution.

IRS (Indian Remote sensing Satellite) is a remote sensing satellite.

Bhaskara was the first IRS. It was launched in 1979. After Bhaskara, many sophisticated remote sensing satellites are launched. These satellites are monitored at master control station of ISRO at Hassan.

4. Satellites and space-stations are used to obtain the information of the planets, stars, galaxies, comets, etc. Experiments conducted in such space shuttles and space station help in growth of science and technology. Satellites are also launched by many countries for espionage.

ISRO

Indian space research organisation was started in 1969, but Indian space programme was started in 1963 at Thumba in Kerala with the launching of an American research rocket.

Space technology started in India in the 1970. Homi J. Bhaba and Vikram A. Sarabhai took India to the forefront in space technology. Space technology was further developed by Satish Dhawan, U.R. Rao and Kasturi Rangan by launching various satellites.

The first Indian rocket was launched in November, 1971 from Thumba in Kerala. It was a sounding rocket which was used to study atmosphere.

Rohini RH-75 was a single stage rocket with only one scientific instrument. Now, multi stage rockets are used.

The first Indian satellite Aryabhata was launched in 1975 by a launch vehicle (rocket) called CI Inter Cosmos of USSR. This satellite weighed about 360 kg and was placed in an orbit at a height of 550 km. This satellite worked efficiently for six months.

Indian technology has been improved and the advancement of the technology has made it possible to build satellite launch vehicles. Four launch vehicles have been built and tested successfully. The launch vehicles are

1. ASLV – Augmented satellite Launch Vehicle
2. PSLV – Polar Satellite Launch Vehicle
3. GSLV – Geo-synchronous Satellite Launch Vehicle
4. SLV – Satellite Launch Vehicle

Space Vehicle Arians launched geo-stationary satellite APPLE in 1981 from French Guiana.

The latest Indian Geo-stationary satellite INSAT-3A and INSAT-3E were launched from French Guiana. INSAT-3A was launched on 19th April 2003. INSAT-3E weighs around 27 tonnes and has a life time of 15 years. This satellite is used in TV services and to provide telecommunication for Indian subcontinent.

Various centres of ISRO are located at Bangalore, Ahmedabad, Lucknow, Thumba and Thiruvananthapuram.

EXAMPLE

The time taken by Mars is 1.88 years to go round the Sun. Find the ratio of average distance between the Mars and the Sun to that between the Earth and the Sun.

SOLUTION

From Kepler's third law:

$$\frac{T_1^2}{T_2^2} = \frac{d_1^3}{d_2^3}$$

where T_1 and T_2 are the periods of Mars and Earth, respectively.

$$T_1 = 1.88 \text{ years}$$

$$T_2 = 1 \text{ year}$$

$$\therefore \frac{T_1^2}{T_2^2} = \frac{d_1^3}{d_2^3}$$

$$\frac{(1.88)^2}{1^2} = \frac{d_1^3}{d_2^3} \quad \frac{3.534}{1} = \left(\frac{d_1}{d_2}\right)^3$$

Taking cube root,

$$\frac{d_1}{d_2} = 1.52$$

EXAMPLE

Two equal masses are separated by a certain distance and the force between them is 8 N. When the distance of separation is increased by 1 m, the force between them reduces to 2 N. Find the initial distance of separation and their masses.

SOLUTION

Let the mass of each body be = m kg

Given $m_1 = m_2 = m$ kg

Let the initial distance of separation be = d m

From universal law of gravitation the force between them is given by,

$$F = \frac{Gm_1m_2}{d^2}$$

where G is the universal gravitational constant.

Let F_1 be the force when the bodies are separated by a distance, d .

$$F_1 = \frac{Gm_1m_2}{d^2} = \frac{Gm^2}{d^2}$$

Let F_2 be the force when the distance is increased by 1 m

$$F_2 = \frac{Gm_1m_2}{(d+1)^2} = \frac{Gm^2}{(d+1)^2}$$

$$\frac{F_1}{F_2} = \frac{\frac{Gm^2}{d^2}}{\frac{Gm^2}{(d+1)^2}}$$

$$\Rightarrow \frac{8}{2} = \frac{(d+1)^2}{d^2} \Rightarrow 4 = \frac{(d+1)^2}{d^2}$$

Taking square root on both sides.

$$2 = \frac{d+1}{d}$$

$$2d = d + 1$$

$$\text{or } d = 1 \text{ m}$$

Since $m_1 = m_2 = m$ and $d = 1$ m and $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$, using

$$F = \frac{Gm^2}{d^2},$$

we get

$$8 = \frac{6.67 \times 10^{-11} \times m^2}{1^2}$$

$$\Rightarrow m^2 = \frac{8}{6.67 \times 10^{-11}} \Rightarrow m^2 = \frac{8 \times 10^{11}}{6.67}$$

$$\Rightarrow m^2 = 1.199 \times 10^{11} = 0.1199 \times 10^{12}$$

$$m = \sqrt{0.1199 \times 10^{12}} = 0.346 \times 10^6 \text{ kg}$$

$$m_1 = m_2 = 0.346 \times 10^6 \text{ kg}$$

EXAMPLE

What is the acceleration due to gravity on the top of Mount Everest, whose height is 8848 m, if acceleration due to gravity on the surface of the earth is 9.8 m s^{-2} ?

Radius of the earth = 6400 km

SOLUTION

In the given problem, height $h = 8848 = 8.848 \text{ km}$

Acceleration due to gravity $g^1 = g \left(1 - \frac{2h}{R} \right)$

$$g^1 = 9.8 \left(1 - \frac{2 \times 8.848 \times 10^3}{6400 \times 10^3} \right)$$

$$g^1 = 9.8 (1 - 0.0028) = 9.8 \times 0.9972$$

$$g^1 = 9.77 \text{ m s}^{-2}$$

EXAMPLE

A satellite is to revolve round the earth in an orbit of height 8000 km. With what speed should the satellite be projected into the orbit? What will be its time period?

SOLUTION

Radius of the orbit in which the satellite revolves $r = R + h = 6400 \text{ km} + 8000 \text{ km} = 14400 \text{ km}$
where 'R' is the radius of the earth and h is the height of orbit of the satellite.

The orbital velocity of the satellite is given by, $v_0 = \sqrt{\frac{GM}{R+h}} = \sqrt{\frac{R^2 g}{R+h}}$

Where 'g' is acceleration due to gravity on the surface of earth.

$$\therefore v_0 = 6.4 \times 10^6 \sqrt{\frac{9.8}{14.4 \times 10^6}}$$

$$= 6.4 \times 10^6 \sqrt{0.68 \times 10^{-6}}$$

$$= 6.4 \times 10^3 \times 0.825$$

$$= 5.28 \times 10^3 \text{ m s}^{-1}$$

$$= 5.28 \text{ km s}^{-1}$$

$$\text{Time period of the satellite, } T = \frac{2\pi r}{v_0}$$

$$\therefore T = \frac{2 \times \pi \times 14400 \times 10^3}{5280} \text{ s}$$

$$= 17127.3$$

$$= 285.5 \text{ minutes}$$

$$= 4.76 \text{ hours}$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Define I.M.A. and A.M.A.
2. Define angular displacement and angular velocity.
3. The functioning of a common balance is based on the principle of _____.
4. The area under the force-displacement graph gives _____.
5. Define linear momentum.
6. Why is the combination of fixed pulley and a moveable pulley preferred to one moveable pulley?
7. State Hooke's law.
8. The ratio of the weight of a body to its mass gives the _____ at the given place.
9. Define work and power (write their dot product).
10. Define centripetal force.
11. Sugar crystals can be separated from molasses, using a _____.
12. The weight of a body is minimum at _____ on the earth.
13. Define couple. Give an example of a couple.
14. What is the mechanical advantage of a sheath of pulleys?
15. Can Newton's law hold good in all frames of reference?
16. A body of mass ' m ' is dropped from a height ' h '. The kinetic energy of the body on reaching the ground is _____.
17. What are parallel forces?
18. Define orbital velocity and escape velocity.
19. What is moment of a force or a torque?
20. Wheel and axle is a lever of _____ order.
21. What is centre of gravity?
22. What is the effect of weight of pulleys in the tackle?
23. Define centripetal acceleration.
24. What is meant by stable equilibrium?
25. Define uniform circular motion.
26. The mechanical advantage of an inclined plane 2 m long and 1 m high is equal to _____.
27. Give an expression which relates orbital velocity and escape velocity.
28. What is a simple machine?
29. The escape velocity on the surface of the earth is _____ km s^{-1} .
30. Give the expression for mechanical advantage of a screw jack.

Short Answer Type Questions

31. Obtain the relation between angular velocity and linear velocity.
32. Why is the efficiency of a multi-stage rocket greater than that of a single stage rocket?
33. Explain the working of a centrifuge.
34. What is banking of roads and rails?
35. What is inertial frame of reference and non-inertial frame of reference?
36. A rocket with a mass of 20,000 kg is blasted upwards with an initial acceleration of 5 m s^{-2} . Calculate the initial force of the blast.
37. Mention the uses of artificial satellites.
38. State Newton's law of gravitation.
39. Why is centrifugal force called a pseudo force?
40. What is the relation between g and G ?
41. What is the effect of mass on the acceleration of a rocket?
42. Obtain the relation between M.A., V.R. and η .



Essay Type Questions

43. Define angular momentum and give its expression.
44. A swing is suspended from two parallel ropes at its ends. Two person weighing $50 \text{ kg}_{\text{wt}}$ and $30 \text{ kg}_{\text{wt}}$ sit at a distance 20 cm and 80 cm from one end. The weight of the swing is $20 \text{ kg}_{\text{wt}}$. Find the tensions on the rope. Length of the plank of the swing is 100 cm.
45. A ball is tied to a string of length 1 m and is whirled in a horizontal circle with a linear speed of 5 m s^{-1} . If the mass of the ball is 1000 g, find its
 - (a) angular velocity,
 - (b) centripetal force acting on the ball, and
 - (c) centrifugal force acting on the ball.
46. Describe an experiment to determine the weight of a body.
47. Obtain an expression for banking angle.
48. Explain the working of wheel and axle.
49. Explain the principle of an orbiting satellite.
50. Explain the working of a screw-jack.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

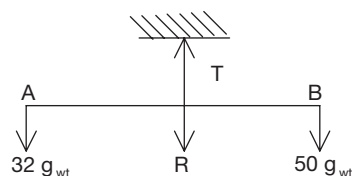
1. The work done by the earth on a satellite revolving around it is zero.
2. The escape velocity of a body on a planet is always greater than the orbital velocity of the body around the planet in an orbit closer to it.
3. The gravitational potential energy of a body is directly proportional to its height above the surface of the earth.
4. The mechanical advantage of an inclined plane is always greater than unity.
5. The resultant of all internal forces acting on a body at rest is zero.
6. Centrifugal force is a reaction to centripetal force.
7. A 10 N force is applied at a distance of 1 m from the hinge of door such that the line of action of force is parallel to the plane of the door. The moment of force produced on the door is 10 N m.

Direction for questions 8 to 14:

Fill in the blanks.

8. Two forces act on either side of a uniform rod AB of negligible mass suspended by string as β shown in the

figure. If R is the resultant force, the tension of the string $T = \underline{\hspace{2cm}} \text{ g}_{\text{wt}}$.



9. A metre scale is suspended at 50 cm mark to a rigid support with a weight of 150 g attached at 5 cm mark. To balance the scale, a weight of 450 g should be attached at $\underline{\hspace{2cm}}$ cm mark.
10. Two planets have average radii of their orbits of revolution in the ratio 64 : 9. Then, the ratio of their periods of revolution is $\underline{\hspace{2cm}}$.
11. A particle moves in a circle whose radius is 20 cm with a linear speed of 10 m s^{-1} . Then its angular velocity is $\underline{\hspace{2cm}} \text{ rad s}^{-1}$.
12. A particle moving along a circular path with the uniform angular velocity ' ω ' is under the action of a force ' F ' directed towards the centre of the circular path. If the radius of the circular path is doubled without changing the linear velocity, the centripetal force acting on the body would be $\underline{\hspace{2cm}}$.
13. The ratio of escape velocity of a tennis ball to that of a basket ball on the surface of the earth is $\underline{\hspace{2cm}}$.
14. If IMA and V.R. are the ideal mechanical advantage and velocity ratio of a pulley, then its efficiency is $\underline{\hspace{2cm}}$.



Direction for question 15:

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

15.	Column A	Column B
A.	Escape velocity ()	a. impulse
B.	Orbital velocity ()	b. $\frac{1}{2}mr^2\omega^2$
C.	Angular momentum ()	c. $\sqrt{gR}$
D.	Linear momentum ()	d. $\sqrt{2gR}$
E.	Centrifugal force ()	e. inertial frame of reference
F.	Kinetic energy ()	f. non-inertial frame of reference
G.	Change in momentum ()	g. mvr
H.	The frame of reference inside a moving satellite ()	h. mv
I.	Newton's laws are valid ()	i. M.A. = 1
J.	Single fixed pulley ()	j. $\frac{mv^2}{r}$

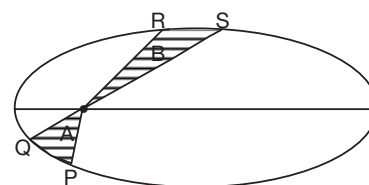
Direction for questions 16 to 45:

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

16. The escape velocity of a body on a planet depends on
 (a) acceleration due to gravity on the planet
 (b) the radius of the planet.
 (c) the mass of the planet.
 (d) All the above
17. The stability of a flexible body depends on
 (a) height of the centre of gravity from the ground.
 (b) base area of the body.
 (c) shape of the body.
 (d) all the above

18. The relation between momentum (P), mass (m), kinetic energy (KE) and velocity (V) of two bodies is
 (a) $P_1 V_1 = P_2 V_2$ where KE is constant.
 (b) $KE_1 m_1 = KE_2 m_2$ where P is constant.
 (c) $KE_1 P_1^2 = KE_2 P_2^2$ when m is constant.
 (d) All the above

19. In the adjacent diagram, the shaded regions A and B are the areas covered by a planet around the sun d_A and d_B , t_A and t_B are the distances traveled by the planet and the time taken by it to cover the paths PQ and RS , respectively. Choose the correct statement.



- (a) $d_A = d_B$ if $t_A = t_B$ (b) $d_A < d_B$ if $t_A > t_B$
 (c) $d_A = d_B$ if $t_A < t_B$ (d) $d_A > d_B$ if $t_A = t_B$
20. The gravitational force of attraction between two bodies at a certain distance is 10 N. If the distance between them is doubled, the force of attraction _____.
 (a) decreases by 50%
 (b) decreases by 75%
 (c) increases by 50%
 (d) increases by 75%
21. Action and reaction
 (a) always act on two different bodies.
 (b) are equal in magnitude.
 (c) act in opposite directions.
 (d) All the above
22. Two particles of equal mass are revolving with the same linear speed on circular paths of radii r_1 and r_2 . The ratio of the centripetal force acting on them will be _____.

- (a) $\frac{r_2}{r_1}$ (b) $\sqrt{\frac{r_2}{r_1}}$
 (c) $\left(\frac{r_1}{r_2}\right)^2$ (d) $\left(\frac{r_2}{r_1}\right)^2$



23. Choose the correct statement.
- In a simple machine, the input energy is always equal to output energy.
 - Actual mechanical advantage > Ideal mechanical advantage.
 - Velocity ratio = $\frac{\text{displacement of the efforts}}{\text{displacement of the load}}$
 - The mechanical advantage of a single fixed pulley is greater than one.
24. While opening a tap with two fingers, the forces applied are
- equal in magnitude.
 - parallel to each other.
 - opposite in direction.
 - All the above
25. A rubber ball of mass 250 g hits a wall normally with a velocity of 10 m s^{-1} and bounces back with a velocity of 8 m s^{-1} . The impulse is _____ N s.
- 0.5
 - +0.5
 - 4.5
 - +4.5
26. The false statement about universal gravitational constant (G) among the following is _____.
- Its dimensional formula is $[M^{-1} L^3 T^{-2}]$
 - It is a vector quantity
 - Its value in SI system is 6.67×10^{-11}
 - Its unit is $\text{N m}^2 \text{ kg}^{-2}$
27. The weight of an object is zero at _____.
- a height equal to half of the radius of earth
 - the centre of the earth
 - the equator
 - both (a) and (b)
28. A force acts on an object while in the state of motion. If the force acting on it is equal to the sum of all the resistance forces, then the object _____.
- stops after covering some distance
 - moves with uniform acceleration
 - moves with uniform velocity
 - moves with uniform retardation
29. In the case of an oscillating simple pendulum, if the air resistance is taken into consideration, then _____.
- amplitude of oscillation remains the same
 - frequency remains the same
 - the resultant acceleration remains the same
 - All the above
30. The magnitude of acceleration due to gravity decreases
- as the height from the surface of the earth increases
 - as the depth from the surface of the earth increases
 - as one moves from the pole of the earth to its equator
 - All the above
31. A body of mass 1 kg moves with a velocity 5 m s^{-1} . A force is applied on it for 1 ms such that its velocity is increased to 7 m s^{-1} . The force applied on the body is _____ N.
- 2000
 - 200
 - 20
 - 2
32. The linear momentum of a body can be changed by _____.
- any force
 - a net external force
 - an internal force
 - Both (b) and (c).
33. Force required to produce an acceleration of 1 m s^{-2} on a body of mass 1 kg is _____ N.
- 1
 - 2
 - 3
 - 4
34. 1 dyne force can produce an acceleration of _____ cm s^{-2} on an object of mass 100 g.
- 1
 - 0.1
 - 10
 - 0.01
35. An object A of mass of 0.1 kg exerts a force of 1N on a body B. Then, the acceleration of the body A is _____ m s^{-2} .
- Zero
 - 10
 - 10
 - 5



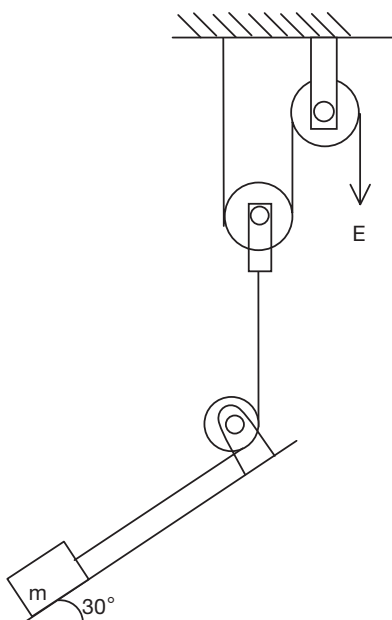
36. Which of the following laws of motion is (are) involved in the motion of the rocket?
- Newton's first law of motion.
 - Newton's second law of motion.
 - Newton's third law of motion.
 - All the above
37. The momentum of a body of mass 0.5 kg dropped from a certain height (h), when it reaches the ground is 10 N s. The value h is _____ m. (take $g = 10 \text{ m s}^{-2}$)
- 20
 - 40
 - 10
 - 80
38. The momentum of a body is increased by 50%. If v_1 is the initial velocity of the body, the change in kinetic energy is
- $2mv_1^2$
 - $\frac{5}{4}mv_1^2$
 - $\frac{5}{8}mv_1^2$
 - $\frac{3}{2}mv_1^2$
39. Work done on a body depends
- only on the magnitude of external force applied on the body.
 - only on the displacement of the body.
 - on both the displacement of the body and the component of the external force acting in the direction of its displacement.
 - None of the above
40. The mechanical advantage of an inclined plane of angle of inclination 60° is equal to _____.
- $\frac{2}{\sqrt{3}}$
 - $\text{cosec } 30^\circ$
 - Both (a) and (b)
 - None of the above
41. A metre scale is suspended at 50 cm mark to a rigid support with a weight of 150 g attached at 5 cm mark. To balance the scale, a weight of 450 g should be attached at _____ cm mark.
- 65
 - 90
 - 95
 - 100
42. A pulley system has a single fixed pulley and a single movable pulley. Its mechanical advantage is _____.
- 1
 - 2
 - 3
 - 4
43. A particle moves in a circle whose radius is 40 cm with a linear speed of 5 m s^{-1} . Then its angular velocity is _____ rad s^{-1} .
- 100
 - 12.5
 - 25
 - 125
44. A particle, moving in a circle of radius 10 cm with a uniform speed, completes a revolution in 4 seconds. The magnitude of the centripetal acceleration it experiences is _____ cm s^{-2} .
- $2.5 \pi^2$
 - $5 \pi^2$
 - $3 \pi^2$
 - $6 \pi^2$
45. Gravity meters measure in units of mGal where 1 Gal (or 1 galileo) is the C.G.S. unit of acceleration due to gravity. A gravity meter shows a reading of +300 mGal at a place where the normal ' g ' is 9.78 m s^{-2} . The correct ' g ' at that place where the reading was taken is _____ m s^{-2} .
- 9.777
 - 9.783
 - 9.750
 - 9.810

Level 2

46. An object ' m ' of mass 50 kg is lifted by using an arrangement as shown in the figure. If the load due to the weight of the pulley and the resistance due to the friction of the pulley is 2.5 kg wt , calculate the effort required to lift the object. If $M.A_1$ and $M.A_2$ are the mechanical advantages of the inclined plane

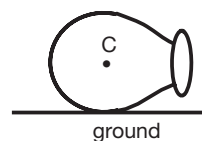
and the pulleys, respectively, derive an expression for the resultant mechanical advantage if the friction force between the object and the inclined plane is negligible.





47. A load of 60 kg is lifted using a wheel and axle, the sum of whose diameters is 1.2 m, by a man and his son who can share their efforts in the ratio 2 : 1. If the radius of the axle is 10 cm, find the effort contributed by the son. ($g = 10 \text{ m s}^{-2}$).
48. An object of certain mass is dropped from the top of a building of height 10 m. At a certain point on its path, the ratio of its potential energy to its kinetic energy is found to be 1:3. The work done by the gravitational force of the earth in moving the body up to this point is 225 J. Determine the mass of the object and the kinetic energy when it reaches the ground. (Take $g = 10 \text{ m s}^{-2}$)
49. A stone is tied to a massless and inextensible string and rotated in a vertical plane. Discuss the variation in centripetal force of the stone from the top to the bottom positions of the circular path if minimum speed is imparted to it so as to continue its circular motion.
50. A scooterist takes a turn through the outer edge of a road of width 10 m. The safe velocity and the radius of curvature of the road are 4.9 m s^{-1} and 24.5 m, respectively. Calculate the speed with which he should drive the scooter to avoid skidding.
51. A metallic vessel having a shape that is a combination of a hemisphere and a truncated cone is placed on the ground in a position as shown in the figure. 'C' is

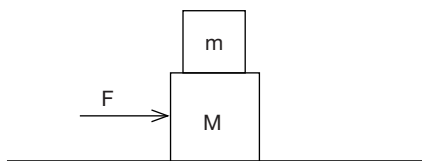
the centre of curvature of the hemispherical part of the vessel. The height of the truncated conical part is less than the radius of curvature of the hemispherical part of the vessel.



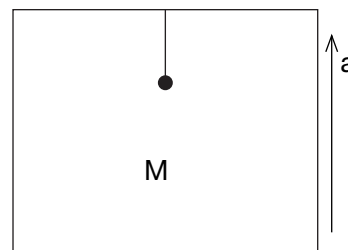
- (i) Locate the centre of gravity of the vessel.
 - (ii) What is the state of equilibrium of the vessel in the position shown?
 - (iii) When the vessel is left in the position shown, what is the effect of the forces acting on the vessel? Discuss.
52. The frame of reference attached to a bus can be either an inertial or a non-inertial frame of reference. Explain with suitable example when it can be inertial and when it can be non-inertial frame of references.
53. A spring balance whose spring can have a spring can have a maximum extension of 20 cm, can sustain a maximum load of $20 \text{ kg}_{\text{wt}}$ within its elastic limit on the surface of the earth. Now the same balance is taken to the moon. Given that $g_{\text{earth}} = 6 g_{\text{moon}}$, what is the maximum mass of the load that can be attached to the balance to have half its maximum extension?
54. A body is projected vertically upwards from ground with a velocity ' u ' and it gains a maximum height ' H 'm. At a point ' x 'm height ($x < H$), the ratio of its potential to Kinetic energy is 1 : 2. Now if the body is projected upwards with a velocity ' $3u$ ' from the ground, find the ratio of its potential to kinetic energy at a point whose height is ' $3x$ 'm.
55. The magnitude of acceleration due to gravity at an altitude ' h ' from earth is equal to its magnitude at a depth ' d '. Find the relation between ' h ' and ' d '. If ' h ' and ' d ' both increase by 50%, are the magnitudes of acceleration due to gravity at the new altitude and the new depth equal?
56. A ball of mass 500 g hits a wall with a velocity 10 m s^{-1} such that it makes an angle 60° with the normal. It bounces back with the same speed making an angle of 60° with the normal. Determine the change in momentum.



57. Why cannot an artificial satellite be parked in its orbit using a single stage rocket instead of using a multi-stage rocket for the purpose?
58. Find the power of a machine gun that can fire 240 bullets per minute, each weighing 50 g, with a velocity of 100 m s^{-1} .
59. A spirit level cannot be used to find out whether the top of the table placed on a rotating platform is horizontal. Explain.
60. An object thrown in the downward direction from a height 10 m with an initial velocity 15 m s^{-1} strikes the ground and bounces back to a height of 12 m. Determine the percentage loss of its energy during collision with the ground. (Take $g = 10 \text{ m s}^{-2}$)
61. A smaller block of mass 'm' is placed on another block of mass M. When a horizontal force F is applied on the block of mass M as shown in the figure, the smaller block does not slide. If the magnitude of friction between the bigger block and the ground is 'f', determine the magnitude and direction of friction between the two blocks.



62. An object of mass M is hanging from the string as shown in the figure. If the uniform acceleration of the cabin in the upward direction is ' a ', determine the tension in the string.



63. A spring that is compressed is stored to its initial position by the restoring force. Similarly, when the spring is elongated, the restoring force gets it back to initial position. Determine whether the work done by the external force on the spring is positive or negative in both the cases.
64. A force of 5 N acting on a body produces a displacement of 2 m in it. If the force acts at an angle 60° to the displacement, then calculate the work done by the force.
65. A ball of mass 1 kg is tied to a string of length 2 m and rotated in a circular path with a uniform speed of 10 m s^{-1} . Calculate the angular velocity, centripetal force and centrifugal force acting on the body.

Level 3

66. When ' n ' number of springs of spring constants $k_1, k_2, \dots, k_n$ are connected in parallel, show that the effective spring constant $k = k_1 + k_2 + \dots, k_n$.
67. A stone of mass ' m ' falls from a height ' h ' into sand pit and moves down into the sand through a distance ' s ' before it comes to the state of rest. Calculate the resistance force offered by the sand on the stone.
68. A bullet of mass 50 g is fired from a stationary rifle into a wooden block of mass 1.95 kg placed on a horizontal wooden surface. On striking, the bullet is embedded into the block and both together cover a distance of 200 m in a straight path before coming to rest. Given the coefficient of friction between the block and the surface is 0.2 and the mass of the rifle from which the bullet is triggered is 14 kg, find the magnitude of the velocity of the recoil of the rifle. (Neglect the resistance of air on the bullet).
69. An object is suspended from the ceiling of a lift by means of a string. When the lift starts moving in the upward direction, the string breaks and the object falls into the lift. Explain giving reasons.
70. A particle loosely held at the circumference of a platform rotating with a uniform velocity flies off during the rotatory motion. Explain its motion,
 (i) as seen by an observer on the ground.
 (ii) as seen by an observer on the platform.
71. A body of mass 5 kg is revolving along a circle of radius 2 m, with a uniform speed of 4 m s^{-1} . Calculate the centripetal force and the power acting on the body.
72. Two bodies A and B having masses in the ratio 1 : 2 are in uniform circular motion along two concentric



circular paths. The angular velocity of A is four times that of B. If the centripetal force on both of them are equal, find the ratio of difference in the radii to the smaller radius.

73. The average radius of the orbit of the revolution of a planet around the sun is three times greater than that of the earth. How many years does the planet take to revolve once around the sun?
74. A metre scale 'PQ' of uniform thickness and weighing $100 \text{ g}_{\text{wt}}$ is suspended by means of a string to a rigid support at a point 'R' on it such that $PR : QR$

$= 2 : 3$. At the end 'P' a load of 85 g_{wt} is attached. Find the load attached at Q such that the scale is in equilibrium. If 'S' is a point on the scale such that $PR : SR = 2 : 1$ and the load at 'Q' is shifted to 'S', find the percentage change in the load, in shifting it from 'Q' and 'S'; to maintain equilibrium state of the scale.

75. Find the power of a machine gun that can fire 240 bullets per minute, each weighing 50 g, with a velocity of 100 m s^{-1} .



CONCET APPLICATION

Level 1

True or false

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

Fill in the blanks

8. 82 9. 65 10. 512 : 27 11. 50 12. $\frac{F}{2}$ 13. 1 : 1 14. $\frac{I.M.A}{V.R}$

Match the following

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

Multiple choice questions

16. (d) 17. (d) 18. (d) 19. (d) 20. (b) 21. (d) 22. (a) 23. (c) 24. (d) 25. (c)
 26. (b) 27. (b) 28. (c) 29. (b) 30. (d) 31. (a) 32. (b) 33. (a) 34. (d) 35. (c)
 36. (c) 37. (a) 38. (c) 39. (c) 40. (c) 41. (a) 42. (b) 43. (b) 44. (a) 45. (b)

Explanation for questions 31 to 45:

31. Force = $m \cdot a$

$$= m \left(\frac{v - u}{t} \right) = \frac{1(7 - 5)}{1 \times 10^{-3}} = 2000 \text{ N}$$

32. The moment of a body can be changed by a net external force.

33. Force $F = ma = 1 \times 1 = 1 \text{ N}$

34. Force $F = ma$

$$1 \text{ dyne} = 100 \times a \Rightarrow a = \frac{1}{100} = 0.01 \text{ cm s}^{-2}$$

35. According to Newton's third law of motion Action = - (Reaction)

$$M_B a_B = -M_A \times a_A$$

$$1 = -0.1 \times a_A$$

$$a_A = -10 \text{ m s}^{-2}$$

36. The upward motion of a rocket can be explained on the basis of Newton's third law of motion.

37. Momentum $p_1 = mv = 10 \text{ N s}$

$$\text{Mass } m, = 0.5 \text{ kg}$$

$$10 = 0.5 \times v \Rightarrow v = \frac{10}{0.5} = 20 \text{ m s}^{-1}$$

Kinetic energy of the body reaching the ground = potential energy at the highest point

$$\frac{1}{2} mv^2 = mgh$$

$$\frac{1}{2} \times (20)^2 = 10 \times h \Rightarrow h = 20 \text{ m.}$$

$$38. K.E. = \frac{1}{2} mv^2 = \frac{1}{2} p.v. = \frac{1}{2} \frac{p^2}{2m}$$

$$p_1 = p, p_2 = p + \frac{p}{2} = \frac{3p}{2} = 1.5p$$

$$K.E_2 = \frac{1}{2} \frac{p_2^2}{2m} = \frac{1}{2} \times \frac{(1.5p)^2}{m} = \frac{9p^2}{8m} = \frac{9}{4} \left(\frac{1}{2} \frac{p^2}{m} \right)$$

$$K.E_2 = \frac{9}{4} KE_1$$

$$\therefore \text{Change in K.E} = KE_2 - KE_1$$

$$= \frac{9}{4} KE_1 - KE_1 = \frac{5}{4} \cdot \frac{1}{2} mv_1^2 = \frac{5}{8} mv_1^2$$

39. The work done on a body due to net force = force $\times$ displacement.

Always the total force applied on a body may not be responsible for its motion. A component of force can also cause displacement in the body.

$\therefore$ Work done = (component of force acting in the direction of displacement of body) $\times$ displacement
 = $(F \cos \theta) \times s$



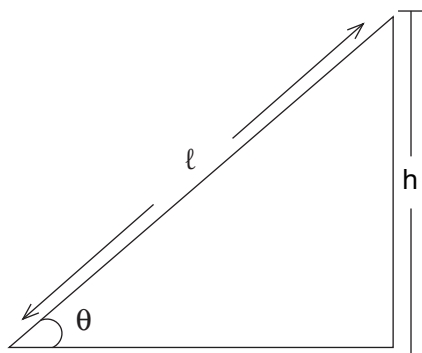
40. Mechanical advantage of an inclined

$$\text{Plane} = \frac{\text{length of plane}}{\text{height of plane}}$$

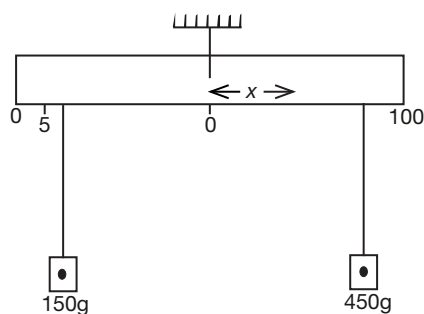
$$= \frac{\ell}{h} = \frac{1}{\sin \theta}$$

$$\therefore \text{M.A} = \frac{4\text{m}}{1\text{m}} = 4$$

$$\frac{1}{\sin 60} = \cos 60^\circ = \frac{2}{\sqrt{3}}$$



- 41.



Let the weight 450g be attached at a distance of x cm from the point of suspension.

$\therefore$ According to the principle of moments. Sum of anticlockwise moments = sum of clockwise moments about the point of suspension

$$\therefore 45 \text{ cm} \times 150 \text{ g} = x \times 450 \text{ g}$$

$$x = \frac{45}{3} \text{ cm} = 15 \text{ cm}$$

$\therefore$ The weight should be attached at a distance of 15 cm from point of suspension (or) at $(50 + 15) \text{ cm} = 65 \text{ cm}$ from the scale.

42. The movable pulley divides the rope into two segments. Tension T acts in upwards direction along the two segments of the rope.

If ' p ' is the effort applied to overcome total load, then $p = T$ and it is obvious that $w = T + T = 2T$ where w is the total load

$$\therefore \text{The mechanical advantage} = \frac{\text{load}}{\text{efforts}} = \frac{2T}{T} = 2$$

If pulley is not rotating and the load due to friction and movable parts is neglected, then both the load and the effort are equal to the tension in the string

$$\text{Thus, } w = p = T$$

$$\therefore \text{Mechanical advantage} = \frac{w}{p} = \frac{T}{T} = 1$$

$$\text{Total mechanical advantage (M.A)} = (\text{M.A}_1) \times (\text{M.A}_2) = 2 \times 1 = 2$$

43. The radius of circular path (r) = 40 cm = 0.40 m
Linear speed of the particle (v) = 5 ms⁻¹

The angular velocity

$$w = v/r = 5/0.4 = 50/4 = 12.5 \text{ rad s}^{-1}$$

44. Radius of circular path (r) = 10 cm
time taken to complete a revolution (T) = 4s
centripetal acceleration (a)?

$$\therefore \text{angular speed} = w = \frac{2\pi}{T} \text{ rad s}^{-1}$$

$$= \frac{V^2}{r} = \frac{(rw)^2}{r} = rw^2$$

$$\therefore a = 10 \text{ cm} \times \frac{4\pi^2}{T^2} = 10 \text{ cm} \times \frac{4}{16}$$

$$= 2.5\pi^2 \text{ cm s}^{-2}$$

45. +300 mGal = $0.3 \times 10^{-2} \text{ m s}^{-2} = 0.003 \text{ m s}^{-2}$

$$\therefore g = 9.78 + 0.003 = 9.783 \text{ m s}^{-2}$$



Level 2

46. (i) For inclined plane $M.A. = \frac{1}{\sin \theta}$
 (ii) For single movable pulley, $MA = 2$
 (iii) $13.75 \text{ kg}_{\text{wt}}$, $MA_1 \times MA_2$
47. (i) From given information, find the load in newtons.
 Find the radii of wheel and axle.
 The mechanical advantage (M.A) of wheel and axle is, $M.A = \frac{R}{r} = \frac{\text{Load}}{\text{Efforts}}$.
 Find the value of effort.
 Here, the son contributes one-third of the total effort.
 Then find the value of effort contributed by the son.
 (ii) 40 N
48. (i) Work done by net force = change in kinetic energy.
 (ii) For a freely falling body, loss of potential energy = gain of kinetic energy
 (iii) 9 kg , 900 J
49. At the top position of the circular path, is centrifugal force, $F = \frac{mv^2}{r}$ equal to the weight of the stone and tension (T) in the string.
 At the bottom position of the circular path, the tension (T) in the string is equal to the weight of the stone and centrifugal force (F).
50. (i) $\tan \theta = \frac{v^2}{rg}$
 When he moves along the outer edge, radius of curvature

$$r_1 = r + \frac{\text{width of the road}}{2}$$

 (ii) $\sqrt{28.91} \text{ m s}^{-1}$
51. Which portion of the metallic vessel, i.e., a hemisphere or a truncated cone, contains more mass?
 Hemispherical portion has more metal. So, centre of gravity (G) of the vessel lies near the bottom.

Find whether the height of the centre of gravity remains constant in any position where the hemisphere part touches the ground.

Then find the state of equilibrium of the vessel.

Here, centre of gravity ' G ' lies near to the base of the vessel, i.e., near the hemisphere. Then find the direction of moment of forces acting on the metallic vessel with respect to C .

52. (i) Frame of reference that is at rest or moving with uniform velocity is inertial frame of reference.
 (ii) Frame of reference that moves with acceleration is non-inertial frame of reference.
53. (i) Find the maximum load, i.e., $20 \text{ kg}_{\text{wt}}$, in terms of newtons.
 Convert 20 cm length in terms of S.I.
 Find the value of force constant (k) from the formula, $F = kx$ (1)
 Now, find the maximum load that is possible on the surface of the moon if $F = mg_m = kx$ (g_m acceleration due to gravity on the moon).
 Substitute the value of $\frac{g_E}{6}$ for g_m (2)
 Now, find the mass of the load that is attached to have its maximum extension (3)
 Divide the value obtained in (3) by (2).
 Then this gives maximum mass of the load that can be attached to the balance to have half its maximum extension.
 (ii) 60 kg
54. (i) Find the ratio of potential to kinetic energy at a height ' x ' from the ground for the body projected vertically upwards from the ground with a velocity ' u '.
 Find the value ' x ' in terms of ' u ' and ' g '.

For the same body, when projected up with a velocity $3u$, the ratio of potential to kinetic energy is at a height ' $3x$ ' from the ground.

Find the velocity of the body at height ' $3x$ ' in terms of u , g and x using the formula $v^2 = u^2 - 2gh$, and then simplify.

- (ii) $1 : 8$



55. (i) Here, acceleration due to gravity at height ' H ', from earth is $g_h = g_o \left(1 - \frac{2h}{R}\right)$.

Then, acceleration due to gravity at a depth ' d ' from earth is $g_d = g_o \left(1 - \frac{d}{R}\right)$.

If $g_h = g_d$, then find the relation between ' h ' and ' d ' - (1)

If the ' g ' and ' d ' both increase by 50%, then $h = h + \frac{h}{2}$ and $d^1 = d + d/2$.

Substitute the value obtained from (1) and find whether $g_h = g_d$.

(ii) $d = 2h$

56. (i) Resolve momentum into horizontal and vertical components.

(ii) Change in momentum is due to change in vertical component of the momentum.

(iii) -5 kg m s^{-1}

57. If the mass of the satellite is more, is it easily possible to lift it to higher altitudes?

Find the difference between the single stage rocket and multistage rocket.

58. (i) How many bullets are fired from the machine gun in one second?

What is the kinetic energy of the bullet?

The work done by the gun in one second is equal to the total amount of kinetic energy of the bullets fired in one second.

Find the value of the power.

(ii) 1 kW

59. What is centripetal force?

Will heavier particle move towards the centre of curvature?

Will air bubble move away from the centre of curvature?

60. (i) Total energy $= \frac{1}{2} mv^2 + mgh_1$

$$\text{Change in energy} = \left(\frac{1}{2} mv^2 + mgh \right) - (mgh_2)$$

% change in energy

$$= \frac{\left(\frac{1}{2} mv^2 + mgh_1 \right) - (mgh_2)}{\frac{1}{2} mv^2 + mgh_1} \times 100$$

(ii) 43.5%

61. The net force acting on the two block system is

$$F - f = (M + m) a$$

$$\therefore a = \frac{F - f}{(M - m)}$$

The smaller block is moving forward and the only force acting on it in the horizontal direction is frictional force between the blocks. Thus, the frictional force acts along the direction of motion of the smaller block

The magnitude of frictional force

$$F^1 = m \left(\frac{F - f}{M + m} \right)$$

62. The forces acting on the object are mg downward, tension (T) upward

$$\therefore \text{Net force } F = T - mg$$

$$ma = T - mg \Rightarrow T = m(a + g)$$

63. When the spring is compressed and elongated by an external force it opposes the change in shape. Thus, the work done by the external force is positive as the force is in the same direction of displacement.

64. Given

Force acting on the body $F = 5 \text{ N}$

Displacement produced in the body is $s = 2 \text{ m}$.

Angle between force applied and displacement $\theta = 60^\circ$

Work done by the force is $W = Fs \cos \theta$

$$= 5 \times 2 \times \cos 60^\circ = 5 \times 2 \times \frac{1}{2}$$

$$W = 5 \text{ J}$$

65. Angular velocity $\omega = \frac{v}{r} = \frac{10}{2} = 5 \text{ rad s}^{-1}$

$$\text{Centripetal force } F = \frac{mv^2}{r} = \frac{1 \times 10^2}{r} = 50 \text{ N}$$

The magnitude of centripetal force is equal to the magnitude of centrifugal force.

Hence, centrifugal force is 50 N but opposite in direction to centripetal force.



Level 3

66. (i) When springs are connected in parallel.

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

$$(ii) k = k_1 + k_2 + k_3 \dots k_n$$

67. (i)
- $v^2 - u^2 = 2as$

$\Rightarrow v^2 = 2gh$. This is the initial velocity in the sand. Using this, find 'n' in sand.

The net force acting on the stone as it moves in sand

$$ma = mg - R_f$$

R_f Resistance force

$$R_f = mg - ma$$

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

$$= m \left(g - \frac{v^2 - u^2}{2s} \right)$$

$$= mg \left(1 - \frac{4}{3} \right)$$

$$\therefore R_f = mg \left(g - \frac{4}{3} \right)$$

$$(ii) mg \left(1 + \frac{h}{s} \right)$$

68. (i) Find the masses of bullet (
- m_b
-) and block (
- m_w
-) in C.G.S. system.

According to the law of conservation of momentum:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Then, take initial velocity of bullet and block as 'u' and 'zero', respectively.

When the bullet is embedded into the block, both have a common velocity.

Let 'v' be the common velocity.

Find the relation between 'u' and 'v'.

By law of conservation of momentum, when both bullet and block together cover 200 m before coming to rest, then, the frictional force,

$$F = \mu (m_b + m_w) g \quad (1)$$

Find the work done to overcome the friction.

The kinetic energy of the system = $\frac{1}{2} (m_b + m_w) v^2$ = work done

Then,

$$(m_b + m_w) v^2 = \mu (m_b + m_w) g s \quad (2)$$

Find the value of 'v' from (2).

Find the mass of the gun m_g from given information.

Apply the law of conservation of momentum.

$$u_g = u_b = 0$$

Then,

$$m_g u_g + m_b u_b = m_g v_g + m_b u_b \quad (3)$$

Find the value 'v_g' from (3)

$$(ii) 4 \text{ m s}^{-1}$$

69. When the lift starts moving in the upward direction with acceleration 'a' then
- $T = m(g + a)$
- .

70. (i) How the motion appears from inertial and non-inertial frames of reference?

(ii) Direction of velocity is along the tangent.

(iii) How the centripetal force acts on the body?

71. Given

$$m = 5 \text{ kg}$$

$$r = 2 \text{ m}$$

$$v = 4 \text{ m s}^{-1}$$

$\therefore$ Centripetal force

$$= \frac{mv^2}{r} = \frac{5 \times 4 \times 4}{2} = 40 \text{ N}$$

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

Since, the work done on a body in circular motion is zero, the power is also zero.

72. Given
- $m_A : m_B = 1 : 2$
- ;

$$\omega_A : \omega_B = 4 : 1 \text{ and}$$

$$F_A = F_B$$

$$\text{Centripetal force } F = mr\omega^2$$

$$\therefore m_A r_A \omega_A^2$$

$$\Rightarrow \frac{r_A}{r_B} = \left(\frac{m_B}{m_A} \right) \left(\frac{\omega_B}{\omega_A} \right)^2 = \left(\frac{2}{1} \right) \left(\frac{1}{4} \right)^2$$

$$\therefore \frac{r_B}{r_A} = 8$$



Hence, the required ratio is

$$\frac{r_B - r_A}{r_A} \Rightarrow \frac{r_B}{r_A} - 1 = 7 : 1$$

73. According to Kepler's law of periods,

$$T^2 \propto R^3$$

$$\Rightarrow \frac{T_2^2}{T_1^2} = \frac{R_2^3}{R_1^3}$$

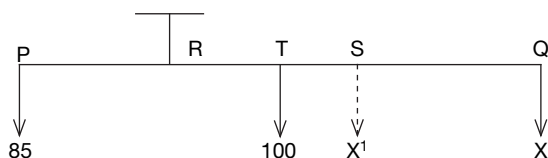
$$\Rightarrow T_2 = T_1 \left(\frac{R_2}{R_1} \right)^{\frac{3}{2}}$$

$$\text{Given } R_2 = R_1 + 3R_1 = 4R_1$$

$$\therefore T_2 = T_1 (4)^{\frac{3}{2}} = 8T_1$$

$$T_1 = 1 \text{ yr.} \quad \therefore T_2 = 8 \text{ yrs.}$$

74.



T is the midpoint of the scale and its weight 100 g acts at this point.

$$\text{Given } PR : QR = 2 : 3$$

$$\text{But } PR + QR = 100 \text{ cm}$$

$$\therefore PR = 100 - QR$$

$$PR = 100 - \frac{3}{2}PR \quad \frac{5}{2}PR = 100$$

or

$$PR = 40 \text{ cm}$$

$$\therefore QR = 60 \text{ cm.}$$

If x is the load attached at Q, then for the scale to be in equilibrium

$$(85 \text{ g})(PR) = x(QR) + RT(100) \Rightarrow (85)(40) = x(60) + 1000$$

$$\Rightarrow x = 40 \text{ g.}$$

$$\text{Given } \frac{PR}{SR} = \frac{2}{1} \Rightarrow SR = \frac{PR}{2} = \frac{40}{2} = 20 \text{ cm}$$

Let x^1 be the load attached at S.

$$\text{Then } (85)PR = (x^1)(SR) + 100(TR)$$

$$85(40) = x^1(20) + 100(10) \Rightarrow x^1 = 120 \text{ g}$$

If the load at Q is shifted to S, the percentage change in the load

$$= \left(\frac{x^1 - x}{x} \right) 100 = \left(\frac{120 - 40}{40} \right) \times 100 = 200\%$$

75. Number of bullets fired per minute = 240.

time, $t = 60 \text{ s}$

mass of each bullet, $m = 50 \text{ g.}$

$$\therefore \text{mass of 240 bullets} = nm = (240)(50) \text{ g.}$$

$$= \frac{24 \times 5}{10} \text{ kg} = 12 \text{ kg}$$

Initial velocity of the bullets (u) = 0 m s^{-1} .

Final velocity of the bullets (v) = 100 m s^{-1} .

$\therefore$ Initial kinetic energy of the bullets

$$= \frac{1}{2} mnu^2 = 0$$

Final kinetic energy of the bullets

$$= \frac{1}{2} mnv^2 = \frac{1}{2} \left(\frac{240 \times 50}{1000} \right) (100)^2$$

$\therefore$ Change in Kinetic energy

$$= \frac{1}{2} mnv^2 - 0 = \frac{1}{2} mnv^2$$

But the change in

Kinetic energy = work done (W).

$$\therefore \text{Power} = \frac{\text{work}}{\text{Time}} = \frac{W}{t} = \frac{1}{2} \frac{mnv^2}{t}$$

$$= \frac{1}{2} \left(\frac{240 \times 50}{1000} \right) \frac{(100)^2}{60} = 1000 \text{ W} = 1 \text{ KW}$$



Chapter 3

Heat



Remember

Before beginning this chapter, you should be able to:

- Make clear distinction between heat and temperature, measurement of temperature with the help of thermometers
- Know good and bad conductors of heat, different modes of heat transfer and their applications
- Understand the change of states of matter on supplying heat, factors affecting heat absorbed and lost by a substance and measurement of heat energy
- State certain laws such as Boyle's Law, Charles' Law, etc.

Key Ideas

After completing this chapter, you should be able to:

- Understand the various factors affecting the heat absorbed by a body and to deduce an expression for heat energy
- Study the different factors affecting the thermal expansion of substance and to understand how this is used in different practical applications
- Understand why there is no change in temperature during the change of state and to deduce an expression for the calculations of latent heat
- Recognize heat as a form of energy and to understand that like other forms of energy, heat energy can also be converted into mechanical energy
- Understand how the conversion of heat energy into mechanical energy is used in heat engines

INTRODUCTION

In the earlier classes, we have learnt that heat is a form of energy, and that some of the other forms of energy can be converted to heat while heat itself can be converted to some of the other forms of energy. Similarly, by the work-energy theorem, we understand that work done on a body can appear in the form of heat. For example, when we rub our palms, the biochemical energy is expended to do the 'work' which results in the warmth in the palms.

Thus, we see that when some form of energy is converted to heat energy, it makes a substance or a body 'hotter'. This degree of hotness (or coldness) is called 'temperature'.

Furthermore, we have also seen that when hot lead shots are dropped into cold water, the temperature of the lead shots decreases while the temperature of the water increases, indicating that heat energy always flows from hot bodies to cold bodies, and this flow of heat stops when the temperatures of the two bodies are equal—a condition known as thermal equilibrium.

To elaborate on this, let us take another example. If an ice-cube at 0°C is dropped into a vessel containing water at 0°C , the ice-cube does not melt, since the two substances are at the same temperature and heat does not flow from water to ice even though water has more heat content (336 J g^{-1}) than ice.

Thus, while heat is a form of energy, rise (or fall) of temperature is one of its effects. Another important effect of heat is that, on supply of heat, matter changes its state—ice melts to become water, a liquid boils to vaporise. Similarly, when heat is taken away from a hot substance, it can also result in change of state—water freezing to form ice, steam condensing into water.

We have also studied that the thermal expansion is another effect of heat and solids as well as liquids and gases expand on heating.

We shall now study calorimetry—measurement of heat energy in greater detail. We will also direct our attention to working principle of heat engines, an important application of thermal energy.

HEAT

Every body contains some amount of heat. This is equal to sum total of kinetic energy and potential energy of all the molecules present in the body. When heat is supplied to a body, average kinetic energy of its molecules increases, thus increasing its temperature. We say that the body has become hot. The opposite happens if heat is removed from a body. Then, we say that the body has cooled. Thus, heat is a form of energy which gives us sensation of hotness or coldness.

Units of Heat

Since heat is a form of energy, its units are same as that of other forms of energy.

S.I. unit of heat is joule (J).

Calorie (cal) is another unit which is specially used for heat.

One calorie is the amount of heat required to raise the temperature of 1 g of water by one degree celsius.

The two units of heat are related as below

$$1 \text{ cal} = 4.1863 \text{ J} \cong 4.2 \text{ J}$$

$$1 \text{ kcal} = 4186.3 \text{ J} \cong 4200 \text{ J}$$

where $1 \text{ kcal} = 1000 \text{ cal}$ is a higher unit of heat.

Heat Capacity

To increase the temperature of a body, we have to supply heat to it. But the rise in temperature is not the same for all bodies for the same amount of heat supplied.

If we supply the same amount of heat to 400 g and 700 g of water, we find that rise in temperature is more in the former than in the latter case. If equal masses of water and milk are supplied with the same amount of heat, the rise in temperature of milk is more than that of water.

Thus, rise in temperature and heat supplied to a body are related by a term called 'heat capacity' or 'thermal capacity' of a body. It is denoted by 'C'.

It is defined as amount of heat needed to raise the temperature of a given mass of a body by 1 K or 1°C .

It is equal to the ratio of total heat 'Q' supplied to the rise in temperature $\Delta\theta$ of a body.

Let Q joule of heat be supplied to a body so that its temperature rises by $\Delta\theta$ K. Then heat capacity (C) of the body = $\frac{Q}{\Delta\theta}$

$$\therefore C = \frac{Q}{\Delta\theta}$$

$$\text{Thus, unit of heat capacity} = \frac{\text{Unit of heat}}{\text{Unit of temperature}}$$

$$\text{Hence, S.I. unit of heat capacity is } \frac{\text{joule}}{\text{kelvin}} (J K^{-1})$$

Other common units of heat capacity (C) are

$$J^\circ\text{C}^{-1}, \text{ cal }^\circ\text{C}^{-1} \text{ or } \text{kcal }^\circ\text{C}^{-1}$$

$$1 \text{ cal }^\circ\text{C}^{-1} = 4.2 \text{ J } K^{-1} = 4.2 \text{ J }^\circ\text{C}^{-1}$$

$$1 \text{ kcal }^\circ\text{C}^{-1} = 4200 \text{ J } K^{-1} = 4200 \text{ J }^\circ\text{C}^{-1}$$

It can be seen that here $^\circ\text{C}$ and K are interchangeable since we consider only the change in temperature.

Factors Affecting Heat Absorbed or Given Out by a Body

Consider two similar containers A and B containing half a litre and one litre of water, respectively. The initial temperatures of water in both the containers (which is equal to

room temperature, say θ_1) is noted with the help of a thermometer. Both these containers are placed on two similar burners that supply heat at a constant rate; and heated. To attain an equal higher temperature, say θ_2 , it is observed that the container B takes more time compared to the time taken by the water in the container A . Thus, heat absorbed by B is greater than that absorbed by A . This implies that larger the mass of a body, greater is the heat absorbed or given out by it.

Now consider two similar containers P and Q having equal volumes of water. Thus, the mass of water in both the containers is equal. Now both the containers are placed on burners that supply heat at a constant rate and heated. If the required rise in temperature of P is more than that of Q , it is observed that P has to be heated for more time compared to Q . Thus, the heat absorbed by P is greater than that absorbed by Q . This implies that the amount of heat absorbed or given out by a body depends on the change in its temperature.

The experimental results shows that

1. Heat absorbed or given out by a body is directly proportional to the mass of the body

$$Q \propto m \quad (3.1)$$

2. Heat absorbed or given out by a body is directly proportional to the rise or fall in temperature of the body

$$Q \propto \Delta\theta \quad (3.2)$$

Combining equations (3.1) and (3.2), we get $Q \propto m \Delta\theta \Rightarrow Q = m s \Delta\theta$ where s is a constant of proportionality, which we shall discuss later.

EXAMPLE

1 g of water needs 4.2 J and 100 g of water needs 420 J of heat energy, respectively so as to raise their temperature by 1°C . Calculate the heat capacity of water in both cases.

SOLUTION

$$\text{Heat capacity (C)} = \frac{\text{heat}}{\text{rise in temperature}}$$

1st case

For 1 g of water

$$C = \frac{4.2 \text{ J}}{1^\circ\text{C}} = 4.2 \text{ J}^\circ\text{C}^{-1}$$

2nd case

For 100 g of water

$$C = \frac{420 \text{ J}}{1^\circ\text{C}} = 420 \text{ J}^\circ\text{C}^{-1}$$

Specific Heat Capacity

From the above example, it is seen that water has different heat capacities for different masses. This is observed in all the substances. As the mass changes, heat capacity also changes. But

for a given mass of a given substance, it is constant. Therefore, heat capacity of a unit mass of substance is taken as reference and is called specific heat capacity. It is denoted by 'c' or 's'

Specific heat capacity is defined as the amount of heat required to raise the temperature of unit mass of substance (1 kg or 1 g) by one kelvin or one degree celsius. Heat absorbed or given out by a body is given by,

$$Q = ms \Delta \theta$$

Thus, the constant of proportionality in the above equation is the specific heat capacity of the given body.

Units of Specific Heat Capacity

From the above equation, we get $s = \frac{Q}{m\Delta\theta}$.

Thus, unit of $s = \frac{\text{Unit of } Q}{(\text{Unit of } m) (\text{Unit of } \Delta\theta)}$

S.I. unit of specific heat capacity is $\frac{\text{joule}}{\text{kilogram} \times \text{kelvin}} = \text{J kg}^{-1} \text{K}^{-1}$.

As change in temperature in kelvin and celsius scales is equal, it can be written as $\text{J kg}^{-1} \text{C}^{-1}$ also.

Other common units of specific heat capacity are $\text{cal g}^{-1} \text{C}^{-1}$ or $\text{kcal kg}^{-1} \text{C}^{-1}$.

$1 \text{ cal g}^{-1} \text{C}^{-1} = 4.2 \text{ J g}^{-1} \text{C}^{-1}$ and $1 \text{ kcal kg}^{-1} \text{C}^{-1} = 4200 \text{ J kg}^{-1} \text{C}^{-1}$

The specific heat capacity of a substance is independent of its mass. It is a characteristic property of a substance. Its value is different for different substances.

Substance	Specific heat capacity		
	$\text{cal g}^{-1} \text{C}^{-1}$	$\text{J g}^{-1} \text{C}^{-1}$	$\text{J kg}^{-1} \text{K}^{-1}$
Water	1.00	4.20	4200
Alcohol	0.52	2.18	2180
Kerosene Oil	0.50	2.10	2100
Turpentine Oil	0.42	1.76	1760
Aluminium	0.21	0.882	882
Flint glass	0.12	0.504	504
Iron	0.115	0.483	483
Copper	0.095	0.399	399
Zinc	0.093	0.391	391
Brass	0.092	0.386	386
Silver	0.056	0.235	235
Tin	0.055	0.231	231
Mercury	0.033	0.139	139
Gold	0.032	0.134	134
Lead	0.031	0.130	130

*Note that specific heat capacity of water is maximum

$$Q = mc\Delta\theta \Rightarrow c = \frac{Q}{m\Delta\theta}$$

$$\Rightarrow \frac{Q}{\Delta\theta} = mc = C \text{ (heat capacity)}$$

$\Rightarrow$ Heat capacity = mass $\times$ specific heat capacity

EXAMPLE

10 g of kerosene oil absorbs 210 J of heat and its temperature rises by 10°C . Find its specific heat capacity.

SOLUTION

Given mass(m) of the kerosene oil = 10 g

Heat absorbed (Q) = 210 J

Rise in temperature ($\Delta\theta$) = 10°C

Specific heat capacity (s) = ?

$$Q = ms\Delta\theta$$

$$\Rightarrow 210 \text{ J} = 10 \text{ g} \times s \times 10^\circ\text{C}$$

$$\therefore s = \frac{210 \text{ J}}{10 \text{ g} \times 10^\circ\text{C}} = 2.1 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$$

EXAMPLE

The specific heat capacity of water is $4.2 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$. Calculate the heat capacity of 20 g of water. How much heat has to be supplied to it to raise the temperature by 10°C ?

SOLUTION

Given

Specific heat capacity (s) = $4.2 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$

Mass (m) = 20 g

Rise in temperature ($\Delta\theta$) = 10°C

Heat capacity for 20 g(C) = ?

Heat supplied (Q) = ?

$$C = ms = 20 \text{ g} \times 4.2 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$$

$$C = 84 \text{ J }^\circ\text{C}^{-1}$$

$$C = \frac{Q}{\Delta\theta} \Rightarrow Q = C \Delta\theta$$

$$= 84 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times 10^{\circ}\text{C}$$

$$\Rightarrow Q = 840 \text{ J.}$$

Specific heat capacity of water is

$$1 \text{ cal g}^{-1} \text{ }^{\circ}\text{C}^{-1} (4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}) \text{ or } 1 \text{ kcal kg}^{-1} \text{ }^{\circ}\text{C}^{-1} (4200 \text{ J kg}^{-1} \text{ }^{\circ}\text{C}^{-1})$$

Thus, one gram of water needs 1 cal or 4.2 J of heat to raise its temperature by 1°C . Specific heat capacity of water is maximum, amongst all solids, liquids and gases. It means the temperature of water doesn't rise or fall quickly as compared to that of other substances. Hence, we find water bodies to be comparatively cool even in sweltering heat of summer.

The high specific heat capacity of water gives rise to some natural phenomenon and has many advantages in our day to day life. Let us discuss some consequences of it.

1. *Land breeze and sea breeze:* The specific heat capacity of water is nearly five times that of land. This means, water needs nearly five times more heat than land to raise its temperature by 1°C . Similarly, water has to lose five times more heat for 1°C fall in temperature. Thus, land heats up and cools five times quicker than water. In coastal areas this gives rise to cool sea breeze from sea to land during day time and land breeze from land to sea during night. This keeps the temperature in coastal areas moderate.
2. We apply hot, water bag to, the swollen parts of our body when sprained to get relief from pain. This is called fomentation as water contains very high amount of heat energy at comparatively low temperature.
3. Water is used as a coolant in number of applications. It can absorb large amount of heat without its temperature increasing appreciably. Hence, it is used as a coolant in car radiators, nuclear plants and in industries.
4. In cold countries, during winter, farmers water their fields in the evening. Owing to its high specific heat capacity, temperature of water doesn't fall quickly. In the absence of external water, due to drop in atmospheric temperature, water in fine capillaries and veins of plants freezes and capillaries burst due to increase in volume, destroying the crop.

EXAMPLE

A 250 W heater is used to heat 500 g of mercury. The heater is on for 1 minute and the initial temperature of mercury is 20°C . Calculate the final temperature of mercury. [Specific heat capacity of mercury = $0.14 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$]

SOLUTION

Given,

Power of heater (P) = 250 W

Heat energy given by heater = $P \times t = 250 \text{ W} \times 1 \text{ minute} = 250 \text{ W} \times 60 \text{ s} = 250 \text{ J} \times 60$
 $\text{s} = 250 \times 60 \text{ J}$

Heat absorbed by mercury = $ms\Delta\theta$

$$m = 500 \text{ g}$$

$$\Delta\theta = 20^\circ\text{C}$$

Let x = final temperature of mercury.

Heat given by heater = heat absorbed by mercury.

$$\therefore 250 \times 60 \text{ J} = 500 \times 0.14 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times (x - 20)$$

$$\frac{250 \times 60}{500 \times 0.14} = x - 20$$

$$\therefore x = 234.28^\circ\text{C}.$$

PRINCIPLE OF MIXTURES

Take few lead shots whose temperature is 70°C and add them to water at 30°C contained in an insulating container and stir well. The temperature of lead shots decreases and that of water rises. This means lead shots lose heat and water gains heat. If no heat is lost to surroundings, then heat lost by lead shots is equal to the heat gained by water. This is the principle of mixtures which states that when a hot body is mixed with a cold body, the hot body loses heat and the cold body gains heat till they are in thermal equilibrium and the heat lost by the hot body is equal to the heat gained by the cold body, provided heat is not lost to the surroundings. This principle is in accordance with the principle of conservation of energy and is used to determine specific heat capacity of solids and liquids.

According to the principle of calorimetry or method of mixtures, heat lost by the hot body = heat gained by the cold body.

Let

m_1 = mass of hot body.

m_2 = mass of cold body.

θ_1 = temperature of hot body.

θ_2 = temperature of cold body.

θ = temperature of both bodies under thermal equilibrium.

s_1 = specific heat capacity of hot body.

s_2 = specific heat capacity of cold body.

Fall in temperature of hot body = $\theta_1 - \theta$

Rise in temperature of cold body = $\theta - \theta_2$

Heat lost by hot body = $m_1 s_1 (\theta_1 - \theta)$

Heat gained by cold body = $m_2 s_2 (\theta - \theta_2)$

$$\therefore m_1 s_1 (\theta_1 - \theta) = m_2 s_2 (\theta - \theta_2)$$

Calorimeter

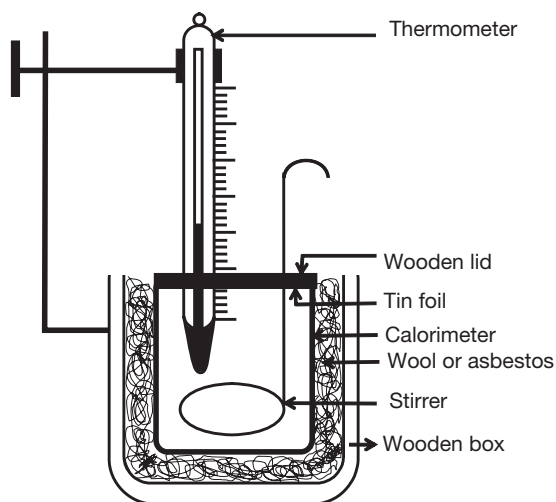


FIGURE 3.1 Calorimeter

Heat is a form of energy. Like other forms of energy, it can be measured. The branch of physics which deals with the measurement of heat is called ‘calorimetry’.

The device which is used to measure quantity of heat is called a calorimeter. It uses the principle of mixtures to find the specific heat capacity of different bodies. Hence, the method is also called the method of mixtures.

Calorimeter consists of a thin cylindrical copper vessel. Its outer and inner surfaces are highly polished to prevent heat loss by radiation. The copper vessel is kept in rectangular wooden box and space between them is filled with materials like asbestos or cotton wool which are good insulators of heat. This prevents heat loss by conduction.

At its top, the box has a wooden lid with two holes, one for inserting a thermometer and the other for a stirrer which is also made of copper. The lid is coated with tin or aluminum foil.

Experiment to Determine Specific Heat Capacity of a Given Solid by Method of Mixtures

A solid whose specific heat capacity is to be measured is taken in the form of small pieces. It is first heated separately and then added to calorimeter which contains cold water. Devices like Sinclair’s heater and hypsometer are suitable for this purpose.

Sinclair’s Heater

It consists of a cylindrical double walled copper vessel fitted with an outlet tube as shown in Fig. 3.2. Water is heated at the lower portion and steam is passed out through steam outlet. Through an opening at the top, a tube is introduced in the outlet tube. This tube is open at both ends. The bottom open end of the tube is tapered so that it fits well at the slope of the outlet tube. The solid which is to be heated is introduced in the tube in the form of small pieces. To measure its temperature, a thermometer is inserted in the tube through a rubber cork. Care should be taken that the bulb of the thermometer is completely immersed in the

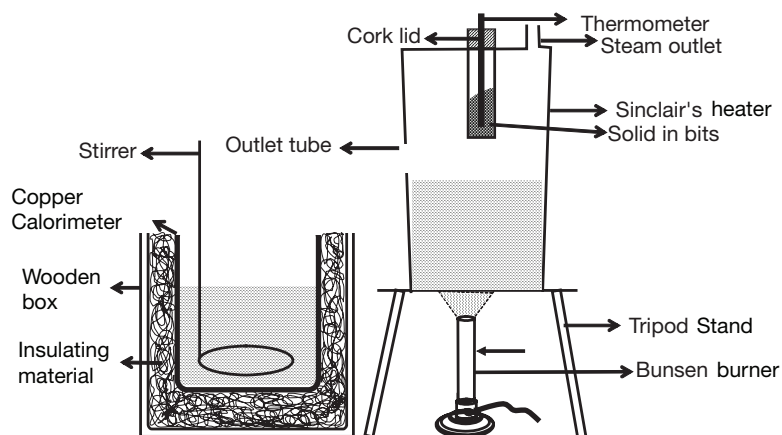


FIGURE 3.2 Sinclair's heater

solid pieces. The cylindrical vessel is now heated by bunsen burner and temperature of solid pieces is noted. The solid gets heated as it is surrounded by steam formed by boiling water. This ensures uniform heating. A wooden partition (not shown in the Fig. 3.2) is kept on the side of this arrangement to prevent heat radiations from reaching the calorimeter into which the hot solid pieces have to be transferred. Once the temperature of solid is sufficiently high and steady, heating is stopped and calorimeter is brought below the outlet tube. The open ended tube along with thermometer is lifted and heated solid pieces are allowed to fall into calorimeter and calorimeter is then closed quickly.

While the solid whose specific heat capacity is to be measured is being heated in the Sinclair's apparatus, the following procedures can be completed.

1. Take dry, clean and highly polished calorimeter and determine its mass with its stirrer, using a physical balance. Let it be $m_1 g$.
2. Now pour water into it at room temperature till it is half full and determine its mass again. Let it be $m_2 g$.
3. Put calorimeter in wooden box and note the temperature of water. Let it be $\theta_1^\circ\text{C}$.
4. Note the temperature of hot solid pieces. Let it be $\theta_2^\circ\text{C}$. Introduce them into the water in the calorimeter and close the wooden lid quickly to prevent heat loss.
5. Stir the mixture well with stirrer and note the steady temperature of mixture. Let it be $\theta^\circ\text{C}$.
6. Remove calorimeter from the wooden box and determine its mass along with solid pieces. Let it be $m_3 g$.

Calculations

When the hot solid pieces are added to water, they lose heat which is absorbed by water and calorimeter. This transfer of heat continues till they are all at same temperature, i.e., they are in thermal equilibrium.

$$\text{Fall in temperature of solid} = \theta_2 - \theta$$

$$\text{Rise in temperature of water} = \theta - \theta_1$$

$$\text{Rise in temperature of calorimeter} = \theta - \theta_1$$

$$\text{Mass of solid} = (m_3 - m_2)g$$

$$\text{Mass of water} = (m_2 - m_1)g$$

$$\text{Heat lost by solid} = (m_3 - m_2) s (\theta_2 - \theta)$$

Where s = specific heat capacity of the solid, which is to be determined.

$$\text{Heat gained by water} = (m_2 - m_1) s_w (\theta - \theta_1)$$

$$\text{Heat gained by calorimeter} = m_1 s_C (\theta - \theta_1)$$

Heat lost by the solid = heat gained by the water + heat gained by the calorimeter.

$$(m_3 - m_2) s (\theta_2 - \theta) = (m_2 - m_1) s_w (\theta - \theta_1) + m_1 s_C (\theta - \theta_1)$$

$$\therefore s = \frac{[m_1 s_C + (m_2 - m_1) s_w] (\theta - \theta_1)}{(m_3 - m_2) (\theta_2 - \theta)}$$

While determining specific heat capacity by the above method, certain precautions need to be taken to ensure the accuracy of measurements. They are as follows.

1. The calorimeter should be clean, dry and highly polished.
2. Good heat insulators should be used in the wooden box of the calorimeter.
3. The thermometer should be highly sensitive.
4. The final temperature of the mixture should be noted one minute after the temperature has stabilized.
5. Calorimeter should not be kept near a source of heat.
6. Water must be stirred continuously, taking care that it doesn't spill over.

EXAMPLE

A solid of mass 70 g at 80°C is dropped into 100 g of water at 20°C contained in a copper calorimeter of mass 60 g and specific heat capacity 0.40 J g⁻¹ °C⁻¹. The final steady state temperature of the mixture is 30°C. Find the specific heat of solid. [Specific heat of water = 4.2 J g⁻¹ °C⁻¹].

SOLUTION

Compile the given information in tabular form as shown below:

Substance	Mass (gram)	Specific heat capacity J g ⁻¹ °C ⁻¹	Initial temperature	Final temperature = 30°C	
				rise in temperature (°C)	Fall in temperature
Solid	70	X	80°C	-	80°C - 30°C Δθ _F = 50°C
Water	100	4.2	20°C	Δθ _R = 30°C - 20°C = 10°C	-
Calorimeter	60	0.40	20°C	Δθ _R = 30°C - 20°C = 10°C	-

$$\text{Heat lost by solid} = ms \Delta\theta_F = 70 \text{ g} \times x \times 50^\circ\text{C} = 3500x \text{ J}$$

$$\text{Heat gained by water} = ms \Delta\theta_R = 100 \text{ g} \times 4.2 \text{ J g}^{-1}^\circ\text{C}^{-1} \times 10^\circ\text{C} = 4200 \text{ J}$$

$$\text{Heat gained by calorimeter} = ms \Delta\theta_R = 60 \text{ g} \times 0.4 \text{ J g}^{-1}^\circ\text{C}^{-1} \times 10^\circ\text{C} = 240 \text{ J}$$

Applying principle of calorimetry, we get

$$3500x = 4200 \text{ J} + 240 \text{ J}$$

$$\therefore x = \frac{4440}{3500} = 1.268 \text{ J g}^{-1}^\circ\text{C}^{-1}$$

Measurement of Specific Heat Capacity of a Liquid by Method of Mixtures

The procedure for measurement of specific heat capacity of a liquid by method of mixtures is same as that for a solid. Liquid whose specific heat capacity is to be determined is taken in calorimeter instead of water. A solid whose specific heat capacity is known is heated and introduced into it.

According to the principle of calorimetry,

heat lost by solid = heat gained by the liquid + heat gained by the calorimeter.

$$(m_3 - m_2) s (\theta_2 - \theta) = (m_2 - m_1) s_\ell (\theta - \theta_1) + m_1 s_C (\theta - \theta_1)$$

$$\therefore (m_2 - m_1) s_\ell (\theta - \theta_1) = (m_3 - m_2) s (\theta_2 - \theta) - m_1 s_C (\theta - \theta_1)$$

$$\therefore s_\ell = \frac{(m_3 - m_2)s(\theta_2 - \theta) - m_1 s_C (\theta - \theta_1)}{(m_2 - m_1)(\theta - \theta_1)}$$

where m_1 , m_2 and m_3 are masses of empty calorimeter, calorimeter with liquid, calorimeter with liquid and solid, respectively; θ_1 , θ_2 and θ are initial temperature of calorimeter and liquid, initial temperature of the hot solid and final steady temperature of the mixture, respectively and s_ℓ , s_C and s are the specific heats of liquid, calorimeter and solid, respectively. In the above procedure, the solid is selected such that it does not dissolve or react with the given liquid.

CHANGE OF STATE

Matter can exist in three states or phases namely solids, liquids and gases. The state of matter can be changed by changing the temperature or pressure. For example, when ice is heated, it converts to water which converts to vapour or steam on further heating. When ice and water are heated, their temperatures rise. But, when ice changes into water or water changes into steam, there is no rise in temperature although heat is supplied continuously. Reverse of this is also true, i.e., when steam on cooling converts to ice, there is no fall in temperature during change of state. Thus, change of state always takes place at constant temperature. When a solid on heating changes to liquid at a constant temperature, the change of state is called melting or fusion. The constant temperature at which the solid melts is called its 'melting point'. Melting point of ice is 0°C . The conversion of liquid into solid on cooling at constant temperature is called freezing. The constant temperature at which liquid freezes to

solid is called freezing point. Freezing point of water is 0°C . The melting point of a substance when it is converted from solid to liquid state has the same value as its 'freezing point' when it is converted from liquid to solid state. Change of a liquid to gas on heating at a constant temperature is called its boiling or vaporization. The constant temperature at which a liquid changes to gas is called boiling point or ebullition point. The change from gaseous to liquid state on cooling at a constant temperature is called condensation. The constant temperature at which condensation occurs is called liquefaction point.

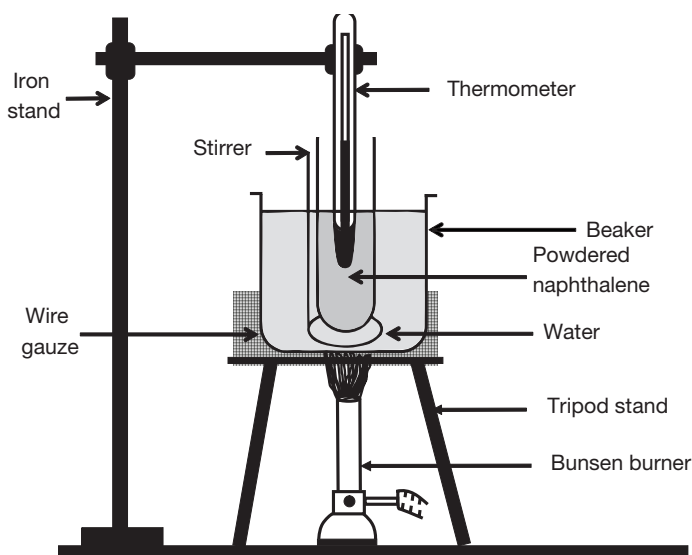


FIGURE 3.3 Apparatus to determine melting point of a substance

Let us perform a simple experiment to determine the melting point of a solid. This method is suitable for solids which have their melting point between 30°C and 100°C . Take some powdered naphthalene in a thin glass test tube fitted with a thermometer. Arrange the apparatus as shown in Fig 3.3.

Turn on the bunsen burner and take thermometer reading after every 1 minute. Plot a graph of temperature versus time, taking temperature on Y-axis and time on X-axis.

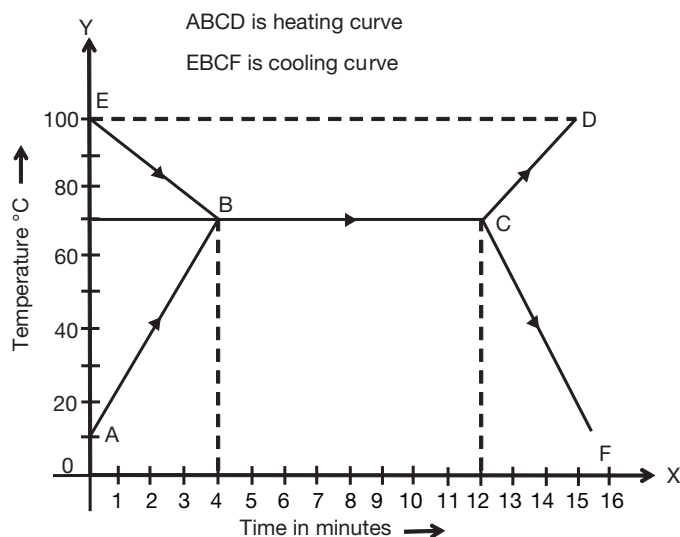


FIGURE 3.4 Temperature vs time graph to obtain melting point of a substance

Initially, we get a straight line inclined to X -axis (AB of graph) indicating that as naphthalene is heated, its temperature rises proportionately. After some time, we get a line parallel to X -axis (BC of graph) indicating that there is no rise in temperature, though naphthalene is being heated continuously. By definition, we know that a change of phase from solid to liquid is taking place during BC . This represents melting of naphthalene. After some time, we again get a straight line graph (CD) inclined to X -axis. This indicates that the temperature of the liquid naphthalene rises on heating. $ABCD$ represents the heating curve of naphthalene.

$AB \rightarrow$ rise in temperature of solid naphthalene on heating.

$BC \rightarrow$ melting of naphthalene on heating at constant temperature.

$CD \rightarrow$ rise in temperature of liquid naphthalene on heating.

The heating is stopped and naphthalene is allowed to cool. Temperature of liquid naphthalene is recorded at an interval of one minute and again temperature versus time graph is plotted, giving us cooling curve $EBCF$.

$EB \rightarrow$ fall in temperature of liquid naphthalene on cooling.

$BC \rightarrow$ freezing of naphthalene at constant temperature.

$CF \rightarrow$ fall in temperature of solid naphthalene on cooling.

The temperature on Y -axis corresponding to BC is the melting point of the solid naphthalene or freezing point of the liquid naphthalene.

Latent Heat of Fusion

We have seen that during melting or vaporization, the temperature of a substance remains constant although heat is continuously being supplied to it. Why doesn't its temperature rise? What happens to heat supplied during change of state?

The heat supplied to a body during its change of state does not result in rise of temperature as it is used for changing its state. The intermolecular space increases when a solid melts overcoming the intermolecular force of attraction.

Thus, the heat supplied to a solid during its change of state is stored as potential energy of liquid molecules. The heat energy that is used to change its state without any rise in temperature is called latent heat or hidden heat. The heat required to change a solid into liquid at its melting point without any rise in temperature is called latent heat of fusion. Thus, heat needed to melt ice into water at 0°C is called latent heat of fusion of ice. The latent heat of fusion depends on the mass of substance. The higher the mass of a solid, the larger is its latent heat of fusion. The latent heat required to convert a unit mass of a solid to liquid at constant temperature is called its specific latent heat of fusion.

Units of Specific Latent Heat of Fusion

$Q = mL$ where Q , m and L are heat supplied to a solid, its mass and its specific latent heat of fusion, respectively.

$$\text{Thus, unit of } L = \frac{\text{unit of } Q}{\text{unit of } m}$$

$\Rightarrow$ S.I unit of ' L ' is J kg^{-1} . Other common units are cal g^{-1} , kcal kg^{-1} and J g^{-1} .

The specific latent heat of fusion of ice is the amount of heat needed to convert a unit mass of ice (1 kg or 1g) at 0°C to water at 0°C . The specific latent heat of fusion of ice is the highest among all substances. Its value is $336 \times 10^3 \text{ J kg}^{-1}$ or 336 J g^{-1} or 80 cal g^{-1} .

Specific Latent Heat of Fusion of Some Substances

Substance→ Latent heat ↓	Ice	Copper	Paraffin wax	Silver	Sulphur	Lead	Mercury
J g^{-1}	336	180	146	88	37.7	27	12.5
J kg^{-1}	336000	180000	146000	88000	37700	27000	12500
cal g^{-1}	80	43	35	21	9	6.42	3

Application and Consequences of High Specific Latent Heat of Fusion of Ice

The specific latent heat of fusion of ice is 336000 J kg^{-1} . Thus, 1kg of ice absorbs $336 \times 10^3 \text{ J}$ of heat when it melts without any rise in its temperature. Conversely, 1kg of water releases $336 \times 10^3 \text{ J}$ of heat when it freezes.

Few natural consequences of this are discussed below:

1. Water bodies such as lakes, ponds and rivers do not freeze suddenly in cold countries with the onset of winter. Also when they do freeze, they give 336 J g^{-1} of heat to the surroundings making the weather moderate.
2. During snow storm, snow is formed due to freezing of water vapour in the atmosphere. It gives out large amount of heat to the surroundings which makes the surrounding weather moderate.
3. During summer, snow melts slowly on mountains as it needs large amount of heat. Hence, there are no flash floods in rivers and they contain water for the whole year.

General Applications

1. Soft drinks and fruit juices are cooled with ice rather than with cold water as ice can absorb 336 J g^{-1} of heat. So, cooling with ice additionally is more effective.
2. Ice cream at 0°C is felt cooler than water at 0°C as ice can absorb 336 J g^{-1} , while water absorbs 4.2 J g^{-1} .

Determination of Latent Heat of Fusion of Ice

To determine latent heat of fusion of ice by the method of mixtures, the following procedure is followed.

1. Take a clean, dry and highly polished calorimeter with stirrer and measure its mass using an accurate physical balance. Let it be $m_1 \text{ g}$.
2. Fill in the calorimeter with water at room temperature till it is half filled. Measure the mass of the calorimeter with water. Let it be $m_2 \text{ g}$.
3. Place the calorimeter in the wooden box having good heat insulating material like cotton wool or asbestos. With the help of a highly sensitive thermometer, note the temperature of water. Let it be $\theta_1^{\circ}\text{C}$.

4. Now take ice pieces made of pure distilled water and crush them into small pieces. Wipe them dry with the help of filter paper and drop them gently and carefully in the calorimeter. Allow the ice pieces to melt by gently stirring the water. Repeat the process till the temperature of mixture falls by about 15°C . Note the stabilized steady temperature of the mixture. Let it be $\theta^{\circ}\text{C}$.
5. Remove the calorimeter from the wooden box and record its mass with the mixture. Let it be m_3 g.

Calculations

1. Mass of water at room temperature = $(m_2 - m_1)$ g.
2. Mass of ice = $(m_3 - m_2)$ g.
3. Rise in temperature of water formed from ice = $\theta - 0^{\circ} = \theta^{\circ}\text{C}$
4. Fall in temperature of water and calorimeter at room temperature = $(\theta_1 - \theta)^{\circ}\text{C}$

Heat gained by ice to change its state to water at 0°C

$$= \text{mass of ice} \times \text{specific latent heat of fusion of ice} = (m_3 - m_2) L_{\text{ice}}$$

Heat gained by water formed from ice = (mass of ice) (specific heat capacity of water) (rise in temperature of water formed from ice)

$$\begin{aligned} &= (m_3 - m_2) \text{ g} \times 4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times \theta^{\circ}\text{C} \\ &= 4.2(m_3 - m_2) \times \theta \text{ J} \end{aligned}$$

$$\text{Heat lost by calorimeter} = m_1 \times 0.40 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times (\theta_1 - \theta)^{\circ}\text{C} = 0.4m_1(\theta_1 - \theta) \text{ J.}$$

$$\text{Heat lost by water} = (m_2 - m_1) \times 4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times (\theta_1 - \theta)^{\circ}\text{C} = 4.2(m_2 - m_1)(\theta_1 - \theta) \text{ J}$$

According to principle of mixtures,

Heat gained by ice = Heat lost by calorimeter + Heat lost by water at room temperature + resulting water

$$(m_3 - m_2) L_{\text{ice}} + 4.2(m_3 - m_2)\theta = 0.4m_1(\theta_1 - \theta) + 4.2(m_2 - m_1)(\theta_1 - \theta)$$

$$\therefore (m_3 - m_2)L_{\text{ice}} = \{0.4m_1 + 4.2(m_2 - m_1)\}(\theta_1 - \theta) - 4.2(m_3 - m_2)\theta$$

$$\therefore L_{\text{ice}} = \left[\frac{\{0.4m_1 + 4.2(m_2 - m_1)\}(\theta_1 - \theta) - 4.2(m_3 - m_2)\theta}{(m_3 - m_2)} \right]$$

Precautions

In addition to precautions already discussed, following precautions need to be taken while finding specific latent heat of fusion of ice.

1. Ice should be prepared using distilled water and should be dried thoroughly before adding to water in the calorimeter.
2. Water in the calorimeter should be stirred gently.
3. Final temperature should be recorded only when all the ice has melted and one minute after the temperature has stabilized.

EXAMPLE

A calorimeter of mass 50 g and specific heat capacity $0.40 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$ contains 200 g of water at 40°C . What amount of ice at 0°C should be added to it so that the final temperature is 10°C ? [specific heat capacity of water = $4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$ and specific latent heat of fusion of ice = $336 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$]

SOLUTION

Substance	Mass (g)	Specific latent heat of fusion/ specific heat capacity	Initial Temp $^{\circ}\text{C}$	Rise in temperature $^{\circ}\text{C}$	Fall in temperature $^{\circ}\text{C}$
Ice	m	$336 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$	0	$\Delta\theta = 10 - 0 = 10$	-
Water	200	$4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$	40		$\Delta\theta = 40 - 10 = 30$
Calorimeter	50	$0.40 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1}$	40		$\Delta\theta = 40 - 10 = 30$

Heat gained by ice to form water at $0^{\circ}\text{C} = mL_{\text{ice}} = m \times 336 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} = 336m \text{ J}$

Heat gained by water formed from ice = $ms \Delta\theta = m \times 4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times 10^{\circ}\text{C} = 42m \text{ J}$

Heat lost by water at $40^{\circ}\text{C} = ms \Delta\theta = 200 \text{ g} \times 4.2 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times 30^{\circ}\text{C} = 25200 \text{ J}$

Heat lost by calorimeter at $40^{\circ}\text{C} = ms \Delta\theta = 50 \text{ g} \times 0.40 \text{ J g}^{-1} \text{ }^{\circ}\text{C}^{-1} \times 30^{\circ}\text{C} = 600 \text{ J}$

Heat gained by ice to form water + Heat gained by water formed from ice = Heat lost by water + Heat lost by calorimeter

$$\Rightarrow 336m + 42m = 25200 + 600$$

$$\Rightarrow 378m = 25800 \Rightarrow m = \frac{25800}{378} = 68.25 \text{ g.}$$

Factors Affecting Melting Point

Melting point of a solid is affected by pressure and impurities present in it.

Effect of Pressure

In general, melting point increases with increase in pressure. But for substances which expand on freezing like water, iron, etc., the melting point decreases with increase in pressure. Thus, pure ice which melts at 0°C under normal pressure will melt at temperature less than 0°C if pressure is increased.

Regelation

It is a phenomenon in which melting point of ice is lowered with increasing pressure and it is restored to normal value when external pressure is removed. This can be illustrated as under.

Take a string and attach weights, to its two ends. Place the string over an ice block. You will find that string passes through the ice block without breaking it and falls down.

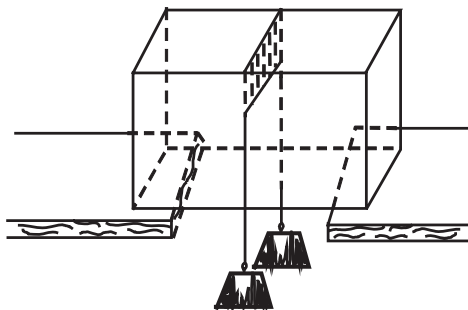


FIGURE 3.5 Apparatus to show regelation

This is due to regelation. When the string is kept on the top surface of the ice block, it exerts pressure on the block due to which its melting point decreases. So, it melts and the string goes down. The water above the string again freezes as the external pressure is removed. In this way, the string slips down the whole of the ice block. It is also due to regelation that an ice skater is able to slide over ice. The ice below the skates melts due to increase in pressure forming a thin layer of water which allows the skater to move ahead smoothly. As soon as the skater goes ahead, the water freezes again.

Effect of Impurities on Melting Point

Addition of impurities decreases the melting point of ice.

Freezing Mixture

A mixture of ice and an impurity like common salt (which is soluble in water) in proper ratio is called freezing mixture. The melting point of freezing mixture is lower than 0°C . For example, the melting point of the mixture of ice and common salt mixed in the ratio 3 : 1 is -22°C . The melting point of mixture of ice and calcium chloride mixed in the ratio 3 : 4 is -55°C . Freezing mixtures are used in preparing ice creams and in laboratories for preserving biological specimens.

Latent Heat of Vapourization

Temperature of a liquid increases when it is heated, till it reaches the boiling point. At boiling point, while liquid vapourizes, its temperature remains constant. During vapourization, the heat supplied is used to overcome intermolecular forces of attraction to increase intermolecular space. This heat is stored in vapour molecules in the form of potential energy. This heat is called latent heat of vaporization. The latent heat of vaporization of a given liquid increases with mass. In order to have a unique or specific value, we define latent heat of vaporization for unit mass of a given liquid. The latent heat of vaporization of a unit mass of a liquid is called its specific latent heat of vaporization.

Units of Specific Latent Heat of Vaporization

$Q = m L$; where Q , m and L are heat supplied to a liquid, mass of a liquid and its specific latent heat of vaporization respectively.

$$\text{Thus, unit of } L = \frac{\text{unit of } Q}{\text{unit of } m}$$

Hence, S.I unit of 'L' is joule per kilogram (J kg^{-1}). Other common units are cal g^{-1} , kcal g^{-1} and J g^{-1}

Specific Latent Heat of Vaporization of Steam

Amount of heat required to convert unit mass of water (1 kg or 1 g) at 100°C to steam at 100°C is called specific latent heat of vapourization of steam. Steam has highest specific latent heat of vapourization. Its value is 2268 J g^{-1} or $226.8 \times 10^4 \text{ J kg}^{-1}$ or 540 cal g^{-1}

Substance	Boiling point	Specific latent heat of vaporization	
		J g^{-1}	J kg^{-1}
Methyl alcohol	64°C	1120	112×10^4
Acetone	57°C	520	52×10^4
Benzene	80°C	400	40×10^4
Carbon disulphide	46°C	360	36×10^4
Carbon tetrachloride	77°C	190	19×10^4
Ethyl alcohol	79°C	850	85×10^4
Mercury	357°C	290	29×10^4
Turpentine oil	156°C	290	29×10^4
Water	100°C	2268	226.8×10^4

Advantages and Natural Consequences of High Specific Latent Heat of Vaporization of Steam

1. For water in soil to evaporate, a very large amount of heat, i.e., $226.8 \times 10^4 \text{ J kg}^{-1}$ heat is needed vaporization slow down. Therefore, plants do not wilt easily even in summer.
2. One gram of water at 100°C contains 100 cal of heat. If the same water is to be converted into steam at the same temperature, it needs 540 cal of additional heat. Thus, 1 g of steam at 100°C contains 640 cal of heat. Therefore, burns caused by steam at 100°C are more severe than these caused by water at 100°C .
3. Steam can carry large amount of heat. Therefore, it is used in thermal power stations where heat energy from coals is carried by steam and converted to electric energy.

Determination of Specific Latent Heat of Vaporization by Method of Mixtures

Follow first three steps mentioned in determination of latent heat of fusion of ice by calorimeter on page 3.9.

4. In this case the wooden lid of the calorimeter box has a third hole for introducing steam into the calorimeter. Steam is generated in a boiling flask and passed through steam trap which removes condensed water vapours. The steam coming out of steam trap is introduced in the calorimeter till the temperature of the mixture rises by about

20°C. The mixture is stirred gently for uniform distribution of temperature. The final steady temperature of mixture is recorded. Let it be $\theta^\circ\text{C}$. The temperature of steam is 100°C.

5. Remove the calorimeter and record its mass. Let it be m_3 .

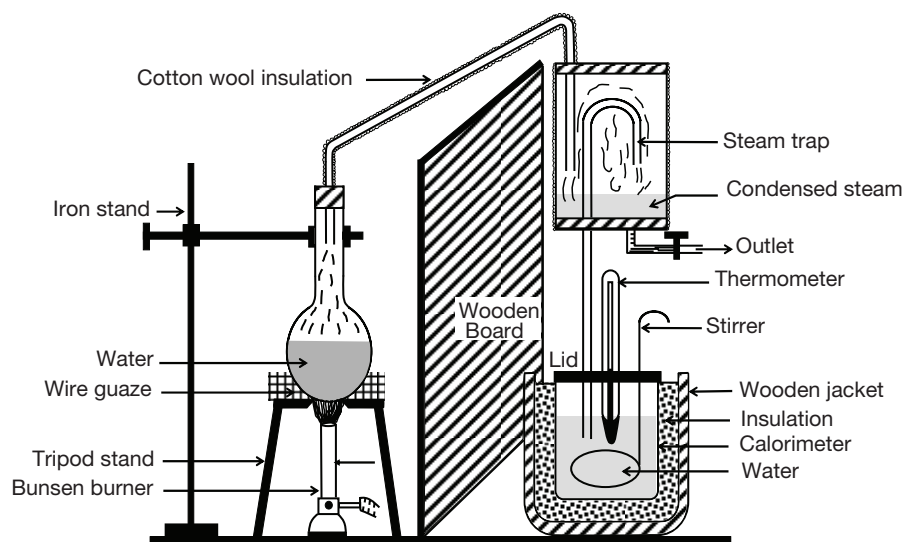


FIGURE 3.6 Apparatus to determine specific latent heat of vaporization

Calculations

Mass of water at room temperature = $(m_2 - m_1)\text{g}$, Mass of steam condensed and mixed with water = $(m_3 - m_2)\text{ g}$

Fall in temperature of water formed from steam = $\Delta\theta = (100 - \theta)^\circ\text{C}$

Rise in temperature of calorimeter and water at room temperature $\Delta\theta = (\theta - \theta_1)^\circ\text{C}$

Heat lost by steam to form water at 100°C

$$\begin{aligned} &= (m_3 - m_2) \times L_{\text{steam}} \\ &= (m_3 - m_2)x, \end{aligned}$$

where $L_{\text{steam}} = x$, the latent heat of vaporisation of water, which is to be determined.

Heat lost by water at 100°C formed from steam

$$\begin{aligned} &= (m_3 - m_2) \text{ g} \times 4.2 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times (100 - \theta)^\circ\text{C} \\ &= 4.2(m_3 - m_2) (100 - \theta)\text{J} \end{aligned}$$

Heat gained by calorimeter = $m_1 \times 0.40 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times (\theta - \theta_1)^\circ\text{C}$

$$\begin{aligned} &\text{Heat gained by water at room temperature} = (m_2 - m_1) \times 4.2 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times (\theta - \theta_1)^\circ\text{C} \\ &= 4.2(m_2 - m_1) (\theta - \theta_1) \text{ J} \end{aligned}$$

By principle of mixtures,

Heat lost by steam = heat gained by calorimeter + heat gained by water at room temperature and resulting water

$$= (m_3 - m_2)x + 4.2(m_3 - m_2)(100 - \theta) = 0.40m_1(\theta - \theta_1) + 4.2(m_2 - m_1)(\theta - \theta_1)$$

$$\therefore x = \left[\frac{\{0.40m_1 + 4.2(m_2 - m_1)\}(\theta - \theta_1) - 4.2(m_3 - m_2)(100 - \theta)}{m_3 - m_2} \right] \text{Jg}^{-1}$$

Precautions

Other than customary precautions with calorimeter, observe the following precautions for steam.

1. Steam should be perfectly dry.
2. Steam should be passed only till temperature of mixtures rises by about 20°C.

EXAMPLE

100 g of water at 10°C is taken in a calorimeter of mass 50 g and specific heat capacity 0.40 Jg⁻¹ °C⁻¹. Calculate the mass of steam which should be passed into the water in the calorimeter so that the temperature of mixture becomes 40°C. [Specific heat capacity of water = 4.2 J g⁻¹ °C⁻¹ and specific latent heat of vaporization of steam = 2260 J g⁻¹.]

SOLUTION

Substance	Mass (g)	L/S	Initial temperature	rise in temperature	Fall in temperature
Steam	x	2260 J g ⁻¹ °C ⁻¹	100 °C	-	$\Delta\theta = 100\text{ °C} - 40\text{ °C} = 60\text{ °C}$
Water	100	4.2 J g ⁻¹ °C ⁻¹	10 °C	$\Delta\theta = 40\text{ °C} - 10\text{ °C} = 30\text{ °C}$	-
Calorimeter	50	0.4 J g ⁻¹ °C ⁻¹	10 °C	30 °C	-

Heat given by steam to form water at 100°C = $m L = 2260x$ J

Heat lost by water formed from steam at 100°C = $m s \Delta\theta$

$$= m \times 4.2 \text{ J g}^{-1} \text{ °C}^{-1} \times 30\text{ °C} = 126x \text{ J}$$

Total heat lost by steam and the water formed from steam = $2260x + 126x = 2386x$ J.

Heat gained by water at 10°C = $100 \text{ g} \times 4.2 \text{ J g}^{-1} \text{ °C}^{-1} \times 30\text{ °C} = 12600 \text{ J}$

Heat gained by calorimeter at 10°C = $50 \text{ g} \times 0.4 \text{ J g}^{-1} \text{ °C}^{-1} \times 30\text{ °C} = 600 \text{ J}$

By the principle of calorimetry,

$$2386x \text{ J} = 12600 \text{ J} + 600 \text{ J}$$

$$\therefore x = 5.53 \text{ g (approx).}$$

Experiment to Determine Boiling Point of a Liquid

Take water in a closed vessel fitted with a thermometer. Heat it with bunsen burner and note the temperature every minute. Plot temperature versus time graph, taking temperature on Y-axis and time on X-axis.

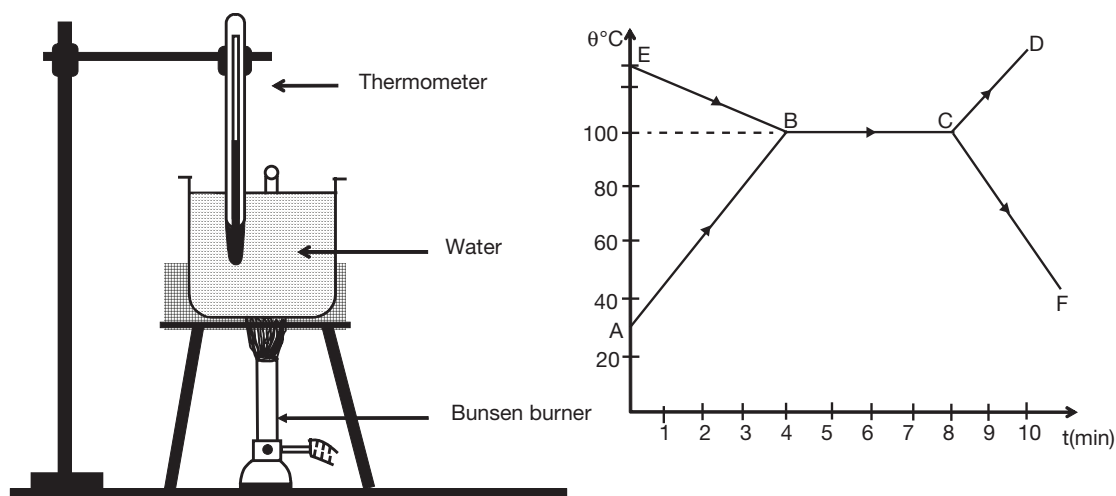


FIGURE 3.7 Apparatus to determine boiling point of a liquid and its graph

ABCD represents heating curve of water.

AB represents rise in temperature of water on heating.

BC represents change of state of water to steam at constant temperature.

CD represents rise in temperature of steam on heating.

Heating is stopped and vessel is allowed to cool and cooling curve *EBCF* is plotted.

EB represents fall in temperature of steam on cooling.

BC represents change in state of steam to water at a constant temperature.

CF represents fall in temperature of water on cooling.

Effects of Pressure and Impurities on Boiling Point

Pressure

Increase in pressure increases the boiling point of a liquid and decrease in pressure decreases its boiling point.

Let us discuss an activity to understand the above fact.

Take some water in a flask. Close the mouth of flask with two holed rubber cork fitted with a delivery tube and a thermometer. Heat the flask and note the temperature of water. It begins to boil at 100°C and steam begins to form. Now partly close the delivery tube so that pressure due to steam increases inside. Check the flask for the temperature at which water boils. You will find that it has increased. Stop heating and allow the water to cool. Close the flask completely. On cooling the steam inside the flask condenses thereby decreasing the

pressure. You will find water boils at lower temperature. Some examples of effect of pressure on boiling point are

1. Pressure cooker is used to cook food quickly.
2. Water boils at a temperature much lower than 100°C at higher altitudes.

Impurities

Addition of impurities increases the boiling point. When 100 g of common salt is added to 100 g of water, the boiling point increases by 1°C .

Evaporation

Wet clothes, when hung on a rope, dry. The water in the wet clothes vapourizes without boiling. If you drop some spirit on your hand, it vapourizes leaving cooling sensation on your hand. The process by which water vapourizes without boiling is called evaporation. The molecules on the surface of water are attracted to water molecules below the surface by cohesive forces and by the surrounding air molecules by adhesive force. If the energy of some molecules on the surface is high, they escape to the surrounding air. Since this process takes place continuously at all temperatures, we find that wet clothes dry after some time. This is due to continuous evaporation. Since the energetic molecules leave water, the average kinetic energy of molecules decreases causing fall in temperature and gives cooling effect. Evaporation is purely a surface phenomenon. Therefore, water stored in an earthen porous container cools faster than that in a metal container. Since evaporation involves escaping of surface molecules to surroundings, the rate of evaporation depends on the following factors:

1. Surrounding temperature
2. Wind velocity
3. Surface area of the liquid

Boiling is different from evaporation, as boiling takes place rapidly at a fixed temperature only and throughout the liquid.

Refrigeration

When a liquid evaporates, it extracts heat energy required for phase change from the surroundings. Therefore, evaporation has a cooling effect. Refrigerator is a device which is used to store food, vegetables and other perishable items at low temperature. It works on the principle that evaporation of a liquid gives cooling effect. Basically, it consists of the following main parts connected to the main frame.

1. Pump
2. Cooling chamber
3. Evaporation tube
4. Condensation tube
5. Copper fins

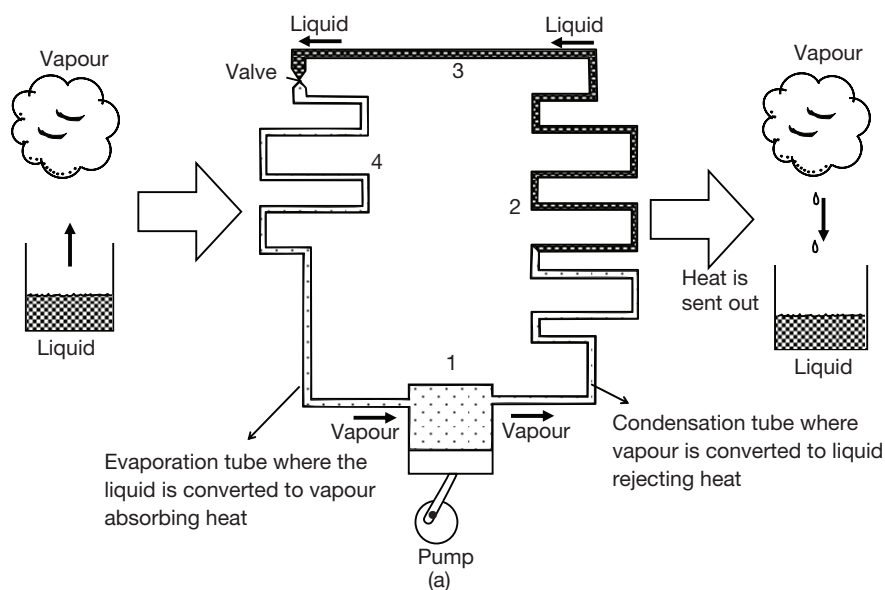


FIGURE 3.8 Pump of the refrigerator

A pump situated behind the main structure of a refrigerator at the bottom, circulates volatile liquid like liquid freon through the evaporation tube. Evaporation tube passes through cooling chamber. When freon reaches cooling chamber, it evaporates, extracting the required heat from the cooling chamber. The temperature of cooling chamber decreases considerably. The vapours then reach condensation tube and pump exerts pressure which condenses them to liquid which is again circulated through evaporation tube. The condensation tube is connected to copper fins which radiate the heat released during condensation. This process is repeated continuously and temperature in cooling chamber is brought down to desired level.

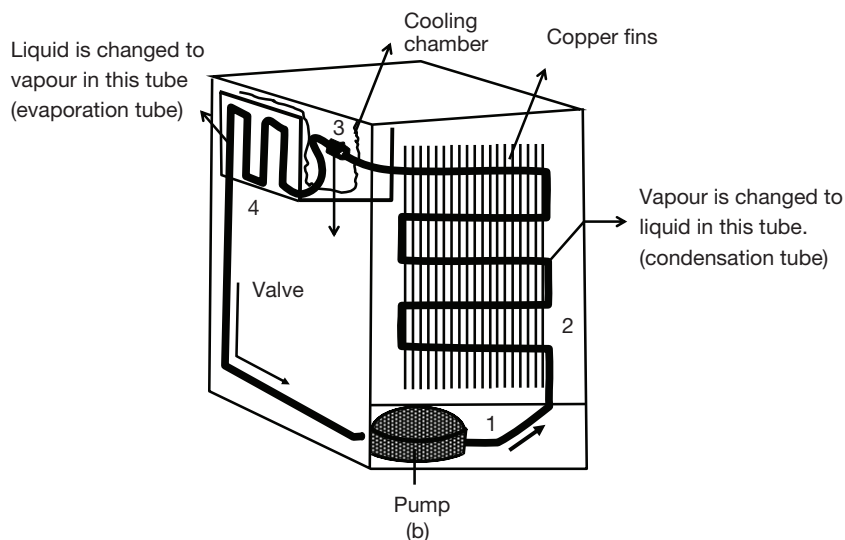


FIGURE 3.9 Main structure of the refrigerator

Sublimation

A solid when heated converts to liquid at melting point and liquid on further heating changes to gas at boiling point. There are few substances which convert to gas from solid state without changing to liquid state. This process is called sublimation.

Example: naphthalene balls, camphor, etc., are some solids that undergo sublimation.

HUMIDITY AND DEW POINT

Almost 70% of earth's surface is covered by water in the form of lakes, rivers, oceans, etc. Thus, water evaporates continuously and forms water vapour in the atmosphere. To prove that the atmosphere always contains certain amount of water vapour, let us discuss a simple experiment. Take some water in a beaker and add a few pieces of ice to it. Melting of ice causes temperature of the mixture to fall. After some time as the temperature has fallen to certain value you will find that the outer surface of the beaker has become blurred due to the formation of condensed water film. This water film develops due to condensation of water vapour present in air due to the fall in temperature.

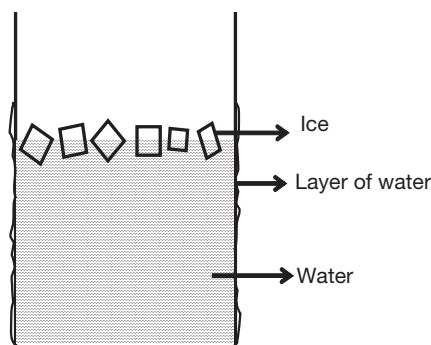


FIGURE 3.10 Mixture of ice and water to observe evaporation

The presence of vapour makes the air moist or damp. This moisture or dampness of air due to water vapour is called humidity. The higher the vapour content present in air, the higher is the humidity of air. Humidity is high in coastal areas. The amount of water vapour present in one cubic metre of air is called its absolute humidity. There is a limit to the mass of water vapour which can be present in a given volume of air. When the mass of water vapour present in air is equal to this limit, i.e., maximum possible value, the air is said to be saturated with water vapour and if it is less than air, it is said to be unsaturated. Sometimes we feel air to be dry and at other times, damp. This feeling not only depends on the exact amount of vapour present in air but also on the difference between this amount and the quantity of water vapour required to saturate the air. If this difference is less, air is felt more damp and if this difference is more, air is felt dry. It is because of this factor that even though the actual amount of water vapour in air is more on a dry summer day than on a moist winter day, the air still is felt drier on summer day. This means that the quantity of water vapour required to saturate given volume of air increases with an increase in temperature. The extent of moistness of air felt by us is determined by a quantity called relative humidity.

Relative Humidity

It is defined as ratio of amount of water vapour actually present in a given volume of air to the amount of water vapour required to saturate the same volume of air at the same temperature.

$$\text{Relative humidity} = \frac{\text{amount of vapour in a given volume of air}}{\text{amount of vapour needed to saturate same volume of air at temperature}} \times 100$$

Thus, relative humidity of completely saturated air is 100%. The air is felt damp if relative humidity is greater than 60%, otherwise it is felt dry. As already discussed the amount of vapour required to saturate a given mass of air depends on temperature. Keeping the amount of unsaturated air and the vapour content in it constant, if its temperature is continuously decreased, the air will get saturated. Now it cannot hold any more amount of vapour for the given temperature. If the temperature is decreased slightly, the vapour in the given volume of air condenses. This is how a thin film of water was formed on the outer surface of the beaker discussed earlier. The water droplets so formed are also called dew. The temperature at which the given volume of air becomes saturated with water vapour without actually increasing the vapour content in it is called dew point. At this temperature, the water vapour in air just begins to condense. During day time you rarely find dew, but during night when the temperature falls below dew point, dew is formed on cold bodies. Sometimes dew is formed on dust particles in the atmosphere forming fog or mist.

Anomalous behaviour of Water

Liquids expand on heating and contract on cooling. Water shows exception to this rule below 4°C . If water at room temperature is cooled, it contracts till its temperature reaches 4°C . On further cooling, as its temperature falls below 4°C , it begins to expand instead of contracting. Conversely if water is heated from 0°C to 4°C , it contracts instead of expanding. This behaviour of water is known as anomalous behaviour of water and the expansion of water on cooling below 4°C is called anomalous expansion of water. The anomalous behaviour of water can be demonstrated with the help of Hope's apparatus.

HOPE'S APPARATUS

It consists of a cylindrical vessel A surrounded by a cylindrical trough B at its centre. Two thermometers can be inserted in the vessel at the top and the bottom as shown in Fig. 3.11.

The vessel is filled with water at 10°C and the trough with a freezing mixture of ice and salt. The changes in temperature of water are recorded by the thermometers.

Following observations are made.

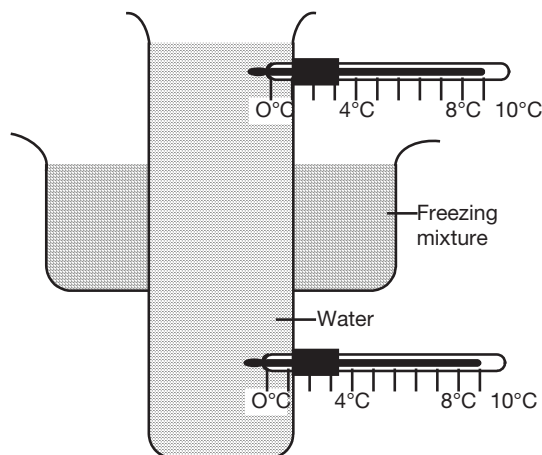


FIGURE 3.11 Hope's Apparatus

1. Initially, the temperature shown by both thermometers is same, i.e., 10°C . As time elapses, the lower thermometer records lower temperatures while temperature shown by the upper thermometer is almost constant. The temperature shown by the lower thermometer decreases gradually till 4°C and then remains constant at 4°C .
2. The temperature shown by the upper thermometer begins to fall till it is 0°C . But the temperature recorded by the lower thermometer remains constant at 4°C .
3. After the upper thermometer shows 0°C , thin layer of ice is formed at the top surface of water.

The above observation can be explained as follows:

Initially, the temperature of water is 10°C . Due to the freezing mixture, the temperature of water at central portion begins to fall and it contracts. As its density increases, the cold water goes to the bottom. Therefore, the lower thermometer records fall in temperatures. This continues till temperature of water at the central portion reaches 4°C . Now as temperature falls further, water expands instead of contracting and its density decreases. Therefore, cold water below 4°C goes up instead of going down. Therefore, temperature of water at the top of the vessel begins to fall till it reaches 0°C as shown by the upper thermometer. At 0°C , water freezes into ice. As density of ice is less than that of water, layer of ice is formed on the top surface. The temperature of water at the bottom of the vessel remains constant at 4°C as ice being a bad conductor of heat, prevents loss of heat from water below it to the surrounding.

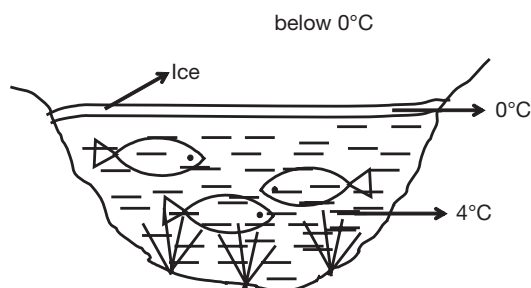


FIGURE 3.12 A water body containing ice layer at surface and temperature of water more than 0°C

Consequences of Anomalous Behaviour of Water

1. The anomalous behaviour of water plays very significant role in the survival of aquatic flora and fauna in cold countries. As explained in Hope's apparatus, the water surface of lakes, ponds or rivers may get frozen in winter, but the temperature of water at bottom remains constant at 4°C .
2. Water pipes in cold countries burst when temperature falls below 4°C as water expands.
3. Fruits and vegetables also get damaged if temperature falls below 4°C as water contained in their capillaries expand.

HEAT ENGINE

Heat is a form of energy. It can be converted to other forms of energy and vice versa. Energy is ability to do work. Thus, heat can also be used to do useful work.

Some examples of work done by heat are:

1. The weight of a pressure cooker is raised when sufficient amount of steam is accumulated in it.
2. James Watt, a Scottish scientist, observed that while making tea, the lid of the tea kettle flew up as steam was generated due to heating of water. James Watt later developed modern steam engine which could transport marine loads over large distances rapidly. Heat energy cannot be used directly to do useful work. The device which converts heat into useful mechanical work is called heat engine.

Heat engines are classified into two types namely, external combustion engine and internal combustion engine.

External Combustion Engine

It consists of a cylinder C fitted with an air tight piston (Fig 3.13). The piston is connected to a crank shaft. The cylinder is connected to a boiler through an inlet valve and to a condenser through an outlet valve. The boiler and condenser are connected to each other through a pump.

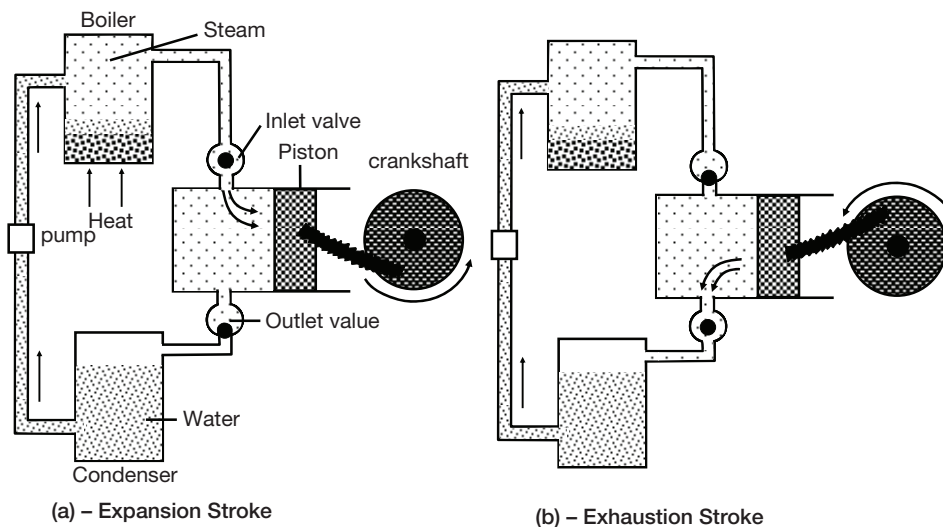


FIGURE 3.13 External combustion engine

Water is heated in the boiler and steam is generated. The pressure of accumulated steam opens the inlet valve and forces the piston outwards. This is called an expansion stroke. The outward or inward movement of the piston is called a 'stroke'. At the end of expansion stroke, the inlet valve is closed and the piston begins to move inwards.

The outlet valve is opened and used steam is passed on to the condenser, where it condenses. The water is then pumped back to the boiler.

This action is repeated. In external combustion engine, steam is used to do useful work. Therefore, it is also called steam engine.

Steam engine is not used extensively as it has certain disadvantages.

1. Steam engines are bulky and cannot be used to run smaller machines.
2. Steam engines can be dangerous as due to high pressure of steam, the boiler may burst.
3. Steam engine cannot be started instantly. To obtain steam at high temperature, some time is needed.

Internal Combustion Engine

Due to these drawbacks, a steam engine cannot be used in many applications. To overcome the drawbacks of a steam engine, a new heat engine was devised. In this heat engine, combustion of fuel and conversion of heat energy to mechanical energy is done inside the cylinder itself. Therefore, it is called internal combustion engine. Depending on the fuel used, internal combustion engines are classified into petrol engines and diesel engines.

Petrol Engine

It consists of a cylinder and an airtight piston which is connected to a crankshaft. Inlet and outlet valves and a spark plug are provided at the head of the cylinder. Petrol engine is connected to carburettor. It mixes petrol and air in proper proportion and supplies it to the cylinder through the inlet valve.

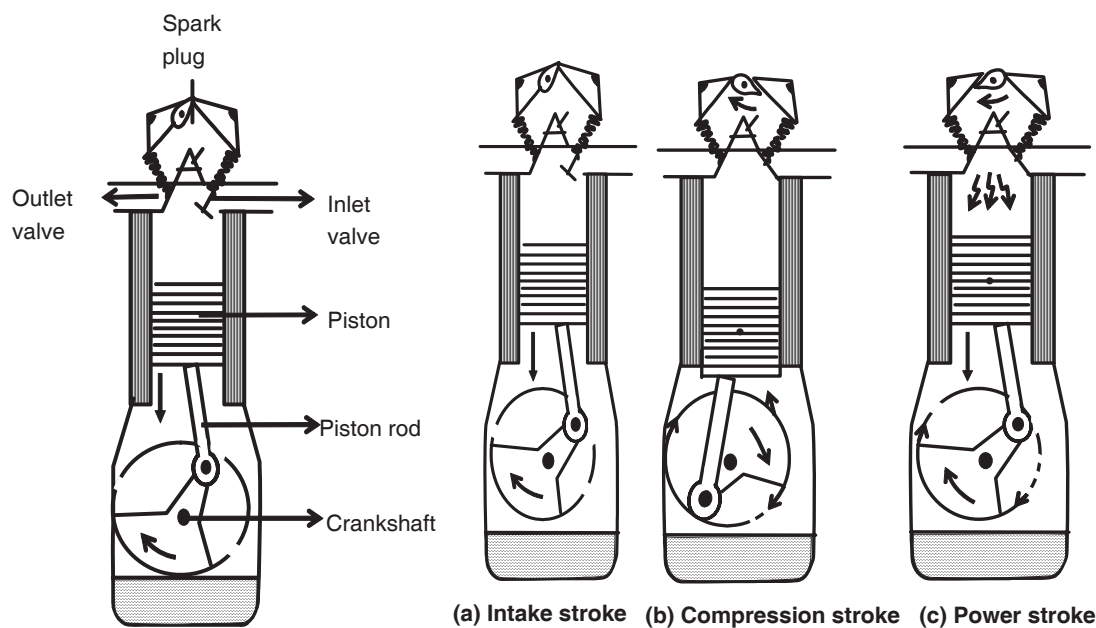


FIGURE 3.14 Petrol engine

One complete operation or cycle of engine involves four stages or four strokes. Each stage is described below:

1. **Intake stroke**: The piston is moved outward. This decreases the pressure in cylinder which opens the inlet valve. The fuel mixture enters the cylinder from the carburettor.
2. **Compression stroke**: The piston is moved inwards towards the cylinder head which compresses the fuel mixture. Both the inlet and the outlet valves are closed.
3. **Power stroke**: The compressed fuel is burnt by the sparks from spark plug. The by-products of combustion like water vapour and carbon dioxide expand rapidly pushing the piston outwards with great force.
4. **Exhaust stroke**: The gases released during combustion are expelled through outlet valve as the piston is moved back and the outlet valve is opened. These four strokes constitute one work cycle. As the cycles are repeated piston moves to and fro rapidly which rotates the crankshaft. The internal combustion engine has to be started with the help of self starter, kick starter or push starter. The internal combustion engine is used in almost all vehicles like scooters, motorcycles, cars, etc.

Diesel Engine

Diesel engine is similar to a petrol engine with few changes in construction. The spark plug is replaced by fuel injection pump. Carburettor is not used in a diesel engine. One work cycle of diesel engine consists of four strokes as in petrol engine.

Intake stroke: Pistons move out and filtered air is taken into the cylinder.

Compression stroke: The air is compressed to $\frac{1}{16}$ th of its volume as piston moves in. The compressed air becomes hot enough to ignite the fuel. Hence, there is no need of spark plug.

Power stroke: At the end of compression stroke, required amount of diesel is injected into the cylinder by fuel injection pump. Diesel bursts into flame instantly. Due to the high pressure generated by combustion and expansion of gases, the piston is pushed out with large force.

Exhaust stroke: The spent gases are expelled in the exhaust stroke. Although internal combustion engine has many advantages over steam engine, its biggest drawback is that it is a single largest source of air pollution. Some of the pollutants released like carbon monoxide, sulphur dioxide and lead compounds are highly toxic and harmful.

Efficiency of Heat Engine

It is defined as ratio of useful work done by heat engine to the total amount of heat supplied to it. It is generally expressed as a percentage.

$$\text{Efficiency} = \frac{\text{work done (useful)}}{\text{total heat supplied}} \times 100$$

No heat engine is 100% efficient. Efficiency of few types of heat engines are given below:

Table below lists efficiencies of some commonly used engines.

S.No.	Type of engine	Efficiency
1	Steam engine	15
2	Jet engine	15
3	Petrol engine	30
4	Steam turbine	35
5	Diesel engine	40

Advantages of an internal combustion engine over a steam engine:

1. An internal combustion engine is more efficient and safer than a steam engine.
2. It can be started instantaneously.
3. Internal combustion engines are less bulky, and can be manufactured in a range of different sizes. They are suitable for small machines also.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. What is a freezing mixture?
2. Define humidity, absolute humidity and relative humidity.
3. In diesel as well as in petrol engines, one complete cycle of operation involves _____, _____, _____ and _____ strokes.
4. State two factors which affect the boiling point of a liquid.
5. Density of water is maximum at _____ °C.
6. In diesel engines, carburetor is replaced by _____.
7. The expansion of water on cooling below 4°C is called _____.
8. Calorimeter works on the principle of _____.
9. Define heat capacity and specific heat capacity.
10. What is fog or mist?
11. The specific latent heat of fusion of ice is _____ J kg⁻¹ K⁻¹ or _____ cal g⁻¹.
12. State the principle of mixtures.
13. Define evaporation.
14. The latent heat of vaporisation of a unit mass of a liquid is called its _____.
15. Define the following:
 - (i) melting or fusion
 - (ii) freezing
 - (iii) boiling
 - (iv) condensation
16. What is an internal combustion engine?
17. How much heat is absorbed when 10 g of ice at 0°C is completely converted to water at 0°C?
18. Define latent heat.
19. State the principle on which a refrigerator works.
20. 1 g of steam at 100°C cools to form water at 80°C. The amount of heat liberated is _____.
(Total heat released = Q + H)
21. Define latent heat of fusion and specific latent heat of fusion of ice.
22. The amount of heat required to raise the temperature of unit mass of a substance by one kelvin is called _____.
23. What is a heat engine and name two types of heat engines?
24. Define latent heat of vapourization and specific latent heat of vapourization of water.
25. What is sublimation?
26. The direction of heat flow between two bodies is determined by _____.
27. State two factors which affect the melting point of a solid.
28. Define the efficiency of heat engine.
29. The temperature at which the given volume of air becomes saturated with water vapour without actually increasing the vapour content in it is called _____.
30. Define regelation.

Short Answer Type Questions

31. Give a few examples and some practical applications of high specific heat of vapourization of water.
32. A body of mass 1 kg absorbs 4 kJ of heat when its temperature rises from 30°C to 40°C. Calculate its specific heat capacity.
33. Explain sublimation.
34. State a few disadvantages of steam engine.
35. Give some natural consequences and a few practical applications of high specific heat capacity of water.
36. 1 kg of ice at 0°C is converted into steam at 100°C. Calculate the heat required
Specific heat of fusion of ice = $336 \times 10^3 \text{ J kg}^{-1}$
Specific heat of vaporization of water = $2260 \times 10^3 \text{ J kg}^{-1}$
Specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1}$
37. Differentiate between evaporation and boiling.
38. Explain the working of a refrigerator.
39. Describe a calorimeter.
40. An electric heater of power 500 W is used to raise the temperature of a liquid from 30°C to 40°C in 2 minutes. Find the heat capacity of the liquid.
41. Explain the formation of dew.



42. 10000 J heat is required to raise the temperature of a metal ball by 20 K. Calculate its heat capacity.
43. Mention few natural consequences, and some practical applications of high specific latent heat of fusion of ice.
44. State a few advantages of an internal combustion engine.
45. Mention a few consequences of anomalous behaviour of water.

Essay Type Questions

46. Describe an experiment to determine specific latent heat of fusion of ice by the method of mixtures.
47. Explain the experiment to find the boiling point of water. Also explain its heating and cooling curves.
48. Describe an experiment to determine the specific heat capacity of a given solid by the method of mixtures.
49. Describe the method to determine specific latent heat of vaporization of water using a calorimeter.
50. Describe an experiment to measure the melting point of naphthalene. Draw heating and cooling curves and explain them.

CONCEPT APPLICATION

Level 1

Directions for questions 1 to 7:

Select whether the following statements are true or false.

- Due to anomalous behaviour of water, volume of ice is more than that of the same mass of water.
- When common salt is added to water, the boiling point of water increases.
- Heat required to change the state of substance at constant temperature is called latent heat.
- Refrigerator is a device which works on the principle that evaporation of a liquid gives cooling effect.
- The specific heat capacity of water is $4200 \text{ J kg}^{-1} \text{ K}^{-1}$.
- The rate of evaporation of a given liquid depends only on the surface area of the liquid exposed to air.
- The SI units of heat and work are the same.

Directions for questions 8 to 14:

Fill in the blanks

- _____ is used as a coolant in car radiators, nuclear plants and in industries.
- The process that is involved when a substance changes to gas directly from solid state without changing to liquid state is called _____.
- The dimensional formula of heat is _____.
- Heat absorbed or lost by a substance is proportional to _____ and _____.
- Boiling is a _____ process where as evaporation is a _____ process in respect with the speed of the process.

- The device which is used to measure specific heat capacity of solids and liquids is _____.
- Calorimeter is highly polished from inside and outside to prevent heat loss by _____.

Direction for question 15:

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

15.

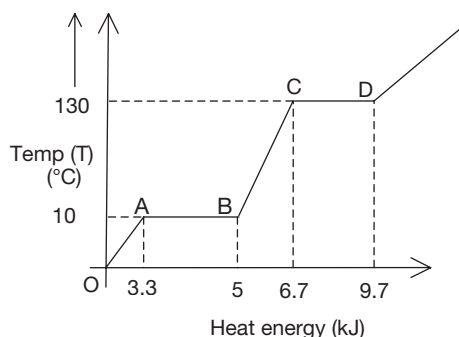
Column A		Column B	
A.	Water equivalent	() (a)	Conversion from solid state to gaseous state directly
B.	High specific heat capacity	() (b)	Heat lost by hot body = heat gained by the cold body.
C.	Bomb calorimeter	() (c)	$\frac{\text{work output (or) heat utilised}}{\text{heat produced}}$
D.	Principle of calorimeter	() (d)	Liquid converts to gas
E.	Evaporation	() (e)	$226 \times 10^4 \text{ J kg}^{-1}$.
F.	Latent heat of vaporization of pure water	() (f)	Burns caused by steam.
G.	Sublimation	() (g)	Petrol engine
H.	Thermal efficiency	() (h)	Water
I.	Scalding	() (i)	Calorific values
J.	Carburettor	() (j)	gram (or) kilogram



Direction for questions 16 to 40:

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

16. In a device, the complete conversion of heat energy into mechanical work _____.
 (a) is not possible at any cost
 (b) depends on type of device in use
 (c) depends on the atmospheric temperature, pressure, etc
 (d) depends on the type of fuel used
17. If water is converted into ice and maintained at 0°C , which of the following statements is true for the molecules of the substance?
 (a) Only kinetic energy decreases
 (b) Only potential energy decreases
 (c) Both the energies increase
 (d) Potential energy increases and kinetic energy decreases
18. Steam engine is not extensively used because
 (a) it is bulky.
 (b) it takes long time to generate the steam.
 (c) high pressure of steam may burst the boiler which is dangerous.
 (d) All the above
19. The specific heat capacity of a substance depends on its
 (a) nature (b) mass
 (c) rise in temperature (d) Both (b) and (c)
20. Study the adjacent graph drawn between the amount of heat energy supplied to 500 g of a substance and its rise in temperature. Identify the correct option.



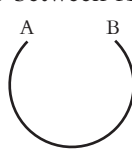
- (a) The melting point of the given substance is 10°C .
 (b) The latent heat of fusion of the given substance is 2300 J.
 (c) The boiling point of the substance 130°C .
 (d) All the above.

21. Sea water and river water are heated to their boiling points. Then
 (a) river water boils at lower temperature.
 (b) sea water boils at lower temperature.
 (c) both boil at the same temperature.
 (d) Cannot be said.
22. The food cooks faster in pressure cooker since
 (a) the pressure exerted by water vapour enclosed in the cooker increases the boiling point of water.
 (b) the pressure exerted by the water vapour enclosed in the cooker decreases the boiling point of water.
 (c) the water vapour pressure does not influence the boiling point of the water.
 (d) there is no loss of heat to the surrounding as the pressure cooker is airtight.
23. During change of state, which of the following is true for molecules of a substance?
 (a) Kinetic energy increases
 (b) Potential energy increases
 (c) Both increase
 (d) Both remain constant
24. At 40°C , the actual amount of water vapour present in 1 m^3 of air is 45 g. If the temperature decreases to 30°C , then amount of water vapour that condenses is _____ g.
 [Take the mass of water vapour present in 1 m^3 of saturated air at 30°C as 30 g].
 (a) 75 (b) 10
 (c) 25 (d) 15

25. In thermal power stations, steam is preferred to convert heat to electric energy because
 (a) steam is good conductor of heat.
 (b) steam is good conductor of electricity.
 (c) steam can flow quickly.
 (d) every gram of steam can give 2260 J of heat.
26. A hot body at temperature θ_1 is mixed with a cold body at temperature θ_2 both having the same heat capacity, such that the rise in temperature of the cold body is equal to the fall in temperature of the hot body. The resultant temperature θ is

- (a) $\frac{\theta_1 - \theta_2}{2}$ (b) $\theta_1 + \theta_2$
 (c) $\frac{\theta_1 + \theta_2}{2}$ (d) $\theta_1 - \theta_2$

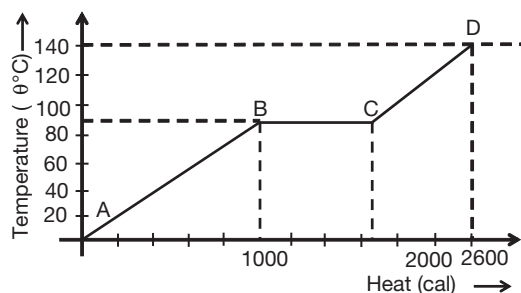


27. Snow balls are formed due to
 (a) melting of ice
 (b) freezing of atmospheric moisture
 (c) regelation
 (d) sublimation
28. A substance of mass m_1 with specific heat capacity s_1 and initial temperature θ_1 is mixed with another substance of mass m_2 , specific heat capacity s_2 and initial temperature θ_2 , respectively. Then, their equilibrium temperature is _____ (take $\theta_1 > \theta_2$)
- (a) $\frac{m_1 s_1 \theta_1 + m_2 s_2 \theta_2}{m_1 s_1 + m_2 s_2}$
 (b) $\frac{m_1 s_1 \theta_1 + m_2 s_2 \theta_2}{m_1 s_1 + m_2 s_2}$
 (c) $\frac{m_2 s_2 \theta_2 + m_1 s_1 \theta_1}{m_1 + m_2}$
 (d) $\frac{m_1 s_1 \theta_1 + m_2 s_2 \theta_2}{m_1 s_1 + m_2 s_2}$
29. Heat gained by 1 g of water when heated from 0°C to 100°C is
 (Specific heat capacity of water = $1 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$)
 (a) 4200 cal. (b) 4.2 cal.
 (c) 100 cal. (d) 1 cal.
30. Two bodies of masses 50 g and 100 g, have their water equivalents as 10 g and 20 g, respectively. The values of their specific heat capacities are _____ $\text{cal g}^{-1} ^\circ\text{C}^{-1}$ and _____ $\text{cal g}^{-1} ^\circ\text{C}^{-1}$.
- (a) $\frac{1}{5}$ and $\frac{1}{5}$ (b) $\frac{1}{3}$ and $\frac{1}{3}$
 (c) $\frac{11}{5}$ and $\frac{11}{5}$ (d) $\frac{1}{2}$ and $\frac{1}{2}$
31. Arrange the following steps in the proper order to explain how a sea breeze occurs, near coastal regions.
 (a) The temperature of land rises rapidly as compared to sea, because the specific heat capacity of land is five times less than that of water.
 (b) Due to the low pressure over the land mass, the cool air over the sea starts blowing towards the land.
- (c) The sun shines equally on the land mass and sea, giving equal amount of heat energy to both.
 (d) The air above the land becomes hot and light, rises up, and hence creates the low pressure over the land.
 (a) a d c b (b) c d a b
 (c) c a b d (d) c a d b
32. Linear expansion of a substance depends upon its
 (a) initial length.
 (b) Change in temperature.
 (c) nature of the material.
 (d) All the above.
33. The area of cross-sections of three metal rods of the equal length and made of the same materials are A_1 , A_2 and A_3 , respectively. When heated through the same change in temperature, their linear expansions are found to be l_1 , l_2 and l_3 , respectively. Which among the following is the correct relation between l_1 , l_2 and l_3 ?
 (a) $l_1 = l_2 = l_3$
 (b) $l_1 > l_2 > l_3$
 (c) $l_1 < l_2 < l_3$
 (d) $l_1 = l_2 < l_3$
34. The coefficient of linear expansion α of steel is $11 \times 10^{-6} ^\circ\text{C}^{-1}$. Then α _____ $\times 10^{-6} ^\circ\text{F}^{-1}$
 (a) 6.11 (b) 19.8
 (c) 11 (d) 43.
35. A copper wire is bent as shown in the figure. When its temperature is increased, the distance between A and B _____.
 (a) decreases
 (b) increases
 (c) remains same
 (d) increases or decreases depending up on its initial temperature.
- 
36. The coefficient of linear expansion α is _____ that of the coefficient of areal expansion.
 (a) double of (b) triple of
 (c) half of (d) equal to
37. The coefficient of linear and areal expansion cannot be defined for liquids, as liquids do not have a definite _____.
 (a) volume (b) shape
 (c) density (d) specific heat capacity

38. Anomalous behaviour of water can be demonstrated with the help of Hope's apparatus. Arrange the following steps of changes taking place in Hope's apparatus in the proper sequence.
- The temperature shown by the lower thermometer reaches to 4°C and remains constant at 4°C .
 - Water freezes into ice at 0°C , and the layer of ice is formed at the top surface because the density of ice is less than that of water.
 - The initial temperature of water is maintained at 10°C . The temperature of water begins to fall due to the freezing mixture at the centre and it contracts.
 - As temperature of water falls below 4°C , water expands instead of contracting and its density decreases. So, water goes up from the centre portion.
 - As density increases, the cold water goes to the bottom. The temperature shown by the lower thermometer falls.
 - The temperature of water at the top of the vessel begins to fall till 0°C as shown by the upper thermometer.
 - Being a bad conductor of heat, ice prevents the loss of heat from water below it into the surroundings.
- c e b f a g d
 - c e a d f b g
 - c e a f d g b
 - c b e g d a f
39. A pendulum clock takes exactly 2 s to perform one oscillation at 20°C . If the pendulum clock is made of copper, then the pendulum _____ at 40°C .
- gains the time
 - loses the time
 - does not oscillate
 - brakes
40. Steam is used in external combustion engine as working medium because of its
- high specific heat capacity.
 - high thermal capacity.
 - high latent heat of vaporization.
 - low liquefaction point (B.P).

Level 2

41. A copper calorimeter of mass 100 g contains 200 g of ice at a temperature of -10°C . Heat is supplied to the system containing calorimeter and ice at a constant rate of 50 cal s^{-1} . Find the time required to raise the temperature of the system to 50°C . [Neglect the loss of heat to the surroundings.] Take specific heat capacity of copper and ice as $0.2\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$ and $0.5\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$. Take latent heat of fusion of ice as 80 cal g^{-1} and specific heat capacity of water as $1\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$.
42. The atmospheric temperature varies over a wide range but human body temperature is more or less constant at 37°C . Explain.
43. What happens when a thermos flask containing liquid is vigorously shaken? Will there be any change in the temperature of the liquid?
44. The graph below shows the rise in temperature of a solid of specific heat capacity $0.5\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$ and the heat supplied to it. Find its mass and specific latent heat of fusion.



Also find the specific heat capacity of the body in its liquid state.

45. A bullet of 50 g is fired from a revolver with a velocity of 100 m s^{-1} into an ice block at 0°C . The bullet stops after it gets embedded into ice. Assuming that all the kinetic energy of the bullet is converted into heat energy which is absorbed by the melting ice, find the quantity of the ice that just melts.
46. A diesel engine does not contain a spark plug. Then, how does ignition takes place in it? Explain.



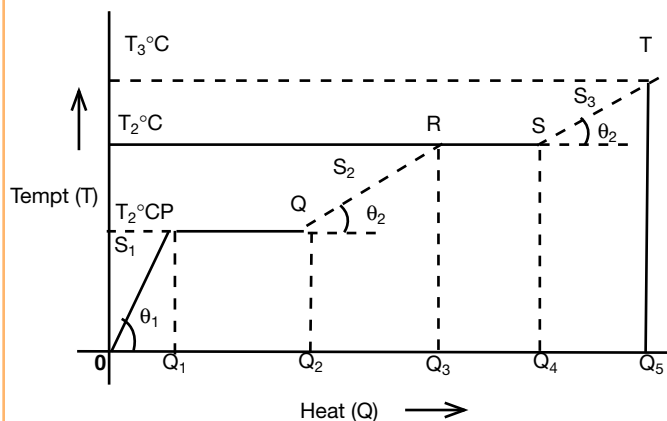
47. How much energy in watt-hour is required for an electric heater to convert 2 kg of ice at 0°C to water at 25°C . Assume the water equivalent of the given heater to be 10 g. (Assume that initially the heater and the ice are in thermal equilibrium).
48. When heat is supplied at constant rate, ice of mass 200 g at 0°C is converted to water at 0°C in 8 minutes. Calculate the time taken to raise the temperature of resulting water to 100°C . (Take latent heat of fusion of ice = $336 \text{ J g}^{-1}^{\circ}\text{C}^{-1}$ and specific heat capacity of water = $4.2 \text{ J g}^{-1}^{\circ}\text{C}^{-1}$).
49. The initial temperature of half a litre of water is 20°C . On supplying heat to it, its temperature rises to 72°F . For every 1°C rise in temperature per gram of water, 4.2 J of heat is needed. Calculate the heat capacity of water.
50. When 40 g of ice at 0°C is added to 160 g of water at 40°C , find the final temperature.
51. Two identical calorimeters 'X' and 'Y', of water equivalent 10 g each, contain equal quantities of same liquid. The mass, initial temperature and specific heat capacity of the liquid present in the two calorimeters are 50 g, 25°C $0.5 \text{ cal g}^{-1}^{\circ}\text{C}^{-1}$, respectively. A 10 g metal piece (say A) of specific heat capacity $0.4 \text{ cal g}^{-1}^{\circ}\text{C}^{-1}$ is dropped in calorimeter 'X' and 25 g of metal piece (say B) of specific heat capacity ' S_B ' is dropped into calorimeter 'Y'. Due to this, the equilibrium temperature in 'X' and 'Y' rises to 30°C and 40°C , respectively. If the initial temperature of 'B' is twice that of 'A', then find the value of ' S_B '.
52. Calculate the mass of steam at 100°C which is needed to just melt 320 g of ice at -10°C . Take specific heat of ice = $0.5 \text{ cal g}^{-1}^{\circ}\text{C}^{-1}$, specific latent heat of vaporization of steam = 540 cal g^{-1} , specific latent heat of fusion of ice = 80 cal g^{-1} .
53. A thermally insulated container has 500 g of mercury in liquid state at its freezing point. The container is connected to a vacuum pump and air above the liquid (mercury) is pumped out of the container. Due to this, some of the liquid evaporates and the remaining liquid solidifies. Then find the mass of the solid that is found by solidification of liquid. Take specific latent heat of fusion, $L_F = 12500 \text{ J kg}^{-1}$ and specific Latent heat of vaporization, $L_V = 290000 \text{ J kg}^{-1}$.
54. 100 g of water at 70°C is added to 120 g of water at 30°C contained in a vessel. The final temperature of mixture is 40°C . Calculate the thermal capacity of the vessel.
55. A mercury thermometer whose markings are in centimeter scale, is used to measure the temperature. It shows 3 cm and 15 cm when kept in melting ice and boiling water, respectively. Find the equilibrium temperature, as recorded by the above thermometer when 10 g of iron ball at 229°C is dropped into 50 g of water at 25°C . Here, the water equivalent of the container is negligible and heat lost to the surroundings is almost zero. (Take specific heat capacity of iron and water as $0.1 \text{ cal g}^{-1}^{\circ}\text{C}^{-1}$ and $1 \text{ cal g}^{-1}^{\circ}\text{C}^{-1}$, respectively)
56. If 1050 J of heat is required to increase the temperature of 15 kg of substance from 25°C to 35°C , find the thermal capacity and water equivalent of the substance.
57. Water falls from a height of 100 m. Find the rise in temperature of the water, when it reaches the bottom, assuming all its energy is converted to heat at the bottom of the water fall. ($g = 10 \text{ m s}^{-2}$, $sw = 4200 \text{ J kg}^{-1} \text{ K}^{-1}$)
58. When some water drops are sprinkled on a hot bulb, why does the bulb break?
59. Why is it that the RCC (cement) slabs on the houses are laid at one stretch?
60. A physicist took a circular metallic sheet of radius 4 cm at a temperature of 27°C . He Heated metallic sheet up to 127°C and found that the diameter of the sheet increased to 8.2 cm, then what is the

Level 3

61. A closed vessel is partly filled with water and connected to a vacuum pump. With help of this vacuum pump, if the pressure inside the vessel is maintained at low level, discuss the effect on water considering various conditions.
62. Three liquids A, B and C of densities in the ratio of 1 : 2 : 3, respectively are taken. Their initial temperatures are 60°C , 50°C and 30°C , respectively. When equal parts (by volumes) of 'A' and 'B' are mixed, the resultant temperature of the mixture is 55°C . When equal parts (by weights) of A and C are mixed, then the equilibrium temperature of the mixture is 40°C . Find the ratio of specific heat capacity of the liquids.



63. The intensity of sunlight incident on a block of ice is 800 W m^{-2} . If ice absorbs 60% of the light, calculate the thickness of ice that would melt in 1 minute (density of ice = 917 kg m^{-3}).
64. Why is that the hot water is preferred to cold water to put off the fire?
65. Prove that when ' x ' grams of steam at 100°C is mixed with ' y ' grams of ice at 0°C and allowed to attain thermal equilibrium, the final temperature of mixture is $\theta = \frac{80(8x - y)}{x - y}$.
68. A substance of mass m_1 with specific heat capacity s_1 and initial temperature θ_1 is mixed with another substance of mass m_2 , specific heat capacity s_2 and initial temperature θ_2 respectively. Then, determine their equilibrium temperature. (take $\theta_1 > \theta_2$)
67. If the length of a steel rod is 100 cm at 0°C , then what should be the original length of a copper rod at 0°C if the difference in their lengths is exactly equal to 5 cm at 100°C .
(α for copper = $1.7 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ and α for steel = $1.1 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$)
68. A pendulum clock takes exactly 2 s to perform one oscillation at 0°C . If the pendulum clock is made up of brass alloy whose ' α ' is $0.00002^\circ\text{C}^{-1}$, then how many seconds will the pendulum lose in one day at 30°C .
69. An alloy (in liquid state) of mass 100 g and at 242°C is transferred into a copper calorimeter of water equivalent 40 g containing 200 g of water. When the equilibrium is reached, the temperature of calorimeter and water rises from 12.1°C to 22.1°C . Now, when the experiment is repeated with the given alloy in the solid state, at the same temperature of 242°C , by dropping it in the calorimeter, the equilibrium temperature was found to be 14°C . Find the latent heat of fusion of the given alloy.
70. The graph below shows the different stages of conversion of given substance from its solid state to vapour state. Compare the specific heat capacities of the given substance in the solid (S_1), liquid (S_2) and gaseous (S_3) states. Here, $\theta_3 < \theta_2 < \theta_1$.



CONCET APPLICATION

Level 1

True or false

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

Fill in the blanks

8. water 9. sublimation 10. $[ML^2T^{-2}]$ 11. Mass, Change in temperature
12. quick; slow 13. calorimeter 14. Radiation

Match the following

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

Multiple choice questions

16. (a) 17. (b) 18. (d) 19. (a) 20. (d) 21. (a) 22. (a) 23. (b) 24. (d) 25. (d)
26. (a) 27. (c) 28. (d) 29. (c) 30. (a) 31. (d) 32. (d) 33. (a) 34. (a) 35. (b)
36. (c) 37. (b) 38. (b) 39. (b) 40. (c)

Explanation for questions 31 to 40

31. Near the coastal regions, when (c) the sun shines equally on the land mass as well as the sea giving an equal amount of heat energy. But, (a) the temperature of land rises rapidly as compared to the sea water, as the specific heat capacity of water is five times greater than that of land. So, water requires more heat energy to raise its temperature by 1°C . Then (d) the air above the land mass becomes hotter and lighter, and hence rises up, which creates a low pressure over the land. (b) Due to the low pressure over the land mass, the cool air over the sea starts blowing towards the land, by this producing sea breeze.

32. The linear expansion of a metal rod of initial length l_0 is $\Delta l = \alpha l_0 \Delta t$. Linear expansion of a substance depends upon the original length, change in temperature and nature of the material.

33. Linear expansion of all the three are same their original length and change in temperature and the material are the same.

34. $\alpha = 11 \times 10^{-6} ^\circ\text{C}^{-1}$

$$= \frac{11 \times 10^{-6}}{1.8^\circ\text{F}} = 6.11 \times 10^{-6} ^\circ\text{F}^{-1}$$

35. The distance between A and B increases when the temperature is increased.

36. The coefficient of linear expansion ' α ' is half of the coefficient of areal expansion.

37. The coefficient of linear and areal expansion cannot be defined for liquids, as liquids do not have a definite shape.

38. (c) Initial temperature of water in the vessel is maintained at 10°C . Due to freezing at the centre, the temperature of water begins to fall. The water contracts and its density increases. (e) As the density of water increases, the cold water goes to the bottom of the vessel and the temperature of water falls to 4°C (a) as shown by the lower thermometer and this remains constant. (d) The temperature of water at the centre falls below 4°C , then the water expands instead of contracting, so, that its density decreases, therefore, the water below 4°C goes to the upper portion (f) The temperature of water falls till 0°C , as shown by the upper thermometer. (b) Water at 0°C freezes into ice and a layer of ice is formed at the top surface, because the density of ice is less than that of water. (g) Being a bad conductor of heat, ice prevents the loss of heat from water below it to the surroundings.



39. When the temperature increases, the length of the pendulum also increases, and hence its time period increases. Thus, it loses time when temperature is increased.
40. Steam at 100°C can carry 540 cal of more heat energy per gram than the water at 100°C . It is possible because water is having high latent heat of vaporization.

Level 2

41. (i) The heat energy required by the system (containing both calorimeter and ice) to raise its temperature from -10°C to 0°C is

$$Q_1 = m_c s_c (10) + m_i s_i (10)$$
 Substitute, mass of calorimeter, m_c mass of ice, m_i and specific heat capacities of calorimeter and ice and find Q_1
 Find the heat energy absorbed by ice to convert into water at $0^\circ\text{C} = Q_2 = mL_F$
 Substitute for latent heat of fusion, L_F and mass m of ice
 Let the heat energy absorbed by the water and calorimeter to increase its temperature from 0°C to $50^\circ\text{C} = Q_3$.

$$Q_3 = m_w s_w (50) + m_c s_c (50)$$
 The total heat supplied = $Q = Q_1 + Q_2 + Q_3$
 The rate of heat supplied to the system = $R = 50 \text{ cal s}^{-1}$
 Time (t) taken by the system, $t = \frac{Q}{R}$
- (ii) 9.4 minute
42. (i) Define specific heat capacity.
 (ii) What is the major constituent of human body and what is its specific heat capacity?
 (iii) What is the consequence of this specific heat capacity on the temperature of human body?
43. When the thermos flask is shaken, work is done on the molecules of the liquid in the flask. By the work-energy theorem, work done is equal to change in energy.
44. (i) Observe the graph carefully and note the quantities represented on X and Y axes.
 (ii) From the graph and using $Q = ms\Delta\theta_R$, find mass (m) of the solid.
 (iii) Find L using the graph and $Q = mL$.
 (iv) From the graph, find the specific heat capacity of liquid using $Q = ms \Delta\theta_R$.
 (v) $0.75 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$
45. (i) The loss of kinetic energy of the bullet

$$= \frac{1}{2}mu^2 - \frac{1}{2}mv^2$$
 Here, $v = 0 \text{ m s}^{-1}$ and $u = 100 \text{ m s}^{-1}$

$$m = \text{mass of the bullet} = \frac{50}{1000} \text{ kg}$$
 We know, $W = JQ$
 Mechanical equivalent of work
 Here, $J = 4.2 \text{ J cal}^{-1}$

$$Q = \frac{\frac{1}{2}mu^2}{4.2} \text{ cal} \quad (1)$$
 Now, this heat energy (Q) is used to melt the ice at $0^\circ\text{C} \Rightarrow Q = mL_F$ (2)
 Find the value of ' m ' from (2)

$$m = \frac{Q}{L_F}$$
 Take the value of $L_F = 80 \text{ cal g}^{-1}$
- (ii) 0.744 g
46. (i) What is the use of a spark plug?
 (ii) How is the temperature of air affected when it is highly compressed?
 (iii) What would happen if diesel is brought in contact of this air?
47. (i) Heat Q supplied to melt the ice at 0°C to water at $0^\circ\text{C} = mL_F$.
 Here L_F = latent heat of fusion of ice.
 Heat supplied to increase the temperature from 0°C to $25^\circ\text{C} = ms\Delta t$
 Here, $\Delta t = 25 - 0 = 25^\circ\text{C}$
 s = specific heat capacity of water.
 m = mass of the substance.
 Take 1 watt hour = 3600 J
- (ii) 245.3 watt hour
48. (i) Use $Q = mL$ to find the heat absorbed by ice when it melts.
 (ii) This heat is supplied over 8 minutes. Find heat supplied per minute.



- (iii) Use $Q = ms\Delta\theta_R$ to find the heat required to raise the temperature of water from 0°C to 100°C .
- (iv) Use heat supplied per minute $\times$ time = heat gained by water, to find time (t).
- (v) 10 minutes

49. (i) Use:
heat capacity = mass of substance $\times$ heat required per gram to raise its temperature by 1°C .

(ii) $2100 \text{ J } ^\circ\text{C}^{-1}$

50. (i) Let θ be the resultant temperature of the mixture.
- (ii) Use $Q = mL$ to find heat absorbed by ice at 0°C to convert into water at 0°C .
- (iii) Use $Q = ms\Delta\theta_R$ to find heat absorbed by melted ice to attain the temperature $\theta^\circ\text{C}$.
- (iv) Use $Q = ms\Delta\theta_F$ to find heat lost by water to attain the temperature $\theta^\circ\text{C}$.
- (v) Add (ii) and (iii) and equate with (iv) to find θ .
- (vi) 16°C

51. (i) In calorimeter X:
Find the initial temperature of metal A by using the principle,
heat lost by metal A = heat gained by liquid and calorimeter X

$$\Rightarrow m_A \cdot s_A (\Delta t)_A = \{50 \text{ g} \times 0.5 \times (30 - 25) ^\circ\text{C} + (5^\circ\text{C} \times 10 \text{ g})\}$$

$$\Rightarrow 10 \times 0.4 \times (T - 30^\circ\text{C}) = (50 \times 0.5 \times 5 + 50 \text{ cal}) \quad (1)$$

In calorimeter Y,

Find the initial temperature of metal B (2T).

The heat lost by metal B = heat gained by (liquid + calorimeter).

$$\Rightarrow m_B \cdot S_B (2T - 40) = \{50 \text{ g} \times 0.5 \times (40 - 25) ^\circ\text{C}\} + (15 ^\circ\text{C} \times 25 \text{ g}) \quad (2)$$

(ii) $S_B = 0.2 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$

52. (i) Use $Q = ms\Delta\theta_R$ to find the heat absorbed by ice to raise its temperature from -10°C to 0°C .
- (ii) Use $Q = mL_{ice}$ to find heat absorbed by ice at 0°C to form water at 0°C .
- (iii) Add 1 and 2 to find total heat absorbed.
- (iv) Use $Q = mL_{vap}$ to find the heat lost by steam at 100°C when it condenses to water at 100°C .

(v) Use $Q = ms\Delta\theta_F$ to find the heat given when water at 100°C cools to 0°C .

(vi) Add 4 and 5 to find total heat given.

(vii) Equate 3 and 6 to find the mass of steam.

(viii) 42.5 g

53. (i) Let the total mass of the liquid = $M = 0.5 \text{ kg}$
Let, the mass of the liquid that is converted to solid = m

If L_v is the latent heat of vaporization and L_F latent heat of fusion, then $mL_F = (M - m)L_v$
Substitute the appropriate values and find the value of m .

(ii) 0.479 kg

54. (i) Use $Q_1 = ms\Delta\theta_F$ to find heat lost by hot water.

(ii) Use $Q_g = ms\Delta\theta_R$ to find heat gained by cold water.

(iii) If H_v is the heat capacity of the vessel, use $H_v\Delta\theta_R$ to find heat gained by it.
(H_v = mass of the vessel $\times$ specific heat capacity of the vessel)

(iv) Add (ii) and (iii) and equate with (i) to find the heat capacity of the vessel.

(v) $756 \text{ J } ^\circ\text{C}^{-1}$

55. (i) Let the equilibrium temperature of the ball and water after the ball is dropped in to water be T .
Apply the principle of mixtures (or) calorimetry:
Heat lost by the hot body = heat gained by the cold body.

$$m_b s_b (\Delta t)_b = m_w s_w (\Delta t)_w$$

$$\Rightarrow 10 \times 0.1 \times (22 \text{ g} - T) = 50 \times 1.$$

$$x (T - 25) \quad (1)$$

Find the value of T from (1).

To find the temperature in new scale, use the formula

$$\left(\frac{T - LFP}{UFP - LFP} \right)_{scale1} = \left(\frac{Length(x) - LFP}{UFP - LFP} \right)_{scale2} \quad (2)$$

$$= \left(\frac{T - 0}{100 - 0} \right) = \left(\frac{X - 3}{15 - 3} \right)$$

(ii) 6.48 cm



56. $Q = 1050 \text{ J}$

$m = 15 \text{ kg}$

$\Delta t = 10^\circ\text{C}$

$$s = \frac{Q}{m\Delta t} = \frac{1050}{15 \times 10} = 7 \times \text{J Kg}^{-1} \text{K}^{-1}$$

$$c = \frac{Q}{m\Delta t} = \frac{1050}{10}$$

$$= 105 \text{ J } ^\circ\text{C}^{-1}$$

$$M = c = \frac{105}{4200} \times 1000$$

$$= 25 \text{ g} = 0.025 \text{ kg}$$

57. $mgh = ms \Delta t$

$$10 \times 100 = s \times \Delta t$$

$$1000 = 4200 \Delta t$$

$$\Delta t = \frac{10}{42} = \Delta t \text{ } 0.238^\circ\text{C}$$

58. The bulb breaks due to the uneven thermal contraction.

59. RCC slab on houses as roofs are laid at a single stretch. By doing this, the slab behaves like a single plate and there will be a uniform expansion and

contraction for temperature changes. Because of this, the building roof does not develop any cracks.

60. Given initial radius $r_1 = 4 \text{ cm}$ at temperature $t_1 = 27^\circ\text{C}$,

$$\text{then } T_1 = t_1 + 27 \text{ K}$$

$$T_1 = 273 + 27$$

$$T_1 = 300 \text{ K Final diameter is } d_2 = 2r_2$$

$$\Rightarrow r_2 = \frac{d_2}{2}$$

$$\text{Given } d_2 = 8.2 \text{ cm}$$

$$\text{then } r_2 = 4 \text{ cm}$$

$$\text{And final temp } T_2 = t_2 + 273$$

$$= 127 + 273 = 400\text{K}$$

Now coefficient of areal expansion β .

$$= \frac{A_2 - A_1}{A_1(T_2 - T_1)} = \frac{[(4.1)^2 - (4)^2]}{16 (400 - 300)}$$

$$= \frac{0.81}{16 (100)}$$

$$= 0.05 \times 10^{-1} = 5 \times 10^{-4} \text{K}^{-1}$$

Level 3

61. Consider the following conditions:

1. temperature of water is above room temperature
2. temperature below room temperature
3. boiling point of water at low pressures.
4. heat losses/exchange to the surrounding.
5. insulation of the vessels.

62. (i) Find the ratio of the densities of A, B and C from given information.

$$\text{Here, density (d)} = \frac{\text{mass}(m)}{\text{volume}(v)} \text{ — (3.1)}$$

When equal volumes of A and B liquids are taken, then find the ratio of their densities. Use principle of mixtures (or) calorimetry and find the ratio of specific heats of A and B. Get the equilibrium temperature of A and C from the given data.

Again, heat lost by 'A' liquid = heat gained by 'C' liquid. $\Rightarrow m_A s_A (\Delta t)_A = m_C s_C (\Delta t)_C$

Given that $m_A = m_C$

Find the ratio of s_A and s_C

$$(ii) \quad 2 : 1 : 4$$

63. (i) From the given data find the heat absorbed (Q) by the ice block per unit area in 1 minute (60 seconds).

(ii) If A is the area of the block, total heat absorbed is QA.

(iii) If t is the thickness of the block, its volume = At and mass = 917At

$$\therefore \text{density of ice} = 917 \text{ kg m}^{-3} \text{ (given)}$$

(iv) Heat absorbed during melting of ice = mL_{ice}
 $= 917 \text{ At} \times 336000 \text{ J}$

$$(\because L_{ice} = 336000 \text{ J g}^{-1})$$

(v) Equate 4 and 2 to find 't'.

(vi) 0.09 m

64. (i) Which one gets converted into water vapour hot water or cold water?

(ii) Engulfed water vapour reduces the supply of oxygen.



65. (i) Let the resultant temperature be θ .
 (ii) Use $Q = mL_{vap}$ to find heat lost when steam at 100°C condenses to water at 100°C .
 (iii) Use $Q = ms\Delta\theta_F$ to find heat lost when water at 100°C cools to $\theta^\circ\text{C}$.
 (iv) Add 2 and 3 to find total heat lost.
 (v) Use $Q = mL_{ice}$ to find heat gained when ice at 0°C melts to form water at 0°C .
 (vi) Use $Q = ms\Delta\theta_R$ to find heat gained when water at 0°C heats to $\theta^\circ\text{C}$.
 (vii) Add 5 and 6 to find total heat gained.
 (viii) Equate 4 and 7 to find θ in the given form.

66. Given that, $\theta_1 > \theta_2$.

Then, heat lost by the first substance is equal to the heat gained by the second substance. Take, equilibrium temperature of the mixture as ' t '.

$$\Rightarrow m_1 s_1 (\theta_1 - t) = m_2 s_2 (t - \theta_2)$$

$$\Rightarrow m_1 s_1 \theta_1 - m_1 s_1 t = m_2 s_2 t - m_2 s_2 \theta_2$$

$$\Rightarrow t = \frac{m_1 s_1 \theta_1 + m_2 s_2 \theta_2}{m_1 s_1 + m_2 s_2}$$

67. Let the lengths of copper and steel rods at 0°C be ℓ_c and ℓ_s , respectively.

Then let the lengths of copper and steel rods at 100°C be ℓ'_c , ℓ'_s , respectively.

$$\text{We know } \ell_2 = \ell_1 [1 + \alpha(\Delta t)]$$

Here, Δt = rise in temperature

$$\Delta t = 100^\circ\text{C} - 0^\circ\text{C} = 100^\circ\text{C}$$

$$\begin{aligned} \Rightarrow \ell'_c &= \ell_c [1 + \alpha_c(100)] \\ &= \ell_c [1 + 1.7 \times 10^{-5} \times 100] \text{ cm} \\ &= \ell_c [1.0017] \text{ cm} \end{aligned}$$

$$\begin{aligned} \Rightarrow \ell'_s &= \ell_s [1 + \alpha_s(100)] \\ &= \ell_s [1 + 1.1 \times 10^{-5} \times 100] \text{ cm} \\ &= \ell_s [1.0011] \text{ cm} \end{aligned}$$

$$\text{Given } \ell_s = 100 \text{ cm}$$

$$\Rightarrow \ell'_s = (100 \times 1.0011) \text{ cm} = 100.11 \text{ cm}$$

$$\text{Given, } \ell'_c \sim \ell'_s = 5 \text{ cm}$$

$$\ell'_c = 100.11 + 5 \text{ cm} = 105.11 \text{ cm}$$

$$\text{Consider, } \Delta \ell_c = (\ell'_c - \ell_c) \text{ and } \Delta \ell_s = (\ell'_s - \ell_s)$$

$$\text{Given the value of } \alpha_c \text{ is greater than } \alpha_s, \ell'_c = \ell_c + 100 \times 1.7 \times 10^{-5}$$

$$\Rightarrow \ell_c = 105.11 - 0.0017 = 105.1083 \text{ cm}$$

$$\text{The length of cu rod at } 0^\circ\text{C is, } \ell_c = 105.1083 \text{ cm}$$

68. The time period of pendulum clock at $0^\circ\text{C} = T_0 = 2 \text{ s}$

$$\text{Let the length of the pendulum at } 0^\circ\text{C be } = L_0$$

$$\text{The time period of pendulum clock at } 30^\circ\text{C} = T_{30}$$

$$\text{Let the length of the pendulum at } 30^\circ\text{C be } = L_{30}$$

$$\text{We know, } L_2 = L_1 [1 + \alpha t]$$

$$\text{Given, } \alpha = 0.00002^\circ\text{C}^{-1}$$

$$t = (30^\circ\text{C} - 0^\circ\text{C}) = 30^\circ\text{C}$$

$$\begin{aligned} L_{30} &= L_0 [1 + \alpha(30^\circ\text{C})] \\ &= L_0 [1 + 0.00002 \times 30] = L_0 [1.00006] \end{aligned}$$

$$\text{We know, } T = 2\pi\sqrt{\frac{\ell}{g}}$$

Consider

$$\frac{T_0}{T_{30}} = \frac{2\pi\sqrt{\frac{L_0}{g}}}{2\pi\sqrt{\frac{L_{30}}{g}}}$$

$$\Rightarrow \frac{T_0}{T_{30}} = \sqrt{\frac{L_0}{L_{30}}}$$

$$\frac{2s}{T_{30}} = \sqrt{\frac{L_0}{L_0(1.00006)}}$$

$$\Rightarrow T_{30} = 2 \times \sqrt{1.00006} \approx 2 \times 1.00003$$

$$T_{30} \approx 2.00006 \text{ s}$$

The difference in time (or) extra time the pendulum takes to perform one Oscillation is $= (2.00006 - 2.0) \text{ s} = 0.00006 \text{ s}$

The number of Oscillations performed by seconds

$$\text{pendulum in 24 h} = \left(\frac{24 \times 60 \times 60}{2} \right)$$

Then for one day, the extra time would be

$$\frac{24 \times 60 \times 60}{2} \times 0.00006$$

$$= 25.92 \text{ s} \approx 26 \text{ s}$$

So, the lose in time $= 26 \text{ s}$

69. The given alloy is in the liquid and solid state at the same temperature of 242°C . This shows that 242° is the freezing or the melting point of the alloy. When the alloy in the solid state is immersed in water in a calorimeter, the temperature of the alloy falls down as it loses heat energy to the water and calorimeter.



Heat lost by the alloy in solid form = Heat gained by (1)
(water + calorimeter)

Now, heat lost by the alloy = $m \times s \times \Delta\theta$

Where $m = 100$ g, $s = ?$, $\Delta\theta = (242 - 14)^\circ\text{C}$

Heat lost by alloy = $100 \times s \times 228$. (2)

Heat gained by (water + calorimeter) = $m \times s \times \Delta\theta$

Substitute $m = (40 + 200) = 240$ g,

$S = 1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$, $\Delta\theta = (14 - 12.1) = 1.9 \text{ }^\circ\text{C}$

Heat gained by (water + calorimeter)

= $240 \times 1 \times 1.9$ (3)

Equating (2) and (3), we get

$100 \times s \times 228 = 240 \times 1 \times 1.9$

$$s = \frac{240 \times 1 \times 1.9}{100 \times 228}$$

$$s = 0.02 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}.$$

When the alloy in the liquid stage is immersed in water in calorimeter, it is at its freezing point.

Heat lost by alloy = $(m L_F) + (m \times s \times \Delta\theta)$.

Substitute $m = 100$ g, $L_F = ?$, $s = 0.02 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$

$\Delta\theta = (242 - 22.1) = 219.9 \text{ }^\circ\text{C}$

Heat lost by the alloy = $100 L_F + 100 \times 0.02 \times 219.9$
(4)

Substitute $m = 240$ g, $s = 1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$,
 $\Delta\theta Q = 22.1 - 12.1 = 10 \text{ }^\circ\text{C}$.

Heat gained by water + calorimeter = $m \times s \times \Delta\theta$
= $240 \times 1 \times 10 = 2400$ (5)

Equating (4) and (5)

$100 L_F + (100 \times 0.02 \times 219.9) = 2400$

$L_F + 0.02 \times 219.9 = 24$

$L_F = 24 - 4.398$

$L_F = 19.602 \text{ cal g}^{-1}$.

70. We know from co-ordinate geometry,

$$(i) \text{ slope of } (OP) \tan\theta_1 = \frac{T_1 - 0}{(Q_1 - 0)}$$

$$= \frac{T_1}{ms_1(T_1 - 0)} = \frac{1}{ms_1}$$

(ii) Slope of PQ = $\tan 0^\circ = 0$. When solid converts liquid, the heat energy supplied to the substance is $Q = Q_2 - Q_1$.

Here, $Q = mL_F$ and L_F is latent heat of fusion.

(iii) Slope of QR = $\tan \theta_2$

$$= \frac{T_2 - T_1}{mS_2(T_2 - T_1)} = \frac{1}{ms_2}$$

(iv) Slope of RS = $\tan 0^\circ = 0$

Here, the liquid converts to gaseous state. The heat energy supplied is $Q_4 - Q_3 = mL_V$. Here L_V is latent heat of vaporization.

$$(v) \text{ Slope of } ST = \tan\theta_3 = \frac{T_3 - T_2}{Q_5 - Q_4}$$

$$= \frac{(T_3 - T_2)}{ms_3(T_3 - T_2)} = \frac{1}{ms_3}$$

Given that, $\theta_1 > \theta_2 > \theta_3$

$$\Rightarrow \frac{1}{ms_1} > \frac{1}{ms_2} > \frac{1}{ms_3}$$

$$\Rightarrow s_1 < s_2 < s_3$$



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Chapter 4

Light



Remember

Before beginning this chapter, you should be able to:

- Study application of rectilinear propagation of light like the formation of shadows, working of pinhole camera, etc.
- Explain the phenomenon of refraction with the help of different examples
- Understand the formation of rainbow, different colours of objects, etc.
- Understand the principle involved in the working of different optical instruments

Key Ideas

After completing this chapter, you should be able to:

- Study reflection of light by plane mirrors and spherical mirrors
- Study refraction through glass slab, prism, refractive index, total internal reflection, and critical angle
- Learn refraction through lenses, and cause of dispersion
- Study the basic terms related to visual photometry, laser and its working, construction and working of cameras, microscopes, telescopes, projectors, etc.

INTRODUCTION

Nature around us is colourful and diverse. It is impossible to enjoy nature without light. Light causes sensation of sight. Investigation of nature of light has opened a treasure of knowledge and development.

NATURE OF LIGHT

Light is a form of electromagnetic radiation and a non-mechanical wave. Non-mechanical waves do not require a material as a medium for propagation. Light exhibits dual nature, i.e., both particle nature as well as wave nature, and some phenomena of light can be explained by considering light as a wave (interference, diffraction and polarization) while other phenomena like, photo-electric effect, etc., can be explained by treating light as a particle.

Light travels at a speed of nearly $3 \times 10^8 \text{ m s}^{-1}$ in air or vacuum. Wavelength of visible light is 400 nm to 800 nm ($4000 \text{ \AA} - 8000 \text{ \AA}$) and the corresponding frequency is $7.5 \times 10^{14} \text{ Hz}$ to $3.75 \times 10^{14} \text{ Hz}$.

Light travels along a straight line and this property is called the rectilinear propagation. This straight line is called a ray, and a bundle of rays is called a beam of light.

When light is incident on a surface, a part of it is reflected, a part of it is refracted and the remaining part is absorbed. Light is reflected by highly polished surfaces (mirrors) and it is refracted partially by transparent media.

Light rays can be focused using mirrors and lenses. If light rays meet at a point after reflection or refraction by a mirror or through a lens respectively, an image is obtained on a screen. These images are called real images.

Thus, real images are formed when the rays after reflection or refraction meet at a point. If the rays appear to meet when produced backwards, then the image formed is virtual. The real image can be caught on a screen but the virtual image cannot be formed on a screen.

Reflection of Light

When light is incident on a surface, separating two media, a part of the light is bounced back to the first medium. This is known as reflection.

AB is the surface, PQ is the incident ray and QR is the reflected ray.

$\angle i$ = angle of incidence

$\angle r$ = angle of reflection

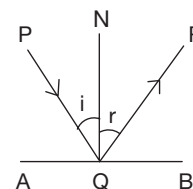


FIGURE 4.1 Reflection of a light ray incident on a plane mirror

LAWS OF REFLECTION

1. The incident ray, the reflected ray and the normal to the reflecting surface at the point of incidence lie in the same plane.
2. The angle of incidence is equal to the angle of reflection ($\angle i = \angle r$).

Reflection by a Plane Mirror

An object AB is placed at a distance ' u ' on one side of the plane mirror. Each point of AB acts as a source. To find the distance and nature of the image, consider a ray AC incident along the normal and another ray AO incident on the mirror at an angle ' i '. The ray AC retraces its path since it is incident along the normal. But the ray AO is reflected along OD at an angle ' r '. The two reflected rays are produced backwards and they intersect at A^1 . Similarly B^1 is the virtual image of point B . Every point of the object will form the corresponding image between A^1 and B^1 . Thus, A^1B^1 is the virtual, erect image of the object AB .

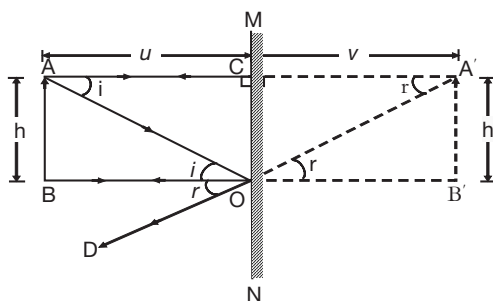


FIGURE 4.2 An extended object AB and its virtual image $A'B'$ formed in a plane mirror MN

So, A' is the image of A .

Image Formed by Plane Mirror

1. The image is virtual and erect.
2. It is of the same size as that of the object.
3. The distance between the object and the mirror is the same as that between the image and the mirror.
4. It is laterally inverted.

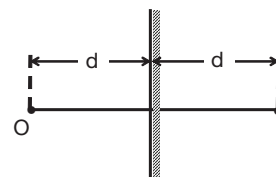


FIGURE 4.3 Distance of image and object from the mirror

SPHERICAL MIRROR

Spherical mirrors are a part of a sphere. Consider a hollow sphere. Now consider slicing a portion out of a sphere and the surface of the portions are silvered on the inner or outer surface.

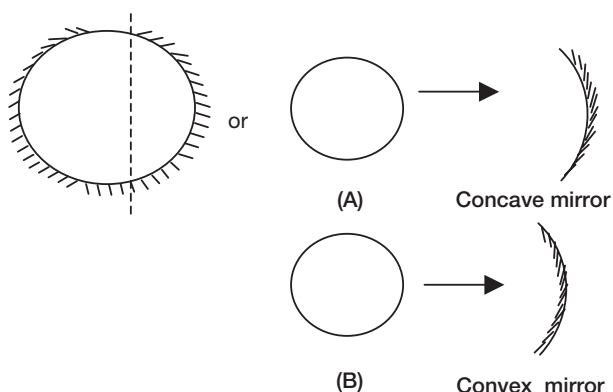


FIGURE 4.4 Convex and concave mirrors sliced from a spherical mirror

Generally, the smaller piece is used as a mirror. If a mirror is obtained from a sphere silvered on the outer side, it is called a concave mirror (shown in *A*). If a mirror is obtained from a sphere silvered inside, it is called a convex mirror (shown in *B*).

Terms Relating to Spherical Mirrors

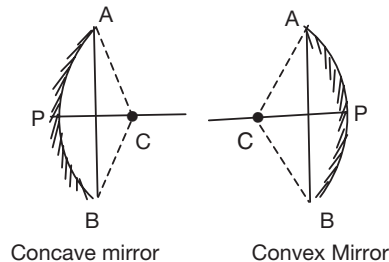


FIGURE 4.5 Concave and convex mirrors

Length AB is the measure of aperture, C is the centre of curvature, P is the pole, and PC is the principal axis.

- Aperture:** The portion available for reflection is called aperture; APB is the aperture.
- Pole:** It is the geometric centre of the reflecting surface. It is denoted by P .
- Centre of Curvature:** It is the centre of the sphere of which the mirror forms a part. C is the centre of curvature.
- Principal Axis:** It is a straight line passing through the centre of curvature and the pole. The line passing through P and C in the figure is the principal axis.
- Radius of Curvature (R):** It is the radius of the sphere of which the mirror forms a part. PC is the radius of curvature.
- Principal Focus:** Consider a parallel beam of light incident on a spherical mirror.

In case of a concave mirror, the parallel beam after reflection converges at a point F which is called the principal focus.

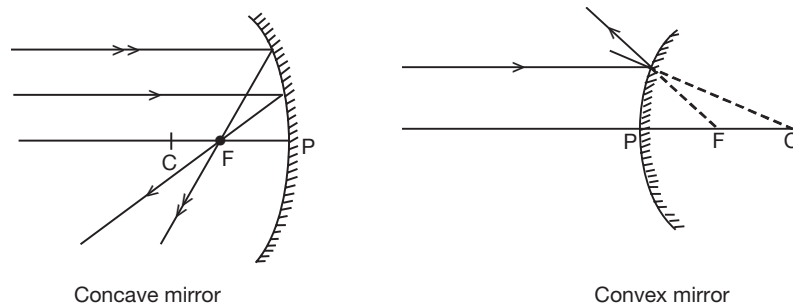


FIGURE 4.6 Reflection of a beam from spherical mirrors

In case of a convex mirror, it appears to diverge from the focus (F). Thus, a concave mirror is called a converging mirror and a convex mirror is called a diverging mirror.

- Focal Length:** It is the distance between the pole and the principal focus. PF is the focal length. It is denoted by ' F '. It is measured in m or cm.

Relation Between Focal Length and Radius of Curvature

Consider a concave mirror of small aperture. P is the pole of the mirror. PC is the radius of curvature = R

CM is the normal to the spherical surface.

PF is the focal length = f

OM is the ray parallel to principal axis and is incident on the mirror at an angle ' i '.

The ray OM after reflection passes through principal focus (F). A ray CM , incident normally, retraces its path after reflection.

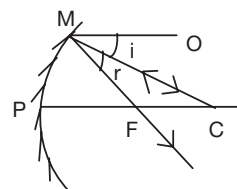


FIGURE 4.7 Reflection of ray OM incident on a concave mirror

From Laws of Reflection:

$$\angle i = \angle r \quad (4.1) \quad (\angle r = \angle CMF)$$

where angle r is the angle of reflection and i is the angle of incidence.

$$\angle MCF = \angle i \text{ (alternate angles)} \quad (4.2)$$

From (4.1) and (4.2)

$$\angle MCF = \angle r \quad (4.3)$$

From geometry

$$FC = FM \quad (4.4)$$

($\because$ base angles of $\Delta_{\text{le}} CMF$ are equal)

Since we are considering a small aperture, $\angle PFM$ is small angle and PM is straight line FM almost coincides with PF

$$\therefore FM = PF \quad (4.5)$$

$$PF + FC = PC$$

$$PF + PF = PC \quad (4.6)$$

($\because PF = FC$) [from (4.4) and (4.5)]

PF is the focal length = f

PC is the radius of curvature = R

$$\therefore f + f = R$$

$$\Rightarrow 2f = R$$

$$\text{or } f = \frac{R}{2}$$

Thus, for a spherical mirror, the radius of curvature is twice its focal length.

Rules to Determine the Path of Reflected Rays

1. In case of a concave mirror, incident rays parallel to the principal axis on reflection pass through principal focus whereas in a convex mirror, the reflected rays only appear to pass through the principal focus, when produced backwards (See Fig 4.6).
2. An incident ray passing through the centre of curvature gets reflected along the same path in case of a concave mirror. In case a convex mirror, the reflected ray only appears to pass through the centre of curvature (See Fig. 4.8a and b).

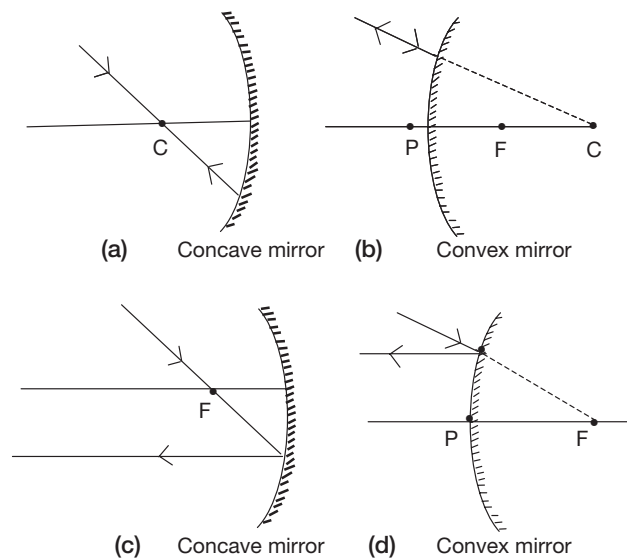


FIGURE 4.8 Incident ray passing through centre of curvature in figure (a) & (b); and through focus in figure (c) & (d)

3. In case of a concave mirror an incident ray passing through the principal focus reflects parallel to the principal axis (See Fig. 4.8c). In case of convex mirror, an incident ray which appears to pass through the focus reflects parallel to the principal axis (See Fig. 4.8d).

Formation of Image by Convex Mirror

OJ is an extended object and IG is an image formed by a convex mirror of small aperture.

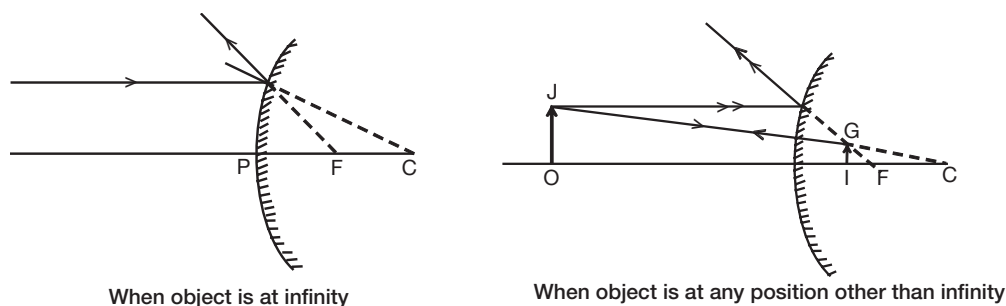


FIGURE 4.9 Formation of image by convex mirror

Formation of Image by Concave Mirror

AB is an extended object and A_1B_1 is an image formed by a concave mirror of small aperture.

S. No.	Object distance	Ray diagram	Nature and position of image
1	$u = \infty$		Real, inverted and highly diminished, $v = f$
2	$R < u < \infty$		Real, inverted and diminished, lies between F & C ie., $f < v < R$.
3	$u = R$		Real, inverted and of equal size as that of object, $v = R$. At C.
4	$f < u < R$		Real, inverted and magnified, beyond 'C'. $v > R$
5	$u = f$		Real, inverted and highly magnified at $v = \infty$.
6	$u < f$		Virtual, erect and magnified and formed behind the mirror.

(Image formed by a mirror of large aperture is not distinct and the image suffers from defects and distortions.)

New Cartesian sign convention by reflection by spherical mirrors:

1. All distances are measured from the pole (P) of the mirror.
2. Distances measured in the direction of the incident ray are taken as positive and the distances measured in the direction opposite to the incident ray are taken as negative.
3. Perpendicular distances (height) above the principal axis are positive and perpendicular distance below the principal axis are negative.
4. Thus, focal length and radius of curvature is negative for concave mirror and positive for convex mirror.

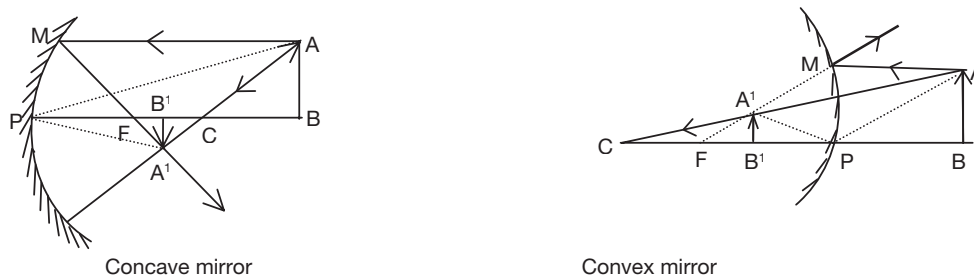


FIGURE 4.10 Formation of image by concave and convex mirror

Consider a spherical mirror (concave or convex mirror) of radius of curvature 'R'. Let 'f' be the focal length of the spherical mirror. AB is an object placed at a distance 'u' from the pole P. A'B' is an image of an object at a distance 'v' from the pole P. PC is the radius of curvature. Triangle ABP and triangle A'B'P are similar.

Concave Mirror

$$\therefore \frac{A'B'}{AB} = \frac{PB'}{PB}$$

Using Cartesian sign convention, we get

$$\begin{aligned} \frac{PB'}{PB} &= \frac{-v}{-u} \\ \frac{A'B'}{AB} &= \frac{-v}{-u} = \frac{v}{u} \end{aligned} \quad (1)$$

From similar triangles, ABC and A'B'C, we have

$$\frac{A'B'}{AB} = \frac{B'C}{BC} = \frac{PC-PB'}{PB-PC}$$

Using Cartesian sign convention and (1)

Convex Mirror

$$\frac{A'B'}{AB} = \frac{PB'}{PB}$$

Using Cartesian sign convention, we get

$$\begin{aligned} \frac{PB'}{PB} &= \frac{v}{-u} \\ \frac{A'B'}{AB} &= \frac{v}{-u} \end{aligned} \quad (1)$$

From similar triangles ABC and A'B'C, we have

$$\frac{A'B'}{AB} = \frac{B'C}{BC} = \frac{PC-PB'}{PC+PB}$$

Using Cartesian sign convention and (1), we get

Concave Mirror	Convex Mirror
$\frac{v}{u} = \frac{-R - (v)}{-u - (-R)}$ $\frac{v}{u} = \frac{-R + v}{-u + R}$	$\frac{v}{-u} = \frac{R - v}{R + (-u)}$ $\frac{v}{-u} + \frac{R - v}{R - u}$
$-uv + vR = -uR + vu$ $\Rightarrow vR + uR = uv + uv \Rightarrow vR + uR = 2uv$ dividing throughout by uvR	$\Rightarrow vR - uv = -uR + uR$ $\Rightarrow uR + vR = uv + uv \Rightarrow uR + vR = 2uv$ dividing throughout by uvR
$\frac{1}{v} + \frac{1}{u} = \frac{2}{R}$ $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$	$\frac{1}{v} + \frac{1}{u} = \frac{2}{R}$ $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$$\therefore \frac{2}{R} = f$$

$\therefore$ The relation between object distance, image distance and the focal length for a mirror is

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}. \text{ This is called mirror formula.}$$

LINEAR MAGNIFICATION (M)

It is the ratio of image height to the object height

$$m = \frac{\text{height of the image } (h^1)}{\text{height of the object } (h^2)} = \frac{A^1B^1}{AB}$$

$$m = \frac{h^1}{h^2} = \frac{-v}{u} \quad \left(\because \frac{A^1B^1}{AB} = \frac{v}{u} \right)$$

(using Cartesian sign convention).

Magnification is positive if the image is erect (and virtual) and it is negative, if the image is (real and) inverted.

EXAMPLE

Find the radius of curvature of a concave mirror of focal length 15 cm.

SOLUTION

$$\text{Focal length} = \frac{1}{2} \text{ radius of curvature (R)}$$

Given

$$f = 15 \text{ cm}$$

$$R = 2f = 2 \times 15 = 30 \text{ cm}$$

Since it is a concave mirror, 'R' is negative (from Cartesian sign).

$$\text{So, } R = -30 \text{ cm}$$

EXAMPLE

A rear view mirror of an automobile has an focal length of 2 m. If it locates a person standing at a distance 4 m from it, find the nature and distance of the image.

SOLUTION

Rear view mirror, of an automobile is a convex mirror.

Given

$$\text{Focal length} = f = 2 \text{ m (focal length is positive)}$$

$$\text{Object distance} = u = -4 \text{ m}$$

$\therefore$ From Cartesian sign convention, object distance is negative as it is in the opposite direction to that of the incident ray

Using mirror formula, we get

$$\Rightarrow \frac{1}{2} = \frac{1}{-4} + \frac{1}{v} \Rightarrow \frac{1}{v} = \frac{1}{2} + \frac{1}{4}$$

$$\frac{1}{v} = \frac{4+2}{4 \times 2} \Rightarrow \frac{1}{v} = \frac{6}{8}$$

$$v = \frac{8}{6} = 1.33 \text{ m}$$

Since v is positive, image is virtual (it is formed at the back of the convex mirror)

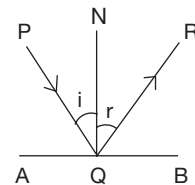


FIGURE 4.11 Reflection of light incident on convex mirror

MAGNIFICATION (M)

$$m = \frac{\text{height of the images}}{\text{height of the object}} = -\frac{v}{u}$$

$$m = \frac{-1.33}{-4} = 0.3325$$

Since magnification is positive, the image is erect and virtual.

EXAMPLE

An object of height 2 cm is placed at distance $2.5 f$ from a concave mirror where ' f ' is its focal length. Find the height of the image.

SOLUTION

Height of the object = 2 cm

Focal length = $-f$ (for concave mirror, f is negative)

Object distance $u = -2.5 f$ (from Cartesian sign convention)

Using the mirror formula, we get

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{-f} = \frac{1}{-2.5f} + \frac{1}{v} \Rightarrow \frac{1}{v} = \frac{1}{-f} + \frac{1}{2.5f} \Rightarrow \frac{1}{v} = \frac{-1}{f} + \frac{2}{5f}$$

$$\frac{1}{v} = \frac{-5f + 2f}{5f^2} \text{ or } v = \frac{-5f}{3} \text{ magnification } m = \frac{h_1}{h_0} = \frac{-v}{u}$$

$$\frac{h_1}{2} = - \left(\frac{\frac{-5f}{3}}{\frac{-5}{2}f} \right) \Rightarrow \frac{-2}{3} \Rightarrow h_1 = \frac{-2}{3} \times 2 = \frac{-4}{3}$$

Image is 1.33 cm long. Minus sign shows it is inverted.

EXAMPLE

A rod of length 10 cm lies along the principal axis of a concave mirror of focal length 10 cm in such a way that the end close to the pole is 20 cm away from it. Find the length of the image of the rod.

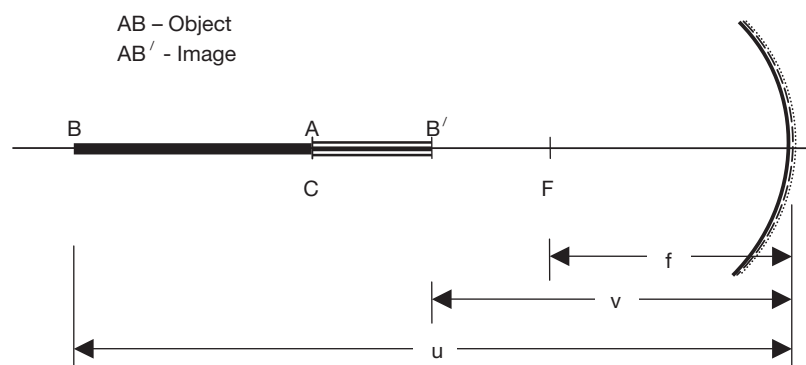
SOLUTION

FIGURE 4.12 Rod AB placed at given distance from concave mirror

Focal length $f = -10$ cm

$\therefore$ Radius of curvature $R = 2f = -20$ cm

Length of the rod $AB = 10$ cm

Distance of the end $A = 20$ cm = R

Since the near end ' A ' of rod is at the centre of curvature, its image A^1 will also be at ' C '.

Distance of the end B of the rod = $20 + 10 = 30$ cm

$\therefore u = -30$ cm (from Cartesian sign convention)

$f = -10$ cm

$v = ?$

From mirror formula

$$\begin{aligned}\frac{1}{f} &= \frac{1}{u} + \frac{1}{v} \\ \frac{1}{-10} &= \frac{1}{-30} + \frac{1}{v} \\ \frac{1}{v} &= \frac{-1}{10} + \frac{1}{30} \Rightarrow \frac{1}{v} = \frac{-30+10}{30 \times 10} \\ \frac{1}{v} &= \frac{-20}{300} \\ v &= \frac{-30}{2} = -15 \text{ cm}\end{aligned}$$

Length of the image = $A^1B^1 = 20 - 15 = 5$ cm

Medium: The substance which allows the light to pass through it is called medium.

REFRACTION

When light passes from one medium to another medium, there is a change in the path of light in the second medium. This is known as refraction. Deviation in the path of light is due to the change in the speed of light when it passes from one medium to another. Refractivity of light is shown in Fig. 4.13 and it shows:

PQ is the incident ray

QR is the refracted ray

MN is the normal

$\angle i$ is the angle of incidence

$\angle r$ is the angle of refraction

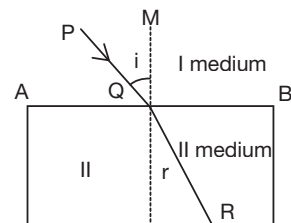


FIGURE 4.13 Refraction from one medium to another

Refractive Index of a Medium

Refractive index of a medium is the ratio of velocity of light in air or vacuum to its velocity in a given medium. This is known as the absolute refractive index.

$$\therefore \mu = \frac{\text{velocity in air or vacuum } (c)}{\text{velocity in air or vacuum } (v)} \Rightarrow \mu = \frac{c}{v}$$

where μ is absolute refractive index. If μ_1 and μ_2 are the refractive indices of two media and v_1 and v_2 are the velocity of light in the medium one and medium two, respectively,

then

$$\mu_1 = \frac{c}{v_1} \quad (4.7)$$

$$\mu_2 = \frac{c}{v_2} \quad (4.8)$$

Dividing (4.7) by (4.8), we get

$$\frac{\mu_2}{\mu_1} = \frac{\frac{c}{v_2}}{\frac{c}{v_1}}$$

$$\frac{\mu_2}{\mu_1} = \frac{v_1}{v_2} = \mu_2$$

Where ${}^1\mu_2$ is the relative refractive index of medium 2 with respect to medium 1.

$$\therefore \mu_2 \text{ or } \mu_2 = \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2}$$

Medium	Absolute refractive index
Air	1.00
Water	1.33
Glass	1.5
Diamond	2.42

Rarer Medium: The medium of lower refractive is called rarer medium.

Denser Medium: The medium of higher refractive index is called denser medium.

When a light ray is incident from rarer medium to the denser medium, the refracted ray bends towards the normal, i.e., $\angle i > \angle r$

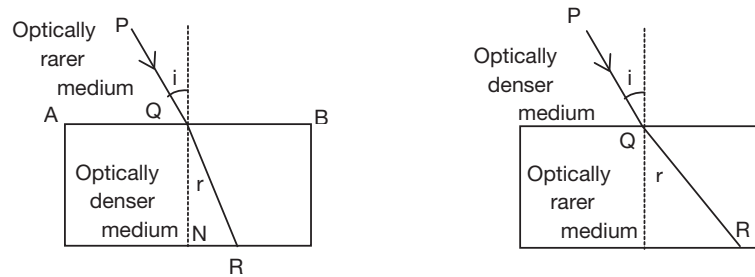


FIGURE 4.14 Refraction of light from rarer medium to denser medium and vice-versa

When a light ray travels from a denser medium to a rarer medium, the refracted ray bends away from the normal, i.e., $\angle i < \angle r$. Thus, the deviation of the ray of light depends on the optical density of the two media.

LAWS OF REFRACTION

1st Law

The incident ray, the refracted ray and the normal to the surface separating the two media at the point of incidence, all lie on the same plane.

2nd Law

The ratio of sine of angle of incidence to the sine of angle of refraction is a constant for a given pair of media and for a given colour of light. This law is also known as Snell's law.

$$\text{Mathematically } \frac{\sin i}{\sin r} = \mu$$

where μ is a constant called refractive index.

It is observed that, when a light ray travels along the normal, drawn to the interface of two medium, no refraction takes places, i.e., $i = r = 0$

$$\therefore \frac{\sin i}{\sin r} = \frac{0}{0} = \text{undefined}$$

So, Snell's law is not applicable when angle of incidence is equal to zero, i.e., when the ray is incident along the normal.

Experiment to Verify Second Law of Refraction or to find Absolute Refractive Index of a Glass

Take a glass slab and place it on a white paper which is fixed to a drawing board.

1. Trace the boundary $ABCD$ of the glass slab and remove it.
2. Draw a normal MN to the glass surface AB , at point Q . Make a suitable angle (angle of incidence) with the normal. This is the line of incidence.

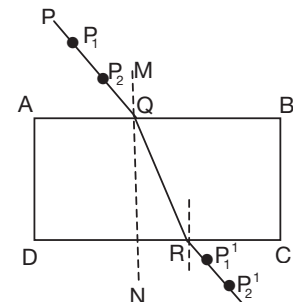


FIGURE 4.15 Refraction through glass slab ABCD

3. Fix two pins P_1 and P_2 on the line of incidence. Such that they are normal to the bond.
4. Replace the glass slab on the boundary traced, i.e., on $ABCD$.
5. Locate the image of the pins P_1 and P_2 looking through the opposite face of the glass slab through CD . How?
6. The image of the pins P_1^1 and P_2^1 appears to be in line with P_1 and P_2 . Fix two pins at these points, i.e., P_1^1 and P_2^1 .
7. Mark the points of the pins P_1 , P_2 , P_1^1 and P_2^1 .
8. Remove the glass slab.
9. Join P_1^1 and P_2^1 to meet the surface CD , and join QR .
10. PQ is the incident ray, and QR is the refracted ray.
11. Measure the angle of refraction, $\angle r = \angle NQR$.
12. Find the refractive index of the glass, using

$$\mu = \frac{\sin i}{\sin r}$$

13. Repeat the experiment for different angles of incidence. Tabulate the results. As follows:
14. In each case, it is found that the ratio of $\sin i$ to $\sin r$ is a constant.

Trial No	Angle of incidence $= \angle i$	Sin i	Angle of refraction $= \angle r$	Sin r	$m = \frac{\sin i}{\sin r}$

PRINCIPLE OF REVERSIBILITY OF LIGHT

If a ray of light travels from medium 1 to medium 2 along a certain path, it retraces the path when it travels from medium 2 to medium 1. Thus, the path of light is reversible. This property is called 'principal of reversibility of path' (See Fig. 4.16).

AB is the refracting surface separating the two media. MN is the normal. A ray of light PQ is incident at an angle ' i ' and is refracted along QR at an angle ' r '.

Refractive index of medium 2 with respect to medium 1 is

$${}^1\mu_2 = {}_1\mu_2 = \frac{\sin i}{\sin r} \quad (4.9)$$

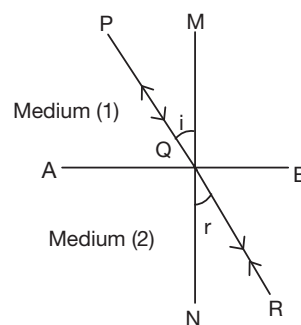


FIGURE 4.16 Reversibility of light

When a ray of light travels from medium 2 to medium 1, according to the principle of reversibility, RQ is the incident ray and PQ is the refracted ray, refracted at an angle ' i '.
Refractive index of medium 1 with respect to medium 2 is

$${}_2\mu_1 = \frac{\sin r}{\sin i} \quad \therefore {}_2\mu_1 = \frac{1}{{}_1\mu_2} \quad (4.10)$$

EXAMPLE

The velocity of light in air is $3 \times 10^8 \text{ m s}^{-1}$. If the refractive index of water is $4/3$, find the velocity of light in water.

SOLUTION

Given

Velocity of light in a $C = 3 \times 10^8 \text{ m s}^{-1}$

Refractive index of water $\mu_1 = \frac{4}{3}$

Refractive index of water $= \frac{c}{v_w}$

Where v_w is the velocity of light in water

$$\begin{aligned} \frac{4}{3} &= \frac{3 \times 10^8}{v_w} \\ v_w &= \frac{3 \times 3 \times 10^8}{4} \\ v_w &= 2.25 \times 10^8 \text{ m s}^{-1} \end{aligned}$$

Velocity of light in water is $2.25 \times 10^8 \text{ m s}^{-1}$.

EXAMPLE

The angle of incidence of a ray of the light is 45° . If a ray of light travels from air to glass, find the angle of refraction. Refractive index of glass, $\mu_g = 1.5$.

SOLUTION

Given $i = 45^\circ = \text{angle of incidence}$

Refractive index of glass $= \mu_g = 1.5$

Angle of refraction $r = ?$

$$\mu_g = \frac{\sin i}{\sin r} \text{ (from snell's law)}$$

$$1.5 = \frac{\sin 45}{\sin r}$$

$$1.5 = \frac{\left(\frac{1}{\sqrt{2}}\right)}{\sin r}$$

$$\sin r = \frac{1}{1.5 \times \sqrt{2}}$$

$\sin r = 0.4728$. From sine trigonometric table, we get $r \approx 28^\circ$.

EXAMPLE

Refractive index of diamond is 2.5 and that of glass is 1.5. Calculate the refractive index of diamond with respect to glass.

SOLUTION

Refractive index of glass, $\mu_g = 1.5$

Refractive index of diamond, $\mu_d = 2.5$

From relative refractive index

$${}^g\mu_d = \frac{\mu_d}{\mu_g} = \frac{2.5}{1.5} = 1.667$$

Example: A stick immersed obliquely in water appears to be bent. This is refraction of light. When a ray of light passes from water to air, it bends away from the normal, hence, the stick appears to be bent and short.

Refraction through a Glass Slab

Consider a glass slab $ABCD$ placed in air. A ray PQ incident from air to glass at an angle i_1 is refracted along QR at an angle i_2 . The ray QR is incident on glass – air interface, then it undergoes refraction along RS at an angle i_3 (RS is called as an emergent ray)

From Snell's law, at the surface AB

$$\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i_1}{\sin i_2} \quad (4.11)$$

where μ_2 is refractive index of glass and μ_1 is refractive index of air.

From equation (4.11)

$$\mu_1 \sin i_1 = \mu_2 \sin i_2 \quad (4.12)$$

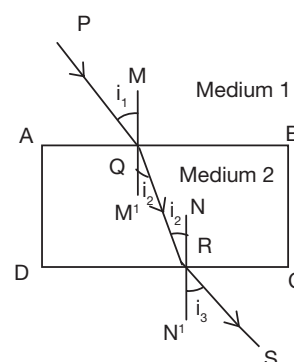


FIGURE 4.17 Refraction through a glass slab

At the interface CD

From Snell's law

$$\frac{\mu_1}{\mu_2} = \frac{\sin i_2}{\sin i_3}$$

$$\mu_1 \sin i_3 = \mu_2 \sin i_2 \quad (4.13)$$

Comparing (4.12) and (4.13)

$$\mu_1 \sin i_1 = \mu_1 \sin i_3$$

Since $\mu_1 = 1$ (refraction index of air)

$$\sin i_1 = \sin i_3 \therefore i_1 = i_3$$

MM^1 and NN^1 are parallel to each other

Thus, the emergent RS ray is parallel to the incident PQ ray.

LATERAL DISPLACEMENT

Consider an optical medium ($ABCD$) of thickness ' t '. PQ is the incident ray, incident at an angle i , the ray PQ undergoes refraction along QR at an angle ' r '. In the absence of an optical medium the ray PQ would have travelled straight without any deviation along PQT . Due to the presence of a medium, the incident ray undergoes shift. This, is known as lateral displacement. Thus, lateral displacement is the perpendicular distance between the emergent ray and the incident ray produced. RT measures lateral displacement.

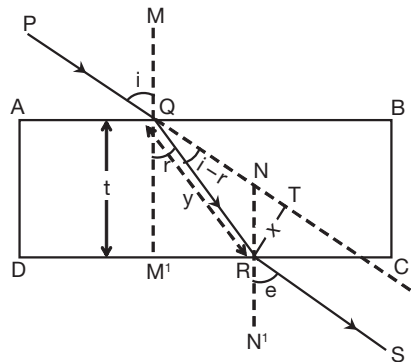


FIGURE 4.18 Lateral displacement shown by refraction of light through glass slab

The lateral displacement depends on the following factors:

- 1. Thickness of the medium:** Lateral displacement is directly proportional to the thickness.
- 2. Refractive index of the medium:** Lateral displacement is directly proportional to the refractive index of the medium.
- 3. Angle of incidence:** Lateral displacement varies directly as the angle of incidence.
- 4. μ will take care of this factor.**

Real and Apparent Depth

Consider an object 'O' placed in an optically denser medium. A ray OM passes without deviation, since it is incident along the normal. A ray OP incident at an angle i undergoes refraction at an angle ' r ' along PR. When refracted ray PR is produced backwards, it meets the normal at I. The object appears to come from I and not from O. I is the virtual image of the object O. IM is the apparent depth and OM is the real depth.

$$\text{Refractive index of the medium} = \frac{\text{real depth}}{\text{apparent depth}}$$

Where real depth—it is the actual depth of the object.

Apparent depth—it is depth of the image of the object.

Example

1. The floor of a swimming pool appears to be raised when seen from the diving board. This is due to refraction.
2. Sun appears before it actually rises. This is due to refraction of light.

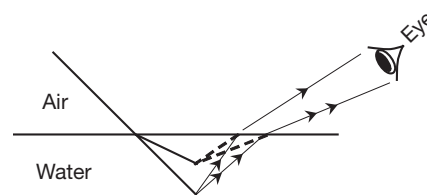


FIGURE 4.19 Apparent bent in a stick

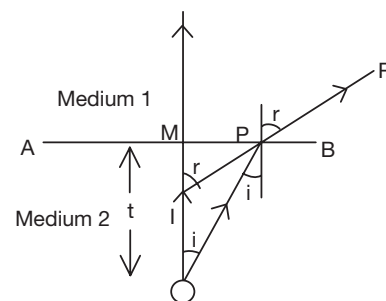


FIGURE 4.20 Showing to show real and apparent depth

EXAMPLE

A coin placed in a beaker containing water appears at a depth of 3 cm from the water surface. What is the real depth of the coin? Refractive index of water = $\frac{4}{3}$

SOLUTION

Real depth = ?

Apparent depth = 3 cm

Refractive index of water = $\frac{4}{3}$

$$\text{Refractive index} = \frac{\text{real depth}}{\text{apparent depth}}$$

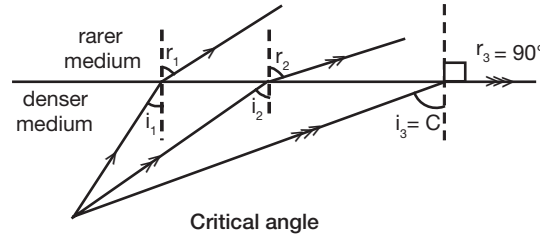
$$\Rightarrow \frac{4}{3} = \frac{\text{real depth}}{3}$$

$$\frac{4}{3} \times 3 = \text{real depth}$$

$$\text{real depth} = 4 \text{ cm}$$

Critical Angle

The angle of incidence in the denser medium at which angle of refraction is 90° is called critical angle.



TOTAL INTERNAL REFLECTION

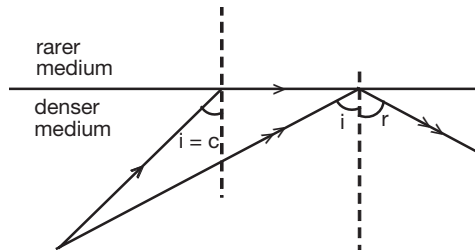


FIGURE 4.21 Total internal reflection

When a ray of light passes from denser to rarer medium, the refracted ray bends away from the normal. Hence, the angle of refraction is greater than the angle of incidence. Gradually if the angle of incidence increases, angle of refraction also increases. At a particular angle of incidence, the refracted ray just grazes the refracting surface making the angle of refraction is equal to 90° . This angle of incidence in the denser medium is called 'critical angle'. If the angle of incidence is further increased, the rays does not undergo refraction, it gets reflected into the same optically denser medium. This is known as total internal reflection.

When angle of incidence in the denser medium is greater than the critical angle the light is reflected back into the same medium. This phenomenon is called total internal reflection.

Conditions for Total Internal Reflection

1. The light ray should travel from denser medium to rarer medium.
2. Angle of incidence in the denser medium should be greater than the critical angle.

Example: Diamonds are cut into sharp angles. This gives rise to a number of refracting surfaces. Light rays entering diamond suffer total internal reflection. Light rays strike the diamond-air interface at greater than 24° (which is the critical angle of diamond). Thus, the light rays get trapped. These trapped light rays make the diamond sparkle.

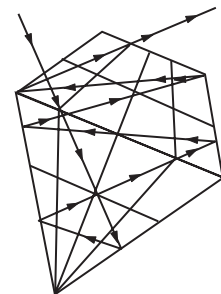


FIGURE 4.22 Diamond

Mirage

Inverted images of distant objects on the ground are usually seen during hot summer days. These images are seen as a result of an

optical illusion called mirage. Such an illusion caused due to perceived presence of water though in reality water is non-existent.

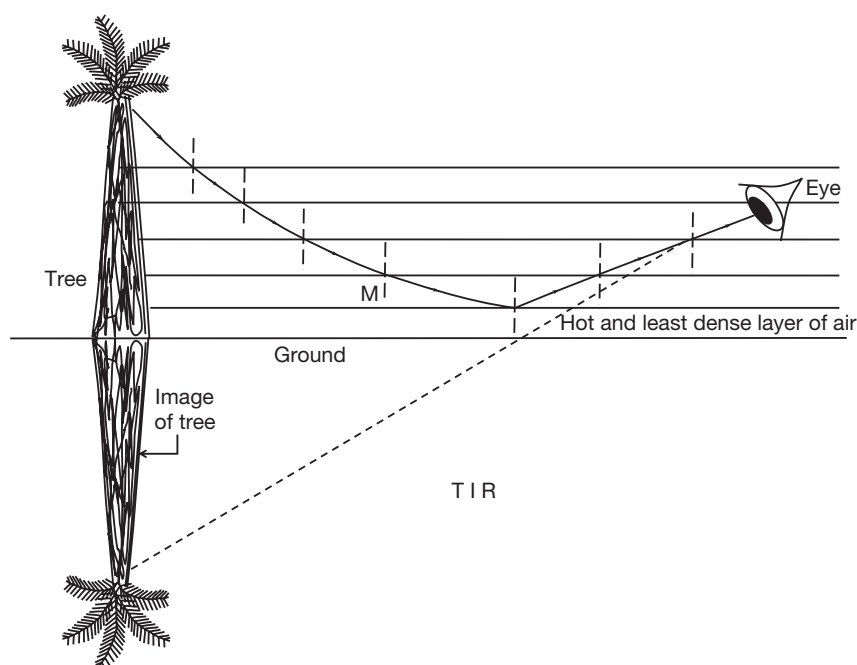


FIGURE 4.23 Formation of mirage

During peak summer days, the layer of air just above the earth is less dense than the air above it. Light travelling from distant or tall object passes from layer of high refractive index (denser medium) to layer of low refractive index (rarer medium). Thus, the refracted ray bends more and more away from the normal.

This happens till the angle of incidence is equal to the critical angle. Once the angle of incidence is greater than the critical angle, light rays undergo total internal reflection and reach the eye and the person sees the image of the tree, as there is water under the tree.

Mirage: Appearance of water without its actually presence is called mirage.

TWINKLING OF STARS

Twinkling of stars is due to atmospheric refraction. Light from stars undergoes continuous refraction as it enters the earth's atmosphere. Since the refracted ray bends towards the normal stars appear at different position and appear slightly higher than their actual positions. The apparent position of the star changes gradually due to change in the earth's atmosphere. Thus, the apparent position of the star fluctuates. As a result, the path of light from the star varies. (amount of light entering the eye also varies).

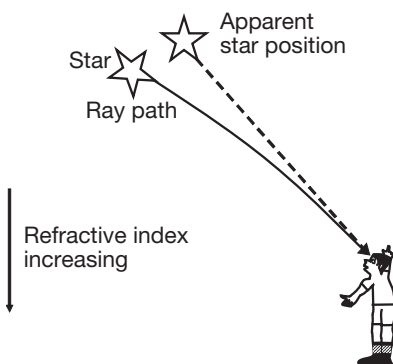


FIGURE 4.24 Apparent star position due to atmospheric refraction

Due to change in the light flux, star appears brighter some times and fainter at the other time. Thus, the twinkling of stars is due to fluctuation of apparent position of the star.

Planets do not twinkle they appear bigger than stars. A planet can be considered as a collection of a large number of point sized objects which nullify the twinkling effect.

Relation between Critical Angle and Refractive Index

Consider a ray of light PQ travelling from denser to rarer medium. Let the ray be incident at the critical angle. The angle of refraction will be equal to 90° .

From Snell's Law

$${}_1\mu_2 = \frac{\sin i}{\sin r} \quad (4.14)$$

but $i = c$ and $r = 90^\circ$

$${}_1\mu_2 = \frac{\sin c}{\sin 90}$$

$${}_1\mu_2 = \frac{\sin c}{1} \quad (\because \sin 90 = 1) \Rightarrow \frac{\mu_2}{\mu} = \sin c$$

$[\mu_2 = \frac{\mu_2}{\mu_1} \text{ from relative refractive index}]$

If the second medium is air, then $\mu_2 = 1$ and $\mu_1 = \mu \frac{1}{\mu} \sin c$ or $\frac{1}{\mu} \sin c$

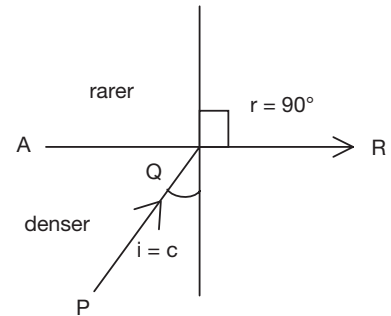


FIGURE 4.25 A ray PQ refracting from denser to rare medium

Differences between Reflection and Total Internal Reflection

Reflection	Total internal reflection
For reflection to take place, smooth polished surface is required.	No smooth polished surface is required for total internal reflection to occur.
It takes place at all angles of incidence.	Total internal reflection can occur only if the angle of incidence is greater than critical angle. and it tends to travel from denser medium to rever medium.
Some percentage of light rays are absorbed by the reflecting material.	No light energy is absorbed.

Total Reflecting Prisms

Total reflecting prisms are right angled isosceles prisms. They are based on the principle of total internal reflection. These prisms are used to rotate light through 90° or 180° . These prisms are also used to obtain erect images of an inverted object.

Deviation through 90°

When a ray of light is incident normally on the surface of a right angled isosceles prism, it does not undergo refraction. But it strikes the surface AC at an angle 45° , which is greater than the critical angle of glass, i.e.,

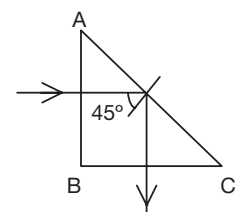


FIGURE 4.26 Total reflecting prisms

42° . The ray undergoes total internal reflection and strikes the face BC normally and emerges out of it. Thus, the ray is rotated through 90° . Surface AC acts like a mirror.

Deviation through 180°

When a ray of light is incident normally on the surface AC of the prism, it passes without deviation and it strikes the surface AB at angle 45° , which is greater than the critical angle for glass. Total internal reflection takes place and the ray further strikes the surface BC at an angle 45° . The ray undergoes another total internal reflection and then it emerges out through AC , because the ray strikes the surface normally. Then, we can say that

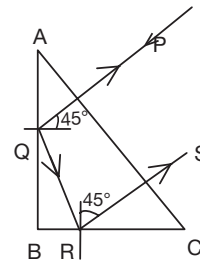


FIGURE 4.27 Total internal reflection in a prism

Erecting Prism or Non-deviation Prism

Rays after refraction from the surface AB strike the surface AC at an angle 45° , which is greater than the critical angle for glass and it undergoes total internal reflection. At surface BC , the rays undergo refraction and emerges out from the surface BC and the image MN appears as inverted.

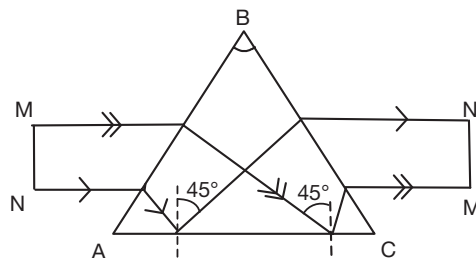


FIGURE 4.28 Erecting prism

Refracting Periscope or Prismatic Periscope

Refracting periscope consists of two right angled isosceles prisms. The light rays entering the periscope are rotated through 180° by the totally reflecting prisms which make the image of a distant object visible.

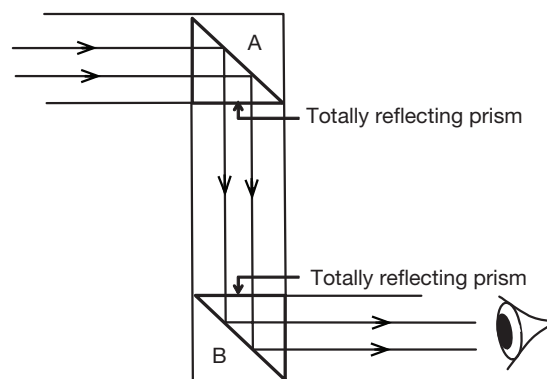


FIGURE 4.29 Prismatic periscope

This periscope is similar to that of reflecting periscope, but the reflecting periscope makes use of plane mirrors instead of reflecting prisms.

Advantages of Refracting Periscope Over Reflecting Periscope

1. Final image formed by the refracting periscope is bright and sharp, since no rays of light are absorbed.
2. The quality of the image is affected by the presence of dust and moisture in reflecting periscope. Moisture and dust does not have any appreciable effect on the image quality in refracting periscope.

OPTICAL FIBRES OR LIGHT PIPES

Optical fibres are devices used to transmit light in any desired path. It works on the principle of total internal reflection.

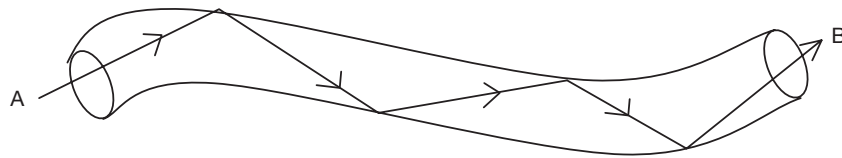


FIGURE 4.30 Total internal reflection in optical fibres

It consists of a thin fibre glass. When a ray of light enters a fibre, it suffers a series of total internal reflections and finally emerges out from the other end. Since the light energy is not absorbed, intensity of light is not lost.

Uses of Optical Fibres

1. **Used in communication:** Optical fibres are used in long distance telephony. Sound energy is converted into electrical energy. Electrical energy is converted into light energy. This light energy is fed to optical fibres and it is transmitted over a long distance through optical fibres. At the receiving end light energy is finally converted to sound energy.
2. Optical fibres are used as endoscopes or fibrescopes. Endoscopes is a device used to examine internal organs of a human body by physicians.

EXAMPLE

Refractive index of a glass is 1.5. Find its critical angle.

SOLUTION

From the relation between critical angle and refractive index.

$$\mu_{\text{glass}} = \frac{1}{\sin c}$$

$$1.5 = \frac{1}{\sin c}$$

$$\sin c = \frac{1}{1.5} = 0.6666$$

$$c = \sin^{-1} 0.666 \sim 42^\circ.$$

Critical angle for glass is 42° .

Refraction through Prisms

Prism is a transparent medium. It is bounded by two triangular surfaces and three rectangular surfaces.

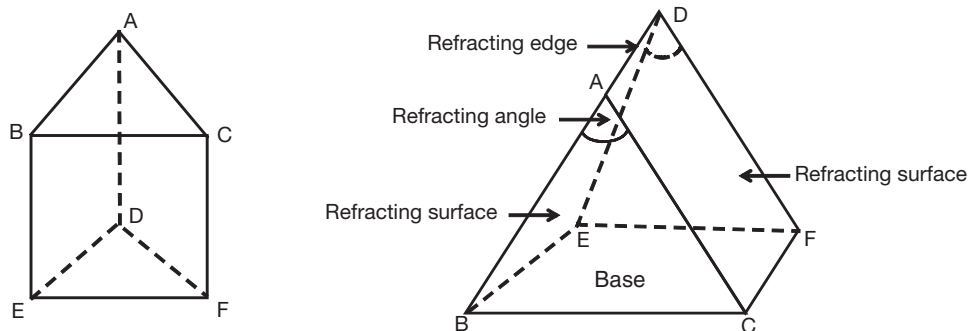


FIGURE 4.31 Prism

Rectangular surfaces are called refracting surfaces. The angle between the two refracting surfaces is called the refracting angle or the angle of the prism. The line joining the refracting surfaces is called the refracting edge. Section of a prism perpendicular to the refracting edge is called the principal section.

Deviation of Light by Prism

ABC is the principal section of an equilateral prism. $\angle A$ is the angle of the prism. PQ is the incident ray, incident at an angle i_1 . Since the ray PQ is travelling from optically rarer medium to denser medium, the refracted ray QR bends towards the normal. r_1 is the angle of refraction on the face AB . The ray QR is incident at an angle r_2 on the surface AC of the prism and emerges out along RS at an angle i_2 . i_2 is called the angle of emergence.

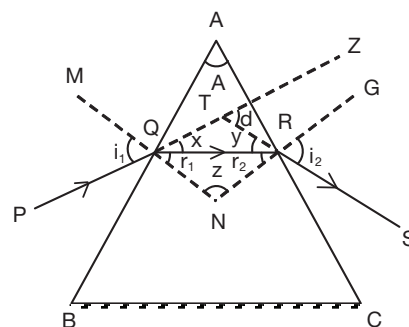


FIGURE 4.32 Deviation of light by prism

The angle between incident ray produced (PQ) and the emergent ray (RS) is called the angle of deviation. Angle of deviation = $\angle STZ = d$

The angle of deviation depends on the following factors.

1. Angle of incidence
2. Refractive index of the material of the prism
3. Angle of the prism

Dependence of Angle of Deviation on Angle of Incidence

Experiment I

1. Place an equilateral prism on a white paper fixed to a drawing board. Trace the principal section ABC of the prism and remove it.
2. Draw normals MN and NK to the refracting surfaces AB and AC , respectively.
3. Make a suitable angle (i) with the normal. This line is the incident ray (PQ).
4. Fix two pins P_1 and P_2 normally on the line of incidence as shown and bring the prism back to its position.
5. Look for the images of the pins P_1 and P_2 through the refracting surface AC . Fix two more pins P_1' and P_2' such that the images of the pins P_1 and P_2 appear in the same straight line, as P_1 and P_2 .
6. Encircle the points of the pins. Remove the prism and the pins.
7. Join the points P_2' and P_1' and produce it to meet the extended line PQ at T .
8. Join QR , QR is the refracted ray. RS is the emergent ray.

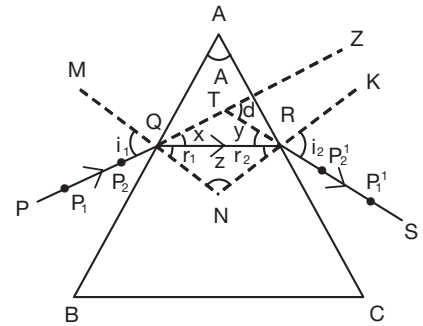


FIGURE 4.33 Refraction through prism

$\angle SRK = i_2$ represents the angle of emergence.

$\angle r_1$ is the angle of refraction on the surface AB .

$\angle r_2$ represents the angle of incidence on the surface AC of the prism.

9. Produce the incident ray (PQ) and the emergent ray (RS) backward. The rays PQ and RS intersect at a point T .

$\angle STZ$ is the angle of deviation = d

It can be proved that angle of deviation, $d = \angle i_1 + \angle i_2 - \angle A$ (1)

Where $\angle A = \angle r_1 + \angle r_2$

10. Measure $\angle i_1$, $\angle i_2$, $\angle r_1$ and $\angle r_2$ and then find angle of deviation by using equation (1).

Trial No	$\angle i_1$	$\angle i_2$	$\angle r_1$	$\angle r_2$	$\angle A$	$\angle d = \angle i_1 + i_2 - \angle A$

It is found that the angle of deviation decreases with increase in the angle of incidence upto a particular angle. This particular angle of incidence where the angle of deviation is minimum is called the minimum deviation position of the prism. Further as the angle of incidence is increased, the angle of deviation also increases. It is found that at the minimum deviation position,

1. angle of incidence is equal to angle of emergence, i.e., $\angle i_1 = \angle i_2$
2. angle of refraction r_1 is equal to angle of refraction r_2 , i.e., $\angle r_1 = \angle r_2$.

Then $d = 2\angle i - \angle A$ and $\angle A = 2r$.

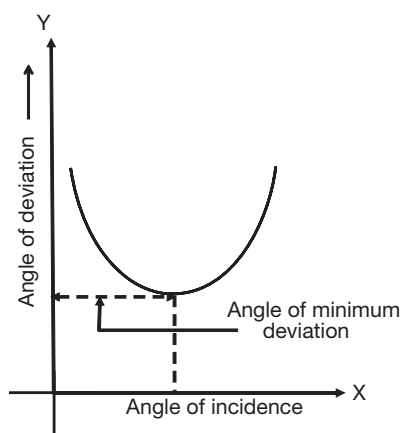


FIGURE 4.34 Graph to show relation between angle of deviation and angle of incidence

Dependence of Angle of Deviation on Refractive Index

If the hollow glass prism is filled with transparent liquids like water, benzene, etc., and the experiment is conducted as explained above, it is found that as the refractive index of the material increases the angle of deviation also increases.

Dependence of Angle of Deviation on the Colour or the Wave Length of Light

The experiment is repeated as explained above, but the pins are first painted red and the angle of deviation is found out. In the next trial, the pins are painted violet and the angle of deviation is found out for the same angle of incidence as that of the red pins. It is found that angle of deviation for violet is greater than the angle of deviation of the red colour.

$\therefore$ Lesser the wavelength, greater is the angle of deviation.

Dependence on Angle of the Prism

Repeat the experiment by taking prism of different angles (of the prism). (90° , 60° , 30° prism). It is found that the angle of deviation decreases with increase in the angle of the prism.

Refraction through Lenses

Lens: A lens is a transparent material which is bounded by two spherical surfaces or one spherical surface and one plane surface.

Lenses are of two types namely,

1. Convex lens or converging lens.
2. Concave lens or diverging lens.

Convex lens:

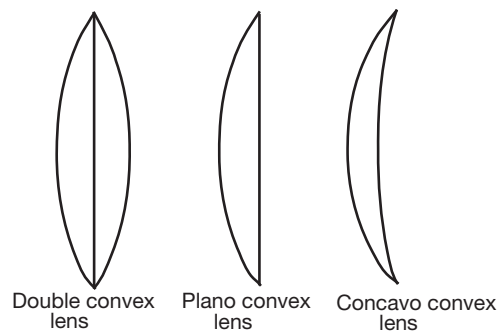


FIGURE 4.35 Types of convex lenses

Convex lens has one or two spherical surfaces, such that it is thicker at the centre than at the edges. Convex lenses are of three types, namely,

1. Double convex lens
2. Plano convex lens
3. Concave–convex lens

Concave lens: Concave lens has one or two spherical surfaces, such that it is thinner at the centre than at its edge.

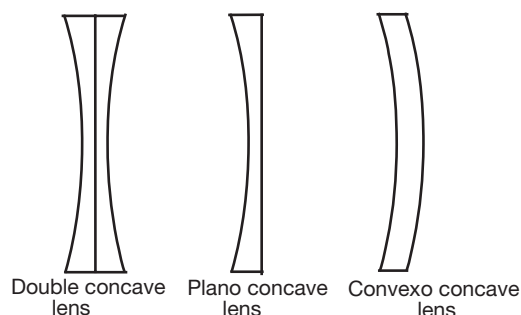


FIGURE 4.36 Types of concave lenses

Concave lens are also of three types, namely,

1. Double concave lens
2. Plano concave lens
3. Convexo–concave lens

Convergent Action of Convex Lens

A lens can be considered to be made up of prisms. The bases of the prisms are downwards in the upper half and prisms in the lower half have their bases upwards. Prisms at the edges have greater refracting angle.

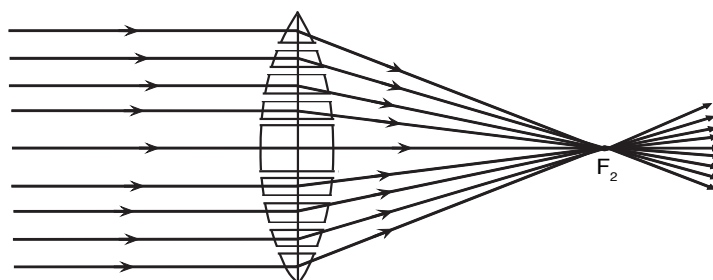


FIGURE 4.37 Rays converging from a convex lens

When a ray of light is passed through a prism, the emergent ray always bends towards the base (broader side) of the prism and greater the refracting angle, lesser will be the deviation. Thus, the rays from the outer edges are deviated more towards the base line and the Light ray passing along the principal axis or principal focus passes without deviation. All these rays converge at a point which is called the focus or principle focus.

When a convex lens is held facing the sun and the screen is placed on the other side of the lens, by adjusting the distance between the screen and the lens, a sharp and bright spot is obtained on the screen. Thus, a convex lens is a converging lens.

Diverging Action of Concave Lens

Concave lens too can be considered to be made up of prisms. The prisms in the upper half have their bases upwards or their refracting angles downwards and the prisms in the lower half have their refracting angles upwards. The rays near the outer edges of the lens are deviated maximum towards the bases of prism and the central ray goes without deviation. These rays do not meet but they are produced backwards, they meet at a point. This point is called focus.

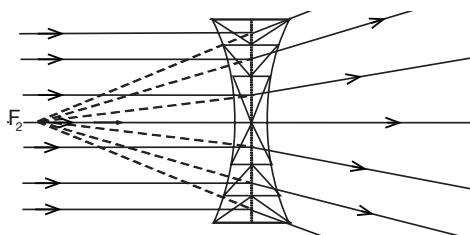


FIGURE 4.38 Rays diverging from a concave lens

When smoke is produced around the concave lens, held in sunlight, the emergent rays are seen to move away from each other. Hence, a concave lens is a diverging lens.

Some Definitions

Each surface of a lens is a part of a sphere. Surface 1 is a part of a sphere S_1 and surface 2 is a part of a sphere S_2 .

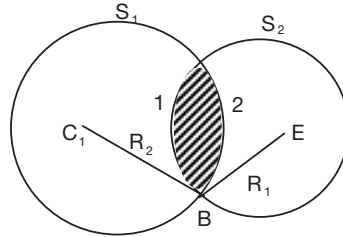


FIGURE 4.39 Spherical lenses

- 1. Centre of curvature of lens (C):** It is the centre of the sphere of which the surface of a lens form S a part.
- 2. Radii of curvature (R):** It is the radius of the sphere from which the spherical surface was obtained. Since a lens generally has two curved surfaces, it has two radii of curvature.
- 3. Principal axis:** It is a straight line joining the centre of curvatures of the two spherical surfaces of the lens.

Optical Centre

In case of thin lens, it is a point on the principal axis such that a ray of light passing through it emerges without deviation or it is a point, where any ray of light directed towards it, will have its emergent ray coincides with the direction of incident ray. Optical centre is denoted by 'O'

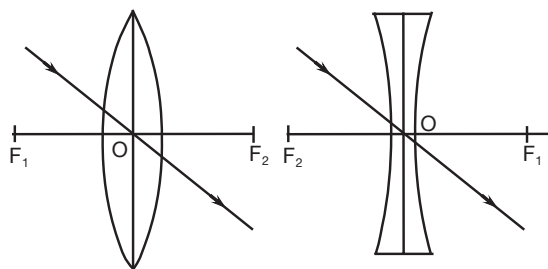


FIGURE 4.40 Incident ray passing through optical centre of spherical lenses

Principal Focus

It is the point on the principal axis to which the incident rays close and parallel to the principal axis of the lens converge after refraction, in case of a convex lens or appear to diverge from, in case of a concave lens. Since the light ray can be incident in either direction of the lens, there are two principal foci, which are at equal distance from the optical centre, provided the medium on either side of lens is the same. These points are referred to as first focal point and second focal point.

Focal Length

Distance between optical centre and the principal focus is called focal length and is denoted by f .

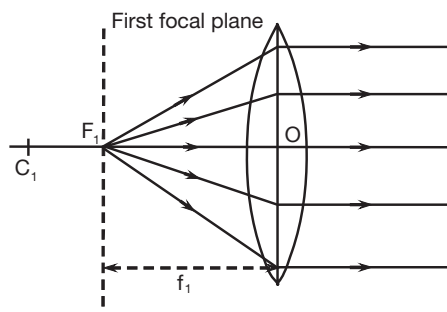


FIGURE 4.41 Incident rays emerging from focus of a convex lens

Focal Plane

It is a vertical plane passing through the focal point.

Rules for Construction of Images Formed by Thin Lenses

To find out the images formed by the lens by considering convenient rays.

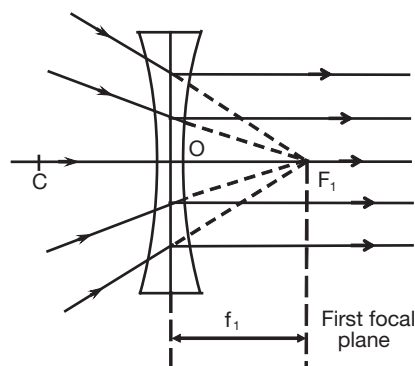
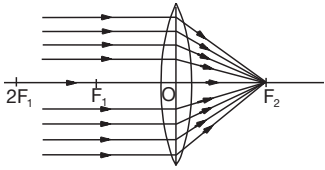
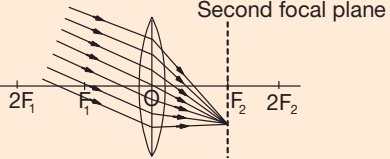
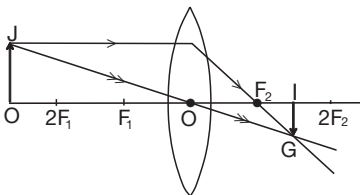
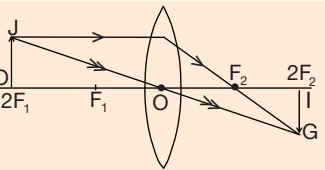
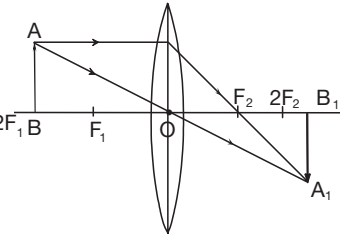
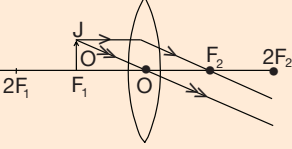
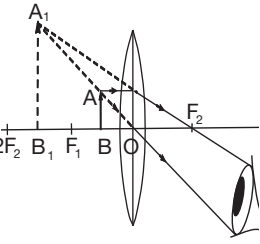


FIGURE 4.42 Incident rays coming from infinity on a concave lens

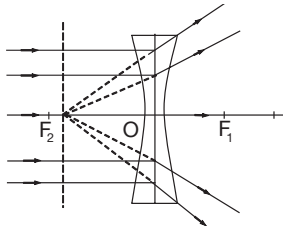
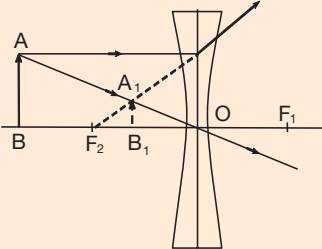
1. The rays parallel and close to the principal axis after refraction pass through the principal focus in a convex lens or appear to diverge from the principal focus in case of a concave lens.
2. Any ray of light which is directed through the principal focus or appearing to meet at it (concave lens), after refraction, always emerges parallel to the principal axis.
3. Any ray of light which passes through the optical centre of a lens emerges without deviation.

The above stated rules are used to obtain the position of the image. The point where the rays intersect or appear to intersect gives the image position.

Formation of Images by Convex Lens

No	Diagram	Object Position	Image Position	Nature	Uses
1		Infinity, rays are parallel to the principal axis	Formed at principal focus on the other side	Real, inverted and highly diminished	Burning glass or magnifying glass
2		Infinity, rays are not parallel to the principal axis	In the focal plane on the other side.	Real, inverted highly diminished	Objective of astronomical telescope
3		Beyond 2F	On the opposite side, between F and 2F	Real, inverted diminished	Photographic camera
4		At 2F	At 2F on the opposite side	Real, inverted, same size	Terrestrial telescope
5		Between 2F and F	Beyond 2F on the opposite side	Real, inverted and enlarged	Cine projection
6		At F	At infinity	Real, inverted and enlarged	Search lights and spot lights
7		Between F and the optical centre	On the same side	Virtual, erect and enlarged	Simple microscope, reading finger prints, to observe biological specimen and weaving patterns

Formation of Images by Concave Lens

No	Diagram	Object Position	Image Position	Nature	Uses
1		Infinity	At F on the same side	Virtual, erect and diminished to a point	Eye lens in Galilean telescope
2		At any distance	On the same side between optical centre and F	Virtual, erect and diminished	Correcting short sight edness.

CARTESIAN SIGN CONVENTION

Depending on the distance of the object from the lens, the image formed on the lens is on the same side or on the opposite side. Therefore, it is necessary to use sign convention. The sign convention rules are as follows.

1. All distances are measured from optical centre.
2. Distance measured in the direction of incident light is positive and distance measured against incident light is negative.
3. Distances measured above the principal axis are positive and distances measured below the principal axis are negative.
4. According to sign convention, focal length of a convex lens is positive and that of the concave lens is negative.

Lens Formula

AB is an extended object placed at a distance ' u ' from the optical centre O. $A'B'$ is the image at a distance ' v ' from O.

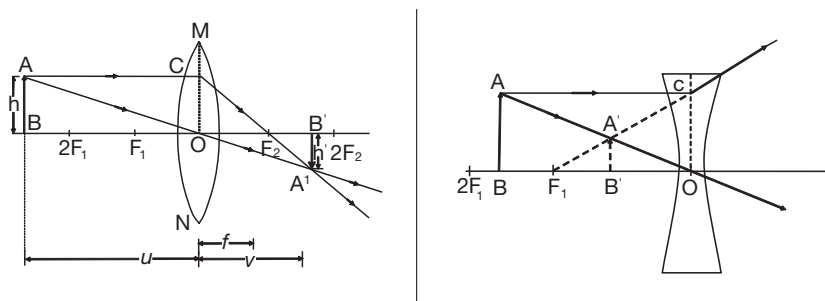


FIGURE 4.43 Image formation by convex and concave lens

Using Cartesian sign

Object distance $OB = -u$

Image distance $OB^1 = v$

Focal length of a convex lens = f

From similar triangles AOB and A^1OB^1

$$\frac{A^1B^1}{AB} = \frac{OB^1}{OB} = \frac{v}{-u} \quad (1)$$

from similar triangles OCF_2 and $A^1B^1F_2$

$$\frac{A^1B^1}{OC} = \frac{B^1F_1}{OF_1} \quad (2)$$

$$\frac{B^1F_1}{OF_1} = \frac{OF_1 - OB^1}{OF_1}$$

$$\frac{B^1F_1}{OF_1} = \frac{OF_1 - OB^1}{OF_1} = \frac{v - f}{f}$$

$\therefore$ (2) can be written as

$$\frac{A^1B^1}{OC} = \frac{v - f}{f} \text{ but } OC = AB$$

$$\frac{A^1B^1}{OC} = \frac{v - f}{f} \quad (3)$$

Comparing (1) and (3)

$$\frac{v}{-u} = \frac{v - f}{f}$$

$$vf = -uv + uf \quad (4)$$

dividing (4) by uvf

$$\frac{1}{u} = \frac{-1}{f} + \frac{1}{v}$$

or

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Using Cartesian sign

Object distance = $-u$

Image distance = $-v$

Focal length of concave lens = $-f$

From similar triangles A^1B^1O and ABO

$$\frac{A^1B^1}{AB} = \frac{OB^1}{OB} = \frac{-v}{-u} = \frac{v}{u} \quad (1)$$

From similar triangles OCF_1 and $A^1B^1F_1$

$$\frac{A^1B^1}{OC} = \frac{B^1F_1}{OF_1} \quad (2)$$

$$\frac{B^1F_1}{OF_1} = \frac{OF_1 - OB^1}{OF_1} = \frac{-f - (-v)}{-f}$$

$$\therefore \frac{B^1F_1}{OF_1} = \frac{-f + v}{-f}$$

$\therefore$ eqn (2) can be written as

$$\frac{A^1B^1}{OC} = \frac{-f + v}{-f} \text{ but } OC = AB$$

$$\frac{A^1B^1}{OC} = \frac{-f + v}{-f} \quad (3)$$

Comparing (1) and (3)

$$\frac{v}{u} = \frac{-f + v}{-f}$$

$$-vf = -uf + uv \quad (4)$$

dividing (4) by uvf

$$\frac{-1}{u} = \frac{-1}{v} + \frac{1}{f}$$

or

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\therefore \frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad (5)$$

Equation (5) is called the lens formula. This equation is general and is valid in all situations. It is applicable to the both convex & concave lenses.

Linear Magnification

It is the ratio of size of the image to the size of the object. Magnification is denoted by 'm'.

$$m = \frac{\text{height of the images (A}^1\text{B}^1\text{)}}{\text{height of the object (AB)}}$$

$$m = \frac{A^1B^1}{AB} \quad \text{From equation (1) of the previous page.}$$

$$\begin{aligned} \frac{A^1B^1}{AB} &= \frac{v}{u} \\ \therefore m &= \frac{v}{u} \end{aligned}$$

$$\text{Thus, magnification } m = \frac{h_i}{h_o} = \frac{v}{u}$$

Where h_i is the height of the image and h_o is the height of the object.

Magnification is positive for a convex lens forming a virtual image and magnification is negative if the image formed by the convex lens is real. Image formed by concave lens is always virtual, hence, magnification for concave lens is always positive.

Power of a Lens

Nature and size of the image depends on the focal length of the lens. A lens of short focal length bends the light to a large extent. Thus, the image formed by lens of short focal length will be closer to the optical centre. Power of the lens is the measure of degree of convergence or divergence of the lens. Power of the lens is defined as reciprocal of focal length in meter and is denoted by P.

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

Unit of power is dioptries, denoted by 'D', when f is in metre.

$$\therefore 1D = \frac{1}{1m}$$

Thus, 1 dioptre is the convergence or divergence produced by a lens of 1metre focal length.

Combination of thin Lenses

If two or more thin lenses are kept in contact, then their equivalent focal length

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3}$$

where $f_1, f_2, f_3, \dots$ are focal lengths of the lenses then the power of the combination of the lenses.

$$P = P_1 + P_2 + P_3, \dots$$

Where
$$P_1 = \frac{1}{f_1}; P_2 = \frac{1}{f_2}, \dots$$

EXAMPLE

An object 5 cm high is placed at a distance of 10 cm from a convex lens of focal length 15 cm. Find the nature, position, size and magnification of the image.

SOLUTION

Using Cartesian convention

Object distance = -10 cm

Focal length of a convex lens = 15 cm

Height of the object = $h_o = 5$ cm

Using lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{15} = \frac{1}{v} = \frac{1}{-10}$$

$$\frac{1}{15} = \frac{1}{v} + \frac{1}{10} \Rightarrow \frac{1}{v} = \frac{10 - 15}{15 \times 10}$$

$$v = -\frac{150}{5} = -30 \text{ cm}$$

Negative sign indicates it is a virtual image

$$m = \frac{v}{u}$$

$$m = \frac{-30}{-10} = 3$$

Positive sign indicates the image is erect.

$$m = \frac{h_i}{h_o} \Rightarrow 3 = \frac{h_i}{5}$$

$\therefore$ height of image = $5 \times 3 = 15$ cm.

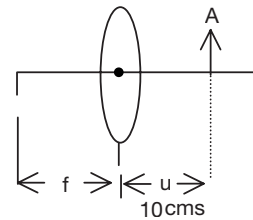


FIGURE 4.44 Formation of image by a convex lens

EXAMPLE

A convex lens throws on a screen 12 m from the lens a magnified image of the object. If the magnification is 15, find the focal length of the lens.

SOLUTION

Magnification $m = 15$

Image distance = v

$$\text{Magnification} = + \frac{v}{u} \quad (1)$$

From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

using Cartesian sign

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{-u}$$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\therefore \frac{1}{u} = \frac{1}{f} - \frac{1}{v}$$

$$\frac{1}{u} = \frac{v - f}{vf}$$

$$u = \frac{vf}{v - f} \quad (2)$$

Substituting (2) in (1)

$$m = \frac{v(v - f)}{vf}$$

$$\therefore 15 = \frac{12 - f}{1}$$

$$15f = 12 - f$$

$$16f = 12$$

$$f = \frac{12}{16} = 0.75\text{m}$$

EXAMPLE

Two convex lenses A and B of focal lengths 0.3 m and 0.2 m respectively, are placed in contact. Calculate the effective focal length and the power of the combination. If B is a concave lens, what is the effective focal length and the power?

SOLUTION

Reciprocal of effective focal length of the combination of the lens

$$\begin{aligned}\frac{1}{f} &= \frac{1}{f_1} + \frac{1}{f_2} \\ \frac{1}{f} &= \frac{1}{0.3} + \frac{1}{0.2} \\ \frac{1}{f} &= \frac{0.2 + 0.3}{0.06} \\ f &= \frac{0.006}{0.5} = 0.12\text{m}\end{aligned}$$

Power of the combination

$$P = \frac{1}{f} = \frac{0.5}{0.06} = 8.33\text{D}$$

Thus, the combination behaves like a convex lens of focal length 0.12 m

If lens B is a concave, then the effective focal length is

$$\begin{aligned}\frac{1}{f} &= \frac{1}{f_1} + \frac{1}{f_2} \\ \frac{1}{f} &= \frac{1}{0.2} + \frac{1}{-0.2} \\ \frac{1}{f} &= \frac{0.2 - 0.3}{0.006} \\ \frac{1}{f} &= \frac{-0.5}{0.06} \\ f &= \frac{-0.05}{0.1} = -0.6\text{m}\end{aligned}$$

Power of the combination

$$P = \frac{1}{f} = \frac{1}{-0.6} = -1.67\text{D}$$

The combination behaves like a power -1.67D concave lens of focal length 0.6 m.

EXAMPLE

A convex lens of focal length 0.12 m produces an image which is thrice the size of the object. Find the distance between the object and the lens.

SOLUTION

Focal length of the lens = 0.12 m

$$\text{Magnification } m = \frac{h_i}{h_o} = \frac{v}{u}$$

$$h_i = 3h_o$$

$$\therefore m = 3$$

$$m = \frac{v}{u}$$

$$3 = \frac{v}{u}$$

$$v = 3u$$

From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Object distance for convex lens = $-u$ (v for a real image, = $+3u$)

$$\frac{1}{0.12} = \frac{1}{3u} - \frac{1}{-u}$$

$$\frac{1}{0.12} = \frac{1}{3u} + \frac{1}{u}$$

$$\frac{1}{0.12} = \frac{4}{3u}$$

$$u = \frac{4 \times 0.12}{3} = 0.16 \text{ m}$$

To obtain real image $u = 0.16$ m

To obtain virtual image v is $-ve$

$$\therefore v = -3u$$

$$\frac{1}{0.12} = \frac{-1}{3u} + \frac{1}{u}$$

$$\frac{1}{0.12} = \frac{-u + 3u}{3u^2}$$

$$\frac{1}{0.12} = \frac{2u}{3u^2}$$

$$u = \frac{2 \times 0.12}{3} = 0.08 \text{ m}$$

To obtain virtual image, object distance = 0.08 m.

Experiment To Determine Focal Length of a Convex Lens

By Distant Method

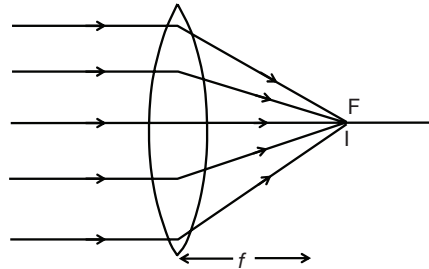


FIGURE 4.45 Focal length of a convex lens by distant object method

1. Mount the lens on a lens stand.
2. Direct the lens towards a distant object such as a tree, etc.
3. Place the screen behind the lens.
4. Adjust the distance between the screen and the lens until a clear and sharp image of the object is obtained.
5. Measure the distance between the screen and the lens. This distance gives the approximate focal length.

By Plane Mirror Method

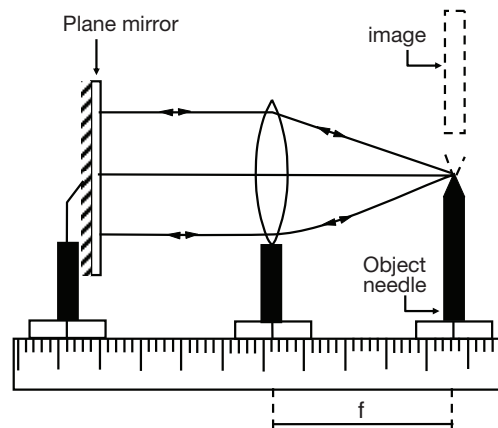


FIGURE 4.46 Formation of image by convex lens by plane mirror method

1. Mount the convex lens on the lens stand.
2. Place a needle in front of the lens and a plane mirror on the other side of the lens, so that the plane of the mirror is vertical and perpendicular to the axis of the lens.
3. Adjust the distance of the lens or the object (needle) until a real and inverted image is formed just above the object.
4. If the tip of the image coincides with the tip of the object, then the distance between the needle and the lens gives the focal length.

Focal Length by $u - v$ method

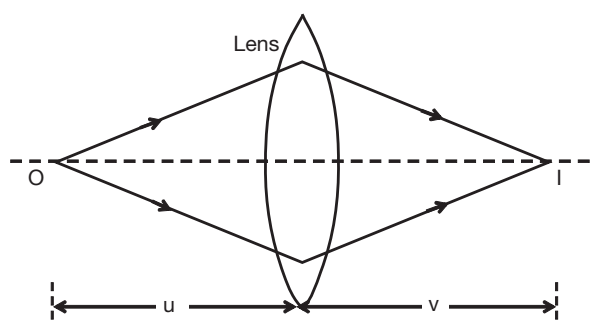


FIGURE 4.47 $u-v$ method

1. Mount a convex lens on a lens stand
2. Place an illuminated object in front of it and a screen behind the lens.
3. Adjust the distance between the screen and the lens until a clear and sharp image is obtained on the screen.
4. Measure the distance between object and the lens. This gives object distance (u).
5. Distance between the screen and the lens gives the image distance v .
6. Focal length is calculated using the formula $f = uv/u + v$ (after appropriate sign convex).

Observation
no

u cm

v cm

$$f = \frac{uv}{u + v} \text{ cm}$$

Application of Lens

1. Lenses are used in optical instruments like telescope, microscope, camera and spectrometer.
2. Lens are used to rectify eye sight of a person having defective eye sight.

Dispersion of Light

Early Discovery of Newton

When Newton was observing stars using astronomical telescope, he found that the stars were coloured near the fringes. He concluded that the colours observed were due to the nature of light but not due to the defect in lens. To prove this, he placed an equilateral prism in a path of narrow beam of light entering through a small aperture of a window in a dark room.

Emergent light from the prism was received in the screen. He found that emergent rays were spread out in bands of seven colours with red at one end merging gradually with orange, yellow, green, blue, indigo and violet.

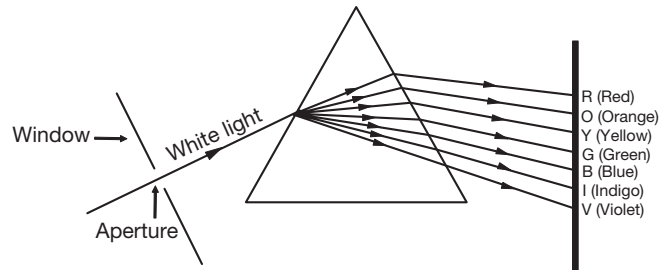


FIGURE 4.48 Dispersion by a prism

This the phenomenon of splitting of white light into its constituent colours is known as dispersion. The medium which brings about dispersion is called dispersive medium.

Example: prism is a dispersive medium. Vacuum or air is a non-dispersive medium.

The band of colours (wavelength) obtained is known as spectrum. Spectra are classified as pure spectrum and impure spectrum.

Pure Spectrum

It is the spectrum in which the constituent colours occupy their respective position (VIBGYOR) and are distinct. For example, spectrum obtained from prism and spectroscope arrangement.

Impure Spectrum

It is a spectrum in which the bands of colours overlap. There are no well defined boundaries between the bands of colours.

Example: Rainbow

Rainbow cause for Dispersion

Dispersion occurs because different colours (wavelengths) are refracted or deviated to different extents because speed of different colours of light is different in a given medium.

$$\mu = \frac{\text{velocity of the light in air or vacuum}}{\text{velocity of light in air given medium}}$$

The refractive index of violet colour in glass is greater than the refractive index of red, or in other words, speed of violet is least in glass and the speed of red is the maximum.

Refrangibility

It is the ability of light to get refracted when passing from one medium to another. It depends on the refractive index of the medium for a given wavelength of light. In the visible light, the refrangibility for violet is maximum and that of red is least. ($\delta_{\text{violet}} > \delta_{\text{red}}$).

Experiment II

Experiment to show how white light splits into its constituent colours and it is not the prism which colours white light.

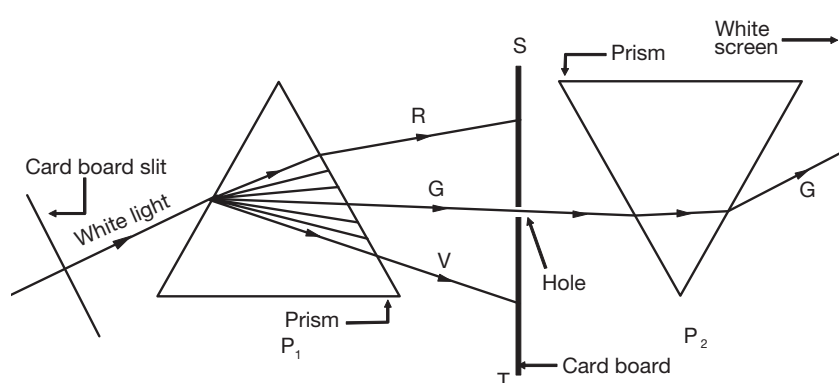


FIGURE 4.49 Refrangibility of white light through prisms

White light from a slit is made to pass through an equilateral prism placed in a dark room. Dispersed light from this prism is obtained on the white screen having a small hole. The coloured light passing through this hole is made to fall on a second prism P_2 , which is placed in an inverted position. The light passing through the second prism gets refracted but does not undergo dispersion.

Experiment III

Newton's experiment on recombination of white light: Newton took two identical prisms P_1 and P_2 . P_2 was placed inverted with respect to P_1 . White light emerging out of the slit was made to fall on P_1 . The spectrum produced by P_1 was interrupted by the prism P_2 . He found that white light emerged out of P_2 . Thus, the spectrum produced by P_1 recombined in the prism P_2 .

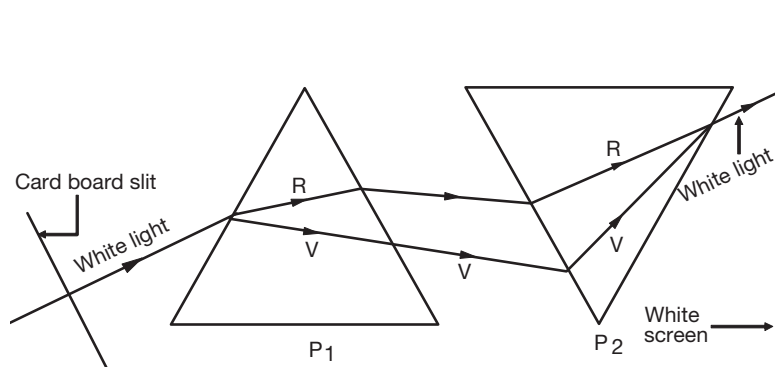


FIGURE 4.50 Recombination of dispersed light

Second prism P_2 bends the dispersed colours, towards its base through different angles such that the rays emerging out from the prism P_2 are incident at the same point. Thus, P_1 is a dispersing prism and P_2 is a recombined prism.

COLOUR OF THE OBJECTS AND PIGMENTS

From the above facts, it is seen that white light consists of seven colours.

Colours It is the sensation produced in the brain, when a certain wavelength in the visible region strikes the retina.

Pigments It is an optically active substance which absorbs most of the wavelengths in the visible regions and reflects selective wavelengths. For example, leaf appears green in colour due to the presence of chlorophyll pigment. Pigments are colourless and get activated when white light is incident on them.

When white light is incident on the object, it absorbs some of the colours and reflects certain colours so the colour of an object is determined by the wavelength it reflects.

Sunflowers appear yellow because of the pigment present in them which absorbs all colours except yellow. An object appears white if it does not absorb any colour and it appears black if it absorbs all the colours. A colour filter is a transparent body which allows certain wavelengths to pass through it and absorbs all other wavelengths.

Primary Colours of Light

Red, blue and green are called primary colours as they are monochromatic. Other colours are obtained by mixing primary colours in proper proportions. If the primary colours are mixed in proper proportion, white light is obtained. Colours obtained by mixing two primary colours are called composite colours or secondary colours.

Example:

Red + Blue = Magenta

Red + Green = Yellow

Blue + Green = Cyan

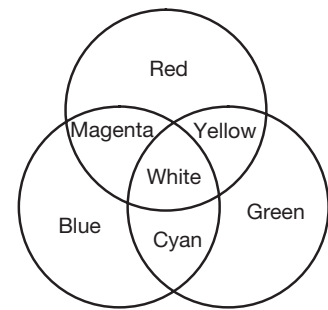


FIGURE 4.51 Primary colours and their derivative colours

Complimentary Pair of Colours

A pair of colours, in which one is a primary colour and the other is a secondary colour, which on mixing in proper proportion gives white light.

Example: Yellow + Blue = White

Colour on the vertex of the triangle represents a primary colour. Colours at the mid points represent composite colours. Colours at the line joining the vertex and midpoint of the side opposite to it represent complimentary colours.

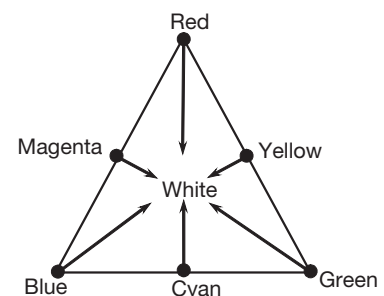


FIGURE 4.52 Colour triangle

RAMAN EFFECT

Tyndall and Rayleigh discovered that when a beam of light is passed through a transparent and homogeneous medium, a part of the incident light is deflected sideways and scattered. The frequency or wavelength of the scattered beam was found to be same as that of incident beam.

Lord Rayleigh explained the blue colour of the sky. He said that the blue colour of the sky is due to the scattering of light by molecules present in the atmosphere. The intensity of the scattered light in a medium is inversely proportional to the fourth power of the wavelength.

$$I_{\max} \propto \frac{1}{\lambda^4}$$

$I_{\max}$ is the maximum intensity, λ is the wavelength of light. Thus, the wavelength of blue light is minimum and it is scattered most. Rayleigh scattering is also called coherent scattering. Coherent scattering is a scattering in which there is no change in the wavelength of light, i.e., scattered light has the same wavelength as that of the incident light.

At sunrise and sunset, sun appears red in colour. This is due to Rayleigh scattering, At sunset and sunrise, light from the sun travels maximum distance. As a result most of the blue light is scattered and the light reaching the earth's surface lacks blue colour. It is red colour which reaches the earth's surface, since it is least scattered.

When Sir C.V. Raman was experimenting the scattering of light by liquids, he discovered that when a monochromatic light is passed through organic liquid like benzene, toluene, etc. It results in the formation of the scattered light which consists of wavelengths of frequencies higher and lower that of the incident light in addition to that of the incident light. This is known as Raman effect. Raman's scattering is an incoherent scattering. Incoherent scattering is a type of scattering in which the scattered light consists of frequencies other than those of the incident light. Raman effect is used to study the structure of molecules.

Spectroscope

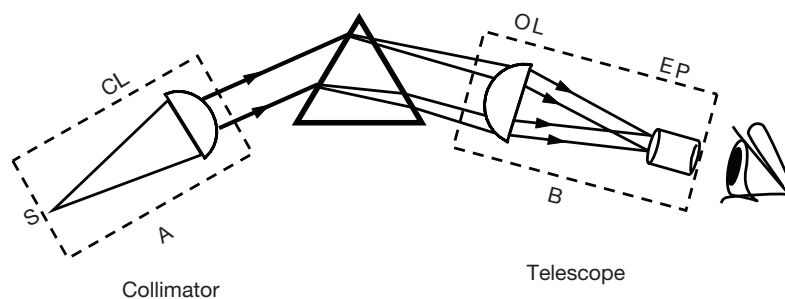


FIGURE 4.53 Spectroscope

Spectroscope is an instrument used to obtain pure spectrum. Spectroscope consists of collimator, prism table and a telescope.

Collimator consists of a slit from which light rays are rendered parallel by the lens. This light is made to fall on a prism placed on the prism table which is in line with the collimator. The rays get dispersed by the prism and the spectrum is observed through a telescope.

Uses of a Spectroscope

Spectrometer helps us to observe spectra. By studying and analysing spectra, information about the sources of light can be obtained. Special spectrometer is required to study Raman lines.

Emission Spectra

Light from a candle or an incandescent bulb consists of all wavelengths present in the visible region. This spectrum is known as continuous emission spectra.

When gases and vapours are made to emit light, the spectrum consists of a number of bright lines against a dark back ground. These spectrum is known as line emission spectrum.



FIGURE 4.54 Emission spectra

Line emission spectra is a characteristic of an element, i.e., different elements give rise to different line spectra. By studying line spectra, elements present in the gas or molecules can be discovered.

By measuring intensities of the line spectra, an approximate amount of each element present can be found out. This technique is called spectro-chemical analysis. This is used in medicine and crime detection.

Absorption Spectra

When white light is passed through gases or vapour at a low temperature, some of the wavelengths are absorbed. Then spectrum formed is known as absorption spectrum.

Example: When a light from carbon arc is passed through sodium vapour, two lines are blotted out in the yellow region (D_1 and D_2) of the spectrum.

When a solar spectrum is observed by Picture a powerful telescope, the spectrum consists of a number of dark lines. These lines are called Fraunhofer lines, named after Fraunhofer who first studied these lines.

By analysing Fraunhofer lines, elements present in the sun can be found out. Helium was discovered by studying Fraunhofer lines.

Electromagnetic Radiations

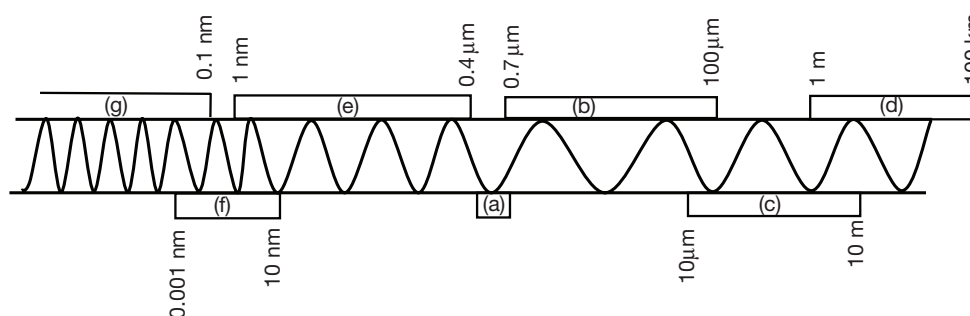


FIGURE 4.55 Various regions of electromagnetic spectrum and their wavelength ranges

(a) Visible spectrum	(b) IR spectrum	(c) Microwaves (Radio waves)
(e) UV spectrum	(f) X-rays	(g) γ -rays

Radiations, IR, visible, UV, radio waves, X-rays, gamma rays and micro waves constitute electro magnetic spectrum. These radiations can be described in terms of oscillating electric and magnetic fields which are at right angles to each other and are perpendicular to the direction of propagation. All radiations travel with the speed of light but differ in their wavelengths or frequencies.

$$c = v\lambda$$

c – where C is the speed of light and λ is the wavelength, v is the frequency

Differences in the properties of different electromagnetic radiations are due to the difference in their frequencies.

Visible Spectrum

The wavelength of visible light ranges from 400 nm to 750 nm ($4000 \text{ \AA}$ to $7500 \text{ \AA}$). The spectrum within this range is called visible spectrum (VIBGYOR)

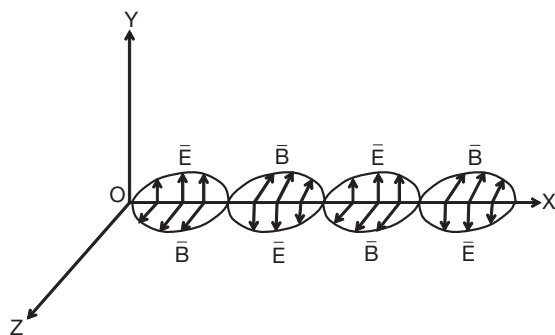


FIGURE 4.56 Electromagnetic wave

Invisible Spectrum

It is the region of spectrum which does not strike the retina.

Radio Waves

The wavelength of radio waves ranges from 1 m to 100 km. They are produced by electro magnetic oscillators of low frequencies. Radio waves are received from extra-terrestrial sources known as radio astronomy. Radio waves of short wavelengths are used in communication which includes satellites, Radars and TV. Longer wavelengths are used in radio broadcasting.

Microwaves

The wavelength of microwave ranges from $10 \mu\text{m}$ to 10 m. These waves are produced by electromagnetic oscillators of high frequency in an electric circuit. They are used in radio detection and ranging, microwave ovens, telemetry and satellite communications.

INFRARED SPECTRUM

It is an electromagnetic radiation beyond the red region. Its wavelength varies from about $8000 \times 10^{-10} \text{ m}$ to $4,00,000 \times 10^{-10} \text{ m}$

Infrared rays were discovered by William Herschel. He obtained a spectrum by passing sunlight through a glass prism. He observed a rise in temperature when he moved a thermometer with a blackened bulb from violet region to red region and there was a sudden increase in temperature beyond the red region. Infrared rays produce heating effect but not the visible effect.

Sources of Infrared Rays

Sun, lamp, burning gases are some of the sources of infrared rays. Any substance which radiates heat is a source of infrared rays. All living beings emit IR rays.

Properties of IR Rays

1. They are electromagnetic radiations which are not affected by electric and magnetic field.
2. They travel with the speed of light.
3. They do not affect photographic plates.
4. They are least scattered by fog and mist because of their long wavelengths.
5. They can be detected by thermopile or thermometer with blackened bulb.
6. They obey the laws of reflection and refraction. Hence, they can be focused by parabolic mirrors or lenses.
7. Infrared rays having wavelength beyond $20,000 \times 10^{-10}$ m can be absorbed by glass.
8. They can penetrate rock salt.

Uses

1. Since they produce heating effect, they are used to relieve pains from muscles and swollen joints.
2. Because of their long wavelength they can travel long distances in fog without much scattering and are used in infrared photography.
3. They are used in surface to air missiles.

A missile is fired in the direction of an enemy plane. Sensor of infrared radiation present in the missile detects the heat trail left by the enemy plane and sends the message to computer. The computer guides the missile towards the target.

4. They are used to detect diseases in crops. Any change in the heat radiation of crops is due to some kind of disease. Heat radiation is measured through satellites.
5. Night vision devices are used to see objects in dark. These devices can detect infrared radiation emitted by hot objects.

ULTRAVIOLET SPECTRUM

The region of spectrum beyond violet region is called ultraviolet spectrum.

This spectrum was discovered by J. Ritter. Ritter discovered that when a silver chloride paper was placed beyond violet region, it first turned to violet, then brown and black. Thus,

the ray which produced strong chemical effect in silver chloride paper was named as chemical ray or actinic ray. Later on the rays were named as ultraviolet rays. Glass absorbs UV rays but quartz does not absorb these rays.

Sources

1. Any source of light at temperature greater than 2500°C is a good source of UV rays.
2. Sunlight, mercury vapour lamps.

Properties

1. They are electromagnetic waves having wavelength between $4000 \text{ \AA}$ to $100 \text{ \AA}$ ($1 \text{ \AA} = 10^{-10} \text{ m}$)
2. They are not affected by electric or magnetic fields.
3. They obey the laws of reflection and refraction.
4. They produce fluorescence when incident on substances like zinc sulphide, quinine sulphate solution.

Fluorescence is a phenomenon in which a substance absorbs light of shorter wavelength and reflects a light of longer wavelength.

5. They produce chemical effects.
6. They travel with the velocity of light.
7. They are absorbed by stratosphere and convert ozone to oxygen.

Uses

1. Ultraviolet rays when absorbed by a human body produces vitamin D which helps in growth of strong bones and teeth but causes blindness when seen directly.
2. Ultraviolet rays are used to detect original gems from fake ones.
3. Ultraviolet rays are used to detect forgery. The document to be checked is placed under ultraviolet rays and any alterations can be easily detected.
4. The UV rays kill germs and microorganisms. Hence, they are used to sterilize surgical instrument and drinking water.

X-RAYS

They have wavelength ranging from $0.01 \text{ \AA}$ to 10 nm ($100 \text{ \AA}$). X-rays are produced when a high speed electron is stopped by a target. X-rays of shorter wavelength are used to study structure of materials because the spacing between the atoms in a solid ranges from $0.1 \text{ \AA}$ to $10 \text{ \AA}$. These X-rays are called hard X-rays. X-rays of longer wavelength called soft X-rays can penetrate flesh but they are stopped by bones and are used in radiography.

GAMMA RAYS

Gamma rays have wavelength ranging from 0.0001 nm to 0.1 m. Gamma rays are produced by radioactive elements. Gamma rays have the highest penetrating power. Gamma rays are used in treatment of cancer. They are used as γ ray microscope and are used to produce photo-electric effect.

PHOTOELECTRIC EFFECT

Max Planck proposed quantum theory in order to explain black body radiation. According to quantum theory, radiation consists of tiny packets of energy called quanta or photon. The energy of each quantum is given by, $E = h\nu$, where h is Planck's constant whose value is $6.63 \times 10^{-34} \text{ J s}$ and ν is the frequency of radiation. These quanta travel with the velocity of light. According to quantum theory, radiation cannot be emitted or absorbed continuously. It can be done in integral multiples of $h\nu$. When light of suitable frequency falls on a metals, electrons are emitted out from the metal surface. This phenomenon is known as photoelectric effect. Electrons emitted are known as photoelectrons. UV rays, X-rays and γ -rays can cause photoelectric effect on certain metals.

The minimum frequency required for the incident light to eject electrons from the metal surface is known as threshold frequency. If the frequency of incident light is less than its threshold frequency, electrons are not emitted from the metal surface. If the frequency of incident light is greater than the threshold frequency, electrons are ejected with kinetic energy or in other words velocity of photoelectrons increases with frequency. Threshold frequency is different for different metals.

Number of photoelectrons depends only on intensity of incident light and the photoelectrons increase with increase in intensity of incident light.

Einstein Explanation of Photoelectric Effect

Einstein made use of Planck's quantum theory in order to explain photoelectric effect. Einstein assumed that tiny packets of energy called photons propagate through space and interact with matter. When a photon of energy $h\nu$ is incident on a metal, it interacts with an electron and transfers the whole of its energy to a single electron. The electrons are bound to the material, and hence, a certain amount of work has to be done to release the electron from the metal surface. If the frequency of incident radiation is lesser than the threshold frequency, electrons cannot be emitted and there is no photoelectric effect. If the frequency of the incident radiation is greater than the threshold frequency, part of the energy is used to release the electron and the remaining part is given as kinetic energy to an electron.

Application of Photoelectric Effect

1. Used to reproduce sound in cinematography.
2. Used in burglar alarms.
3. Used in automatic opening and closing of doors

4. Used in automatic control of traffic signals.
5. Used in exposure meter.
6. Used in automatic switching on and off street lights.

Theories of Light (a Historical Review)

First century A.D.	The Greek scientists Euclid and Hero suggested that light travelled in straight lines and that light originated at the eye and travelled towards the object of vision.
~ 1000 A.D.	The Arab scientist Alhazen proposed that light radiating from a luminous source gets reflected from the objects to the eyes allowing them to be seen.
16th century	The English thinker Francis Bacon interpreted light as a disturbance that could be detected by the eye and that this disturbance gets 'stained' when they get reflected from an object causing the colours.
Early 17th century	Galileo and Kepler succeeded in the construction of a refracting telescope proving the laws of refraction, and Snell refined these laws.
17th century	Sir Isaac Newton and his contemporary Christian Huygens, a Dutch scientist, came up with contradictory theories on light stirring a debate over the truth in their proposals. While Huygen proposed his wave theory Newton came up with the corpuscular theory. Newton's theory was more readily accepted and prevailed for almost a century.

NEWTON'S CORPUSCULAR THEORY

Based on his experiments in 1666 and the laws of mechanics, Newton proposed his corpuscular theory on the following assumptions.

1. Light is made up of point-like particles called corpuscles having negligible mass.
2. These particles are perfectly elastic and travel in straight lines.
3. Based on the laws of motion interfaces of different optical media exert forces of attraction and repulsion leading to the phenomena of reflection and refraction.
4. Speed of light is greater in a denser medium.
5. The different of the corpuscles account for the different colours.

He went on to explain that just as a perfectly elastic collision takes place when a ball hits or strikes a rigid surface, reflection of light takes place when corpuscles strike a reflecting surface.

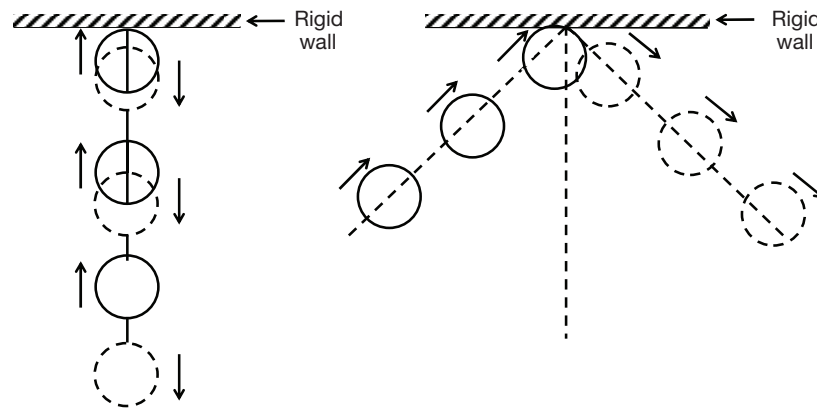


FIGURE 4.57 Elastic collision of a rubber ball and a rigid wall

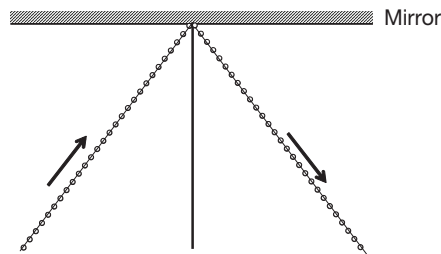


FIGURE 4.58 Reflection of light corpuscles

To explain the phenomenon of refraction, Newton suggested that as the light particles enter a denser medium they are attracted by particles of the medium and so travel faster resulting in the bending of the path traced.

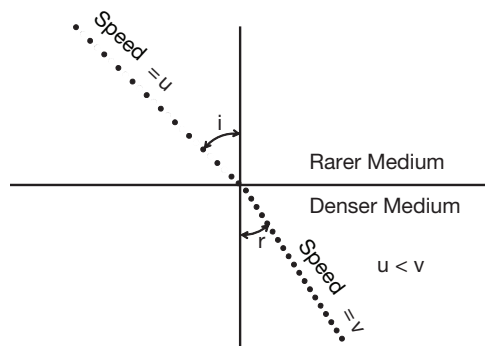


FIGURE 4.59 Motion of particles during refraction

Drawbacks of Newton's Corpuscular Theory

1. Newton proposed that velocity of light in a denser medium is greater than its velocity in a rarer medium but it was found that velocity of light in the rarer medium is greater than its velocity in the denser medium.
2. There was no justification for the assumption that different colours were due to different sizes of the corpuscles.
3. Newton's theory could not explain phenomenon like interference, diffraction and polarization.

HUYGEN'S WAVE THEORY

A group of scientists led by the Dutch physicist Christian Huygens challenged Newton's corpuscular theory by claiming that the wave theory gave a better explanation of reflection and refraction. They put forth the following proposals to explain the behaviour of light.

1. All space is filled with an invisible substance called ether and light travels in the form of longitudinal mechanical waves.
2. Every luminous body which is a source of light, either point or extended (a line) would be at the geometrical centre of the propagation of wave and is called the primary source.
3. Any point in the medium which would act as a source of light for further propagation is referred to as a secondary source.
4. All points in the medium which receive the light from the source, either primary or secondary, at the same time would lie along a curved surface called wavelet.
5. The envelope of all wavelets in the same phase—receiving light at the same time—would form a wave front.
6. The 'ray of light' would be along the normal, drawn at a point.
7. At large distances from the primary source, (luminous body) the radius of curvature of a wave front would be large such that small portions of the wave front may be approximated to a plane.

On the basis of the above hypotheses, spherical, cylindrical or plane wave fronts may be constructed.

Newton-huygen Debate

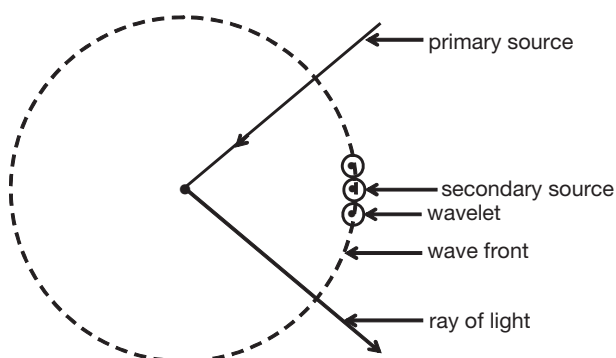


FIGURE 4.60 Spherical wave front

1. Huygen reiterated that reflection and refraction as well as dispersion of light could be convincingly explained with the help of wave theory.
2. Newton attacked the wave theory. He pointed out that if the wave theory was true then light should bend round the corners, just as sound and water waves do.

(Interference and diffraction were not known until Fransesco Grimaldi's experiments later indicated that light does bend at corners).

3. Newton's supposition that speed of light increased in denser medium was disproved when Foucault and Fizean's experiments on speed of light pointed out that light travelled faster in a rarer medium.

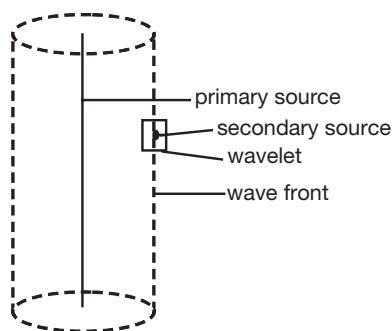


FIGURE 4.61 Cylindrical wave front

4. The assumption made by Huygens that space was filled with matter called ether could not be proved and as such did not gain much support.
5. Newton's theory suffered a major setback when first Thomas Young (1801) and later Fresnel, Malus and Fraunhofer discovered interference and diffraction, which could not be explained by the corpuscular theory, thus, giving strength to the wave theory of Huygens.
6. Huygen's postulate that light travelled as mechanical waves was disproved when in 1872 James Maxwell discovered the existence of electromagnetic waves; and Heinrich Hertz showed that these electromagnetic waves displayed all the phenomena of light, suggesting that light is also an electromagnetic wave, which is fundamentally a transverse wave.

Light was first believed to be possessing a particle nature giving rise to the particle theory of light. But then it was found that, while some observations could be explained using this theory there were observations which could not be explained. This led to the profounding of new theory put forward by Huygen called the 'wave theory of light'. But then certain observations explained by the particle theory of light could not be explained about the wave theory- to resolve this problem certain scientists came up with the idea that light behaves both as a particle and a wave leading to a new consolidated idea of 'dual nature of light'.

RIPPLE TANK EXPERIMENT

Certain phenomena like polarization of light confirmed the transverse wave nature of light. Even waves produced on the surface of water, also called ripples are also transverse waves. Hence, certain phenomena of light which can be explained by its wave nature can be easily understood by taking an analogy between water waves, i.e., ripples and light waves. For this purpose, we consider a water tank made of glass or perspex (a transparent material) mounted on four legs kept as supports, at a height. The side view of the tank is shown in the Fig. 4.62.

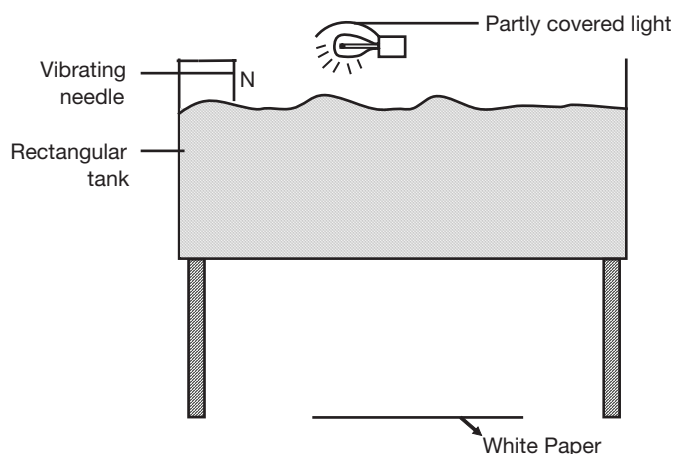


FIGURE 4.62 Ripple Tank (side view)

A small needle, which is fixed to one end of a metallic strip is connected to a vibrator and held above the water surface so that when the vibrator is switched on, the needle vibrates to and fro and produces ripples in the water. These ripples consist of crests and troughs and are circular in shape. The circular ripples produced at the needle expand while the wave moves in all directions.

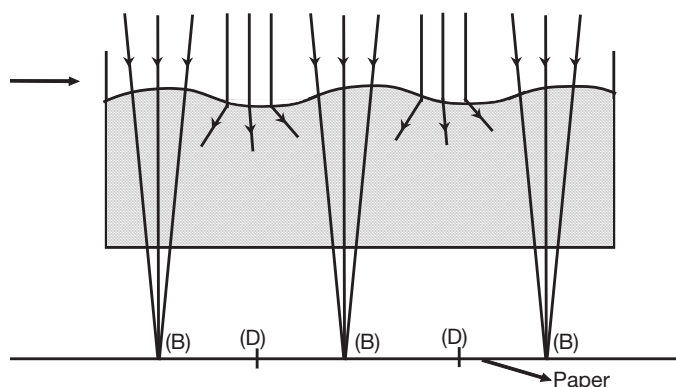


FIGURE 4.63 Formation of bright (B) and dark (D) bands on paper placed below the ripple tank

A white paper is placed below the tank on the ground surface. A bulb is held horizontally above the water surface. The light from the bulb passes through the water towards the paper kept below the ripple tank. The crest portion of the waves acts as a convex lens, and thus forms a bright band of light on the paper placed below the tank. Similarly, the trough portion of the waves acts as a concave lens, and thus forms a dark band of light on the paper placed below the tank. Thus, the motion of ripples in the tank can be understood by the motion of dark and bright bands of light on the paper.

Reflection of Waves in a Ripple Tank

Consider a ripple tank as described earlier, with a pin arrangement which vibrates and produces ripples in the tank. The circular ripples produced will be reflected by a hard surface like the wall of the tank. The top view of the ripple tank where the circular ripples are produced at source 'O' and reflected at the wall of the tank 'AB' is shown in the Fig. 4.62.

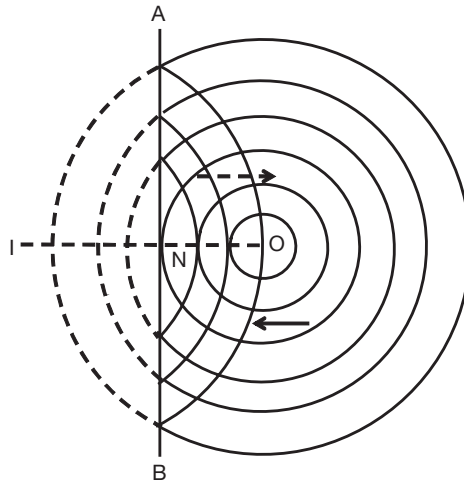


FIGURE 4.64 Reflection of waves in a ripple tank

The ripples would reflect at AB such that the centre of the reflected ripples would be at ' I '. Thus, ' I ' is the image of ' O ' and the distance $ON = IN$, which implies that the object distance is equal to image distance, considering AB as the reflecting surface.

The phenomenon of reflection can be studied by observing the movement of bright and dark bands of light on the white paper placed below the ripple tank.

Refraction of Waves in a Ripple Tank

For refraction to take place we require two media with different densities such that waves from one medium travel to another medium. In a ripple tank this is possible by introducing a pile of plates at the bottom portion covering half the area. The side view of such an arrangement in a ripple tank is shown in the Fig. 4.65.

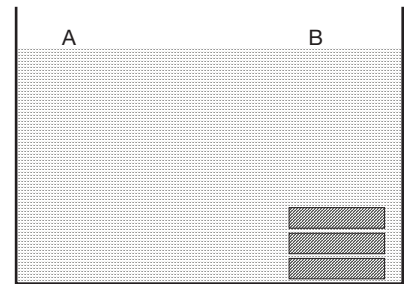


FIGURE 4.65 Ripple tank

The ripple tank is considered to be of two portions ' A ' and ' B '. In portion ' B ' at the bottom of water a pile of plates is placed such that the depth of water in the region ' B ' is decreased and becomes shallow. So, region ' A ' is a deep water region. The velocity of water waves

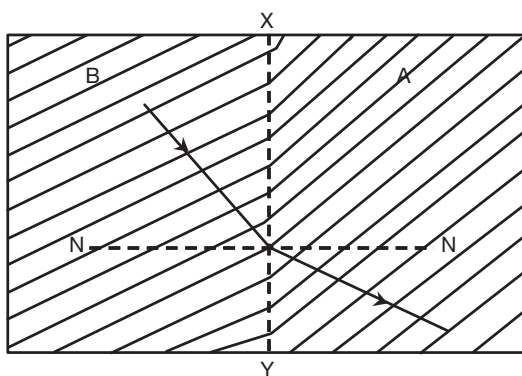


FIGURE 4.66 Refraction of waves in a ripple tank

depends on the depth of water. The waves produced in the region ' A ' while travelling toward region ' B ' change their velocity; and hence their wavelength. In this case, a small straight strip like scale is used to produce waves instead of a small needle so as to produce plane waves in place of circular waves. The horizontal portion of the scale is in contact with water and vibrated to produce plane waves. In the top view of the ripple tank shown in the Fig. 4.66, XY is an imaginary line which acts as a boundary between shallow region ' B ' and deeper region ' A '. The waves produced in region ' A ' travel towards ' B ' and in this process their velocity is decreased. Hence, the wavelength of the

waves is also decreased. This can be understood by observing the distance between two bright bands of light formed on the white paper below the tank in both the regions 'B' and 'A'. The bold lines in the Fig. 4.66 indicate the plane wave fronts and the lines with arrows which are normal to the waves indicate the direction of rays. It can be understood that the rays while travelling from rarer to denser medium bend towards the normal. A similar effect takes place in light.

SUPERPOSITION OF WAVES

Consider two vibrating pins placed at different locations in a ripple tank. The waves produced from these two pins propagate in all possible directions and they meet in a common region. When the waves meet, the net effect (displacement) of the vibrating particles produced at a point is the sum of the individual effects (displacements) produced at the point by the two waves. The total displacement at a given point is equal to the vector sum of displacements at that point due to individual waves. This is caused due to the overlapping or combination of the two waves at the point. This phenomenon is known as superposition and according to the principle of superposition of waves, when two or more waves travel through the same medium and meet at a point, the resultant displacement of the vibrating particle at a point is the vector sum of the displacements due to the individual waves at that point.

If a crest or trough of one wave combines with the crest or the trough of another wave respectively at a given point, the net displacement at the point is maximum and it is called 'constructive superposition'. Similarly when the trough or crest of one wave combines with the crest or the trough of another wave respectively at a given point, a net displacement at the point is minimum and it is called as 'destructive superposition'.

INTERFERENCE OF WAVES

During the superposition of waves, if the waves produced from two sources have the same frequency and amplitude and travel in the same direction, the superposition of such waves produce well defined constructive and destructive superposition in space and this phenomenon is called 'Interference'.

In interference, when constructive superposition takes place it is called 'constructive interference' and similarly when destructive superposition takes place it is called 'destructive interference'. To obtain a sustained interference pattern, i.e., a regular arrangement of maxima and minima, the following conditions are essential.

1. The waves that take part in interference must be in phase or have a constant phase difference between them. Such waves which have a constant phase difference between them are called coherent waves and the corresponding sources are called coherent sources.
2. The frequency or wave length of the two waves must be equal.
3. To get a maximum at a point in interference, the phase difference between the two waves must be $2n\pi$, where $n = 0, 1, 2$, etc.
4. To get a minimum at a point in interference, the phase difference between the two waves must be $(2n-1)\pi$ where $n = 1, 2, 3$, etc.

Interference of Water Waves in a Ripple Tank

Consider two pins, N_1 and N_2 arranged in a ripple tank instead of a single pin. These are used to produce ripples in the tank. Let these two pins vibrate simultaneously with the same frequency such that circular ripples are produced at the two locations ' N_1 ' and ' N_2 ' and travel in all possible directions.

The top view of the ripple tank with the above described arrangement is shown in the Fig. 4.67.

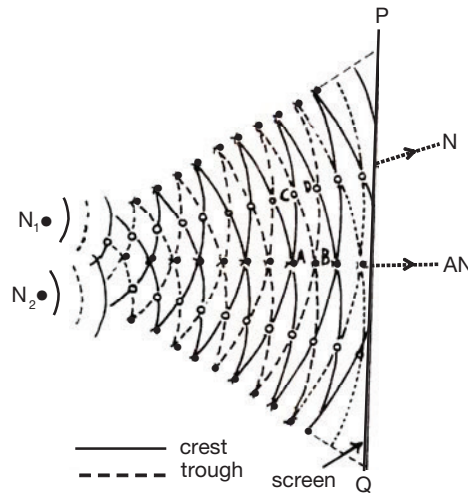


FIGURE 4.67 Interference of water waves in a ripple tank

When the distance between the two sources (N_1 and N_2) of the waves is lesser compared to their distance from screen PQ an interference pattern is observed. The positions where two crests or two troughs of waves from two sources ' N_1 ' and ' N_2 ' combine and produce constructive interference are marked with dots and the positions where a crest from one wave combines with a trough of another wave and produces destructive interference are shown by circles. Thus, on the screen ' PQ ' we observe the interference pattern, with maximum displacement of the water particles at some points and minimum displacement of the water particles at some points. The points of maximum displacement fall on the antinodal line and the points of minimum displacement fall on the nodal line. We also observe that these nodal and antinodal lines are distributed uniformly on the screen.

Similar to the interference of water waves taking place in a ripple tank, interference also takes place in light and on the screen where we observe interference pattern, the brightness of the light varies from maximum to minimum at equidistant locations forming bands of light called 'fringes'. The band of light where brightness is maximum is called a bright band and is caused by constructive interference of light. Similarly, the band of light where brightness is minimum is called a dark band and is caused by destructive interference of light.

Diffraction of Waves

Consider a ripple tank where a single pin is placed for producing ripples. The ripples produced are circular in shape. As the wave formed moves away from the source, the circular wavefronts are formed.

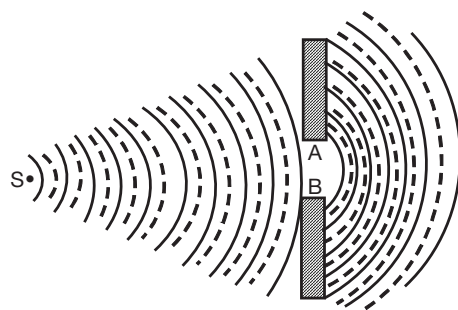


FIGURE 4.68 Bending of waves at the opening 'AB'

In such a situation, when an obstacle is placed such as a wooden plank with a wide hole 'AB' called an 'aperture' (only cross section of the plank is shown in the Fig. 4.68) as shown in the Fig. 4.68, the part of the wave striking the opening 'AB' will pass through it. But the hole *AB* itself becomes a 'secondary source' and waves travel in all directions beyond the hole on the other side of the plank. In the Fig. 4.69, the top view of the ripple tank with waves that are passing through the opening 'AB' is shown.

This bending and travelling of the waves as they pass through the edge of an obstacle is known as diffraction. The bold lines in the Fig. 4.68 indicate the crests of wave fronts while the dotted lines indicate the troughs. If the diameter of the opening, i.e., the hole decreases one can observe that the ripples which pass through the opening are likely to be more circular and this opening will act as another source that produces waves.

The hole itself acts as an obstacle and when the size (i.e., diameter) of the hole decreases to such an extent that the diameter of the hole is comparable with the wave length of waves, the diffraction pattern is more prominent.

Diffraction of light

The wavelength of light is of the order of angstroms. So, when light waves encounter obstacles of very small sizes, the light waves bend around the edges of the obstacle and travel. This is known as diffraction of light. It is due to the diffraction of light that a sharp shadow of an object cannot be obtained on any screen placed behind it. Due to diffraction, light bends and travels into the region of geometrical shadow of the object, and thus complete darkness is not found in the shadow. The brightness of light gradually decreases towards complete darkness as we go gradually into the geometrical shadow of the obstacle.

Diffraction of Waves at a Straight Edge

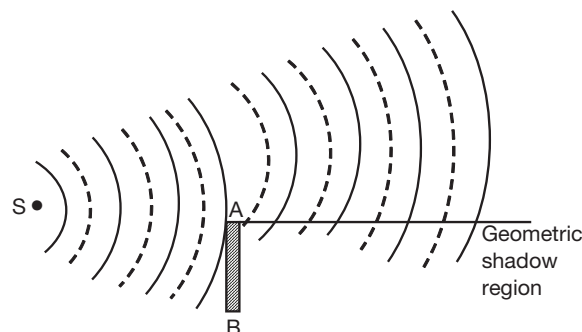


FIGURE 4.69 Diffraction of waves at a straight edge

If a lengthy strip like object, for example a half meter scale (AB), is held perpendicular to the motion of waves in a ripple tank such that the width of the scale is perpendicular to the surface of water as shown in the Fig. 4.69, the bottom portion of the waves is obstructed by the obstacle ' AB ' and the upper portion of the waves advances further.

But the waves moving beyond ' AB ' bend and travel into the geometric shadow region of the obstacle. This is the diffraction of waves observed due to a straight edge. Similar diffraction is observed when light is diffracted at a straight edge and the light after diffraction encroaches into the geometric shadow of the straight edge where one can observe a gradual decrease in brightness of light in the shadow.

Visual Photometry

When we tend to study in the light of a candle during night, we place ourselves near the candle. When we move away from the candle it becomes difficult for us to read; even though the amount of light emitted by the candle does not change. Hence, for clear vision, we need a light of sufficient brightness. Our eyes cannot bear too much of brightness of light also. So, there is a need to measure the brightness of light. The branch of physics which deals with the measurement of brightness of light is known as 'visual photometry'. Brightness of light from different sources cannot be compared just like that by observing and if it is done that way, it is not authentic. So, certain standards and techniques are used to measure the brightness of light from a source. The branch of physics which deals with measurement of brightness of light emitted by different sources using certain standards and some special techniques is known as visual photometry. The following are some of the basic terms that are used in visual photometry.

1. **Luminous flux or light flux (ϕ):** A source of light emits radiations depending on its temperature and the surface of the body. But eye is sensitive only to the amount of visible energy emitted by it. Luminous flux is the amount of radiant visible (luminous) energy emitted per second from the source. It is denoted by ϕ and is measured in Lumen.
2. **Solid angle:** Consider a small portion of an area on the surface of a sphere as shown in the Fig. 4.70. From the centre of the sphere, draw the normal lines on to the boundary of the area considered on the surface of the sphere. These lines form a cone.

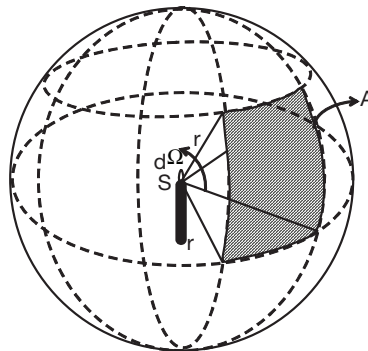


FIGURE 4.70 Concept of solid angle

The angle enclosed by the conical surface is known as solid angle. It is equal to the ratio of the area of the portion on the surface of the sphere to the square of the radius of the sphere.

If the area of the portion on the spherical surface is ' A ' and the radius of the sphere is ' r ', then the solid angle is given by, $\Omega = (A/r^2)$, and is measured in steradians (sr).

NOTE

The total surface area of a sphere is $4\pi r^2$ where ' r ' is its radius.

$$\therefore \text{Solid angle in a sphere} = \frac{4\pi r^2}{r^2} = 4\pi \text{ sr.}$$

- 3. Luminous intensity:** A light source emits light in all directions. The luminous flux emitted by a light source per unit solid angle in a particular direction is called luminous intensity. It is denoted by I .

So,
$$I = \frac{\phi}{\Omega}.$$

Luminous intensity is measured in units of candela (cd)

- 4. Candela (cd):** Luminous intensity of a point source is said to be 1 candela if one lumen of luminous flux is emitted per unit solid angle.

$$1 \text{ cd} = 1 \text{ lm sr}^{-1}$$

- 5. Lumen (lm):** Lumen is the unit of luminous flux. One lumen is defined as the amount of luminous energy emitted per second by a uniform source of light of luminous intensity one candela within a cone of unit solid angle.

$$1 \text{ lm} = 1 \text{ cd sr}$$

$$1 \text{ lm} = \frac{1}{683} \text{ W at } 555 \text{ nm of wavelength.}$$

- 6. Candle power:** Candles emit different intensities of light in different directions. The luminous intensity of the light source in a particular direction is known as candle power. It is expressed in candela (cd).

LASER

It is the acronym of light amplification by stimulated emission of radiation. Amplification is the process of increasing the energy and that is done in the light by stimulated emission of radiation; and so it is called laser. Lasers can be identified by their characteristic properties and because of them they differ from ordinary light.

Let us have a comparative study of ordinary light and a laser.

Property	Ordinary light	Laser
1. Phase difference	The light waves emitted from an ordinary source of light do not have a constant phase difference between them. The phase difference may change with time. Thus, ordinary light is incoherent.	The light waves emitted from a laser source have a constant phase relationship between them which does not change with time. This is called temporal coherence.
2. Directionality	An ordinary light source emits light in all directions due to divergence.	Laser emits light only in one particular direction, and hence has high directionality.
3. Monochromaticity	In case of an ordinary light, intensity is maximum at a particular wavelength. But the intensity of light is not zero in the neighbourhood of that particular wavelength. So, it has a band width and it is of the order of $1000 \text{ \AA}^\circ$.	For a laser, the intensity of light is maximum at a particular wavelength and in the neighbourhood of that wavelength, the intensity of light is zero. So, the bandwidth of laser is very less and it is of the order of $10 \text{ \AA}^\circ$.
4. Intensity	The light energy received per second per unit area is intensity. It is less in the case of ordinary light as an ordinary source spreads light uniformly in all directions.	The light from a laser source is limited to a small region, and it is not spread out like an ordinary light. So, intensity of light is high in laser light.

The above differences between ordinary light and laser light help in the study of characteristics of laser light which makes it different from an ordinary light.

Characteristics of Laser Light

1. Generally light is emitted from a source by transition of electrons in atoms from an excited state to ground state. When transitions take place in a random manner, there is no phase relationship between light waves emitted during the transitions of electrons. But in the case of a laser source, this transition of electrons from an excited state to ground state takes place in a regular order. Due to this, there exists a definite phase relationship between light waves emitted during the transition, which does not change with time. Thus, we say that these waves are coherent and the phenomenon relating to the constancy of this phase relationship is known as 'temporal coherence'. This is an important property of laser light.
2. We know that the light from a normal source is divergent and moves in all possible directions, distributing the light energy over a large area. But the light from a laser source is spread over very small area when compared to ordinary light. Thus, we can say that laser light is more limited to a particular direction and this property is known as 'directionality'.
3. The energy received per unit time per unit area is known as intensity. Since the laser light is not spread over a large area and is limited to a smaller one, all the light is incident on a small portion. So, the intensity of laser light is many times more than that of an ordinary light.

4. It is observed that the intensity of light varies with its wave length. As the wave length of light increases, its intensity increases and at a particular value of wavelength, it is maximum. Further, as the value of the wavelength becomes higher the intensity gradually decreases. So, the wavelength of a light is specified as the wavelength at which its intensity is maximum. The intensity of light does not abruptly become zero for certain wavelength range on either sides of the wavelength corresponding to maximum intensity. This range of wavelength, about a wavelength corresponding to maximum intensity is called 'bandwidth' and this band width is very less for laser light when compared to that of ordinary light. Hence, we can specifically assign a single value of wavelength to a laser light than to mention the band width of wavelength. This property of laser light is known as 'monochromaticity', as 'chromaticity' refers to colour which is a characteristic of wavelength of light.

Working of Lasers—The Process

The process involved in working of lasers are

1. absorption
2. spontaneous emission
3. pumping and population inversion
4. stimulated emission of electro magnetic radiation.

Light is emitted from a source when electrons have a transition from higher energy level to a lower energy level. So, for a transition to take place, electrons are initially excited from the ground state to a higher state (energy level).

Absorption

Consider two energy levels E_1 and E_2 . When a photon of energy $h\nu$ (ν is the frequency of radiation) is incident on an atom, the electron absorbs this energy, and if this energy $h\nu = E_2 - E_1$, the electrons jumps from the ground state E_1 to the excited state E_2 . In cases of gases or solid, a large number of atoms participate in the absorption of electromagnetic energy from an external source.

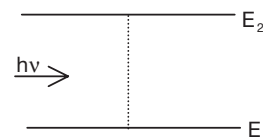


FIGURE 4.71 Absorption of energy by an atom

Spontaneous Emission

Electrons absorb energy from an external source like ordinary light. Once energy is absorbed from an external source, the electrons move from ground state to an excited state. But the electrons in the excited state cannot be maintained there for a long time and tend to come back to the ground state, on their own. Thus, electrons from excited state are transmitted to the ground state spontaneously and the resultant emission of light due to that spontaneous transition is known as spontaneous emission. But these spontaneous transitions of electrons take place at random, and hence, the light energy in spontaneous emission lacks coherence.

Population Inversion

To have a coherent radiation, a special system called ‘active system’ is introduced whose energy level lies between the ground state and the excited state of electrons, and the electrons transited to this active level (active state) from excited state remain in the state for longer period than their stay in the excited state. The radiation which is emitted when electron transitions take place from excited state to the active state, is very less and is completely absorbed by the active medium as thermal energy. Hence, this radiation is ‘invisible radiation’. The stability of the electrons in the active state is more and is called the ‘meta stable state’. As the transition of electrons from excited state to active state continues, a stage may be reached where the number of electrons in the active state may be more than that in the ground state. Thus, the number of electrons in the active medium in the meta stable state is more than that in the ground state and this stage of increasing electrons in the meta stable state (i.e., active medium) is called ‘population inversion’.

This achievement of population inversion can be done by inducing radiation to the active state from an external source. The process of achieving population inversion by inducing radiation from an external source is called pumping.

Consider three states of energy level E_1 , E_2 and E_3 .

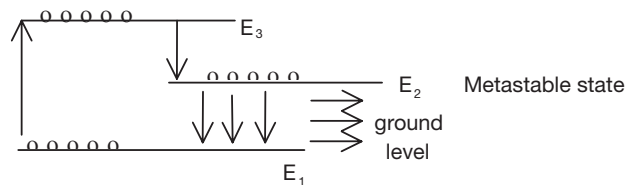


FIGURE 4.72 Active system for population inversion

When a photon of energy $h\nu = E_3 - E_1$ is incident, the electrons from the ground state are excited to energy level E_3 . But the lifetime of the electrons in the excited state is very short (10^{-8} s). As a result electrons return to the ground state by spontaneous emission but some electrons jump to energy level E_2 emitting a small amount of energy equal to $E_3 - E_2$. This energy is absorbed as thermal energy by the medium. This is known as non-radiative transition.

Electrons in the energy level E_2 have comparatively longer lifetime (milli seconds). This energy level is called meta stable state. At some instant the number of electrons in the meta stable state is greater than the number of electrons in the ground state. This is known as population inversion.

Stimulated or Induced Emission

The induced radiation (whose energy is equal to the energy difference of active and ground levels) stimulates the electrons in the active state and so is also called stimulated radiation. When a large number of electrons in the active state are stimulated, they are transited from the active state to the ground state simultaneously which gives rise to a temporal coherent beam of light. This process is called ‘stimulated emission’ which increases the intensity of light.

The stimulated emission can be made dominant by placing the active medium discussed above in a cavity so that multiple reflections of light take place before the beam comes out, thereby amplifying the light energy.

Thus, the incident light is amplified by stimulated emission of radiation, and hence LASER.

ACTUAL LASER AND ITS WORKING

Actual laser consists of an active medium in a resonator. Two mirrors, one perfectly reflecting and the other partially reflecting are fixed, one at each ends of the resonator. The mirrors are parallel to each other. Energy is supplied by a flash of light from an external source for optical pumping which results in population inversion.

During stimulated emission, light or photon travels to and fro (perpendicular to mirror surface) after being reflected by the mirrors. Intensity of light increases due to multiple reflection. This amplified light escapes through a partially reflecting mirror as a narrow beam of monochromatic light.

Types of Lasers

Different types of lasers that are available are, solid state lasers like ruby laser, liquid and dye lasers and gaseous lasers like helium neon (He-Ne) lasers.

In lasers, solid, liquid or gas is used. Thus, laser can be broadly classified as

1. solid laser,
2. liquid and dye laser
3. gaseous lasers

Ruby laser is a solid laser and the active system used is ruby (Al_2O_3 , Cr^{3+}). Xenon discharge tube provides flash light required for optical pumping. Wavelength of ruby laser is $6943 \text{ \AA}$. Helium – Neon laser is a gas laser. Neon acts as the active system. Radio frequency is used for optical pumping. Wavelength of He-Ne laser is $6328 \text{ \AA}$.

Uses of Lasers

Lasers have many applications in the fields of medicine, industry and in science and technology. Some of them are mentioned below.

1. These are used in bloodless surgeries, where surgeries are done without cutting the body parts with knife.
2. Lasers are used for welding and cutting heavy metallic parts in industries.
3. They are used to store and retrieve a large amount of information in compact discs.
4. They are used to destroy inter continental ballistic missiles in air itself without the help of any other missile.
5. They are used in three dimensional photography called holography.
6. They are used in the field of communication through fibre optics.
7. Lasers are used to study Raman scattering to analyse the molecular structure of a material.
8. Lasers are used to separate isotopes.

OPTICAL INSTRUMENTS

Instruments like mirrors, lenses, etc., which deal with light are called optical instruments.

The human eye is a sense organ which causes the sensation of vision, and this helps us to ‘see’ the objects and also perceive their colours. But the human eye has certain limitations. Some of the limitations are listed below.

1. Defects of vision, like short sight, long sight, colour blindness, etc.
2. Range of visibility.
3. Inability to see very small objects like cells, etc.
4. Make visual recording for posterity.

To overcome these limitations, man has invented optical instruments like spectacles, microscopes, telescopes, etc. To record visual observations for further reference, photographic camera, video camera, etc, were invented.

There has been a continuous effort to make these instruments more sophisticated and effective with the advances made in science and technology.

THE HUMAN EYE

The eye is a spherical ball having a diameter of about 2.5 cm, with a slight bulge in the front portion. The posterior part of the eye-ball is filled with a fluid called vitreous humour which helps in preventing the eye-ball from collapsing. The exterior part of the eye ball is covered by a thick fibrous tissue called sclerotic which gives a definite shape to the eye-ball and protects the interior parts.

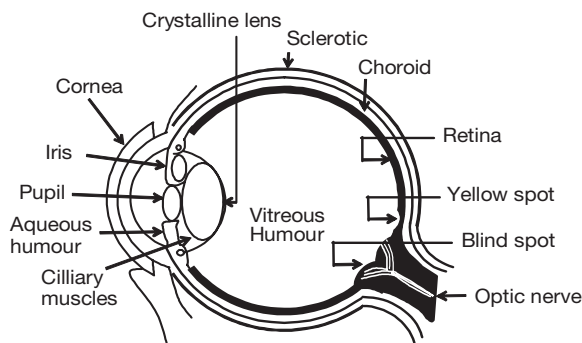


FIGURE 4 73 The human eye

A crystalline lens is located in the front part of the eye. The focal length of the lens is varied with the help of ciliary muscles along the periphery such that the image of the object viewed falls on the retina, which forms the screen. This process of altering the focal length of the lens is known as accommodation of the eye. Several thousand nerves coming from the brain enter the eye from the rear and terminate along the retina in the form of light sensitive cells. These cells are of two types—rods and cones, and they help us to perceive the brightness and colour of the objects viewed.

The choroid between the sclerotic and the retina is a dull grey membrane preventing internal reflections, and thus keeping the interior of the eye-ball dark.

The slight bulge in the front is due to the presence of a fluid called aqueous humour in front of the crystalline lens. This fluid forms a primary lens of almost a fixed focal length. It prevents collapsing of eye due to changes in atmospheric pressure.

Light enters the aqueous humour through the cornea which is a thin membrane holding the aqueous humour in place.

Behind the cornea is the iris which is an opaque muscular diaphragm having a small aperture or an adjustable opening called the pupil. This controls the light entering the retina. When the muscles contract, the size of the pupil increases allowing more light to enter and vice versa.

The light passing through the pupil falls on the eye lens which is held in position by ciliary muscles. These rays after passing through the eye lens are focused on retina. Real inverted image is formed on the retina. Any image formed on the retina is converted into optical impulses which are sent to the brain through the optic nerve.

Yellow spot is situated at the centre of the retina and is the most sensitive part of the retina that helps us to view objects closely. The blind spot refers to the portion of the retina where there are no light sensitive cells.

Two eye-balls are present in the front part of the head to estimate the distances of objects and their relative visual depth. The human brain cannot perceive more than two images formed on the retina within an interval of $1/16$ th second. This is called persistence of vision.

Formation of Images on Retina

The images formed on the retina are always real, inverted and highly diminished. While viewing distant objects (at infinity) the ciliary muscles relax and this leads to an increase in the focal length of the lens. In this case, the image is focused on the retina. While viewing nearer objects the ciliary muscles contract. This leads to a decrease in the focal length of the lens and the focus is formed in front of the retina such that the image would form on the retina, i.e., between f and $2f$.

Least distance of distinct vision: It is the minimum distance at which objects can be seen more distinctly without strain. It is also called the near point of the eye. It is denoted by D . For a normal person least distance of distinct vision is 25 cm. Infinity is referred to as far point.

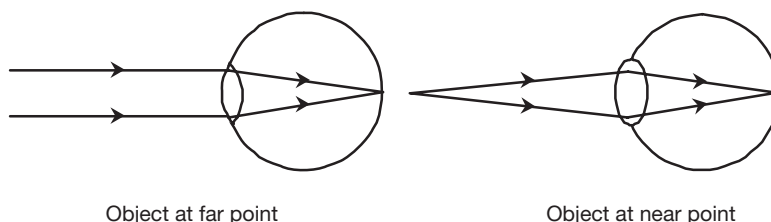


FIGURE 4.74 Formation of images on retina

Perception of Colours

The rod shaped cells on the retina respond only to the intensity of the incident light, but cannot perceive colours. The cone shaped cells are sensitive to colours. There are three types of cones responding to each of the three primary colours—red, green and blue, helping us perceiving and distinguishing between different colours. Absence of certain cone cells sensitive to specific colours would lead to a defect known as colour blindness in some people.

Defects of Vision and Rectification

1. **Myopia or Short sightedness:** It is the ability to see near objects and inability to see distant objects. This defect occurs due to slight elongation of the eye ball. As a result, the distance between eye lens and retina is greater and the image is formed in front of the retina and not on the retina.

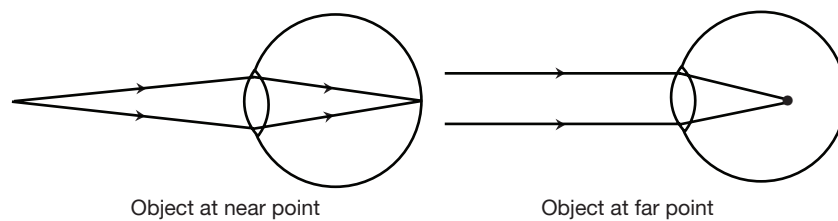


FIGURE 4.75 Myopic eye

Correction

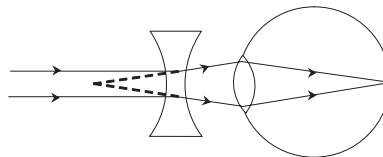


FIGURE 4.76 Use of concave lens for myopic eye

Myopia can be corrected by using a concave lens of suitable focal length to have the apparent position of the far point at near point.

Image formation with the Corrective Lens

2. **Hypermetropia or long-sightedness:** Ability to clearly and comfortably see objects at a distance and inability to see clearly objects that are nearby is referred to as hypermetropia, more commonly known as long-sightedness.

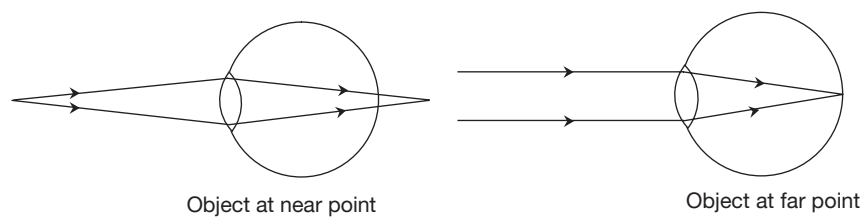


FIGURE 4.77 Hypermetropic eye

This defect is caused by slight flattening of the eye ball. The distance between the eye lens and the retina is less than in case of a normal eye. As a result the image formed by nearby objects is behind the retina.

Correction

Hypermetropia can be corrected by using a convex lens of suitable focal length to make the image form on the retina, i.e., by decreasing the combined focal length or by increasing the power of the combination.

Image Formation with Corrective Lens

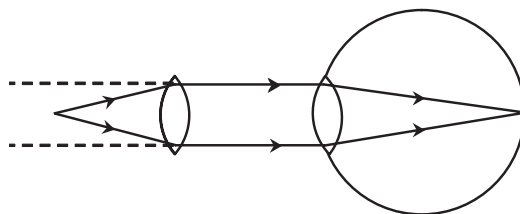


FIGURE 4.78 Use of convex lens for hypermetropic eye

- 3. Presbyopia:** Inability to see clearly objects that are near due to the ageing of the ciliary muscles is referred to as presbyopia. Thus, presbyopia is the condition of hypermetropia due to ageing.

Presbyopia can be corrected by using a ‘reading glass’, i.e., a suitable convex lens—a magnifying glass.

A bi-focal lens is often used when the defects of myopia and hypermetropia exist together, i.e., the person is unable to see both far distant objects as well as near objects.

- 4. Astigmatism:** When the cornea is not spherical and is curved differently in different directions, then focusing simultaneously on horizontal and vertical lines becomes difficult. Such a condition is referred to as astigmatism.

Astigmatism can be corrected by using a cylindrical lens.

- 5. Cataract:** Due to ageing, a thin membrane forms over the crystalline lens making it hazy. This leads to decrease in the brightness of objects and may also lead to blindness. This condition is called cataract and can be corrected by suitable surgery.

Bees have some retinal cones which are sensitive to ultraviolet light. Humans retina are not sensitive to ultraviolet light, and hence, we cannot see objects in the ultraviolet light. Cones of chicks are sensitive to bright light only, and hence, chicks wake up with sunrise and sleep in the dusk.

Camera

Camera is used to record image on a film. When an object is beyond $2F$ a real, diminished, inverted image is formed between F and $2F$ on the other side of convex lens.

A camera consists of a convex lens of small focal length fixed to one end of a box. To the other end is a light sensitive film. The inner sides of the box are blackened to prevent

internal reflection. Distance between the screen and the lens can be adjusted by the knob. A circular plate having an aperture in it is placed behind the lens and it is called diaphragm. The diameter of the aperture can be varied and the aperture controls the amount of light falling on the film. The size of the aperture is expressed as f -numbers.

f -number is defined as the ratio of the focal length of the lens to the diameter of the aperture.

$$\therefore f\text{-number} = \frac{\text{Focal length of the lens}}{\text{Diameter of the aperture}}$$

According to the intensity of light, the f -number may be adjusted. In dim-light lower f -number is used and higher f -number is used in bright light.

To control the exposure time of the film, a shutter is provided, whose speed can be controlled.

To take a photograph of an object the distance between the lens and the film is adjusted, so as to get a clear image in the view finder. Then f -number and shutter speed are adjusted depending upon the intensity of light. When the button is pressed, the film gets exposed to the light entering through the lens. The film is then treated chemically, a process known as 'development' and then prints of the film are taken on a photographic paper.

Comparison between a Camera and The Eye

A camera in many ways is similar to the human eye. Perhaps the human eye was the source of inspiration for the design of a camera.

The important differences between the two are as follows:

1. In a camera, the distance between the lens and the screen can be adjusted but not the focal length of the lens, whereas, in the case of the eye, the ciliary muscles adjust the focal length keeping the distance between the lens and the retina constant.
2. The interior of the eye-ball is filled with vitreous humour but in a camera, the chamber is hollow and empty.
3. The image formed on the retina is temporary and its impression is recorded in the brain as memory. The image formed on the film is a permanent record.
4. Distance between crystalline lens and retina remains the same but in camera distance between the lens and the film can be changed.
5. Retina converts light signals to electrical impulses which are transmitted to brain whereas in camera film gets exposed when light is incident on it, due to chemical reactions.
6. Eye is subjected to a number of defects whereas in camera there are no such defects.

SIMPLE MICROSCOPE

A convex lens of short focal length which is used to observe small objects clearly is known as a simple microscope. It is also called a magnifying glass. To construct a simple microscope, a convex lens of short focal length is fixed in a circular metallic frame provided with a handle to hold.

Working

The size of the image of an object formed on our retina increases if the distance of the object from our eyes decreases. This happens due to the fact that as the object comes closer to our eyes, the angle subtended by the object at our eyes increases and so the size of the image of the object on the retina also increases. This is known as ‘angular magnification’.

If an object of size ‘ h ’ is placed at the least distance of distinct vision (D) from the eye, the angle which it subtends at the eye can be given by, $\alpha_0 = \frac{h}{D}$.

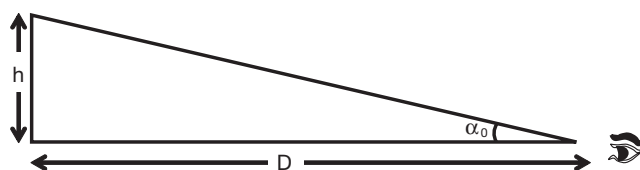


FIGURE 4.79 An object placed at the least distance of vision from eye

If this angle is increased, the size of the image of the object increases and this can be done by placing a convex lens of short focal length between the eye and the object such that the distance between the lens and the object is equal to the focal length of the convex lens. Then the image of the object is formed at an infinite distance. In this situation, the image can be observed with the least strain to eye. This adjustment is called normal adjustment.

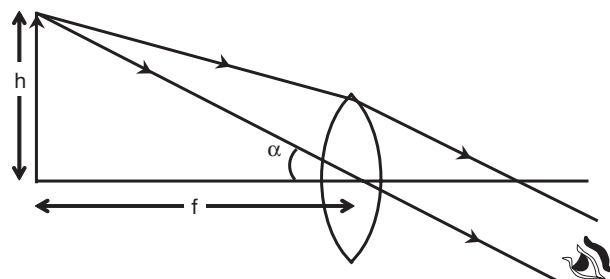


FIGURE 4.80 Simple microscope (convex lens) placed between the object and the eye

Here, the angle subtended by the object at the eye is equal to the angle subtended by the object at the optic centre of the lens (α) and it is greater than the angle subtended by the object, when it is placed at ‘ D ’ from the eye. So, the image of the object is magnified.

Here

$$\alpha = \frac{h}{f}$$

Magnification in Normal Adjustment

Magnifying power of the image of the object is the ratio of the angle subtended by the object at the eye in the normal adjustment situation to the angle subtended by it at the eye when it was at the least distance of distinct vision (D).

$$\therefore \text{Magnification } M = \frac{\alpha}{\alpha_0} = \frac{h/f}{h/D} = \frac{D}{f}$$

Magnification When The Object is Placed between The Focus and Optical Centre of the Lens

If the object is placed before the lens at a distance less than its focal length, a virtual, erect and a magnified image is formed on the same side of the lens to which the object is placed. The distance of the object from the lens can be adjusted so that the image is formed at a distance from the lens which is equal to ' D ' from the lens.

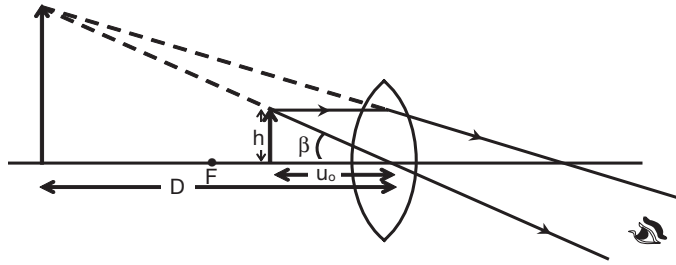


FIGURE 4.81 Object placed before simple microscope

Now, the angle subtended by the object on the lens and on the eye is ' β ' and the angular magnification now is given by $m, = \frac{\beta}{\alpha_0}$.

But
$$\beta = \frac{h}{u_0} \text{ and } \alpha_0 = \frac{h}{D}.$$

$$\therefore m = \frac{h / u_0}{h / D} = \frac{D}{u_0}$$

The lens formula is $\frac{1}{f} = \frac{1}{v} = \frac{1}{u}$ where f , u and v are focal length of the lens, object distance and image distance, respectively. Using the sign convention, we get $v = -D$, $u = -u_0$.

So,
$$\frac{1}{f} = \frac{1}{-D} - \frac{1}{-u_0}$$

$$\Rightarrow \frac{1}{u_0} = \frac{1}{f} + \frac{1}{D} \text{ or } \frac{D}{u_0} = \frac{D}{f} + \frac{D}{D} \Rightarrow \frac{D}{u_0} = 1 + \frac{D}{f}$$

As $\frac{D}{u_0} = m$, the magnification $m = 1 + \frac{D}{f}$.

Uses

1. Used as reading glass.
2. To observe weaving patterns and to read vernier scale.

COMPOUND MICROSCOPE

A simple microscope can produce images having magnification up to a certain limit. It is not possible for a simple microscope to produce images of greater magnification. When images of greater magnification are required, we use another convex lens in combination with the one used in a simple microscope. The combination of these two lenses which is used to obtain images of greater magnification is called 'compound microscope'.

Construction and Working

The two lenses that are used in a compound microscope are each fixed to the outer ends of two hollow tubes one tube can slide one over the other such that their principal axes of two lenses coincide. The lens that faces the object is called an 'objective' and is of smaller focal length when compared to the focal length of the other lens which faces the eye and is called the 'eye piece'.

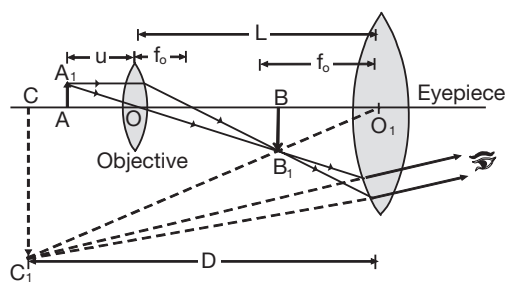


FIGURE 4.82 Formation of image by a compound microscope

A screw is provided so that on rotating, the distance between the objective and the eye piece can be adjusted.

An object AA_1 is placed beyond the principal focus of the objective and its image BB_1 is formed between the objective and the eye-piece. This image (BB_1) is inverted, real and magnified with respect to the object. This first image acts as an object to the second convex lens, i.e., eye piece. The distance of the first image ' BB_1 ' from the eye piece is less than the focal length of the eye piece. So, it is further magnified and a second and final image ' CC_1 ' is formed beyond ' BB_1 '. The final image is inverted with respect to the object but virtual with respect to the first image. It is highly magnified when compared to the first image.

MAGNIFICATION

The magnification of the compound microscope is the ratio of the size of the final image to the size of the object.

$$m = \frac{CC_1}{AA} = \frac{CC_1}{BB_1} \times \frac{BB_1}{AA_1} = m_e \times m_o$$

Where, m_o = magnification produced by the objective.

m_e = magnification produced by the eye piece.

When the final image is formed at infinity

$$\therefore m = m_o \times m_e = L/f_o \times D/f_e$$

Where, L = length of the tube = distance between the lenses

D = least distance of distinct vision

f_o = focal length of the objective

f_e = focal length of the eye piece

TELESCOPES

When an object is very far from the eye, the angle it subtends at the eye is very small and so it appears to be small. To make the object appear nearer to the eye, the angle it subtends at the eye should be increased. To make the distant objects appear nearer, the optical instrument used is called a telescope.

There are two types of telescopes, viz., the astronomical telescopes and the terrestrial telescopes. The astronomical telescopes are used to observe the celestial bodies and the terrestrial telescopes are used to observe distant objects on the earth's surface.

ASTRONOMICAL TELESCOPE

An astronomical telescope has the same construction as that of a compound microscope, but the focal length of the objective is larger when compared to the focal length of the eye piece.

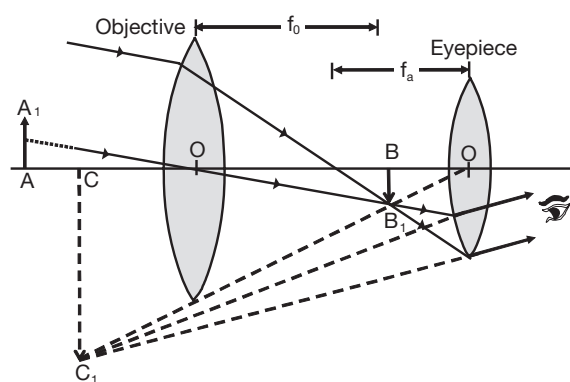


FIGURE 4.83 Formation of image by astronomical telescope

Working

A parallel beam of light rays from a distant object (AA_1) almost parallel to the principal axis of the objective are incident on the objective and an image (BB_1) of the object is formed between the objective and the eye piece. This first image which is diminished, inverted and real acts as an object for the eye piece. The distance between the first image and the eye-piece is less than the focal length of the eye piece. So, a magnified and a virtual image (CC_1) is formed on the same side of the eye piece to which the first image lies. The final image is erect with respect to the first image but is inverted with respect to the object. The angle subtended by the final image at the eye piece and so at the eye is larger than that of the angle subtended by the object at the eye. So the final image is magnified and appears to be having larger size than that of the object.

If the first image formed by the objective (i.e., BB_1) is formed at the principal focus of the eye piece, the final image is formed at infinity. This situation is called 'normal adjustment'. In the normal adjustment position, the length of the telescope (L) (which is the distance between objective and eye piece) is equal to the sum of the focal lengths of the objective and the eye piece ($L = f_o + f_e$). In the normal adjustment position, the magnification obtained by the telescope is given by $m = \frac{f_o}{f_e}$

TERRESTRIAL TELESCOPE

In an astronomical telescope, the final image obtained / formed is inverted with respect to the object. Due to this reason, it cannot be used to view distant objects on the earth's surface. Thus, the astronomical telescope is modified by adding one more lens between the objective and the eye piece. The purpose of this lens is to make the image erect with respect to the object and so it is called an image erecting lens (EL) or simply erecting lens.

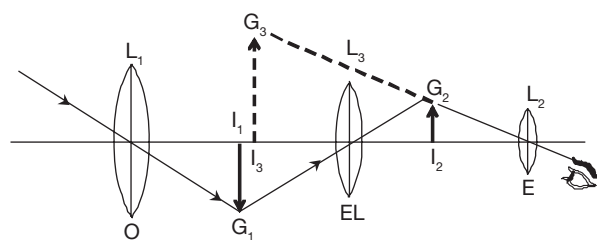


FIGURE 4.84 Formation of image by a terrestrial telescope

The first image (I_1G_1) formed by the objective is real, inverted and diminished and is formed at the centre of curvature of the erecting lens. This image (I_1G_1) acts as an object for the erecting lens and a second image (I_2G_2) is formed at the centre of curvature of the erecting lens between the erecting lens and the eye piece. The size of the second image (I_2G_2) is equal to that of I_1G_1 . It is erect with respect to the original object and inverted with respect to I_1G_1 . I_2G_2 acts as an object for the eye piece. The distance between I_2G_2 and eye piece is less than the focal length of the eye piece and so a third and final image I_3G_3 is formed. This image is erect with respect to I_2G_2 . So, the final image is erect with respect to the object.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Define power of a lens.
2. _____ mirror can form virtual and diminished image.
3. What is luminous flux?
4. According to Huygen's theory, the colours of light are due to difference in the _____.
5. What is magnification?
6. What is spontaneous emission?
7. What is the condition required for constructive interference to take place?
8. Snell's law is not applicable when the angle of incidence is equal to _____.
9. Which spherical mirror is used as rear view mirror?
10. Which type of lens is used to correct hypermetropia?
11. What is the principle of superposition?
12. When an ink spot which is at the bottom of a glass ($\mu = \frac{3}{2}$) slab of thickness 9 cm is viewed from top, the image of the ink spot appears to be raised by _____ cm.
13. What is refraction?
14. What is presbyopia?
15. Why do different electromagnetic radiation have different properties?
16. In a human eye colour is perceived by _____.
17. When is the angle of incidence greater than the angle of refraction?
18. An optical fiber used for telecommunication works on the principle of _____.
19. What is meant by refrangibility?
20. Astigmatism can be verified by a suitable _____ lens.
21. Define refractive index.
22. The S.I. unit of luminous intensity is _____.
23. Define candela.
24. How does lateral displacement vary with wavelength?
25. For an object placed at a certain distance in front of a convex mirror the magnification is 0.8. If the focal length of the convex mirror is 40 cm, then the distance of the object from the mirror is _____ cm.
26. What is coherent scattering?
27. The angle of incidence of a ray of light passing through the centre of curvature of a concave mirror is _____.
28. What are the factors on which angle of deviation depends?
29. Both particle and wave nature are attributed to light according to _____ theory and _____ theory, respectively.
30. What are composite colours?

Short Answer Type Questions

31. Draw a ray diagram to obtain the image position when the object is beyond 2F of a convex lens.
32. Derive the expression for the magnification of an astronomical telescope in normal adjustment.
33. What is line emission spectrum?
34. State the condition for total internal reflection.
35. Explain briefly about a terrestrial telescope.
36. What is photoelectric effect?
37. What is astigmatism? Explain how it can be corrected.
38. What are total reflecting prisms?
39. What are the uses of lasers?
40. What are the postulates of Newton's corpuscular theory?
41. What are infrared rays? Name the source of IR rays and write their uses.
42. What is a refracting periscope?
43. Explain the construction of wavefronts using Huygen's principle.
44. What is Raman effect?
45. What are optical fibres?



Essay Type Questions

46. Distinguish between ordinary light and a laser.
47. Explain the construction and working of a compound microscope with a ray diagram. Derive the expression for magnification when image is formed at infinity.
48. State the new cartesian sign convention used in reflection by spherical mirrors
49. Explain the formation of mirages.
50. Derive lens formula.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

1. Interference takes place whenever two or more wave motions combine in space.
2. In the minimum deviation position of a prism, the refracted ray is always parallel to its base.
3. A person suffering from myopia cannot see distant objects clearly.
4. The focal length of a given lens depends on the surrounding medium.
5. Prismatic periscopes use the principle of total internal reflection.
6. A dentist uses a convex mirror to view the inner parts of a patient's mouth.
7. The solar spectrum in general is an absorption spectrum.

Direction for questions 8 to 14:

Fill in the blanks.

8. A yellow coloured dress would appear to be _____ when viewed through a green filter.
9. Due to _____ of laser, large energy can be concentrated into an extremely small bandwidth.
10. The combination of a convex lens of power + 2 D and a concave lens of power -2 D, acts as a _____
11. The minimum length of a plane mirror required to view the full image of a person 6 feet tall is _____.
12. A bird is flying 12 m above the surface of a pond.

The apparent position of the bird as viewed by a fish 1m below the surface is _____. $\left({}_a\mu_w = \frac{4}{3} \right)$

13. An object is placed on the principal axis of a concave mirror at a distance of 60 cm. If the focal length of the concave mirror is 40 cm, then the magnification obtained is equal to _____
14. The power of a biconcave lens having focal length 25 cm is _____.

Direction for question 15:

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

15.

Column A	Column B
A. Plane mirror ()	a. Primary colours
B. Convex lens ()	b. 4π steradian
C. Spectroscope ()	c. Incoherent scattering
D. Atmospheric scattering of light ()	d. Magnification always one
E. RB RBG ()	e. Terrestrial telescope
F. Opt Optic fibre ()	f. Burglar alarm
G. Sol Solid angle in a sphere ()	g. Virtual and magnified image
H. Photo electric effect ()	h. Blue colour of effect the sky
I. Raman effect ()	i. Observing and studying spectrum
J. Erecting lens ()	j. Total internal reflection



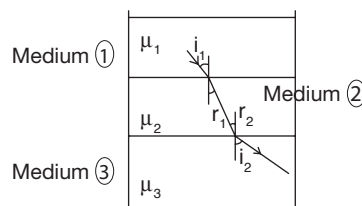
Direction for questions 16 to 45:

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

16. A mirage takes place due to _____.
 (a) reflection
 (b) refraction
 (c) total internal reflection
 (d) Both (b) and (c)
17. Raman effect is an example of _____.
 (a) coherent scattering of light.
 (b) incoherent scattering of light
 (c) coherent interference of light
 (d) incoherent interference of light
18. The optical phenomenon which Newton's theory of light failed to explain is _____.
 (a) interference
 (b) polarization
 (c) diffraction
 (d) All the above three
19. An observer moves towards a stationary plane mirror at a speed of 4 m s^{-1} . The speed of image with respect to mirror is _____.
 (a) 4 m s^{-1} towards the mirror
 (b) 8 m s^{-1} towards the mirror
 (c) 4 m s^{-1} away from the mirror
 (d) 8 m s^{-1} away from the mirror
20. The process in which the electrons in the excited atoms are released on their own from their higher energy state to the ground state is called _____.
 (a) forced emission
 (b) population inversion
 (c) spontaneous emission
 (d) None of these
21. The refractive index of diamond is 2.4. If the velocity of light in air or vacuum is $3 \times 10^8 \text{ m s}^{-1}$, then the velocity of light in diamond is _____ $\times 10^8 \text{ m s}^{-1}$.
 (a) 1.25 (b) 12.5
 (c) 0.8 (d) 125
22. A convex mirror is used
 (a) by a dentist
 (b) for shaving
 (c) as a rear view mirror in vehicles
 (d) as a light reflector for obtaining a parallel beam of light.
23. When an equilateral glass prism is in minimum deviation position
 (A) the refracted ray is parallel to the base of the prism.
 (B) the angle of incidence is equal to the angle of emergence
 (a) Only A is true
 (b) Only B is true
 (c) Both A and B are true
 (d) Both A and B are false
24. The colour of a green leaf, when white light passing through a yellow filter is incident on it, is _____.
 (a) black (b) yellow
 (c) red (d) green
25. Spectrometer is used to measure _____.
 (a) angle of prism
 (b) refractive index of material of a prism
 (c) the dispersion
 (d) All the above
26. The expression for the magnification of a spherical mirror in terms of focal length (f) and the distance of the object from mirror (u) is
 (a) $\frac{-f}{u-f}$ (b) $\frac{f}{u+f}$
 (c) $\frac{-f}{u+f}$ (d) $\frac{f}{u-f}$
27. According to Newton, different colours of light are due to the difference in _____ of the corpuscles.
 (a) mass (b) nature
 (c) shape (d) size
28. If the speed of light in medium - 1 and medium - 2 are $2.5 \times 10^8 \text{ m s}^{-1}$ and $2 \times 10^8 \text{ m s}^{-1}$, respectively, then the refractive index of medium - 1 with respect to medium - 2 is _____.
 (a) $\frac{3}{2.5}$ (b) $\frac{2}{2.5}$
 (c) $\frac{2.5}{3}$ (d) $\frac{2.5}{2}$



29. A coin is placed at the bottom of a swimming pool. To obtain a vertical shift of 20 cm of the image of the coin, the required height of the water column is _____ $\left(\mu_{\text{water}} = \frac{4}{3}\right)$.
- (a) 20 cm (b) 2 m
(c) 80 m (d) 80 cm
30. The apparent vertical shift of the image of a coin placed at the bottom of a water tank having constant depth of water is proportional to _____.
- (a) μ (b) $\frac{1}{\mu}$
(c) $\mu - 1$ (d) $\mu + 1$
31. Facts about the light
- (a) Light is a form of electromagnetic radiation and a non-mechanical wave.
(b) Light waves do not require a material as a medium for propagation.
- (a) Only A is true.
(b) Only B is true.
(c) Both A and B are true.
(d) Both A and B are false.
32. Find the correct statements related to the image formed by the plane mirror from the given below.
- (a) The image formed is laterally inverted, virtual and erect.
(b) The size of the image is equal to the size of the object.
(c) The object distance from the plane mirror is equal to the image distance from the plane mirror.
(d) All the above.
33. When a light ray is directed towards the principal focus of a concave mirror
- (a) real image is formed
(b) a diminished image is formed
(c) inverted image is formed
(d) All the above
34. An object is placed in front of a spherical mirror at a distance of 20 cm from it. A virtual image is formed at a distance of 30 cm from it. Arrange the following steps in the proper sequence to determine the nature and focal length of the mirror.
- (a) Substitute the values of v and u in the mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
(b) Check whether the focal length obtained is a negative or a positive integer.
(c) Decide whether the mirror is a convex or a concave mirror based on the sign of the focal length obtained.
(d) Assign proper signs to the object distance and image distance by using the sign convention.
(e) Obtain the value of focal length.
- (a) d a e b c (b) a d b e c
(c) a b d e c (d) b d c a b
35. Total reflecting prisms are prism.
- (a) right angled.
(b) acute angled isosceles.
(c) right angled isosceles.
(d) obtuse angled isosceles.
36. The final image formed by the refracting periscope is than the reflecting periscope.
- (a) bright (b) sharp
(c) dimmer (d) Both (a) and (b)
37. Light is made to travel from medium 1 to medium 3 through medium 2 as shown in figure. If μ_1 , μ_2 and μ_3 are the refractive indices of first, second and third media and $i_2 > i_1$, then



- (a) $\sin r_1 = \sin r_2$; $\sin i_1 < \sin i_2$.
(b) ${}^1\mu_2 > {}^2\mu_1$; ${}^2\mu_3 < {}^3\mu_2$
(c) ${}^1\mu_3 < {}^3\mu_1$
(d) All the above.

38. What are the factors that determine the angle of deviation in a prism?
- (a) angle of incidence (b) wave length
(c) angle of the prism (d) all the above
39. Astigmatism can be rectified by a suitable lens.
- (a) concave (b) convex
(c) cylindrical (d) None of the above



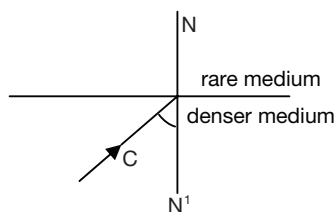
40. Human eye has maximum luminous efficiency to light.
 (a) yellow (b) red
 (c) violet (d) green
41. Arrange the proper sequence of the steps to determine the refractive index of a prism by using angle of minimum deviation method.
 (a) Fix a white sheet of paper on a drawing board.
 (b) Draw the outer line of the prism by placing its triangular cross-section (ABC) on the paper,
 (c) Draw a line which makes a certain angle with the normal. This is the incident ray.
 (d) Mark a point on one of the sides and draw a normal at that point.
 (e) Fix two pins P and Q on this line.
 (f) Place the prism inside its outer line and observe the pins P and Q from the other side of the prism.
 (g) Fix two more pins R and S on the other sides such that the images of the pins P and Q , R and S are in a straight line.
 (h) Join the points R and S and the line segments PQ and RS . (i) Remove the pins and the prism from the paper.
 (j) Draw a normal XY where the line segment RS meets the side BC .
 (k) Draw a graph by taking the angle of incidence and angle of deviation along the X and Y axes, respectively.
 (l) Extend line segments PQ and RS and determine the angle between them. This is known as the angle of deviation.
 (m) Determine refractive index as μ
- $$\mu = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$
- (n) Repeat the experiment for different angles of incidence and in each case, determine the angle of deviation.
 (o) Determine angle (A) between the refracting surfaces of the prism. (p) Determine the minimum value of angle of deviation (D_m).
 (a) a b c d e f g i h j k l m o n p
 (b) a b d c e f g h i j l k o n p m
 (c) b a c d e j k h i j m l n o p
 (d) a b d c e f g l h k m i p o j
42. Find out the correct option from the following.
 (a) The magnification is positive for all virtual images and is negative for all real images.
 (b) The magnification of concave lens and convex mirror is always positive whereas the magnification of convex lens and concave mirror can be positive or negative depending on the position of the object before the lens.
 (a) Only A is true.
 (b) Only B is true.
 (c) Both A and B are true.
 (d) Both A and B are false.
43. Find the incorrect statements related to the rainbow
 (a) The rainbow is formed in the same direction to the position of the sun.
 (b) When the light rays undergo dispersion and total internal reflection the water droplets present in the atmosphere forms rainbow.
 (c) A rainbow is formed in the shape of circle.
 (d) When light rays undergo one internal reflection and two refractions produce primary rainbow whereas two internal reflections and two refractions produces secondary rainbow.
44. Choose the incorrect option from the following options:
 (a) When a monochromatic light is passed through organic liquid like benzene, toluene, etc. it results in the formation of the scattered light. Which consists of wavelengths of frequencies higher and lower than that of incident monochromatic light also that of the incident light.
 (b) Incident scattering is a type of scattering in which the scattered light consists of frequencies other than those of the incident light.
 (c) The intensity of the scattered light in a medium is inversely proportional to the fourth power of the wavelength.
 (d) Rayleigh scattering is called incoherent scattering and Raman scattering is coherent scattering
45. A student performs an experiment to study the nature of the image formed by a convex lens. Arrange the steps in the proper sequence.
 (a) Place the lens on a V -shaped stand.
 (b) Place the object at $2F_1$.
 (c) Place the object between $2F_1$ and F_1 .
 (d) Determine the focal length of the lens by focusing the lens to a distant object like a tree.



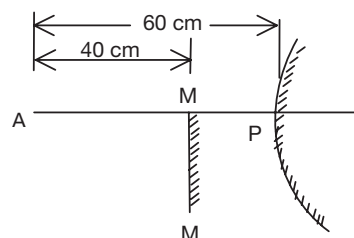
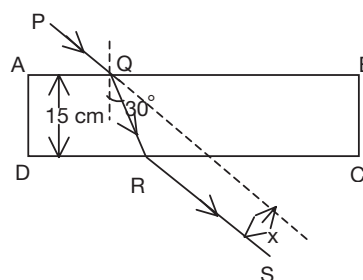
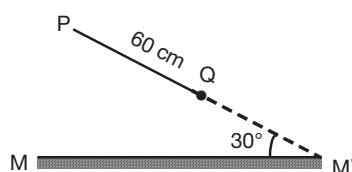
- (e) Adjust the position of the screen behind the lens to obtain a clear image and study the nature of the image.
- (f) Mark the positions of F_1 , $2F_1$, F_2 and $2F_2$.
- (g) Focus the lens to a distant object like a tree.
- (h) Place the object just behind $2F_1$.
- (i) Place the object at F_1 .
- (j) Place the object between F_1 and optic centre of the lens and observe that the image formed is virtual.
- (a) a f d h e g e b e c e e j
- (b) b a f h e g e c j
- (c) a d f g e h e b e c e i e j
- (d) a d f g e h e c e b e j e

Level 2

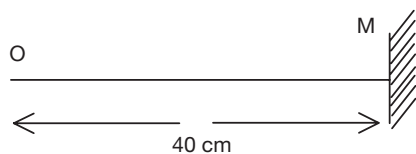
46. The critical angle of the material of a prism ABC is 40° . For a ray of light incident on the face AB , to emerge from the face AC , what should be the maximum value of angle A ?
47. Two lenses, one convex and another concave, of focal lengths 10 cm and 20 cm, respectively are taken together and used as a single lens. If a point object is held at a distance of 20 cm from the compound lens, find the position of its image.
48. A white light source is placed in a denser medium. For a ray of white light, shown in the diagram below, the angle of incidence equals the critical angle for green colour light. Which colours pass into rarer medium? Which colours are reflected back? Explain.



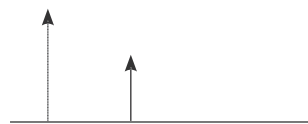
49. Two thin biconvex lenses L_1 and L_2 having focal lengths 10 cm and 15 cm, respectively are placed coaxially. What distance (d) should be maintained between them so that a parallel beam of light parallel to their axis, incident on the lens L_1 emerges from L_2 undeviated? If the distance between them is increased by ' d ', at what distance from L_1 , on the axis, does the emergent beam converge?
50. An ant moves with a uniform speed along a straight line path from P to Q , 60 cm apart, in front of a mirror and takes two minutes to cover this distance. The line segment PQ is inclined to the mirror MM' at an angle of 30° . What is the rate at which the distance between the ant and its image changes?
51. $ABCD$ represents a glass slab and $PQRS$ indicates the path of a light ray passing through the slab. If the refractive index of the glass is $\sqrt{3}$, find ' x '. (See figure below)
52. When an object can be seen with one eye, why is it that we have a pair of eyes? Explain.
53. A lens of focal length 20 cm produces a real image of a stationary object having magnification 2. Find the distance by which the lens should be moved so that it produces a virtual image of the same magnification.
54. An object A is placed on the principal axis of a convex mirror at a distance of 60 cm in front of it. A plane mirror is inserted between the object and the convex mirror at a distance of 40 cm from the object with the reflecting surface of the plane mirror facing the object. If the images formed by the two mirrors coincide, find the focal length of the convex mirror.



55. If an object is placed at a distance of 20 cm from the pole of a concave mirror, the magnification of its real image is 3. If the object is moved away from the mirror by 10 cm, find the decrease in its image magnification.
56. Why are red coloured lights are used in traffic signals to stop the vehicles?
57. A convex lens forms a real image on a screen when an object is placed at 10 cm from the screen. On shifting the lens by 2 cm, a real image is again formed on the screen. Find the focal length of the lens.
58. A bird flying above a pond starts moving vertically down towards the water below at a speed of $v \text{ m s}^{-1}$. Find its apparent velocity as viewed by a fish located at a depth of $d \text{ m}$ below the surface of water.
59. An object (O) and a plane mirror (M) are placed in the positions as shown in the figure. If the object and the mirror move simultaneously towards right in a straight path at uniform speeds of 2 cm s^{-1} and 5 cm s^{-1} respectively, find the shift in the image of the object at the end of 10 seconds.



60. An object and its image are as shown in the diagram below.



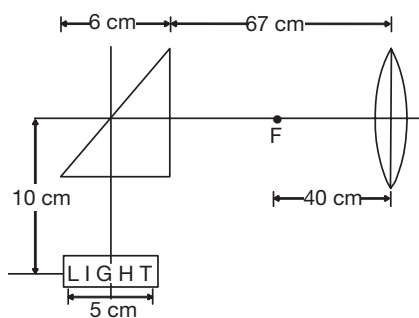
If the object image distance is 4 cm and the magnification is 3, find the ratio $u : v : f$. What is the type of the lens used? Draw the ray diagram to show the position of the lens and the principal foci.

61. An object is placed on the principal axis of a concave mirror at a distance of 60 cm. If the focal length of the concave mirror is 40 cm, then determine the magnification of the obtained image.
62. In which colour an yellow coloured dress would appear when viewed through a blue filter?
63. Three filters, one of cyan (C), one of magenta (M) and the last, yellow (Y) are placed in front of a 100% transparent equilateral glass prism as shown in the figure. A screen (S) is placed on the other side of the prism. When a white light ray is allowed to pass through the filters as shown in the figure and incident on the prism, what colours are obtained on the screen?
64. A bird is flying 12 m above the surface of a pond. What is the apparent position of the bird as viewed by a fish 1m below the surface?

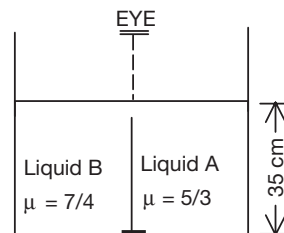
$$\left({}_a\mu_w = \frac{4}{3} \right)$$

Level 3

65. An isosceles right angled prism and a convex lens (focal length = 40 cm) are placed as shown in the adjoining figure, and a 5 cm wide strip with the letters 'LIGHT' written on it is placed as indicated. What is the nature and the position of the image formed after refraction through the prism and the lens. Given the critical angle of the glass used for the prism and the lens is 42° .



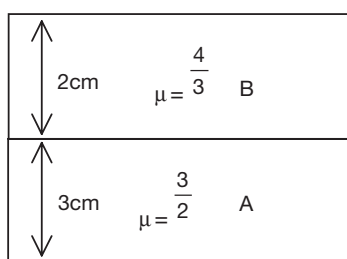
66. A circle is painted at the bottom of a trough exactly in line with the interface of two liquids as shown in the figure. The trough is divided into two parts by a very thin glass sheet. Viewed along the interface from above, the circular ring would appear to be split into two halves.



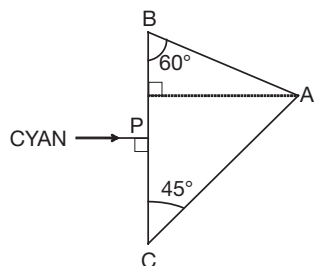
- (i) Give reasons for the apparent split in the circular ring.



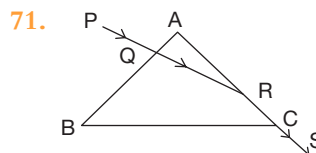
- (ii) Find the difference in the levels of the two images.
- (iii) How can the two parts of the ring be made to appear at the same level?
67. A point object is placed at a distance of 10 cm from a convex lens of focal length 5 cm. A convex mirror is placed at a distance of 4 cm from the lens on other the side of the lens opposite to the object such that the center of curvature of the convex mirror coincides with the image formed by the convex lens. Show the position of the final image with the help of a ray diagram. Find the focal length of the convex mirror.
68. The figure shows an arrangement of two transparent slabs *A* and *B* with their respective thickness and refractive indices as shown. Find the vertical shift of the image of a point object placed at the bottom of *A* due to both the slabs. Also find the effective refractive index of the compound slab.



69. The refractive index of the glass prism shown in the figure is 2 for green light. A ray of cyan colour light is incident at *P* on the face *BC* of the prism. From which side would the light emerge? Given the critical angle for blue colour is greater than 15° .

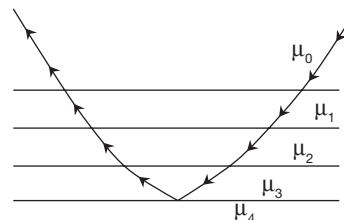


70. The refractive index of glass is $\sqrt{2}$. Find the angle of minimum deviation produced by an equilateral prism made of this glass.

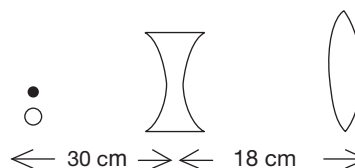


ABC represents the principal cross-section of an equilateral prism made with a transparent material. If *PQRS* indicates the path of a light ray, find the refractive index of the material.

72. A ray of monochromatic light follows the path shown in the figure as it passes through five layers of different optical media of refractive indices μ_0 , μ_1 , μ_2 , μ_3 and μ_4 . If the angle of incidence in the first medium is 30° ,
- compare the refractive indices of the media.
 - determine the angle of deviation on the whole.



73. The critical angle for a medium *X* is 60° and for another medium *Y* is 45° . Calculate the ratio of velocity of light in the medium *X* to that in medium *Y*.



74. An point object (*O*) is placed in front of a concave lens of focal length 20 cm as shown in figure. Determine the focal length of the convex lens if it forms a real image at a distance of 30 cm.



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. black 9. high monochromatic nature 10. glass slab 11. 3 feet 12. 15 m 13. 2 14. $-4D$

Match the following

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

Multiple Choices Question

16. (d) 17. (b) 18. (d) 19. (a) 20. (c) 21. (a) 22. (c) 23. (c) 24. (d) 25. (d)
26. (d) 27. (d) 28. (b) 29. (d) 30. (b) 31. (c) 32. (d) 33. (d) 34. (a) 35. (c)
36. (d) 37. (d) 38. (d) 39. (c) 40. (d) 41. (b) 42. (c) 43. (a) 44. (d) 45. (c)

Explanation for questions 31 to 45

31. Light is a form of electromagnetic radiation and a non-mechanical wave which do not require a material as a medium for propagation.

32. The image formed by a plane mirror is laterally inverted, virtual, erect and having same size as that of the size of the object. The distance of the object from the mirror is equal to the distance of the image from the mirror.

33. When a light ray is directed towards the principal focus of a and concave mirror, a real magnified and diminished image is formed.

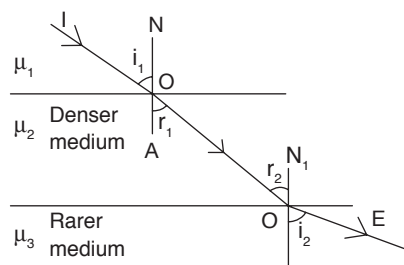
34. Initially proper sign is assigned to object distance and the image distance according to the sign convention. The values of u and v are substituted in the mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. The sign of f indicates whether the mirror used is convex or concave.

35. Total reflecting prism are right angled isosceles triangle.

36. Final image formed by the refracting periscope is bright and sharp then reflecting periscope since no rays of light are absorbed.

The quality of the image is affected by the presence of dust and moisture in case of reflecting periscope but least in case of refracting periscope.

37.



Given, $i_2 > i_1$

From figure $r_1 = r_2$

Because $\angle AOO^1 = \angle OO^1N_1$ are alternate angles

$\Rightarrow \sin r_2 = \sin r_2$ and $\sin i_2 > \sin i_1$, let $r_1 = r_2 = r$

$$\text{here, } {}^1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_1}{\sin r}$$

$${}^2\mu_1 = \frac{\mu_1}{\mu_2} = \frac{\sin r_1}{\sin i_1} = \frac{\sin r}{\sin i_1}$$

$${}^2\mu_3 = \frac{\mu_3}{\mu_2} = \frac{\sin r_2}{\sin i_2} = \frac{\sin r}{\sin i_2}$$

$${}^3\mu_2 = \frac{\mu_2}{\mu_3} = \frac{\sin i_2}{\sin r_2} = \frac{\sin i_2}{\sin r}$$



Since, $\sin i_1 > \sin r$

$$\Rightarrow \frac{\sin i_1}{\sin r} > \frac{\sin r}{\sin i_1} \Rightarrow {}^1\mu_2 > {}^2\mu_1$$

Since, $\sin i_2 > \sin r$

$$\Rightarrow \frac{\sin i_2}{\sin r} > \frac{\sin r}{\sin i_2} \Rightarrow {}^2\mu_3 > {}^3\mu_2$$

Since, $\sin i_1 > \sin r$

$$\Rightarrow \frac{\sin i_1}{\sin i_2} < \frac{\sin i_2}{\sin i_1}$$

38. The angle of deviation depends on the angle of incidence and wavelength of the incident light, angle of prism and refractive index of the prism.
39. A suitable cylindrical lens rectifies astigmatism.
40. Human eye has its maximum sensitivity around 555 nm which belongs to green region.
41. Initially the white paper is fixed on the drawing board and the prism is placed on the paper. The outline of the prism is drawn on the paper and a point is marked on one of the sides. A normal is drawn at that point and a line which makes a certain angle with the normal is drawn on the paper. Two pins P and Q are fixed on the line and the prism is placed in its initial position. The images of the pins P and Q are viewed from the other side of the prism. Two more pins R and S are fixed such that R and S are on the same line with the images of P and Q . Remove the pins and join the line segment RS with the side of the prism. Join the line segments PQ and RS . Extend the lines

PQ and RS . Determine the angle between PQ and RS . This is known as the angle of deviation. Repeat the experiment for different angles of incidence and determine the angle of deviation in each case. Plot a graph by taking the angle of incidence along the X-axis and angle of deviation along the Y-axis. Determine the angle of minimum deviation and determine the refractive index

$$\mu = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

42. The magnification is positive for virtual images and is negative for real images. The concave lens and convex mirror form virtual images and its magnification is positive whereas convex lens and concave mirror can produce both real and virtual images, hence, their magnification is negative and positive respectively.
43. The rainbow is always formed in a opposite direction of the position of the sun.
44. Rayleigh scattering is called incoherent scattering whereas Raman scattering is an coherent scattering.
45. To study the nature of the image, the lens is initially placed on a 'V' shaped stand and its focal length is determined by focusing the lens to an object at infinite distance. The points F_1 , $2F_1$, F_2 and $2F_2$ are marked on the paper and the lens is focused to the object at infinity, just behind $2F_1$, at $2F_1$, between F_1 and $2F_1$, at F_1 and between F_1 and optic centre. In each case the position of the screen is adjusted and the nature of the image is studied.

Level 2

46. (i) Consider two cases where angle of incidence is 0° and 90° .
Then the angle of refraction (r_1) at first face will be 0° and C respectively, where C is the critical angle.
Find the corresponding angles of refraction (r_2) at other face of the prism.
Find the angle of the prism when angle of refraction r_2 is less than critical angle and above critical angle.
 $A = r_1 + r_2$.
Get the condition, when $\angle A < C$ and $\angle A > 2C$, then find what happens when $\angle A$ is in between C and $2C$.
- (ii) 80°
47. (i) Find the focal length of the compound lens.
(ii) Take the focal lengths of the convex and the concave lenses as positive and negative respectively.
(iii) Find whether the compound lens is a converging one or a diverging one.
(iv) Use the lens formula to find the position of the image.
(v) infinity
48. (i) When white light passes through a prism, it undergoes dispersion.
Here violet, indigo and blue colors are more deviated than green, yellow, orange and red colours ($\mu_{\text{violet}} > \mu_{\text{red}}$).



When white light ray passes from denser medium to rarer medium, and the angle of incidence is equal to the critical angle for green colour light, how does green light emerge out of the interface separating the two media?

From $\mu = \frac{1}{\sin C}$, find which colours will be

refracted and which colours will be reflected into the same medium.

- (ii) Red, orange and yellow pass into rarer medium; blue, indigo and violet reflect back into denser medium.

49. (i) Is the emergent beam a parallel beam parallel to the axis?
 (ii) What should be the position of the object to get the image at infinity?
 (iii) Does the first image formed serve as an object to the lens L_2 ?
 (iv) 25 cm, 74 cm

50. (i) Find the value of uniform speed of the ant. Shift the mirror horizontally and coincide it with the point Q. Apply the trigonometric formula. Find the distance of the ant from the mirror. The object distance is equal to the image distance. Then find the distance between the ant and its image, when ant is at P and Q. Find the difference between the distance of the ant and the image, when present at P and Q. Divide the obtained distance by the time taken. Then, from this find the rate at which the distance between the ant and its image changes.

- (ii) 0.5 cm s^{-1}

51. (i) Find angle of incidence i from $\mu = \frac{\sin i}{\sin r}$.

- (ii) Find the angle of deviation, $d = i - r$.

- (iii) Find the lateral shift using the formula for it.

- (iv) $5\sqrt{3}$ or 8.66 cm

52. With one eye closed and looking with one eye, try to estimate the distance of an object. What difficulties do you have?

53. (i) Find the nature of the lens with the help of given information.
 (ii) Use lens formula.

- (iii) Find the object distance in the two cases and then find the distance moved by the lens.

- (iv) 20 cm

54. (i) Find the object-distance with respect to the convex mirror.

Is the object-distance and the image-distance equal in the case of a plane mirror?

Find the distance between the plane mirror and the convex mirror.

Find the distance between the convex mirror and the image formed in the plane mirror.

Determine the image-distance for the convex mirror.

Find the focal length of the convex mirror by

using the mirror formula $\left(\frac{1}{f} = \frac{1}{v} + \frac{1}{u}\right)$.

- (ii) 30 cm

55. (i) Using mirror formula, express magnification ' m ' in terms of focal length ' f ' and object distance ' u '.

- (ii) Use the expression to find the magnification in both the cases.

- (iii) Find the new object distance and then find the magnification.

- (iv) Difference in magnification gives the answer.

- (v) 2

56. What is Rayleigh's scattering principle?

In all the seven colours, which colour deviates the least?

Which colour has more wavelength?

From Rayleigh's scattering formula, $I_{\max} = \frac{1}{\lambda^4}$, find

whether red colour scatters more or less?

Can a least scattering colour be used as danger sign in traffic signals?

57. (i) **Case 1:**

Take the object distance from convex lens as ' x ' cm.

Then, the image distance will be $(10 - x)$ cm.

Substitute the values in lens formula $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

and find the value of focal length (f) of the lens in terms of ' x '.

(1)

Case 2:

When the lens is shifted by 2 cm, take the object distance from convex lens as $(x + 2)$ cm.



Find the image distance from the lens. $(10 - x - 2)$

Substitute the values in lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

to find the focal length (f) of the lens in terms of 'x' (2).

(use sign convention)

Is the focal length of a lens constant for a given medium?

Compare (1) and (2), and find x . Then, find the value of ' f '.

(ii) 2.4 cm

58. (i) Which is the observer – bird or fish?

Which is the object?

What is the speed of the bird?

What is the distance travelled by the bird in one second?

If the real distance of the bird is RD_1 ($x + d$) and after one second the real distance of the bird becomes RD_2 from the free surface of the water, where $RD_2 = (x - v + d)$, then find the relation between RD_2 and RD_1 .

What is the relation between real depth, apparent depth and refractive index?

What is the apparent depth of the bird as viewed by the fish?

Apparent velocity is equal to the rate of change in apparent depth.

Then find the value of apparent velocity of the bird as viewed by the fish.

(ii) μv

59. (i) Represent the positions of the object, mirror and the image along X- axis.

(ii) Difference in the final and initial positions of the image.

(iii) 80 cm

60. (i) From the given problem, the distance between the object and image is 4 cm.

The distance between object and image = $x = 4$ cm.

Find the image distance, v .

$$v = u + x. \quad (1)$$

What is the formula for magnification?

$$\left(m = \frac{u}{v}\right) \quad (2)$$

Find value of u , v from (1) and (2).

Find the focal length (f) of the lens by using lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}.$$

To find the type of lens used, draw a straight line passing through the two arrow tips and draw another straight horizontal line from tip of arrow of the smaller line.

Draw the refracted ray and produce backward.

In the ray diagram, locate the lens, object and image

(ii) $u : v : f = 2 : 6 : 3$

61. $u = -60$ cm; $f = -40$ cm, $v = ?$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}; \Rightarrow \frac{1}{40} = -\frac{1}{60} + \frac{1}{v} \Rightarrow \frac{1}{v} = \frac{1}{60} - \frac{1}{40}$$

$$\frac{1}{v} = \frac{2-3}{120} = \frac{-1}{120} \Rightarrow v = -120 \text{ cm}$$

$$m = \frac{-v}{u} = \frac{+120}{60} = -2$$

62. Yellow = Red + Green; So, blue coloured filter allows only blue colour and absorbs all the remaining colours. So, yellow coloured dress appears black.

63. White light, while passing through the cyan filter, emerges as cyan light.

Cyan, being a combination of blue and green, renders the emergent white light passing through the magenta filter, blue.

As magenta is a combination of blue and red, green colour of cyan is absorbed by the filter and only blue is transmitted.

The third filter is yellow, which is a combination of red and green.

Thus, the yellow filter completely absorbs the blue light incident on it and transmits none. Thus, no light is incident on the prism and no colours are observed on the screen.

64. $h = 12$ m, $h' = ?$

$$\mu_w = \frac{4}{3}$$

$$d = 1 \text{ m}$$

$$\mu_w = \frac{h'}{h_1}; \frac{4}{3} = \frac{h}{12} \Rightarrow h' = \frac{4}{3} \times 12 = 16 \text{ m}$$

Total height $h' + d = (16 + 1) \text{ m} = 17 \text{ m}$



Level 3

65. Find the critical angle of the glass used for prism.
Find the angle of incidence of light on prism.
Will the letter LIGHT undergo total internal refraction in an isosceles right-angled prism at hypotenuse side of the triangle?
Are the emergent light rays from the prism parallel?
Find whether the object distance can be taken as infinity.
Find the focal length of the convex lens from given information.
Find the image distance for convex lens.
Find the nature of the image formed due to convex lens.

66. (i) $\mu = \frac{\text{Real depth}}{\text{apparent depth}}$

- (ii) 15 cm, 1 cm
15 : 14

67. (i) What is the value of ' u ' and ' f ' for convex lens?
(Follow sign convention.)
What is the distance between convex lens and convex mirror?
Find the value of the image distance, ' v ' for convex lens by using the lens formula,
$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}.$$

Here, $v = 4 + 2f$ (where f = focal length of convex mirror).
Find the value of ' f '.

- (ii) 3 cm

68. (i) $\Delta h = \Delta h_1 + \Delta h_2.$

(ii) $\Delta h = h \left(1 - \frac{1}{\mu} \right).$

- (iii) 1.5 cm

68. Find the refractive index of the glass prism for green light from the given information.

What colours are present in cyan?

Find the critical angle for green colour light, using

the formula $\mu = \frac{1}{\sin C}.$

Bending power of blue colour light is more than that for green colour. Then will the critical angle for blue be less or more?

At point P , find the angles of incidence and refraction.
Find the angle of incidence of the light rays on the face AC with the help of a ray diagram.

Find whether it undergoes total internal reflection.

Then, will the light ray incident on the face AB ?

Find the angle of incidence on the face BC .

Is this angle equal to the critical angle for green colour?

Then, find whether green colour grazes out from the face AB .

From geometry, show that blue colour emerges from the face AC .

70. Given the prism is an equilateral prism.

$\Rightarrow$ angle of the prism, $A = 60^\circ$

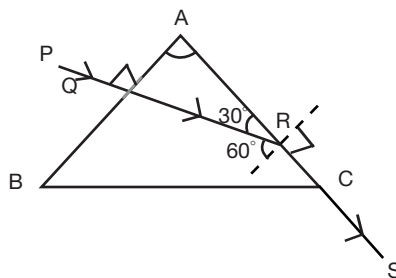
Given the refractive index of the glass $\mu = \sqrt{2}$

If D is the angle of minimum deviation,

$$\text{Then, } \mu = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \Rightarrow \sqrt{2} = \frac{\sin\left(\frac{60^\circ+D}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$\Rightarrow \sin\left(\frac{60^\circ+D}{2}\right) = \frac{1}{\sqrt{2}} = \sin(45^\circ) \Rightarrow D = 30^\circ$$

- 71.



From the figure, it is clear that the angle of incidence of the light may be on the face AC of the prism inside; it is 60° .

As the emergent ray grazed the face AC , the critical angle of the material of the prism is 60°

$$\text{Hence, } \mu = \frac{1}{\sin 60^\circ} \Rightarrow \frac{2}{\sqrt{3}}$$



72. At each interface, the rays deviate away from the normal. Therefore, $\mu_0 < \mu_1 < \mu_2 < \mu_3 < \mu_4$. At the interface of medium 3 and medium 4, total internal reflection takes place.

Angle of deviation in the cases of reflection

$$= 180^\circ - 2i$$

$$= 180^\circ - 60^\circ = 120^\circ$$

73. Critical angle of medium X is $C_X = 60^\circ$.
Critical angle of medium Y is $C_Y = 45^\circ$.
Let C_1 and C_2 are velocities of light in X and Y respectively.
Let μ_1 and μ_2 are the refractive indices of X and Y respectively.

$$\text{Then } \mu_1 = \frac{1}{\sin C_X} = \frac{1}{\sin 60^\circ} = \frac{1}{\left(\frac{\sqrt{3}}{2}\right)} = \frac{2}{\sqrt{3}}$$

$$\text{And } \mu_2 = \frac{1}{\sin C_Y} = \frac{1}{\sin 45^\circ} = \left(\frac{1}{1/\sqrt{2}}\right) = \sqrt{2}$$

Let 'C' be velocity of light in air then μ_1

$$= \frac{C}{C_1} \text{ and } \mu_2 = \frac{C}{C_2} \therefore \frac{C}{C_1} = \frac{2}{\sqrt{3}} \quad (1) \text{ and}$$

$$\frac{C}{C_2} = \sqrt{2} \quad (2)$$

Dividing equation (1) with equation (2)

$$\frac{\left(\frac{C}{C_1}\right)}{\left(\frac{C}{C_2}\right)} = \frac{\left(\frac{2}{\sqrt{3}}\right)}{(\sqrt{2})} \text{ or } \frac{C_2}{C_1} = \frac{\sqrt{2}}{\sqrt{3}} \text{ or } \frac{C_1}{C_2} = \frac{\sqrt{3}}{\sqrt{2}} = \sqrt{\frac{3}{2}}$$

74. For concave lens, $f = -20$ cm $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$-\frac{1}{20} = \frac{1}{v} - \left(\frac{-1}{30}\right) \Rightarrow \frac{1}{v} = -\frac{1}{20} - \frac{1}{30};$$

$$\frac{1}{v} = \frac{-30 - 20}{600}$$

$$v = \frac{600}{-50} = -12 \text{ cm}$$

For convex lens.

$$u = -(12+18) = -30 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{f} = \frac{1}{30} - \left(\frac{-1}{30}\right)$$

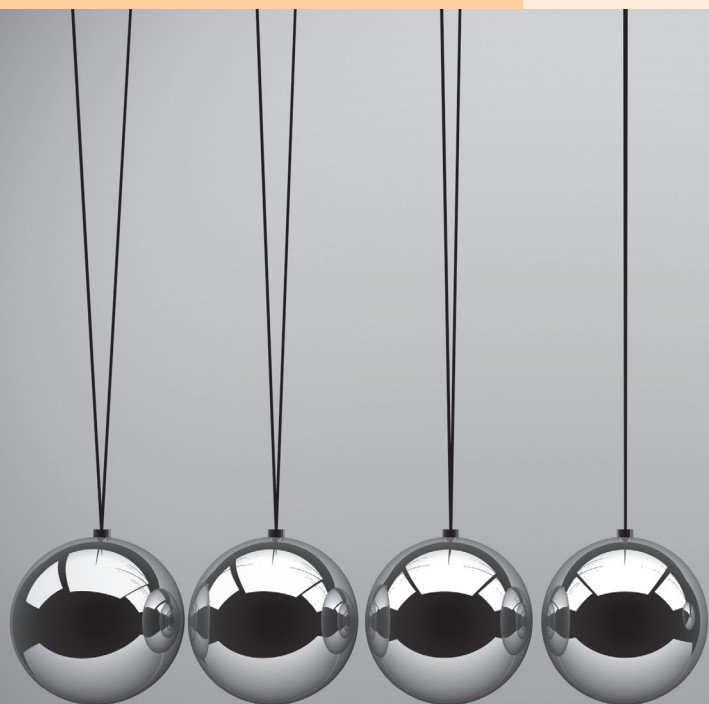
$$= 2\left(\frac{1}{30}\right) \Rightarrow f = 15 \text{ cm}$$



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Chapter 5

Hydrostatics



Remember

Before beginning this chapter, you should be able to:

- Understand how pressure varies of a fluid with the height of the fluid columns
- Learn the principle, construction and working of manometer and different barometers
- Explain Pascal's Law and its applications in Bramah Press, Hydraulic Press and Hydraulic Brakes
- Explain Archimedes' principle, Laws of floatation and their applications
- Learn construction, principle and working of hydrometers
- Understand surface tension and viscosity

Key Ideas

After completing this chapter you should be able to:

- Understand the term pressure and to deduce the expression for fluid pressure
- Discuss about atmospheric pressure and its applications
- Understand the reason for the apparent loss of weight of an object when immersed in a fluid and to derive an expression for upthrust and applications of Archimedes' principle
- Discuss the reason for surface tension and to understand the applications of surface tension
- Study the different types of fluid flows and use scientific principles valid for the flow of fluids

INTRODUCTION

We observe that a balloon filled with hydrogen gas goes up but a balloon filled with air falls down. A small iron nail sinks in water, but huge ships made of iron float. A stone weighs less in water than in air. To seek answers to these questions, we need to understand how liquids and gases at rest react to external forces. This involves the study of a branch of physics called hydrostatics. In previous classes, you have studied many laws, terms, etc., associated with hydrostatics.

THRUST AND PRESSURE

Thrust

Force acting normally on a body is called thrust. For example, the weight exerted by a book placed on table is normal to its surface. Hence, it is called thrust. Since thrust is a force, its units are same as those of force.

Units of thrust:

S.I. – newton (N)

C.G.S. – dyne

Gravitational units:

S.I. – kg_f or kg_{wt}

C.G.S. – g_f or g_{wt}

Thrust is a vector quantity.

The dimensional formula of thrust is $[M^1L^1T^{-2}]$.

Pressure

Consider a force of 20 N acting normally on a surface whose area is 2 m^2 . Thrust acting on

$$\text{a unit area is} = \frac{20\text{N}}{2\text{m}^2} = 10\text{Nm}^{-2}$$

We say that pressure of 10 N m^{-2} acts on the surface.

Thus, pressure is thrust acting on a unit area.

$$\therefore \text{Pressure} = \frac{\text{Thrust}}{\text{Area}}$$

$$\text{i.e., } P = \frac{F}{A}$$

Units of pressure:

S.I. unit: N m^{-2}

1 N m⁻² is called pascal (Pa) in honour of the French Scientist Blaise Pascal. Pressure is said to be 1 pascal if a force of 1 N acts normally on a surface of area 1 m².

C.G.S. unit of pressure is dyne cm⁻²:

Gravitational unit is kg_f m⁻² or kg_{wt} m⁻²

$$1 \text{ kg}_f = 9.8 \text{ N}$$

$$\therefore 1 \text{ kg}_f \text{ m}^{-2} = 9.8 \text{ N m}^{-2} = 9.8 \text{ Pa}$$

$$\begin{aligned} 1 \text{ Pa} &= 1 \frac{\text{N}}{\text{m}^2} = \frac{1 \times 10^5 \text{ dyne}}{(10^2)^2 \text{ cm}^2} \\ &= \frac{1 \times 10^5 \text{ dyne}}{10^4 \text{ cm}^2} \\ &= 10 \text{ dyne cm}^{-2} \end{aligned}$$

Pressure is a scalar quantity. The dimensional formula of pressure is [ML⁻¹T⁻²].

Pressure in Fluids

Any substance which can flow and has no definite shape is called a fluid. Thus, liquids and gases together are referred to as fluids.

Solids exert pressure on a surface on which they rest due to their weight. Liquids and gases also have weights. Hence, they also exert pressure. However, fluids exert pressure in all directions.

A fluid enclosed in a vessel exerts pressure at all points and in all directions. Fluid molecules are in constant random motion, due to which they collide with the walls of the container. In doing so, their momentum changes in a very short interval of time. This acts as thrust on the walls due to the fluid molecules.

The thrust on a unit area at a point gives rise to fluid pressure at that point. Since molecules move randomly, on an average equal number of molecules move in each direction. Thus, fluid pressure at any point inside it is same in all directions. The pressure exerted by a fluid on the walls of the container is called lateral pressure.

Mathematical Expression for Pressure in Fluids

Consider a vessel containing a liquid of density ' d ' and a coin of area of cross section ' a ' placed at the bottom. A liquid column of height ' h ' and area of cross section ' a ' forms an imaginary cylinder above the coin. This column exerts its weight on the coin giving rise to liquid pressure.

Volume of imaginary liquid column = area of cross section $\times$ height

$$V = ah$$

Mass of liquid column = volume $\times$ density

$$m = V\rho$$

Substituting for V ,

$$m = ah\rho$$

Weight of the liquid column = mass $\times$ acceleration due to gravity

$$= mg = ah\rho g$$

$\therefore$ thrust exerted by the liquid column = $ah\rho g$

But pressure due to liquid column (P) = $\frac{\text{Thrust}}{\text{Area}}$

$$\therefore P = \frac{ah\rho g}{a}$$

$$\text{i.e., } P = h\rho g$$

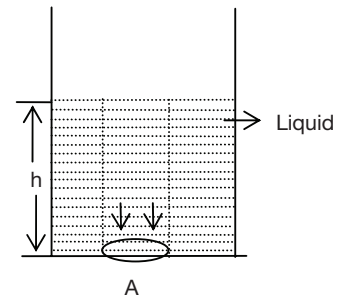


FIGURE 5.1 A coin immersed in a liquid container

Thus, pressure at a point inside a liquid is proportional to the depth of the point below the free surface of the liquid and its density.

EXAMPLE

Calculate the pressure at the bottom of a tank due to a water column of height 200 m. (Take $g = 10 \text{ m s}^{-2}$)

SOLUTION

Given

$$h = 200 \text{ m}$$

$$\rho = 10^3 \text{ kg m}^{-3} \text{ (density of water)}$$

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

$$P = h\rho g$$

$$P = 200 \times 10^3 \times 10 = 2 \times 10^6 \text{ N m}^{-2}$$

$$= 2 \times 10^6 \text{ Pa}$$

EXAMPLE

A liquid column of vertical height 1.2 m exerts a pressure of 19992 Pa at its bottom. Find the density of the liquid (Take $g = 9.8 \text{ m s}^{-2}$).

SOLUTION

$$P = h\rho g$$

$$\therefore \rho = \frac{P}{hg}$$

$$= \frac{19992}{1.2 \times 9.8} = 1700 \text{ Kg m}^{-3}$$

Factors on Which the Pressure at a Point in a Fluid Depends

The pressure at a point inside a liquid is directly proportional to the following three factors:

1. The depth of the point below the free surface or the height of the fluid column above it.
2. The density of fluid.
3. The acceleration due to gravity.

The Pressure at a Point in Fluid does not Depends On

1. The shape and size of the vessel in which the fluid is contained.
2. The area of the surface on which it acts.

Let P_o be the atmospheric pressure acting on the liquid surface. The total pressure acting at a point inside the liquid is

$P = \text{atmospheric pressure} + \text{pressure due to the liquid column}$

$$P = P_o + hdg$$

EXAMPLE

A rectangular plate $10 \text{ cm} \times 5 \text{ cm}$ is placed horizontally below the water surface in a trough at a depth of 2 m. If the atmospheric pressure is $1.013 \times 10^5 \text{ N m}^{-2}$, calculate the total thrust on the plate.

SOLUTION

Pressure at a point 2 m below the water surface = atmospheric pressure + pressure due to the water column of height 2 m.

$$\begin{aligned} \text{Pressure due to water} &= hdg \\ &= 2 \text{ m} \times 10^3 \text{ kg m}^{-3} \times 10 \text{ m s}^{-2} \\ &= 0.2 \times 10^5 \text{ N m}^{-2} \end{aligned}$$

$$\begin{aligned} \text{Total pressure} &= (1.013 \times 10^5 + 0.2 \times 10^5) \text{ N m}^{-2} \\ &= 1.213 \times 10^5 \text{ N m}^{-2} \end{aligned}$$

$$\text{Area of the plate} = 10 \text{ cm} \times 5 \text{ cm} = 50 \text{ cm}^2 = 50 \times 10^{-4} \text{ m}^2$$

$$\text{Total thrust acting on the plate} = \text{total pressure} \times \text{area} = 1.213 \times 10^5 \times 50 \times 10^{-4} = 606.5 \text{ N.}$$

LAWS OF LIQUID PRESSURE

Consider a piston fixed to an air tight cylinder which contains a spring (from its base to piston). When the external pressure on the piston increases, it is pushed into the cylinder. The spring fixed between the piston and the base of the cylinder helps the piston recover

its original position as soon as the external pressure is removed. Insert this cylinder in a container containing a liquid. As depth increases, the piston is pushed more into the cylinder.

1. It means the pressure exerted by the liquid increases as we go deeper in the liquid.
2. Select a point at a particular depth in the liquid. Place the cylinder at this depth and rotate it by 360° . We find that the depth of the piston inside the cylinder remains the same. This shows that the pressure at a point in a liquid is the same in all directions.
3. Move the cylinder along the same horizontal level at a particular depth. We find that the depth of the piston inside the cylinder remains same. This shows that the pressure is the same at all points in a horizontal plane in a stationary liquid.
4. If the cylinder is immersed to the same depth in another liquid with higher density, the piston gets compressed more. This shows that the pressure at a point in a liquid increases with increase in the density of the liquid.

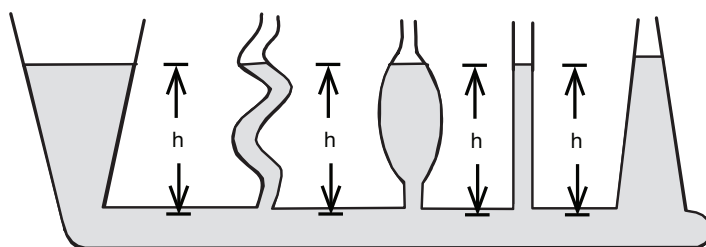


FIGURE 5.2 Apparatus to verify law of liquid pressure

Take an apparatus consisting of a number of tubes of different shapes and sizes connected together at the bottom as shown in Fig. 5.2.

Pour a liquid through any one of the tubes. We find that the liquid level in all the tubes is same. This shows that a liquid seeks its own level. This experiment proves that pressure at a point does not depend on shape or size of that vessel.

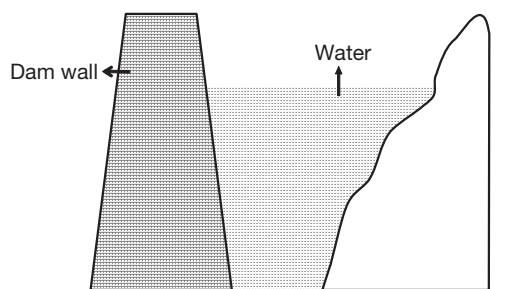


FIGURE 5.3 Wall of dam made thicker at the bottom to bear greater fluid pressure at the bottom

Following is one of the consequences of liquid pressure.

1. The wall of a dam is made thicker at the bottom. The pressure exerted by the water increases with depth. At greater depth, higher pressure is exerted by the water on the wall of the dam. Therefore, the thickness of wall is more at the bottom to prevent it from collapsing as shown in Fig. 5.3.

EXAMPLE

A rectangular container of dimensions 50 cm × 30 cm × 100 cm is filled completely with water. Determine

- (i) the thrust at the bottom of the vessel,
- (ii) the pressure at a depth of 10 cm from the free surface and
- (iii) the net force experienced by a metal sheet held vertically at a depth of 10 cm.

SOLUTION

Volume of the container = $l \times b \times h$

$$= \frac{50}{100} \text{ m} \times \frac{30}{100} \text{ m} \times \frac{100}{100} \text{ m}$$

$$= 0.15 \text{ m}^3$$

$$\begin{aligned} \text{Thrust at the bottom of the container} &= \text{weight of water in the container} \\ &= mg = \text{volume} \times \text{density} \times g \\ &= 0.15 \text{ m}^3 \times 10^3 \text{ kg m}^3 \times 10 \text{ m s}^{-2} \\ &= 0.15 \times 10^4 \text{ N} \end{aligned}$$

2. Pressure at a point inside a liquid is given by,

$$\begin{aligned} P &= h \rho g \\ &= \frac{10}{100} \times 1000 \times 10 = 1000 \text{ N m}^{-2} \end{aligned}$$

3. The net force acting on the metal sheet will be zero because the lateral thrust exerted by the water on each face of the sheet is equal and opposite.

Transmission of Pressure in Liquids—Pascal's Law

When pressure is applied at a point on a confined fluid, it is transmitted to other parts of the fluid. For example, if you press a balloon filled with air or water at a point, it bulges out at some other point. This shows that a liquid can transmit pressure. Pascal summarised this in a statement called Pascal's law.

PASCAL'S LAW

Pressure applied anywhere in a confined fluid is transmitted equally and undiminished in all directions throughout the fluid.

Consider a vessel as shown in the Fig. 5.4.

It is filled with water and has four identical water tight pistons P, Q, R and S. Let a pressure of 1 Pa be applied to piston P which moves inwards. The remaining three pistons are found to move outwards. To prevent them from moving out, 1 Pa pressure has to be applied to each one of them. This clearly shows that pressure applied at one point has been transmitted to the other points equally and undiminished in all directions.

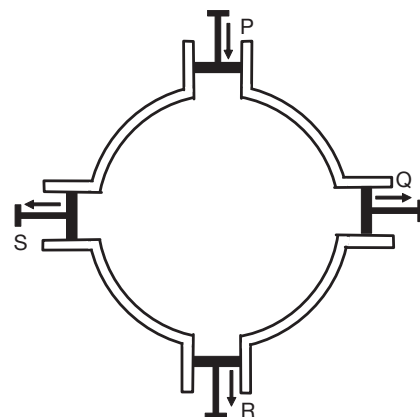


FIGURE 5.4 Apparatus to verify Pascal's law

Applications of Pascal's Law

The working of hydraulic machines such as hydraulic press, hydraulic jack and hydraulic brakes is based on Pascal's law.

Principle of Hydraulic Machine

Consider two cylindrical vessels P and Q connected by a horizontal tube R . The vessels are filled with water or any other liquid and fixed with air tight pistons M and N , respectively. Let A_1 and A_2 be the area of cross section of the two pistons, respectively such that $A_2 > A_1$. A weight is kept on piston M which exerts a force F_1 on it. This force is acting on area A_1 .

Hence, the downward pressure P_1 due to it is $P_1 = \frac{F_1}{A_1}$ (5.1)

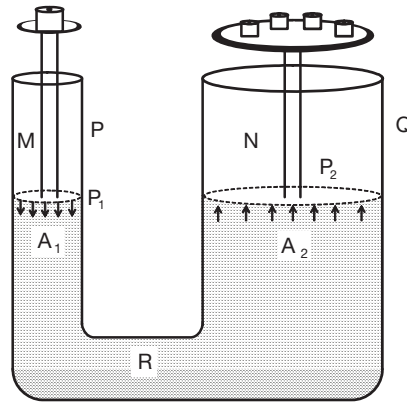


FIGURE 5.5 Hydraulic machine

According to Pascal's law, this pressure is transmitted equally and undiminished throughout the liquid. Hence, the pressure acting on the piston N in upward direction is P_1 and the piston tends to move up. To prevent it from moving up, a force F_2 should be applied to it in downward direction by putting certain weight on it.

$$F_2 = \text{pressure on } N \times \text{area of cross section}$$

$$F_2 = P_1 \times A_2$$

$$\therefore F_2 = \frac{F_1}{A_1} \times A_2 \quad [\text{from equation (5.1)}]$$

Since $A_2 > A_1$, therefore, $F_2 > F_1$.

Thus, a small thrust applied to the smaller piston can be used to exert a larger thrust on the bigger piston.

Examples of Hydraulic Machines

1. **Bramah Press (Hydraulic Press):** Its working is based on Pascal's law.

Uses of Bramah Press

It is used in the following applications

1. For pressing books, cotton bales, etc.
2. For squeezing the oil out of oil seeds
3. For punching holes in metals
4. For extracting juice of sugar cane, sugar beet, etc.

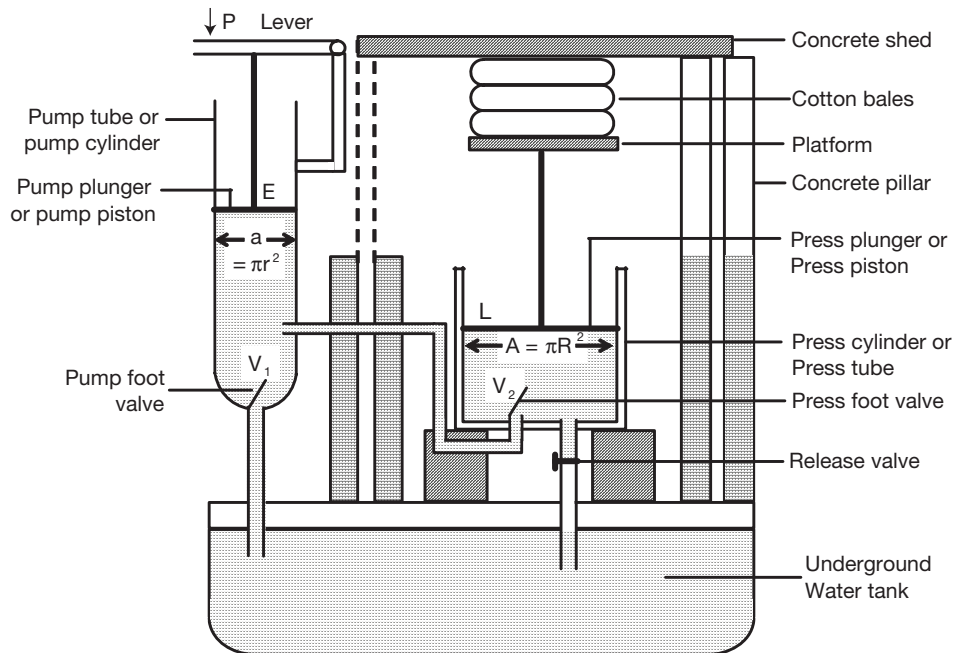


FIGURE 5.6 Hydraulic press

EXAMPLE

The ratio of area of cross section of the two pistons in a hydraulic machine is 1 : 15. Find the force that should be applied on the narrower piston to overcome a force of 120 N on the bigger piston.

SOLUTION

$$A_1 : A_2 = 1 : 15$$

$$F_2 = 120 \text{ N}$$

$$F_1 = ?$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \quad (\text{Pascal's law})$$

$$F_1 = F_2 \times \frac{A_1}{A_2} = \frac{120}{15}$$

$$F_1 = 8 \text{ N}$$

2. **Hydraulic Brakes:** To stop a heavy vehicle moving with a high velocity, a large force has to be applied. These vehicles have hydraulic brakes which are hydraulic machines working on Pascal's law.

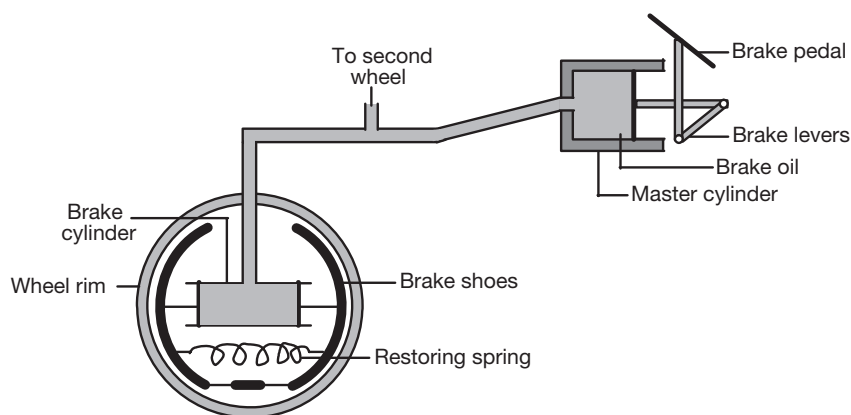


FIGURE 5.7 Hydraulic brakes

ATMOSPHERIC PRESSURE

Our earth is surrounded by air to a height of about 300 km. The envelope of air around the earth is called atmosphere. Atmosphere exerts thrust on the earth due to its weight. This thrust acting on a unit area of earth is called atmospheric pressure. Considering the extent of the atmosphere, the pressure exerted by it is huge. Its average magnitude is approximately $10 \times 10^3 \text{ kg}_f \text{ m}^{-2}$ or 10^5 Pa in SI system or $10^3 \text{ g}_f \text{ cm}^{-2}$ in CGS system.

That atmosphere exerts its pressure on the earth can be demonstrated by the following experiment. Take a tin can and fill it with water to its half. Heat the can till water begins to boil. The steam formed drives away the air in the can. Now close the can with air tight cover. Stop heating it. Now, pour some cold water over the can. It is found that the metallic can gets crushed in. This can be explained as follows: As the steam inside to its half it condenses to water, the pressure inside the can decreases appreciably. However, atmospheric pressure is still acting on it from outside. It must be very large, since it is able to crush the can.

Some Consequences of Atmospheric Pressure

1. We are able to consume soft drinks and juices using a straw due to the atmospheric pressure.
2. Hand pump or lift pump can draw under ground water making use of the atmospheric pressure.

Measurement of Atmospheric Pressure

A device used to measure atmospheric pressure is called a barometer. There are three types of barometers.

They are:

1. Simple barometer or Torricellian barometer
2. Fortin's barometer
3. Aneroid barometer

Simple Barometer

It was first constructed by Italian scientist Torricelli. The atmospheric pressure is measured in terms of height of the mercury column taken in a glass tube. Pressure due to any liquid column is given by $P = h\delta g$

At a given place and for a given liquid, acceleration due to gravity, ' g ' and the density of the liquid, ' δ ' are constant. Therefore, pressure can be expressed in terms of the height of a liquid column.

A simple barometer consists of a glass tube of uniform narrow bore and of length 1m, filled completely with dry and pure mercury. This tube is inverted into a trough containing pure mercury.

Depending upon the pressure acting on the mercury in the trough, some mercury from the tube flows into the trough. The empty space created at the top of the tube is called torricellian vacuum. At the sea level, it is found that the height of the mercury column in the tube is approximately 76 cm.

The pressure exerted by 76 cm of mercury is taken as
1 atmospheric pressure.

$$1 \text{ atm} = 76 \text{ cm of Hg} = 0.76 \text{ m of Hg} \therefore P = h\delta g$$

$$\therefore P = 0.76 \text{ m} \times 13.6 \times 10^3 \text{ kg m}^{-3} \times 9.8 \text{ m s}^{-2}$$

$$\therefore P = h\delta g$$

$$= 1.01292 \times 10^5 \text{ Pa}$$

$$\therefore 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

Other units which are used to measure the atmospheric pressure are

$$1 \text{ torr} = 1 \text{ mm of Hg}$$

$$1 \text{ bar} = 10^5 \text{ Pa}$$

The Vertical Height of the Barometric Liquid

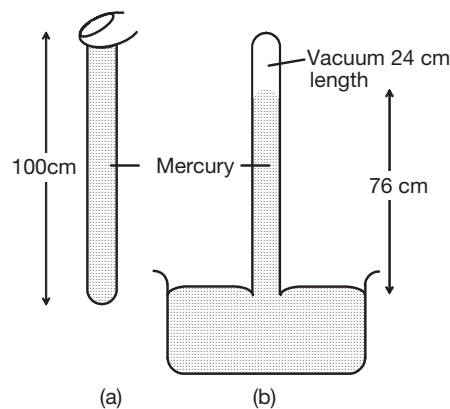


FIGURE 5.8 Simple barometer

1. It is found that vertical height of the barometric liquid is independent of the size and shape of the tube and
2. remains unaffected, even if the tube is tilted.

The factors which affect the barometric height are:

1. The presence of moisture in mercury
2. The presence of impurities in mercury
3. The altitude of a place above the sea level
4. Temperature
5. Humidity

Mercury is the most preferred barometric liquid as its density is very high. Hence, the height of mercury column even at the sea level is only 76 cm. If water is used as a barometric liquid, the height of water column would be approximately 10.34 m. If the pressure due to water and mercury columns is $h_w d_w g$ and $h_{Hg} d_{Hg} g$ respectively, then $h_w d_w g = h_{Hg} d_{Hg} g$ (since both water and mercury columns are supported by the same atmospheric pressure).

$$\frac{h_w}{h_{Hg}} = \frac{d_{\text{mercury}}}{d_{\text{water}}}$$

$$\therefore h_w = \frac{d_{\text{mercury}} \times h_{\text{mercury}}}{d_{\text{water}}}$$

$$\therefore h_w = \frac{13.6 \times 10^3 \times 0.76 \text{ m}}{1000}$$

$$\text{i.e., } h_w = 10.366 \cong 10.3 \text{ m}$$

Defects of a Simple Barometer

1. The free surface of mercury in the trough does not always coincide with the zero mark of the scale attached to the barometric tube. Mercury from the tube flows into the trough and vice versa depending on the changes in the atmospheric pressure and temperature. Hence, the tube has to be raised or lowered whenever the reading of the atmospheric pressure is to be taken.
2. The barometer is exposed to the surroundings. The mercury can get contaminated, which affects the barometric readings.
3. The mercury can spill over when the barometer is moved from one place to another.
4. It is quite bulky.
5. It is difficult to keep the glass tube vertical.

In order to overcome these defects, Fortin's barometer is used.

Fortin's Barometer

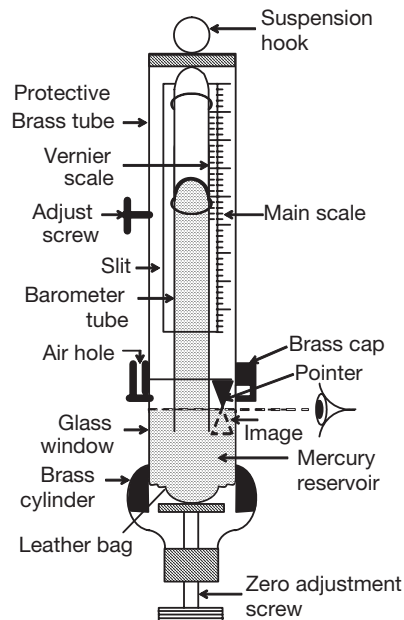


FIGURE 5.9 Fortin's barometer

It consists of a brass enclosure which contains the glass test tube inverted into a glass vessel having a leather cup at its bottom. Both are filled with dry and pure mercury. At the bottom of brass enclosure, there is a screw. By adjusting this screw, the leather cup can be raised or lowered and the mercury level in the glass vessel is made to be in level with zero mark. An ivory pointer is fitted in the brass tube such that when its tip just touches the mercury level in the vessel, the mercury level would correspond to the zero mark. A vernier scale is also provided at the top of the tube for accurate readings.

Aneroid Barometer

It contains no liquid. It is light and portable and can be placed in any orientation.

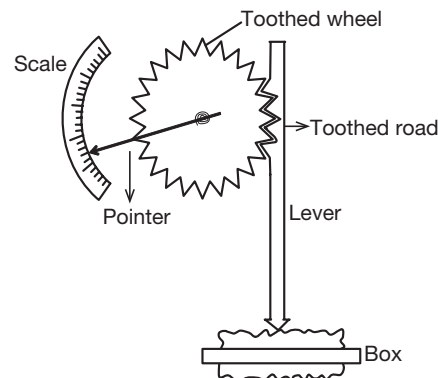


FIGURE 5.10 Aneroid barometer

It consists of an evacuated box with a diaphragm at the top. At the centre of the diaphragm a toothed rod is attached. A circular toothed wheel fits into the teeth of the rod so that as the

atmospheric pressure changes, the diaphragm may get pressed down or raised which lowers or raises the rod. The toothed wheel in turn rotates, and the needle pointer pivoted to it deflects on a circular scale calibrated to give atmospheric pressure.

Manometer

It is a device used to measure the pressure of gas in a container. It consists of a U-shaped glass tube of uniform cross section filled with a liquid. The ends of the U-tube are open. When exposed to the atmosphere, the liquid level in both the arms is same. One arm of the tube is connected to the gas container. If the pressure exerted by the gas is less than the atmospheric pressure, the level of the liquid in that arm goes up as shown in Fig. 5.11(b).

If P_o = atmospheric pressure, P = pressure exerted by the gas.

Since the points C and B are at the same level, $PC = PB$.

$$\text{i.e., } P + hdg = P_o$$

where h = difference in liquid levels in the two arms, and d = density of the liquid.

$$\therefore P = P_o - hdg$$

If $P > P_o$, then $P = P_o + hdg$ (Fig. 5.11c).

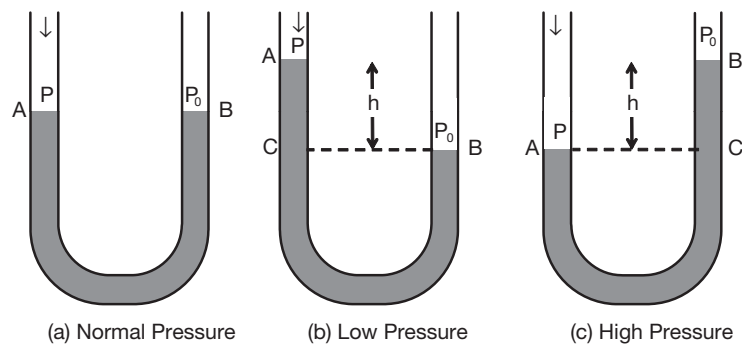


FIGURE 5.11 Manometer

Variation of Atmospheric Pressure with Altitude

The atmospheric pressure decreases with increase in the altitude from the sea level due to two factors.

1. As the altitude increases, the height of the air column exerting the atmospheric pressure decreases
2. The density of air at higher altitude is less than the density of air at the surface of the earth.

Taking the average density of air as 1.29 kg m^{-3} , we can prove that near the surface of the earth 105 m of air column on an average exerts the same pressure as 1 cm of mercury.

The variations in the atmospheric pressure with altitude is shown in the graph shown in Fig. 5.12.

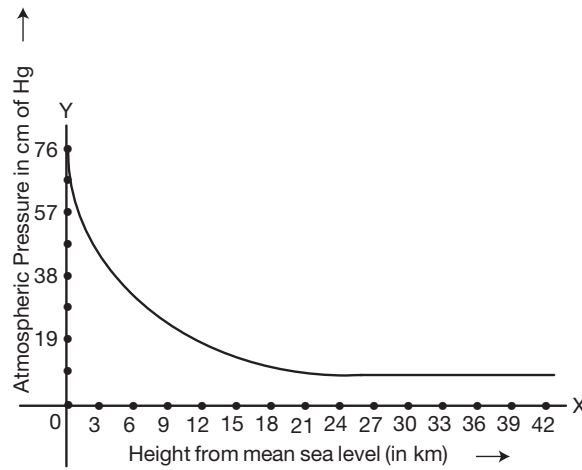


FIGURE 5.12 Variation of atmospheric pressure with altitude

Altimeter

A barometer, measuring atmospheric pressure, can also be used to determine the altitude. It is called altimeter. An aneroid barometer whose scale is calibrated in terms of altitude above sea level is commonly used as an altimeter.

Upthrust

When a solid is immersed completely in a liquid, it experiences liquid pressure from all directions. The thrust due to pressure on its sides is called lateral thrust, on the top it is called downward thrust and at the bottom, upward thrust.

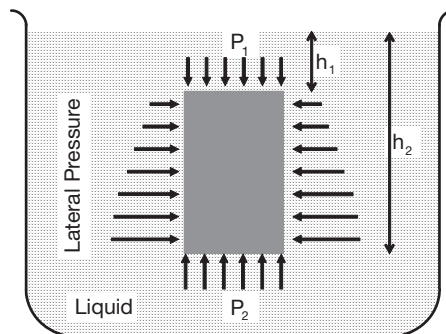


FIGURE 5.13 Upthrust

Figure 5.13 shows pressure exerted by a liquid on a body of area of cross section ' A ' and height ' h '. The top and base of the body are at the depths h_1 and h_2 , respectively such that $h_2 - h_1 = h$

From the Fig. 5.13,

$$P_1 = h_1 d_\ell g$$

$$P_2 = h_2 d_\ell g$$

where d_ℓ = density of the liquid

$$P_2 > P_1 \text{ as } h_2 > h_1$$

Downward thrust acting on the top surface = $AP_1 = Ah_1 d_\ell g$

Upward thrust acting on the bottom surface = $AP_2 = Ah_2 d_\ell g$

$\therefore$ Net thrust (F) acting on the body is in upward direction, and is given by,

$$F = Ah_2 d_\ell g - Ah_1 d_\ell g$$

$$\text{i.e., } F = A \times (h_2 - h_1) d_\ell g$$

$$= Ahd_\ell g \quad (\because h_2 - h_1 = h)$$

$$= Vd_\ell g \quad (\because Ah = \text{volume } (V) \text{ of the body inside the liquid})$$

volume of the body inside the liquid is also equal to the volume of the liquid (V_ℓ) displaced by it

$$\therefore F = V_\ell d_\ell g$$

$\therefore$ This net force acting on the body due to the fluid in upward direction is called ‘upthrust’ or buoyant force.

$$F = m_\ell g \quad (\because V_\ell d_\ell = \text{mass of the liquid displaced by the immersed part of the body})$$

$$F = W_\ell \quad (\because m_\ell g = \text{weight of the liquid displaced})$$

Thus, the upthrust acting on a body immersed completely in a liquid is equal to the weight of the liquid displaced by it. The same result is obtained when a body is partly immersed in a liquid. Hence, we can say that ‘Upthrust acting on a body immersed partly or wholly in a liquid is equal to the weight of the liquid displaced by it.’

Factors Affecting the Upthrust

The factors on which the upthrust acting on a body, either partially or completely immersed in a liquid depends are:

1. Volume of the liquid displaced which is equal to the volume of the immersed part of the solid.
2. Density of the liquid in which the solid is immersed.
3. Acceleration due to gravity at that place.

EXAMPLE

An iron rod of volume 100 cm^3 and density $7.8 \times 10^3 \text{ kg m}^{-3}$ is completely immersed in water. Calculate the upthrust acting on it. (Take $g = 10 \text{ m s}^{-2}$, density of water = 10^3 kg m^{-3})

SOLUTION

$$\text{Upthrust } (F) = V_{\ell} d_{\ell} g$$

V_{ℓ} = volume of water displaced by iron rod

= volume of the rod

$$= 100 \text{ cm}^3 = 10^{-4} \text{ m}^3$$

$$\therefore F = 10^{-4} \text{ m}^3 \times 1000 \text{ kg m}^{-3} \times 10 \text{ m s}^{-2} = 1 \text{ N}.$$

ARCHIMEDES' PRINCIPLE

When a body is immersed completely or partially in a liquid, it is acted upon by two forces.

1. weight of the body, w acting vertically down and
2. upthrust due to liquid acting vertically up.

As a result of these opposing forces, the body appears to weigh less in the liquid than in air.

The apparent loss in weight of the body when immersed either partially or completely in a liquid is equal to the upthrust acting on it. The more the upthrust, the more is the apparent loss in weight of the body.

This fact was discovered by the famous Greek scientist Archimedes and is known as the Archimedes' principle which is stated below.

'When a body is immersed completely or partially in a liquid, it experiences an apparent loss in weight, which is equal to the weight of the liquid displaced by it'.

Archimedes' principle is applicable to bodies immersed in liquids as well as in gases. However, the upthrust due to the atmosphere is negligible since the density of air is far less than that of a solid, and for all practical purposes, we may consider the weight of the body in air as its true weight. Thus, the difference in the weights of a body in air and in a liquid gives the magnitude of the upthrust acting on it, i.e., the weight of the liquid displaced.

EXAMPLE

A body weighs 250 g in air and 235 g when completely immersed in water. Calculate

- (a) the apparent loss in weight of the body and
- (b) upthrust acting on it.

SOLUTION

Let W_1 = weight of the body in air = 250 g_f

W_2 = weight of the body in water = 235 g_f

Apparent loss in weight = $W_1 - W_2$

$$= 250 \text{ g}_f - 235 \text{ g}_f = 15 \text{ g}_f$$

The apparent loss in weight of a body is also equal to the upthrust acting on it.

$$\therefore \text{upthrust} = 15 \text{ g}_f$$

EXAMPLE

A cube of a metal whose density is 8.2 g cm^{-3} and side 7 cm is tied to a thread and completely immersed in a liquid of density 1.2 g cm^{-3} . Calculate the tension in the string.

SOLUTION

Tension in the string = net downward force acting on the cube.

Volume of the cube = $7 \text{ cm} \times 7 \text{ cm} \times 7 \text{ cm} = 343 \text{ cm}^3$

Mass of the cube = Volume $\times$ density
 $= 343 \text{ cm}^3 \times 8.2 \text{ g cm}^{-3}$
 $= 2812.6 \text{ g}$

$\therefore W = \text{Weight of the cube} = 2812.6 \text{ gf}$

This weight acts in the downward direction.

Upthrust = Volume of cube $\times$ density of liquid $\times$ acceleration due to gravity

$\therefore U = 343 \text{ cm}^3 \times 1.2 \text{ g cm}^{-3} \times \text{g cm s}^{-2}$
 $= 411.6 \text{ gf}$

Net downward force = $W - U$

$\therefore = (2812.6 - 411.6) \text{ gf}$

$\therefore \text{Tension in the string} = 2401 \text{ gf}$

Relative Density

Density of a substance is defined as the ratio of its mass and volume.

$$d = \frac{m}{v}$$

Its unit is kg m^{-3} in S.I. system and g cm^{-3} in C.G.S system

Relative density (R.D.) of a substance is the ratio of the density of the substance to the density of water at 4°C .

R.D. is also called specific gravity.

$$\begin{aligned} \text{R.D.} &= \frac{\text{Density of the substance } (d_s)}{\text{density of water } (d_w) \text{ at } 4^\circ\text{C}} \\ &= \frac{\text{mass of unit volume of the substance}}{\text{mass of unit volume of water at } 4^\circ\text{C}} \\ &= \frac{\text{mass of the substance } (m_s)}{\text{mass of equal volume of water at } 4^\circ\text{C } (m_w)} \end{aligned}$$

$$\text{R.D.} = \frac{\text{weight of the substance } (w_s)}{\text{weight of equal volume of water at } 4^\circ\text{C} (W_W)}$$

Let W_1 = weight of the substance in air

W_2 = weight of the substance when it is completely immersed in water

$W_1 - W_2$ = apparent loss in weight of the substance in water.

= Weight of the water displaced

Here, the volume of the water displaced is equal to the volume of substance

$$\text{Thus, relative density} = \frac{\text{Weight of the body in air}}{\text{Apparent loss of weight in water}}$$

$$\therefore \text{R.D. of substance} = \frac{W_1}{W_1 - W_2}$$

Relative density, being a ratio of same physical quantities, has no unit.

EXAMPLE

The R.D. of iron is 7.8. Calculate its density in S.I. system of units.

SOLUTION

$$\text{R.D.} = \frac{\text{density of iron}}{\text{density of water}}$$

$$\begin{aligned} \therefore \text{density of iron} &= \text{R.D.} \times \text{density of water} \\ &= 7.8 \times 1000 \text{ kg m}^{-3} \\ &= 7.8 \times 10^3 \text{ kg m}^{-3} \end{aligned}$$

EXAMPLE

A solid weighs 60 g in air and 52 g when completely immersed in water. Calculate the volume and relative density of the solid (Take density of water = 1 g cm^{-3}).

SOLUTION

$$\text{Loss in weight of solid} = 60 \text{ g}_f - 52 \text{ g}_f = 8 \text{ g}_f$$

$$\therefore \text{Weight of the water displaced} = 8 \text{ g}_f$$

$$\text{i.e., mass of water displaced} = 8 \text{ g}$$

$$\text{Volume of the water displaced} = \frac{m}{d_1} = \frac{8 \text{ g}}{1 \text{ g cm}^{-3}} = 8 \text{ cm}^3$$

Volume of the solid is equal to the volume of water displaced by it.

$$\therefore \text{volume of the solid} = 8 \text{ cm}^3$$

$$\text{R.D. of solid} = \frac{\text{weight of solid in air}}{\text{loss of weight in water}} = \frac{60g_f}{8g_f}$$

$$\therefore \text{R.D.} = 7.5$$

Relative Density by Balancing Columns

The pressure at a point inside a liquid is given by $P = h d g$

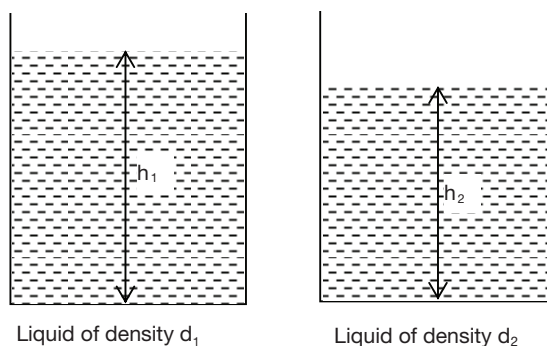


FIGURE 5.14 Relative density by balancing columns

Let us consider columns of two liquids whose densities are d_1 and d_2 . Consider two points in them at the depth of h_1 and h_2 , respectively such that pressure due to the liquid at these points is same i.e., $P_1 = P_2$.

$$\therefore h_1 d_1 g = h_2 d_2 g$$

$$\frac{d_2}{d_1} = \frac{h_1}{h_2}$$

$$d_2 = \frac{h_1}{h_2} \times d_1$$

If the first liquid is water, then $d_1 = \text{density of water} = 1000 \text{ kg m}^{-3}$, therefore, density of other liquid is

$$d_2 = \left(\frac{h_1}{h_2} \times 1000 \right) \text{ kg m}^{-3} \text{ in S.I. system}$$

or

$$d_2 = \frac{h_1}{h_2} \times 1 \text{ g cm}^{-3} \text{ in CGS system}$$

Thus,
$$\frac{d_2}{d_1} = \frac{h_1}{h_2}$$

If d_1 is the density of water at 4°C ,

$$\text{R.D. of liquid} = \frac{h_1}{h_2} = \frac{\text{height of water column}}{\text{height of liquid column}}$$

This leads us to the principle of balancing columns which states that when two liquid columns of different densities and heights balance each other, the pressure exerted by them is equal.

The Hare's apparatus which is used to find relative density of liquid works on the principle of balancing liquids.

HARE'S APPARATUS

It consists of an inverted, U-shaped glass tube of uniform cross section. The top of glass tube has an outlet which is connected to a rubber tube provided with a pinch cock. The uniform glass tube is fixed to a vertical stand with the help of clamps such that it can be easily raised or lowered. The two ends of the U-tube are immersed in two beakers kept on a horizontal stand. One of the beakers contains water while the other contains liquid whose specific gravity is to be determined. A vertical scale is fixed between the two arms of the U-tube so that the liquid levels in the beaker and the arms of the U-tube can be measured. The pinch cock is removed and air is sucked out from the rubber tube. The liquids rise in the arms of the U-tube. The pinch cock is replaced again.

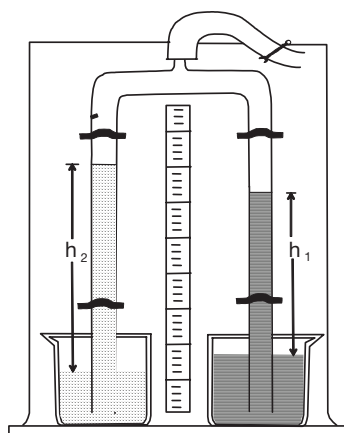


FIGURE 5.15 Hare's apparatus

The levels a_2 and a_1 of water in the beaker and in the tube, respectively are noted. Difference in these two levels ($a_1 - a_2$) gives the height of the water column in the tube. Let it be h_1 . Similarly $h_2 = b_1 - b_2$ gives the height of the liquid column in the second tube.

Applying the principle of balancing columns

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

$$\text{R.D.} = \frac{h_1}{h_2}$$

EXAMPLE

Levels of water in the tube and beaker in the Hare's apparatus are 40.4 cm and 5.3 cm and corresponding levels of liquid are 35 cm and 5 cm. Find the specific gravity of the liquid.

SOLUTION

$$a_1 = \text{level of water in the tube} = 40.4 \text{ cm}$$

$$a_2 = \text{level of water in the beaker} = 5.3 \text{ cm}$$

$$h_1 = a_1 - a_2 = 40.4 - 5.3 = 35.1 \text{ cm}$$

$$b_1 = \text{level of liquid in the tube} = 35 \text{ cm}$$

$$b_2 = \text{level of liquid in the beaker} = 5 \text{ cm}$$

$$h_2 = b_1 - b_2 = 35 - 5 = 30 \text{ cm}$$

$$\text{R.D.} = \frac{h_1}{h_2} = \frac{35.1}{30} = 1.17$$

EXAMPLE

Using Hare's apparatus, R.D. of a liquid was found to be 1.25. If the height of the liquid in one of the tube was 32 cm, find the height of the water in the another tube.

SOLUTION

$$\text{R.D.} = 1.25$$

$$h_2 = 32 \text{ cm}$$

$$h_1 = ?$$

$$\text{R.D.} = \frac{h_1}{h_2}$$

$$1.25 = \frac{h_1}{32}$$

$$h_1 = 32 \times 1.25 = 40 \text{ cm.}$$

EXAMPLE

In Hare's apparatus, the levels of the water in the tube and the beaker are 38.3 cm and 4.7 cm, respectively. The specific gravity of liquid is 1.05 and its level in the tube is 35.5 cm. Find its level in the beaker.

SOLUTION

$$a_1 = 38.3 \text{ cm}$$

$$a_2 = 4.7 \text{ cm}$$

$$h_1 = a_1 - a_2 = 38.3 - 4.7 = 33.6 \text{ cm}$$

$$b_1 = 35.5 \text{ cm}$$

$$b_2 = ?$$

$$\text{R.D} = \frac{h_1}{h_2} = \frac{a_1 - a_2}{b_1 - b_2}$$

$$1.05 = \frac{33.6}{35.5 - x}$$

$$(35.5 - x) = \frac{33.6}{1.05} = 32$$

$$\therefore x = 35.5 - 32 = 3.5 \text{ cm}$$

FLOATATION

Consider a body immersed in a liquid. Two forces act on it simultaneously. They are

1. The weight (W) of the body acting vertically down at its centre of gravity (C.G).
2. The upthrust or buoyant force (F_B), equal to the weight of the liquid displaced, acting vertically upwards.

The point where the total upthrust due to the liquid displaced by the immersed part of the body acts is called the centre of buoyancy (B).

The weight of the body acts vertically down whereas the buoyant force acts vertically up. Depending upon their magnitudes, following situations arise.

1. $W > F_B$

If the weight of the body is greater than the weight of the liquid displaced, the net force acting on the body is in the downward direction. Hence, the body sinks.

$$W = V d g$$

where V = volume of the immersed part of the body in the liquid and d = density of the body.

$$F_B = V d \ell g$$

where V = volume of the liquid displaced by the immersed part of the body and $d \ell$ = density of the liquid

$$W > F_B$$

$$V d g > V d \ell g$$

$$\therefore d > d \ell$$

Thus, a body sinks in a liquid if its density is greater than that of the liquid.

2. $W = F_B$

If the weight of the body immersed in a liquid is equal to the weight of the liquid displaced by it, then the net force acting on the body is zero. Hence, the body remains in static equilibrium wherever it is placed inside the liquid.

Thus, the condition for a body to be in static equilibrium when completely immersed in a liquid is

$$W = F_B$$

$$Vdg = Vd_1 g$$

$$d = d_1$$

3. $W < F_B$

If the weight of the body immersed in a liquid is less than the weight of the liquid displaced by it, the net force acting on the body is in the upward direction. Thus, the body moves up in the liquid till some part of it emerges out of the liquid surface. As the volume of the body inside the liquid now decreases the upthrust also decreases, until the upthrust acting on the body is equal to the weight of the body. In this condition, the body is in equilibrium and it floats on the liquid surface with certain fraction of it below the surface. Such a body is called a floating body.

Therefore, the condition for floating is

$$W < F_B$$

$$Vdg < Vd_\ell g$$

$$d < d_\ell$$

Thus, a body floats in a liquid if its density is less than that of the liquid.

From the above discussion, it is clear that only those bodies whose weight is less than the weight of the liquid displaced when completely immersed in the liquid, rise upto the liquid surface. However, when such bodies float in a liquid, their weight acting vertically down is equal to the buoyant force acting on them vertically up.

This forms the law of floatation, which can be stated as below.

‘For a solid floating in a liquid, its weight acting vertically down at its centre of gravity is equal to the weight of the liquid displaced by the immersed part of the solid acting vertically up at its centre of buoyancy’.

In the floating condition, the apparent weight of the solid is zero and the body is said to be weightless.

LAWS OF FLOATATION

1. The weight of the floating body is equal to the weight of the liquid displaced. (Net force acting on the body is zero)
2. The centre of gravity of the floating body and the centre of buoyancy lie in the same vertical line. (Net turning effect is zero)

Mathematical Expression for the Law of Floatation

Consider a wooden cylinder floating in a liquid of density d_ℓ . Consider

V = total volume of the wooden cylinder

h = total height of the cylinder

V_1 = volume of the part of the cylinder inside the liquid

h_1 = height of the cylinder inside the liquid

a = area of cross section of the cylinder

d = density of the liquid

d_ℓ = density of the cylinder.

Mass of cylinder $m = V \times d$

$$= a h d$$

Weight of cylinder $W = mg = ah dg$

Volume of liquid displaced $V_1 = ah_1$

Mass of liquid displaced = $V_1 \times d_\ell$

weight of liquid displaced = $ah_1 d_\ell g$

By the law of floatation,

weight of the cylinder = weight of the liquid displaced by the cylinder

$$ah dg = ah_1 d_\ell g$$

$$hd = h_1 d_\ell$$

$$\frac{d}{d_\ell} = \frac{h_1}{h}$$

If the liquid used is water, the relative density = $\frac{h_1}{h} = \frac{\text{length of the cylinder in the water}}{\text{total length of the cylinder}}$

Also,

$$Vdg = V_1 d_\ell g$$

$$\therefore \frac{d}{d_\ell} = \frac{V_1}{V}$$

$$\text{i.e., } d = \frac{V_1}{V} d_L$$

If the liquid is water at 4°C , $d_\ell = 1$. (in C.G.S system)

$$\therefore \frac{d}{1} = \frac{V_1}{V} = \frac{\text{volume of the cylinder in the water}}{\text{total volume of the cylinder}}$$

Stability of Floating Bodies

Consider a stationary ship floating in water. Since it is floating, it satisfies the following two conditions.

1. The weight of the ship is equal to the weight of the water displaced by the immersed part of the ship.
2. The centre of gravity of the ship and the centre of buoyancy (B), which is the C.G. of the displaced water, lie on the same vertical line.

This vertical line which connects the C.G. of ship and centre of buoyancy (B) is called the centre line as shown in Fig. 5.16.

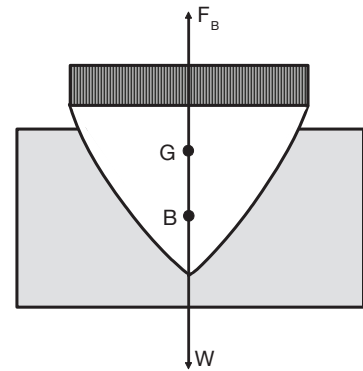


FIGURE 5.16 A stationary ship floating in water

If the ship is caught in turbulent waters or storm, it may tilt. Now the second condition mentioned above will not be satisfied as the position of 'B' changes to B_1 . In fact a vertical line from B_1 intersects the centre line at a point. This point is called the meta centre (M).

The weight of the ship and the upthrust acting on it through the new centre of buoyancy are in opposite directions. Their lines of action being parallel, they set up a couple. This couple can be either clockwise or anti-clockwise depending on the position of M with respect to the C.G (G). This determines the state of equilibrium of the ship.

1. **Stable equilibrium:** If 'G' lies below M, i.e., if the ship is tilted in the anti-clockwise direction, the couple set up is in the clockwise direction which restores the ship to its original position as shown in Fig. 5.17.

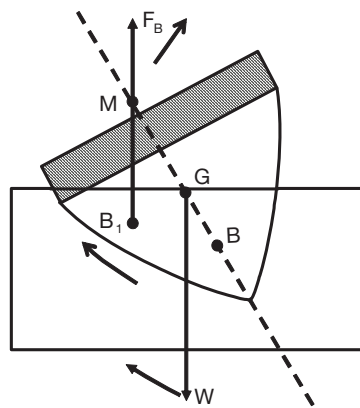


FIGURE 5.17 The ship in a stable equilibrium

Stable equilibrium is possible if the base of the ship is made heavy, which lowers its C.G.

2. **Unstable equilibrium:** If 'G' lies above M, and if the ship is tilted in the anti-clockwise direction the couple set up is also in anti clockwise direction which increases the tilt of ship and eventually sinks it. This condition is said to be unstable equilibrium as shown in Fig. 5.18.

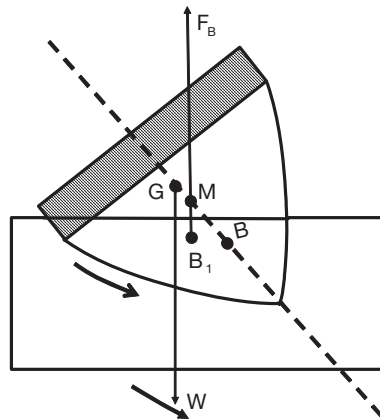


FIGURE 5.18 The ship in an unstable equilibrium

This condition of 'G' lying above 'M' is possible if the ship is heavy at the top. To avoid this, the bottom of the ship is usually filled with sand bags and weights called 'ballast'. There is a line marked on the lateral side of the ship called 'water line' and every ship has to float up to this line for stability and hence, safe sailing.

- 3. Neutral equilibrium:** If 'G' and 'M' coincide as shown in the Fig. 5.19 even when the ship is tilted anti-clockwise, it is not acted upon by any couple. In this condition, the ship is said to be in neutral equilibrium as it neither tilts further nor does it come back to its original position as shown in Fig. 5.19.

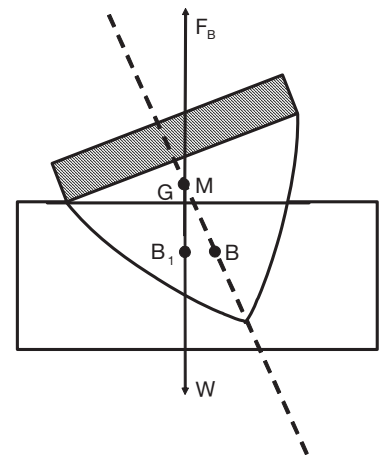


FIGURE 5.19 The ship in a neutral equilibrium

EXAMPLE

The densities of water and ice are 1 g cm^{-3} and 0.917 g cm^{-3} . Find the fraction of an iceberg floating above the water surface and the fraction below it.

SOLUTION

Let V = the total volume of the iceberg.

V_1 = volume of the iceberg above the water surface

$\therefore V - V_1$ = volume of the iceberg below the water surface.

By the law of floatation weight of the iceberg = weight of the water displaced by the immersed part of the iceberg.

$$V \times 0.917 \times g = (V - V_1) \times 1 \times g$$

$$V_1 = (1 - 0.917) V$$

$$\frac{V_1}{V} = \frac{0.083}{1}$$

$$= \frac{1}{12} \text{ (approx)}$$

Thus, $\frac{1}{12}$ th part of the total volume of the iceberg floats above the water surface.

$\therefore \frac{11}{12}$ th part of iceberg is submerged in water.

It means most of the iceberg is beneath water.

EXAMPLE

A block of wood floats on water with $\frac{2}{5}$ th of its volume above the surface. If it is made to float in brine solution of R.D. 1.20, what fraction of the wood is below the surface of the brine solution?

SOLUTION

Let V = Total Volume of the block

d = density of the block

$$\begin{aligned}\text{volume of the block immersed} &= V - \frac{2}{5}V \\ &= \frac{3}{5}V\end{aligned}$$

By the law of floatation,

$$W = U$$

$$\text{i.e., } Vdg = \frac{3}{5}V \times 1 \times g$$

$$\therefore d = \frac{3}{5} = 0.6 \text{ g cm}^{-3}$$

Density of the brine solution = 1.20 g cm^{-3}

$$\therefore V \times 0.6 \text{ g cm}^{-3} = V_1 \times 1.20 \text{ g cm}^{-3}$$

$$V_1 = \frac{0.6}{1.20} V = 0.5V$$

Thus, 50% of total volume of the wooden block is submerged in the brine solution.

PLIMSOLL LINES

Ships are used to transport passengers and cargoes. As load in a ship is increased, it sinks more in water. Ship may sink completely, if loaded beyond a permissible limit. But this limit on load cannot be calculated as ship travels through waters of different densities. Consider a heavily loaded ship travelling through cold waters of North Atlantic sea. Due to the high density of the sea water there, the upthrust acting on the ship is high and the ship stays

a float. When it enters warm tropical fresh water, it will sink more due to the low density of the sea water there. Hence, it is better to know how far a ship would sink in particular waters than to measure its load. To specify upto which level a ship may be allowed to sink or to determine the maximum load for a ship, Samuel Plimsoll in 1876 suggested that ships should be marked with load lines which would suggest how much a ship when loaded would sink in waters of a particular region. These lines are called Plimsoll lines. The line for tropical fresh water which has lowest density is at the top and the line for North Atlantic seas with water having maximum density is at the bottom. A ship is loaded till it sinks to the appropriate line. This ensures that irrespective of its destination, it would float at the safe level.

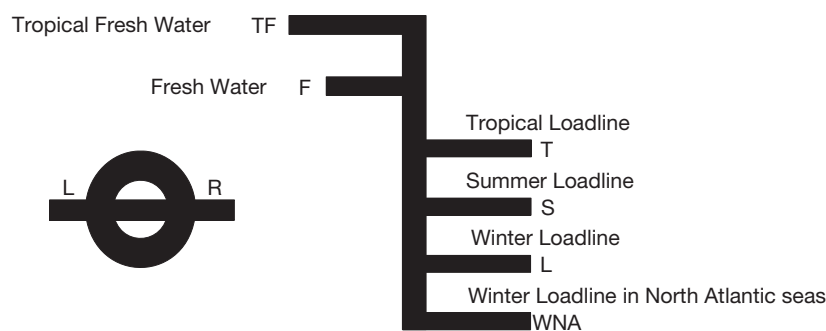


FIGURE 5.20 Plimsoll lines

HYDROMETER

It is a device used to find relative density of a liquid. It works on the law of floatation. When a body floats in a liquid, its weight is equal to the upthrust which is equal to the weight of the liquid displaced.

There are two types of hydrometers. They are

1. variable immersion hydrometer, and
2. constant immersion hydrometer.

In a variable immersion hydrometer, the weight of the hydrometer is kept constant so that its depth of immersion varies depending on density of the liquid in which it floats. In a constant immersion hydrometer, the depth of immersion is kept constant in different liquids by changing its weight suitably.

Common Hydrometer

It is a variable immersion hydrometer. It consists of a uniform narrow glass stem which terminates into a broader glass bulb also called floatation or buoyancy bulb. A gravity or stability bulb is attached to the glass bulb at the bottom. Gravity bulb is filled with mercury or lead shots so as to make the bottom heavier and give stability to the hydrometer so that it floats upright in a given liquid. The glass stem is graduated suitably to measure the density of the liquid.

The common hydrometers are of two types. Hydrometers that are used

1. to measure liquids having density less than that of water and
2. to measure liquids having density greater than that of water.

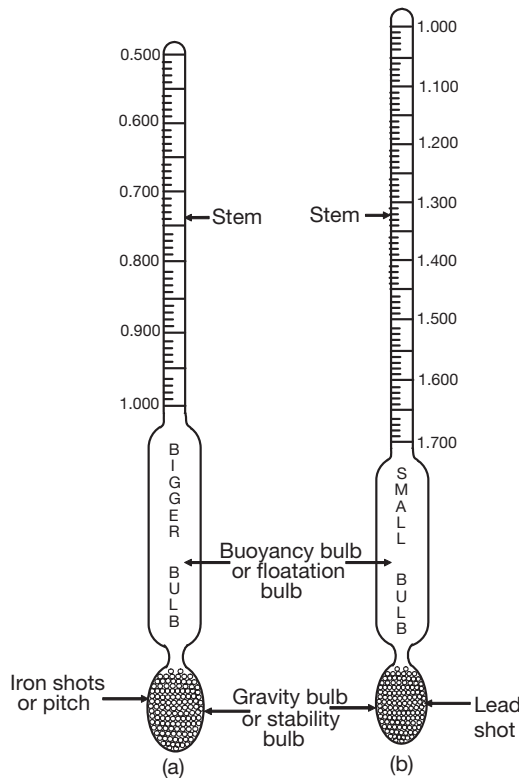


FIGURE 5.21 Hydrometer (a) Hydrometer for lighter liquids, (b) Hydrometer for heavier liquids

Uses of Common Hydrometers

Hydrometers are commonly used to measure densities of various liquids in pathological labs, research centres, factories, breweries, etc.

Some hydrometers are used to measure density of only one liquid. The lactometer, for example, is used to measure density of milk. If the density shown by lactometer is different from that of pure milk, the milk is said to be adulterated with water.

In a lactometer as shown in Fig. 5.22, floatation and gravity bulbs are fused together and only one bulb is present. The top reading gives the density of water, whereas the bottom reading shows the density of pure milk (1.045 g cm^{-3}).

Acid battery hydrometer is used to measure the density of acids used in batteries. Knowing the density of sulphuric acid in a battery, we can make out whether the battery is charged or discharged.

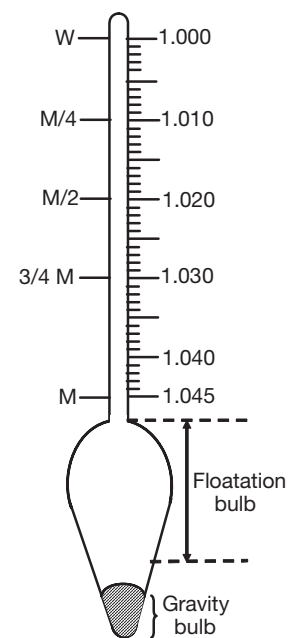


FIGURE 5.22 Lactometer

Alcohol meter is used to measure relative density of alcohol. Hydrometers are also used to find the strength of brine solution and variations in density of waters of different seas and oceans.

Test Tube Float

It consists of a flat bottomed uniform test tube. Its bottom is made heavy by adding mercury, lead shots or sand to it. This gives it stability. The test tube is graduated in centimeters to measure the depth of immersion in liquids. Test tube float is used to find specific gravity of liquids and works on the law of floatation.

- 1. Test tube float as variable immersion hydrometer:** In two similar tall jars, pour water and a liquid whose R.D is to be determined, to the same level. Tie a long twine near the mouth of the test tube float and lower it in water. Avoid touching the tube to the sides of the jarr. Take care that air bubbles do not stick to the sides of the float. Note down the height h_1 of the test tube inside the water.

Remove the test tube out of water and wipe it dry with a clean cloth. Holding the twine, immerse it in the liquid till it floats freely. Do not add or remove lead shots from the test tube.

Note the height h_2 of test tube inside the liquid.

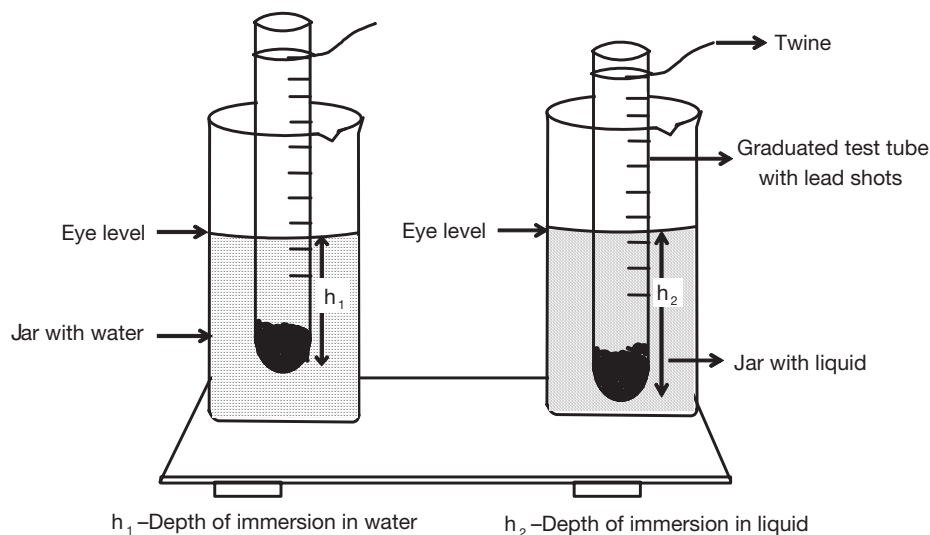


FIGURE 5.23 Test tube float as a variable immersion hydrometer

Since the weight of the float is same in both the cases, the weight of water displaced and weight of liquid displaced are equal according to the law of floatation.

$$\text{Weight of water displaced} = ah_1d_1g$$

$$\text{weight of liquid displaced} = ah_2d_2g$$

Where, a = area of cross section of the test tube, d_1 and d_2 are densities of water and liquid, respectively.

According to the law of floatation,

$$ah_1d_1g = ah_2d_2g$$

$$\therefore \frac{d_2}{d_1} = \frac{h_1}{h_2}$$

$$\text{R.D.} = \frac{h_1}{h_2}$$

$$\text{R.D. of liquid} = \frac{\text{depth of immersion of the float in water}}{\text{depth of immersion of the float in liquid}}$$

EXAMPLE

The depth of immersion of the test tube float in water is 16.8 cm and in a liquid it is 15.8 cm. Calculate the specific gravity of the liquid.

SOLUTION

Depth of immersion in water, $h_1 = 16.8$ cm

Depth of immersion in the liquid, $h_2 = 15.8$ cm

$$\text{The relative density of the liquid} = \frac{h_1}{h_2} = \frac{16.8}{15.8} = 1.063$$

EXAMPLE

Relative density of a liquid is 0.78 and depth of immersion of the float in it is 17.5 cm. Find the depth of immersion when the tube floats in water.

SOLUTION

R.D. of the liquid = 0.78

Depth of immersion in liquid, $h_2 = 17.5$ cm

Depth of immersion in water, $h_1 = ?$

$$\text{R.D.} = \frac{h_1}{h_2}$$

$$0.78 = \frac{h_1}{17.5}$$

$$h_1 = 0.78 \times 17.5$$

$$h_1 = 13.65 \text{ cm.}$$

2. Test tube float as constant immersion hydrometer: The test tube float is immersed in water and its depth of immersion h is noted. The float is removed from water, wiped dry and suspended from the hook of a spring balance and its weight W_1 is noted. The float is then floated in a liquid whose R.D. is to be determined. By removing or adding lead shots, it is made to float to the same depth ' h ' as in water. Its weight W_2 is measured with the help of a spring balance after removing it from the liquid and wiping it dry.

The volume of water displaced and the volume of liquid displaced by the float is same since its depth of immersion in both is same. According to the law of floatation, the weight of a body floating in a liquid is equal to the weight of the liquid displaced by it.

$$\therefore \text{Weight of water displaced} = W_1$$

$$\text{Weight of liquid displaced} = W_2$$

The volume of water and liquid displaced are equal.

$$\text{R.D. of the liquid} = \frac{\text{Weight of the float in liquid}}{\text{weight of the float in water}}$$

$$= \frac{W_2}{W_1}$$

$$\therefore \text{specific gravity of the liquid} = \frac{\text{weight of the float in liquid}}{\text{weight of the float in water}}$$

EXAMPLE

The weight of a test tube float in water is 43 g_{wt} and in a liquid is 44 g_{wt}. If the depth of immersion of the float in both is same, find the specific gravity of the liquid.

SOLUTION

$$W_1 = 43 \text{ g}_{\text{wt}} = \text{weight of the float for immersion in water}$$

$$W_2 = 44 \text{ g}_{\text{wt}} = \text{weight of the float for immersion to same level in liquid}$$

$$\text{R.D. of liquid} = \frac{W_2}{W_1} = \frac{44}{43} = 1.023$$

EXAMPLE

The R.D. of a liquid is 1.027 and a float of weight 38 g_{wt} is allowed to float upto a certain depth in it. What additional weight should be added to the float if it is to float to the same depth in water as in liquid?

SOLUTION

Weight of the float $W_2 = 38 \text{ g}_{\text{wt}}$

Relative density of the liquid = 1.027

Weight of the float when it floats to the same level in water = W_1

$$\text{R.D.} = \frac{W_2}{W_1}$$

$$1.027 = \frac{38}{W_1}$$

$$W_1 = \frac{38}{1.027} = 37 \text{ g}_{\text{wt}}$$

Since $W_1 < W_2$, additional weight need not be added to the float, but 1 g_{wt} of mass has to be removed from float.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. What is torricellian vacuum?
2. Hydraulic press works on the principle of _____.
3. What is a test tube float? What are the different types of test tube floats?
4. Apparatus used to determine the relative density of liquids is _____.
5. Define hydrostatics.
6. Define and write units of thrust and pressure.
7. Define fluids.
8. What do you understand by barometric liquid and barometric height?
9. Plimsoll lines are marked on ships to protect the ships from sinking into water due to _____.
10. An object weighs W_1 in air and W_2 when half of its volume is immersed in water. The relative density of the object is _____.
11. Write the expression for pressure exerted by a liquid. What do the terms in the expression stand for?
12. Pressure of the gas enclosed inside a cylinder can be measured using _____.
13. State Archimedes' principle.
14. A balloon of volume ' v ' and density ' d ' is moving in upward direction in air. If the density of air is ' D ', then the effective upward acceleration of the body is _____.
15. State Pascal's law.
16. Density of air at higher altitudes is _____ than that at the surface of earth.
17. Define centre of buoyancy.
18. Define metacentre.
19. Give the average magnitude of the atmospheric pressure in SI and CGS units.
20. Define stable, unstable and neutral equilibrium.
21. What is a hydrometer? Mention different types of hydrometers,
22. A cylindrical container is filled with water upto the brim. If the pressure exerted by the water at the bottom of the container is 100 Pa, the height of the container is _____ cm (Take $g = 10 \text{ m s}^{-2}$).
23. What is a barometer? Mention different types of barometers.
24. Why does Fortin's barometer give more accurate readings?
25. The upthrust acting on a body when immersed in two different liquids are 10 N and 15 N, respectively. The ratio of densities of liquids is _____.
26. Define manometer.
27. Define altimeter.
28. Define upthrust.
29. Define relative density or specific gravity.
30. The ratio of the area of cross-sections of the smaller and bigger pistons of a hydraulic press is 1 : 4. When a 100 N force is applied on the smaller piston, the number of weights each of weight 1 kg_{wt} that can be placed on the bigger piston is _____ ($g = 10 \text{ m s}^{-2}$).

Short Answer Type Questions

31. Why are the walls of a dam broader at the base?
32. Obtain an expression for the upthrust experienced by a body when immersed in a liquid and state the factors affecting it.
Factors affecting the upthrust.
(1) volume of the immersed part of the body
(2) density of the liquid
33. Mention a few defects of a simple barometer.
34. Obtain the expression for pressure exerted by a liquid
35. Give some uses of Bramah press.
36. State the laws of floatation.
37. Why is mercury preferred as a barometric liquid?
38. What is lateral pressure? Why is the net lateral pressure acting on a body immersed in a liquid zero?



39. Mention some consequences of atmospheric pressure.
40. What are the advantages of an aneroid barometer over simple barometer?
41. State the forces acting on a body when it is immersed partially or completely in a liquid.
42. Enlist the factors on which the pressure at a point in a fluid (liquid or gas) depends. Also, state the factors which do not affect it.
43. State the factors which affect the vertical height of a barometric liquid.
44. Write a note on variation in atmospheric pressure with altitude.
45. State laws of liquid pressure.

Essay Type Questions

46. Explain how Hare's apparatus is used to find R.D of a liquid.
47. Explain how a test tube float can be used as constant and variable immersion hydrometer.
48. What is relative density? Show that $R.D. = \frac{W_1}{W_1 - W_2}$, where W_1 is the weight of the body in air and W_2 is its weight in water.
49. Write a note on manometer.
50. Explain the three conditions which arise when the body is immersed in a liquid.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

1. A floating body is said to be in stable equilibrium if its metacentre coincides with the centre of gravity.
2. Hydraulic press works on the principle of Bramah's press.
3. The principle of working of a hydrometer is based on the 'law of floatation'.
4. The magnitude of pressure measured in SI system is greater than that measured in CGS system.
5. The upward thrust exerted on the body by a liquid acts vertically upwards through the centre of gravity of the displaced liquid.
6. The vertical height of the mercury column in a barometer remains unaffected even if the tube is tilted.
7. Hare's apparatus works on Archimedes principle.

Direction for questions 8 to 14:

Fill in the blanks.

8. For greater mechanical advantage, the diameter of the press piston of a hydraulic lift must be ____ the diameter of the pump piston.
9. A solid when immersed in water displaces half a litre of water. The same solid floats with three fourth of its volume below the surface of a given oil and displaces 800 g of oil. Then the relative density of the body and the oil are _____ and _____, respectively.
10. When a truck is loaded, heavy objects should be placed at _____.
11. The readings on a variable immersion hydrometer are marked in increasing order from _____ to _____ on its stem.
12. Hand pump lifts the underground water, making use of _____.



13. The fraction of volume of a floating body inside water, gives _____ of the body.
14. The densities of two liquids are in the ratio of 1 : 3 and their volumes are in the ratio of 2 : 1. If the liquids are filled inside two identical containers, the ratio of pressure exerted by them at the bottom of the containers is _____.

Direction for question 15:

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

15.

Column A	Column B
A. Pascal's Law	() a. altitude
B. Archimedes' principle	() b. used to measure the hollowness of a body
C. Stability of a floating body	() c. hydraulic brake
D. Test tube float	() d. pressure of a gas inside a container
E. Liquids and gases	() e. height of centre of gravity
F. Barometer	() f. less than or equal to the density of the liquid variable
G. Manometer	() g. immersion hydrometer
H. Density of a floating body	() h. atmospheric pressure
I. Altimeter	() i. fluids

Direction for questions 16 to 39:

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

16. If a block of wood is floating in a river water, then the apparent weight of the floating block is
 (a) equal than weight of the displaced water
 (b) zero
 (c) greater than the weight of the displaced water
 (d) equal to the actual weight of the block
17. When the left arm of a mercury manometer is connected to a cylinder filled with a gas, the level of the mercury in the right arm rises by 2 cm. If

the pressure of the gas in the container is 110160 Pa, the atmospheric pressure is _____ cm of Hg. (Take $g = 10 \text{ m s}^{-2}$)

- (a) 79 (b) 85
 (c) 77 (d) 81

18. A test tube of mass ' m ' sinks upto mark 'X' in water and the same test tube sinks below the mark 'X' in a given liquid. Then the density of water is
 (a) less than the density of the given liquid.
 (b) more than the density of the given liquid.
 (c) equal to the density of the given liquid.
 (d) product of depths of immersion in water and the given liquid.
19. When a lactometer is used in a given sample of milk 'A', it floats in the milk such that half of the length of its stem is immersed in the milk. When it is used in another sample of milk 'B', the length of the stem immersed in the milk is one fourth of the total length. Then, which of the following statement(s) is(are) true?
 (A) Water content in A is more than that in B.
 (B) Density of the sample A is less than the density of the sample B.
 (a) A is true, but B is false
 (b) A and B are false
 (c) A and B are true
 (d) A is false but B is true
20. Find the odd choice among the given ones. The weight of the floating body is equal to the
 (a) weight of the displaced liquid.
 (b) buoyant force acting on the floating body.
 (c) the weight of the liquid that occupies the portion of the volume of the body that is inside the liquid.
 (d) the weight of the liquid whose volume is equal to the volume of the part of the body that is above the liquid surface.
21. The pressure at a point inside a liquid is directly proportional to _____.
 (a) the depth of the point below the free surface
 (b) the density of the fluid
 (c) acceleration due to gravity
 (d) All the above



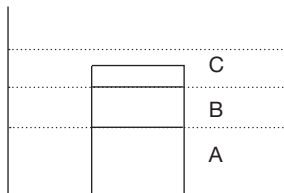
22. The mercury level in a simple barometer falls gradually, at constant temperature indicates that
- weather gradually changes to summer.
 - weather gradually changes to rainy.
 - weather changes to an anti-cyclone one.
 - weather gradually changes to winter.
23. A plastic ball moves from the bottom of a container filled with water to the top. Then
- its velocity increases
 - its acceleration remains same
 - its velocity remains same
 - both (a) and (b)
24. A body is floating in a given liquid with half of its volume above the surface of the liquid. If the body is slightly pushed into the liquid, then the body
- sinks in the liquid and settles at the bottom.
 - come back to its position after some time.
 - starts oscillating in vertical direction, with constant amplitude.
 - it jumps into the air and falls on the liquid.
25. A block of wood floats separately in river water and then in ocean water. Then, the weight of the displaced river water is
- equal to the weight of the displaced ocean water.
 - less than the weight of the displaced ocean water.
 - more than the weight of the displaced ocean water.
 - not dependent on the density of the wooden block.
26. In pressure cooker, the food is cooked faster, because the boiling point of water in the cooker ____.
- is above 100°C
 - is below 100°C
 - is equal to 100°C
 - depends upon the amount of the steam/water present inside the cooker.
27. Choose the wrong statement among the following.
- Weight of a body measured by using a spring balance in air is its apparent weight.
 - Apparent weight of a floating body varies with the density of the liquid.
 - Volume of a floating body is equal to the volume of the liquid displaced by it
 - None of the above
28. A bucket containing a liquid is suspended from a spring balance. When an iron sphere is suspended from a thread and immersed in the liquid contained in the bucket, without touching the walls of bucket, then the amount of increase of weight of the bucket is equal to
- the actual weight of the iron sphere.
 - the weight of the displaced liquid.
 - the apparent weight of the iron sphere in the liquid.
 - None of the above
29. A barometer which measures atmospheric pressure more accurately is ____.
- Fortin's barometer
 - mercury barometer
 - anaeroid barometer
 - Torricelli barometer
30. If the centre of gravity of the body lies above the meta centre, then the body is said to be in ____.
- stable equilibrium
 - unstable equilibrium
 - neutral equilibrium
 - Both (b) and (c)
31. A pressure cooker is used at higher altitude since the atmospheric pressure at higher altitude is
- less than 76 cm of Hg
 - more than 76 cm of Hg
 - equal to 76 cm of Hg
 - depends upon the boiling point of water
32. Apparent loss of weight of a body when immersed in a liquid can be explained on the basis of
- molecular theory.
 - electron theory.
 - Archimedes' principle.
 - Bernoulli's principle.
33. A balloon of volume ' V ' and density ' d ' is moving in upward direction in air. If the density of air is ' D ', then the effective upward acceleration of the balloon is ____.
- $\frac{g(D-d)}{d}$
 - $g\left(\frac{d-D}{d}\right)$
 - $g\left(\frac{d-D}{d}\right)$
 - $g\left(\frac{D-d}{D}\right)$



34. Write the following steps in a sequence to verify Archimedes' principle.
- The object is completely immersed in a liquid.
 - The weight of the object in air is measured by using a spring balance (w_1).
 - The weight of the object in the given liquid is determined (w_2).
 - The loss of weight of the object ($w_1 - w_2$) is determined.
 - The weight of the liquid displaced by the object (w) is determined.
 - The value of ($w_1 - w_2$) is compared with the value of (w).
- a b c d e f
 - a b d c f e
 - a b c d e f
 - f e c a b d
35. _____ suggested that the ships should be marked with load lines.
- Samuel Plimsoll
 - Einstein
 - Newton
 - Archimedes
36. Surface tension is explained on the basis of
- molecular theory.
 - electron theory.
 - Archimedes principle.
 - Bernoulli's principle.
37. For which of the following options, surface tension is not the basis?
- Rise of sap in trees and plants.
 - Absorption of water by a blotting paper.
 - Rise of oil in an oil wick.
 - Lifting of an aeroplane wing.
38. Arrange the following steps in a sequence to determine the apparent weight (w_1) of an object immersed in water.
- Immerse the object completely in water and collect the water displaced by it.
 - Determine the weight of the object (w_1).
 - Determine the weight of the water displaced (w_2).
 - Determine the value of ($w_1 - w_2$).
- a b c d
 - a d c b
 - b a c d
 - b c d a
39. An air bubble rises up in water because,
- there is no gravity in water.
 - pressure inside the bubble is less than the pressure outside it.
 - the upthrust acting on the bubble is more than the weight of the bubble.
 - air cannot dissolve in water.

Level 2

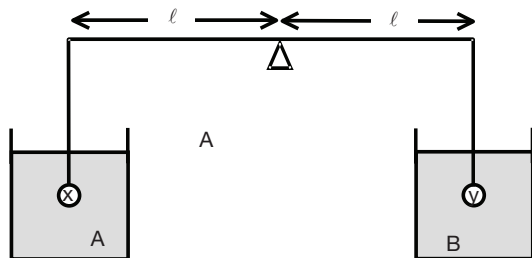
40. While using Hare's apparatus, ratio of specific gravities of two liquids A and B was found to be 1 : 4, respectively. The differences in the level of liquids A and B in the tube were found to be 16 cm. The difference in the level of liquids A and B in the beaker was found to be 5 cm. Find the levels of liquids A and B in the tube, given the level of one of the liquids in the beaker is 3.0 cm.
41. Three identical cubes of side 2 cm and density 4 g cm^{-3} are placed one over the other in a container filled with three immiscible liquids A, B and C as shown in the figure. If the densities of A, B and C are 3 g cm^{-3} , 2 g cm^{-3} and 1 g cm^{-3} , respectively, determine the net force exerted by the cubes at the bottom of the container.



42. A sphere, with a cavity in it, is made of a material of mass 200 g and density 10 g cm^{-3} . When it is immersed in water, its weight is found to be 170 g. Determine the volume of the cavity.
43. A wooden cube of volume 1000 cm^3 floats in water with $\frac{2}{5}$ th of its volume above the surface of water level. If the given cube is made to float on a liquid of relative density 0.8, then find the amount of extra force required to completely submerge it in the given liquid.
44. A sphere of volume V is immersed in two immiscible liquids (mercury and water) taken in a vessel. If half of the volume of the sphere is in mercury and the other half of its volume is in the water, find the relative density of the sphere. (The densities of mercury and water are 13.6 g cm^{-3} and 1 g cm^{-3} , respectively.)
45. Two spheres X and Y of masses 1 kg and 1.1 kg are taken. They are made up of same material and are balanced in two liquids A and B as shown in the figure.



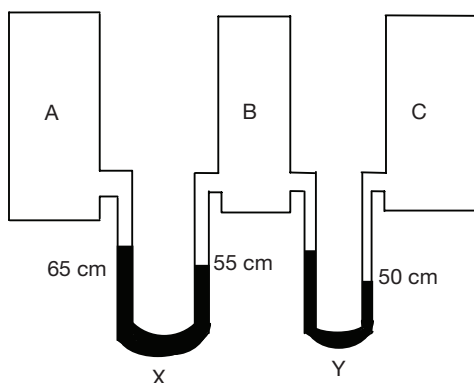
If the ratio of density of this material and liquid 'A' is 9, find the value of density of liquid 'B'. (Given that specific gravity of liquid 'A' is 2.0).



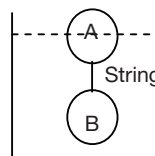
46. The length of a rounded bottomed test tube is 20 cm. The test tube is made to float, in turn, in two different liquid whose densities are 2 g cm^{-3} and 7 g cm^{-3} , respectively. The corresponding depths of immersion of the test tube in the above mentioned liquids are 15 cm and 5 cm, respectively. Find relative density of the third liquid in which the test tube immerses by 10 cm.

47. A balloon of volume 1000 m^3 is filled with hot air of density 0.4 kg m^{-3} . The mass of the balloon is 120 kg and a weight ' w ' is attached to it. The balloon is coming down to the ground. For what value of the weight ' w ', do the balloon come down with zero acceleration? (neglect the air resistance, take the density of cold air as 1.3 kg m^{-3} and g as 10 m s^{-2}).

48. Three cylinders A, B and C are filled with gases at different pressures. Two mercury manometers X and Y are connected to the three cylinders as shown in the figure. When the right arm of the manometer X is disconnected from the cylinder B, the level of the mercury in its left arm rises by 23 cm. If the initial level of the mercury in the limbs of the manometers is 60 cm, determine the pressure exerted by the gases in the cylinders A, B and C (atmospheric pressure = 76 cm of Hg).



49. A common hydrometer has a long uniform stem. When floating in pure water, 4.5 cm of stem lies below the water surface. The same hydrometer immerses up to 1.5 cm in a liquid of specific gravity 2.0. Find the specific gravity of another liquid in which this hydrometer immerses up to 0.5 cm.



50. A container is filled with a liquid of density 4 g cm^{-3} . Two objects A and B of equal volume are tied to each other with the help of a string held in equilibrium in the liquid as shown in the figure. The densities of the objects A and B are 0.5 g cm^{-3} and 6 g cm^{-3} , respectively. What fraction of the total volume of the object A is immersed in the liquid?

51. The pressure exerted by a force acting perpendicular on a horizontal surface is 200 Pa. Calculate the pressure exerted when the surface is rotated such that it makes an angle of 60° with its original position without altering the line of action of the force about the horizontal axis.

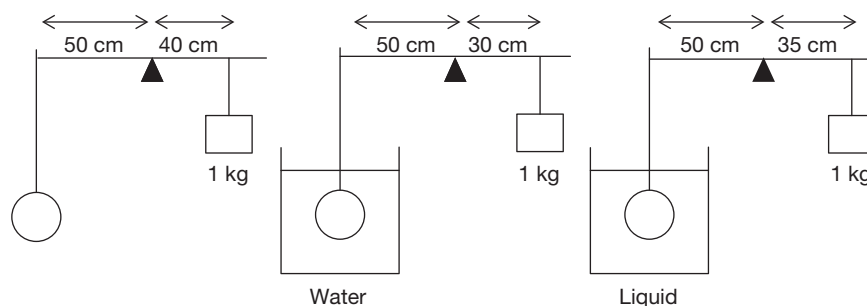
52. In a Hare's apparatus, one limb is immersed in a solution of specific gravity 0.5 and the other in water. When air is sucked out, the levels of water in the beaker and the tube are 10.0 cm and 21.5, cm respectively. Find the level of solution in the tube, if the level in the beaker is 14.7 cm.

53. An ice cube, having a stone of 500 g placed on its top, is floating in water with its lateral sides placed vertically. It displaces 5 kg of water. Suddenly, the stone slips into water. Because of this ice cube rises by $\frac{1}{10}$ th of its length above the water level. What is the density of the ice cube?

54. The length of a test tube is 20 cm. The test tube is made to immerse in two different liquids whose densities are 2 g cm^{-3} and 6 g cm^{-3} , respectively. The depths of immersion of the test tube in the above mentioned liquids are 15 cm and 5 cm, respectively. Find relative density of the liquid in which the test tube immerses by 10 cm.



55. A meter scale is balanced on a sharp knife edge. A solid is suspended at one end of the scale and its position is fixed. A standard weight of 1 kg is used to balance the solid.



The positions of the standard weight to balance the given substance in air, water and a given liquid are 40 cm, 30 cm and 35 cm, respectively as shown in the figure. Find the relative density of the liquid.

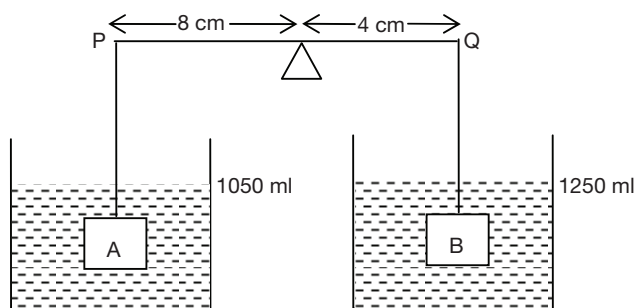
56. A teacher gave an unknown liquid and solid spheres of relative densities 5 and 3.75, respectively to Raju and asked him to find out the density of the liquid with the help of two solid spheres. Raju first measured the masses of the two spheres and found them to be 500 g and 750 g, respectively. Then he took a uniform rod and suspended the two spheres to its ends such that both the spheres balance each other inside the liquid. Using this data, he successfully measured the density of the given liquid. Find the density of the given liquid.
57. A plate of area 100 cm^2 rests on a layer of oil whose coefficient of viscosity is $3 \times 10^{-1} \text{ Pas}$. If a horizontal force of 1 N is required to move the plate with uniform speed of 30 cm s^{-1} then find the thickness of layer of oil.
58. Rahul took a wooden cube of volume 1000 cm^3 and put it in water. He observed that $\frac{3}{5}$ of its volume is below the level of water. Later, he floated the cube in a liquid of density 0.8 g cm^{-3} and applied extra force on the cube to completely submerge it in the given liquid. Calculate how much extra force Rahul applied on the cube.
59. An ice cube floats in a liquid with 25% of its volume above the liquid surface. If the density of ice is given as 930 kg m^{-3} , find the density of the liquid in g cm^{-3} .

Level 3

60. In a faulty barometer, some inert gas is entrapped above the mercury level in 1 m long glass tube. The height of mercury column is $x \text{ cm}$ and the length of the space above the mercury is 10 cm. When the tube is pulled out of the trough by 10 cm, the space above mercury level is doubled. Now, 5 cm of the tube lies below the mercury level in the trough. Find the correct atmospheric pressure.
61. One end of a rod of mass 10 kg and length 20 m is tied at the bottom of a water tank by means of a rope with 15 m of its length below the surface of water. Determine the tension in the rope. The specific gravity of the rod is 0.5.
62. A student used a constant immersion hydrometer to determine the concentration of hydrochloric acid. A test tube of weight 50 gf with 10 lead shots each of weight 5 g floats in water to a mark x on it. To keep the test tube float at the same mark in the HCl solution, he added 2 lead shots into it. Determine the volume percentage of the solution.
- (Given density of pure water is 1 g cm^{-3} and density of HCl is 1.18 g cm^{-3})
- $$\text{Volume percentage} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100.$$



63. A cube made up of a metal weighs 308 g in air and 260 g in water but a cavity is present inside it. Find the volume of the cavity if the relative density of the metal is 11.
64. A uniform rod PQ of mass 1 kg is held in equilibrium position as shown in the figure given below. If the initial volumes of the water in the containers are equal and the density of objects A and B are 3.5 g cm^{-3} and 4 g cm^{-3} , respectively, determine the weight of objects A and B.

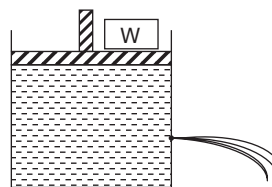


65. An ice cube has a stone of 500 g placed on its top, is floating in water with its lateral sides placed vertically. It displaces 5 kg of water. Suddenly, the stone slips into water. Because of this, ice cube rises by $\frac{1}{10}$ th of its length above the water level. What is the density of the ice cube?
66. An aeroplane wing has an area 50 m^2 . The speed of air flowing above the wing is 100 m s^{-1} and below

the wing is 80 m s^{-1} . Find the aerodynamic lifting force acting on the aeroplane wing if density of air is 1.3 kg m^{-3} .

67. A capillary tube when immersed in a liquid of density d , the capillary rise observed is h . When another capillary tube of 4 times cross sectional area as the first tube is immersed in another liquid of density $2d$, what is the observed capillary rise. Assume angle of contact of capillary tube with both liquids is 0° the ratio of surface tensions of the two liquids is 1 : 2.
68. The length of a uniform test tube of mass 50 g is 10 cm. It can float vertically in water with half of its length in the water. Find the maximum and minimum density of the liquids that can be measured, with help of this test tube. (Assume that the test tube can be balanced when minimum of 1 cm of tube is inside any liquid.)
69. A cylinder of height one metre is filled with water and is provided with light, frictionless piston. The radius of the piston is 40 cm. A W weight of $10 \text{ kg}_{\text{wt}}$ is placed over the piston

If a small hole is made at the level of the centre of gravity, then what is the pressure of the water that rushes out? ($g = 10 \text{ m s}^{-2}$)



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. greater than 9. 1.6 and 2.15 10. bottom 11. top and bottom
12. atmospheric pressure 13. relative density 14. 2 : 3

Match the following

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

Multiple choice questions

16. (b) 17. (c) 18. (a) 19. (c) 20. (d) 21. (d) 22. (b) 23. (d) 24. (b) 25. (a)
26. (a) 27. (c) 28. (b) 29. (a) 30. (b) 31. (a) 32. (c) 33. (a) 34. (a) 35. (a)
36. (a) 37. (d) 38. (c) 39. (c)

Explanation for question 31 to 39:

31. At higher altitude a pressure cooker is used as the water boils at a temperature less than 100 °C. This is because the pressure at higher altitude is less than 76 cm of Hg.

32. Apparent loss of weight is explained on the basis of Archimedes principle.

33. Net force on the balloon having volume V is

$$Ma = U - W$$

$$Ma = VDg - Vdg$$

$$Vda = VDg - Vdg$$

Effective acceleration $a = g \left[\frac{D-d}{d} \right]$, a is effective acceleration of balloon.

W is weight of balloon.

U is upthrust on balloon.

Mass of balloon is $M = Vd$.

34. The weight of the object in air (w_1) is determined by using a spring balance (b).

Now the object is completely immersed in the given liquid and the apparent weight in the liquid (w_2) is determined.

The value of ($w_1 - w_2$) is determined. (a, c, d).

The weight of the liquid displaced by the object (w) is determined (e).

The values of (w) and ($w_1 - w_2$) are compared and they are equal (f).

35. Samuel Plimsoll suggested that the ships should be marked with load lines.

36. Surface tension is explained on the basis of molecular theory.

37. An aeroplane wing experiences aerodynamic lift due to the pressure difference between the bottom and top parts of the wing which can be explained on the basis of Bernoulli's principle.

38. Initially, the weight of the object (w_1) is determined by using a spring balance (b). Immerse the object completely in water and collect the water displaced by it (a). Determine the weight of the water displaced (w_2) (c). Determine the value of the ($w_1 - w_2$) (d).

39. An air bubble rises up in water because the upthrust acting on the bubble is more than the weight of the bubble.



Level 2

40. (i) $\frac{h_A}{h_B} = \frac{d_B}{d_A}$
 (ii) $h_A = 31$ cm
 $h_B = 15$ cm
41. (i) Determine the upthrust acting on each part.
 Net force = Total weight – total upthrust.
 (ii) 0.4704 N
42. (i) Weight of the body in air – weight of the body in water = apparent loss of weight = upthrust
 $= V_{\text{liquid}} d_{\text{displace}} \times d_{\text{liquid}} \times g$
 $d = \frac{1}{2}$
 (ii) 10 cm³
43. (i) Find the volume of a wooden cube (V_d) from given data.
 Find the volume of the water displaced from the given information.
 Here, weight of the cube is equal to the weight of the water displaced.
 Find the density of the cube (d_c) from law of floatation.
 That is, $V_c \cdot d_c \cdot g = \frac{1}{2} V_c \cdot d_w \cdot g$ (1)
 Then, find the weight of the cube = $V_c \cdot d_c \cdot g$
 When the same cube is made to float in the liquid of density 0.8 g cm⁻³, find the volume of the displaced liquid (V_c) from the law of floatation.
 $V_c \cdot d_c \cdot g = v_L \cdot d_L \cdot g$ (2)
 Find the value of ' V_L ' from (2)
 Take the extra force required to completely submerge it in the given liquid as (F).
 Then, weight of the cube + $F = (100 \text{ cm}^3)(0.8 \text{ g cm}^{-3})g$ (3)
 Find the value of ' F ' from the 3rd equation.
 (ii) 2 N
44. (i) By law of floatation, the weight of the floating body is equal to the weight of the liquid displaced, If d is the relative density of the sphere.

$$Vdg = \frac{V}{2} \times 13.6 \times g + \frac{V}{2} \times 1 \times g$$

- (ii) 7.3 g cm⁻³

45. (i) Find the net force acting on the spheres x and y , which is equal to [weight(u) – upthrust (u)]

By principle of moments

$$(W_x - U_x)l = (W_y - U_y)l \quad (1)$$

substitute the below data in equation (1).

$$W_x = V_x d_x g; W_y = V_y d_y g;$$

$$U_x = V_A d_A g = V U_x d_A g;$$

$$U_y = V_B d_B g - V_y d_B g$$

$$\text{Take } d_x = d_y = d;$$

$$\text{Given } \frac{d}{d_A} = 9;$$

$$d_A = 2 \text{ g cm}^{-3}; \Rightarrow d = 18 \text{ g cm}^{-3}$$

$$\text{Take, } V_x = \frac{m_x}{d}; V_y = \frac{m_y}{d}.$$

Substitute the value of

$$W_x, V_x, W_y \text{ and } U_y \text{ in (1),}$$

then find the value of d_B .

- (ii) 3.45 g cm⁻³

46. (i) Let V be the volume of the hemispherical part of the test tube, x be the height of this part and the length of the test tube submerged in a liquid of density d then

$$\begin{aligned} [V + A(1 - x)] &= \text{weight of the liquid displaced} \\ &= \text{weight of the test tube} \\ &= \text{constant.} \end{aligned}$$

- (ii) 3.1

47. (i) Find the weight of hot air present in the balloon.
 $= (\text{Volume of balloon}) \times (\text{density of hot air}) \times g$. (1)
 Find the upthrust acting on the balloon due to cold air.
 $= (\text{volume of balloon}) (\text{density of cold air}) \times g$ (2)
 Now, find the weight of the balloon and also the weight attached to it from the given data.
 Find the net forces acting on the balloon.

By the law of floatation, i.e.,

$$\text{Wt. of balloon} + W + \text{Weight of hot air} = \text{upthrust} \quad (3)$$

Then, the sum of all forces acting on the balloon is zero because the balloon comes down with zero acceleration.



Substitute the appropriate value in (3), we get the value of W .

- (ii) 780 kg_{wt} or 7800 N.
48. (i) $P_A = \text{atmospheric pressure} - \Delta l$
 $P_B = P_A + \Delta l_1$
 $P_C = P_B + \Delta l_2$
 Where Δl , Δl_1 , Δl_2 are the change in levels of the mercury columns
- (ii) 20 cm of Hg, 30 cm of Hg, 50 cm of Hg
49. (i) Let the volume of the floatation bulb = $V \text{ cm}^3$, and the area of cross-section of the stem = $a \text{ cm}^2$.
 By the law of floatation the weight of the floating body
 = Weight of the displaced liquid
 = Upthrust acting on common hydrometer.
 Here, take the density of the liquid as d_L where Hydrometer immerses only upto 0.5 cm.
 Then, $W = (\text{Volume of the displaced liquid}) (\text{density of the liquid}) (\text{acceleration due to gravity})$

$$W = (V + a \cdot l) d_L g$$

 Obtain the expression as,

$$W = [V + a(4.5)] \cdot g = [V + a(1.5)] \cdot 2 \cdot g$$

$$= [V + a(0.5)] d_L \cdot g.$$

 Determine the value of V in terms of a .
 Obtain the value of d_L by solving the expression.
- (ii) 3.
50. (i) When the object floats freely,
 $V_{\text{in}} \times d_l g = V_A \times d_A g$
 Where V_{in} , V_A are the volume immersed and total volume of the object A , respectively d_l , d_A are the density of the liquid and the object A , respectively.
 The extra force acting on the object A = weight of the object B – upthrust acting on it
- (ii) 5/8
51. (i) Pressure = $\frac{\text{Thrust}}{\text{Area}}$
 Thrust is the force acting perpendicular to the surface
- (ii) 100 Pa
52. (i) Find the densities of water and the given liquid. Find the levels of water in the beaker and the tube from the given data.

Find the height of the water column in the tube.

By using the formula, $h_A d_{Ag} = h_B d_{Bg}$ (1)

Find the height of the liquid column, i.e., h_2 .

If the level of liquid in the beaker is 14.7 cm, then find the level in the tube.

(ii) 37.7 cm.

53. (i) By the law of floatation,
 $[\text{mass of cube (ice)} + \text{mass of stone}]g$
 $= [\text{mass of displaced water}]g$ (1)
 Then, find the mass of the ice cube from (1).
 When a stone weighing 500g placed on its top, slips into water, the ice cube rises by $\frac{1}{10}$ th of its length.
 Because of this, the mass of the water displaced changes by 500 g.
 The change in the volume of the ice cube is equal to $\left(a \frac{1}{10}\right)$

Then, this value is equal to the change in the volume of the is equal water displaced.

$$\text{Then } \left(a \frac{1}{10} a l\right) = 500 \text{ cm}^3 \quad (2)$$

Then find the volume of the cube (V_i) from (2)

Here, mass of the cube = 4500 g.

This means, $V_i \cdot d_i = 4500$ (3)

Substitute ' V_i ' from (2) in (3).

Find the value of d_i .

(ii) 0.9 g cm⁻³

54. (i) Take the area of cross-section of the test tube as ' a '.
 Then find the volumes of the two displaced liquids by the immersion of the test tube
 Use the law of floatation.
 i.e., weight of the floating body (W) = Weight of the displaced liquid.
 Here, $W = V_T \cdot d_T \cdot g$ (1)
 $\Rightarrow V_T \cdot d_T \cdot g = V_L \cdot d_L \cdot g$ (2)
 Find the density of the unknown liquid using equation (2).

(ii) 3.



55. From the law of moments,

The clockwise and anticlockwise moments are equal.

In Air, $w_1 \times 50 \text{ cm} = 1000\text{g} \times 40 \text{ cm}$

$$\Rightarrow w_1 = \frac{40 \times 1000}{50} = 800\text{g}$$

In water, $w_1 \times 50 \text{ cm} = 1000\text{g} \times 30 \text{ cm}$,

$$\Rightarrow w_1 = \frac{30}{50} \times 1000 = 600\text{g}$$

$\therefore$ The apparent weight of the body in water = 600 g.

The apparent loss of weight of the body in water = 200 g.

In liquid (Given)

In water, $w_1 \times 50 \text{ cm} = 1000 \text{ g} \times 35 \text{ cm}$,

$$W_1 = \frac{1000 \times 35}{50} = 700\text{g}$$

The Apparent weight of the body in liquid = 700 g.

The apparent loss of weight of the body in the liquid = 100 g.

The relative density of the liquid (given)

$$= \frac{\text{Apparent loss of weight of body in liquid}}{\text{Apparent loss of weight of body in water}} \\ = \frac{100 \text{ g}}{200 \text{ g}} = 0.5$$

56. The volume of the first body.

$$V_1 = \frac{\text{mass of the body}}{\text{density of the body}}$$

$$V_1 = \frac{500}{5} = 100 \text{ cm}^3$$

Similarly, the volume of the second body

$$V_2 = \frac{750}{3.75} = 200 \text{ cm}^3, \frac{V_1}{V_2} = \frac{100}{200} = \frac{1}{2}$$

When these bodies are in equilibrium,

$$\Rightarrow W_1 - U_1 = W_2 - U_2 \Rightarrow m_1 g - V_1 d_\ell g = m_2 g - V_2 d_\ell g$$

$$\Rightarrow V_1 D_1 g - V_1 d_\ell g = V_2 D_2 g - V_2 d_\ell g$$

$$\Rightarrow V_1 g (D_1 - d_\ell) = V_2 g (D_2 - d_\ell)$$

$$\Rightarrow \frac{V_1}{V_2} [5 - d_\ell] = [3.75 - d_\ell]$$

$$0.5 \times 5 - 0.5 d_\ell = 3.75 - d_\ell$$

$$0.43 d_\ell = 30 - 19.95$$

$$\Rightarrow d_\ell = \frac{30 - 19.95}{0.43} = 2.5 \text{ g cm}^{-3}$$

$$= 2.5 \times 10^3 \text{ kg m}^{-3} = 2500 \text{ kg m}^{-3}$$

57. Given,

$$\text{Area of plate, } A = 100 \times 10^{-4} \text{ m}^2 = 10^{-2} \text{ m}^2$$

$$\text{Coefficient of viscosity of oil, } \eta = 3 \times 10^{-1} \text{ Pa s}$$

$$\text{Force required to move the plate, } F = 1 \text{ N}$$

$$\text{Speed of plate, } V = 30 \text{ cm s}^{-1} = 0.3 \text{ m s}^{-1}$$

$$\text{Thickness of layer, } x = ?$$

$$\text{Force required to move the plate, } F = \eta A \frac{V}{x}$$

$$1 = 3 \times 10^{-1} \times 10^{-2} \times \frac{0.3}{x}$$

$$x = 0.9 \times 10^{-3} \text{ m} = 0.9 \text{ mm}$$

58. The volume of the wooden cube = 1000 cm
- ³

Case I: The weight of the floating body = The weight of the displaced water.

$$V \times d_{\text{cube}} \times g = \frac{3}{5} \times V \times 1 \times g$$

$$d_{\text{cube}} = 0.6 \text{ g cm}^{-3}$$

Case II: When the given cube is floated on a given liquid, the density of the liquid = 0.8 g cm⁻³.

The weight of the floating body = the weight of the displaced liquid.

$$V \times d_{\text{cube}} = V^1 \times 0.8$$

$$\Rightarrow V^1 = \frac{1000 \times 0.6}{0.8} = 750 \text{ cm}^3$$

The weight of the floating body (cube) $w = V \cdot d_{\text{cube}} \cdot g$
 $= (1000) 0.6 \times 1000 = 6 \times 10^5 \text{ dynes}$.

When the cube is completely submerged inside the given liquid, the net force (F) is to be applied on the cube.

$$W + F = U$$

The upthrust acting on the cube,

$$U = V d_{\text{liquid}} \times g = 1000 \times 0.8 \times 1000 = 8 \times 10^5 \text{ dynes}.$$

$$\therefore F = U - W.$$

$$F = 8 \times 10^5 - 6 \times 10^5 = 2 \times 10^5 \text{ dyne}.$$

$\therefore F = 2 \times 10^5 \text{ dyne}$ or 2 N is to be applied vertically on top of the cube.



59. % volume of the ice above the surface of the liquid = 25%.

% volume of the object immersed in the liquid = 75%.

Density of ice, $d_{\text{ice}} = 930 \text{ kg m}^{-3}$.

For a floating body weight of the body = upthrust.

$$V_{\text{ice}} \times d_{\text{ice}} g = v_{\text{im}} \times d_1 \times g$$

$$V_{\text{ice}} \times 930 \times g = \frac{3}{4} v_{\text{ice}} \times d_1 \times g$$

$$d_1 = \frac{930 \times 4}{3} \text{ kg m}^{-3}$$

$$1240 \text{ kg m}^{-3} = 1.24 \text{ g cm}^{-3}$$

Level 3

60. (i) **Part I:**

Find the length of the Hg column and entrapped gas in a one metre tube from the given data.

Find the volume of entrapped gas (V_1).

Then atmospheric pressure, (P_a) = Pressure due to entrapped air (P_1) + Pressure due to 'x' cm of Hg column (1)

Part II:

When a test tube is pulled out by 10 cm from the trough, find the length of the air column.

Find the volume of the entrapped gas (V_2).

Now, P_a = Pressure due to 'x' cm of Hg column + pressure due to entrapped air (P_2) (2)

From Boyle's law.

$$P_1 V_1 = P_2 V_2 \quad (3)$$

Substitute the values of P_1 and P_2 that are obtained in (1) and (2) into (3).

Solve the equation thus obtained to get the value of ' P_a '.

- (ii) 75 cm of Hg.

61. (i) $T + mg = (\text{upthrust})$

Upthrust = (mass/unit length) $\times$ length

$$\text{immersed} \times \left(\frac{\text{density of liquid}}{\text{density of the body}} \right)$$

- (ii) 49 N

62. (i) Weight of the test tube + Weight of lead shots = Weight of liquid displaced

- (ii) 55.56%

63. (i) Find the weight of the cube in air (W_1) and in water (W_2).

Find the apparent loss in the weight of the cube i.e., ($W_1 - W_2$) (1)

But ($W_1 - W_2$) = upthrust acting on the cube.

$$\Rightarrow W_1 - W_2 = V \cdot d_{\text{water}} \cdot g \quad (2)$$

From (2), find the volume of the cube (V_1)

Find the relative density (d) of the metal from the given data.

Find the volume of the metal (V_2) from using the formula.

$$V_2 = \frac{W_1}{d}$$

Now, the volume of the cavity = $V_1 - V_2$.

- (ii) 20 cm^3 .

64. $175 \text{ g}_{\text{wt}}$, $1000 \text{ g}_{\text{wt}}$

65. Let volume of the ice cube be = $\ell^3 \text{ cm}^3$

Let its density be = $d_i \text{ g cm}^{-3}$

Weight of the floating body = weight of the displaced liquid.

$$\Rightarrow (500 + m)g = 5000g$$

$$m = 5000 - 500$$

$$m = 4500 \text{ g} \quad (1)$$

Now, when stone slips and falls into water.

$$\Rightarrow 500 \text{ g} = \ell^2 \cdot \frac{1}{10} \ell \cdot 1 \text{ g}$$

$$\ell^3 = 5000 \text{ cm}^3 \quad (2)$$

$\therefore$ The density of the ice cube

$$= \frac{m}{v} = \frac{4500 \text{ g}}{5000 \text{ cm}^3} = 0.9 \text{ g cm}^{-3}$$

66. Given,

Velocity of air below the aeroplane wing

$$V_1 = 80 \text{ m s}^{-1}.$$

Velocity of air above the aeroplane wing

$$V_2 = 100 \text{ m s}^{-1}.$$

Area of aeroplane wing $A = 50 \text{ m}^2$.

Aerodynamic lifting force $F = ?$

$$\text{Aerodynamic lifting force } F = (P_1 - P_2) A. \rightarrow (1)$$

Where P_1 and P_2 are pressures of air at the bottom and top of the wings respectively.



According to Bernoulli's theorem,

$$\frac{P_1}{\rho} + \frac{1}{2}V_1^2 = \frac{P_2}{\rho} + \frac{1}{2}V_2^2$$

$$\text{Or } (P_1 - P_2) = \frac{1}{2}\rho (V_2^2 - V_1^2) \quad (2)$$

Substituting (2) in (1)

$$\therefore F = \frac{1}{2}\rho (V_2^2 - V_1^2)A$$

[density of air $\rho = 1.3 \text{ kg m}^{-3}$]

$$F = \frac{1}{2} \cdot 3.1 \times (100^2 - 80^2) \times 50$$

We get $F = 117 \times 10^3 \text{ N}$.

67. Capillary rise in second capillary tube is

$$h = \frac{2T_1 \cos 0^\circ}{r_1 d_1 g} \quad (1)$$

(given angle of contact $\theta = 0^\circ$)

here r_1 is radius of the bore of second capillary tube

$d_1 = d$ is density of first liquid.

T_1 = is surface tension of first liquid.

Capillary rise in second capillary tube is

$$\frac{2T_2 \cos 0^\circ}{r_2 d_2 g} \quad (2) \text{ [given } \theta = 0^\circ \text{]}$$

here r_2 is radius of the bore of second capillary tube

$d_1 = d$ is density of second liquid.

T_2 is surface tension of second liquid.

Dividing equation (1) and (2)

$$\begin{aligned} \frac{h}{h_2} &= \frac{\frac{2T_1}{r_1 d_1 g}}{\frac{2T_2}{r_2 d_2 g}} \quad [\text{since } \cos 0^\circ = 1] \\ \frac{h_1}{h_2} &= \frac{T_1}{T_2} \times \frac{r_2 d_2}{r_1 d_1} \Rightarrow \frac{h}{h_2} = \frac{1}{2} \times \frac{r_2}{r_1} \times \frac{2d}{d} \\ \frac{h}{h_2} &= \frac{r_2}{r_1} \end{aligned} \quad (3)$$

Given: Area of cross section for second capillary tube
 $A_2 = 4A_1$

[A_1 is area of cross section of first capillary tube]

$$r_2^2 = 4 r_1^2 \therefore r_2 = 2r_1 \therefore \frac{h}{h_2} = \frac{2r_1}{r_2} \Rightarrow h_2 = \frac{h}{2}$$

68. **Case 1:** The test tube immerses completely in a liquid of minimum density.

The length of the test tube = 10 cm

The weight of the test tube = 50 g

Let the area of cross section of the test tube = a

Let the density of test tube = D_{TT}

If half of the length of the test tube floats inside the water

Weight of the floating body = weight of the displaced liquid

$$50 g_{wt} = \frac{V}{2} d_w g$$

$$\Rightarrow V \cdot D_{TT} \cdot g = \frac{V}{2} (1) g \Rightarrow D_{TT}$$

$$= \frac{1}{2} = 0.5 \text{ g cm}^{-3}$$

The depth of immersion of the test tube inside this liquid is 10 cm

$$\Rightarrow V \cdot D_{TT} \cdot g = V D_L \cdot g$$

Therefore, the minimum density = 0.5 g cm^{-3}

The density of this liquid = density of test tube

$$= 0.5 \text{ g cm}^{-3}$$

Case 2: In a liquid with maximum density the test tube floats with a minimum height inside the liquid.

The minimum height at which the test tube can be balanced is $1 \text{ cm} = h/10$.

$$\therefore \text{Volume of the test tube} = a \cdot h$$

$$\Rightarrow V \cdot D_{TT} \cdot g = \frac{V}{10} \cdot d_L \cdot g$$

$$\begin{aligned} d_L &= 10 \times D_{TT} = 10 \times 0.5 \text{ g cm}^{-3} \\ &= 5 \text{ g cm}^{-3} \end{aligned}$$

The maximum density of the liquid that can be measured using this test tube is 5 g cm^{-3} .



69. The height of the water level from the hole = 50 cm

The pressure at the hole, only due to water level is
hdg

$$\text{hdg} = 0.5 \text{ m} \times 10^3 \text{ kg m}^{-3} \times 10$$

$$P_1 = 5 \times 10^3 \text{ Pa}$$

The pressure exerted due to 10 kgwt is P_2

$$P_2 = \frac{\text{Weight}}{\text{area of cross section}}$$

$$P_2 = \frac{10 \times 10 \text{ N}}{\frac{22}{7} \times 0.4 \times 0.4 \text{ m}^2}$$

$$P_2 = \frac{100 \times 7}{22 \times 0.16} = 198.8 \text{ Pa}$$

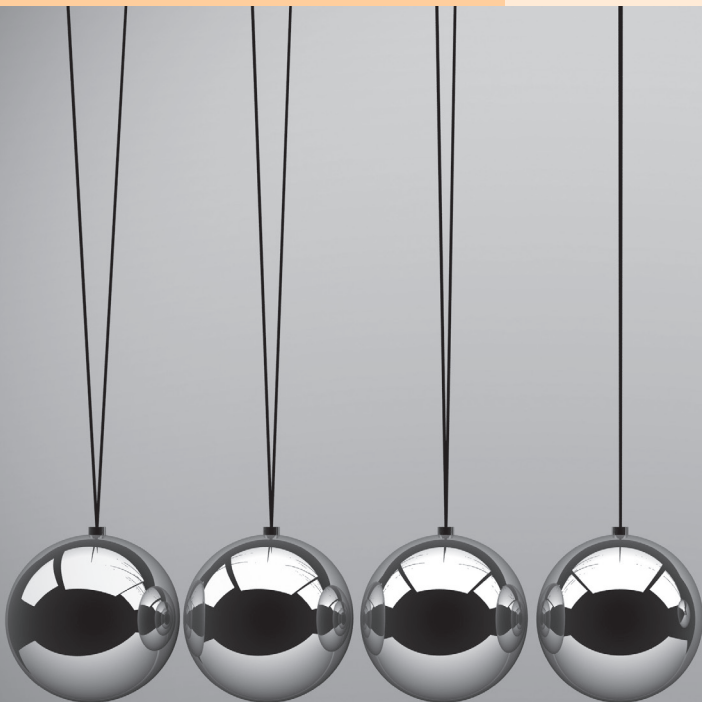
The pressure with which water rushes out = $P_1 + P_2$
 $= 5000 + 198.8 = 5,198 \text{ Pa}$



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Chapter 6

Wave Motion and Sound



Remember

Before beginning this chapter, you should be able to:

- Learn about the different types of wave motion and to represent simple harmonic motion graphically
- Learn how a sound is produced and the classification of sound based on its frequency
- Understand the formulae of velocity of sound and the factors that affect the velocity
- Learn about natural and forced oscillations and resonance

Key Ideas

After completing this chapter, you should be able to:

- Understand the classification of waves, sound as a mechanical wave
- Learn different types of vibrations, vibrations of stretched string, etc.
- Study about simple harmonic motion
- Find relation between velocity, wavelength and frequency of sound
- Study the phenomenon of resonance
- Understand terms and concepts related to sound like pitch, intensity, quality, noise pollution, recording and reproduction of sound, etc.

INTRODUCTION

Sound is a form of energy causing the sensation of hearing through the vibrating ear drum. A loud thunder or high intensity sound produced by a low-flying jet plane results in the rattling of window panes and doors. We know that work is done at the expense of energy and the rattling of doors and windows is caused by the sound, thus indicating that sound is a form of energy.

The source of sound energy is the mechanical energy possessed by vibrating bodies. In other words, sound is produced by vibrating bodies. This can be demonstrated by a simple experiment.

VIBRATING BODIES PRODUCE SOUND

A tuning fork is clamped to a wooden base and the prongs are gently struck with a leather or rubber hammer. As the sound is produced from the tuning fork, a pith ball suspended from a string is brought into contact with the tuning fork. It is found that as soon the pith ball comes in contact with the tuning fork, it instantaneously moves away. On the other hand, the pith ball does not jump away when it comes in contact with a tuning fork that does not produce sound. The jumping away of the pith ball is indicative of the vibrations of the tuning fork and this experiment illustrates that a tuning fork produces sound only when it vibrates.

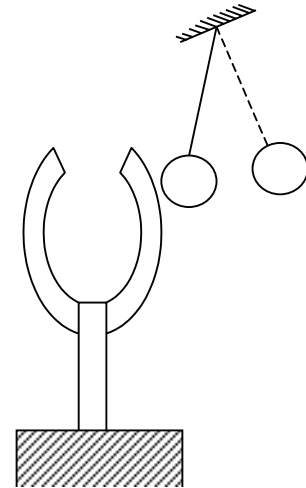


FIGURE 6.1 A tuning fork and a pith ball producing sound on collision

Do all the vibrating bodies produce audible sound? It has been found that bodies vibrating with a frequency in the range 20 Hz to 20 kHz only can cause a sensation of hearing in humans, and this range is called audible range of frequencies. Animals, birds and insects in general are sensitive to sound with a frequency outside this range also. If the frequency of the vibrations is less than 20 Hz, it is called infrasonic sound and the sound produced by bodies vibrating with a frequency greater than 20 kHz, is called ultrasonic sound.

PROPAGATION OF SOUND

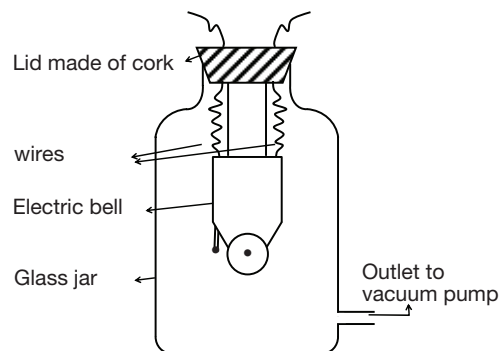


FIGURE 6.2 Bell-jar experiment

A little earlier, we had mentioned that sound is a sensation produced in the brain through the vibrations of the ear drum—a thin membrane in the ear. For the vibrations of the tuning fork to be transmitted to the ear, the intervening material medium plays an important role. In other words, material medium is required for the propagation of sound energy. This is demonstrated in the bell-jar experiment. The sound produced by the electric bell located inside the bell-jar can be heard from the outside, only when there is air inside the jar. It is observed that the sound produced by the electric bell is not heard when the jar is completely evacuated. No wonder we can only see the sun but not hear the roaring solar flames!

The important properties of a material medium that help in the proportion of sound energy are the elasticity and inertia of the medium.

WAVE MOTION

Consider the row of bicycles parked in a cycle-stand. If the bicycle at one end is pushed, progressively all the bicycles would fall and within a few seconds the bicycle at the other end also would fall. Without physically going to it, the last bicycle is successfully pushed down. This is the principle of wave motion, in which the vibrations of the particles of the intervening material medium are utilized to transmit the energy without the actual translatory motion of the source causing the disturbance, just as the intermediate bicycles help in pushing the last bicycle in the row.

A wave is a disturbance created at a place in a medium and travels in all possible directions in the medium. When a wave propagates from one place to another, the particles of the medium do not undergo any translatory motion but have only vibratory or oscillatory motion.

Types of Waves

Waves may be classified in three different ways. The first classification is based on the requirement of a medium for the wave propagation (mechanical and electromagnetic waves); the second classification is based on the direction of the vibration of the particles of the medium with respect to the direction of the wave propagation (transverse and longitudinal waves); and the third classification is based on the limitation of the propagation of the waves (progressive waves and stationary waves).

Mechanical and Electromagnetic Waves

Mechanical waves, also called elastic waves, require a material (an elastic) medium for their propagation.

Examples: Sound waves, water waves, etc.

Electromagnetic waves are the waves which do not require any material medium for their propagation. They can propagate even through vacuum.

Examples: Light waves, X-rays, radio waves, etc.

Transverse and Longitudinal Waves

If the direction of the vibration of the particles of the medium is perpendicular to the direction of the propagation of the wave, the wave is called a transverse wave.

Examples: Ripples on water surface, a wave pattern set in a stretched string.

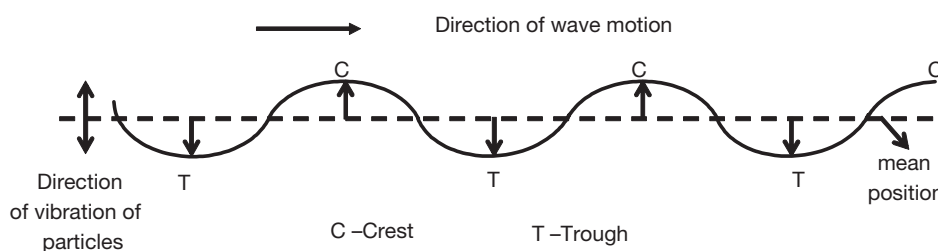


FIGURE 6.3 A transverse wave

Given below are the definitions of standard terms describing the properties of a wave.

1. **Crest:** The position of the maximum upward displacement of a vibrating particle from the mean position in a transverse wave is called a **crest**.
2. **Trough:** The position of the maximum downward displacement of a vibrating particle from the mean position in a transverse wave is called a **trough**.
3. **Amplitude:** The maximum displacement of a vibrating particle from the mean position (either upward or downward) in the wave is called **amplitude** and is measured in metres or centimetres.
4. **Phase:** The state of a vibrating particle in the wave with regard to its displacement from the mean position and the direction of vibration is called phase and is measured in radians. If the phase of any two particles in a wave is equal, i.e., they have a phase difference of 2π radians, they are said to be in phase else they are said to be out of phase.
5. **Wavelength:** The distance between any two successive particles of the wave which are in phase is known as **wavelength (λ)** and is measured in metres or centimetres.
6. **Time period:** The time taken by a vibrating particle to complete one full vibration or the time taken to produce one complete wave pulse is known as **time period (T)** and is measured in seconds.
7. **Frequency:** The number of vibrations made by a vibrating particle in one second or the number of waves produced per second is known as **frequency** and is measured in hertz (Hz). It is denoted by ν (mv) or n or f .

If the direction of the vibration of particles of the medium is parallel to the direction of the wave propagation, the wave is called a 'longitudinal' wave.

Example: Sound waves in air or in a gas; waves set in a long spring.

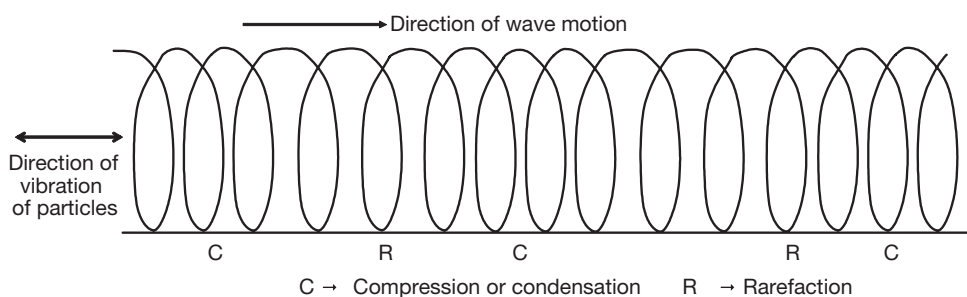


FIGURE 6.4 A longitudinal wave set in a spring

When a long spring is placed horizontally on a table and one end is vibrated as shown in Fig. 6.4, there are certain regions formed in the spring where the rings of the spring are much closer to each other than they would be when they are at rest position. Such regions are called **compressions** or **condensations**. Similarly, there are certain regions formed in the spring where the distance between the rings is more than the distance when they are at rest position. These regions are known as **rarefactions**.

Progressive and Stationary Waves

When a wave starts from a point in a medium and propagates in all the possible directions and never returns, the wave is called a **progressive wave**. When a progressive wave strikes a hard surface and is reflected, the incident wave and the reflected wave superpose forming a standing wave, also called a stationary wave. In such a wave, the amplitude of vibration of different particles.

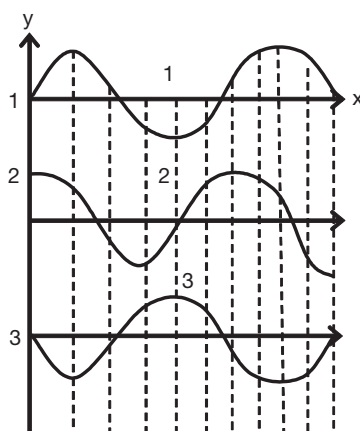


FIGURE 6.5 Progressive waves

Phase difference between waves (1) and (3) is π , i.e., if the shape of the wave in (1) is described by $y = \sin x$, the shape of the wave in (3) is given by, $y = \sin (x + \pi) = -\sin x$.

$\therefore$ When wave in (1) reaches a maximum, wave in (3) reaches a minimum and vice-versa.

Phase difference between (1) and (2) is $(\pi/2)$, i.e., if the wave in (1) is given by, $y = \sin x$, the wave in (2) is given by,

$$y = \sin \left(x + \frac{\pi}{2} \right) = \cos x.$$

Therefore, if a wave on reflection undergoes a phase change π , the shape of the wave before and after reflection at the wall would appear as below.

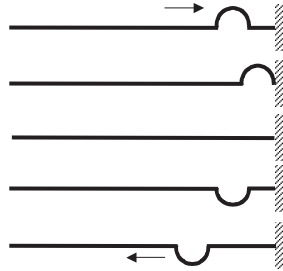


FIGURE 6.6 The shape of the wave before and after reflection at the wall

Stationary Wave Formation in a Stretched String

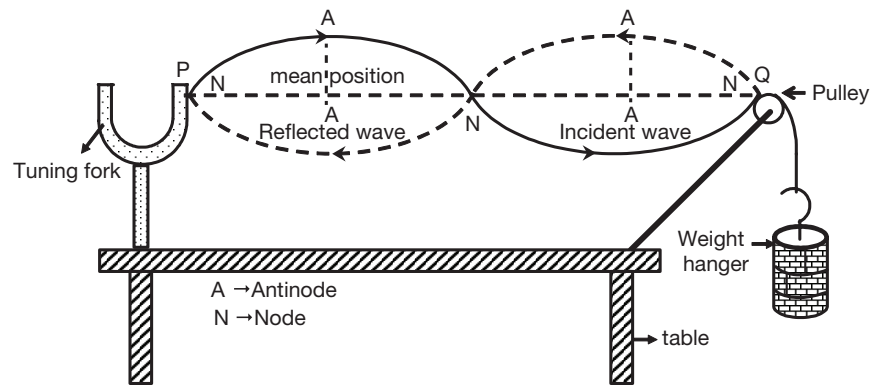


FIGURE 6.7 Formation of stationary waves in a string

Fix a tuning fork of some frequency and a smooth frictionless pulley at the ends of a table as shown in Fig. 6.7. One end of a string is tied to one of the prongs of the tuning fork and the other end passes over the pulley. To this free end of the string, a weight is attached. The weight attached provides the tension in the string. When the tuning fork is excited with a rubber hammer, the vibrating tuning fork sends a wave in the string which propagates from 'P' to 'Q'. It is called an incident wave. At the pulley 'Q' the wave is reflected. The incident wave and the reflected wave superpose to form a stationary wave as shown in the Fig. 6.7. The positions where the amplitude of the vibrating particles is zero or minimum are shown as 'N' in the Fig. 6.7 and are called '**nodes**'. Similarly the positions where the amplitude of the vibrating particles is maximum are shown as 'A' in the Fig. 6.7 and are called '**antinodes**'. When the wave is reflected at 'Q', a phase change of π radians takes place. The string between the points 'P' and 'Q' appears as loops due to persistence of vision.

Differences Between Progressive and Stationary Waves

Progressive waves	Stationary waves
These waves are produced at a point and progress in all the possible directions till they die out due to damping.	These waves are limited between two positions and appear to be standing.
These waves cause crests and troughs or compressions and rarefactions.	These waves cause nodes and antinodes.
The amplitude of vibration of all the particles in the wave is equal.	The amplitude of vibration of different particles in the wave is different. It is maximum at antinodes and minimum or zero at nodes.
There is a continuous phase difference between particles in the wave.	All the particles between two successive nodes in the wave are in phase.
The distance between any two adjacent crests (or compressions) or troughs (or rarefactions) is one wavelength (λ).	The distance between any two successive nodes or two successive antinodes is one half of the wavelength ($\lambda/2$).
The energy associated with these waves is kinetic in nature and is transmitted from one place to another.	The energy associated with these waves is potential in nature and it is stored in the medium between two fixed points.
In a progressive wave, there is no instant when all the particles cross the mean position together.	In a standing wave, all the particles cross their mean positions together.
In a traveling wave, there is no particle which is always at rest.	In a standing wave, the particles at nodes are always at rest.

Sound Waves

Sound waves are longitudinal waves due to the compressions and rarefactions produced in the material medium surrounding the source.

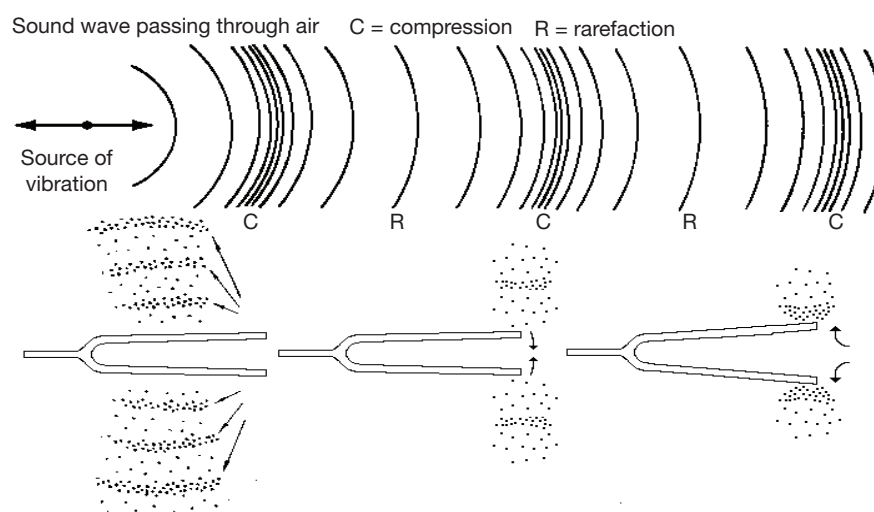


FIGURE 6.8 Sound waves produced by a tuning fork

Sound waves can propagate in solids, liquids as well as gases. Put your ear to one end of a long pipe, say 100 m, long and ask your friend to gently tap the other end. Almost immediately, you would be able to hear the sound at your end.

Propagation of Sound Through Liquids

Place a trough of water on a hollow wooden box (sound box) open at one end. Fix the stem of a tuning fork to a metallic disc. The prongs of the tuning fork are set to vibrate and the disc is gently made to come in contact with the water surface as shown in the Fig. 6.9. It is found that immediately the sound of the tuning fork with greater intensity is heard from the sound box.

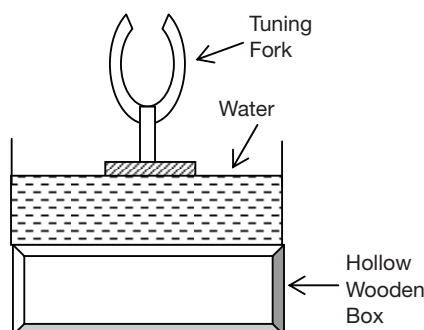


FIGURE 6.9 Propagation of sounds through liquids

SIMPLE HARMONIC MOTION (SHM)

The transmission of sound is by longitudinal wave propagation caused by the vibration of the particles of the medium resulting in compressions and rarefactions. These vibrations are periodic and oscillatory in nature, i.e., the motion of each particle repeats itself along the same path at regular intervals of time (periodic motion) and at the same time, the motion is to and fro along the path (oscillatory). The oscillations of the bob of a simple pendulum, the vibrations of a body suspended from a spring, to and fro motion of the air molecules during the propagation of sound are all examples of harmonic motion.

A harmonic motion is categorized as a simple harmonic motion if it satisfies the following conditions.

1. The acceleration of the body is always directed towards its mean position. In other words a restoring force acts on the body directed always towards the mean position. In the oscillations of a simple pendulum tangential component of gravitational force is always directed towards the mean position.
2. The magnitude of acceleration (a) is directly proportional to the displacement (x) of the body from its mean position. Since the acceleration at any given position is directed towards the mean position and the displacement is considered away from the mean position, we have

$$\vec{a} \propto -\vec{x}$$

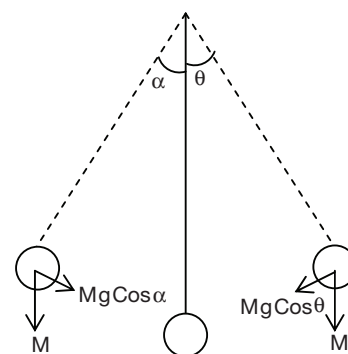


FIGURE 6.10 Simple harmonic motion of a pendulum

A simple harmonic motion is particularly characterized by (1) constant time-period (T), which also implies a constant frequency ν (Greek letter 'nu') (2) a constant amplitude and (3) a constant total mechanical energy, i.e., the sum total of kinetic energy and potential energy is same at every point on its path. The bob of a simple pendulum has kinetic energy at its mean position which is conserved as potential energy at its extreme positions.

Graphical Representation of SHM

When we plot displacement time graph of a body suspended freely from a spring executing free oscillations, we get a curve as shown in the Fig. 6.11.

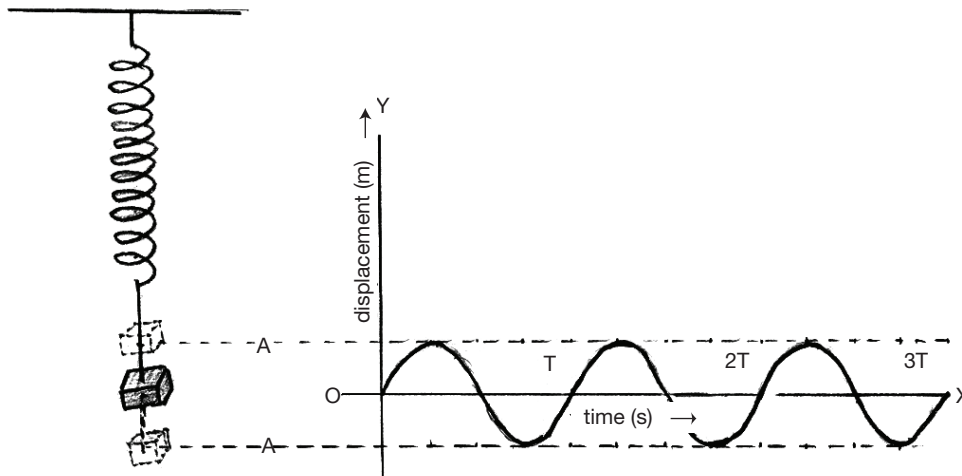


FIGURE 6.11 Graphical representation of simple harmonic motion

We find that the curve is in the form of a wave. Displacement–time graph of the particles in a transverse wave (water surface) and the pressure–time graph of a longitudinal wave are also similar to this graph.

1. Displacement time graph for a longitudinal wave propagation.

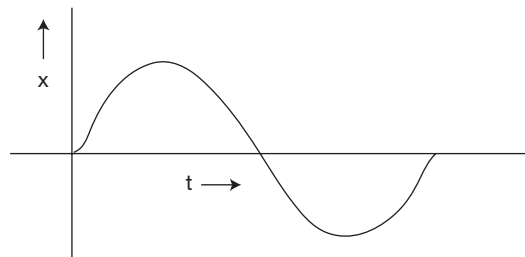


FIGURE 6.12

2. Pressure time graph for a sound wave.

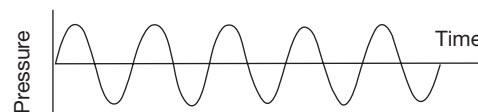


FIGURE 6.13

The crest in a transverse wave corresponds to a compression in a longitudinal wave, and the trough corresponds to the rarefaction.

If T is the time-period of oscillations and λ is the wavelength of the wave propagating then the velocity (v) of the wave propagation is given by,

$$v = \frac{\lambda}{T}$$

Since
$$v = \frac{1}{T}, f = v\lambda$$

VELOCITY OF SOUND

Expression for the velocity of sound waves in a medium was given by Sir Isaac Newton as

$V = \sqrt{\frac{E}{d}}$, where ' V ' is the velocity of the waves, ' E ' and ' d ' are the elasticity and the density of the medium, respectively. The elasticity factor changes with the state of matter, i.e., solids, liquids or gases and we get the expression for the velocity of sound in the corresponding medium accordingly.

Velocity of Sound in Solids

The elasticity factor in solids is given by Young's modulus (Y) and so, the expression for the velocity of sound in solids is given as

$$V = \sqrt{\frac{E}{d}},$$

where ' Y ' and ' d ' are Young's modulus of elasticity and density of the given solid medium, respectively.

Velocity of Sound in Liquids

The elasticity factor in liquids is taken as its bulk modulus of elasticity (K) and so, the expression for the velocity of sound in liquids is given as

$$V = \sqrt{\frac{K}{d}},$$

where ' K ' and ' d ' are the bulk modulus of elasticity and the density of the liquid, respectively.

Velocity of Sound in Gases

The elasticity factor in a gas is, also bulk modulus which is equal to its pressure. Thus, the Newton's formula for the velocity of sound in a gas changes to

$$V = \sqrt{\frac{P}{d}},$$

where ' P ' and ' d ' are pressure and density of the given gas. On theoretical calculation, at normal temperature, velocity of sound in air (a mixture of gases) using Newton's formula was obtained as 280 m s^{-1} whereas experimental value was found to be nearly 330 m s^{-1} . Owing

to the large difference between theoretical and experimental values of velocity of sound in air, Newton's assumptions in arriving at his formula for velocity of sound in a given gas were reviewed and a correction was made by Laplace. Thereby, the formula for the velocity of sound in a gas was given as

$$V = \sqrt{\frac{\gamma P}{d}},$$

where ' γ ' is a constant for a given gas and is defined as the ratio of the specific heat capacity of the given gas at constant pressure (C_p) to its specific heat capacity at constant volume (C_v).

Factors Affecting the Velocity of Sound in a Gas

- 1. Absolute Temperature of Gas:** The velocity of sound in a gas is directly proportional to the square root of its absolute temperature. Mathematically, $V \propto \sqrt{T}$ where ' V ' is the velocity of sound in a gas and ' T ' is its absolute temperature. If ' V_1 ' and ' V_2 ' are the velocities of sound in a gas at absolute temperatures ' T_1 ' and ' T_2 ', respectively, then

$$V_2 = K \sqrt{T_1} \quad (6.1)$$

$$\text{and } V_2 = K \sqrt{T_2} \quad (6.2)$$

On Dividing (6.1) by (6.2),

$$\text{we get} \quad \frac{V_1}{V_2} = \sqrt{\frac{T_1}{T_2}}$$

- 2. Density of a Gas:** The velocity of sound in a gas is inversely proportional to the square root of its density. Mathematically,

$$V \propto \frac{1}{\sqrt{d}}$$

where ' V ' is the velocity of sound in a gas and ' d ' is its density. If ' V_1 ' and ' V_2 ' are the velocities of sound in two gases having densities ' d_1 ' and ' d_2 ', respectively, other

parameters of the gases being constant, then $\frac{V_1}{V_2} \propto \sqrt{\frac{d_2}{d_1}}$

- 3. Molecular Weight of a Gas:** 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 ' and ' M ' are the velocity of sound in a gas and the molecular weight of the given gas, respectively. If ' V_1 ' and ' V_2 ' are the velocities of sound in two gases whose

molecular weights are ' M_1 ' and ' M_2 ', respectively, the other parameters of gases being constant, then

$$\frac{V_1}{V_2} = \sqrt{\frac{M_2}{M_1}}.$$

Factors that do not Affect Velocity of Sound in a Gas

- 1. Pressure of a Gas:** When the pressure of a gas is changed at a constant temperature, its density also changes accordingly such that the ratio ' P/d ' is always a constant. For a given gas, the value of ' γ ' is also constant. So, the variation in the pressure of a gas does not affect the velocity of sound in it, provided its temperature is kept constant.
- 2. Amplitude:** Amplitude is the maximum displacement of a vibrating particle from its mean position. The amplitude of a sound wave in a medium does not affect its velocity.
- 3. Frequency:** Frequency is the number of waves produced per second. The velocity of sound in a gas or any medium does not depend on its frequency.
- 4. Wavelength:** Wavelength is the distance between two successive particles of a medium which are vibrating in phase. The velocity of a wave in a medium does not depend on the wavelength of the wave.

The Velocity of Sound in Air

Air is a mixture of gases. So, the factors that affect the velocity of sound in gases also affect the velocity of sound in air. If V_0 and V_t are the velocities of sound in air at 0°C and $t^\circ\text{C}$,

respectively, then they are related as

$$V_t = V_0 \left(1 + \frac{t}{546} \right).$$

Another factor (to be considered) which affects the velocity of sound in air is humidity. Humidity is the amount of water vapour present in air. The presence of humidity decreases the density of air. So, higher the humidity, less is the density of air and more is the velocity of sound in it. Thus, the velocity of sound in air increases as the humidity in air increases.

Relation between Velocity, Wavelength and Frequency of Sound

In one time period (T), a sound wave advances in a medium by one wavelength (λ). So, the velocity of sound in the given medium is given by,

$$V = \frac{\text{S(distance)}}{t(\text{time})} = \frac{\lambda}{T}.$$

But as $\frac{1}{T} = n$, the frequency of sound, we have, $V = n\lambda$.

REFLECTION OF SOUND

Echo

Like the light waves, sound waves also undergo reflection on striking a hard surface. The reflected sound is known as an echo.

When a person makes a sound in front of a big wall, he hears two sounds, one produced by him and the other is the reflected sound. The person can hear the two sounds distinctly if they reach his ear with a time gap of at least 0.1 s. This is known as **persistence of hearing**. Consider a person standing at 'P' at a distance 'd' from a wall (reflector of sound) as shown in Fig. 6.14.

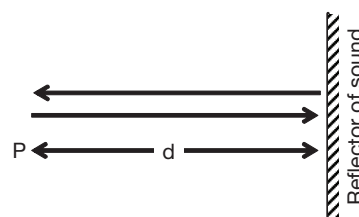


FIGURE 6.14 Echo

The person produces a sound and hears an echo after 't' seconds. Then the velocity of sound in air is given by the expression, $V = \frac{2d}{t}$. If the velocity of sound is known, the distance between the person and the reflector is given by, $d = \frac{Vt}{2}$. Since the persistence of hearing (the minimum time gap between two sounds reaching the ear) is 0.1 second, the minimum distance required to hear an echo = $\frac{V(0.1)}{2} = \frac{V}{20}$ m. $\approx \frac{340\text{m}}{20} \approx 17\text{m}$.

Applications of Reflection of Sound (Echo)

1. Echo can be used to find out the velocity of sound in air.
2. The reflection of sound can be used in instruments like megaphone and in hearing aids.
3. The reflection of sound is used in sound boards and whispering galleries.
4. The reflection of sound is an important phenomenon used in SONAR, which is a special technique to find the depth of ocean beds.
5. Bats produce ultrasonics and can even sense their reflections from objects. With the help of this phenomenon, they can move even in darkness.

Determination of Velocity of Sound in Air by Echo Method

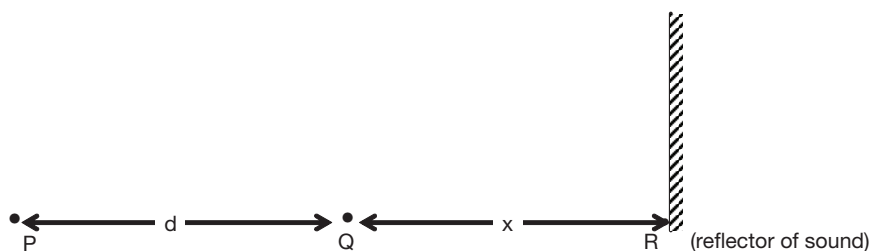


FIGURE 6.15 Determining the velocity of sound in air by echo method

Consider a person standing at position 'P' in the front of a wall (reflector of sound) (R). He produces a sound and hears the echo after 't₁' seconds. He then moves to a new position 'Q' towards the reflector by a distance 'd' in a direction normal to it. Now, he produces the sound again and hears the echo after 't₂' seconds.

If the velocity of sound in air is ' V ', then $V = \frac{2(d+x)}{t_1}$ and also $V = \frac{2(x)}{t_2}$

$$\therefore Vt_1 = 2d + 2x \text{ and } Vt_2 = 2x$$

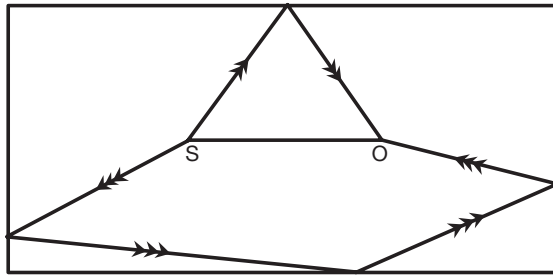
$$\therefore Vt_1 = 2d + Vt_2$$

$$\therefore V(t_1 - t_2) = 2d$$

or

$$V = \frac{2d}{t_1 - t_2}$$

Reverberation



S → Source of sound
O → Observer of sound

FIGURE 6.16 Reverberation

Consider a source and an observer of sound placed in a closed room as shown in Fig. 6.16. The observer hears the sound that travels not only directly from the source, but also indirectly from a series of reflections taking place at the walls of the room. So, the observer can hear the sound even after the source has stopped producing it due to multiple reflections taking place at the walls of the enclosure. This phenomenon is known as '**reverberation**'. Reverberations are often heard in empty halls, theatres and auditoriums.

Acoustics

Taking the effects of echo and reverberation into consideration in designing an auditorium and the interior of buildings is called acoustics. The time required to reduce the intensity of sound to one millionth of its initial value is called reverberation time. This time plays an important role in designing an auditorium. Generally a reverberation time of 0.5 is considered as optimum value for speeches whereas for good acoustic effect in a music hall, a reverberation time of 2 to 2.5 is taken into consideration. Reflecting surfaces like walls and ceiling are covered with good sound absorbing materials and the floor is carpeted. Curtains and sound absorbing hangings are also used for better acoustic effect.

Natural Vibrations

If a body is set into vibrations and allowed to vibrate on its own, the vibrations of the body are known as '**natural**' or '**free vibrations**'. The frequency with which the body vibrates is known as natural frequency and the corresponding time period is known as natural time period.

Examples:

1. The strings of musical instruments that vibrate freely when plucked.
2. Oscillating pendulum that is suspended freely.
3. A blade clamped at one end and plucked at the other end.
4. A tuning fork when hit by a rubber hammer.

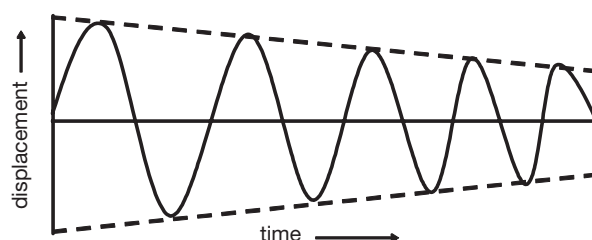


FIGURE 6.17 Displacement versus time graph for damped vibration

Damped Vibrations

When a pebble is thrown on the surface of still water, ripples are formed and these ripples travel in all possible directions. As the ripples move away from the source of disturbance, we observe that the amplitude of the waves decreases continuously and finally the wave vanishes. This 'damping' of the wave takes place because the medium itself absorbs the energy of the wave that is propagated in the medium.

The vibrations whose amplitude progressively decreases with time or with position or with both as the wave is propagated in a medium are called '**damped vibrations**'.

Examples:

1. When a simple pendulum is disturbed from its mean position and left alone, the amplitude of the pendulum decreases with time and eventually stops. These oscillations are damped oscillations.
2. If a blade is clamped at one end and plucked at the other end, the amplitude of the vibrating blade decreases with time. These vibrations of the blade are damped vibrations.
3. When the string of a musical instrument like veena or sitar is plucked once, the amplitude of the vibrations in the string progressively decreases with time.

Forced Vibrations

If a body is set into vibrations by the influence of another vibrating body or an external periodic force, the vibrations executed by the former are known as forced vibrations.

Examples:

1. The vibrations executed by the pendulum of a clock are forced vibrations as they are caused under the influence of a main spring which is wound.
2. Musical instruments with strings contain hollow sound boxes. When a string of an instrument like veena is plucked, the sound produced by the vibrating string causes the air in the sound box to vibrate at the same frequency as the string and a loud sound is heard. The vibrations of air in the sound box are forced vibrations.

RESONANCE

Consider two simple pendula 'A' and 'B' of different lengths ($\ell_A > \ell_B$) suspended from an elastic, rigid support like a thin rod as shown in Fig. 6.18. Since the natural frequency of a simple pendulum is inversely proportional to the square root of its length, the natural frequency of 'A' (n_A) is less than that of 'B' (n_B). When only pendulum 'B' is made to oscillate, we observe that after some time, pendulum 'A' also begins to oscillate under the influence of 'B'. So, vibrations of 'A' are forced vibrations. Now since 'A' is oscillating under the influence of 'B', it will oscillate with the frequency of 'B' and not with its own natural frequency.

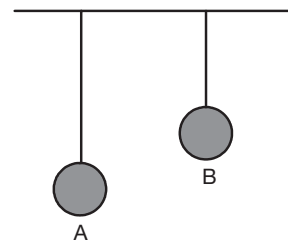


FIGURE 6.18 Two simple pendula of different lengths

Similarly, if 'B' is at rest and 'A' is set into oscillations, after some time, we observe that 'B' also oscillates with a frequency equal to the natural frequency of 'A' and not with its own natural frequency. So, here the oscillations of 'A' are free oscillations and those of 'B' are forced oscillations.

The forced oscillations take place due to the transfer of energy from one pendulum to another. If 'A' has forced oscillations, it will derive energy from 'B'. Since the natural frequencies of the two pendula are not equal, the transfer of energy from pendulum 'B' to pendulum 'A' is not maximum. This maximum transfer of energy from one pendulum to another takes place when their natural frequencies are equal, i.e., when the lengths of the two pendula are equal.

Consider two pendula 'C' and 'D' of equal length suspended from an elastic rigid support as shown in Fig. 6.19. As they have equal length, their natural frequencies are also equal. If one of them, say 'C' is set into oscillations, the other being at rest; the second pendulum 'D' too oscillates after sometime. The pendulum 'D' oscillates with the maximum possible amplitude because both C and D have the same natural frequency and so, energy transmitted from 'C' to 'D' is the maximum. This phenomenon is known as '**resonance**'.

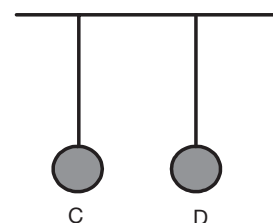


FIGURE 6.19 Two simple pendula of same length

Thus, resonance can be defined as "the phenomenon in which when one of the two bodies having confusing natural frequencies is set into vibration, then under its influence the other body also vibrates with increased amplitude".

Resonance in Sound Boxes

Consider two hollow boxes 'P' and 'Q' with one end open placed adjacent to each other, such that their open ends face each other. Two tuning forks 'A' and 'B' having equal frequencies

are fixed on boxes 'P' and 'Q', respectively. A pith ball suspended from a hook is in contact with the fork 'B' as shown in Fig. 6.20.

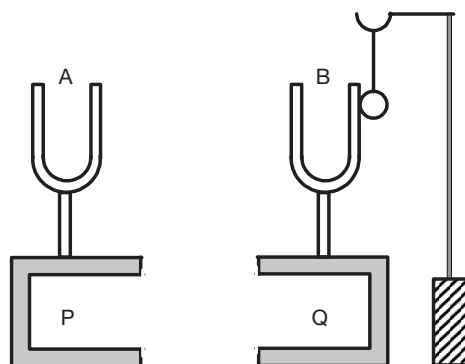


FIGURE 6.20 Apparatus to find resonance in sound boxes

When the fork 'A' is struck gently with a rubber hammer, it vibrates and after some time, we observe that the pith ball which is in contact with fork 'B' flies outward, indicating that fork 'B' too vibrates with maximum amplitude. At the same time, a loud booming sound is heard. This is due to the resonance between the two forks 'A' and 'B'.

The vibrations of the fork 'A' produce forced vibrations in the box 'P', which produce forced vibrations in the air in the box 'Q'. These vibrations of air lead to vibrations in the box 'Q' and through it to the fork 'B'. Since the two forks, 'A' and 'B' are of equal frequency, maximum energy transfer takes place, and thus, 'B' is in resonance with 'A'. The vibrations of 'B' which are forced vibrations and in resonance with those of 'A', are also known as '**sympathetic vibrations**'.

Conditions for Resonance

1. The vibrations of a body causing resonance should be strong enough to set forced vibrations in the other body.

Examples:

1. A single soldier marching on a rope bridge cannot cause sympathetic vibrations in the bridge, but a large group of soldiers marching to rhythmic steps on the bridge could cause the bridge to collapse.
2. The natural frequency of the given body (A) causing vibrations must be equal to either the natural frequency or an integral multiple of the natural frequency of the vibrating body (B).

Examples: The resonance in air columns takes place only at certain lengths of the air columns that correspond to the resonating lengths.

Resonance—Examples and Applications

1. We observe a rattling sound in a bus when the natural frequency of vibrations of the body of the bus equals the natural frequency of the vibrations of its engine. When the speed of the bus changes, the frequency of the vibrations of the engine changes.

When this frequency of the vibrations of the engine equals the natural frequency of the vibrations of the body of the bus, both are in resonance and the body of the bus vibrates with larger amplitude producing a rattling sound.

2. When a group of soldiers march across a rope bridge, they are asked to march out of step. This is because, when they march in step across the bridge, the natural frequency of the rhythmic marching of soldiers may become equal to the natural frequency of the vibrations in the bridge. If this happens, resonance takes place between the marching soldiers and the bridge which then vibrates with maximum amplitude leading to its collapse.
3. A wine glass kept before a loud speaker vibrates to the musical notes emitted by the speaker. When the frequency of the musical note is equal to the frequency of the vibrating wine glass, resonance takes place and the glass vibrates with larger amplitude. This may topple or even break the glass.
4. The basic principle involved in the transmission of radio and television programmes is resonance between the frequency of signals emitted from the station and the frequency of the radio or the television set. The resonance that takes place here is not of sound waves but of electromagnetic waves.

Resonance in Air Columns

Air Column

A long tube about 40 cm in length and 6 cm in diameter, open at both the ends or closed at one end forms an 'air column'. If it is open at both the ends, it is called an 'open end tube'. If it is closed at one end, it is called a 'closed end tube'.

Resonating Air Column

When a tuning fork is excited with a rubber hammer and is held at the open end of an air column such that the vibrating prongs are perpendicular to the length of the air column, as shown in Fig. 6.21, the air in the tube vibrates (forced vibrations). If the natural frequency of the air column matches with that of the tuning fork, a loud sound is produced. This happens as the vibrating air column is in resonance with the given tuning fork. The air column in this condition is known as 'resonating air column'.

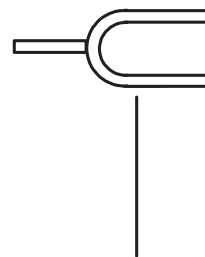


FIGURE 6.21 A tuning fork placed perpendicular to vibrating prongs

Closed End Resonating Air Column

Consider a long cylindrical glass jar of length of about 50 cm and 6 cm diameter, filled with water to more than $(3/4)$ th of its height as shown in the Fig. 6.22. Let a glass tube of smaller diameter (say 2 cm) and length approximately about 40 cm and open at both ends be inserted into the jar as shown in the Fig. 6.22. The length of the smaller tube above the water level in the jar can be adjusted, thus, varying the length of the air column above the water surface in the smaller tube.

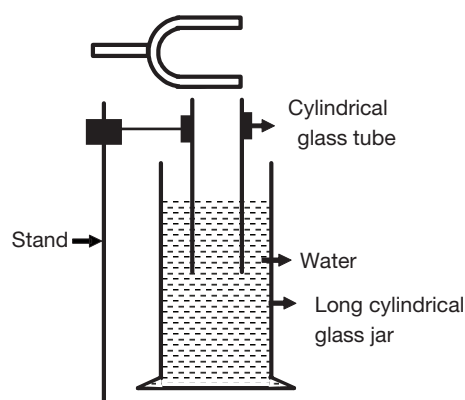


FIGURE 6.22 Closed end resonating air column

When a vibrating tuning fork is held horizontally above the open end of the smaller tube, it sets vibrations in the air in the tube, thus, producing forced vibrations in the air column. The other end of the smaller tube being immersed in water jar, the water surface acts as a reflecting surface to the waves set in the air column. Thus, the smaller tube acts as a closed end tube.

The compressions and rarefactions formed at the open end by the vibrating tuning fork travel towards the water surface, get reflected and again travel back towards the open end. So, the incident and reflected waves superpose each other to form stationary longitudinal waves in the air column. At the open end of the air column, the particles are free to vibrate. So, this end corresponds to a rarefaction. The closed end (water surface) is rigid and the air particles at this location are not free enough to vibrate longitudinally (along the length of the tube). So, at the closed end, a compression is formed.

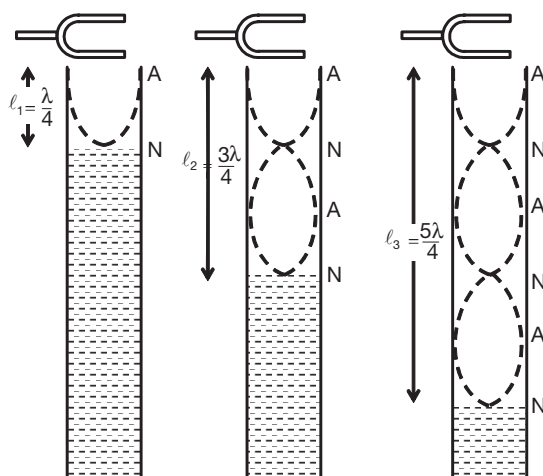


FIGURE 6.23 Resonating air columns

The length of the air column can be adjusted and when it is equal to $(\lambda/4)$ where ' λ ' is the wavelength of the sound wave, resonance occurs between the tuning fork and the air column. This can be confirmed by a loud (booming) sound heard. The length of the air column is the '**first resonating length**' of the air column. It is observed that resonance takes place

whenever the length of the air column is an odd integral multiple of ' $(\pi/4)$ '. The general expression for resonating length of an air column is given by,

$$\ell_n = \frac{(2n-1)\lambda}{4}$$

where $n = 1, 2, 3, \dots$. Thus, for a given tuning fork of a certain frequency, the resonating lengths of air column are

$$\text{1st resonating length, } \ell_1 = \frac{(2 \times 1 - 1)\lambda}{4} = \frac{\lambda}{4};$$

$$\text{2nd resonating length, } \ell_2 = \frac{(2 \times 2 - 1)\lambda}{4} = \frac{3\lambda}{4};$$

$$\text{3rd resonating length, } \ell_3 = \frac{(2 \times 3 - 1)\lambda}{4} = \frac{5\lambda}{4} \text{ and so on.}$$

When the reflection of a sound wave takes place at the water surface in the closed tube, phase change does not take place at the instant of reflection. Thus, a compression is reflected as compression and a rarefaction is reflected as rarefaction. As these reflected compressions or rarefactions reach the open end of the tube, phase change occurs. The reflected compression becomes rarefaction and the reflected rarefaction becomes compression on reaching the open end. This occurs due to the volume changes of air taking place in the tube.

As a reflected rarefaction reaches the open end, due to low pressure, some of the air is pushed into the tube making a compression. Similarly, as a reflected compression reaches the open end, due to excess pressure, some of the air is pushed out of the tube creating a rarefaction. When such a rarefaction reaches the mouth of the tube, another rarefaction is produced by the tuning fork at the mouth, therefore, these two rarefactions superpose giving the maximum amplitude and an antinode is formed at the mouth of the tube.

Similarly, when a compression reaches the mouth of the tube, another compression is produced by the tuning fork at the mouth of the tube, therefore, these two compressions superpose giving the maximum amplitude, and so, an antinode is formed at the mouth of the tube.

Thus, "whenever resonance occurs between the vibrating air column and the tuning fork, an antinode is formed at the mouth of the tube and a node is formed at the closed end of the tube".

Resonance—Velocity of Sound in Air

Consider the glass jar and the glass tube shown in Fig. 6.22. Hold a vibrating tuning fork of frequency ' n ' horizontally over the mouth of the tube, having an air column of less than 10 cm. Gradually, increase the length of the air column by raising the tube and at one particular length of the air column, say ' ℓ_1 ', we hear a booming sound indicating that the length ' ℓ_1 ' of the air column is in resonance with the given tuning fork.

This is the first resonating length, therefore, $\ell_1 = \frac{\lambda}{4}$. On further increasing the length of the air column, holding the vibrating tuning fork at the mouth of the tube, we get another

booming sound for the air column of length, say ' ℓ_2 ' such that this is the second resonating length of the air column. So, $\ell_2 = \frac{3\lambda}{4}$.

Thus,
$$\ell_2 - \ell_1 = \frac{3\lambda}{4} - \frac{\lambda}{4} = \frac{2\lambda}{4} = \frac{\lambda}{2} \therefore \lambda = 2(\ell_2 - \ell_1).$$

If ' n ' is the frequency of the tuning fork, and ' v ' is the velocity of sound in air, we have $v = n\lambda = n_2(\ell_2 - \ell_1) \therefore v = 2n(\ell_2 - \ell_1)$. From the above expression, we can find out the velocity of sound in air at room temperature.

Resonance in Open Organ Pipe

Resonance of sound can take place in open organ pipes also. An open organ pipe is a tube with both ends open, and in this case both the ends correspond to antinodes. For fundamental frequency one node is formed at the centre of the pipe and the length of the tube (ℓ) corresponds to half the wavelength, being the distance between two consecutive antinodes.

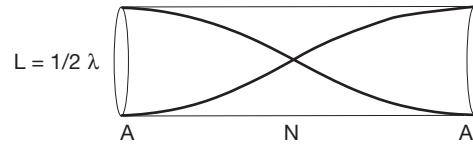


FIGURE 6.24 Resonance in open organ pipe

Thus, we have

$$\ell = \frac{\lambda}{2} \text{ or } \lambda = 2\ell$$

Since $v = \nu\lambda$,

$$v = \frac{\nu}{\lambda} = \frac{\nu}{2\ell}$$

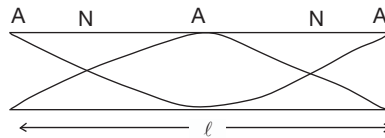


FIGURE 6.25 First overtone in open organ pipe

This frequency is called the 'fundamental' frequency and is denoted as $\nu_o = \frac{v}{2\ell}$.

For the first overtone or second harmonic, two nodes are formed inside the tube. In this case the length of the tube corresponds to λ , the wavelength, as shown in the Fig. 6.25.

$\therefore \ell = \lambda$ and
$$\nu_1 = \frac{v}{\ell} = 2\nu_o$$

Hence, ν_1 , the frequency of the first overtone is twice the fundamental frequency, ν_0 .

The second overtone or the third harmonic is produced when three nodes are formed inside the tube as shown. A total of four antinodes are formed such that ℓ , the length of the tube corresponds to $(3\lambda/2)$. Thus, we have

$$\ell = \frac{3\lambda}{2} \text{ or } \lambda = \frac{2\ell}{3}$$

and

$$\nu_2 = \frac{\nu}{\lambda} = \frac{3\nu}{2\ell} = 3\nu_0$$

Therefore, frequency of the second overtone is thrice the fundamental frequency.

Thus, the frequencies in an open organ pipe are in the ratio $1 : 2 : 3$ indicating that all harmonics are present, whereas in a closed-end pipe the ratio of the frequencies is $1 : 3 : 5 \dots$ showing that only the odd harmonics are present.

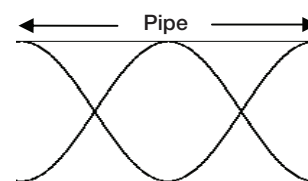


FIGURE 6.26 Second overtone in open organ pipe

Vibrations in Stretched Strings

A string is a thin wire or a thread which is inextensible. When such a string is stretched by applying a force that acts along the length of the wire, the force applied is known as 'tensile force' or 'tension'. When a stretched wire is plucked, stationary waves perpendicular to its length are produced.

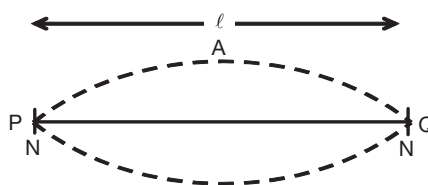


FIGURE 6.27 Stationary waves in strings; string vibrating in fundamental mode

Consider a string stretched between two points 'P' and 'Q'. When the string is plucked at the middle, a transverse stationary wave is set up in the string with nodes (N) at the fixed end points 'P' and 'Q' and an antinode (A) at the middle of the string, as shown in the Fig. 6.27.

The distance between two successive nodes or antinodes in a stationary wave is equal to half the wavelength $\left(\frac{\lambda}{2}\right)$. If ' ℓ ' is the length of the vibrating string between the fixed ends 'P' and 'Q', then $\ell = \frac{\lambda}{2}$ or $\lambda = 2\ell$. If ' n ' is the frequency of vibration and ' ν ' is the velocity of the wave set in the string then, $\nu = n\lambda \Rightarrow \nu = n(2\ell)$.

But the velocity of the wave set in the string is given by,

$$v = \sqrt{\frac{T}{m}}$$

where ' T ' is the tension in the string and ' m ' is mass per unit length (linear density) of the string.

$$\therefore \sqrt{\frac{T}{m}} = n(2\ell)$$

or

$$n = \frac{1}{2\ell} \sqrt{\frac{T}{m}} \quad (6.3)$$

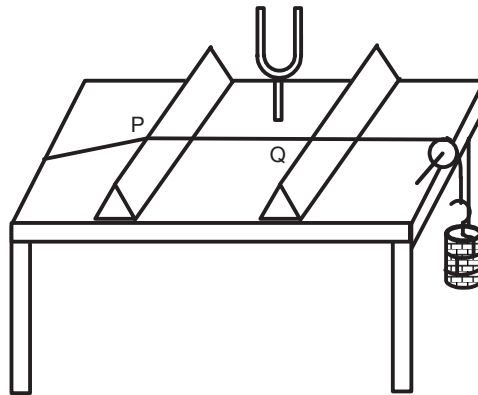


FIGURE 6.28 Vibrations in stretched strings by a tuning fork

If the string described above is considered to be placed on a table and stretched between two fixed points ' P ' and ' Q ' and a vibrating tuning fork of frequency ' n ' is kept in between the fixed points ' P ' and ' Q ' as shown in Fig. 6.28, resonance takes place in the stretched string between ' P ' and ' Q ', and the tuning fork. A stationary wave is set up in the string as shown in Fig. 6.27. Then the length ' ℓ ' of the string between the fixed points ' P ' and ' Q ' is called the resonating length.

This resonating length of the string is said to be vibrating in fundamental mode and the corresponding frequency of the vibrating string, given by,

$$n = \frac{1}{2\ell} \sqrt{\frac{T}{m}},$$

is known as the fundamental frequency or first harmonic.

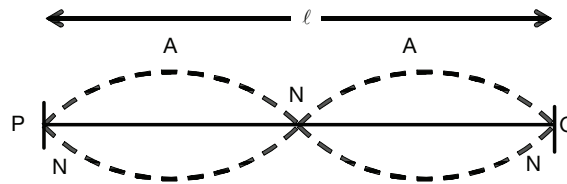


FIGURE 6.29 String vibrating in second harmonic

The length ' ℓ ' of the stretched string is found to be in resonance with another higher frequency ' n_1 ' with the tension (T) and linear density (m) being constant. Then, the string is found to be vibrating in two segments, with two antinodes (A) and three nodes (N) as shown in Fig. 6.29. Then, the length of the vibrating stretched string is $\ell = \lambda$ and so frequency.

$$n_1 = \frac{1}{\ell} \sqrt{\frac{T}{m}} = \frac{2}{2\ell} \sqrt{\frac{T}{m}} = 2 \left(\frac{1}{2\ell} \sqrt{\frac{T}{m}} \right) = 2n \quad (6.4)$$

So, this frequency ' n_1 ' is double the fundamental frequency and is called 'second harmonic' or 'first overtone'. We get similar resonating lengths whenever length of the string

$$\ell = \frac{K\lambda}{2}$$

where $K = 1, 2, 3 - - -$.

So, the corresponding frequencies obtained are tabulated as follows.

Value of P	Length of string (ℓ)	Wavelength (λ)	Frequency	Number of loops	Description of frequency
1.	$\frac{\lambda}{2}$	$\frac{2\ell}{1}$	$n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$	One	Fundamental frequency or 1st harmonic
2.	$\frac{2\lambda}{2}$	$\frac{2\ell}{2}$	$n_1 = \frac{1}{\ell} \sqrt{\frac{T}{m}}$ $= \frac{2}{2\ell} \sqrt{\frac{T}{m}} = 2n$	Two	2nd harmonic or 1st overtone
3.	$\frac{3\lambda}{2}$	$\frac{2\ell}{3}$	$n_2 = \frac{1}{\left(\frac{2\ell}{3}\right)} \sqrt{\frac{T}{m}}$ $= \frac{3}{2\ell} \sqrt{\frac{T}{m}} = 3n$	Three	3rd harmonic or 2nd overtone
K	$\frac{K\lambda}{2}$	$\frac{2\ell}{K}$	$n_{k-1} = \frac{K}{2\ell} \sqrt{\frac{T}{m}}$ $= Kn$	K	Kth harmonic or (K-1)th overtone

LAWS OF VIBRATING STRETCHED STRINGS

The expression for the fundamental frequency of a stretched vibrating string is given by,

$$n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}.$$

From this, three laws are derived for the frequency of a vibrating stretched string and are as follows.

1. **Law of length:** The frequency of a vibrating stretched string, vibrating in a fundamental mode, is inversely proportional to its length, when its tension and linear density are constant. Mathematically, $n \propto \frac{1}{\ell}$ when ' T ' and ' m ' are constant. $\Rightarrow n\ell = \text{constant}$.

If ' ℓ_1 ' and ' ℓ_2 ' are the lengths of two strings vibrating in the fundamental frequency having their linear density and tension constant and ' n_1 ' and ' n_2 ' are their fundamental frequencies, respectively, then $n_1 \ell_1 = n_2 \ell_2$

2. **Law of tension:** The frequency of a vibrating stretched string, vibrating in a fundamental mode, is directly proportional to the square root of its tension, when length and linear density remain constant. Mathematically, $n \propto \sqrt{T}$, when ' ℓ ' and ' m ' are constant.

$$\Rightarrow \frac{n}{\sqrt{T}} = \text{constant}.$$

If ' T_1 ' and ' T_2 ' are the tensions of two strings whose length and linear density are constant and vibrating in the fundamental mode and ' n_1 ' and ' n_2 ' are their fundamental frequencies, respectively, then $\frac{n_1}{\sqrt{T_1}} = \frac{n_2}{\sqrt{T_2}}$.

3. **Law of linear density:** The frequency of a vibrating stretched string, vibrating in a fundamental mode, is inversely proportional to the square root of its linear density, when its length and tension are constant. Mathematically, $n \propto \frac{1}{\sqrt{m}}$ when ' ℓ ' and ' T ' are constant.

$$\Rightarrow n\sqrt{m} = \text{constant}.$$

If ' m_1 ' and ' m_2 ' are the linear densities of two strings vibrating in fundamental mode having equal length and tension and ' n_1 ' and ' n_2 ' are their fundamental frequencies, respectively, then $n_1\sqrt{m_1} = n_2\sqrt{m_2}$.

SONOMETER

It is a hollow wooden box about one metre long on which a peg is fixed at one end and a smooth frictionless pulley is fixed at the other end on the top surface which is also called as a sonometer table as shown in the Fig. 6.30. Wedge-shaped wooden pieces known as bridges are placed on the table and they are movable. At one end of the Sonometer table, along its length, a metre scale is fixed. A string is tied at one end to the peg and other end is passed over the two

bridges and the pulley, and attached to a weighted hanger. The weights attached to the hanger provide tension in the string. On the lateral walls of the sonometer box, holes are provided.

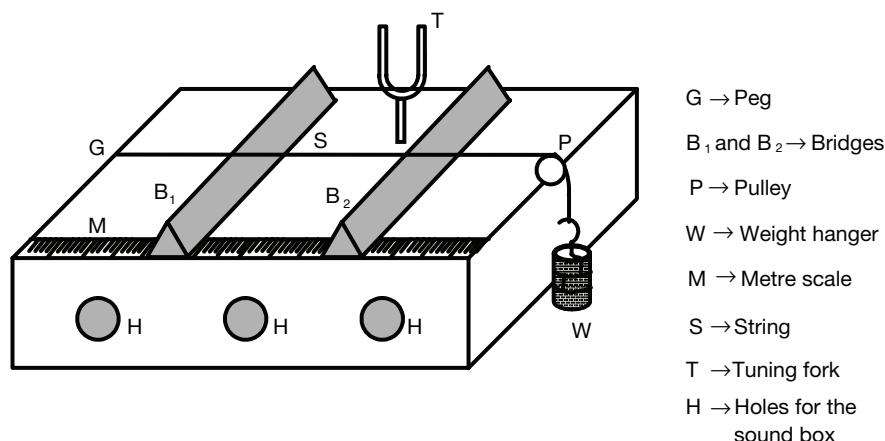


FIGURE 6.30 Sonometer

Sonometer is used to verify the laws of transverse vibrations in a stretched string. Excite a tuning fork of frequency ' n_1 ' and keep it on the sonometer table between the bridges as shown in Fig. 6.30. Adjust the distance between the bridges to change the length of the vibrating string between the bridges. At a particular length, say ' ℓ_1 ', the wire between the bridges vibrates with maximum amplitude and this can be confirmed by the flying away of a small paper rider of light weight and inverted V -shape (Δ) placed on the string between the bridges. Then, the length ' ℓ_1 ' of the wire is in resonance with the tuning fork. The procedure is repeated by taking another tuning fork of frequency ' n_2 ' and the resonating length ' ℓ_2 ' is obtained. The first law of vibrating stretched strings is verified by showing $n_1 \ell_1 = n_2 \ell_2$. Similarly, other two laws of vibrating stretched string can also be verified.

MUSIC AND NOISE

Sound that causes a pleasing sensation to ears is called music. Sound that causes an unpleasant or irritating sensation to ears is called noise. A sound cannot be strictly classified into either music or noise, as a sound that causes a pleasing sensation to one person can cause an unpleasant sensation to another person. But based on certain characteristics, we can broadly classify any sound note into either music or noise.

Characteristics of Musical Sound

Pitch

It is a special characteristic of sound based on which we can differentiate between two sounds having equal loudness. The pitch of a given sound can be measured by its frequency.

Example: Female voices in general are high pitched compared to male voices though both the female voice and the male voice may have equal loudness.

Intensity

Intensity is a measure of loudness of sound. It is defined as the energy that passes through unit area per unit time.

The following are the factors on which the intensity of sound depends.

- 1. Amplitude:** The intensity of a sound wave varies directly as the square of its amplitude. Mathematically, intensity (I) $\propto$ (amplitude)².
- 2. Distance from source:** The intensity of a sound wave varies inversely as the square of the distance of the point of observation from the source.

$$\text{Mathematically, intensity } (I) \propto \frac{1}{(\text{distance})^2}$$

- 3. Density:** The intensity of a sound wave varies directly as the density of the medium through which it is propagated.

$$\text{Mathematically, intensity } (I) \propto \text{density } (\rho).$$

NOTE

The intensity level of sound is measured in units of decibels (dB).

A normal human being can bear sound having an intensity level of maximum 80 dB. Sounds having intensity level less than 10 dB and more than 180 dB are inaudible.

Quality or Timbre

The quality or the timbre of a musical sound is a special characteristic by means of which two sounds having equal pitch or loudness can be differentiated. Two musical notes having equal loudness and pitch, one originating from one instrument, say veena; and the other produced from another instrument, say violin; can be identified separately even though they are produced simultaneously. The wave form of the sound note produced signifies its quality.

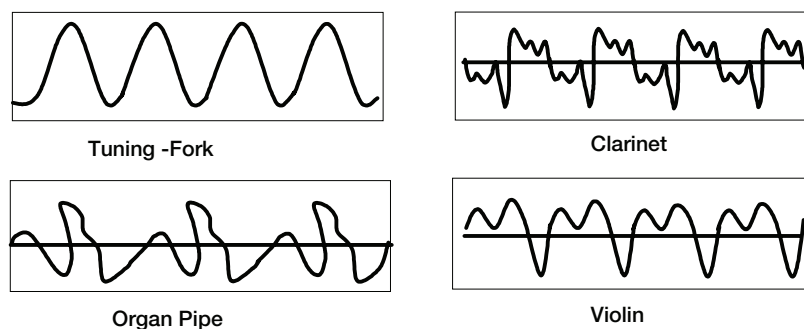


FIGURE 6.31 Quality of a sound by different musical instruments

Differences between Music and Noise

- 1.** Music produces a pleasing effect whereas noise produces an irritating effect in our ears.
- 2.** Music has variations in amplitude or frequency at regular intervals of time whereas in noise, the variations in amplitude or frequency are abrupt.
- 3.** Musical sound has a definite waveform which repeats itself at regular intervals of time; whereas noise does not have any regular or definite waveform.

Drum

It is an instrument that produces sound by vibrating membrane. It is a hollow cylindrical box to which the processed skin of animals (leather) is attached at sides like a membrane. The membranes are stretched and then excited at any point on the membrane to produce sound.

Bell

A cone shaped metallic object, which produces sound when excited is known as a bell. It has a complex mode of vibration. When a bell is struck at its edge, it is divided into an even number of vibrating sectors and it produces transverse stationary waves.

Pollution Due to Noise

Noise, in general, disturbs the regular work. It causes strain, irritation, etc. Thus, noise is undesirable and uncomfortable and can be considered as a pollution.

The undesirable un audible, harsh and irritating sound produced in the surroundings is called noise pollution. The noise which can be called pollution depends on its (1) loudness (2) duration.

Effects of Noise Pollution

1. It disturbs the normal work, conversations.
2. It produces irritation, strain, headache, etc.
3. Very loud noise may cause temporary or permanent deafness.
4. Noise may also create night blindness and colour blindness.

Sources of Noise Pollution

Grinders, mixers, vacuum cleaners using at home, loud speakers, exploding crackers in various functions, hawkers in streets, various machines used in factories create a large amount of noise in our surroundings. Along with these, various transportation means such as trains, buses, air crafts, etc., also create noise pollution.

Controlling of Noise Pollution

Nowadays, in modern society, it is not easy to eliminate the noise pollution but by taking some measures and precautions, it can be decreased. Various means that can be followed are:

1. The volume levels of various audio, video systems should be lowered, as much as possible.
2. The factories and various industries should be established very far from residential areas.
3. It is better to ban the various musical entertainments in public places.
4. The vehicles that produce loud sound should not be allowed in residential areas.
5. All machines, automobiles, generators, motors should be designed in such a way that less noise is produced.

Recording and Reproduction of Sound

Sound can be recorded and can be reproduced, when it is desired. Microphone is an instrument which can convert sound vibrations into electrical signals. These electrical signals can be converted back to sound by using loud speakers. The recording of sound can be done either on magnetic tapes or photosensitive films.

Recording and Reproduction of Sound by Using Magnetic Tapes

The tape is very thin, flexible and usually made of polyvinyl chloride. One side of it is coated with ferric oxide (Fe_2O_3) paste. Before recording any sound, the molecules of magnetic paste align such that the net magnetic moment is zero.

Sound Recording

The major part of the sound recording equipment is the recording head. Recording head is a soft iron ring having a narrow gap. It is wound by an insulated conducting wire. The two ends of which are connected to an amplifier which in turn is connected to a microphone. The unrecorded magnetic tape is made to run in front of the narrow gap of recording. Microphone converts the sound vibrations created in front of it into electrical signals which are amplified by the amplifier.

When these signals are made to pass through the wire wound around the recording head, it acts as an electromagnet. Because of the varying electrical signals the magnetic field created in the narrow gap also varies and accordingly the molecules of ferric oxide realign. The amount of realignment depends on the strength of magnetic field produced.

Sound Reproduction

In sound reproduction process equipment, the major part is playback head which is similar to the recording head used in the recording process. The ends of insulated conducting wire wound around the play back head is connected to loud speaker through an amplifier. During the reproduction the recorded tape is made to run in front of the narrow gap of the playback head. The varying magnetic impressions recorded on the tape create a varying magnetic field in the gap of the head. This produces electrical signals in the wire wound around the head. These signals are amplified by amplifier and sent to a loud speaker which converts electric signals into sound vibrations.

Recording and Reproduction of Sound by Using Films

The sound is recorded on the photosensitive film in the form of zigzag patches called sound track. In this method a phosphor-bronze loop is suspended between the concave poles a magnet. The loop is attached by a small mirror. The mirror reflects the light coming from an intense source towards a narrow slit behind which the photosensitive film is made to run at constant speed.

The sound to be recorded is converted into electrical signals by a microphone and is passed through a phosphor-bronze loop. Due to these signals, the loop and the mirror deflect in

different orientations. Depending on the amount of deflection of the mirror a zigzag patch of different widths are formed on the film.

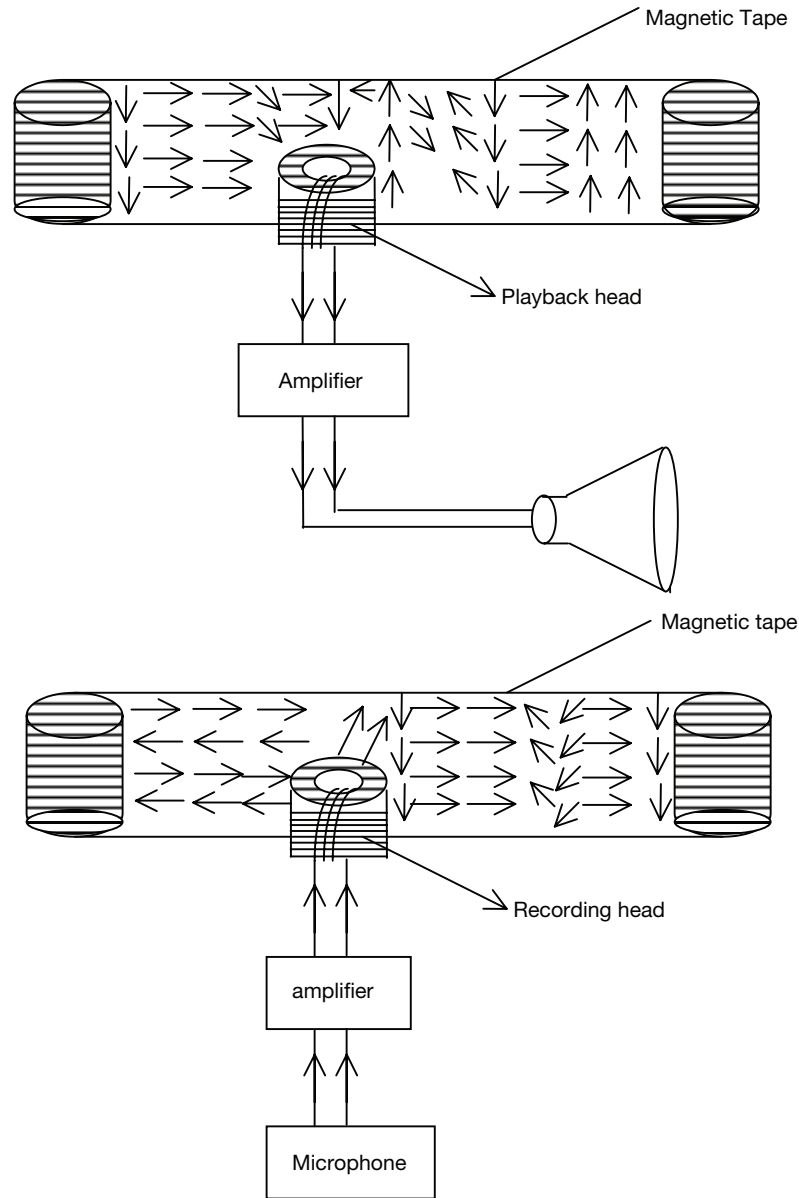


FIGURE 6.32 Recording and reproduction of sound by using films

Sound Reproduction

The sound track is exposed to the light coming from an intense source after passing through a converging lens system. The emergent light is allowed to fall on a photo cell, which works on the principle of photo electric effect. Because of variations in the intensity of light emerging from film, photo cell produces varying electric signals. These are converted into sound by using a loud speaker.

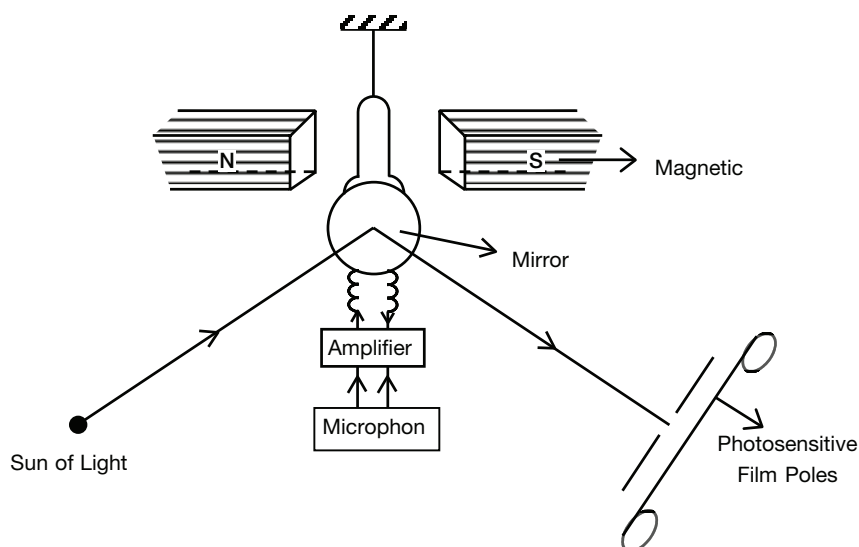


FIGURE 6.33 Sound reproduction

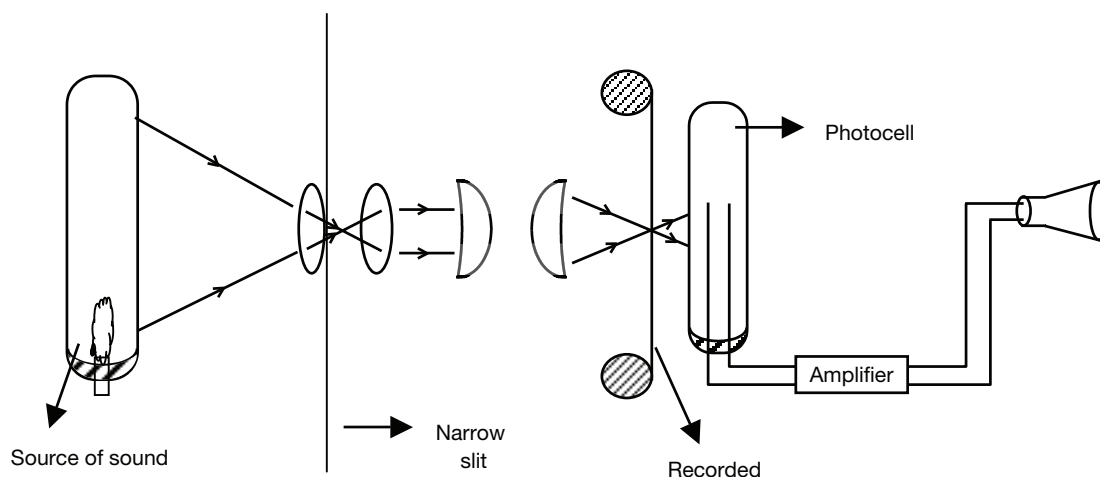


FIGURE 6.34 Sound reproduction in a loudspeaker

EXAMPLE

The ratio of specific heat at constant pressure to that at constant volume (γ) of a gas is 1.5. Its density is $2 \times 10^{-3} \text{ g cm}^{-3}$. Whereas its pressure is to 80 cm of Hg column. Find out the velocity of sound in the gas (taking $g = 1000 \text{ cm s}^{-2}$).

SOLUTION

$$\gamma = 1.5$$

$$P = 80 \text{ cm of Hg}$$

$$= 80 \times 13.6 \times 1000$$

$$= 1088 \times 10^3 \text{ dynes cm}^{-2}$$

$$d = 2 \times 10^{-3} \text{ g cm}^{-3}$$

$$\begin{aligned}
 \text{Velocity of sound in gas, } V &= \sqrt{\frac{\gamma P}{d}} \\
 &= \sqrt{\frac{1.5 \times 10^8 \times 10^3}{2 \times 10^{-3}}} \\
 &= 28.5 \times 10^3 \text{ cm s}^{-1} \\
 &= 285 \text{ m s}^{-1}
 \end{aligned}$$

EXAMPLE

The Young's modulus of a solid is given by, 6.25×10^{11} dynes cm^{-2} . If the velocity of sound in the solid is 2500 m s^{-1} , find its density.

SOLUTION

Velocity of sound in a solid

$$V = \sqrt{\frac{Y}{d}}$$

$\Rightarrow$ density,

$$\begin{aligned}
 d &= \frac{Y}{V^2} = \frac{6.25 \times 10^{11}}{(250000)^2} \\
 &= \frac{6.25 \times 10^9}{625 \times 10^8} = 10 \text{ g cm}^{-3}
 \end{aligned}$$

EXAMPLE

The velocity of sound in oxygen is at STP 100 m s^{-1} . Find the velocity of sound in hydrogen.

SOLUTION

Velocity of sound in a gas,

$$V \propto \frac{1}{\sqrt{\text{Molecular weight } M}}$$

$$\frac{V_1}{V_2} = \sqrt{\frac{M_2}{M_1}}$$

$$\frac{V_{H_2}}{V_{O_2}} = \sqrt{\frac{M_{O_2}}{M_{H_2}}} = \sqrt{\frac{32}{2}} = \sqrt{16} = 4.$$

$$\begin{aligned}
 V_{H_2} &= 4 \times V_{O_2} \\
 &= 4 \times 100 = 400 \text{ m s}^{-1}
 \end{aligned}$$

EXAMPLE

A person standing at a distance 200 m from a hill blows a horn. After what time can he hear the echo? (Given that the velocity of sound in air is 300 ms^{-1}).

SOLUTION

Let ' d ' be the distance of reflector from the source. Then, reflector, $V = \frac{2d}{t}$
' t ' is time taken to receive the echo.

$$\therefore t = \frac{2d}{v} = \frac{2 \times 200}{300} = \frac{400}{300} = \frac{4}{3} \text{ s} = 1.33 \text{ s}$$

EXAMPLE

A person, trying to determine the velocity of sound in air by the echo method, produces a sound at a certain time and hears the echo after 10 seconds. If the reflector is at a distance of 1700 m, find the velocity of sound in air.

SOLUTION

Velocity of sound, $V = \frac{2d}{t} = \frac{2 \times 1700}{10}$

$$= \frac{3400}{10} = 340 \text{ m s}^{-1}$$

EXAMPLE

In a resonating air column method, the first and second resonating lengths are recorded as 25 cm and 75 cm, respectively. If the velocity of the sound in air is 300 m s^{-1} , find the frequency of the tuning fork used.

SOLUTION

$$v = 300 \text{ m s}^{-1}$$

$$\ell_1 = 25 \text{ cm} = 0.25 \text{ m}$$

$$\ell_2 = 75 \text{ cm} = 0.75 \text{ m}$$

$$v = 2n(\ell_2 - \ell_1)$$

$$n = \frac{v}{2(\ell_2 - \ell_1)} = \frac{300}{2(0.75 - 0.25)} = \frac{300}{2 \times 0.5}$$

$$= \frac{300}{\ell} = 300 \text{ Hz.}$$

EXAMPLE

In a sonometer experiment, the mass suspended from the string is 1 kg. The resonating length for a given tuning fork is noted as 20 cm. If the mass suspended is increased to 4 kg, find the resonating length of the string for the same frequency.

SOLUTION

In a stretched string,

$$n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$$

Since the frequency ' n ' and linear mass density ' m ' are constant;

$$\frac{\sqrt{T}}{\ell} = \text{constant}$$

$$\text{i.e. ,} \quad \frac{\sqrt{T_1}}{\ell_1} = \frac{\sqrt{T_2}}{\ell_2} \quad (1)$$

$$T_1 = 1 \text{ kg} \times 10 = 10 \text{ N}, \ell_1 = 20 \text{ cm}$$

$$T_2 = 4 \text{ kg} \times 10 = 40 \text{ N } \ell_2 = ?$$

From (1), we have

$$\frac{\ell_2}{\ell_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{40}{10}} = \sqrt{4} = 2$$

$$\ell_2 = 2 \ell_1 = 2 \times 20 = 40 \text{ cm}$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Define echo.
2. What are forced vibrations? Give an example.
3. In resonance, the body undergoing forced vibrations vibrates with _____ amplitude.
4. What is meant by the fundamental frequency of a vibrating stretched string?
5. How does humidity in air affect the velocity of sound in it?
6. What is the expression for the velocity of sound in air using resonating air column method?
7. How does the intensity of sound vary with its amplitude and density of a medium?
8. The energy carried by a progressive wave is the sum of _____ and _____ of the vibrating particles of the medium.
9. Define audible range of frequencies.
10. What are damped vibrations? Give an example.
11. Define transverse and longitudinal waves.
12. When a tuning fork of 512 Hz is used, the first and the second resonating lengths of closed air column are obtained as 16 cm and 48 cm, respectively. What is the velocity of sound in air in metre per second?
13. What is the characteristic of sound that distinguishes between two sounds of equal amplitude and frequency?
14. What is the expression for the velocity of a stationary wave set in a stretched string?
15. Define progressive and stationary waves?
16. What are infrasonics and ultrasonics?
17. The time taken to reduce the intensity of sound to _____ of the initial value is called reverberation time.
18. What is resonating air column?
19. Mention Newton's formula for the velocity of sound in a medium, and Laplace correction to Newton's formula.
20. What is the pitch of a sound?
21. How does the intensity of sound vary with the distance of the point of observation from the source of sound?
22. What is the principle used in a mega-phone?
23. How does the velocity of sound in a gas vary with its absolute temperature?
24. Define reverberation.
25. Hertz is the unit of _____.
26. How many antinodes are obtained when a closed end resonating air column vibrates in the fundamental mode?
27. How does the velocity of sound in a gas vary with its molecular weight, and pressure?
28. If the fundamental frequency of a vibrating stretched string is 200 Hz, what are frequencies of its 1st and 2nd overtones?
29. What are natural vibrations? Give an example.
30. By changing either the wavelength or the frequency of a sound wave, is it possible to change the velocity of sound in a medium?

Short Answer Type Questions

31. Explain resonance with an example.
32. A string is stretched by a tension of 200 N. If its linear density is $2 \times 10^{-2} \text{ kg m}^{-1}$, what is the velocity of waves set in the string?
33. Explain the formation of stationary waves in a stretched string.
34. In a resonating air column method, the first and the second resonating air columns are 16 cm and 48 cm, respectively. If the frequency of a tuning fork used is 500 Hz, find the velocity of sound in air.
35. The first resonating length of a closed end air column is 30 cm. At approximately, what length of the air column, do we obtain the second resonance?
36. Differentiate between progressive and stationary waves.



37. The fundamental frequency of an air column in a closed end tube is 30 Hz. Find the frequency of the third harmonic.
38. If the velocity of sound in air is 300 m s^{-1} , express the audible range in terms of wavelength.
39. Explain the factors on which the velocity of sound in a given gas depends.
40. The velocity of the sound in a gas is 300 m s^{-1} . The density of gas and the ratio of specific heats of gas are given by, 0.002 g cm^{-3} and 2, respectively. Find the pressure of the gas.
41. If the velocity of sound in air is 330 m s^{-1} , what is the minimum distance between the source or the observer of sound and the reflector to hear an echo?
42. What are the factors which do not affect the velocity of sound in a gas?
43. The molecular weights of two gases A and B are given as 36 units and 16 units, respectively. If the velocity of sound in gas A is 300 m s^{-1} , find the velocity of sound in B.
44. The velocity of sound in a gas at 0°C is $x \text{ m s}^{-1}$. At what temperature of the gas, does the velocity of sound become $2x \text{ m s}^{-1}$?
45. How do you determine the velocity of sound in air using an echo?

Essay Type Questions

46. Explain the formation of transverse stationary waves in stretched strings and their different modes of vibrations.
47. Explain resonance in sound boxes.
48. Explain resonance in air columns.
49. Explain the laws of transverse vibrations in stretched strings.
50. Describe an experiment to find out the velocity of sound in air using resonating air columns.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

1. The frequency of a note produced by a stretched string is directly proportional to the square root of linear mass density of the string.
2. The phenomenon of resonance is used in receiving the radio and television programmes.
3. In order to transmit sound waves, the medium should possess elasticity and inertia.
4. In simple harmonic motion, the acceleration is inversely proportional to the displacement of the body from its mean position.
5. The frequency of damped vibrations remains same but the amplitude decreases gradually.
6. In a standing wave, the amplitude is maximum at nodes.
7. In an open pipe, the pressure variation at the ends of the pipe is maximum.

Direction for questions 8 to 14:

Fill in the blanks.

8. At a given temperature, the velocity of sound in hydrogen is _____ than its velocity in oxygen.
9. γ is the ratio of molar specific heat capacity of the given gas at constant _____ to its specific heat capacity at constant _____.
10. The pitch of a given sound can be measured by its _____.
11. The pitch of the sound produced by a stretched string gets higher as the tension _____.
12. In a standing wave, the distance between two successive antinodes is 15 cm. The distance covered by it in producing 4 waves is _____ m.
13. A rope is vibrating with a frequency 20 Hz . If the velocity of the wave in the rope is 20 m s^{-1} , then the distance between a crest and the successive trough is _____.
14. If d is the distance between the source of sound and reflector, t_1 , t_2 are times at which first two echoes are heard, the expression for determination of velocity of sound in air by echo method is _____.



Direction for question 15:

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

15.

Column A	Column B
A. Elastic waves	() a. nodes and antinodes
B. Infrasonic sound waves	() b. reflection of sound waves
C. Phase	() c. laws of transverse vibrations in a stretched string
D. Stationary waves	() d. water waves
E. SHM	() e. Sound track
F. Newton's formula	() f. frequency less than 20 Hz
G. Whispering galleries	() g. measured in radians
H. Damped vibrations	() h. Isothermal change
I. Sonometer	() i. constant time period
J. Photosensitive films	() j. decrease in amplitude

Direction for questions 16 to 40:

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

16. A man moving towards a vertical cliff at a constant velocity of $u \text{ m s}^{-1}$, fires a gun and hears the echo after $t \text{ s}$. If he was at a distance of $d \text{ m}$ from the cliff when he fired the gun, the velocity of sound in air is _____ m s^{-1} .
- (a) $\frac{2d}{t}$ (b) $\frac{2d}{t} + u$
- (c) $\frac{2d}{t} - u$ (d) $\frac{d}{t}$
17. For a body executing simple harmonic motion,
- (a) acceleration of the body is always directed towards the mean position.
- (b) acceleration of the body directly proportional to the displacement from the mean position.
- (c) the total mechanical energy is constant at any point in its path.
- (d) All the above

18. In a resonating air column, the first booming sound is heard when the length of air column is 10 cm. The second booming sound will be heard when length is about
- (a) 20 cm (b) 30 cm
- (c) 40 cm (d) None of the above
19. The general expression for the resonating length of an air column in organ pipes with one end closed is given by, _____.
- (a) $\frac{(2n-1)\lambda}{2}$ (b) $\frac{n\lambda}{4}$
- (c) $\frac{(2n-1)\lambda}{4}$ (d) $\frac{(n+1)\lambda}{2}$
20. If the amplitude of a sound is doubled, then its
- (a) velocity is doubled
- (b) frequency is doubled
- (c) wavelength is doubled
- (d) None of the above
21. In a resonating air column, the second resonating length is 60 cm. The first resonance occurs when the length of the air column is _____ cm.
- (a) 30 (b) 10
- (c) 20 (d) 60
22. In a closed end organ pipe, if ℓ_1 and ℓ_2 are two successive resonating lengths, then $2(\ell_2 - \ell_1)$ is _____.
- (a) $\frac{\lambda}{2}$ (b) λ
- (c) 2λ (d) None of these
23. In a stationary wave,
- (a) energy is carried away throughout the infinite medium
- (b) energy is confined to a limited region of the medium
- (c) different particles in a loop have different amplitudes
- (d) Both (b) and (c)



24. The energy of the wave that passes through unit area per unit time is called as _____.
 (a) pitch (b) quality
 (c) intensity (d) amplitude
25. If the velocity of sound in a gas is 200 m s^{-1} when the temperature is 127°C , then the velocity of sound in the same gas when temperature is increased by 900 K is _____ m s^{-1} .
 (a) $200\sqrt{3}$ (b) 300
 (c) $100\sqrt{5}$ (d) 450
26. A normal human being can hear sound having an intensity level of maximum _____.
 (a) 50 dB (b) 80 dB
 (c) 100 dB (d) 150 dB
27. The ratio of densities of two media is $5 : 2$. Then, the ratio of intensities of a given sound wave in the two media is
 (a) $25 : 4$ (b) $2 : 5$
 (c) $5 : 2$ (d) $1 : 1$
28. If the tension in a string is doubled and its linear density is halved, then the velocity of the wave in the string
 (a) is quadrupled (b) is halved
 (c) remains constant (d) is doubled
29. When a compression propagates in a resonating tube, the phase change when it is reflected from the water surface is
 (a) π radians (b) $\frac{\pi}{2}$ radians
 (c) $\frac{3\pi}{2}$ radians (d) zero radians
30. A man blows a whistle and hears an echo after 1.2 seconds. The distance between the man and the reflector of the sound is _____ m. (take velocity of sound in air is 330 m s^{-1}).
 (a) 250 (b) 190
 (c) 298 (d) 198
31. hertz is the unit of
 (a) wavelength. (b) amplitude.
 (c) frequency. (d) None of these
32. The velocity of sound in air depends upon
 (a) its density and pressure only.
 (b) its ratio of specific heat capacities and pressure only.
 (c) its ratio of specific heats capacities and density only.
 (d) its ratio of specific heat capacities, density and pressure.
33. The audible range of frequency of sound waves for human beings is _____.
 (a) 10 Hz to 10,000 Hz
 (b) 20 Hz to 20,000 Hz
 (c) 5 Hz to 50,000 Hz
 (d) 50 Hz to 20,000 Hz
34. Which of the following quantity decrease as sound wave travels through a medium.
 (a) Amplitude (b) frequency
 (c) velocity (d) wavelength
35. The ratio of intensities of two sound waves is $16 : 25$. The ratio of their amplitudes is
 (a) $1 : 2$ (b) $5 : 4$
 (c) $2 : 1$ (d) $4 : 5$
36. The frequency of sound waves is 11 kHz and its wavelength is 20 cm, then the velocity of sound waves is _____.
 (a) 220 m s^{-1} (b) 220 cm s^{-1}
 (c) 2200 cm s^{-1} (d) 2200 m s^{-1}
37. The ratio of frequencies of 1st and 2nd overtones produced in the vibrating stretched strings is _____.
 (a) $1 : 3$ (b) $3 : 2$
 (c) $2 : 3$ (d) $1 : 2$
38. The length of a stretched string is 2 m. The tension in it and its mass are 10 N and 0.80 kg, respectively. Arrange the following steps in a sequence to find the third harmonic of transverse wave that can be created in the string.
 (a) Find the linear mass density (m) using the formula, $m = \frac{\text{mass (M) of the string}}{\text{length (}\ell\text{) of the string}}$
 (b) Collect the data from the problem and find the length (ℓ) tension (T) and mass (M) of the stretched string.
 (c) The fundamental frequency of a stretched vibrating string is given by, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$.



- (d) The frequency of 2nd overtone or 3rd harmonic

$$\text{is given by, } n_2 = \frac{3}{2\ell} \sqrt{\frac{T}{m}} = 3n.$$

- (a) a b c d (b) d b c a
(c) b a c d (d) b d c a
39. In a resonating air column method, the first and second resonating lengths of the air columns are 16 cm and 48 cm, respectively. If the frequency of a tuning fork used is 500 Hz, arrange the following steps in a sequential order to find the velocity of sound in air.
- (a) Find the first and second resonating lengths of the air columns and frequency of the tuning fork from the given problem.
- (b) The difference of lengths of two resonating air columns is, $\ell_2 - \ell_1 = \lambda/2$ and $\lambda = 2(\ell_2 - \ell_1)$.
- (c) Find the first and second resonating lengths ' ℓ_1 ' and ' ℓ_2 ' in terms of ' λ ', i.e., $\ell_1 = \frac{\lambda}{4}$ and $\ell_2 = 3\lambda/4$.
- (d) The velocity of sound, $V = n\lambda = 2n(\ell_2 - \ell_1)$. Substitute the corresponding values and obtain the value of ' V '.

- (a) acbd (b) abcd
(c) dcba (d) cdba

40. Arrange the following steps in a sequential order to prove the law of length in vibrating stretched strings.

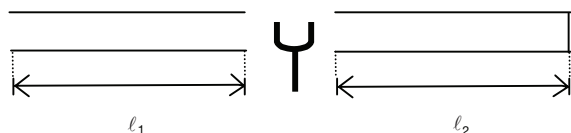
- (a) At a particular length ' ℓ_1 ', the wire between the bridges vibrates with maximum amplitude and this is confirmed by the flying away of a small paper rider placed on the string.
- (b) Excite a tuning fork of frequency ' n_1 ' and keep it on the sonometer table between the bridges and adjust the distance between the bridges (from minimum to maximum).
- (c) The first law of vibrating stretched strings is verified by showing $n_1 \ell_1 = n_2 \ell_2$.
- (d) The procedure is repeated by taking another tuning fork of frequency ' n_2 ' and the resonating length ' ℓ_2 ' is obtained.
- (a) b a d c (b) a b c d
(c) b c a d (d) b a c d

Level 2

41. Two wires of same material and area of cross section, having lengths 30 cm and 40 cm are stretched between two ends with tensions 10 N and 20 N, respectively. The difference between the fundamental frequencies of two wires is 4.0 Hz. Find the linear mass density of the wire.
42. A person speaks at one end of a metal pipe 200 m long and a person at other end hears two sounds at an interval of 0.5 seconds. If the velocity of sound in air is 300 m s^{-1} , answer the following questions:
- (a) In which of the two media, air or pipe, does sound travel faster?
- (b) Why are two sound notes heard at two different instants?
- (c) Find the speed of sound in the metal pipe.
43. For a certain organ pipe, three successive resonant frequencies are observed at 225 Hz, 375 Hz, and 525 Hz, respectively. If the velocity of sound in air is 330 m s^{-1} , find whether the pipe is closed at one end or open at both the ends. Also find the length of the pipe.
44. A ball floating on water is pushed slightly into water and released. Explain in detail what type of motion it would execute.
45. A sonar fixed to a stationary submarine is used to detect a shoal of fish. It sends waves in east direction and the reflected waves from the shoal of fish are observed at the end of 8 seconds. After 20 minutes, again the waves are sent in east direction and the reflection is observed at the end of 2.0 seconds. Find the speed and direction of motion of the shoal of fish. Take the velocity of sound in water as 1500 m s^{-1} .
46. A gas having molar mass of 48 g was found to transmit sound with a velocity of 290 m s^{-1} at a temperature of 27°C . If $R = 8.3 \text{ J K}^{-1} \text{ mole}^{-1}$, find the constant γ .
47. A person drops a stone in a well of depth 80 m and hears the sound of the splash after 4.25 seconds. If the acceleration due to gravity is 10 m s^{-2} , find the velocity of sound in air.
48. The velocity of sound in a gas at 0°C is 335 m s^{-1} . If its γ value is 1.4, find the molecular weight of the gas. [$R = 8.3 \text{ J K}^{-1} \text{ mole}^{-1}$].



49. Find the temperature in $^{\circ}\text{C}$ at which sound travels in hydrogen with the same velocity as in oxygen at 1007°C .
50. A man stands in front of a cliff and finds that when he claps at regular time interval of 1.2 seconds, he does not hear the echo distinctly. Then he moves closer to the cliff by 32 m and finds that he cannot hear the echo distinctly when he claps at an interval of 1 second. Find the velocity of sound waves.
51. A sonometer wire of length ' l ' under tension ' T ' is vibrating with its fundamental frequency. If its length is decreased by 45% and tension is increased by 21%, find the percentage change in its frequency.
52. Explain why the pitch of sound increases gradually when a vessel is being filled by a water tap.
53. Empty vessels make more vibrations than the vessels filled with a liquid when they are disturbed. Explain.
54. A vibrating tuning fork is held between an open organ pipe P_1 and a closed organ pipe P_2 of lengths ℓ_1 and ℓ_2 , respectively as shown in the figure.



If the first overtones are produced in each organ pipe, find the ratio of the lengths of the two organ pipes.

55. If the tension in a stretched string is quadrupled, find the change in the fundamental frequency of the transverse wave that can be created in the stretched string.
56. A block of mass 3 kg is suspended from the ceiling of a lift through a string having a linear density of $32.4 \times 10^{-3} \text{ kg m}^{-1}$. Find the speed with which a wave can move on the string, if the lift accelerates upward at a rate of 2 m s^{-2} . (Take $g = 10 \text{ m s}^{-2}$)
57. An open pipe of length 12 cm in its fundamental mode vibrates in resonance with the first overtone of a closed organ pipe of length 13.5 cm, which is filled with some gas. If the velocity of sound in air is 320 m s^{-1} , find the velocity of sound in the unknown gas.
58. A straight wire is made up of two copper wires welded in the middle. This wire is used as a sonometer wire. Stationary waves are set up in the wire with tension T and welded joint as a node. If one half of the wire vibrates with 3 loops and the other half with 6 loops, find the ratio of velocities of the waves in one half to that in the other half of the wire. Is the thicknesses of each half of wire same? If no, find the ratio of the radii of the two halves.
59. A sonometer resonates with a given tuning fork forming stationary waves with 8 antinodes between the two pegs, when a load of 9 kg is suspended from the wire. When this load is increased by 7 kg, then the wire resonates with the same tuning fork. Find the number of antinodes formed between the two pegs when load is increased.

Level 3

60. A straight wire is made up of two copper wires welded in the middle. This wire is used as a sonometer wire. Stationary waves are set up in the wire with tension T and welded joint as node. If one half of the wire vibrates with 3 loops and the other half with 6 loops, find the ratio of the velocities of the waves in one half to that in the other half of the wire. Is the thicknesses of each half of wire same? If no, find the ratio of the radii of each half of the wires.
61. Why is the sound heard when a piece of paper or cloth is torn? Why does the pitch of sound increase when the speed of tearing is increased?
62. Find the ratio of velocities of sound in hydrogen to oxygen at STP. The γ values of hydrogen and oxygen are same.
63. The vibration of a string of length 20 cm and mass 2 g stretched between two ends and those in a closed end tube of length 40 cm are compared. The difference in the frequencies of the tube in its fundamental mode and the string in its first overtone is 10 Hz. On decreasing the tension in the string, the difference in their frequencies decreases, then find the tension in the string. (Velocity of sound in air is 320 m s^{-1})
64. A source of sound at rest produces sound waves, which move with velocity v . Wind blows with velocity $0.2v$ towards an observer standing at a distance from the source. Find the percentage change in the wavelength and frequency of the sound as heard by the observer.



65. A scooterist is at a distance of 150 m from a wall. He blows a horn after 1 s when he starts moving away from the wall with a velocity of 12 m s^{-1} . If he hears the echo after 1 s, find the velocity of sound in air.
66. A simple pendulum which has a bob made of metal oscillates with a time period T . The bob of the pendulum is immersed in a non-viscous liquid and then oscillated. If the density of the metal bob is 5 times the density of the liquid, then find the time period of the oscillation of pendulum.
67. A pointer is attached to the prong of a tuning fork of frequency 56 Hz mounted on a stand such that the pointer strikes the vertical plate as the tuning fork vibrates. If the vertical plate falls freely from rest through 10 cm, find how many times the pointer strikes the plate during the descent of the plates?
68. In a resonating air column method, two tuning forks of frequency 300 Hz and 400 Hz are used. The first tuning fork gives a loud sound at a minimum length of 27 cm of resonating tube while the other gives loud sound at a minimum length of 20 cm. Determine the velocity of sound waves in air.
69. In an experiment, a closed organ pipe of length l was filled with a gas A at an atmospheric pressure and the fundamental note was produced when a tuning fork of certain frequency was held above the pipe. When a gas B, at an atmospheric pressure was filled in the organ pipe, the first overtone was obtained for the same length with the same turning fork. If $\gamma_A : \gamma_B = 2 : 1$, find the ratio of densities of the two gases.



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. more (or greater) 9. constant pressure, constant volume 10. frequency
 11. increases 12. 1.2 13. 0.5 m 14. $\frac{2d}{t_1 - t_2}$

Match the following

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

Multiple choice questions

16. (c) 17. (d) 18. (b) 19. (c) 20. (d) 21. (a) 22. (b) 23. (d) 24. (c) 25. (b)
 26. (b) 27. (c) 28. (d) 29. (d) 30. (d) 31. (c) 32. (d) 33. (b) 34. (a) 35. (d)
 36. (d) 37. (c) 38. (c) 39. (a) 40. (a)

Explanation for questions 31 to 40:

31. hertz is the SI unit of frequency.

32. Velocity of sound in air is given by, $V = \sqrt{\frac{\gamma P}{\rho}}$,
 where $\gamma = \frac{C_p}{C_v}$, where C_p , C_v are specific heat capacities of gas at constant pressure and volume, respectively. $\rho \rightarrow$ density of gas.

33. The audible range of frequency of sound waves for human beings is 20 Hz to 20 kHz.

34. When sound wave propagates through a medium, the amplitude of vibration decreases.

35. Since the intensity (I) varies directly as the square of the amplitude A , we can write

$$\frac{I_1}{I_2} = \frac{A_1^2}{A_2^2} \Rightarrow \frac{16}{25} = \frac{A_1^2}{A_2^2}$$

Taking the square root, we get $\frac{A_1}{A_2} = \frac{4}{5}$

36. The frequency of sound wave (n) = 11 kHz
 $n = 11 \times 10^3 \text{ Hz}$
 Wavelength of sound wave (λ) = 20 cm = 20×10^{-2} m.

$$\begin{aligned} \therefore \text{Velocity of sound wave } (V) &= n \lambda \\ &= (11 \times 10^3 \times 20 \times 10^{-2}) \text{ m s}^{-1} \\ &= 11 \times 2 \times 10^2 \text{ m s}^{-1} = 2200 \text{ m s}^{-1} \end{aligned}$$

37. The ratio of frequencies produced, by a vibrating stretched string is 1 : 2 : 3 : 4 etc. The fore, the ratio of frequencies of 1st overtone (second harmonic) and 2nd overtone (3rd harmonic) is = 2 : 3.

38. Collect the data from the problem and find the length (ℓ), tension (T) and mass (M) of the stretched string (b). Find the linear mass density (m) using the formula, $m = M / \ell$ (a). The fundamental frequency of a stretched vibrating string is given by, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$ (c). The frequency of 2nd overtone or 3rd harmonic is

$$\text{given by, } n_2 = \frac{3}{2\ell} \sqrt{\frac{T}{m}} = 3n \text{ (d)}$$

39. Find the first and second resonating lengths of air columns and frequency of the tuning fork from the given problem (a). Find the first and second resonating lengths ' ℓ_1 ' and ' ℓ_2 ' in terms of ' λ '. $\ell_1 = \lambda/4$ and $\ell_2 = 3\lambda/4$ (c). The velocity of sound $V = n\lambda = 2n(\ell_2 - \ell_1)$ (b) Substitute values and get value of ' V ' (d).
 40. Excite a tuning fork of frequency n_1 and keep it on the sonometer table between the bridges and adjust



the distance between the bridges (b). At a particular length ' ℓ_1 ', the wire between the bridges vibrates with maximum amplitude and this is confirmed by the flying away of a small paper rider placed on the string (a). The procedure is repeated by taking

another tuning fork of frequency ' n_2 ' and the resonating length ' λ_2 ' is obtained (d). The first law of vibrating stretched strings is verified by showing $n_1 \ell_1 = n_2 \ell_2$ (c).

Level 2

41. (i) For a stretched string, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}}$.

$$n_2 - n_1 = 4 \text{ Hz}$$

(ii) $6.4 \times 10^{-3} \text{ kg m}^{-1}$

42. (i) Find the distance the sound travels to reach the observer from source of sound.

Find the interval of time heard between the two sounds that passes through the pipe and air x.

Find the velocity of sound in air from the given information.

Find time taken by sound to reach from source to observer through air, by using formula time,

$$t_1 = \frac{\text{distance}}{\text{velocity}}$$

since u the velocity of sound in solids more than that of the air then, the time taken by sound to travel in solids is less than that in air.

Time taken by sound to travel in metallic pipe,

$$t_2 = \left(t_1 - \frac{1}{2} \right) \text{s}.$$

Find the time taken by sound to reach the observer through the metallic pipe.

Find the velocity of sound in metallic pipe by dividing distance by ' t_2 '.

- (ii) Sound travels faster in pipe.
 (iii) Speed of sound is different in the two media.
 (iv) 1200 m s^{-1}
43. (i) Fundamental frequency for a closed pipe
- $$n = \frac{v}{4\ell}$$
- (ii) closed pipe, 110 cm

44. What is SHM?

When a wave passes through a medium, will the particles in the medium execute SHM?

When ball is pushed slightly into water, will it produce waves on the surface of the water?

Do the particles on the surface of water execute SHM?

Will the ball also execute the motion similar to the particles present on the water surface.

45. (i) Find the time taken by the reflected waves from the shoal of fish to reach the stationary submarine two times in an interval of 20 minutes from the given data.

Take them as t_1 and t_2 .

Find the velocity of sound in water using given information.

Here, $v = \frac{2d}{t}$ (1)

By using the formula, (1) for echo, find the distance of the shoal of fish from the submarine. (Take it as d_1 and d_2).

Now, the speed of the shoal of fish, v is equal to the distance moved by the shoal of fish in one second

$$\text{Consider, } v = \frac{d_1 \sim d_2}{t}$$

What is the direction in which sonar sends waves?

Find the direction of the motion of the fish

- (ii) 3.75 m s^{-1} (west)
46. (i) $v = \sqrt{\frac{\gamma RT}{M}}$
- (ii) 1.62
47. (i) What is the depth of the well?

What is the initial velocity of the stone?

What is the time (t_1) taken by the stone to reach the bottom of the well?



Find the value of “ t_1 ” by using the formula,

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

Take the time taken by the person to hear sound of splash as ‘ t_2 ’.

Find the time interval between t_2 and t_1 by using the formula $\Delta t = (t_2 - t_1)s$.

Then, find the velocity of sound in air by dividing the depth of the well by Δt .

- (ii) 320 m s^{-1}

48. (i) Find $\frac{P}{\rho}$ from $\sqrt{\frac{P}{\rho}}$

(ii) Substitute it in $\frac{P}{\rho} = \frac{RT}{M}$

- (iii) 28

49. (i) $v \propto \sqrt{T}$, $v \propto \frac{1}{\sqrt{M}}$

- (ii) -193°C

50. (i) **Case 1:**

When a man claps at regular time interval of 1.2 seconds, he does not hear the echo distinctly.

Now, find the time taken to produce echo (t_1). Consider the distance between man and cliff as ‘ d_1 ’.

Case 2:

The man moves closer to the cliff by 32 m and claps at regular interval of time of 1 second. He doesn't hear the echo distinctly.

Find the time taken for producing an echo (t_2). Now, consider the distance between man and cliff as “ d_2 ”.

Find the relation between d_1 and d_2 .

$$d_2 = d_1 - 32 \quad (1)$$

The formula for velocity of sound using echo method is:

$$V = \frac{2d_1}{t_1} = \frac{2d_2}{t_2} \quad (2)$$

Substitute the value of ‘ d_2 ’ in terms of ‘ d_1 ’.

Calculate the value of ‘ v ’ from 2nd equation.

- (ii) 320 m s^{-1}

51. (i) $n \propto \frac{\sqrt{T}}{\ell}$

(ii) Percentage change in frequency = $\frac{n_2 - n_1}{n_1} \times 100$

- (iii) 100%

52. Which physical quantity is a measure of pitch? How does it vary in the case of vibrating air columns?

When a vessel is filled by a water tap, will the length of the vibrating air column decreases?

Will this decrease in the length affect the frequency of the vibrations?

Find the relation between the frequency and the length of the resonating column.

Now, find the relation between the pitch and frequency.

53. (i) How the frequency depends on length of the air column?

- (ii) How the presence of water influences the frequency of vibrations.

54. (i) Take the velocity of sound in air as ‘ v ’.

Take the frequency of the tuning fork as “ n ”.

When the first overtone (or) second harmonic

is considered, then, $\ell_1 = \lambda$ and $\ell_2 = 3\frac{\lambda}{4}$ (1)

Obtain the value of ‘ λ ’ in terms of ℓ_1 and ℓ_2 and substitute it in the formula $v = n\lambda$.

Find the ratio of ‘ ℓ_1 ’ to ‘ ℓ_2 ’.

- (ii) 4 : 3

55. The original tension in the string = T_o .

The tension is quadrupled, $T^1 = 4T_o$.

Let the original fundamental frequency of the string = n_o .

The new frequency of the stretched string = n^1 .

We know, $n = \frac{1}{2\ell} \sqrt{\frac{T}{m}} \Rightarrow n \propto \sqrt{T}$

$$\Rightarrow n_o \propto \sqrt{T_o}$$

And $n^1 \propto \sqrt{T^1} \Rightarrow n^1 \propto \sqrt{4T_o}$.

$$\frac{n^1}{n_o} = \sqrt{\frac{4T_o}{T_o}} = 2$$

$$n^1 = 2n_o$$



The change in the frequency,

$$\Delta n = n^1 - n_0 = 2n_0 - n_0 = n_0 = \text{the original frequency.}$$

56. Velocity of a wave in a string, $v = \sqrt{\frac{T}{m}}$

$$T = M(a + g) = 3(2 + 10)$$

$$T = 3 \times 12 = 36 \text{ N}$$

$$m = 32.4 \times 10^3 \text{ kg m}^{-1}$$

$$\begin{aligned} v &= \sqrt{\frac{T}{m}} = \sqrt{\frac{36}{32.4 \times 10^{-3}}} = \sqrt{\frac{1}{9 \times 10^{-4}}} \\ &= \sqrt{\frac{10^4}{9}} = \frac{100}{3} = 33.3 \text{ ms}^{-1} \end{aligned}$$

57. Fundamental frequency of an open pipe,

$$n_1 = \frac{v_{\text{air}}}{2\ell}$$

$$v_{\text{air}} = 320 \text{ m s}^{-1}$$

$$\ell = 12 \text{ cm} = 0.12 \text{ m}$$

Fundamental frequency of closed pipe,

$$n_1 = \frac{v_{\text{gas}}}{4\ell}$$

$$v_{\text{gas}} = ?$$

$$\ell = 13.5 \text{ cm} = 0.135 \text{ m}$$

Frequency of first overtone,

$$n_2 = 3 \left(\frac{v_g}{4\ell} \right)$$

$$n_1 = n_2$$

$$\frac{320}{2 \times 0.12} = 3 \left(\frac{v_g}{4 \times 0.135} \right)$$

$$v_g = \frac{320 \times 4 \times 0.135}{2 \times 0.12 \times 3} \Rightarrow v_g = 240 \text{ ms}^{-1}$$

58. Let the length of each half of the wire be L .

Let the wavelength of each half be λ_1 and λ_2 as the number of loops are different in each half.

$$\lambda_1 = \frac{V_1}{v} \text{ and } \lambda_2 = \frac{V_2}{n} \Rightarrow \frac{V_1}{V_2} = \frac{n\lambda_1}{\lambda_2} = \frac{\lambda_1}{\lambda_2} \quad (1)$$

$$3 \frac{\lambda_1}{2} = L \Rightarrow \lambda_1 = \frac{2L}{3} \Rightarrow 6 \frac{\lambda_2}{2} = L \Rightarrow \lambda_2 = \frac{2L}{6} = \frac{L}{3}$$

$$\text{Substituting in (1)} \quad \frac{V_1}{V_2} = \frac{2L}{3} \times \frac{3}{L} = 2 \quad (2)$$

Each half of the wire consists of copper wire of different thickness because the wavelength of waves is different in each half of the wire.

$$\text{Now, } V_1 = \sqrt{\frac{T}{M}} \text{ and } V_2 = \sqrt{\frac{T}{M_2}} \frac{V_1}{V_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{A_2 \times d}{A_1 \times d}}$$

where d is the density which is the same $\frac{V_1}{V_2}$

$$= \sqrt{\frac{A_2}{A_1}} = \sqrt{\left(\frac{r_2}{r_1} \right)^2} = \frac{r_2}{r_1}$$

$$\text{From (2)} \quad \frac{r_2}{r_1} = 2 \Rightarrow \frac{r_1}{r_2} = 1 : 2$$

59. Let the frequency of tuning fork used be x .

When 8 antinodes are formed due to resonance between tuning fork and transverse vibrating string then

Frequency of tuning fork = Frequency of vibrating string

(number of antinodes = number of loops formed)

$$n = \frac{8}{2\ell} \sqrt{\frac{T_1}{m}} \quad (1)$$

where $T_1 = 9 \text{ kg wt}$ (as load attached is 9 kg and $T_1 = Mg$; m is linear density of string of length ℓ). When load is increased by 7 kg , tension becomes

$T_2 = (9 + 7) \text{ kg wt}$, i.e., $T_2 = 16 \text{ kg wt}$. Let the string now resonate with the same tuning fork forming x number of antinodes. Then in resonance again

$$n = \frac{x}{2\ell} \sqrt{\frac{T_2}{m}} \quad (2) \text{ from (1) and (2)}$$

$$\frac{8}{2\ell} \sqrt{\frac{T_1}{m}} = \frac{x}{2\ell} \sqrt{\frac{T_2}{m}}$$

Substituting T_1 and T_2 and solving, we get $x = 6 \therefore$ 6 antinodes are formed.



Level 3

60. (i) Take the length of one half of the wire as ' ℓ '.
Take tuning fork of frequency ' n ', to excite the sonometer wire.

How are the velocities (v), frequency (n) and wavelengths (λ) in each half related?

Find the values of λ in terms of ' ℓ ' for both the sides (halves).

Find the ratio of velocities of both the halves, using the formula,

$$v = n \lambda \quad (1)$$

Does the tension (T) in two halves of the wire remain same?

Find the formula that shows the relation between v , T and linear density (m).

Is it,
$$V = \sqrt{\frac{T}{m}} \quad (2)$$

Now, Take linear densities of first and second half as M_1 and M_2 .

Linear density, $M = \frac{\text{mass of wire}(m)}{\text{length of the wire}(\ell)}$

Then,
$$\frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{m_2}{m_1}}$$

Is the metal of the two halves of the wire same?

Will the density (d) of the two halves be equal?

Then, find the value of ' m ' in terms of volume and density.

Here, volume (V) of the wire = (Area of cross-section) (length of the wire)

Then, $V = \pi r^2 \ell$.

Take the radii of two halves of the sonometer wire as ' r_1 ' and ' r_2 '

Now, find the ratio of v_1 and v_2 interms of r_1 and r_2 .

- (ii) 1 : 2 or 2 : 1 (ratio of velocity)

- (iii) 2 : 1 or 1 : 2 (ratio of radii)

61. Pitch of the sound depend on frequency.

62. (i) Find the values of temperature, pressure and volume at S.T.P.

Get the formula for the velocity (v) of the sound in the gas.

Are the values of ' λ ' for Hydrogen and oxygen, equal?

Then,
$$v \propto \frac{1}{\sqrt{d}} \quad (1)$$

Is density (d) of the gas directly proportional to the molecular weight of the gas at S.T.P?

Then,
$$\frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{m_2}{m_1}} \quad (2)$$

Find the values of M_1 and M_2 , i.e., molecular weights of hydrogen and oxygen and substitute in (2).

Find the ratio of v_1 and v_2 from (2).

- (ii) 4 : 1

63. (i) Frequency of first overtone of a stretched string = 2(fundamental frequency of the closed tube)

2. $n_2 > n_1$

- (ii) 17.64 N

64. (i) When the source of sound and observer are at rest, is there any apparent change in the frequency of the sound?

Will it result in Doppler effect?

Find the relation between the velocity of the sound (v_1) and its wavelength (λ_1), when frequency of the sound remains constant.

Find λ_1 in terms of v_1 and f .

Is the direction of the wind and sound same?

Does the velocity of the sound increase? (Take it as v_2)

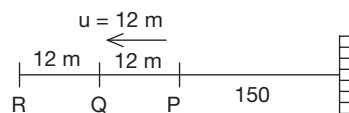
Find the value of ' v_2 ' interms of ' v_1 '

$V_2 = v + 0.2v$, Find λ_2 .

Ratio of frequency is the ratio of velocity of sound with respect to the observer to that with respect to the source.

- (ii) 20% change in wavelength, zero per cent change in frequency.

65. Initially the person is at ' P ' at a distance of 150 m from the wall.



In 1 s he moves a distance of 12 m.

When he is at a distance of 162 m from the wall, he blows the horn.

Time taken to hear an echo = 1 s

Total distance traveled by the sound

$$= (162 \times 2) + 12$$

$$= 324 + 12 = 336 \text{ m}$$

$$\text{Velocity of sound} = 336/1 = 336 \text{ m s}^{-1}$$

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

When the bob is immersed in a liquid, net downward force = weight of bob – upthrust

$$ma = mg - m\frac{\rho_\ell}{\rho_m}g = mg\left(1 - \frac{\rho_\ell}{\rho_m}\right)$$

Given $\rho_m = 5\rho_\ell$

$$ma = mg\left(1 - \frac{1}{5}\right) = mg\left(\frac{4}{5}\right)$$

$$T^1 = 2\pi\sqrt{\frac{m\ell}{mg\left(\frac{4}{5}\right)}} = T\sqrt{\frac{5}{4}}T^1 = \sqrt{\frac{5}{4}}T$$

67. The time taken by the plate to fall through 10 cm can be found by the equation of motion for a freely falling body.

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

In this case, $u = 0$ and $a = g$. So,

$$s = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2s}{g}}$$

Substitute $s = 10 \text{ cm} = 0.1 \text{ m}$

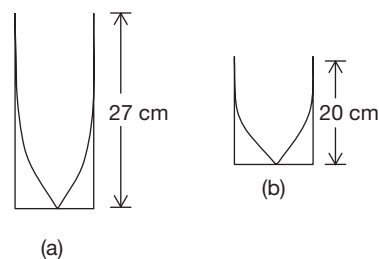
$$T = \sqrt{\frac{2s}{g}} = \sqrt{\frac{2 \times 0.1}{9.8}} = \sqrt{\frac{2}{98}} = \frac{1}{7} \text{ second.}$$

The number of oscillations of the tuning fork in $1/7$ second

$$= 56 \times \frac{1}{7} = 8 \text{ oscillations}$$

The pointer strikes the plate 8 times during the fall of the plate.

68. The stationary waves are formed as shown in the figure below.



Let 'e' be the end correction. For the first tuning fork,

$$\frac{\lambda}{4} = 0.27 + e \Rightarrow \lambda = 4(0.27 + e)$$

$$\text{As } n = \frac{V}{\lambda}$$

$$\Rightarrow 300 = \frac{V}{4(0.27 + e)}$$

$$\Rightarrow 0.27 + e = \frac{V}{4 \times 300}$$

$$= \frac{V}{1200} \quad (1)$$

For the second tuning fork,

$$\frac{\lambda}{4} = 0.2 + e \Rightarrow \lambda = 4(0.2 + e)$$

$$\text{As } n = \frac{v}{\lambda} \Rightarrow 400 = \frac{V}{4(0.2 + e)}$$

$$0.2 + e = \frac{V}{4 \times 400} = \frac{V}{1600} \quad (2)$$

Subtracting (2) from (1),

$$(0.27 + e) - (0.2 + e) = \frac{V}{1200} - \frac{V}{1600}$$

$$\Rightarrow 0.27 + e - 0.2 - e = \frac{V}{400} \left(\frac{1}{3} - \frac{1}{4} \right)$$

$$\Rightarrow 0.07 = \frac{V}{400} \times \frac{1}{12} \Rightarrow V = 0.07 \times 400 \times 12$$

$$V = 7 \times 4 \times 12 = 7 \times 48 = 336 \text{ ms}^{-1}$$



69. In this first case, $(n)_A = \frac{v_A}{4\ell}$

In the second case, $(n_1)_B = \frac{3v_B}{4\ell}$

Since, $(n_0)_A = (n_1)_B \Rightarrow \frac{v_A}{4\ell} = \frac{3v_B}{4\ell}$,

$$\therefore \frac{v_A}{v_B} = 3$$

$$\text{i.e., } \sqrt{\frac{\lambda_A}{\lambda_B} \times \frac{d_B}{d_A}} = 3 \quad (\because \text{Pressure is same})$$

$$\sqrt{\frac{2}{1} \frac{d_B}{d_A}} = 3 \Rightarrow \frac{d_A}{d_B} = \frac{2}{9}$$

$$\therefore d_A : d_B = 2 : 9.$$

Chapter 7

Electricity



REMEMBER

Before beginning this chapter, you should be able to:

- Study the different methods of charging bodies and the concept of electric field and electric potential
- Study the different properties of electric charges in motion
- Learn the concept of electric current and electric resistances

KEY IDEAS

After completing this chapter, you should be able to:

- Study the nature and properties of electric charges when they are at rest and in motion
- Understand current in conductors and electrolytes
- Discuss the heating effect, chemical effect and lighting effects of electricity and their applications
- Study some laws such as Ohm's law, Joule's Law, laws of electrolysis, etc., related to electricity
- Learn the detailed concept of resistances in series and parallel

INTRODUCTION

In the chapter heat, you have studied that heat is a form of energy. The other forms of energy are light, mechanical, chemical energy, etc. Among all forms of energy, electric energy is the most useful and convenient for mankind. It can be converted to almost all forms of energy easily and can be stored and transmitted over long distances with very little wastage. Electric bulbs, motors, all phones, air conditioners, heaters, computers and heavy machinery all use different effects of electric energy. In fact, it is difficult to imagine our lives without electric energy. The origin of electric energy lies in electric charges. The branch of physics which deals with the study of electric charges and their effects is called electricity.

In order to understand the topic of electricity better, we shall first recall some of the properties of electric charges which you have studied in detail in previous classes.

Electric Charges-Properties

1. Electric charge is of two types viz., positive and negative charge.

Proton is said to be charged positively and electron is said to be charged negatively.

2. Like charges repel and unlike charges attract. Thus, a proton repels a proton and attracts an electron.
3. The force of attraction or repulsion between two point charges is given by Coulomb's law.

$$F = \frac{Kq_1q_2}{r^2}$$

where q_1 and q_2 are charges.

K = constant of proportionality.

r = distance between the charges.

4. Charge can neither be created nor destroyed. The charge from one body can be transferred to another body but the total charge of a system remains constant. This is called the principle of conservation of charge.
5. Protons and electrons are elementary charged particles. Though the charge on them is opposite in nature, the magnitude of charge possessed by them is same, i.e., 1.6×10^{-19} C. It is denoted by ' e '. Charge on a body is always an integral multiple of this value. This property is called 'quantization' of charge.
6. When a body gains electrons, it becomes negatively charged. When it loses electrons it becomes positively charged. The positive charge being bound firmly in the nucleus does not participate in charging.

The study of electricity is classified into two parts.

1. **Static electricity:** It deals with electric charges at rest and their effects.
2. **Current electricity:** It deals with charges in motion and their effects.

This chapter deals with charges in motion, i.e., current electricity.

CONDUCTORS AND INSULATORS

Current electricity is the study of charges in motion. Hence, it is of our interest to know the substances which allow charges to flow through them easily and which resist it. Accordingly, substances are classified as conductors and insulators.

Conductors

The substances which conduct electricity easily are called electric conductors.

Since positive charges cannot flow, the conduction of electricity is primarily due to flow of free electrons. Hence conductors have large number of free electrons.

Example: All metals are good conductors of electricity.

Insulators

The substances which do not conduct electricity are called electric insulators.

Example: Wood, rubber, mica, Insulators do not have free electrons.

ELECTRIC CURRENT

The rate of flow of charge is known as electric current. It is denoted by I . If ' q ' is the net charge passing through any cross section of a conductor in time ' t ', then

$$\text{Current } (I) = \frac{\text{Charge}(q)}{\text{Time}(t)}$$

Current is a scalar quantity. S.I. unit of current is ampere (A). Multiple units of current are kiloampere ($1 \text{ kA} = 10^3 \text{ A}$), Megaampere ($1 \text{ MA} = 10^6 \text{ A}$).

Submultiple units are 1 mA ($1 \text{ milliampere} = 10^{-3} \text{ A}$) and microampere ($1 \mu\text{A} = 10^{-6} \text{ A}$).

One Ampere

Now ampere is defined in terms of force between two thin and long current carrying conductor kept parallel to each other in vacuum.

The current passing through a conductor is said to be one ampere when the net flow of charge per second through its cross section is one coulomb.

The charge transferred is always an integral multiple of the fundamental charge (charge of a proton). This property is referred to as **quantization of charge**.

i.e., $Q = ne$

$$\text{Since current } (I) = \frac{Q}{t} \text{ or } I = \frac{ne}{t}$$

where e = magnitude of charge of an electron.

n = number of electrons flowing across any point in time ' t '

Electric Potential

It is our common observation that water flows from a place at a higher level to a place at a lower level, irrespective of the amount of water at the two levels. Heat flows from a body at a higher temperature to a body at a lower temperature, irrespective of the amount of heat contained by the two bodies. Similarly electric charges move from one point to another if there exists a difference in the electric potential irrespective of the concentration of charges at the two points. Thus, electric potential determines the direction of flow of electric current. Charge flows from a body at higher potential to a body at lower potential. By convention, a positively charged body is at a higher potential as compared to a negatively charged body. If positive charges like protons or positive ions are free to move, they would move from higher potential point to lower potential point. Usually, the movement of charges implies movement of electrons. Since electrons are oppositely charged (i.e., negatively charged), they move from lower potential point to higher potential point. This constitutes electronic current. Since the convention is that flow is always from higher to lower level, the conventional current is taken opposite to the electronic current. It should be remembered that conventional current implies the movement of positive charges whereas electronic current is the movement of electrons.

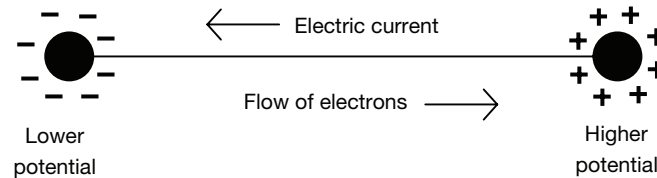


FIGURE 7.1 Electric potential of two bodies

As discussed earlier, concentration of charges determines the electric potential at a point. This can be increased by bringing charges at that point. In doing so some work has to be done on the charge. This work is stored as electric potential at that point. The electric potential can be measured in terms of work done and is defined as the work done in bringing a unit positive charge from infinity to a point in an electric field.

The electric potential is measured in volts (V). The electric potential at a point is said to be 1 volt if 1 joule of work is done in bringing a positive charge of 1 coulomb from infinity to that point.

Potential Difference

To bring a unit positive charge from infinity to a point in an electric field, some work has to be done which is called electric potential. Within an electric field, if a unit positive charge has to be moved from one point to another against the direction of the field, some work has to be done which is called as potential difference between the two points.

Like electric potential, the potential difference is also measured in volts (V). Let Q coulomb charge be moved from point A to the point B in an electric field when work done is W . Let V be the potential difference between the two points. Therefore, the work done in moving unit positive charge is

$$= \frac{W}{Q}.$$

By definition, this work done is also the potential difference.

$$\therefore V = V_1 - V_2 = \frac{W}{Q}$$

where V_1 = Potential at point A.

V_2 = Potential at point B.

When 1 joule of work is done in moving a positive charge of 1 coulomb from one point to another in an electric field, the potential difference between the two points is 1 volt.

i.e.,
$$1V = \frac{1 \text{ joule}}{1 \text{ coulomb}} = 1 \text{ Jc}^{-1}$$

NOTE

Since potential difference is measured in volts, it is sometimes called 'voltage' or 'voltage' drop.

EXAMPLE

5 joule of work is done in moving 12.5×10^{18} electrons from one end to the other end of a conductor. What is the potential difference between the two ends of the conductor?

SOLUTION

The charge on 6.25×10^{18} electrons is 1 C.

$\therefore$ Charge on 12.5×10^{18} electrons is 2 C.

$\therefore Q = 2 \text{ C}$.

Work done (W) in moving 2 C charge = 5 J. (given)

The potential difference (V) between the ends of conductor is

$$\begin{aligned} V &= \frac{\text{Work done}}{\text{charge}} \\ &= \frac{5 \text{ J}}{2 \text{ C}} = 2.5 \text{ JC}^{-1} \\ V &= 2.5 \text{ volts.} \end{aligned}$$

EXAMPLE

Electric potential at a point in an electric field is 0.5 V. When a charge of 3 C was brought from infinity to that point, how much work has to be done?

SOLUTION

Electric potential (V) = 0.5 volts

Charge (Q) = 3 C

Work done (W) = ?

$$\begin{aligned}
 V &= \frac{W}{Q} \\
 \therefore W &= VQ \\
 &= 0.5 \text{ V} \times 3 \text{ C} \\
 &= 1.5 \text{ V C} \\
 &= 1.5 \text{ J.}
 \end{aligned}$$

EXAMPLE

The electric potentials at the two ends of a conductor are 10 V and 5 V, respectively. 5 J of work needs to be done to move certain amount of charge from the end at higher potential to the end at lower potential. Find the amount of charge moved.

SOLUTION

The potential difference between the two ends of the conductor (V) = 10 V – 5 V = 5 V.

Work done (W) = 5 J

Charge (Q) = ?

$$\text{Potential difference} = \frac{\text{work}}{\text{charge}}$$

$$\begin{aligned}
 V &= \frac{W}{Q} \\
 &= \frac{5\text{J}}{5\text{V}} = 1 \text{ coulomb.}
 \end{aligned}$$

CURRENT IN CONDUCTORS AND ELECTROLYTES

Rate of flow of charge is called current. We have already seen that charge moves from one point to another if there exists a potential difference between them. Thus, whether the current is flowing through a conductor or electrolyte, a potential difference is necessary for it. You have also studied in previous classes that cell or battery is used to provide potential difference.

Current in a Conductor

A potential difference can be produced between a conductor in the form of a metallic wire, if it is connected between the two terminals of a cell. The end of the wire connected to the positive terminal is at a higher potential while the end connected to the negative terminal is at a lower potential. A conventional current is set up between these two ends.

A conductor has of a large number of free electrons which are in random motion just like molecules in air. When it is connected across a cell or a battery, these free electrons begin to drift from lower potential to higher potential. This constitutes the electronic current. Thus, the free electrons are responsible for the flow of electric current in conductors. However, the direction of conventional current is taken opposite to that of electronic current, i.e., from higher potential to lower potential.

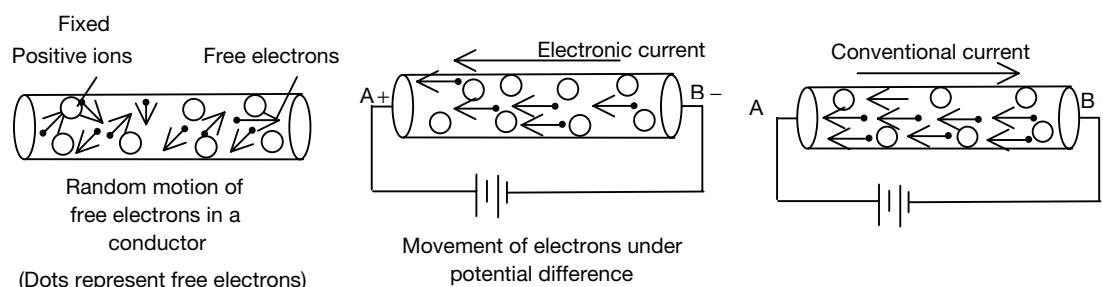


FIGURE 7.2 Current passed in a conductor

When the metallic wire is not connected to a battery, although the electrons are moving, the net flow in any particular direction is zero. Hence, no current flows through it in the absence of potential difference.

Current in An Electrolyte

A liquid or a solution which conducts electricity is called an electrolyte.

For example, copper sulphate (CuSO_4), sodium chloride (NaCl) or common salt solution.

When a potential difference is applied across an electrolyte, it undergoes a chemical change and decomposes into its constituents. This process is called electrolysis.

Take some water in a beaker and add common salt (NaCl) to it. Insert two metallic rods A and B in the solution. They are called electrodes. Connect A to positive and B to negative terminal of a cell. A is at higher or positive potential and is called anode while B which is at lower or negative potential is called cathode.

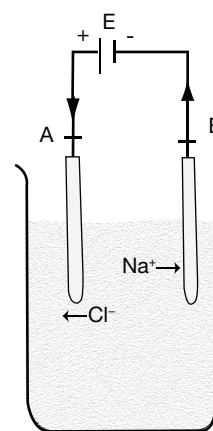


FIGURE 7.3 Electrolysis

The solution dissociates into positive sodium ions (Na^+) and negative ions (Cl^-). The positive Na^+ ions move towards cathode B and gain electrons to form Na atoms. The negative Cl^- ions migrate towards anode A through electrolyte and form chlorine atoms by giving away electrons. The bubbles of chlorine gas can be seen coming out from A.

Thus, in an electrolyte, both positive and negative ions move through it towards opposite electrodes. The rate of flow of charge is electric current. However, the conventional current is taken as movement of positive ions through electrolyte towards cathode B. Through the external wire connecting the cell to the electrodes, electrons enter from cathode and move towards anode A. If a bulb is connected, it begins to glow confirming the flow of current.

Thus, in an electrolyte, the movement of ions is responsible for electric current.

Electrical Resistance

Conductors conduct electricity owing to the presence of a large number of free electrons. When a potential difference is applied across a conductor, these electrons begin to drift from the end at low potential to the end at high potential. While drifting they collide with other

electrons as well as fixed positive ions. The fixed ions are formed from the atoms which give free electrons. Thus, even as, conductor conducts electricity, at the same time it offers some obstruction to the flow of charges.

The obstruction offered by a conductor to the flow of electric current is called its resistance.

As the collisions suffered by drifting electrons increase, the resistance offered by the conductor also increases. Thus, the resistance depends basically on the arrangement of atoms and the configuration of electrons around the atoms of the conductor.

Units of Resistance

The SI unit of resistance is ohm. It is denoted by Greek symbol Ω (Omega).

Higher units of resistance

1. kilo-ohm($k\Omega$) = $10^3 \Omega$
2. mega-ohm($M\Omega$) = $10^6 \Omega$
3. giga-ohm($G\Omega$) = $10^9 \Omega$

Electrical Conductance

The reciprocal of resistance is known as electrical conductance. It is denoted by G. It is a measure of ease with which a charge can flow in a conductor.

$$G = \frac{1}{R}. \text{ Unit of conductance is } \text{ohm}^{-1} \text{ or siemen.}$$

Electrical Conductivity

The reciprocal of resistivity is called conductivity.

$$\text{It is denoted by } \sigma. \sigma = \frac{1}{\rho}; \text{ The unit of conductivity is mho/metre or siemen/metre.}$$

Super Conductors

Conductors exhibit a phenomenon known as super conductivity at a very low temperature known as critical temperature. At critical temperature, a metal offers zero resistance to the passage of electricity. These type of conductors are called superconductors.

The temperature below which a conductor offers no resistance to the flow of electric current is known as its **critical temperature**.

Factors Affecting Resistance

1. Resistance of a conductor depends upon its nature.
2. **Law of length:** Resistance of a conductor is directly proportional to its length.

Let ℓ and R be the length and resistance of conductor, then consider two conductors of same material such that ℓ_1 and ℓ_2 are their lengths and, R_1 and R_2 are their resistances.

respectively. Then

$$\begin{aligned} R_1 &\propto \ell_1 \\ R_2 &\propto \ell_2 \\ \therefore \frac{R_1}{R_2} &= \frac{\ell_1}{\ell_2} \end{aligned}$$

3. Law of area of cross section: Resistance of a conductor is inversely proportional to its area of cross section.

Let a be the area of cross section of a conductor whose resistance is R .

$$R \propto \frac{1}{a}$$

Considering two conductors of area of cross sections a_1 and a_2 and resistances R_1 and R_2 .

Then,

$$\begin{aligned} R_1 &\propto \frac{1}{a_1} \\ R_2 &\propto \frac{1}{a_2} \\ \therefore \frac{R_1}{R_2} &\propto \frac{a_2}{a_1} \\ &= \frac{\pi r_2^2}{\pi r_1^2} \quad (\because a = \pi r^2) \\ \frac{R_1}{R_2} &= \frac{a_2}{a_1} = \left(\frac{r_2}{r_1} \right)^2 \end{aligned}$$

Where r_1 and r_2 are the radii of the two conductors.

Combining the 2nd and 3rd laws, we get

$$\begin{aligned} R &\propto \frac{\ell}{a} \\ \therefore R &= \rho \frac{\ell}{a} \end{aligned}$$

Where ρ is the constant of proportionality.

SPECIFIC RESISTANCE OR RESISTIVITY

We have seen that

$$R = \rho \frac{\ell}{a}$$

The constant of proportionality ‘ ρ ’ is called the specific resistance or resistivity of a given conducting material like copper, aluminum, etc. It is a characteristic property of conducting material and independent of the size and shape of the conductor.

$$\rho = R \frac{a}{\ell}$$

Consider a conductor having unit area of cross section and unit length.

$$\rho = R \frac{1}{1}$$

$$\therefore \rho = R.$$

Thus, specific resistance or resistivity can be defined as the resistance of a conducting material having unit area of cross section and unit length.

Unit of Resistivity

$$\begin{aligned} \text{Unit of } \rho &= \frac{\text{unit of } R \times \text{unit of } a}{\text{unit of } \ell} \\ &= \frac{\text{ohm} \times (\text{metre})^2}{\text{metre}} \end{aligned}$$

$$\text{unit of } \rho = \text{ohm-metre} = \Omega \text{ m}$$

Sometimes, a hybrid unit $\Omega \text{ cm}$ is also used.

EXAMPLE

The length of copper wire is 100 m and its radius is 1 mm. Calculate its resistance if resistivity of copper is $1.72 \times 10^{-8} \Omega \text{ m}$.

SOLUTION

Length of copper wire (ℓ) = 100 m.

Area of cross section (a) = $\pi r^2 = 3.14 \times (10^{-3} \text{ m})^2 = 3.14 \times 10^{-6} \text{ m}^2$

Resistivity (ρ) of copper = $1.72 \times 10^{-8} \Omega \text{ m}$

Resistance offered by a conductor is given by,

$$\begin{aligned} R &= \rho \frac{\ell}{A} \\ &= \frac{1.72 \times 10^{-8} \times 100}{3.14 \times 10^{-6}} = 0.55 \Omega \end{aligned}$$

In this numerical, length of copper wire is 100 m. If the length is 1000 m, i.e., 1 km, the resistance offered by it would be 5.5Ω which is very less. Thus, copper is a good conductor of electricity.

EXAMPLE

The resistance of 1 m of nichrome wire is $6\ \Omega$. Calculate its resistance if its length is 70 cm.

SOLUTION

Given

1st case

Length of nichrome wire (ℓ_1) = 1 m = 100 cm

Resistance of nichrome wire (R_1) = $6\ \Omega$

2nd case

$\ell_2 = 70\text{ cm}$

$R_2 = ?$

By 1st law of resistance

$$\frac{R_1}{R_2} = \frac{\ell_1}{\ell_2}$$

$$\frac{6\Omega}{R_2} = \frac{100\text{ cm}}{70\text{ cm}}$$

$$\therefore R_2 = 4.2\ \Omega$$

EXAMPLE

Two wires made of German-silver are taken such that the length and area of cross-section of the second wire are twice and thrice respectively those of the first wire. If the resistance of the second wire is $12\ \Omega$, find the resistance of the first wire.

SOLUTION

1st case

ℓ_1 = length of German silver wire

a_1 = area of cross section

R_1 = resistance

$$R_1 = \rho \frac{\ell_1}{a_1} \tag{1}$$

2nd case

ℓ_2 = length of wire = $2\ell_1$

a_2 = area of cross section of wire = $3a_1$

R_2 = resistance of wire = $12\ \Omega$

$$R_2 = \rho \frac{\ell_2}{a_2}$$

$$\therefore 12 = \rho \frac{2\ell_1}{3a_1} \quad (2)$$

dividing (1) by (2)

$$\frac{R_1}{12} = \frac{\rho \ell}{a_1} \times \frac{3a_1}{\rho(2\ell_1)} = \frac{3}{2}$$

$$\therefore R_1 = 18 \, \Omega$$

Effect of Temperature on Resistance

The resistance of a conductor increases with an increase in temperature. Let the resistance of a conductor at 0°C be R_0 .

Let the resistance of the conductor at $t^\circ\text{C}$ be R_t .

Then, $R_t = R_0(1 + \alpha t)$,

where ' α ' is known as the **temperature coefficient**. **Define it of resistance.**

Pure metals have positive temperature coefficient of resistance. That is resistance of metals increases with an increase in temperature.

Alloys have a very less temperature coefficient of resistance. So the resistance of alloys like Manganin and Constantan vary very little with an increase in temperature. Because of this property, they are used in making standard resistances.

Semiconductors like germanium, silicon and bad conductors like glass, pure water, etc., have negative temperature coefficient. The resistance of these materials decreases with an increase in temperature.

Effect of Impurities on Resistance

1. Resistance of conductors increases with addition of impurities.
2. Resistance of semiconductors decreases with addition of selected impurities.

ELECTRIC CIRCUITS AND CIRCUIT DIAGRAMS

In order to make use of electric energy, the current has to be passed through various devices and electric components. For this they need to be connected properly with respect to each other and electric source. This systematic arrangement of electric components and devices with the electric source is called an electric circuit. It is also important that the circuit arrangement be represented schematically. The schematic representation of an electric circuit is called a circuit diagram. In order to draw a circuit diagram, various electric components and devices are represented by suitable symbols.

The table below gives conventional symbols for some common components.

Electrical Components	Symbol
A cell	
A battery	
Alternating current source	
Plug key	
Switch	
Tapping Key	
Conducting (connecting) Wire	
An ammeter	
A Voltmeter	
A resistance (fixed value)	
A variable resistance or rheostat	
Galvanometer	
Loadw	
Heater	
Bulb	

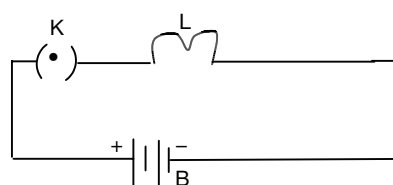


FIGURE 7.4 Basic circuit diagram

The Fig. 7.4 is a circuit diagram showing the connection of lamp (L) with a battery (B). The key (K) is used to connect or disconnect the lamp with the battery.

OHM'S LAW

We have studied that when a potential difference is applied between the ends of a conductor, current begins to flow through it. George Simon Ohm, a German physicist performed a series of experiments to determine the exact relationship between the potential difference and the electric current. On the basis of these experiments, he formulated a law which is called Ohm's law and can be stated as, the potential difference (V) applied between the ends of a conductor bears a constant ratio with the electric current (I) flowing through it, provided the physical state of the conductor remains the same. The factors which constitute physical state of conductor are its length, area of cross section, temperature and material.

According to Ohm's law

$$V \propto I$$

i.e.,

$$V = (\text{constant}) I$$

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

The constant in the above relation is called resistance (R) of the conductor.

$$\therefore \frac{V}{I} = R$$

$$V = IR$$

If the potential difference is measured in volts and current in amperes, the resistance of conductor is said to be in ohms.

$$\frac{\text{volt}}{\text{ampere}} = \text{ohm.}$$

The resistance of a conductor is said to be 1 ohm if the potential difference of 1 volt causes a current of 1 ampere to pass through the conductor.

$$\frac{1\text{volt}}{1\text{ampere}} = 1\text{ohm.}$$

EXAMPLE

An electric bulb whose resistance is $60 \, \Omega$ is connected to a source of potential difference of 230 V. Find the current flowing through it.

SOLUTION

Potential difference (V) applied to the bulb = 230 V

Resistance (R) of bulb = $60\ \Omega$

Current (I) flowing through bulb = ?

According to Ohm's law

$$V = IR$$

$$\therefore I = \frac{V}{R}$$

$$= \frac{230\text{V}}{60\Omega}$$

$$\therefore I = 3.83\text{ A.}$$

EXAMPLE

Study the following circuit diagram

Find the potential difference provided by the cell.

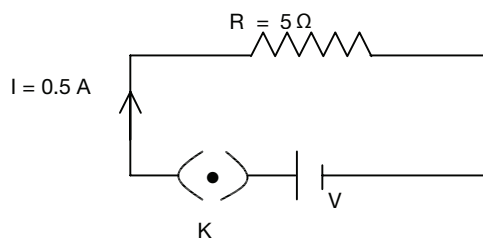


FIGURE 7.5 Circuit diagram consisting a resistance of $5\ \Omega$

SOLUTION

Current (I) flowing through the resistor = 0.5 A

Resistance (R) of the resistor = $5\ \Omega$

Potential difference (V) = ?

According to Ohm's law

$$V = IR$$

$$= 0.5\text{ A} \times 5\ \Omega$$

$$V = 2.5\text{ V}$$

Experimental Verification of Ohm's Law**Voltmeter—Ammeter Method**

Connect a battery (B), an ammeter (A), a resistor (R), a rheostat (Rh) and a voltmeter (V) as shown in the Fig. 7.6.

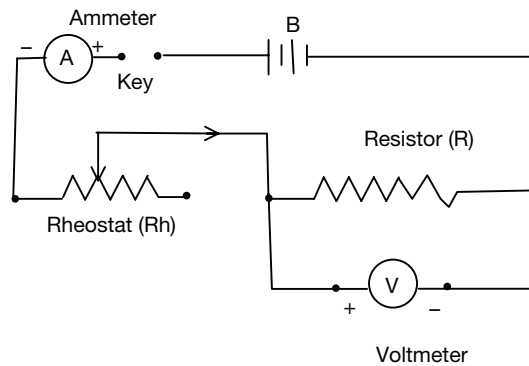


FIGURE 7.6 Experiment to verify Ohm's law

Move the slider position of the rheostat for different values of current in the circuit. The reading of current and voltage across the resistor for different positions of the slider switch are noted. In each case, the ratio of voltage to current is found.

It is observed that, the ratio V/I remains constant showing that the (voltage potential difference) is proportional to current ($V \propto I$).

Potentiometer Method

Connect a potentiometer (a resistance wire of 1 m length) AB stretched between two brass terminals, as shown in the Fig. 7.7.

Close the key and record the voltage in the voltmeter connected parallel to A and jockey at different points.

Experimental set up of potentiometer method.

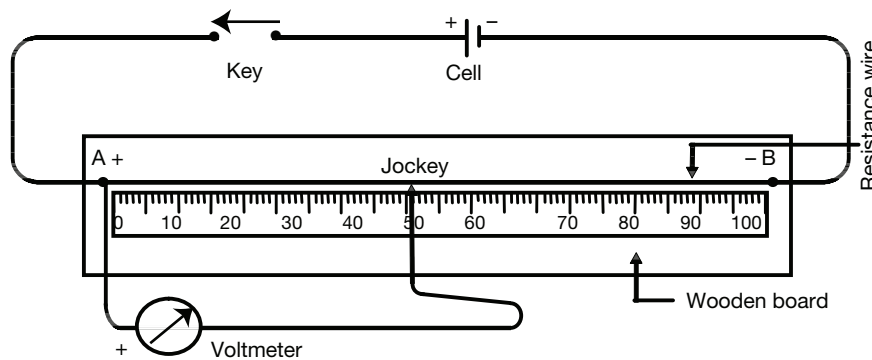


FIGURE 7.7 A potentiometer

The ratio of the voltage to the corresponding length at each reading will be constant showing $\frac{V}{L} = \text{constant}$, but $L \propto R$

$$\Rightarrow \frac{V}{R} = \text{constant}$$

Graphical Representation of Ohm's Law

Plot voltage (V) on x -axis and current (I) on y -axis

Observation: A straight line passing through the origin is obtained (implies $V \propto I$).

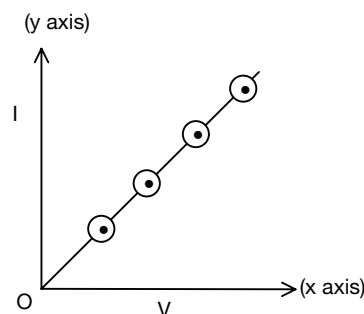


FIGURE 7.8 Graphical representation of Ohm's Law

Ohmic and Non-ohmic Conductors

Ohmic conductors are those conductors which obey Ohm's law. Hence, they are referred to as linear conductors.

Example: All metals.

The conductors which do not obey Ohm's law are known as **non-ohmic conductors**.

Example: Electrolytes, semiconductor devices like diodes, transistors, etc.

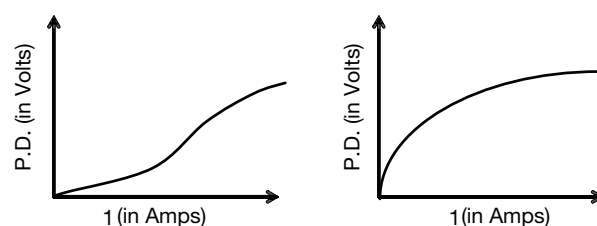


FIGURE 7.9 V-I graph for Ohmic & Non-Ohmic conductors

V-I graph for non-ohmic conductors is not linear. (not a straight line).

Resistances in Series

Resistors are said to be connected in series, when there exists only one path for the flow of current and the current through each resistor is same.

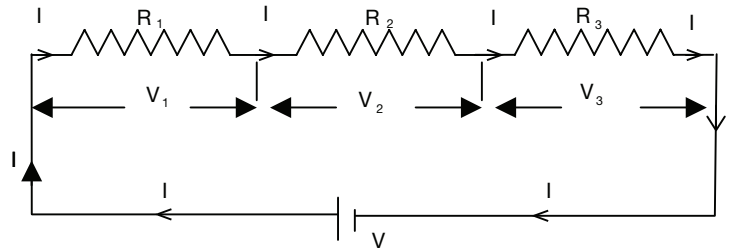
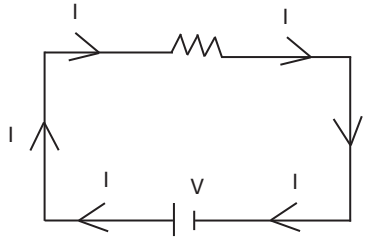


FIGURE 7.10 Resistors in series

Resistors R_1 , R_2 and R_3 are connected in series as shown above. Apply a voltage ' V ' across the series combination. Let V_1 , V_2 and V_3 be the voltage drop across R_1 , R_2 and R_3 respectively as shown in the Fig. 7.9. Let the current I flow through all the three resistances.



Therefore, the voltage V_1 across R_1 : $V_1 = IR_1$ (By Ohm's Law)

The voltage V_2 across R_2 : $V_2 = IR_2$

The voltage V_3 across R_3 : $V_3 = IR_3$

The applied voltage $V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$

If R_{eff} is the effective resistance, or equivalent resistances of the combination, then $V = IR_{\text{eff}}$

$$IR_{\text{eff}} = IR_1 + IR_2 + IR_3$$

$$IR_{\text{eff}} = I(R_1 + R_2 + R_3)$$

$$\therefore R_{\text{eff}} = R_1 + R_2 + R_3$$

Characteristics of a Series Circuit

1. Same current is flowing through all the resistances.
2. The effective resistance is the sum of the individual resistances. Effective resistance $R_{\text{eff}} = R_1 + R_2 + R_3$.
3. The applied voltage $V = V_1 + V_2 + V_3$

EXAMPLE

Find the effective resistance, when 1Ω , 10Ω and 4Ω resistances are connected in series.

SOLUTION

When resistors are connected in series, the effective resistance is given by,

$$R_{eff} = R_1 + R_2 + R_3$$

$$R_{eff} = 1 + 10 + 4 = 15\Omega$$

Resistors in Parallel

Resistors are said to be connected in parallel, when identical potential difference exists across all of them, i.e., the potential drop across each resistor is the same.

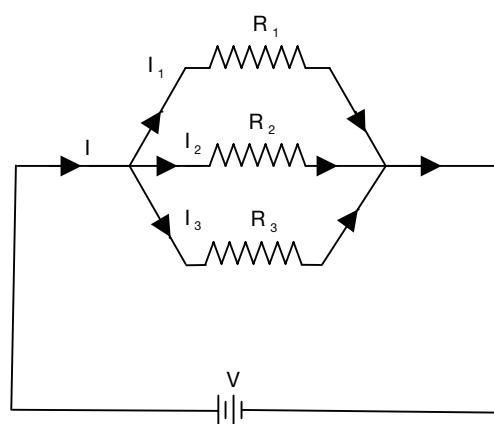


FIGURE 7.11 Resistors in parallel

Let three resistors R_1 , R_2 and R_3 be connected across the voltage source V in parallel. The current I drawn from the battery is divided into three parts I_1 , I_2 and I_3 flowing through the resistors R_1 , R_2 and R_3 , respectively as shown in Fig. 7.11.

The total current $I = I_1 + I_2 + I_3$

By Ohm's law to R_1 , R_2 and R_3 , we get

$$I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, \text{ and } I_3 = \frac{V}{R_3}$$

$$\text{As, } I = I_1 + I_2 + I_3$$

$$= \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \quad (7.1)$$

Let R_{eff} be the effective resistance.

$$\text{Applying Ohm's law } I = \frac{V}{R_{\text{eff}}} \quad (7.2)$$

From equation (7.1) and (7.2), we get

$$\therefore \frac{V}{R_{\text{eff}}} = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right); \Rightarrow \frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Characteristics of a Parallel Circuit

1. The potential difference across each resistance is the same.
2. The reciprocal of the effective resistance is equal to the sum of the reciprocals of the individual resistances.
3. Current in the circuit $I = I_1 + I_2 + I_3 + \dots$
4. The effective resistance is less than the least resistance in the circuit.

EXAMPLE

Find the equivalent resistance when 3 ohm and 6 ohm resistances are connected in parallel.

SOLUTION

When resistances are connected in parallel, the equivalent resistance is given by,

$$\begin{aligned} \frac{1}{R_{\text{eff}}} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{R_{\text{eff}}} &= \frac{1}{3} + \frac{1}{6} = \frac{2+1}{6} = \frac{3}{6} = \frac{1}{2} \\ R_{\text{eff}} &= 2\Omega \end{aligned}$$

EXAMPLE

For the given circuit, find the effective resistance between

- (i) A and B
- (ii) B and C
- (iii) A and C

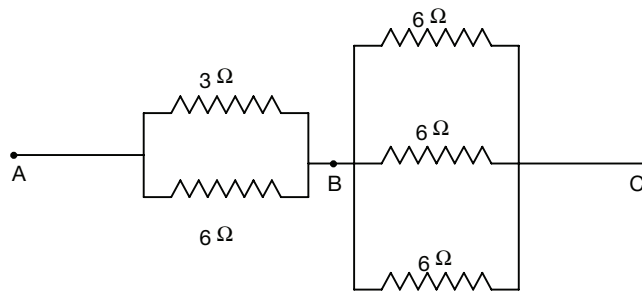


FIGURE 7.12 A circuit consisting resistors in series & parallel

SOLUTION

(i) Effective Resistance between A and B is

$$\frac{1}{R_{AB}} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{1}{R_{AB}} = \frac{1}{3} + \frac{1}{6} = \frac{2+1}{6} = \frac{1}{2}$$

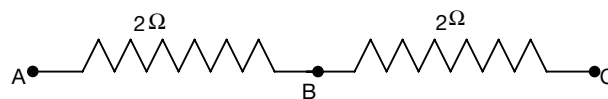
$$\therefore R_{AB} = 2\Omega$$

(ii) Effective Resistance between B and C is

$$\frac{1}{R_{BC}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{6} + \frac{1}{6} + \frac{1}{6} = \frac{3}{6} = \frac{1}{2}$$

$$\therefore R_{BC} = 2\Omega$$

(iii) Resistance between A and C is obtained by drawing the simplified circuit as follows:
Now, R_{AB} and R_{BC} are in series,



$$R_{AC} = 2 + 2 = 4\Omega$$

FIGURE 7.13 Simplified circuit consisting resistance in series

$$\therefore R_{AC} = R_{AB} + R_{BC}$$

$$R_{AC} = 2 + 2 = 4\Omega$$

Colour Coding of Resistors

The value of resistance is usually coded where by three bands of colours, followed by one band for the tolerance. The first two bands of colours indicate the first two digits. The third band gives the value of the multiplier, and the fourth band gives the value of tolerance.

The following Chart gives the Colour Code of Resistances:

Colour	First digit	Second digit	Multiplier	Tolerance
Black	0	0	10^0	-
Brown	1	1	10^1	-
Red	2	2	10^2	-
Orange	3	3	10^3	-
Yellow	4	4	10^4	-
Green	5	5	10^5	-
Blue	6	6	10^6	-
Violet	7	7	10^7	-
Grey	8	8	10^8	-
White	9	9	10^9	-
Gold	-	-	10^{-1}	5%
Silver	-	-	10^{-2}	10%
No colour	-	-	-	20%

1. Red, red, orange and no colour indicate the value of resistance = $22000\ \Omega \pm 20\%$
2. Red, orange, orange and gold indicate the value of resistance = $23000\ \Omega \pm 5\%$

Bulbs in Series

If the second terminal of a bulb is connected to the first terminal of the next bulb and so on, then the bulbs are said to be connected in series.

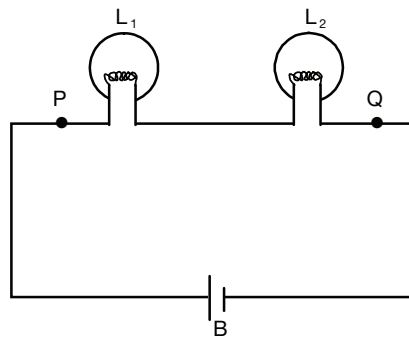


FIGURE 7.14 Bulbs in series in a circuit

If a voltage (V) is applied across the bulbs in series, then

1. voltage applied is divided among the bulbs.
2. same current exists in all the bulbs.
3. the brightness of each bulb depends on the number of bulbs connected
4. failure of any bulb leads to a break in the circuit.

Bulbs in Parallel

If the first terminal of all the bulbs are connected together and the second terminals of all the bulbs are connected together, then the bulbs are said to be connected in parallel.

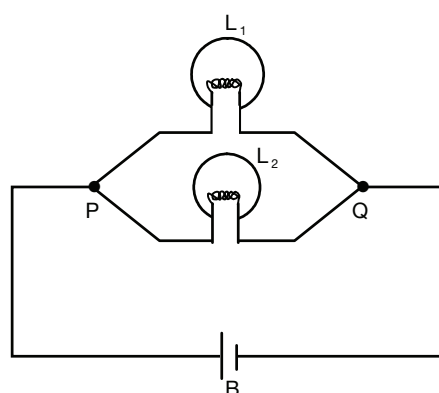


FIGURE 7.15 Bulbs in parallel

If a voltage (V) is applied across the bulbs connected in parallel, then

1. the voltage across each bulb remains the same.
2. the current is divided among the bulbs.
3. the power consumption of each bulb remains the same, even when the other bulb is removed.
4. the brightness of each bulb remains the same, even when the other bulbs is removed.
5. the failure of a particular bulb has no effect on the working of the other bulbs in parallel.

Electric Cell

An electric cell is a device which provides a constant potential difference between the ends of conductor connected across its two terminals. It converts chemical energy into electrical energy.

Open and Closed Circuits

As a result of constant potential difference provided by a cell, a current flows through the circuit connected to it. A circuit is a path through which the current flows. If the path is broken due to an open switch or if there is an insulator within the path, current cannot flow and such a path is called an open circuit. The closed continuous path made of conductors is called a closed circuit.

Electromotive Force (EMF) of a Cell

When no current is drawn from a cell, i.e., it is an open circuit, the potential difference between the terminals of the cell is called the emf of the cell.

In the older days, emf was an abbreviation for electron motive force. It was thought that a cell generates a force, which is responsible for the motion of, i.e., flow of electricity.

The EMF is a characteristic of a cell and is different for different cells. For eg., EMF of a voltaic cell is 1.08 V and for Leclanche cell, it is 1.5 V. It is denoted by symbol E . The EMF is equal to the work done in taking a unit positive charge through the external circuit connected to the cell and the electrolyte inside the cell.

Terminal Voltage

The potential difference between the two terminals of the cell, when current is drawn from it, i.e., the cell is in closed circuit, is called its terminal voltage. It is denoted by ' V '.

Terminal voltage is equal to the work done in taking a unit positive charge around the external circuit only, connected across the terminals of the cell. The terminal voltage is, therefore, always less than the EMF of cell.

The difference between E and V of a cell is called lost volt. The voltage is lost because of the resistance offered by the cell itself to the flow of current.

Internal Resistance of Cell

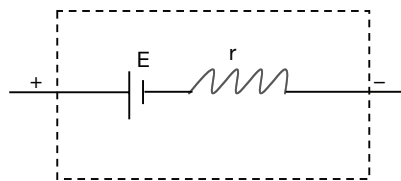


FIGURE 7.16 Internal resistance of a cell

When a current is drawn from a cell, in the external circuit it flows from anode to cathode and inside the cell through electrolyte, it flows from cathode to anode to maintain the continuity. The electrolyte offers certain resistance to the flow of current. This is called the internal resistance of cell. It is denoted by symbol r . If current I is drawn from the cell, the lost voltage or voltage drop across the internal resistance ' r ' of the cell is given by,

$$v = Ir$$

The internal resistance is considered to be in series with the cell.

EMF = terminal voltage + internal voltage drop.

$$E = V + v$$

The internal resistance of the cell depends upon the following factors:

1. It is directly proportional to the distance between the two electrodes.
2. It is inversely proportional to the area of cross section of the electrodes.
3. It depends upon the nature, concentration and temperature of the electrolyte.

The terminal voltage depends on external resistance, internal resistance and emf of the cell, whereas emf is independent of external and internal resistance

Relation between emf, terminal voltage and internal resistance

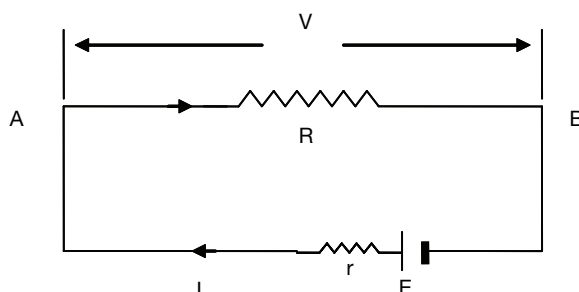


FIGURE 7.17 Circuit diagram to show relation between emf, terminal voltage and internal resistance

When the cell is connected to an external resistance ' R ', a current ' I ' is drawn from the cell. The total voltage ' E ' of the cell is dropped across the internal resistance ' r ' and the external resistance ' R '.

According to Ohm's law, the voltage drop across the internal resistance ' r ' is equal to Ir .

Similarly the voltage drop across the external resistance ' R ' is equal to IR . Since both the resistances are connected in a series $E = Ir + IR$.

Let the voltage across the terminals AB be V . then,

$$V = IR \text{ or } E = Ir + V.$$

$$\Rightarrow E - V = Ir \text{ or } = \frac{E - V}{I}$$

$$\text{Since } I = \frac{V}{R}, r = \frac{E - V}{V/R} = \left(\frac{E - V}{V} \right) \times R = \frac{E - V}{I} (\because V/R = I).$$

The smaller the internal resistance, the better is the cell. With the passage of time, the internal resistance of a dry cell increases.

Cells in Series

When the negative terminal of a cell is connected to the positive terminal of the next cell and so on, the cells are said to be in series.

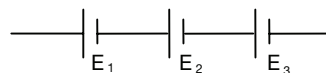


FIGURE 7.18 Cells in series

Cells connected in series are shown in Fig. 7.18.

When several cells are connected in a series, the total emf is the sum of the emf's of individual cells.

$$E = E_1 + E_2 + E_3$$

When the cells are connected in a series, the total internal resistance is equal to the sum of the internal resistances of the individual cells.

$$r = r_1 + r_2 + r_3$$

Cells in Parallel

When the negative terminals of all the cells are connected together and all the positive terminals are connected together, as shown in Fig. 7.19 then the cells are said to be in parallel.

When several identical cells are connected in parallel, the total emf is the same as the emf of individual cells.

When the cells are connected in parallel, the equivalent internal resistance is given by ‘reciprocal of the total internal resistance is equal to the sum of the reciprocals of individual internal resistances’.

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

If cells are identical, then $r_{eq} = r/n$

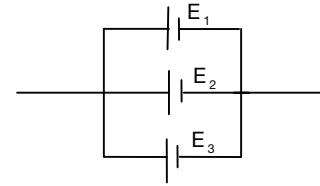


FIGURE 7.19 Cells in parallel

Heating Effect of Current

When a potential difference is applied between the ends of a conductor, current begins to flow through it. The current flows as large number of free electrons present in the conductor begin to drift from the end at lower potential to the end at higher potential. In the process, they constantly keep on colliding with positive ions of the conductor. The ions gain energy and begin to vibrate more vigorously about their mean positions. The average kinetic energy of atoms of conductor increases. This results in a rise in the temperature of the conductor and we say that the conductor has been heated. Thus, flow of current has a heating effect on the conductor. The heat produced (Q) depends on the following factors.

1. **Resistance of conductor:** More the resistance of conductor more is the number of collisions between free electrons and ions. Hence, if a conductor offers more resistance to the flow of current, the heat produced in it will be more.

$$Q \propto R$$

2. **Current flowing through the conductor:** Heat produced increases with the increase in the strength of the current flowing through conductor.

$$Q \propto I^2$$

3. **Time of flow of current:** As the time of flow of current increases, the heat produced also increases.

$$Q \propto t$$

Thus, a conductor having larger resistance will generate more heat when a stronger current passes through it for a longer time.

If I is the current flowing a conductor of resistance R for time t , the heat produced (Q) is given by,

$$Q \propto I^2 R t$$

ELECTRIC ENERGY AND ELECTRIC WORK

The energy spent in moving an electric charge through a conductor is called electric energy. This energy is provided by a cell which converts chemical energy into electric energy.

The work done in moving an electric charge through a conductor, when some potential difference is applied at its ends is called electric work.

Let ' W ' work is done in moving charge Q under potential difference V .

$$V = \frac{W}{Q}$$

or

$$W = VQ$$

$$\text{But } Q = It$$

$$\therefore W = VIt \quad (7.3)$$

According to Ohm's law

$$V = IR$$

Substitute this in equation (7.3)

$$\therefore W = (IR)It$$

$$W = I^2 R t$$

$$\text{Also } I = \frac{V}{R}$$

Substitute this in equation (7.3)

$$W = V \left(\frac{V}{R} \right) t$$

$$W = \frac{V^2}{R} t$$

$\therefore$ Electric work or energy can be expressed as

$$W = VIt = I^2 R t = \frac{V^2}{R} t = VQ$$

If the current is flowing through a heating element like in a heater, the electric energy is converted to heat energy.

Electric Power

The rate at which electric work is done is called electric power.

or

The amount of electric work done in one second is called electric power.

Let a cell do work W in time t , the power delivered by it is

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

Units of Electric Power

If work done is measured in joule and time in second, power is measured in watt (W).

$$\text{Watt} = \frac{\text{Joule}}{\text{second}}$$

The power developed is 1 watt if 1 joule of work is done in 1 second.

$$1 \text{ Watt} = \frac{1 \text{ Joule}}{1 \text{ second}}$$

Higher units of power

$$1 \text{ kilowatt (kW)} = 1000 \text{ W} = 10^3 \text{ W}$$

$$1 \text{ Megawatt (MW)} = 10^6 \text{ W}$$

$$1 \text{ Horsepower (hp)} = 746 \text{ W}$$

$$1 \text{ KW} = 1.34 \text{ hp}$$

$$P = \frac{W}{t} \quad (7.4)$$

But $W = VIt$

$$\therefore P = \frac{VIt}{t}$$

$$P = VI$$

Power is also measured in volt-ampere

$$W = I^2 R t$$

Put in equation (7.4)

$$P = \frac{I^2 R t}{t}$$

$$\therefore P = I^2 R$$

$$W = \frac{V^2}{R} t$$

Substitute in eqn. (7.4)

$$P = \frac{\frac{V^2}{R} t}{t}$$

$$P = \frac{V^2}{R}$$

$$\therefore P = \frac{W}{t} = VI = I^2 R = \frac{V^2}{R}$$

Commercial Units of Electrical Energy

$$\begin{aligned}\text{Electric power} &= \frac{\text{electric work}}{\text{time}} \\ &= \frac{\text{electric work}}{\text{time}}\end{aligned}$$

$$\therefore \text{electric energy} = \text{electric power} \times \text{time}$$

$$\text{unit of electric energy} = \text{unit of electric power} \times \text{unit of time} = \text{watt} \times \text{second}$$

The unit watt second gives the energy consumed by an electrical appliance, in t seconds whose power is P watt.

However, for practical purposes, higher units of energy are used. The higher units of electrical energy are watt-hour (W h) or kilowatt-hour (kW h).

If an electric appliance of power P watt is used for 1 hour, the energy consumed by it is 1 watt hour.

$$\begin{aligned}1 \text{ watt hour} &= 1 \text{ watt} \times 1 \text{ hour} \\ &= 1 \text{ W} \times (60 \times 60) \text{ s} = 3600 \text{ W s}\end{aligned}$$

$$1 \text{ Watt hour} = 3600 \text{ J.} \quad (\text{W s} = \text{J})$$

One kilowatt hour is the energy consumed in 1 hour by an electric appliance whose power is 1 kilowatt.

$$\begin{aligned}1 \text{ kilowatt - hour} &= 1 \text{ kilowatt} \times 1 \text{ hour} \\ &= 1 \text{ kW} \times (60 \times 60) \text{ s} \\ &= 1000 \text{ W} \times 3600 \text{ s}\end{aligned}$$

$$1 \text{ kilowatt hour} = 3.6 \times 10^6 \text{ J}$$

$$1 \text{ kW h} = 3.6 \text{ MJ}$$

The electric meter installed at our homes measures the energy consumed in kilowatt hour.

EXAMPLE

Two resistors of $15 \, \Omega$ and $4 \, \Omega$ in series are connected to a cell of EMF 2 V and internal resistance $1 \, \Omega$. Draw the circuit diagram and find the following:

- (i) current in the circuit
- (ii) voltage drop across each resistor
- (iii) terminal voltage of the cell
- (iv) lost voltage

SOLUTION

The circuit diagram based on the given information is shown in Fig. 7.20:

1. Current in the circuit:

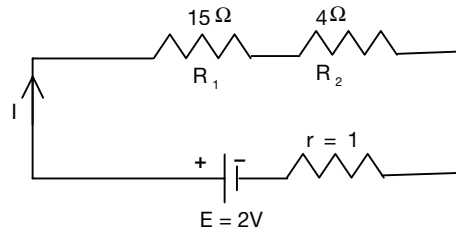


FIGURE 7.20

$$I = \frac{\text{EMF}(E)}{\text{Total circuit resistance } (R)}$$

The internal resistance of cell is in series with the external resistances.

$$\therefore R = R_1 + R_2 + r = 15 \, \Omega + 4 \, \Omega + 1 \, \Omega$$

$$R = 20 \, \Omega$$

$$I = \frac{20V}{20\Omega}$$

$$I = 0.1 \, \text{A}$$

2. Voltage drop or potential difference (V_1) across R_1

$$V = IR_1 \quad (\text{Ohm's law})$$

$$V_1 = 0.1 \, \text{A} \times 15 \, \Omega$$

$$V_1 = 1.5 \, \text{V}$$

Similarly,

$$V_2 = IR_2 = 0.1 \, \text{A} \times 4 \, \Omega$$

$$V_2 = 0.4 \, \text{V}$$

3. Terminal voltage

It is equal to the total voltage drop in external circuit.

$$V = V_1 + V_2$$

$$= 1.5 \, \text{V} + 0.4 \, \text{V}$$

$$= 1.9 \, \text{V}$$

4. Lost voltage is the voltage drop across the internal resistance of cell.

$$v = Ir$$

$$= 0.1 \times 1 = 0.1 \, \text{V}$$

Also,

$$v = E - V$$

$$= 2 \, \text{V} - 1.9 \, \text{V} = 0.1 \, \text{V}$$

EXAMPLE

A 20 V electric bulb is connected to a 20 V battery of negligible resistance. The resistance offered by the bulb is $5\ \Omega$. Find:

- (i) Current flowing through the bulb.
- (ii) Power of the bulb.
- (iii) Electric energy consumed by it in 3 hours.

SOLUTION

Given,

Voltage of bulb (V) = 20 V

Resistance of bulb (R) = $5\ \Omega$

Time (t) = 3 hours = $3 \times 60 \times 60 = 10800\ s$

1. Current (I) through bulb = $\frac{V}{R}$

$$I = \frac{20V}{5\Omega} = 4A$$

2. Power (P) = $V \times I$
 $= 20\ V \times 4\ A = 80\ W$

3. Electrical energy (W) = $V \times I \times t$
 $= 80 \times 10800$
 $= 864000\ J$

$$W = \frac{864000}{3.6 \times 10^6}\ \text{kW h} = 0.24\ \text{kW h}$$

EXAMPLE

The resistance of a electric heater is $200\ \Omega$ and it draws a current of 1A. Calculate its power and potential difference at its ends.

SOLUTION

Given,

Resistance of heater (R) = $200\ \Omega$

Current through heater (I) = 1 A

Power of heater (P) = ?

Potential difference (V) = ?

$$P = I^2 R$$

$$= (1)^2 \times 200$$

$$P = 200 \text{ W}$$

$$V = IR = 1 \text{ A} \times 200 \text{ } \Omega$$

$$V = 200 \text{ V}$$

WATT HOUR METER

Watt hour is a unit in which the amount of electric energy consumed by a device is measured. A meter which measures the electric energy consumed by various electric appliances is called watt hour meter. It is commonly called a electric meter which is installed at every house by the state electricity board.



FIGURE 7.21 Kilowatt hour meter

It is connected before the main switch so that the total current drawn by all the appliances in the house passes through it and it can give the reading of energy consumed. The meter readings at the beginning and end of month are noted. The difference in the readings gives the energy consumed in that month in watt hour. This reading when multiplied by rate, fixed by the state electricity board per unit (one kW h), gives the monthly bill which has to be paid by the owner of the house.

EXAMPLE

What should be the bill for the month of March for a heater of resistance $60.5 \text{ } \Omega$ connected to 220 V mains? The cost of energy is Rs.2 per kW h and the heater is used for 3 hours daily.

SOLUTION

Given,

Resistance (R) of heater = $60.5 \text{ } \Omega$

Potential difference (V) = 220 V .

Power (P) of heater is

$$P = \frac{V^2}{R}$$

$$P = \frac{220 \times 220}{60.5} = \frac{48400}{60.5}$$

$$= \frac{48400}{60.5}$$

$$P = 800 \text{ W}$$

$$\begin{aligned}\text{Energy consumed by heater in a day} &= P \times t \\ &= 800 \text{ W} \times 3 \text{ h} \\ &= 2400 \text{ W h}\end{aligned}$$

There are 31 days in the month of March

$$\begin{aligned}\therefore \text{Energy consumed by heater in 31 days} \\ &= 2400 \text{ W h} \times 31 \text{ days} \\ &= 72000 \text{ W h} = 72 \text{ kW h}\end{aligned}$$

For 1 kW h, the charge is ₹ 2

$$\begin{aligned}\text{So, for 72 kW h, the charge will be} \\ &= 72 \times 2 = ₹ 144\end{aligned}$$

EXAMPLE

Calculate the monthly bill if the following appliances are used as indicated below at the rate of ₹ 5 per unit.

- (i) A heater of 1000 watt for 2 hours daily.
- (ii) Ten 60 watt bulbs for 5 hours daily.

SOLUTION

Energy consumed by 1000 watt heater for 2 hours = $1000 \times 2 = 2000$ watt hour

Energy consumed by ten 60 watt lamp for 5 hours = $10 \times 60 \times 5 = 3000$ watt hour

Total energy consumed per day = $2000 + 3000 = 5000$ watt hour = 5 kW h

Total energy consumed for the month = $5 \times 30 = 150$ kW h

Cost per kW h = Rs.5

Cost for 150 kW h = $150 \times 5 = \text{Rs.}750$

WATTAGE

The amount of electrical energy consumed by an electrical appliance per unit time is known as wattage.

$$\text{Wattage } (P) = I^2 R \text{ or } = \frac{V^2}{R} \text{ or } Vi$$

Unit of wattage is watt (W).

Multiple units are kW (10^3 W) and MW (10^6 W).

JOULE'S LAW

If W is the mechanical work done by a body (in joule) and Q is the quantity of heat produced by it (in calories), then is $W \propto Q$ or $W = JQ$ where J is the mechanical equivalent of heat or Joule's constant. $J = 4.18 \text{ J cal}^{-1}$.

We have seen that when electric current passes through a resistor, the electric energy spent or electric work done in moving the charges is converted into heat energy. In fact work done in any form, i.e., mechanical, chemical, etc., can be converted into heat energy. Joule conducted a series of experiments and found that the same work done in different forms produces the same quantity of heat in all cases. This is called Joule's law.

Joule showed that there is a definite relation between work done and heat produced by it.

Let W is the mechanical work done and Q is the heat produced in calories.

According to Joule's law

$$W \propto Q$$

$$W = JQ$$

where J is the constant of proportionality also called mechanical equivalent of heat

$$J = \frac{W}{Q}$$

The value of J is 4.18 J cal^{-1} if work done and heat produced are measured in joules and calories, respectively. If both are measured in joules, then the value of J becomes unity.

Determination of the value of J using the Joule's calorimeter experiment

1. Take a calorimeter with a stirrer having a mass of w_1 gm.
2. Take some quantity of water in a calorimeter, let the mass of the calorimeter with stirrer and water be w_2 gm.
3. Place the calorimeter in a wooden box. Insert a thermometer and note the initial temperature of water. Let it be $t_1^\circ\text{C}$.
4. Immerse a heater or coil (H) in water. Its two ends are connected to a plug key, a battery, an ammeter and a rheostat. A voltmeter is connected in parallel with the coil. (See Fig. 7.22).

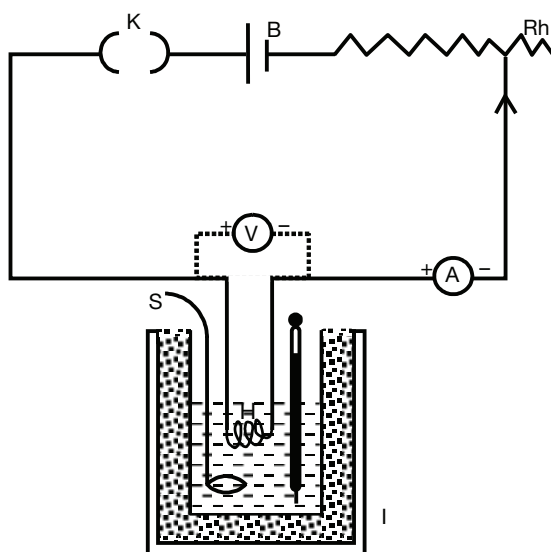


FIGURE 7.22 Joule's experiment

With the plug key (k) closed, adjust the rheostat, so that a current of I ampere flows through the heater. Pass the current for a period of 30 minutes. Unplug the new key and note the new temperature of water. Let it be $t_2^\circ\text{C}$.

The electrical work (w) done by heater = VIt

Heat developed by the heater (Q) is given by the sum of the heat gained by the calorimeter with stirrer (Q_1) and water (Q_2)

$$\Rightarrow Q = Q_1 + Q_2$$

$$Q = w_1 s_c (t_2 - t_1) + m_w s_w (t_2 - t_1) = (t_2 - t_1) (w_1 s_c + m_w)$$

where w_1 = mass of the calorimeter with stirrer

s_c = specific heat of copper

s_w = specific heat of water = $1 \text{ g } 1 \text{ calorie g}^{-1} \text{ }^\circ\text{C}^{-1}$

mass of water, $m_w = (w_2 - w_1)$

According to Joule's law

$$W = JQ$$

$$J = \frac{W}{Q} = \frac{VIt}{(t_2 - t_1)[w_1 s_c + m_w]}$$

Experimentally, it is found that $J = 4.18 \text{ J cal}^{-1}$

Applications of Heating Effect of Electric Current

1. **Electric heater:** It uses nichrome wire as a heating coil. The spiral coil of nichrome wire is placed in a groove in a porcelain frame in a zig zag manner. When current is

passed through it, the wire gets red hot due to high resistance. The heat generated is used for cooking or heating purposes. Porcelain being an insulator of heat, does not become hot.

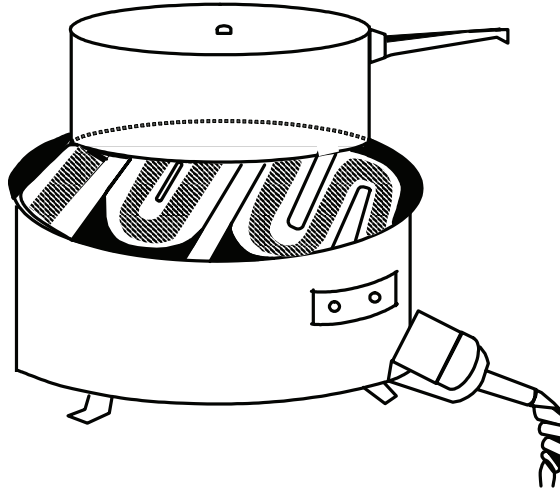


FIGURE 7.23 An electric stove

2. **Electric iron:** The coil of high resistance nichrome wire is enclosed in mica sheets which are placed in a heavy metal block. The coil is connected to power supply and transfers its heat to the metal block which is used to iron clothes. The heating coil is embedded between mica sheets as mica is a good conductor of heat but bad conductor of electricity.

Lighting Effect of Electricity

When current passes through a conductor, it gets heated up. On being sufficiently heated, it may begin to emit light. This is called lighting effect of electricity.

For example: electric bulbs and tubes.

Thus, electric lamps work on lighting effect of electricity. Following types of electric lamps are commonly used.

1. Filament lamp
2. Discharge lamp
3. Fluorescent lamp
4. Electric arc lamp

Incandescent or Filament Lamp

Incandescence is a phenomenon in which an object emits light when heated to a high temperature.

This phenomenon is used in electric lamps which are called incandescent lamps. The element which is heated is connected in lamps in the form of a thin filament. Hence, it is also called a filament lamp. Tungsten filament is most suitable for this purpose because of its following characteristics.

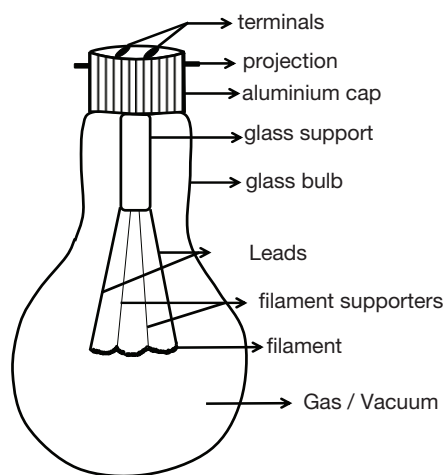


FIGURE 7.24 An electric bulb

1. Its melting point is very high about 3665°C .
2. It offers high resistance. Hence, it gets heated quickly.
3. It does not get oxidized easily.

The temperature of long thin tungsten filament can rise upto 3000°C . It is usually operated for a long period of time. Hence, it evaporates and condenses on the inner side of the glass surface of the bulb forming a layer on it. This decreases the life and efficiency of the lamp. To prevent this, the bulb is evacuated and filled with a gas at low pressure. The rate of evaporation decreases and filament can reach a higher temperature.

In olden days carbon filament was used in bulbs. The melting point of carbon is 1600°C which is low considering the heat generated in the bulb. On evaporation, black layer of carbon gets deposited on the inner side of bulb. Life of carbon filament bulb is short.

Discharge Lamps

They are so called because they use discharge tubes. Discharge tube is used to study conduction of electricity through gases. It consists of a glass tube having two electrodes fused to it and filled with one or more gases at very low pressure. A high potential difference is applied across the electrodes which ionises the gases. The ions get accelerated towards electrode with opposite polarity during which they collide with neutral gas atoms. If the pressure of gas is 1.65 mm of Hg, the tube begins to glow due to successive collisions. The nature of gas determines the color of light emitted.

Sl. No.	Gas in the discharge tube	Colour of light
1	Neon	Orange
2.	Nitrogen	Red
3.	Sodium	Yellow
4.	Mercury	White
5.	Chlorine	Green
6.	Hydrogen	Blue

Fluorescent Lamps

Discharge lamp when coated with fluorescent material from inside is called a fluorescent lamp.

A high voltage applied to coils heat them which results in emission of electrons. These electrons collide with the atoms of mercury vapours present in the tube. These collisions cause emission of invisible ultraviolet (uv) material which emits visible bright light.

Compact fluorescent lamps (CFL) use small fluorescent tubes. Electronic circuits control the intensity of current. Main advantage of CFL is that it consumes small amount of electrical energy.

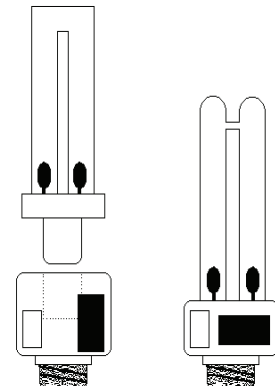


FIGURE 7.25 Fluorescent lamps

The advantages of fluorescent lamps over incandescent lamps are listed below:

1. Fluorescent lamps have a longer life span, almost 5 times that of incandescent lamps.
2. They consume less electrical energy.
3. The shadow formed by fluorescent lamps is faint when compared to incandescent lamps.
4. The brightness of fluorescent lamp is more for the same power consumed by them.

Electric arc Lamps

They are used to produce high intensity light as in search lights or cinema projector.

It consists of two carbon rods having pointed tips at one end. The tips are separated by a very small gap. A potential of about 40 V to 60 V is applied across the carbon rods and a glow is produced between the pointed tips. The glow emits very intense light. Using concave mirrors, this light can be focused on a point or can be converted to a parallel beam.

HOUSEHOLD DISTRIBUTION OF CURRENT

Fuse

Fuse is a very important safety device in an electric circuit. It is a thin wire which melts and breaks the electric circuit due to 1) overloading 2) short circuit 3) fluctuation in power supply

Characteristics of Fuse

1. It should have a low melting point. Generally a fuse wire is made from an alloy containing 50% lead and 50% tin. Its melting point is around 200°C .
2. Since fuse should melt, before the excess of current reaches electric appliances and damages them, the temperature of fuse should rise quickly. This is possible if the resistance of fuse is very high.

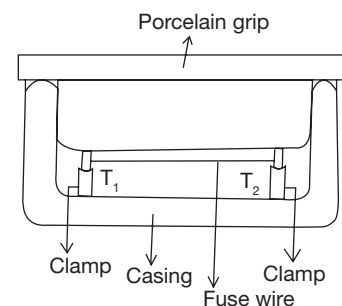


FIGURE 7.26 A fuse

A fuse wire is stretched between two terminals T_1 and T_2 fixed to porcelain casing or holder which fits into porcelain grip or socket. The porcelain socket is connected to live wire. For any reason, if excessive current begins to flow the fuse wire gets heated up more quickly than conducting wires and melts, breaking the circuit. Thus, the excessive current is prevented from flowing through electric appliances, which may damage them.

Current Rating of Fuse

Different electric circuits can withstand certain maximum amount of current without getting heated up and damaging themselves. For example, for a lighting circuit, this limit is 5 A and for a heating circuit, it is 15 A. If current approaches this value, fuse wire will melt. Thus, the current ratings of fuse should be less than the maximum current that can safely flow through the circuit.

Fuse should be connected in live wire of a circuit. If it is connected to neutral wire, the fuse will melt when current exceeds its rating, but the appliance will still be connected to high potential of supply through live wire. If a person touches the appliance, his body provides a path for current to flow to earth which is at zero potential. Thus, person may get severe shock which may prove fatal. Hence fuse is connected to live wire so that if it melts, the appliance is no longer connected to the high potential of the supply and possibility of electric shock is eliminated.

Earthing

When the insulation of live wire in a circuit inside a electric appliance melts due to some reasons, the live wire may touch the metal casing of the appliance. Thus, metal casing is connected to high potential. This metal casing of appliances such as mixer, fan, refrigerator, toaster, etc., is continuously touched by us by our bare hands. Hence we may get a severe shock as current will flow through our body to earth which is considered as zero potential. To prevent this, metal casings of all appliances are connected to earth by a conducting wire. This is called earthing.

Thus, earthing involves connecting metal body of electric appliance to thick copper wire which is connected to a copper plate buried deep in the earth. The copper plate is surrounded by a mixture of charcoal and common salt.

Earthing helps in two ways. When live wire comes in contact with metal casing, the current instead of flowing through the person touching it, flows through earth wire. Also when live wire touches wire, i.e., during short circuit, the current from metal body flows through earth wire which offers very less resistance. Thus, a large current is drawn which melts the fuse instantly. The appliance does not receive current any more thus preventing it from potential damage.

Household Distribution of Current

Electricity is supplied to houses through over head wires on poles or through underground cable. The electric cable consists of 3 wires, viz., live wire or phase wire, neutral wire and earth wire. The company which supplies electric power installs its fuse near the pole or before the kWh meter. If the house draws more than allotted current, this fuse which is called pole or company fuse melts and supply is cut off.

At the power station, neutral and earth wire are connected together so that both are at ground or zero potential. The live and electrical wire are connected to the input terminals of kWh meter and the earth wire to the body of meter. On the output side of kWh meter, fuse is connected in series with live wire. This fuse is called main fuse. After this, live and neutral wires are connected to the main switch.

The main switch is an iron clad double pole switch. It is operated by a single lever and can connect and disconnect both live and neutral wire simultaneously to the house. These two wires then carry power to whole house. The distribution of electric power in the house is done by two types of wiring system.

1. Tree type
2. Ring type

TREE SYSTEM

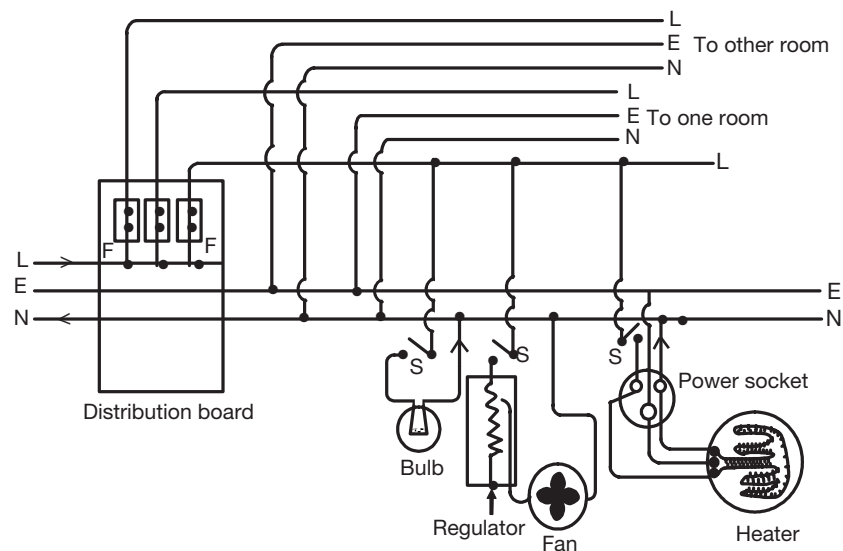


FIGURE 7.27 Tree system of wiring in household circuits

Phase wire to different rooms is taken from the main board, through a fuse on the main board. Neutral and earth wire is common to all the circuits.

The different circuits coming from the main board is connected in parallel.

If there is a short circuit in one particular circuit, then only the fuse of that circuit is broken and the power supply to other parts of the circuit will not be affected. This is the major advantage of parallel circuit.

Disadvantages of Tree System

A long length of wire is required as all the wires are to be drawn from the main board itself. It increases the initial installation cost. When the fuse of a particular line melts, it affects all the appliances connected to that circuit.

Ring System

It consists of a ring formed by all the three wires—phase, neutral and earth and runs through all the rooms and comes back to the main board. Each appliance is connected to this ring. Appliances which are likely to get short circuited are protected by a fuse near the appliance.

Advantage

As one ring feeds the entire house, it requires less length of wire. It reduces installation cost. As there is an individual fuse for each appliance, only faulty appliance will not work and all the other appliances will not be affected. It is easier to install.

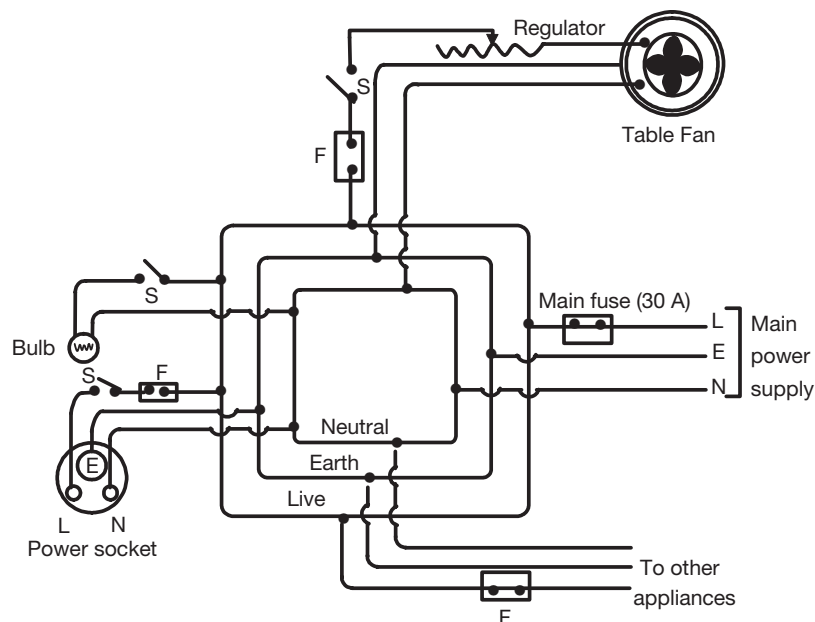


FIGURE 7.28 Ring system of wiring in household circuits

Switch

Switch is a device to connect or disconnect an electric appliance.

1. Lever type switch is used for light, fan, heater, etc.
2. Push switch is used in devices like calling bell.
3. Single pole double throw switch is used for staircase lights.
4. One staircase bulb can be switched on or off either from the first floor or from the ground floor.

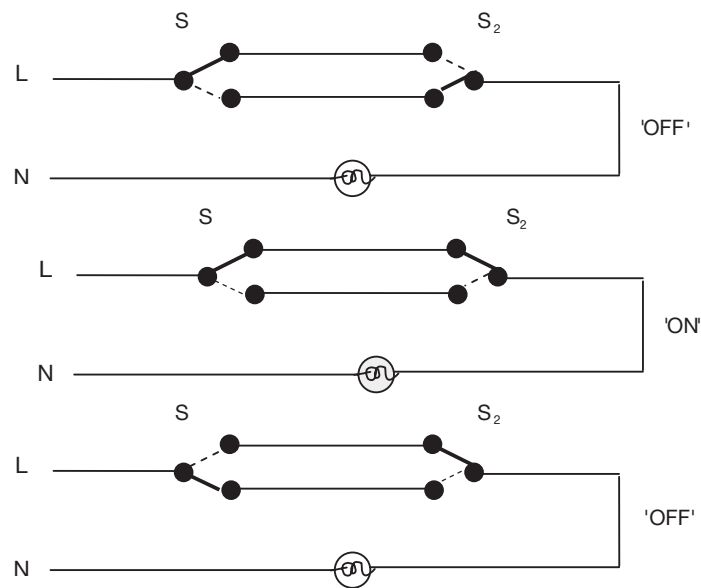


FIGURE 7.29 Switches in electric circuit

The same switch is used near the room entrance and near the bed, so that we can switch on the light as we enter the room and switch it off when we go to bed.

The functioning of a staircase type switch is shown below.

We should always connect the switch in the live wire and not on the neutral wire. This is for safety reasons. Suppose the switch is connected to neutral, the live wire remains connected to the appliance even when the switch is in off position. This may prove fatal if proper earthing is not there. We should not touch the switch with a wet hand as it may act like a conducting path and one receives a fatal electric shock.

Socket

Sockets are elements of electric circuit from where we draw power to movable electric appliances like radio, electric iron, toaster, etc. It has three terminals live, neutral, and earth. The bigger hole at the top is the earth terminal, Live terminal is on the right and neutral terminal is on the left.

Plugs

It is the counterpart of socket which is kept as the input terminal to electrical appliances. It has three pins. Live pin is on the right, neutral pin is on the left and the earth pin is thick and at the top.

Plugs and sockets are available for different applications like 5 A and 15 A. Proper sockets and plugs are to be used as otherwise it will overheat the socket/plug and burn.

Colour Coding of Wires

All electrical appliances are to be wired as per some standard. The old convention is Red wire for Live, Black wire for Neutral and Green wire for Earth.

According to the specifications of a recent international convention live wire is to be connected to brown, neutral wire to be connected to light blue and earth wire is connected to green or yellow wire.

Power Transmission

Mainly, we use alternating current as it is easy to step up and step down ac Voltage using a transformer. Now, let us see how the power from the power generating station reaches us.

- At the generating station, electricity is produced at a potential of 11 kV.
- It is stepped up by a transformer to 220 kV and sent to cities located far away.
- At the city outskirts, it is stepped down to 11 kV.
- At the street level, it is further reduced to 440 V (three phase) (220 volt single phase) and supplied to the houses.

The schematic diagram of power distribution is shown in Fig. 7.30.

Let us now see why it is necessary to step up the voltage at the transmitting end and step down the voltage at the receiving end.

We know power = VI

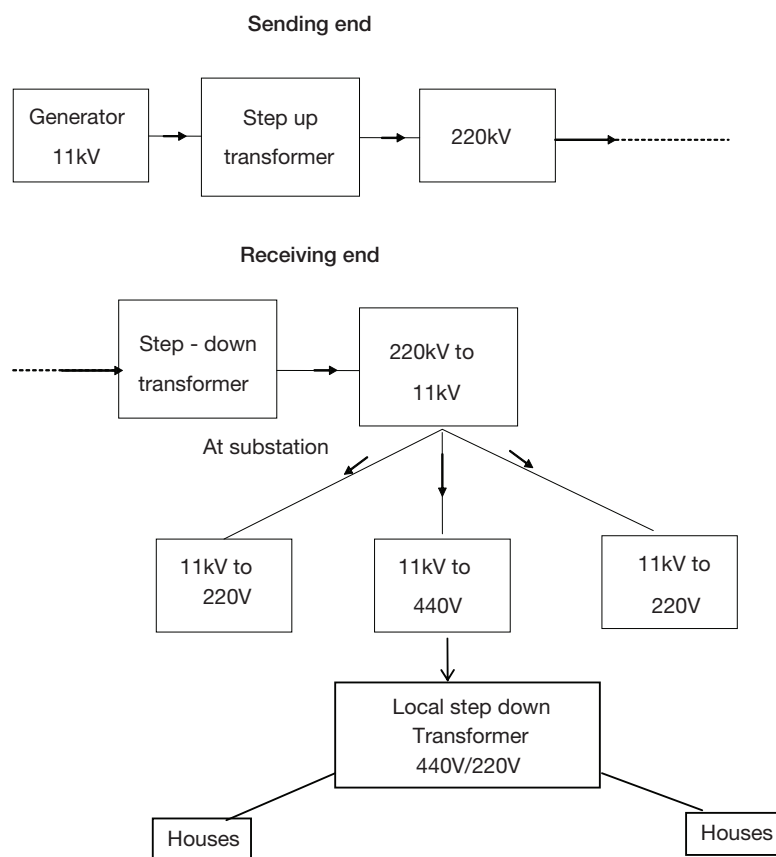


FIGURE 7.30 The schematic diagram of power distribution

For example, power required at Hyderabad can be sent from the power station at Nagarjunasagar in two ways. If we send at 220 volt a large current flows through the transmission wires and hence the heat loss due to transmission will be large.

This is because the power lost as heat is I^2R . Since current is more for a given conductor, the loss is more.

Further, we require thick wires which cost more.

If we send power at high voltage, then less current would flow for a given power and hence the loss will be minimized.

Further more, we can use thin wires as compared to earlier case. This reduces the cost of transmission wires.

CHEMICAL EFFECT OF ELECTRICITY

The most common chemical effect of current electricity is electrolysis. Just like solids, some liquids also conduct electricity. Such liquids are called electrolytes. When electric current passes through an electrolyte, it decomposes into its constituents.

Electrolysis

The process in which an electrolyte undergoes decomposition into its constituents when an electric current is passed through it are called electrolysis.

The plates inside the electrolyte through which the electric current is passed from the external battery are called **electrodes**.

The electrode which is connected to the positive terminal of the battery is called an **anode**.

The terminal which is connected to the negative terminal of the battery is called a **cathode**.

The vessel in which the electrolyte is kept is called a **voltameter**.

Following are the characteristics of electrolysis process.

1. The concentration of electrolyte remains unaffected during electrolysis.
2. The anode gains electrons as negative ions come to it and cathode loses electrons to positive ions which are attracted to it.
3. Number of electrons gained by anode is equal to number of electrons lost by cathode.
4. During electrolysis, mass of cathode increases while that of anode decreases by same amount.

Electrolysis of Water

Take some water in a glass vessel and add a few drops of sulphuric acid. Take two copper rods and connect them to two terminals of a battery.

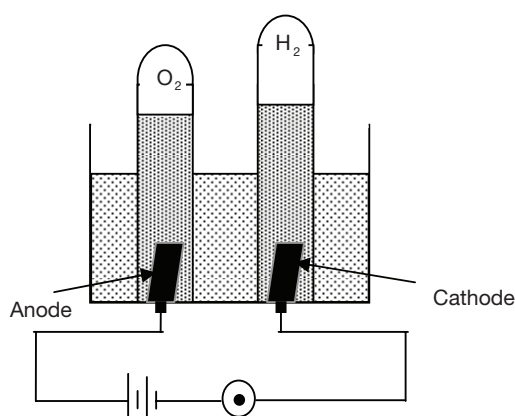


FIGURE 7.31 Electrolysis of water

When current is passed through them, the water molecules dissociate into hydrogen ions and oxygen ions.

Negatively charged oxygen ions are attracted by the positive electrode anode. Positively charged hydrogen ions are attracted by the negative electrode cathode. So Hydrogen and Oxygen ions are collected at the cathode and the anode, respectively.

Electrolysis of Copper Sulphate

Here copper sulphate is the electrolyte and both the electrodes are copper rods.

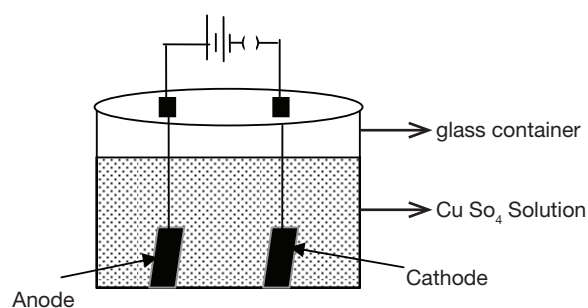


FIGURE 7.32 Electrolysis of copper sulphate

When current is passed through the copper sulphate solution, copper sulphate molecules split into copper ions Cu^{++} and sulphate ions SO_4^{--}



When current is passed, the positive copper ions are attracted by the cathode and a coating of copper is observed on the cathode. The negative sulphate ions are attracted by the anode. They react with copper and CuSO_4 molecules are formed, thereby maintaining the concentration of electrolyte.

Uses of Electrolysis

Electroplating, extraction of metals from ore (i.e., Metallurgy), purification of metals, electrotyping, etc.

Electroplating

The process of depositing a thin layer of a desired metal over another metal by passing an electric current through some electrolyte is called electroplating.

The object to be electroplated is taken as cathode and the metal to be coated is kept as anode. Suitable electrolyte is used.

Some common electroplating applications

Copper Plating

Cathode	: Article to be plated
Anode	: Copper rod
Electrolyte	: Copper sulphate solution

Silver Plating

Cathode	: Article to be plated
Anode	: A silver rod
Electrolyte	: Silver nitrate solution AgNO_3

Nickel Plating

Cathode	: Article to be plated
Anode	: Nickel rod
Electrolyte	: Nickel ammonium sulphate solution $\text{NiSO}_4(\text{NH}_4)_2\text{SO}_4\cdot 6\text{H}_2\text{SO}_4$

Chromium Plating

Cathode	: Article to be plated
Anode	: Chromium rod
Electrolyte	: Chromic acid solution H_2CrO_4

LAWS OF ELECTROLYSIS

Michael Faraday carried out a series of experiments and proposed two laws which are known as 'Faraday's laws of electrolysis'.

Faraday's First Law of Electrolysis

The mass of the substance deposited at the cathode is directly proportional to the quantity of electricity. (i.e., charge) and the time for which the current is passed through the Electrolyte.

Larger current passing through a given electrolyte for a given time or the same current passing for a longer time will deposit more mass on the cathode.

$$m \propto I; \text{ or } m \propto t; \text{ } m \propto It$$

Since

$$Q = It, \text{ } m = ZQ$$

The constant Z is known as **electrochemical equivalent** of the substance.

The electrochemical equivalent of a substance is defined as the mass of the substance which is produced during electrolysis by passing one coulomb of charge. The unit of Z is g C^{-1} .

E.C.E. (Electro Chemical Equivalent)

The mass of ions liberated at the electrode when 1 coulomb of electricity is passed through the electrolyte is known as e.c.e. It is denoted by Z and $Z = m/q$.

Units of Z are g C^{-1} (or) $\text{g A}^{-1} \text{ s}^{-1}$.

Faraday's Second Law of Electrolysis

When the same quantity of electricity passes through different electrolytes, the masses of ions liberated at the respective electrodes are proportional to their chemical equivalents.

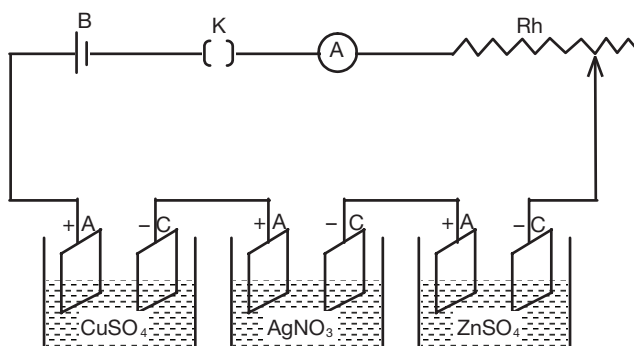


FIGURE 7.33 Faraday's experiment

If E_1 , E_2 and E_3 , are the chemical equivalents and Z_1 , Z_2 and Z_3 , are the electro chemical equivalents of three substances, says Cu, Ag and Zn, respectively and their masses liberated are m_1 , m_2 and m_3 , when the same quantity of electricity is passed through their respective electrolyte then according to Faraday's second law of electrolysis

$$\frac{m_1}{E_1} = \frac{m_2}{E_2} = \frac{m_3}{E_3} \text{ or}$$

$$m_1 : m_2 : m_3 : = E_1 : E_2 : E_3 \quad (7.5)$$

This is one form of Faraday's second law. If we apply the first law, then

$$\begin{aligned} m_1 &= Z_1 q & m_2 &= Z_2 q & m_3 &= Z_3 q \\ m_1 : m_2 : m_3 : &= Z_1 : Z_2 : Z_3 \end{aligned} \quad (7.6)$$

Combining equations (7.5) and (7.6), we get

$$Z_1 : Z_2 : Z_3 : = E_1 : E_2 : E_3$$

Chemical Equivalent (E)

The ratio of the atomic weight of an element to its valency is known as the chemical equivalent. It is denoted by E.

The amount of charge which on passing through an electrolyte liberates 1 gram equivalent of the substance at an electrode is called Faraday constant. The value of Faraday constant is 96500 C.

EXAMPLE

The e.c.e. of copper is $0.33 \times 10^{-3} \text{ g C}^{-1}$. If 1A current is passed for 2 hr. through copper sulphate find the mass of copper deposited on cathode.

SOLUTION

Given,

Current (I) = 1A

Time (t) = 2 h = $2 \times 3600 = 7200$ seconds

e.c.e. (z) of copper = $0.33 \times 10^{-3} \text{ g C}^{-1}$

mass (m) of copper deposited = ?

we have

$$Z = \frac{m}{It}$$

$$\therefore m = Zit$$

$$= 0.33 \times 10^{-3} \times 1 \times 7.2 \times 10^3 = 2.376 \text{ g}$$

EXAMPLE

During gold plating, 3 A current is passed for 1000 seconds and 2 g of gold is deposited. Find electro chemical equivalent of gold.

SOLUTION

Given,

Mass (m) of gold deposited = 2 g

time(t) from which current is passed = 1000 s

e.c.e. of gold (Z) = ?

$$Z = \frac{m}{It} = \frac{2\text{g}}{3 \times 1000} = 0.000666\text{gC}^{-1}$$

DRY CELL

A dry cell is a form of primary cell which is used widely in torches, transistor radios, electric toys, clocks, etc.

It consists of a zinc container at the centre of which a carbon rod is fixed. Carbon rod acts as an anode while the zinc body acts as cathode. The dry paste of ammonium chloride (NH_4Cl) and zinc chloride (ZnCl_2) serves as an electrolyte. The electrolyte is mixed with powdered coke. The carbon rod is surrounded by graphite and manganese dioxide. The top of carbon rod is connected to a brass cap to improve electrical conductivity. The container is sealed with sealing wax to make it air and water tight.

Zinc atoms from the container lose two electrons when the cell is connected to a electric circuit

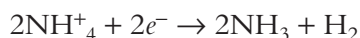


These electrons flow through external conducting wire and reach carbon electrode. This constitutes electric current. The conventional current is taken from carbon rod to zinc body.

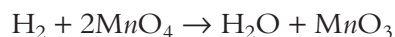
The ammonium chloride in the electrolyte dissociates as



The electrons lost by zinc combine with positive ammonium ions (NH_4^+)



The hydrogen gas produced is reduced by manganese dioxide.



The positive zinc ions combine with negative chlorine ions to form zinc chloride.



The powered carbon present in electrolyte facilitates the movements of charges.

Dry cell gives an emf of 1.5 volt. Since it is primary cell, once the chemicals present in cell are used up, cell has to be replaced by a new cell.

There are many secondary cells or accumulators which are also in wide use nowadays in which chemical reactions can be reversed by passing current in reverse direction. For example, lead sulphuric acid battery is widely used in automobiles and industries. Cell phones are powered by battery which can be easily recharged.

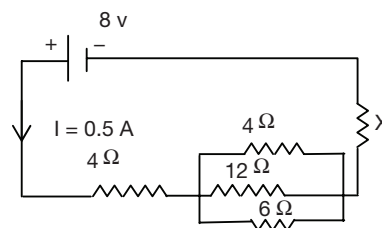
TEST YOUR CONCEPTS

Very Short Answer Type Questions

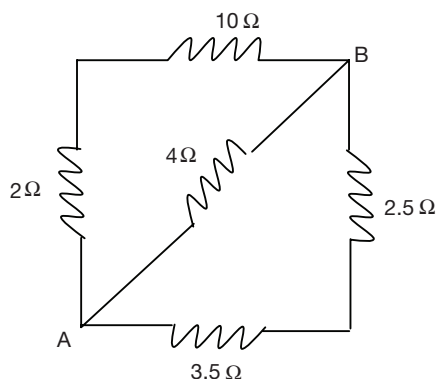
- Define resistance and one ohm resistance.
- How is equivalent resistance varies as resistances are connected in series and parallel?
- What is a fuse and specify its uses?
- What is Incandescence?
- State laws of resistance and define resistivity.
- What is electricity?
- Find the total internal resistance of the cells when they are all connected in
(a) series and (b) parallel
- The net charge flowing through a cross-section of conductor in unit time is called _____.
- What is the use of kilowatt-hour meter?
- Define static and current electricity.
- What is the value of mechanical equivalent of heat (J)?
- The unit of resistance is _____.
- Define conductance, conductivity and super conductors.
- What are conductors and insulators? Give one example of each _____.
- Define terminal voltage, internal resistance and lost voltage.
- Unit of electric charge is _____.
- What happens to the value of resistance when each of the length and the area of cross section of a conductor are tripled?
- What is the reason for conduction of electricity?
- What is watt hour?
- Electric potential is measured in _____.
- On increasing the temperature what is the variation of the resistance of a metallic conductor and semi-conductor?
- Define electric current.
- Define electric energy or work.
- Define electric potential, potential difference, and EMF
- What is the relation between current (I), emf (E), terminal voltage (V) and internal resistance (r)?
- Fuse should be connected to _____ wire of the circuit.
- Define electric power and give its unit in S.I. system.
- What is meant by conventional and electronic current?
- State Ohm's law and what are ohmic and non-ohmic conductors.
- What is electro plating?

Short Answer Type Questions

- Give reasons why the terminal voltage is less than the emf of a cell.
- Why is it desirable to transmit high voltage and low current during the transmission of power?
- How are the following systems connected?
(a) ring system
(b) tree system
- Three resistors of $5\ \Omega$, $3\ \Omega$ and $7\ \Omega$ are connected in series across a battery of potential difference 3 V. Find the current flowing through $3\ \Omega$ and $7\ \Omega$ resistors.
- Explain the factors influencing the internal resistance of a cell.
- Calculate the value of resistor X.
- Explain how earthing is done.
- Two heaters of 200 W each and two bulbs of 40 W each operate 4 hours daily on the supply of 200 V. If the cost of energy is 3 rupees per kW h. Find the bill for the month of April.



39. Give an expression for equivalent internal resistance when cells of different internal resistances are connected in series and parallel.
40. Find the equivalent resistance of the following circuit, between junction A and B.



41. When does a fuse melt?
42. The length and area of cross section of a wire are 1m and 0.040 cm^2 , respectively. If its resistance is 4 ohm, calculate its resistivity.
43. Derive $r = \frac{E - V}{I}$ where r is internal resistance, E – emf, V – terminal voltage, I – current.
44. What is the need for a step up and step down transformers at various stages of power transmission?
45. Show that $1 \text{ kW h} = 36 \times 10^5 \text{ J}$.

Essay Type Questions

46. State Joule's law. Explain an experimental method to determine the value of J .
47. State Faraday's first law and second law of electrolysis and verify them experimentally.
48. Derive an expression for equivalent resistance of resistors connected in series.
49. Explain the working of the following
(1) Filament lamp
(2) Fluorescent lamp
(3) Discharge lamp
(4) Electric arc lamp
(5) Drycells
50. Derive an equivalent emf when cells are connected in series and parallel.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

- Conventional current always flows from a body having high charge density to the body having low charge density.
- At constant temperature, the resistance of a conductor changes according to the applied voltage.
- The used up chemicals in a dry cell can be re obtained by charging it.
- In an electrolyte, the movement of ions is responsible for electric current.
- Electrotyping is an application of electrolysis.

- Electric potential at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point.
- Earthing of electric appliances prevents electric shock.

Directions for questions 8 to 14:

Fill in the blanks.

- Power transmission is carried out at high _____ and low _____.
- Switch is always connected to the _____ wire.
- Rate at which electric work is done is called _____.



11. The process of depositing a thin layer of a desired metal over another metal by passing an electric current through some electrolyte is called ____.
12. Conductance is the reciprocal of ____.
13. For a given cell, its terminal voltage depends on ____ and ____.
14. The amount of work done by the cell on a unit positive charge carrier to force it to go to the point of higher potential is called ____.
18. The colour code of a resistor is brown, black and brown. Then the value of resistance is ____.
- (a) $10\ \Omega$ (b) $100\ \text{m}\Omega$
(c) $0.1\ \text{k}\Omega$ (d) $100\ \Omega + 5\%$
19. The free electron density is more in ____.
- (a) conductors. (b) insulators.
(c) semi conductors. (d) electrolytes.
20. Among the following statements,

Direction for question 15:

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

15.

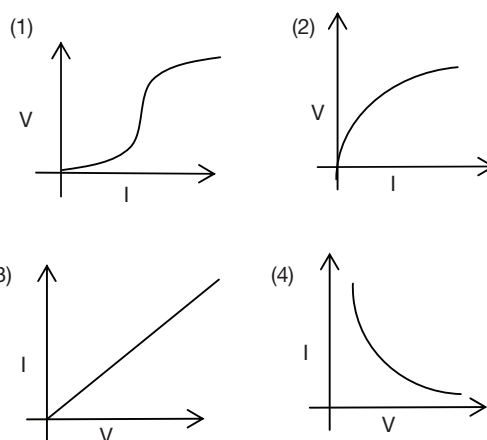
Column A	Column B
A. Electric potential	(f) a. Transistor
B. Commercial unit of electrical energy	(g) b. ohm-meter
C. Resistance	(h) c. $E = E_1 + E_2 + E_3$
D. Superconductor	(i) d. $Q = i^2 R t$
E. 1 ohm	(j) e. Black
F. Non-ohmic conductor	(a) f. $v = W/Q$
G. Resistivity	(b) g. kW h
H. Cells connected in series	(c) h. $\frac{\rho L}{A}$
I. Heat produced in a conductor	(d) i. Zero resistance
J. Neutral wire	(e) j. 1 volt/1 ampere

Direction for questions 16 to 40:

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

16. One kilowatt is equal to ____ horse power.
- (a) 1.34 (b) 1.32
(c) 1.28 (d) 1.38
17. In a series circuit,
- (a) current flow is same in all the resistors of the circuit
(b) potential difference across each resistor in the circuit is same.
(c) Both (a) and (b)
(d) None of these

- (A) A discharge lamp uses a discharge tube which is filled with a gas at a very low pressure.
(B) Always white light is emitted independent of gas taken in the lamp.
- (a) Only A is true
(b) Only B is true
(c) Both A and B are true
(d) Both A and B are false
21. The quantity of heat produced by a current in a conductor is directly proportional to ____ in the conductor.
- (a) the time of current flow.
(b) the square of magnitude of current.
(c) the resistance.
(d) All the above
22. Which of the following graphs represents a ohmic conductor?



23. During the electrolysis process,
- (a) mass of anode decreases
(b) mass of cathode decreases
(c) amount of the electrolyte increases
(d) Both (a) and (c)



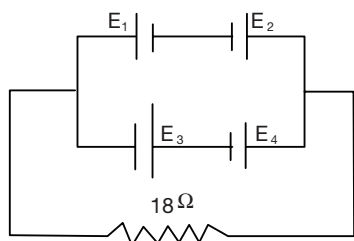
24. Among identical spheres A and B having charges as -5 C and -16 C
- -5 C is at higher potential.
 - -16 C is at higher potential.
 - both are at equal potential.
 - it cannot be said.
25. _____ is independent of size and shape of a conductor.
- Resistance
 - Conductance
 - Resistivity
 - all the above
26. The mass of the element deposited at the electrode when one coulomb of charge is passed through the electrolyte is called _____ of the element.
- equivalent weight
 - electrochemical equivalent
 - mass equivalent
 - None of these
27. In a parallel circuit of bulbs,
- same current exists in all the bulbs
 - voltage across each bulb remains the same
 - failure of any bulb leads to a break in the circuit
 - All the above
28. Resistance of a metallic conductor depends on _____.
- its length
 - its area of cross section
 - temperature
 - all the above
29. Three resistors each of $10\ \Omega$ are connected in series to a battery of potential difference 150 V . The current flowing through it is _____ A.
- 45
 - 5
 - 15
 - 20
30. The terminal voltage of a cell in an open circuit condition is
- less than its emf.
 - more than its emf.
 - equal to its emf.
 - depends on its internal resistance.
31. The potential difference across a resistor of resistance $10\ \Omega$, if 10^{20} electrons flow through it in one second, is _____ V.
- 320
 - 400
 - 80
 - 160
32. Arrange the following steps to verify the Ohm's law in proper sequence.
- Switch on the electric circuit.
 - Move the position of the slider of the rheostat and note down the ammeter and voltmeter readings.
 - Connect ammeter, key, battery, rheostat and resistor in series by using conducting wires.
 - Note down the Ammeter and voltmeter reading.
 - Connect a voltmeter across the resistor.
 - Determine the ratio of voltmeter reading and ammeter reading in each case.
 - Note that the ratio of voltmeter and ammeter reading are equal in each case.
- (a) c a e d b f g (b) c e a d b f g
(c) a b e c d f g (d) b c e d f h g
33. Arrange the following steps to determine the resistivity of a material in proper sequence.
- Switch on the circuit and take the voltmeter and ammeter readings.
 - Determine the resistance of the wire as resistance $R = V/I$
 - Connect the wire, battery and ammeter in series.
 - Determine the length (ℓ) and area of cross-section (A) of the wire
 - Connect a voltmeter across the wire. (f) The resistivity of the material is $\rho = RA/\ell$
- (a) e b c d f a (b) a c b e d f
(c) c e a b d f (d) b c a d f e
34. An electric bulb marked 15 V is connected to a battery of 15 V which has a negligible resistance. If the resistance offered by the bulb is $5\ \Omega$ the power of the bulb is _____ W.
- 225
 - 75
 - 30
 - 45
35. During the electrolysis of CuSO_4 solution using copper electrodes, the
- mass of cathode increases.
 - mass of anode increases.
 - Both (a) and (b)
 - None of these
36. Fuse should be connected to _____ wire of the circuit.
- earth
 - neutral
 - phase
 - Any of the above



37. The mass of the substance deposited at the cathode is
 (A) inversely proportional to quantity of electricity passed through electrolyte.
 (B) directly proportional to quantity of electricity passed through electrolyte.
 (C) directly proportional to the time for which electricity is passed through the electrolyte.
 (D) inversely proportional to the time for which electricity is passed through the electrolyte
 (a) A and B are true (b) B and D are true
 (c) B and C are true (d) A and D are true
38. Which of the following statements is true?
 (a) In tree type distribution of electric power, fuses are present only on the main board
 (b) In ring type distribution of electric power, there is an individual fuse for each appliance
 (c) Ring type distribution of electric power is advantageous than the tree type distribution
 (d) All the above
39. If i is the current flowing through a conductor of resistance R for time t , then the heat produced (Q) is given by _____.
 (a) $\frac{i^2 R}{t}$ (b) $\frac{i R^2}{t}$
 (c) $i^2 R t$ (d) $i R t^2$
40. A fuse wire should have _____.
 (a) high resistance (b) low melting point
 (c) Both (a) and (b) (d) None of these

Level 2

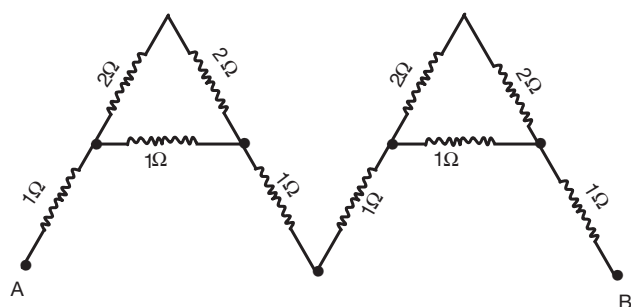
41. In a three pin plug, why is the earth pin longer and thicker than the other pins?
42. Given below are the characteristics of wires made of different materials.
 Wire A: low resistivity and high melting point.
 Wire B: low resistivity and low melting point.
 Wire C: high resistivity and low melting point.
 Wire D: high resistivity and high melting point.
 Which of the wires can be used as a (i) conducting wire (ii) fuse wire (iii) heating element?
43. How does the power-voltage rating of an electrical appliance decide the type of connecting wires to be used?
44. Two bulbs 60 W, 220 V and 100 W, 220 V are connected in series to a 440 V supply. Which of the two bulbs fuses? What happens if these bulbs are connected in parallel?
45. Four cells each of emf 1.9 V and internal resistance 1Ω are connected to an external resistance of 18Ω as shown in the figure. Find the terminal potential difference of this combination.
46. A technician has two resistance coils. By using them individually, in series or in parallel, he is able to obtain resistances of 3Ω , 4Ω , 12Ω and 16Ω (not in the same order). What is the resistance of the two coils?
47. The heat generated in the coil of resistance 180Ω which is connected to a silver voltmeter is 364.5 K J. If a steady current is passed through the circuit for 15 min, find the mass of Ag that gets deposited on the cathode. Relative atomic mass of silver is 108 g and Faradays constant is 96500 C.
48. A 200W, 220V light bulb has a greater resistance than a 100W, 200V light bulb.
49. When a 3Ω resistance coil is connected across the terminals of a battery, the current is 1.5 A. When a 5Ω resistance is connected across the same battery, the current is 1 A. Find the internal resistance of the battery.
50. Even currents of very low magnitude can lead to death. Is heat produced by the electric current responsible for the death? Explain.
51. It is easier to start a car on a warm day than on a cold day. Explain.
52. The table given below given the current (in amperes) passing through conductors A and B for different values of potential difference (V). All values are measured at the same temperature.



A		B	
V	I	V	I
4	2.8	4	9
5	3.5	5	11.25
6	4.1	6	13.5

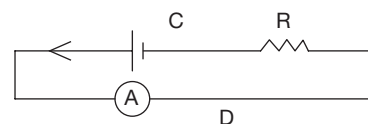
Which among A and B is an ohmic conductor? Also, find the resistance of that conductor.

53. Calculate the effective resistance between A and B.

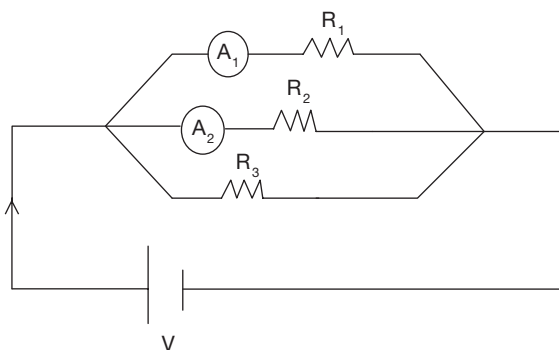


54. 'A current carrying conductor is electrically charged.' Explain with reason whether the statement is true or false.
55. Electric power of a heater is 1200 W when connected to a 240 V supply. The resistivity and area of cross section of the coil are $10^{-5} \Omega \text{ m}$ and 0.4 mm^2 , respectively. If the radius of each turn is 7 mm, find the number of turns present in the coil.
56. When a body is rubbed with another body a certain number of electrons are transferred. If the same number of electrons are allowed to flow through the cross section of a conductor in 2 s, 10 A electric cur-

rent can flow through it. Determine the number of electrons transferred.



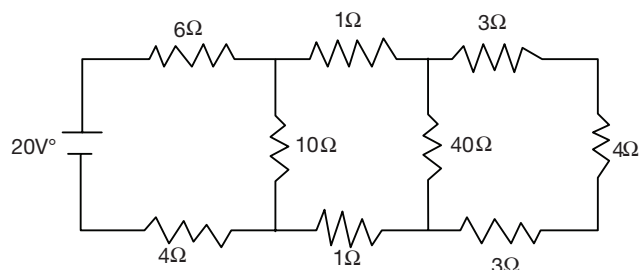
57. In the circuit diagram shown above, explain what happens if a wire is connected between the points C and D.
58. A current of 5 A flows through a conductor. Calculate the number of electrons flowing through the conductor in 2 s. (Take charge of electron as $1.6 \times 10^{-19} \text{ C}$)
59. Calculate the work done to move a charge 5 C between two points A and B, if both the points are maintained at same potential of 6 V.
- 60.



Three identical resistors are connected in parallel as shown in the figure. Explain what happens to the ammeter readings in A_1 and A_2 when the resistor R_3 is removed.

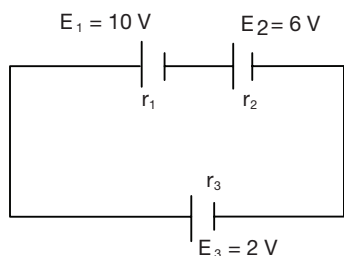
Level 3

61. In the given circuit, find the power dissipated in the 6Ω resistance.

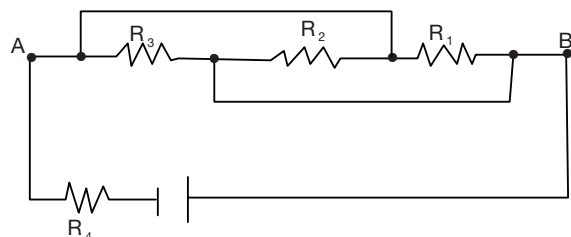


62. When electric heater is switched on, it is noticed that the lamps in the room become dimmer for a short interval of time and then regain their original brightness. Explain
63. Three batteries with emf E_1 , E_2 , E_3 are connected as shown in the figure. If their terminal voltages are 4 V, 2 V, 6 V, respectively, then find the ratio of their internal resistances.

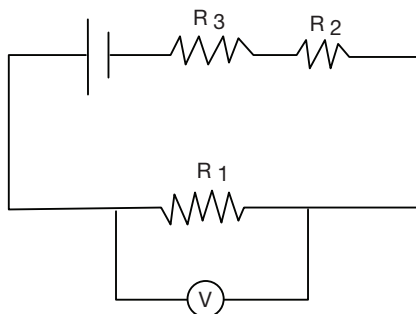




64. Find the current through the resistor R_4 if $R_1 = R_2 = R_3 = 20\ \Omega$, $R_4 = 40\ \Omega$. The emf of the battery is 4 V.



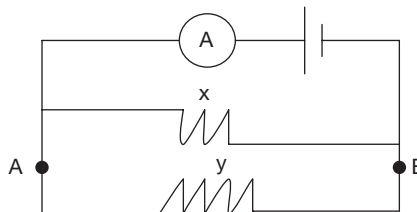
65. Three resistors R_1 , R_2 , R_3 of which $R_1 = 20\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$ connected to a battery of emf 24 V as shown in the figure. If the resistance of the voltmeter is $20\ \Omega$, find the reading of the voltmeter.



66. Show that the resistance across any opposite sides of a conductor in the shape of cube is inversely proportional to the length of its side.

67. A student connected a dry cell of emf 1.5 V to an external resistance of $10\ \Omega$. When he measured the potential difference across the terminals of the cell, he was surprised to see that the voltmeter reading was 1.4 V instead of 1.5 V. State the reason for the difference in the reading. Determine the magnitude of the physical quantity responsible for the difference in the voltmeter reading.

68



In the electric circuit shown below two identical coils x and y , each of resistance $100\ \Omega$, are connected across a potential difference of 200 V. When a copper voltmeter is connected across the terminals A and B, the ammeter reading is found to be 10 A. Determine the heat developed in the coil y and the mass of copper deposited at the respective electrode after 1 hour. (Given that e.c.e of copper = $0.000332\ \text{g C}^{-1}$)

69. Two bulbs A and B are connected to a 220 V supply. The maximum current that can flow through A and B is 0.5 A and 1.2 A, respectively. The effective resistance of the two bulbs in series and parallel is $280.0\ \Omega$ and $60.0\ \Omega$ respectively. Which of the two bulbs, the one with high wattage or low wattage will fuse when connected in series? What happens when they are connected in parallel?



CONCEPT APPLICATION

Level 1

True or False

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

Fill in the Blanks

8. voltage, current 9. phase/live 10. electric power 11. electroplating
12. resistance 13. external resistance, internal resistance 14. emf

Match the following

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

Multiple Choice Questions

16. (a) 17. (a) 18. (c) 19. (a) 20. (a) 21. (d) 22. (c) 23. (a) 24. (a) 25. (c)
26. (b) 27. (b) 28. (d) 29. (b) 30. (c) 31. (d) 32. (b) 33. (c) 34. (d) 35. (a)
36. (c) 37. (c) 38. (d) 39. (c) 40. (b)

Explanation for Questions 31 to 40.

31. $V = iR = 10^{20} \times 1.6 \times 10^{-19} \times 10 = 160 \text{ V}$.

32. Initially the ammeter, rheostat, resistor and the battery are connected in series by using connecting wires. Connect the voltmeter across the resistor. Switch on the electric circuit. Determine the ammeter and voltmeter reading and change the position of the slider of the rheostat and note down the ammeter and voltmeter readings. Change the magnitude of current flowing through the circuit and in each case determine the ratio of voltmeter and ammeter reading. It can be shown that the ratio is constant in all the cases.

33. Initially the wire, ammeter, battery and key are connected in series. Connect a voltmeter across the wire in parallel. Switch on the circuit and determine the voltmeter and ammeter readings. Determine ratio of voltmeter and ammeter reading. This gives the resistance of the wire. The length and area of cross-section of the wire are determined. Now the resistivity

of the wire can be determined as $\rho = \frac{RA}{\ell}$

34. $V = 15 \text{ V}$
 $R = 5 \Omega$

$$P = \frac{V^2}{R} = \frac{15 \times 15}{5}$$

$$P = 45 \text{ W}$$

35. During the electrolysis of CuSO_4 solution using copper electrode, the positive copper ions are attracted by the cathode and copper is deposited on cathode, so the mass of cathode increases.

36. Fuse should be connected to live / phase wire of the circuit. If it is connected to neutral wire, the fuse will melt when excess current flows, but the appliance will still be connected to high potential through live wire. Thus, if a person touches the appliance, he receives shock. Hence,

37. According to Faraday's First law of electrolysis, the mass of a substance deposited at the cathode is directly proportional to quantity of electricity passed and the time for which it is passed through the electrolyte. So, statements B and C are true.

38. In tree type distribution of electric power, fuses are present only on the distribution board where as in ring type, there is an individual fuse for each appliance. As there is an individual fuse for each appliance in ring type, only faulty appliance will not work and all the other appliances will not be affected. It is easier to install. So, ring type is advantageous than that of tree type. Hence,

39. If ' I ' is the current flowing through a conductor of resistance ' R ' for time ' t ', then the heat produced (Q) is given by, $Q = i^2 R t$.

40. A fuse wire should have high resistance and low melting point.



Level 2

41. (i) The earth pin gets connected to the terminal first as compared to live or neutral pins.
(ii) Thicker earth pin can never enter in live or neutral cylinder of the socket.
42. (i) A conducting wire, ideally, should not offer any resistance to the current. A conducting wire, sometimes carry a large current, which may melt it. A fuse wire should melt easily whenever excess current flows through it.
Also, the heat energy required to melt the fuse wire will be produced when it offers high resistance to the current.
A heating element is required to produce large amount of heat energy which is possible if it offers high resistance to the given current.
Also, a heating element should not melt due to large amount of heat produced in it.
(ii) wire A
(iii) wire C
(iv) wire D
43. The thickness of connecting wire carrying large current is more than the one carrying smaller current. An electrical appliance of high power voltage rating draws larger current.
44. (i) Use $R = \frac{V^2}{P}$ to find resistances R_1 and R_2 of both the bulbs.
Determine the current flowing through bulbs by using $I = \frac{V}{R_1 + R_2}$.
Find the potential difference V_1 and V_2 across each bulb, by using $V_1 = IR_1$ and $V_2 = IR_2$.
The bulb whose potential difference is greater than 220 V will fuse.
If the bulbs are connected in parallel across 440 V, the PD across them will be greater than the maximum value of 220 V.
(ii) 60 W bulb fuses when connected in series. Both bulbs fuse when connected in parallel.
45. (i) When cells are connected in series $E = E_1 + E_2$.
(ii) When cells are connected in parallel
$$E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

(iii) 10.8 V
46. (i) The maximum resistance of $16\ \Omega$ is obtained when the resistors are connected in series.
The minimum value of $3\ \Omega$ is obtained when the resistors are connected in parallel.
(ii) $4\ \Omega$ and $12\ \Omega$
47. (i) Heat generated $q = i^2 R t$
(ii) $m = Z i t$
(iii) $m_1 : m_2 : m_3 = E_1 : E_2 : E_3$
(iv) 1.5 g
48. Determine the resistance of the two bulbs using the formula, $R = \frac{V^2}{P}$.
where R is the resistance of the filament, V is potential difference and P is the power.
49. (i) Terminal voltage $V = E - i r$
(ii) $1\ \Omega$
50. Remember that nerves are the carriers of electric signals. What is their current carrying capacity?
51. A car starts due to current supplied by the storage battery. The ionic dissociation of the electrolyte present in the battery is more at higher temperatures than at lower temperatures.
52. (i) Definition of ohmic resistor.
(ii) Conductor B, $0.5\ \Omega$
53. (i) The equivalent resistance can be formed by successively simplifying the given circuit.
Find the equivalent resistance of the two $2\ \Omega$ resistors which are connected in series.
These together are connected in parallel to the $1\ \Omega$ resistor. This combination is in series with the other resistors.
Thus, using the formulas for series and parallel connections, find the equivalent resistance in three steps.
(ii) $5.6\ \Omega$
54. A body is charged when it loses or gains electrons. The number of electrons leaving from one end of the current carrying conductor is equal to the number of electrons entering through its other end.
55. (i) $R = \frac{V^2}{P}$
(ii) $R = \frac{\rho \ell}{A}$



(iii) Length of each turn = $2\pi r$

(iv) No. of turns = $\frac{L}{2\pi r}$

(v) 44

56. Electric current $I = \frac{Q}{t}$

$$10 = \frac{Q}{2} \Rightarrow Q = 20C$$

$$Q = ne$$

where e is the of an electron

$$\therefore 20 = n \times 1.6 \times 10^{-19} C$$

$$n = \frac{20}{1.6 \times 10^{-19}} = \frac{200}{16} \times 10^{19}$$

$$= 12.5 \times 10^{19} = 125 \times 10^{18}$$

57. If a wire is connected between C and D, the current flowing through the circuit increases and hence the ammeter reading rises suddenly. This is known as short circuiting.

58. Current flowing $i = \frac{Q}{t}$

Charge flowing

$$Q = it = 5 \times 2 = 10 C$$

But $Q = ne$

Where n is number of electrons passing through conductor in 2 s and e is the charge of electron $10 = n \times 1.6 \times 10^{-19}$

number of electrons $n = 6.25 \times 10^{19}$.

59. Since both the points A and B are at same potential, the potential difference between A and B is $V = 0$
Work done to move the charge between the points A and B is zero

60. When studies on electric current were done, the resistor R_3 is removed, the effective resistance in the circuit increases and hence the current flowing through the circuit decreases. Thus, the total current flowing through the circuit is less than that in the previous case. As less current is flowing between the two resistors the ammeters A_1 and A_2 show a lower reading than in the previous case but have the same reading as the current flowing through the resistors R_1 and R_2 remains the same.

Level 3

61. (i) Equivalent resistance $R = R_1 + R_2$, when connected in series.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \text{ when connected in parallel.}$$

(ii) Power dissipated = $V I$

(iii) 9 W

62. Compare the resistances and current drawn by the heater and the bulb.

63. (i) $E_{\text{net}} = E_1 + E_2 - E_3$

$$(ii) I = \frac{E_{\text{net}}}{r}$$

(iii) $V_1 = E_1 - ir_1$, $V_2 = E_2 - ir_2$, $V_3 = E_3 + ir_3$

(iv) Find the ratio of r_1 , r_2 , r_3 .

(v) 3 : 2 : 2

64. (i) R_1 , R_2 , R_3 in parallel are in series with R_4 .

$$(ii) I = \frac{V}{R_{\text{eff}}}$$

(iii) 46.7 Ω , 0.08 A

65. (i) Resistor R_1 and resistance of voltmeter are in parallel. Let $R_{\text{eq}} = R_4$

(ii) R_4 , R_2 , and R_3 are in series. Calculate the net effective resistance, R .

(iii) When resistors are in series $V_1 : V_2 : V_3 = R_4 : R_2 : R_3$

(iv) 4 V

66. Let ℓ be the length of the side, ' ρ ' be the resistivity and ' R ' be the resistance

$$R = \frac{\rho \ell}{A} = \frac{\rho \times \ell}{\ell^2} = \frac{\rho}{\ell}; \rho \text{ is a constant.}$$

$$\therefore R \propto \frac{1}{\ell}$$

$\therefore$ Resistance of a cubical structured conductor is inversely proportional to the length of its side.



67. The reason for the difference in reading is internal resistance offered by the cell.

$$E = V + Ir$$

where the symbols represent quantities as in the above equation.

Putting the values as per the given data,

$$1.4 = I \times 10; I = 0.14$$

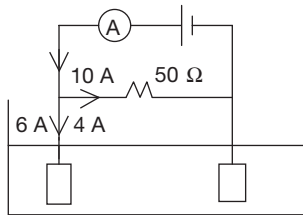
$$1.5 = I(10 + r)$$

$$\therefore 1.5 = 0.14(10 + r)$$

$$\Rightarrow r = 0.71 \Omega$$

68. Effective resistance

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{100 \times 100}{200} = \frac{100}{2} = 50 \Omega$$



Current flowing through the 50Ω resistor

$$i = \frac{V}{R} = \frac{200}{50} = 4 \text{ A.}$$

Current flowing through the electrolyte = 6 A.

Mass of copper deposited = Zit

$$= 0.000332 \times 6 \times 3600 = 7.1712 \text{ g}$$

Current flowing through the resistor $y = 2 \text{ A}$

Heat developed $Q = i^2 R t$

$$= 2^2 \times 100 \times 3600 = 400 \times 3600$$

$$= 144 \times 10^4 \text{ J.}$$

69. Current through A, $i_A = 0.5 \text{ A}$

Current through B, $i_B = 1.2 \text{ A}$

When A and B are in series, $R_s = 280.0 \Omega$

$$I_s = \frac{V}{R_s} = \frac{220}{280.0} = 0.78 \text{ A.}$$

Hence, bulb A will fuse when A and B are in series.

When A and B are in parallel, $R_p = 60 \Omega$

$$i_p = \frac{V}{R_p} = \frac{220}{60} = 3.7 \text{ A.}$$

Hence, both the bulbs will fuse.

$$R_1 + R_2 = 280.0 \Omega \quad (1)$$

$$\frac{R_1 R_2}{R_1 + R_2} = 60.0 \Omega$$

$$R_1 R_2 = 280 \times 60 = 16800$$

$$(R_1 - R_2)^2 = (R_1 + R_2)^2 - 4R_1 R_2$$

$$= (280)^2 - (4 \times 16800) = 11200$$

$$R_1 - R_2 = 106 \quad (2)$$

$$\therefore R_1 = 193 \Omega$$

$$R_2 = 87 \Omega$$

$$\therefore \text{Power of bulb A, } P = i_1^2 R_1 = (0.5)^2 \times 193$$

$$P_A = 48 \text{ W}$$

$$\text{Power of bulb B, } P = i_2^2 R_2 = (1.2)^2 \times 87$$

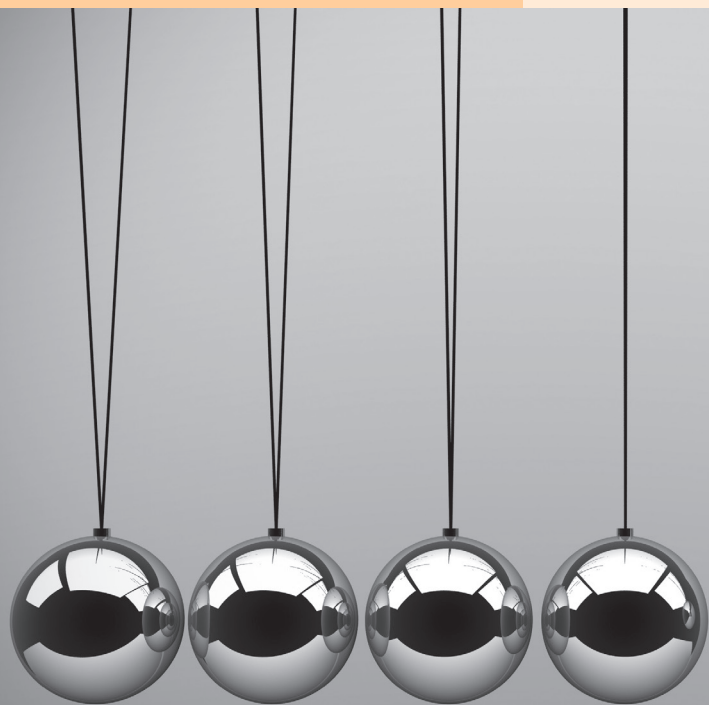
$$P_B = 125 \text{ W}$$

Hence, the bulb with low wattage will fuse.



Chapter 8

Electromagnetism



Remember

Before beginning this chapter, you should be able to:

- Learn the important terms such as a magnet, magnetic field, modern theory of magnetism
- Classify various magnetic substances
- Learn about the different elements of earth's magnetic field, magnetic field produced by bar magnet in the earth's magnetic field in different orientations
- Understand the concept in electromagnetism and different instruments using magnetic effect of electric current

KEY IDEAS

After completing this chapter, you should be able to:

- Learn the important properties of magnets, magnetic field and field lines, Ewing's Molecular Theory, inverse square law of magnetism, magnetic induction, modern electron theory, classification of magnetic materials, and terrestrial magnetism
- Study Oersted's Experiment, rules that help to find the direction of magnetic field
- Find magnetic field due to a long straight and circular current carrying wires, solenoid and application of Fleming's left-hand rule
- Understand Faraday's experiments and laws of electro magnetic induction including Lenz's Law and Fleming's right-hand rule
- Study about electric generator, RMS voltage and peak voltage, self and mutual induction, transformer, eddy currents, etc.

INTRODUCTION

In 1820, Hans Christian Oersted discovered that current carrying conductor produces a magnetic field around it. Later Micheal Faraday showed that current can be induced in a conducting coil, when there is relative motion between the coil and a magnet. Thus, electric current has magnetic effect and changing magnetic fields can induce electricity. Together, their study forms a very important branch of physics called electromagnetism. Large scale generation of electricity worldwide and most of the devices which work on it are based on the principles of electromagnetism.

In the previous chapter, you studied electricity. Before we begin the study of electromagnetism, let us understand some important aspects of magnetism.

MAGNETISM

Since ancient times it was known that ferrous oxide (Fe_3O_4) had the ability to attract substances like iron, nickel, etc. Substances having this ability are called magnets. Fe_3O_4 is called natural magnet as it is naturally occurring while those substances in which this ability is artificially imparted are called artificial magnets.

The substances which are attracted towards a magnet and can become magnets are called magnetic substances. Example: iron, nickel, cobalt. etc.

The substances which are not attracted towards a magnet and cannot be magnetized are called non-magnetic substances. Example: wood, paper, plastic. etc.

Important Properties of Magnets

- 1. Property of attraction:** Magnets attract small pieces of materials like iron, nickel, and cobalt. The property of a magnet to attract small pieces of iron seems to be concentrated in small regions at the ends of the magnet. These regions are called magnetic poles.
- 2. Property of direction:** A freely suspended magnet always aligns itself in the North-South direction. The pole which points towards geographic north is called North pole of the magnet and the pole which points towards geographic south is called South pole of the magnet.
- 3.** Like-poles of magnets repel each other and unlike-poles attract each other, just as like-charges repel and unlike-charges attract. Since a magnet can attract small pieces of iron and also the opposite pole of another magnet, property of attraction is not a sure test to find whether a given piece is a magnet or not. Repulsion is a sure test to confirm whether a given piece is a magnet or not.
- 4. Property of induction:** A magnet can induce magnetism in substances like soft iron, cobalt, nickel, etc.
- 5.** Breaking a magnet successively into smaller pieces would still produce tiny magnets each with a north pole and south pole. The above phenomena is observed till we reach molecular stage.
- 6.** Magnetic poles always exist in opposite pairs.

Magnetic Field and Field Lines

The area surrounding magnet, in which its effect can be felt, is called a magnetic field of the magnet.

Place a bar magnet on a cardboard. Randomly sprinkle iron filings on the cardboard and tap it lightly. The iron filling arrange themselves in a particular pattern.

Draw lines along these patterns. These lines form continuous, closed curves between the poles of the magnet. Place a magnetic needle near the north pole of bar magnet and mark the north pole end of needle. Now place the needle with its S-pole at this mark and mark the new position of its N-pole. It is found that the needle always traces a path formed by above mentioned curved lines. These lines are called magnetic lines of force. Thus, a magnetic field can be represented by lines of force.

Magnetic lines of force are those lines in a magnetic field along which an imaginary free isolated north pole moves.

1. Lines of force are continuous lines.
2. Outside a bar magnet, the lines of force are directed away from North pole and towards the South pole.
3. Inside a bar magnet, the lines are directed from South pole to the North pole.
4. Lines of force do not intersect.
5. The magnetic field is strong at places where the lines of force are crowded and weak where the lines of force are far apart.
6. The direction of magnetic field at a point is tangential to the line of force at that point.

EWING'S MOLECULAR THEORY OF MAGNETISM

If we break a magnet into two parts, each part becomes a magnet with a north pole at one end and a south pole at the other end. If we break it further, we observe the same behaviour. This will continue even if we break the magnet to its molecular level.

Each molecule of a magnetic substance is an independent magnet irrespective of whether the substance is magnetized or not, these tiny magnets are called molecular magnets.

In an unmagnetized state [Fig 8.1 (a)], the molecular magnets are arranged in random manner. Therefore, the net magnetic effect is zero.

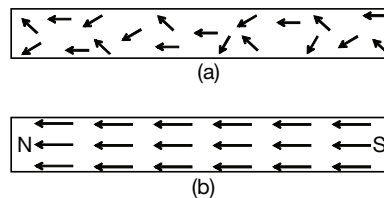


FIGURE 8.1 (a) An unmagnetized state, (b) A magnetized state

In the magnetized state [Fig. 8.1 (b)], these molecular magnets are arranged in an order. All the south poles are aligned in one direction and the north poles in the other direction. Therefore, a strong magnetic field is created.

In general, perfect alignment of all the molecular magnets in the entire magnet is difficult to obtain. When this condition is obtained, it is called the point of saturation and magnetizing the magnet further cannot increase the strength of the magnet. These postulates are known as Ewing's molecular theory named after the scientist who proposed them.

However, Ewing's molecular theory could not explain why the individual molecules of a magnetic substance like iron behave as tiny magnets. Also it failed to explain, why molecules of non-magnetic substances, like brass, do not behave like magnets. The theory could not explain the fact that substances like bismuth, copper are repelled by strong magnets.

INVERSE SQUARE LAW OF MAGNETISM

The ability of the pole of a magnet to attract or repel another magnetic pole is called its **pole strength**. It is denoted by ' m '. Its SI unit is ampere-metre.

Consider two hypothetical isolated magnetic poles of pole strengths m_1 and m_2 separated by a distance ' r '.

According to inverse square law of magnetism, given by Coulomb, the force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them and acts along the line joining the poles.

Mathematically,

$$F \propto m_1 \times m_2$$

$$\text{and } F \propto \frac{1}{r^2},$$

$$\text{or, } F = K \frac{m_1 m_2}{r^2}$$

where K is the constant of proportionality. Its value depends on the magnetic properties of the medium surrounding the magnetic poles and the system of units used.

If we choose SI units, and if vacuum or air is the medium surrounding the poles, then the value of K is denoted by to be $\left(\frac{\mu_0}{4\pi}\right)$.

$$\therefore F = \left(\frac{\mu_0}{4\pi}\right) \frac{m_1 m_2}{r^2} \quad (8.1)$$

where μ_0 is called permeability of vacuum or air.

The value of μ_0 is $4\pi \times 10^{-7}$ henry metre⁻¹.

If any medium other than vacuum or air surrounds the poles, then

$$F_1 = \frac{\mu}{4\pi} \times \frac{m_1 m_2}{r^2} \quad (8.2)$$

where ' μ ' is absolute magnetic permeability of the medium.

Some Important Terms

Magnetic Permeability

Magnetic permeability (μ) of a medium is defined as its ability to allow the magnetic lines of force to pass through it or to allow itself to be influenced by magnetic field.

On dividing equation (8.2) by equation (8.1), we have

$$\frac{F}{\mu_0} = \mu_r F \Rightarrow \mu = \mu_0 \mu_r$$

where μ_r is called **relative permeability** and it is defined as the ratio of magnetic force in a medium to the magnetic force in vacuum.

μ_r being a ratio has no units. For air or vacuum, $\mu_r = 1$.

Unit Pole Strength

The unit magnetic pole is defined as that pole which repels an identical pole at 1 metre distance with a force of 10^{-7} N.

By taking $\mu_0 = 4\pi \times 10^{-7}$ henry metre⁻¹, $r = 1$ m and $m_1 = m_2 = 1$ (A-m), we have

$$\begin{aligned} F &= \frac{\mu_0}{4\pi} \times \frac{m_1 m_2}{r^2} \\ &= \frac{\mu_0}{4\pi} \times \frac{1 \times 1}{1^2} = \frac{4\pi \times 10^{-7}}{4\pi} = 10^{-7} \text{ N} \end{aligned}$$

Magnetic Flux Density 'B'

The space around the magnet where the influence of the magnet can be felt is called **magnetic field**. Let us imagine this field as constituted by magnetic lines of force. The total number of lines passing through the given area is called **magnetic flux 'φ'**. The unit of magnetic flux in S.I system is weber (Wb). If a magnetic substance exists in this field, then the lines of force pass through it. These lines of force are called magnetic induction lines as these lines induce magnetism in the magnetic substance.

Magnetic flux per unit area is called magnetic flux density or magnetic induction.

$$\text{i.e.,} \quad B = \frac{\phi}{A}$$

Magnetic induction can also be defined as the force experienced by a unit north pole kept in a magnetic field.

We know that the force experienced by two poles m_1 and m_2 is given by,

$$F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{d^2}$$

Let m_1 be the pole strength of unit N pole.

$$\therefore m_1 = 1 \text{ A-m}$$

Let $m_2 = m$

$$\therefore F = \frac{\mu_0}{4\pi} \frac{m}{r^2}$$

By definition magnetic induction at a point in a magnetic field is the force experienced by a unit north pole placed at that point.

$$\therefore B = \frac{\mu_0}{4\pi} \frac{m}{r^2}$$

The SI unit of flux density is Wb m^{-2} or tesla (T). The CGS unit of flux density is gauss (G).

$$1 \text{ T} = 10^4 \text{ G}$$

Its other unit is $\text{N A}^{-1}\text{m}^{-1}$. The force experienced by a north pole of pole strength ' m ', kept in a magnetic field of induction ' B ', is given by,

$$F = mB. \text{ or } B = \frac{F}{m}$$

Intensity of Magnetic Field (H)

The intensity of magnetic field refers to the strength of a magnetic field at a point in C.G.S. units.

We know that

$$F = K \frac{m_1 m_2}{r^2}$$

where $K = \frac{1}{\mu}$ and μ is the permeability of free space which is equal to 1 in C.G.S system.

In the above equation, if m_1 is unit north pole and $m_2 = m$, then

$$F = \frac{m}{r^2}$$

This force is called intensity of magnetic field (H)

$$\therefore H = \frac{m}{r^2}$$

Thus, intensity of magnetic field can be defined as the force acting on unit north pole independent of the medium.

In S.I. system,

$$H = \frac{m}{4\pi r^2}$$

Since $K = \frac{1}{4\pi}$ in S.I system, the S.I. unit of H is ampere metre⁻¹ (A m^{-1}).

In C.G.S. system, its unit is oersted.

Both H and B represent strength of magnetic field at a point, the difference being that H is independent of the medium. H and B are related as follows:

$$B = \mu_0 H$$

Magnetic Moment 'M'

The magnetic moment of a bar magnet is given by the product of its length and pole strength. Let us take the length of the magnet as ' $2l$ ' and magnetic pole strength of the magnet as ' m '. Then the magnetic moment of the magnet is given by,

$$M = (2l) \times m$$

S.I. unit of magnetic moment is ampere – metre²(A m²)

Magnetic Field Induction of a Bar Magnet on the Axial Line of the Magnet

The line joining the north pole and south pole of a magnet is called the axial line. The magnetic induction ' B ' of a short bar magnet on the axial line is given by,

$$B = \left(\frac{\mu_0}{4\pi} \right) \frac{2M}{d^3}$$

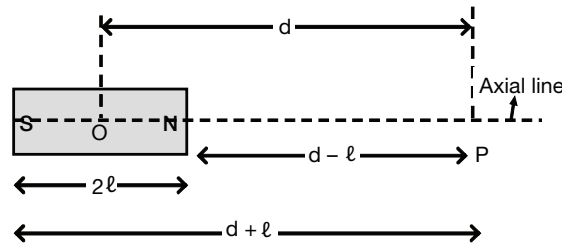


FIGURE 8.2 Diagram to show magnetic field induction of a bar magnet on the Axial Line of the Magnet

Where μ_0 is the permeability of free space, M is the magnetic moment of the magnet and ' d ' is the distance of the point ' P ' from the centre of the magnet. The direction of B is along the axis, parallel to $\overrightarrow{SN}$ vector.

Magnetic Field Induction of a Magnet on the Equatorial Line of the Magnet

A line perpendicular to the axis and passing through the midpoint of the magnet is called the equatorial line. The magnetic induction ' B ' of a short bar magnet on the equatorial line is given by

$$B = \left(\frac{\mu_0}{4\pi} \right) \cdot \frac{M}{d^3} \text{ N A}^{-1}\text{m}^{-1},$$

where μ_0 is the permeability of free space, M is the magnetic moment of the given magnet and ' d ' is the distance of the point ' P ' on the equatorial line from the magnet.

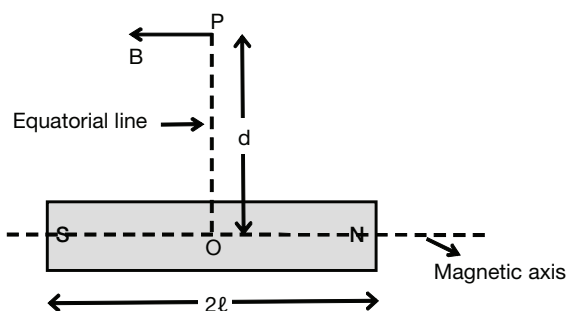


FIGURE 8.3 Diagram to show magnetic field induction of a magnet on the equatorial line of the magnet

The direction of B is parallel to the axis of the magnet and is in the $\overrightarrow{NS}$ direction.

ORIGIN OF MAGNETISM—MODERN ELECTRON THEORY

One of the major drawbacks of Ewing's theory is that it fails to explain why molecules of magnetic substances like iron behave like tiny magnets while those of non-magnetic substances like wood do not. The modern electron theory offers an explanation to this. A molecule consists of two or more atoms. Each atom consists of electrons which revolve around the nucleus in orbits and rotate or spin about an axis. Since electrons carry negative charge, the orbital and spin motion of electrons give rise to electric current which produces a magnetic field.

For substances like iron, the net magnetic moment due to a molecule is not zero hence they are magnetic in nature. The net magnetic moment due to a molecule is zero in wood hence it is non-magnetic.

Magnetic Properties

- 1. Intensity of magnetisation 'I':** It is the magnetic moment acquired per unit volume when a substance is placed in a magnetic field. Its unit is $A\ m^{-1}$.
- 2. Magnetic susceptibility 'χ':** It is the measure of capability of a medium to get magnetized. Susceptibility of a substance is defined as the ratio of intensity of magnetization 'I' to the intensity of applied magnetic field 'H'. Soft iron has high susceptibility.

$$\chi = \frac{1\ (Am^{-1})}{H\ (Am^{-1})}$$

Magnetic susceptibility is a constant for a given substance. Since it is a pure ratio, it has no unit.

- 3. Retentivity:** It is a property of magnetic material by virtue of which it retains the magnetic property even after removal of the applied magnetic field. Steel has high retentivity. Due to this reason, steel is used for making permanent magnets.

Classification of Magnetic Materials

Based on the magnetic properties, all materials can be classified as:

1. Diamagnetic substances
2. Paramagnetic substances
3. Ferromagnetic substances

Diamagnetic Substances

The resultant magnetic moment of an atom in a substance depends on the orientation of electron orbits and the axes about which electrons spin.

The substances in which the net magnetic moment of any atom in them is zero are called diamagnetic substances.

1. A diamagnetic substance is feebly repelled by a powerful magnet.
2. When suspended in a non-uniform magnetic field, it settles at right angles to the direction of the field.
3. Its relative permeability (μ_r) is approximately equal to or less than 1 ($\mu_r \leq 1$).
4. Magnetic susceptibility is negative very small, e.g., for bismuth, $\chi = -0.000015$

Example: air, water, copper, bismuth, etc.

PARAMAGNETIC SUBSTANCES

Those substances in which the orientation of electron orbits and axes of their spins are such that the net magnetic moment of any atom is not zero, are called paramagnetic substances. Those atoms which have unpaired electrons acquire resultant magnetic moment.

1. Paramagnetic substances are feebly attracted by a strong magnet.
2. When placed in a non-uniform external magnetic field, it aligns itself with the direction of the field and moves from weaker to stronger region of the field.
3. Its relative permeability is slightly greater than 1 ($\mu_r > 1$).
4. Its magnetic susceptibility (χ) is small and positive, e.g., for platinum, its value is 0.0001
5. Example: aluminium, platinum, chromium

Ferromagnetic Substances

Like paramagnetic substances, the atoms of these elements have resultant magnetic moment. But unlike paramagnetic substances, they achieve high degree of magnetic alignment due to a special effect called 'exchange coupling'.

The elements Fe, Co, Ni, Gd and Dy are examples of ferromagnetic substances.

Ferromagnetic substances are those in which the resultant magnetic moments of individual atoms align themselves parallel to each other due to a special effect which leads to spontaneous magnetisation.

1. They are strongly attracted by magnets.
2. They align in the direction of the applied field.
3. Their relative permeability is very high ($\mu_r \gg 1$).
4. Magnetic susceptibility (χ) is very high and positive. Therefore, they can be easily magnetised and made into magnets.

DOMAIN THEORY

Domain theory explains the properties of ferromagnetic substances. According to domain theory, a large number of small local regions are formed in ferromagnetic substances, called **domains**. Within each domain, the magnetic dipoles of all the atoms align themselves parallel to each other giving rise to magnetism. The direction of magnetisation in each domain is different from that in the other domains as indicated by arrows in the Fig. 8.4.

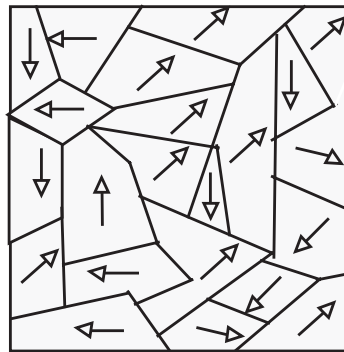


FIGURE 8.4 Different domain showing direction of magnetization by arrows

In the diagram, boundary lines indicate different domains and arrows indicate direction of magnetisation of respective domains. In the absence of applied magnetic field, the arrow of each domain point along different directions. As a result, the net magnetisation of the specimen as a whole is zero. This explains why an iron rod is not a magnet by itself.

When a ferromagnetic specimen is magnetised the domains expand and all arrows align parallel to each other in one direction. In an ideal magnet, there is a single domain with all the arrows pointing in one direction. This way the specimen becomes a magnet. Ferromagnetic substances exhibit retentivity because on demagnetising them, the original domains are not formed immediately, so that a certain amount of magnetisation is still retained.

Terrestrial Magnetism

Our earth behaves like a magnet. This is proved by the fact that a freely suspended bar magnet or a compass needle always come to rest in north–south direction. It is as if a huge bar magnet is buried at the centre of the earth with its south pole at the geographic north and vice versa. The axis of the earth's magnet makes an angle of about 17° with the geographic axis.

It is supposed that electric currents in the molten outer core rich in iron give rise to the earth's magnetism. The study of the earth's magnetism and its various elements constitutes terrestrial magnetism.

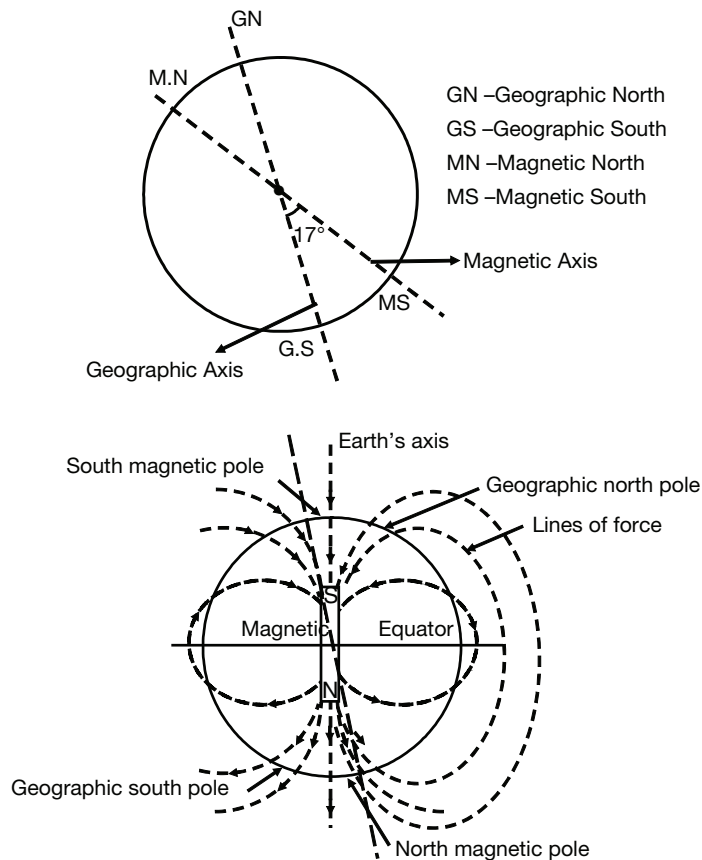


FIGURE 8.5 Terrestrial magnetism

Elements of Earth's Magnetism

1. **Angle of dip or inclination:** A magnetic needle suspended at its centre of gravity and free to rotate in vertical and horizontal planes comes to the rest in the direction of the earth's magnetic field. The angle made by the axis of magnetic needle with the horizontal is called angle of dip or inclination.

The angle of dip is maximum at the magnetic poles and its value is 90° . At magnetic equator of the earth, its value is zero.

2. **Angle of declination:** The vertical plane passing through a place and containing geographic north and south poles is called geographic meridian.

The vertical plane passing through a place and containing the earth's magnetic north and south pole is called magnetic meridian.

The angle between geographic and magnetic meridian at a place is called angle of declination.

Mapping Neutral Points

The magnetic field due to a bar magnet consists of number of lines of force which emerge from its north pole and enter the south pole. At the same time the effect of the horizontal component (B_H) of the earth's magnetic field is also felt at a given place. The magnetic field induction (B) due to the bar magnet is large near it and decreases with the distance, whereas B_H remains constant in magnitude and direction at a given place. Thus, within the magnetic field of a bar magnet, the lines of force represent the net effect of B and B_H . There are some points within the magnetic field where B and B_H are equal in magnitude and opposite in direction and cancel each other. These points where the resultant magnetic field is zero are called as 'neutral points'. The location of neutral points also depend on the orientation of the bar magnet.

1. **North pole of the bar magnet facing the geographical north of the earth:** At the geographical north pole lies the magnetic south pole of the earth and vice versa. The earth's magnetic lines of force are thus directed from geographical south to north. Hence the horizontal component (B_H) of the earth's magnetic field neutralizes the magnetic field induction (B) of the bar magnet at two diametrically opposite points lying on the equatorial line of the bar magnet.

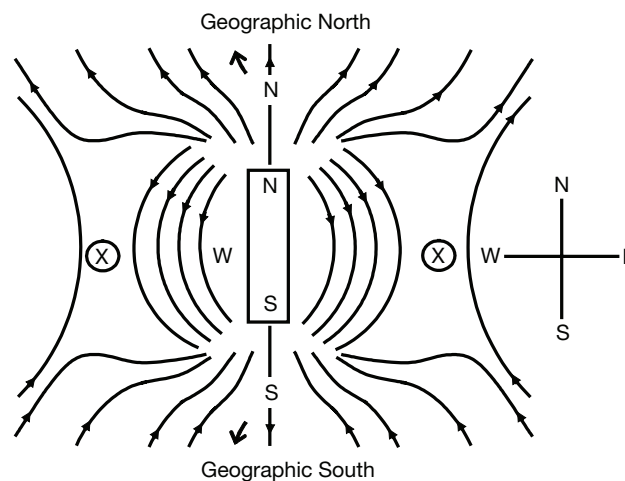


FIGURE 8.6 Magnetic field around a bar magnet whose N-pole is facing the geographical north of the earth

These points are the neutral points when N-pole of the bar magnet points towards geographical north. If a compass needle is placed at any of these points, it points in any random direction.

2. **South pole of the bar magnet facing geographical north pole of the earth:** In this orientation, the south pole of the bar magnet faces the magnetic south pole of the earth.

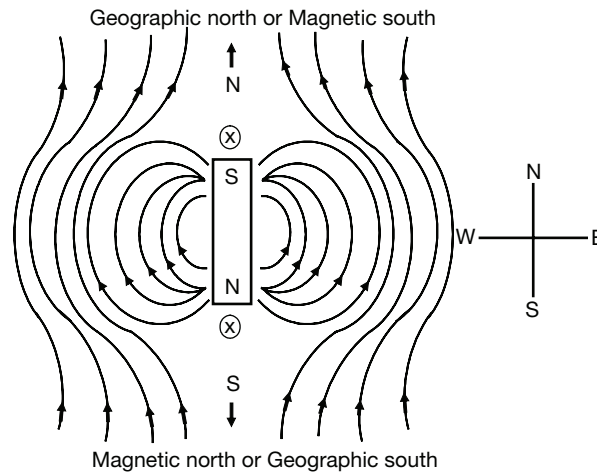


FIGURE 8.7 Magnetic field around a bar magnet whose S-pole is facing the geographical north of the earth

Along the axial line of the bar-magnet, the lines of force due to the magnetic fields of the earth and bar magnet are oppositely directed. Hence at two particular points along the axial line, one nearer to the south pole and the other closer to the north pole of the bar magnets, the B_H nullifies the B . These two points represent the neutral points.

Calculation of Magnetic Moment M of a Bar Magnet

At the neutral points, the magnetic field intensity due to a bar magnet equals horizontal component of earth's magnetic field (B_H). Knowing B_H at a given place (which is 0.39×10^{-4} T in Andhra Pradesh) and distance ' d ' of neutral point, we can determine M .

Case I:

When neutral points lie on equatorial line,

$$B = \frac{\mu_0}{4\pi} \times \frac{M}{d^3} w$$

Substituting

$$B_H = 0.39 \times 10^{-4} \text{ T}, \frac{\mu_0}{4\pi} = 10^{-7}$$

Simplifying,

$$\text{we get } M = 390d^3 \text{ A m}^2.$$

Knowing the length of the magnet, we can find m .

The value of m can be calculated as

$$m = \frac{M}{2I} = \frac{390d^3}{2I} \text{ Am}$$

Case II:

When neutral points are on axial line,

$$B = B_H = \frac{\mu_0}{4\pi} \frac{2M}{d^3}$$

Substituting the values of B_H and $\mu_0/4\pi$, we get

$$\frac{2M}{d^3} = 390,$$

and we get

$$M = 195d^3 \text{ A m}^2$$

Knowing the value of d , the value of m can be calculated.

If we know the length of the bar magnet, we can find its pole strength m as

$$m = \frac{M}{2l} = \frac{195d^3}{2l} \text{ A m}$$

OERSTED EXPERIMENT

Oersted was the first to put forth the direct relation between electricity and magnetism. He conducted several experiments to determine the magnetic effect of a current carrying wire. The following describes the Oersted experiment conducted to establish that a current carrying wire acts as a magnet.

A long straight wire is connected to an external battery and an electric current is passed through it. When a magnetic needle is placed below the wire such that the wire is parallel to the axis of the magnetic needle and the current flows in the south to north direction, a deflection in the needle is observed. It is observed that the north pole of the needle is deflected westwards and as the magnitude of current is increased, the deflection increases till the north pole of the needle turns towards exact west. It is also observed that if instead of placing the magnetic needle below the wire, if it was placed above the wire, the north pole of the magnetic needle is deflected eastwards. From this experiment, Oersted concluded the following facts.

1. Any current carrying wire produces a magnetic field around it, as it can deflect a magnetic needle placed near it.
2. The intensity of the magnetic field is proportional to the magnitude of the current passing through the wire.
3. The magnetic field setup acts at right angles to the direction of the flow of current.
4. The direction of the magnetic field depends upon the direction of the flow of current.

The direction of the magnetic field produced due to a current carrying wire may be determined using any one of the following rules.

AMPERE'S SWIMMING RULE

Imagine a man swimming along the conductor in the direction of current, facing a magnetic compass kept near and below the conductor. Then the north pole of the needle will be deflected towards his left hand.

AMPERE'S RIGHT-HAND THUMB RULE

Imagine you are holding the current carrying wire with your right hand, with the thumb pointing the direction of current. Then the direction of fingers encircling the wire show the direction of magnetic field.

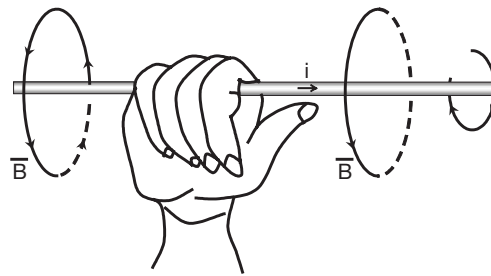


FIGURE 8.8 Ampere's right-hand thumb rule

MAXWELL'S CORK SCREW RULE

Imagine a right handed cork screw held by your hand. Rotate the screw's head such that its tip advances in the direction of the current. Then the direction in which the head rotates gives the direction of the magnetic field.

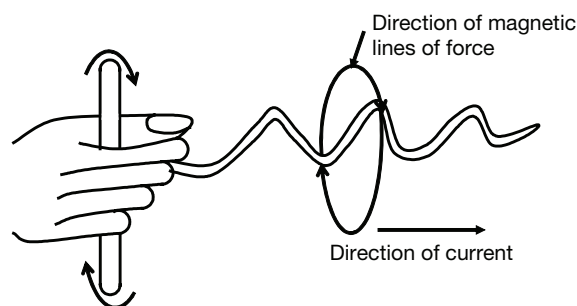


FIGURE 8.9 Maxwell's Cork Screw Rule

Magnetic Field Due to Current

- I. **Magnetic field due to a long straight current carrying wire:** The following experiment helps us study the magnetic field around a long straight current carrying wire.

Take a cardboard and fix a white paper over it. Make a small hole at its centre. Clamp this cardboard, to a stand in a horizontal position. Sprinkle some iron filings over it. Pass an insulated copper wire through the small hole at the centre of the cardboard and perpendicular to it.

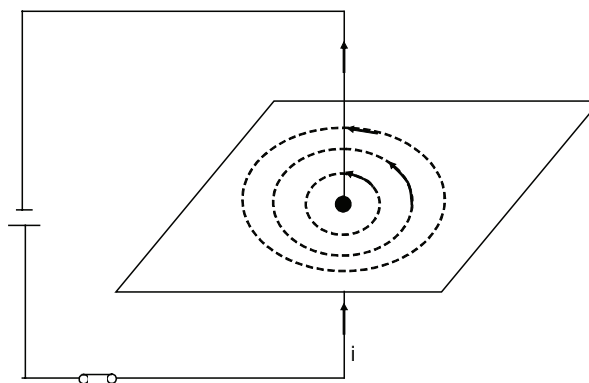


FIGURE 8.10 Magnetic field due to a long straight current carrying wire

A battery, a switch and a variable resistance are connected in series to the wire and when the circuit is closed, a current (i) flows through the wire. The iron filings on the cardboard form concentric circles around the wire showing that a current carrying conductor sets up a magnetic field around the conductor. The direction of the magnetic field at any point is in the plane of the paper and is always tangential to the circle passing through that point.

Observations	Conclusions
If the magnitude of the current in the wire is increased, then the number of concentric circles increases (i.e., the number of magnetic lines of forces increases).	The magnetic field induction ($\vec{B}$) is directly proportional to the current flowing through the wire. $\Rightarrow B \propto i$
If a magnetic needle is brought near the conductor, the deflection in the needle is more and when it is moved away, the deflection decreases.	As the distance from the wire increases, magnetic field ($\vec{B}$) decreases. The magnetic induction (B) at a point is inversely proportional to the distance of the point from the wire. Hence, $B \propto \frac{1}{r}$

From these conclusions, we have

$$B \propto i \text{ and } B \propto \frac{1}{r}$$

$$\therefore B \propto \frac{1}{r} \Rightarrow B = \frac{Ki}{r}$$

Where K is the constant of proportionality and may experimentally be verified to be equal to $\frac{\mu_0}{2\pi}$

(in S.I system), where μ_0 is called the permeability constant of free space or vacuum, whose value is given as

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1} \therefore 1.26 \times 10^{-6} \text{ T m A}^{-1}$$

Hence,

$$B = \frac{\mu_0 i}{2\pi r}$$

EXAMPLE

The Fig. 8.11 shows two long parallel wires carrying currents i_1 and i_2 in opposite directions. What is the magnitude and direction of the resultant magnetic field at the point P ?

SOLUTION

The magnetic field B_1 at P due to i_1 is given as,

$$B_1 = \frac{\mu_0 i_1}{2\pi r_1} = \frac{\mu_0}{2\pi} \times \frac{15 \text{ A}}{0.05 \text{ m}} = \frac{150\mu_0}{\pi} \text{ T}$$

The magnetic field B_2 at P due to i_2 is given as

$$B_2 = \frac{\mu_0 i_2}{2\pi r_2} = \frac{\mu_0}{2\pi} \times \frac{30 \text{ A}}{0.1 \text{ m}} = \frac{150\mu_0}{\pi} \text{ T}$$

By the Right-hand thumb rule, we find that both B_1 and B_2 are in the same direction at P . Thus, the resultant magnetic field at P is

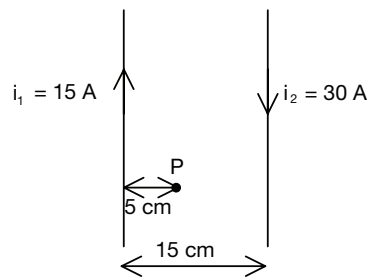


FIGURE 8.11 Two parallel long long wires carrying current

$$\begin{aligned} B &= B_1 + B_2 = \frac{150\mu_0}{\pi} + \frac{150\mu_0}{\pi} \\ &= \frac{300 \times 4\pi \times 10^{-7}}{\pi} = 1200 \times 10^{-7} \text{ T} \\ &= 1.2 \times 10^{-4} \text{ T} \end{aligned}$$

The direction of B is perpendicular to the plane of the conductors.

2. Magnetic field due to a circular current carrying wire: Let us now study the magnetic field due to a circular current carrying conductor. Take a copper wire, bend it in the form of a circular coil. Connect this coil to a battery with a rheostat and a switch in series. Pass this copper wire over two holes of a cardboard covered with a white paper. Sprinkle iron filings on the cardboard.

It is observed that iron filings arrange themselves in concentric circles as shown in the figure below.

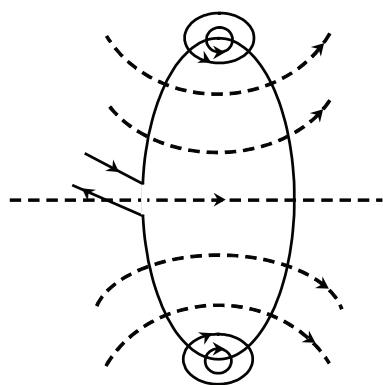


FIGURE 8.12 Magnetic field lines due to a circular current carrying conductor

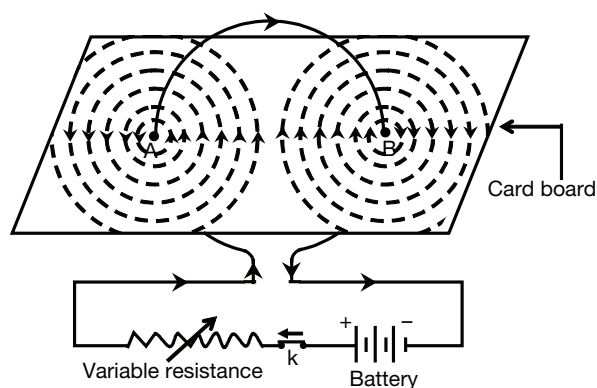


FIGURE 8.13 Magnetic field due to a circular current carrying wire

Observations	Conclusions
An increase in the magnitude of the current in the coil increases the number of magnetic lines of force.	Magnetic field induction is directly proportional to the current flowing in the wire.
It is observed that a magnetic compass shows more deflection if the circular coil is bent into a circle of less radius compared to a coil bent into a circle of larger radius.	As the radius of circular coil increases, the magnetic induction decreases. It means, $B \propto \frac{1}{R}$

Near the conductor, the field is circular and the direction of the field is given by right hand thumb rule. As we move away from the wire towards the centre of the coil, the radius curvature of magnetic lines increases, i.e., they become straighter and almost parallel to each other. At the centre of the coil, the magnetic line of force is perpendicular to the plane of the coil.

The magnitude of the magnetic field at the centre of the circular current carrying wire is found to be:

1. directly proportional to the strength of the current passing through the wire.
2. inversely proportional to the radius of the circular coil.

∴ If B is the magnetic field at the centre, then

$$B \propto i$$

$$B \propto \frac{1}{r}$$

∴
$$B = K \frac{i}{r},$$

Where K is the proportionality constant and is equal to $\frac{\mu_0}{2}$ (in S.I. system)

$$\therefore B = \frac{\mu_0}{2}$$

Where μ_0 as defined earlier is the permeability constant of vacuum and is equal to $4\pi \times 10^{-7} \text{ T m A}^{-1}$.

If there are ' n ' turns in the circular coil, then each turn will contribute to the magnetic field at the centre. So the total magnetic field at the centre due to ' n ' turns will be equal to $\frac{n\mu_0 i}{2r}$

Electromagnetism

Properties of Magnetic Lines of Force Around a Circular Coil

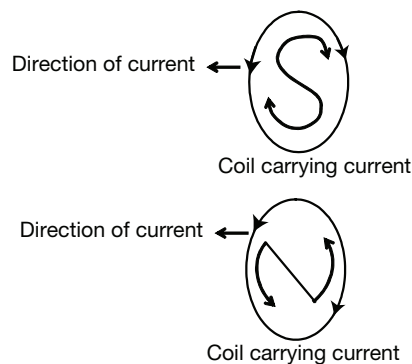


FIGURE 8.14 Sign conventions for magnetic field around a circular coil

1. At the points where current enters or leaves coil is like a straight wire. Hence, the lines of force around these points are almost circular.
2. The lines of force inside coil are in same direction.
3. Magnetic field near the centre of coil is uniform as the lines of force are parallel to each other.
4. At the centre, the plane of magnetic field is perpendicular to the coil. The magnetic field strength increases with the increase in current.
5. Looking at a face of coil, if current is flowing in clockwise direction, the face develops south polarity. If it is in anti clockwise direction, the face develops north polarity.

EXAMPLE

Find the magnetic induction field B at a distance of 10 cm from a long straight conductor carrying a current of 10 A.

SOLUTION

The magnetic induction field near a straight conductor is given by,

$$B = \frac{\mu_0 i}{2\pi r} \quad (1)$$

In the given problem,

$$R = 10 \text{ cm} = 0.1 \text{ m}, i = 10 \text{ A}, \mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$$

Substituting above values in equation (1),

$$\begin{aligned} B &= \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 0.1} \\ &= 2 \times 10^{-7} \times 10 \times 10 \\ &= 20 \times 10^{-6} \text{ T} \\ &= 20 \text{ } \mu\text{T}. \end{aligned}$$

EXAMPLE

Find the ratio of the magnetic fields, at distances 5 cm and 50 cm from a long straight current carrying conductor.

SOLUTION

Let the fields be B_1 and B_2 at distances 5 cm and 50 cm, respectively. As current remains same, we can write

$$\begin{aligned} B &\propto \frac{1}{r} \\ \Rightarrow \frac{B_1}{B_2} &= \frac{r_2}{r_1} \end{aligned} \quad (1)$$

Substituting the value of r_1 and r_2 in equation (1), we get

$$\frac{B_1}{B_2} = \frac{50}{5} = 10$$

$\therefore$ The ratio of fields is 10 : 1.

EXAMPLE

A circular coil of radius π cm and 100 turns is carrying a current of 10 A. Find the magnitude of the magnetic induction field at the centre of the coil.

SOLUTION

The induction field at the centre of the coil is given by,

$$B = \frac{n\mu_0 i}{2r} \quad (1)$$

In the problem, the values given are, $r = \pi$ cm = $\pi \times 10^{-2}$ m, $n = 100$, $i = 10$ A

$$B = ?$$

Substituting the above values in equation (1), we get

$$B = \frac{100 \times 4\pi \times 10^{-7} \times 10}{2 \times \pi \times 10^{-2}} = 2 \times 10^{-2} \text{ T} = 0.02 \text{ T}$$

- 3. Magnetic field due to a solenoid carrying current:** An insulated copper coil wound around some cylindrical cardboard or some other core such that its length is greater than its diameter is called a solenoid or a helix.

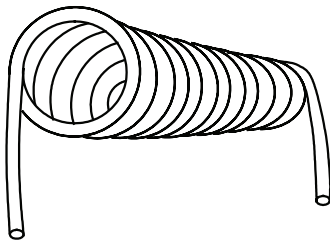


FIGURE 8.15 A Helix of Solenoid

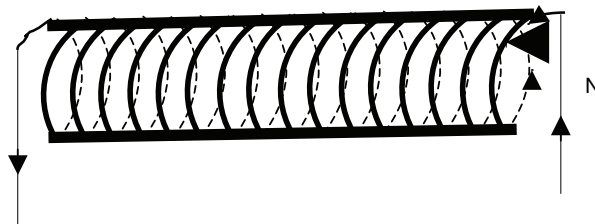


FIGURE 8.16 An insulated copper coil wound around a solenoid

When an electric current flows in the solenoid then each turn of the coil behaves like an independent magnet. All these magnets are arranged in order and therefore the total magnetic strength of the solenoid depends upon the number of turns. Thus, the solenoid acts like a bar magnet.

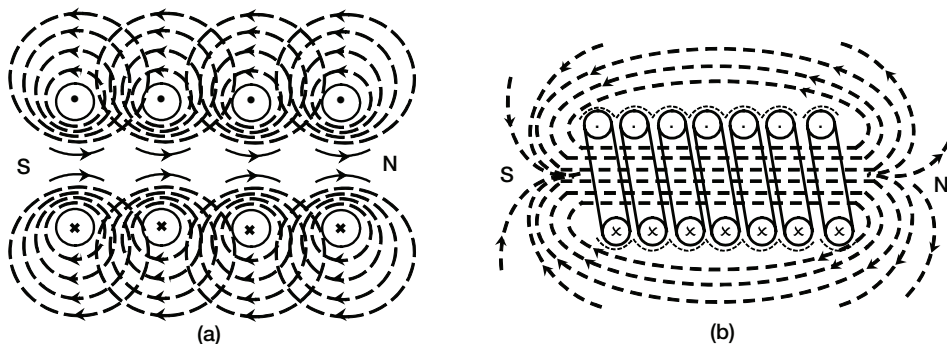


FIGURE 8.17 (a) Magnetic field inside a solenoid, (b) Magnetic field lines around a solenoid

The end in which current flows in an anticlockwise direction becomes a North Pole and the other end where the current flows in clockwise direction, becomes a South pole.

Properties of a Solenoid

1. The magnetic field due to solenoid is directly proportional to the number of turns per unit length of the solenoid.
2. The magnetic field due to the solenoid is directly proportional to the current passing through the solenoid.
3. The field depends upon the nature of material on which the coil is wound.
4. If an iron core is kept inside the solenoid, the field becomes stronger.
5. Laminated soft iron core increases the intensity of the magnetic field inside a solenoid.
6. The magnetic lines of force within the solenoid are almost parallel to each other and to the axis of solenoid.

Force on a Current Carrying Conductor Kept in a Magnetic Field

It is observed that when a current carrying conductor is kept in a magnetic field, it experiences a force.

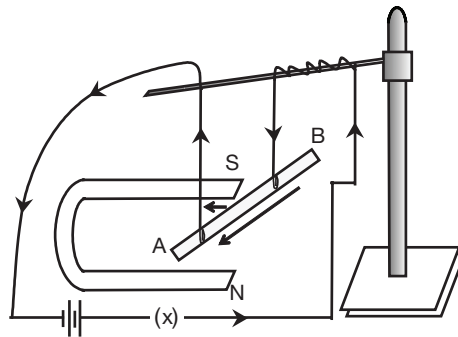


FIGURE 8.18 A current carrying rod, AB experiences a force perpendicular to the length and the magnetic field

Explanation

The lines of force representing the magnetic field between the poles of a horseshoe magnet would be straight and parallel to each other as shown in Fig. 8.19 (a) below.

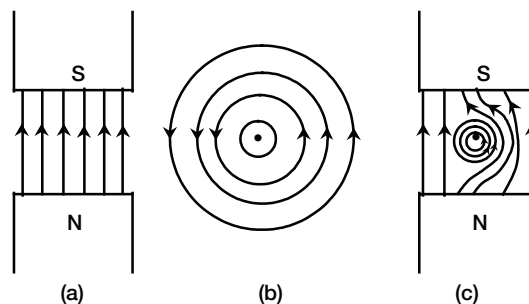


FIGURE 8.19 (a) Parallel magnetic field lines between the poles of a horseshoe magnet, (b) The magnetic field lines around a current carrying conductor, (c) Magnetic field lines when circular current carrying conductor is placed between poles of permanent magnet

The magnetic field lines around a current carrying conductor would be as shown in Fig. 8.19 (b). When this conductor is placed between the poles of the permanent magnet, the two fields would superimpose and there would be a tendency for the lines to crowd on the right side. These lines acting like stretched elastic strings would tend to straighten themselves, and thus push the conductor towards the left. If the current in the conductor is reversed, the effect would be opposite.

The force acting on the current carrying conductor depends upon the following factors:

1. The force on the conductor is directly proportional to the current in the wire.

$$F \propto i \quad (8.3)$$

2. The force on the conductor is directly proportional to the strength of the magnetic field.

$$F \propto B. \quad (8.4)$$

3. The force on the conductor is proportional to the length of the conductor.

$$F \propto \ell \quad (8.5)$$

From (8.3), (8.4) and (8.5), we have $F \propto Bil$

$\Rightarrow F = kBil$, where 'k' is the constant of proportionality.

4. Let the force on a conductor of length 1m, carrying 1 current of 1A and placed in magnetic field of induction 1 T be 1N, then

$$1 \text{ N} = K \times \frac{1\text{N}}{\text{Am}} \times 1 \text{ A} \times 1 \text{ m}$$

$$\therefore K = 1$$

$$\therefore F = Bil$$

The equation is applicable only when the current carrying conductor is placed at a right angle to the direction of the magnetic field B.

To find the direction of the force acting on the current carrying conductor, **Fleming's Left Hand Rule** is used which states as follows:

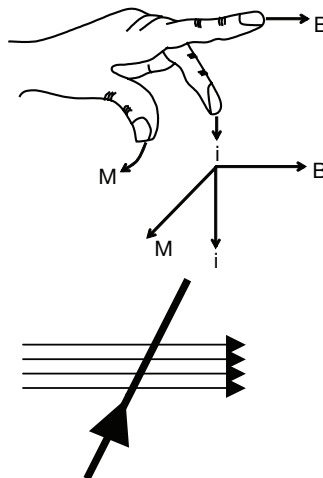


FIGURE 8.20 Fleming's Left-hand Rule

Stretch the forefinger, middle finger and thumb of your left hand in three mutually perpendicular directions. Now, if the forefinger points the direction of magnetic field (B) and the middle finger points in the direction of current (i), then the thumb will point in the direction of motion of the conductor (M), i.e., the force acting on it.

If the magnetic field is not perpendicular to the current carrying wire, then the magnitude of force is given by, $F = B i l \sin \theta$, where θ is the angle which the current carrying wire makes with the direction of the magnetic field.

MOVING COIL GALVANOMETER (SUSPENSION TYPE)

Principle

A current carrying coil kept in a magnetic field experiences a couple which is proportional to the current. It is used to detect and find the direction of the flow of current. Voltmeter and ammeter are modified forms of a galvanometer.

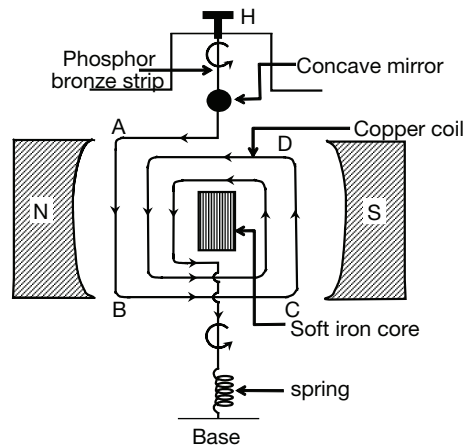


FIGURE 8.21 Moving coil galvanometer

Construction

A moving coil galvanometer consists of a rectangular coil of thin, insulated copper wire suspended between the poles of a strong horseshoe magnet NS by means of a strip of phosphor bronze. It is attached to a torsion head 'H'. There is a small mirror attached to the phosphor bronze strip. This is to observe the deflection produced by the coil, when a current is passed through it. Current enters through the torsion head 'H' and leaves through the spring at the phosphor bronze bottom.

The magnet is made concave in shape so that its magnetic field is always parallel to the plane of the coil when the coil rotates and the magnitude of the magnetic field is the same at every point of time. This type of magnetic field is called radial magnetic field. Furthermore, soft iron core is kept suspended within the coil to increase the magnetic field.

Working

The current carrying coil ABCD is kept in a magnetic field such that the direction of the current and the field are perpendicular to each other. The direction of the current in

the arms AB and CD are equal and opposite, therefore, both of them experience equal and opposite forces, forming a couple. Which tries to rotate the coil. This is called the deflecting couple. The direction of the rotation of the coil is given by Fleming's left hand rule.

As the coil rotates, the suspension wire and the loose spring of phosphor bronze get twisted, thus opposing the rotation of the coil. This gives rise to an opposing couple called restoring couple. As the phosphor bronze wire is highly tensile, it does not break when the spring and wire are twisted.

When the moment of force produced by the deflecting couple is equal to the moment of force due to restoring couple, the coil comes to rest, at a new position.

The angle through which the coil has rotated can be measured by lamp and scale arrangement. It is found that the tangent of the angle of deflection is directly proportional to the strength of the current.

$$\tan \theta \propto i.$$

$$\therefore i = k \tan \theta,$$

where k is a constant and its value depends on

1. The number of turns in the coil,
2. The area of cross section of the coil and
3. The strength of the magnetic field

The value of k is given by the manufacturers of galvanometers and knowing the deflection, we can calculate the current. Most often, using the given k the scale is directly calibrated in terms of current for a given galvanometer.

DC motor

A motor is a device which converts electrical energy into mechanical energy.

Principle: It works on the principle that a current carrying coil experiences a couple when placed in a magnetic field, which sets it into continuous rotations.

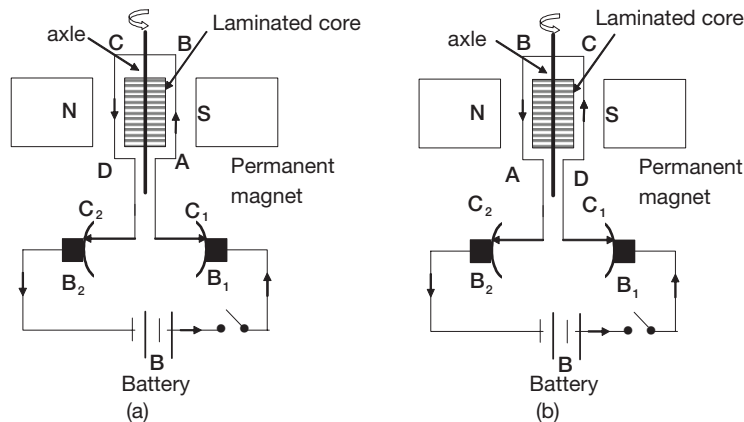


FIGURE 8.22 (a) Clockwise rotation of a motor by passing current, (b) Commutator reverses the current in DC motor.

The main parts of a motor are:

1. Permanent magnet N, S
2. Armature coil A, B, C, D
3. Commutator C_1, C_2
4. Brushes B_1, B_2
5. Battery B

The permanent magnet produces the necessary magnetic field. Its poles are made concave in shape so as to give radial field. In big motors, in order to have strong magnetic field, electromagnets are used.

Armature coil consists of a large number of insulated copper coils wound on a laminated soft iron core. The function of the coil is to set up magnetic field when a current is passed through it. The core is laminated to avoid any eddy current loss, and to provide strong magnetic field when current flows through the coil.

Commutator

The ends of the wire are connected to the two split rings C_1 and C_2 of the commutator. The function of the commutator is to change the direction of the current after half a rotation of the coil.

Brushes

The function of the two brushes B_1 and B_2 is to give electrical connection from the battery wire to the rotating coil, i.e., between the stationary parts and the moving parts of the electric circuit.

Battery

The function of the battery is to give the motor the necessary electrical energy.

Working of the Motor

The current from the positive terminal of the battery passes through the brush B_1 , split ring C_1 , and the armature coil ABCD returns via split ring C_2 , brush B_2 , to the negative terminal of the battery. The coil is placed in such a way that the magnetic field created by it is perpendicular to field due to magnets.

The current carrying coil is kept in the magnetic field of the permanent magnet. Therefore it will experience a torque.

As per Fleming's left hand rule, the arm AB of the coil experiences a force perpendicular to the plane of the paper and into the paper. The arm CD experiences a force perpendicular to the plane of paper and outwards (opposite to that of end AB) as shown in Fig. 8.22(a). These two forces constitute a couple and the motor rotates in *clockwise direction*.

When the coil turns through 90° , the magnetic field due to the coil and the field due to the permanent magnet become parallel to each other. Therefore rotation should stop as there

will not be any couple when the two fields are parallel. But due to the inertia of motion, it continues to rotate and it turns through 180° .

Now the commutator reverses the direction of the current which flows along DCBA. (as shown in Fig. 8.22(b)). The arm CD of the wire experiences a force perpendicular to the plane of the paper and into the paper, and the arm AB experiences a force perpendicular to the plane of the paper and outwards (opposite to that of end AB). Thus, the motor rotates continuously in one direction.

The revolutions per minute of a motor coil depends on the following:

1. The number of the turns of the coil
2. The area of the coil
3. The magnitude of the current
4. The strength of the magnetic field.

Electromagnetic Induction

We have seen that when current flows through a conductor, it produces a magnetic field. Micheal Faraday, through series of experiments, showed that current can be induced in a coil if it is moved in a magnetic field or if magnet is moved relative to coil. Due to the relative motion between them, the magnetic flux (Φ_0) linked with the coil, i.e., the number of lines of force passing normally through it, changes. This sets up an emf at the end of which causes current to flow. Faraday found that the current flows as long as there is continuous change in the magnetic flux passing through the conducting coil. Thus, even if both the coil and magnet are stationary, current can still be induced in coil, if the magnetic field is changed continuously which is possible by using electromagnets. This phenomenon of inducing current by changing the magnetic field associated with an electric circuit containing no source is called electromagnetic induction.

Faraday's Experiments

When a magnet is moved towards a coil with its north pole facing the coil as shown in the Fig. 8.23, Faraday observed a deflection in the galvanometer. The amount of deflection is found to be more if the speed of magnet is more.

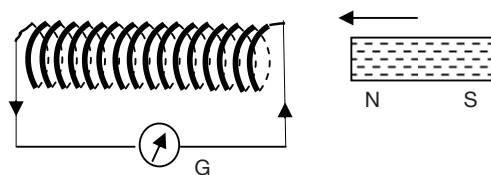


FIGURE 8.23 A magnet moved towards a coil with its north pole facing the coil

When the magnet is moved away from the coil, then it produces a deflection in the opposite direction as compared to the case, when the magnet is moved towards the coil.

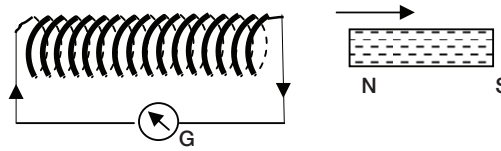


FIGURE 8.24 A magnet moved away from the coil

When the magnet is moved towards the coil with its south pole pointing towards the coil, then it produced a deflection in the opposite direction as compared to the case, when the north pole was pointing towards the coil.

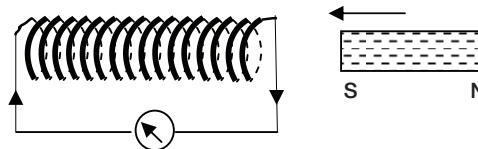


FIGURE 8.25 A magnet moved towards the coil with its south pole pointing towards the coil

Once again, if the magnet is moved away from the coil with the south pole pointing towards the coil, then it produces deflection in the opposite direction as compared to the case when the magnet is moved towards the coil.

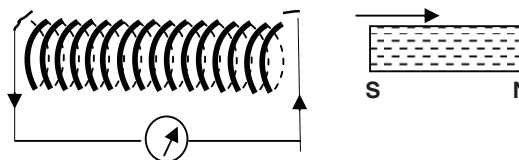


FIGURE 8.26 A magnet moved away from the coil with the south pole pointing towards the coil

Similar observations were made when the coil was moved towards or away from a stationary magnet. The deflections in the galvanometer were governed by the orientation of the magnet and the direction of the motion of the coil.

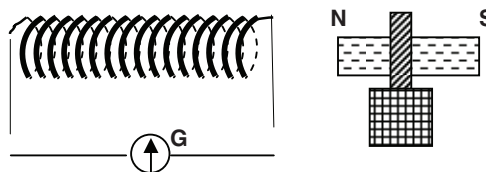


FIGURE 8.27 The coil moved towards or away from a stationary magnet.

Now, if we fix both the magnet and the coil such that there is no relative motion, then no deflection is observed in the galvanometer.

On the basis of the observations made in his experiments, Faraday formulated the following laws.

There are only two laws of EM induction, due to Faraday.

FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

1. Whenever the magnetic flux linking a coil changes, then an emf is induced in the coil.
2. The magnitude of the induced emf is directly proportional to the rate of the change of flux.

From the above observations, we can conclude that if there is a *relative motion between the magnet and the coil*, an emf is induced in the coil.

1. This emf lasts so long as there is a relative motion between the magnet and the coil.
2. If there is no relative motion, no emf is induced.
3. The magnitude of emf depends upon the relative speed.
4. The magnitude of emf depends upon the number of turns in the coil.

Following the above conclusions, Faraday formulated the law for induced emf in a coil as, the induced emf in a coil is equal to the negative rate of the change of magnetic flux linked with the coil.

Thus,
$$E = -N \frac{d\phi}{dt}$$

The observations of Faraday's experiments on electromagnetic induction and his laws can also be studied by replacing the permanent magnet with an electromagnet.

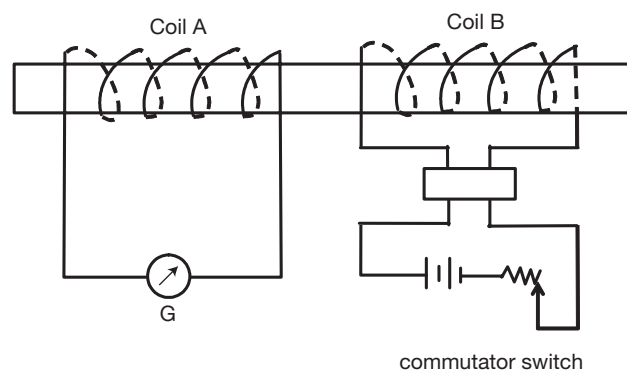


FIGURE 8.28 Faraday's Experiment

Wind two coils on a soft iron core separated by some distance, connecting the ends of coil A to a galvanometer and the ends of B to a battery through a rheostat (to vary the current) and a commutator switch (to reverse the current). It is observed that the needle of the galvanometer instantly deflects to one side and returns to zero quickly whenever the key

is closed. When the key is opened, thus disconnecting the coil from the battery, a greater deflection is observed in the galvanometer, but in the opposite directions.

Repeating the experiment after reversing the direction of current in coil B, similar observations are recorded.

LENZ'S LAW

According to Lenz's law, the direction of induced current is such that it opposes the very cause that produces it.

Consider a bar magnet moving towards a coil with its north pole facing the coil. Due to (Fig. 8.23) movement of the magnet, current is induced in anti-clockwise direction in the coil when it is viewed from magnet. The face pointing towards the magnet becomes north pole and opposes its movement. When magnet is pulled away such that its north-pole leaves the coil, (Fig. 8.24) current is induced in clockwise direction giving the face of the coil pointing towards magnet a south polarity. Thus, the movement of magnet which is responsible for induced current, is always opposed by the current itself.

Let $d\phi_B$ be the change in the magnetic flux in a short interval of time dt . The induced emf (E), according to Faraday's law is given by,

$$E = \frac{d\phi_B}{dt} \quad (8.6)$$

According to Lenz's law, the induced emf is such that it opposes the cause producing it. Hence equation (8.6) on application of Lenz's law becomes

$$E = - \frac{d\phi_B}{dt} \quad (8.7)$$

If the coil contains N turns, equation (8.7) becomes

$$E = - N \frac{d\phi_B}{dt}$$

Fleming's Right-hand Rule

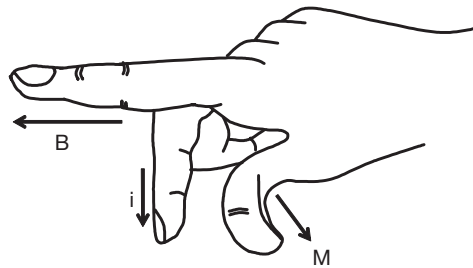


FIGURE 8.29 Fleming's Right-hand Rule

To determine the direction of induced current in a conductor, when it is moved across a magnetic field, Fleming proposed the 'Right-hand rule'.

Stretch the forefinger, middle finger and thumb of your right hand in three mutually perpendicular directions, such that the forefinger points the direction of magnetic field(B), the thumb indicates the direction of motion(M), then the middle finger represents the direction of induced current (i) in the conductor.

Moving Coil Microphone

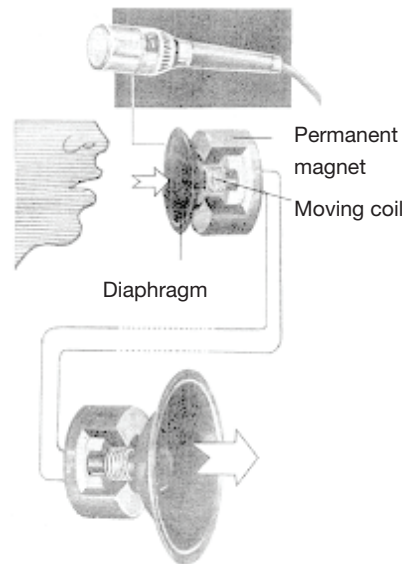


FIGURE 8.30 Microphone and loudspeaker

It is a device which converts sound energy into electric energy. It works on the principle of electromagnetic induction.

It consists of a diaphragm, a moving coil and a permanent magnet. The coil is kept in the magnetic field. As a person speaks into microphone, diaphragm is set into vibrations. The moving coil connected to it begins to vibrate accordingly. It being under magnetic field, a electric current is induced in it whose variations represent the vibrations of original sound. This electrical signal is amplified and then fed to a loud speaker.

Loud Speaker

It converts electric energy into sound energy. It consists of a permanent magnet, moving coil and a diaphragm in the form of paper cone as shown in the Fig. 8.30.

The electrical signal corresponding to the variations of original sound from the microphone is fed to the coil placed between the poles of permanent magnet. The coil begins to vibrate and sets the paper cone into vibrations. The air around the loudspeaker vibrates reproducing the original sound more loudly.

ELECTRIC GENERATOR

An electric generator is a device which converts mechanical energy into electrical energy. When a coil is rotated in a magnetic field, an emf is induced in it. The mechanical energy required to rotate the coil is converted into an electrical energy. Hence, an electric generator converts mechanical energy into electrical energy.

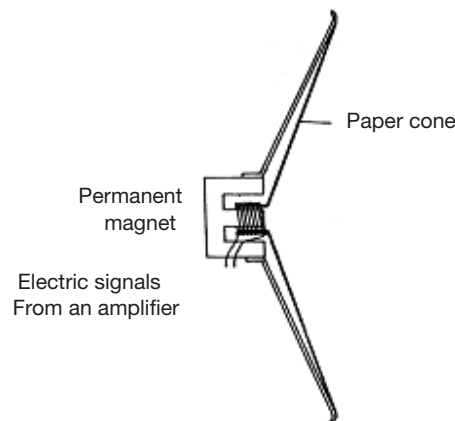


FIGURE 8.31 Parts of a loud speaker

There are two types of generators—Alternating Current (AC) generator and Direct Current (DC) generator. In the former, the current changes direction after every half-rotation. In the latter, the current is unidirectional throughout.

The Alternating Current Generator

The main parts of an AC generator are the horseshoe magnet, armature (coil), slip rings and carbon brushes.

Construction

The construction of an electric generator is similar to that of an electric motor. An AC generator consists of a rectangular coil ABCD known as armature. This armature is rotated rapidly between the poles of a permanent horseshoe magnet. The ends of the rectangular coil A and D are connected to two circular metal pieces called slip rings A_1 and A_2 . The slip rings rotate along with the coil. The two pieces of carbon brushes B_1 and B_2 are kept in contact with the slip rings. The carbon brushes are capable of tapping the current produced in the rotating coil.

Working

1. Assume that the rectangular coil ABCD is in horizontal position initially [See Fig. 8.32 (1)].
2. Let the rectangular coil ABCD be rotated from 0° to 90° , such that during its rotation, the side AB of the coil moves downwards and the side CD of the coil upwards. Hence the flux linked decreases, but the rate of change in the flux increases from zero to maximum. Hence, emf induced increases from zero to maximum, (according to Faraday's laws of electromagnetic induction). The current flows in the direction ABCD according to Lenz's Law.
3. On further rotation from 90° to 180° , the side AB of the coil starts moving upwards while the side CD of the coil moves down. Hence, flux linked increases from zero to maximum. But the rate of change in flux decreases from maximum to zero. The emf induced in the coil decreases from maximum to zero. The current continues to flow in the direction ABCD, but the magnitude of the current decreases.

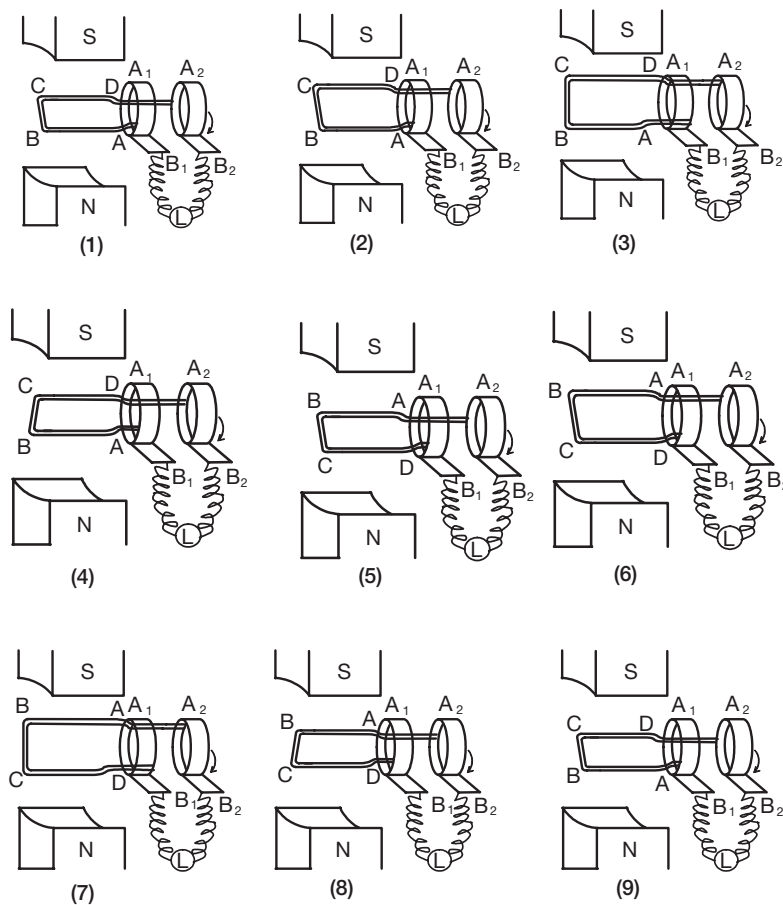


FIGURE 8.32 Working of an AC Generator in various steps showing positions of coil.

4. On further rotation of the coil from 180° to 270° , the side AB of the coil which is now once again horizontal moves upwards while the side CD of the coil moves downwards. The flux linked by the coil decreases from maximum to zero. But the rate of change in flux increases from zero to maximum in the opposite direction. Hence the emf induced is maximum, but in opposite direction, and the current starts flowing in the direction DCBA, with the magnitude increasing, in accordance with the Lenz's Law.
5. On further rotation of coil from 270° to 360° , the side AB of the coil moves downwards while the side CD of the coil moves upwards. The flux linked by the coil increases from zero to maximum and the rate of change in flux decreases from maximum to zero in opposite direction. Therefore, the emf induced also decreases from maximum to zero in opposite direction, with decreasing current continuing to flow in the direction DCBA.

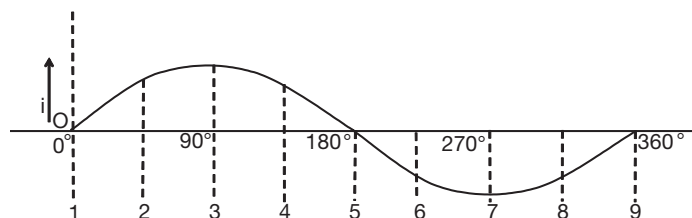


FIGURE 8.33 The variation in the current produced for various positions of the coil

In the above, the direction of induced current at any instant can be found using Fleming's right hand rule or Lenz's Law. For one complete rotation of the coil, i.e., from 0° to 360° , the coil produces an alternating voltage (AC). The variation in the current produced for various positions of the coil is shown in the graph.

Alternating Current (AC) Dynamo

Principle

When a conducting coil in a closed circuit in a constant uniform magnetic field rotates, the magnetic flux passing through it changes continuously producing an induced emf or current in the circuit.

Construction

It consists of four major parts.

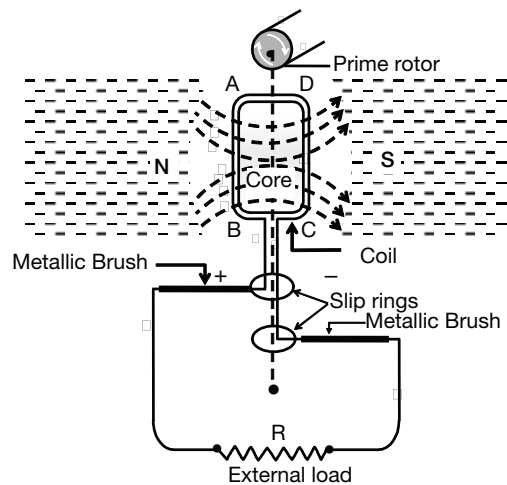


FIGURE 8.34 An Alternating Current (AC) Dynamo

1. **Armature:** It consists of insulated copper coil wound over a rectangular frame and soft iron core which is laminated. In the Fig. 8.34, ABCD represents armature.
2. **Slip rings:** S_1 and S_2 are two metallic rings connected to the ends of the rectangular coil. They rotate along with the coil about the same axis.
3. **Carbon brushes:** B_1 and B_2 are two carbon brushes used as electrical contact between moving parts (S_1 and S_2) and stationary part (load R).
4. **Permanent magnet:** N-S is powerful horse shoe magnet having concave cylindrical poles. It produces a uniform radial magnetic field.

Working

As the armature ABCD is rotated between the poles of magnet, the magnetic flux linked with it changes continuously resulting in generation of induced emf which causes current to

flow through the coil and load resistance R . As the position of amature coil changes due to its rotation, the magnitude of induced current also changes as shown in following diagram.

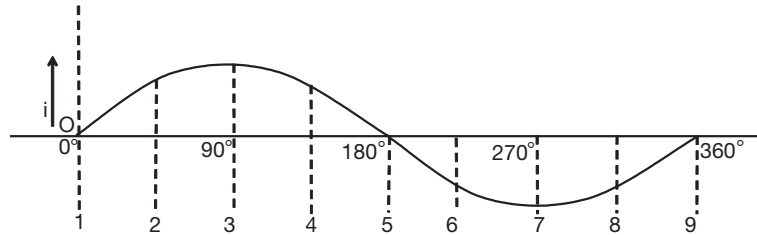


FIGURE 8.35 Graph of the magnitude of induced current

In its initial position where angle of rotation is zero, the plane of the coil is perpendicular to the magnetic lines of force or magnetic flux (ϕ_B). Maximum number of lines of force pass through coil but the induced current is zero as coil is stationary. Let the coil be rotated in counter clockwise direction such that arm AB goes down and CD comes up. As the coil rotates by 90° $\pi/2$, its plane becomes parallel to lines of forces. The magnetic flux linked with it is zero but the change in magnetic flux ($d\phi_B$) with respect to original position is maximum. Hence, maximum induced current flows. The direction of this current can be found by applying Fleming's right hand rule. As the arm AB moves in downward direction and lines of force are from right to left, current flows from B to A in the arm AB. Arm CD has moved in upward direction, hence current through it flows in opposite direction, i.e., from D to C. Through the load R , it flows from B_1 to B_2 . As the coil rotates further by 90° , it again becomes perpendicular to magnetic flux with AB below CD. The magnetic flux passing through the coil is same as in initial position. Hence the change $d\phi_B$ is zero causing the induced current to decrease from maximum to zero in the same direction. From this position as the coil rotates by 90° , AB moves up and CD down such that its plane is parallel to magnetic flux. As the change in the flux ($d\phi_B$) is maximum with respect to 'O' the induced current increases from zero to maximum in opposite direction which can be verified by applying Fleming's right hand rule. Now the current flows from A to B, in AB, C to D in CD and B_2 to B_1 in R . As the coils comes back to its original position by rotating more by 90° , current decreases from maximum to zero in the same direction. This cycle is repeated as coil continues its rotational motion.

It can be seen that during 1st half of rotation, i.e., from 0 to π , current flows from B_1 to B_2 in R , while during 2nd half from π to 2π , it flows from B_2 to B_1 . Thus, current changes its direction after regular intervals of time. Hence alternating current is generated. This reversal in current direction is brought about by slip rings S_1 and S_2 which alternately connect the two ends of coil to B_1 and B_2 .

The magnitude of induced current can be increased by increasing:

1. The number of turns in coil.
2. The area of cross section of coil.
3. The intensity of magnetic field.
4. The speed of rotation of coil.

RMS Voltage and Peak Voltage

In this type of a generator, we observe that the induced voltage across the output terminals alternates between $+V_0$ and $-V_0$ as shown in the Fig. 8.35. The alternation from $+V_0$ to $-V_0$ and again back to $+V_0$ (or $-V_0$ to $+V_0$ to $-V_0$) is referred to as one cycle, and if the frequency is n Hz, it implies that n cycles are completed in one second. The voltage V_0 is called peak value.

If the terminals of this generator are connected across a resistor, the current flowing through the circuit would also alternate at the same frequency and is referred to as alternating current. Thus, such a source of electrical energy is referred to as AC source or AC supply. The symbol for an AC source is. $\odot$

If a heater coil is connected to an AC supply of peak voltage V_0 , the heater coil gets continuously heated even though the direction of current alternates. It is found that the heating effect produced by such a source would be the same as that caused by a constant voltage source such as a cell of terminal p.d. equal to $V_0/\sqrt{2}$. It can be shown that this value is the square root of the mean of the squares of the instantaneous voltages across the terminals of the AC supply. Hence, it is called the Root Mean Square (RMS) value.

$$\therefore V_{\text{RMS}} = \frac{V_0}{\sqrt{2}} \text{ and } I_{\text{RMS}} = \frac{I_0}{\sqrt{2}}$$

EXAMPLE

Find the RMS value of +4, +2, 0, -2 and -4.

SOLUTION

Let $x_1 = 4$, $x_2 = +2$, $x_3 = 0$, $x_4 = -2$ and $x_5 = -4$.

Then, $x_1^2 = x_5^2 = 16$

$$x_2^2 = x_4^2 = 4$$

$$x_3^2 = 0$$

$$\therefore x_1^2 + x_2^2 + x_3^2 + x_4^2 + x_5^2 = 16 + 4 + 0 + 4 + 16 = 40$$

$$\text{Mean of the squares} = \frac{40}{5} = 8$$

$$\text{Square root of the mean} = \sqrt{8} = 2\sqrt{2}$$

$$\therefore \text{The RMS value of the given numbers} = 2\sqrt{2}$$

EXAMPLE

If an AC supply is rated as 220 V, find the peak voltage.

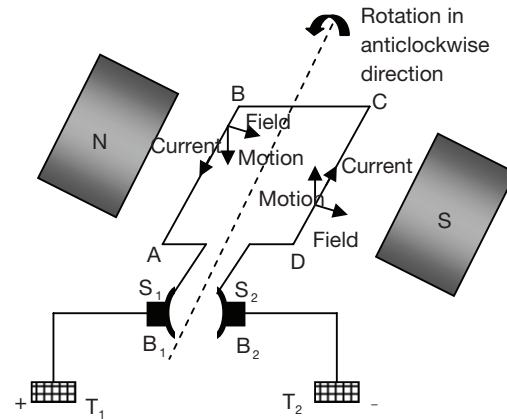


FIGURE 8.36 DC Generator

SOLUTION

The rating of an AC supply refers to its RMS value

Thus, $V_{\text{RMS}} = 220 \text{ V}$

$$\text{i.e., } \frac{V_0}{\sqrt{2}} = 220 \text{ V}$$

$$\therefore V_0 = 220\sqrt{2} \text{ V}$$

Therefore, the peak voltage is $220 \sqrt{2} \text{ V} \approx 311 \text{ V}$.

The Direct Current Generator

When the current flows continuously in one direction, the current is referred to as direct current. To obtain such a DC current, the AC generator is modified by replacing the slip rings with a commutator (half-slip rings or split rings) $S_1 S_2$.

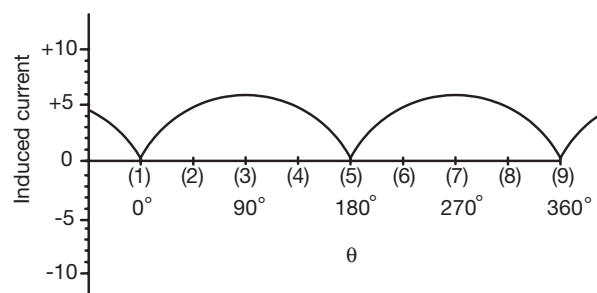
Working

FIGURE 8.37 Graph of direct current

Let the generator coil ABCD be initially in the horizontal position. Let the coil be rotated in an anticlockwise direction as shown in the Fig. 8.37, side AB downwards and side CD

upwards. According to Fleming's right-hand rule, the induced current flows in the direction BA in the side AB and in the direction DC in the side CD. Thus, induced current flows in the direction DCBA during the first half of rotation.

After half rotation, arms AB and CD interchange their positions. When the coils interchange their positions, the commutator split rings S_1 and S_2 automatically change their contact with the carbon brushes. Due to this, the current flowing in the load remains in one direction. Thus, the brush B_1 remains always positive and the brush B_2 remains always negative. Thus, the current would always be flowing out from the terminal T_1 .

Inductance of a Coil

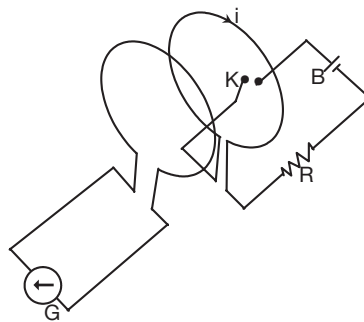


FIGURE 8.38 Circuit diagram to show a coil and a magnet induces an emf in the coil

The relative motion of a coil and a magnet induces an emf in the coil. This emf is referred to as dynamically induced emf, as since the emf is induced due to the actual motion of either the magnet or coil. If a change in the current in one coil induces an emf in another coil (due to changing magnetic field linked with each other), then the emf induced in the second coil is referred to as statically induced emf.

Inductance is the property of a coil to induce emf in the same coil or another coil placed near it due to the changes in the current in the coil.

Self-Induction

Every current carrying coil produces a magnetic field which is linked to the same coil. When the current in the coil changes, the magnetic flux produced also changes and is linked to the coil itself. According to Faraday's law of induction, this change in magnetic field produces an induced emf which opposes the change.

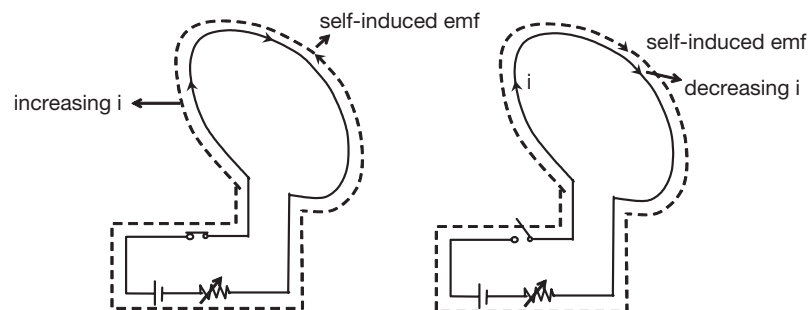


FIGURE 8.39 Self-induction in current carrying coils

This phenomenon in which an induced emf is produced in a coil due to a change in the current in the same coil is called self-induction, and the induced emf is generally referred to as self-induced emf.

The induced emf is equal to the rate of change of flux.

$$E = -\frac{d\phi}{dt}$$

The negative sign indicates the induced emf opposes the applied emf.

But $\frac{d\phi}{dt} \propto \frac{di}{dt}$ and so $\frac{d\phi}{dt} = L \frac{di}{dt}$

$\therefore E = -L \frac{di}{dt}$ where 'L' is the constant of proportionality and is called self-inductance of the coil.

$$L = \frac{-E}{(di/dt)}$$

The self inductance 'L' of a coil is numerically equal to the ratio of the induced emf to the rate of change of current in the coil.

Mutual Induction

The phenomenon, due to which a change in current in one coil induces an emf in another coil held close to it, is called 'mutual induction'.

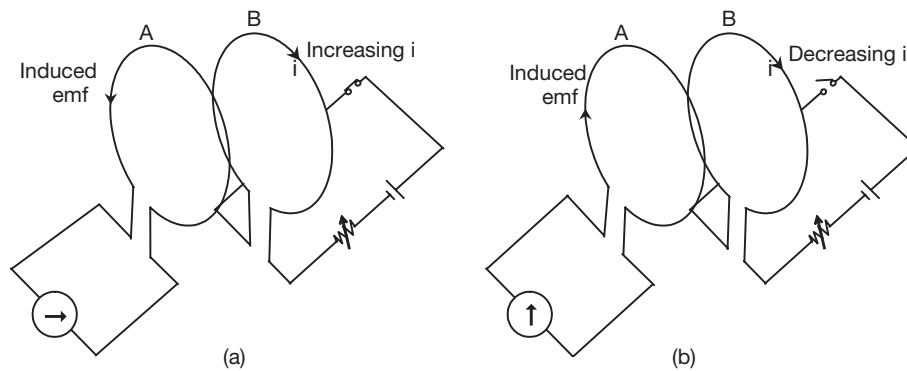


FIGURE 8.40 (a) Induced emf in coil A on increasing current in coil B, (b) Induced emf in coil A on decreasing current in coil B

Here, the current is changing in coil 'B'. Therefore the flux associated with the coil B is changing. If we place one more coil 'A' near it, the changing magnetic field in coil 'B' will produce an emf in the second coil 'A'. This phenomenon is known as mutual induction.

$$E_A \propto -\frac{di_B}{dt}$$

$$E_A = -M_{AB} \frac{di_B}{dt}$$

Here, the constant of proportionality ' M ' is called the 'mutual inductance'.

The negative sign indicates that the induced emf opposes the change producing it. The mutual inductance of a coil is numerically equal to the ratio of the induced emf in the coil to the rate of change of current in the another coil, placed near it.

$$M_{AB} = - \frac{E_A}{di_B/dt}$$

The unit of inductance (self-inductance and mutual inductance) is Henry (H) and $1 H = 1 V s A^{-1}$ (volt second per ampere).

Transformer

It is a static electrical device used to step-up a low voltage to a high voltage or to step-down a high voltage into a low voltage and is used on AC circuits. Transformer works on the principle of mutual induction. The main parts of a transformer are:

1. A soft iron laminated core
2. A primary coil
3. A secondary coil

Core

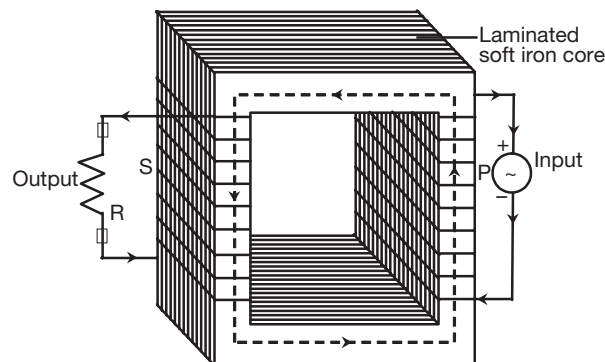


FIGURE 8.41 The core of a transformer

The core is made up of a rectangular frame made up of silicon steel. Each sheet is insulated from the neighbouring sheet by varnishing it.

1. It is made up of soft iron to increase the magnetic permeability.
2. It is made up of laminations to avoid eddy current loss.

Primary Coil

The input of the alternating voltage is connected to this coil. Since the voltage changes with respect to time, changing magnetic flux is introduced by this coil. This changing flux is coupled to the secondary coil through the core.

Secondary Coil

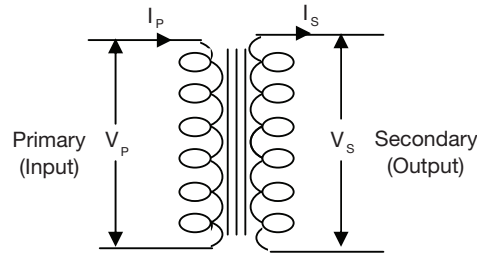


FIGURE 8.42 Secondary coil

The output from the transformer is taken from this coil. The changing flux due to changing voltage in the primary coil is coupled to the secondary coil. This will produce an alternating voltage.

The symbolic representation of a transformer in electric circuits is as shown below.

Step-Up Transformer

A step-up transformer steps the primary (incoming) voltage up to a higher value. If the number of turns of the secondary coil is more than the number of turns of the primary coil, it is called a step-up transformer. In this case, the secondary voltage will be more than the primary voltage. The secondary current is less than the primary current.

Step-Down Transformer

A step-down transformer steps the primary voltage down to a lower value. If the number of turns of the secondary coil is less than that of the primary coil, it is called a step-down transformer. In this case, the secondary voltage will be less than the primary voltage. The secondary current is more than the primary current in a step-down transformer.

Working

If an AC voltage V_1 is applied to the primary coil of N_1 turns, an alternating current flows in the primary coil and produces a changing magnetic flux. This magnetic flux is linked to the N_2 turns of the secondary coil, thereby, an emf is induced in the secondary coil. Let it be V_2 .

According to Faraday's law of induction,

$$E = -N \frac{d\phi_B}{dt}$$

$$\text{i.e., emf per turn, } E_{\text{turn}} = \frac{E}{N} = -\frac{d\phi_B}{dt} = \text{constant}$$

Thus, emf per turn is the same for both primary and secondary coils.

$$\therefore \frac{V_1}{N_1} = \frac{V_2}{N_2}$$

Thus, the relation between the number of turns and the voltage in a transformer is given by,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \quad (8.8)$$

Since in an ideal transformer, there is no loss of power,

power in the primary = power in the secondary coils. If I_1 and I_2 are the currents in the primary and secondary coils, respectively,

$$P = V_1 I_1 = V_2 I_2$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} \quad (8.9)$$

From (8.8) and (8.9),

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$V_2 = V_1 \frac{N_2}{N_1} \text{ (transformation of voltage)}$$

$$I_2 = I_1 \frac{N_1}{N_2} \text{ (current transformation)}$$

$\therefore N_2 > N_1 \Rightarrow$ step-up transformer

$\therefore N_2 < N_1 \Rightarrow$ step-down transformer.

EXAMPLE

In a transformer, the ratio of the number of turns of a primary to a secondary coil is 2 : 5. If the current through the primary coil is 10 A and input power is 300 W, find the current and voltage in the secondary coil.

SOLUTION

The turn-ratio and currents are related as

$$\frac{N_1}{N_2} = \frac{I_2}{I_1} \quad (1)$$

In the problem, values given are $\frac{N_1}{N_2} = \frac{2}{5}$, $I_1 = 10$ A

Substituting the above values in (1) and solving for I_2 , we get

$$\frac{2}{5} = \frac{I_2}{10}$$

$$\Rightarrow I_1 = \frac{2}{5} \times 10 \Rightarrow I_2 = 4 \text{ A}$$

In an ideal transformer, the input and the output powers are equal. Therefore, we can write

$$V_1 I_1 = V_2 I_2 \quad (2)$$

But the input power is given as 300 W. Substituting this in equation (2), we get

$$V_2 I_2 = 300$$

Substituting $I_2 = 4 \text{ A}$ in the above equation, we get

$$V_2 \times 4 = 300 \Rightarrow V_2 = \frac{300}{4}$$

$$\Rightarrow V_2 = 75 \text{ V.}$$

Energy Loss in Transformers

1. Due to the finite resistance of the primary and secondary coils, there will be a power loss in the primary and secondary coils due to heat energy developed in them. This is known as copper loss or heat loss.

$$\text{Copper loss} = I^2 R$$

2. A part of the energy is wasted on account of the magnetic flux in the soft iron core. This is known as magnetic loss or hysteresis loss.
3. A part of energy is wasted on account of the eddy current. This is known as eddy current loss. This is minimized by using laminated core.
4. Loss due to flux leakage.

Uses of a Transformer

1. At the generating station, a transformer is used to step-up the voltage before transmitting it for long distances to avoid losses. At the receiving end, it is used to step-down to the required level to supply to the domestic users. It is used to change the voltage to required level.
2. In a radio, TV, X-ray tube, etc., either the step-up or step-down transformers are used.
3. In stabilizers, step-up-cum-step-down transformers are used to control the fluctuations in voltage.

Eddy Currents

Induced currents produced in a solid core piece of metal placed in changing magnetic field is called an eddy current. It has advantages and disadvantages.

Let us see why eddy currents are undesirable. The eddy currents produced heat up the metallic solid core. The heating of core by eddy currents is undesirable because

1. it results in the loss of useful energy.
2. it increases the risk of the breakdown of the insulation of the winding.

Eddy currents can be eliminated by the following methods.

1. The solid metal is cut in such a manner so as to increase the path for the eddy current. Hence the resistance increases and eddy current reduces.
2. Eddy currents can be reduced by using a laminated core. Instead of using a solid core, if we use thin sheets packed together and insulated between two layers, the resistance increases and the eddy current is reduced. This is the reason why the coil of a transformer is wound on a laminated core and not on the solid core.

Uses of Eddy Current

We can make use of the eddy current for some useful purpose. Eddy currents produce heat in metals. Hence, metals can be melted using the eddy current. This is the principle in induction melting and heating furnaces.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. State the expression for magnetic induction field on axial and equatorial line. Give its direction.
2. Define retentivity.
3. What is meant by an electromagnetic induction?
4. State Fleming's right hand rule.
5. Define a neutral point. Give the location of neutral points when the North Pole of a bar magnet faces geographic north and geographic south.
6. Give the relation between V , N and I with respect to the primary and secondary coils of a transformer.
7. State Lenz's law.
8. Explain the principle of an electric generator.
9. Define: (1) magnetic field (2) magnetic lines of force
10. Define intensity of magnetisation, magnetic susceptibility and retentivity. Give their SI units.
11. Which observation made in Oersted's experiment with a current carrying conductor concludes that the magnetic induction is proportional to the strength of the current in the conductor?
12. What is the difference between an AC dynamo and a DC dynamo?
13. What is magnetic saturation?
14. Define dia, para and ferromagnetic substances. Give examples.
15. Why the magnetic lines of force away from a straight conductor carrying current are elliptical?
16. Define: (a) inductance (b) selfinduction (c) mutual induction
17. Define the pole strength of a magnet. What is its S.I. unit?
18. What is a domain in ferromagnetic substances?
19. What type of magnetic field is observed at the centre of a circular coil carrying current?
20. Give the principle of a transformer. State the types of transformers.
21. What is meant by electromagnetism?
22. Why is Ewing's theory called molecular theory of magnetism?
23. What is meant by a solenoid?
24. Why do magnetic lines of force pass through iron more freely than through air?
25. According to Ewing's molecular theory, why is steel used to make permanent magnets?
26. Which rule is used to find the force on a current carrying wire placed in a magnetic field?
27. Mention the energy conversions taking place in a loud speaker and a microphone.
28. Define magnetic induction field B . Intensity of magnetic field (H) and state their units.
29. What happens to the length of a iron bar when it is magnetised?
30. State the principle of a moving coil galvanometer.

Short Answer Type Questions

31. Compare the properties of
(a) diamagnetic (b) paramagnetic
(c) ferromagnetic substances
32. Explain how will you calculate magnetic moment (M) of a bar magnet using neutral points.
33. Explain domain theory.
34. Give the properties of a solenoid.
35. Calculate magnetic field induction B due to a long straight conductor carrying a current of 5 A at a perpendicular distance of 10 cm from it.
36. Write a note on important magnetic properties.
37. Give various characteristics of magnetic lines of force.
38. Describe Ewing molecular theory.
39. Calculate magnetic field induction ' B ' at the centre of a circular coil having 500 turns, radius π cm and carrying a 5 A of current.
40. Explain Oersted's experiment.
41. Explain why isolated magnetic poles do not exist.
42. What is modern electron theory?



43. Explain Faraday's experiment using a magnet and a coil and state Faraday's laws of electromagnetism
44. Explain magnetic induction 'B' and intensity of magnetizing field.
45. Distinguish between absolute and relative permeability of a medium.

Essay Type Questions

46. Describe a moving coil galvanometer.
47. Explain in detail:
(a) Electric motor (b) AC generator
(c) DC generator (d) Transformer
48. Write a note on terrestrial magnetism.
49. Write a note on:
(1) self-inductance (2) mutual inductance
50. How do you locate the neutral points when
(1) the North Pole of a bar magnet faces geographical north and
(2) when the south pole of bar magnet faces geographical north?

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

- In a DC electric motor, a pair of split rings is used as commutator.
- According to Ewing's molecular theory, every molecule of a given substance is a magnet by itself.
- A transformer is an electrical device that works on the principle of self-induction.
- Outside the magnet, the magnetic lines of forces pass from north pole to the south pole and inside the magnet, they pass from south to the north pole.
- Lenz's law is used to find out the magnitude of the induced emf.
- Relative permeability and absolute permeability have the same units.
- The angle between geographic and magnetic meridian is called angle of dip.

Direction for questions 8 to 14:

Fill in the blanks.

- The phenomenon of production of back emf in a coil due to flow of varying current through it is called _____.
- The unit of self-inductance in SI system is _____.
- The point where resultant magnetic field strength is zero is called _____.
- Fleming's left-hand rule is used to find the direction of _____ acting on the current carrying conductor placed in a/an _____ field.
- _____ is the measure of the ability of a given magnetic pole to attract or repel another magnetic pole.
- The product of pole strength of a magnet and its magnetic length is called its _____.
- An emf is induced in a coil when _____ linked with it changes.



Direction for question 15:

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

15.

Column A		Column B
A. μ	()	a. Faraday's law of electromagnetic induction
B. Diamagnetic substance	()	b. Magnetic equator
C. H	()	c. $\mu_0\mu_r$
D. Angle of dip = 0	()	d. Deflection of coil directly proportional to the current flowing through the coil
E. $\tan \theta \propto I$	()	e. $\frac{B}{\mu_0}$
F. $E = -N \frac{d\phi}{dt}$	()	f. Thick copper wire in the secondary winding.
G. Moving coil galvanometer	()	g. force on a current carrying conductor placed perpendicular to field.
H. Step down transformer	()	h. Tangent galvanometer
I. $F = Bi\ell$	()	i. Susceptibility is very small and negative.
J. Solenoid	()	j. Uniform magnetic field.

Direction for questions 16 to 40:

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

16. A transformer

- (a) converts AC to DC
- (b) converts DC to AC

- (c) increases or decreases (step up or step down) AC voltage
- (d) increases or decreases (step up or step down) DC voltage.

17. In an AC generator, maximum number of lines of force pass through the coil when the angle between the plane of coil and lines of force is _____.

- (a) 0°
- (b) 60°
- (c) 30°
- (d) 90°

18. Magnetic induction field due to a short bar magnet on its equatorial line at a certain distance is B . Its value at the same distance on the axial line is _____.

- (a) $2B$
- (b) $\frac{B}{2}$
- (c) $3B$
- (d) $\frac{B}{3}$

19. Magnetic field inside the solenoid is _____.

- (a) radial
- (b) uniform
- (c) Both (a) and (b)
- (d) circular

20. A step down transformer steps up _____ and steps down _____.

- (a) current, voltage
- (b) voltage, current
- (c) power, energy
- (d) voltage, power

21. The power of a DC motor can be increased by

- (a) increasing the area of the cross section of the coil.
- (b) increasing the current flowing through the coil.
- (c) laminating the soft iron core.
- (d) All of the above

22. Keeping the distance between two magnetic poles constant, if the two poles are connected by an iron rod, the force between the two poles _____.

- (a) increases
- (b) decreases
- (c) remains same
- (d) None of these

23. In a suspension type of moving coil galvanometer, the couple developed in the suspension wire and the loose spring is called a _____.

- (a) deflecting couple
- (b) restoring couple
- (c) twisting couple
- (d) None of these

24. The right hand thumb rule is used to find

- (a) force on a charged particle passing through the magnetic field.
- (b) force on a current carrying conductor placed in a magnetic field.



- (c) direction of induced current.
- (d) direction of B around a current carrying straight conductor.

25. Looking from one side towards the face of a coil, the current in it flows in clockwise direction. On looking from the opposite side towards the second face of the coil, the current flows in

- (a) anti-clockwise direction and this face represents the south pole.
- (b) clockwise direction and this face represents the north pole.
- (c) anticlockwise direction and this face represents the north pole.
- (d) clockwise direction and this face represents the south pole.

26. The relative permeability of a paramagnetic substance is ____.

- (a) much more than one
- (b) slightly more than one
- (c) less than one but greater than zero
- (d) zero.

27. Ferromagnetic substances achieve a high degree of magnetic alignment due to the effect known as ____.

- (a) pole swapping
- (b) exchange coupling
- (c) magnetic poling
- (d) None of these

28. An AC generator can be converted into DC generator by replacing ____.

- (a) armature with coil
- (b) concave magnets with horse shoe magnet
- (c) slip rings with split rings
- (d) All of the above

29. Magnetic permeability is the ratio of

- (a) magnetic induction to susceptibility.
- (b) magnetic induction to magnetizing field.
- (c) magnetizing field to magnetic induction.
- (d) magnetizing field to susceptibility.

30. When a piece of iron is placed in a changing magnetic field, it gets heated due to flow of ____.

- (a) Eddy current
- (b) Faraday's current
- (c) Fleming's current
- (d) None of the above

31. The magnetic induction field B around a current carrying straight conductor is

- (a) perpendicular to the current.
- (b) parallel to the current.
- (c) opposite to the direction of flow of current.
- (d) None of the above.

32. _____ is used to make permanent magnets.

- (a) Soft iron
- (b) Steel
- (c) Nichrome
- (d) Copper

33. A transformer works with

- (a) AC voltages only.
- (b) DC voltages only.
- (c) Both (a) and (b).
- (d) None of these

34. Eddy currents are produced in a metallic conductor when

- (a) the magnetic flux linked with it changes.
- (b) it is placed in a changing magnetic field.
- (c) it is placed in a magnetic field.
- (d) Both (a) and (b).

35. The self or mutual induction takes place when magnetic flux through a coil ____.

- (a) remains steady
- (b) decreases
- (c) increases
- (d) Both (b) and (c).

36. Which of the following statements is incorrect? In the process of electromagnetic induction, the magnitude of the induced emf depends on ____.

- (a) the number of turns of the coil.
- (b) the magnetic flux linked with the coil.
- (c) the rate of change of magnetic flux linked with the coil.
- (d) area of the coil.

37. Write the following steps in a sequential order to find the current and voltage in the secondary coil. The ratio of the number of turns of a primary to a secondary coil, current through the primary coil and input power are given.

- (a) Let the given data be taken as $\frac{N_1}{N_2}$ (turn-ratio), i_1 , (input current) and P (input power).

- (b) Substitute the given values of $\frac{N_1}{N_2}$ and i_1 , in the above formula and get the value of i_2 .



- (c) Write the relation between turn-ratio and the currents as $\frac{N_1}{N_2} = \frac{i_2}{i_1}$, where i_2 is the current in the secondary coil.
- (d) Write the relation between input power and output power in terms of V_1, i_1, V_2, i_2 , i.e., $V_1 i_1 = V_2 i_2 = P$, where V_1 and V_2 are the voltage in the primary and secondary coils, respectively.
- (e) Substitute the values of i_2 and P in the above relation to get the value of V_2 .
- (a) a d b c e (b) b c a d e
(c) a c b d e (d) d b c a e
38. Write in the sequential order the following steps of an experiment to show that a current carrying conductor sets up a magnetic field around it.
- (a) Pass the insulated copper wire through the small hole at the centre of the cardboard and perpendicular to it.
- (b) Paste a white paper on a rectangular cardboard and make a small hole at its centre.
- (c) Connect this wire to a battery, a switch and a variable resistor in series.
- (d) Clamp this cardboard to a stand in a horizontal position and sprinkle some iron filings over it.
- (e) Now, when the circuit is closed, the iron filings on the cardboard form concentric circles around the wire.
- (a) b d a c e (b) b a c e d
(c) a d b e c (d) e d a b c
39. Write the following steps of an experiment (in a sequential order), to establish that a circular current carrying wire creates a magnetic field around it.
- (a) Sprinkle iron filings on the cardboard and switch on the circuit.
- (b) Make two holes on a piece of cardboard covered with white paper. Pass this copper wire through the two holes of a cardboard.
- (c) Take a copper wire and bend it in the form of a circle.
- (d) Now connect the ends of the copper coil to a battery with a rheostat and a switch in series.
- (e) You observe that the iron filings arrange themselves in concentric circles.
- (a) a c b d e (b) c b d a e
(c) c a d b e (d) b c d a e
40. Two long parallel wires A and B separated by a distance d , carry currents i_1 and i_2 respectively in the same direction. Write the following steps in a sequential order to find the magnitude of the resultant magnetic field at a point 'P', which is between the wires and is at a distance 'x' from the wire A. (All the physical quantities are measured in SI units)
- (a) Note the given values of i_1, i_2, d and x .
- (b) Write the formula to find the magnetic field due to a long straight current carrying wire, i.e.
- $$B = \frac{\mu_0 i}{2\pi r}.$$
- (c) Find the directions of the magnetic field at 'P' due to two wires A and B, using right hand thumb rule.
- (d) Determine the magnetic field at P due to wire A, using $B_1 = \frac{\mu_0 i_1}{2\pi x}$.
- (e) If the directions of magnetic field are same, then the resultant magnitude is equal to the sum of B_1 and B_2 .
- (f) Determine the magnetic field B_2 due to wire B at point P, i.e. $B_2 = \frac{\mu_0 i_2}{2\pi(d-x)}$.
- (g) If the directions of magnetic fields are opposite to each other, then the resultant magnitude is equal to the difference of B_1 and B_2 .
- (a) d f c e g b a (b) c d f e g b a
(c) a c b d f e g (d) a b d f c e g

Level 2

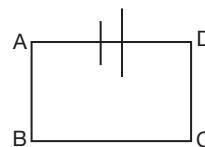
41. When a short magnet is placed with its south pole pointing the geographic north of the earth, the neutral point is at a distance 10 cm. At what distance the neutral point will be formed, when the magnet is rotated through 180° ?

$$\left[\text{Take } \frac{1}{3\sqrt{2}} = 0.88(\text{app}) \right]$$



42. Calculate the magnetic force per unit length on a conductor carrying a current of 10 A and making an angle of 30° with the direction of a uniform magnetic field of 0.3 T.
43. In a moving coil galvanometer, why do we not use a magnet with flat poles? Explain.
44. A circular coil of area 1.5 m^2 is placed normal to a uniform magnetic field of induction 2 Wb m^{-2} . The field is increased uniformly to 4 Wb m^{-2} in 20 s. Calculate the induced emf.
45. At a given point in a magnetic field, is it possible to have different magnetic induction fields? At two different points in a magnetic field, is it possible to have same magnetic induction field? Explain.
46. Why does a solenoid contract when a current passes through it?
47. The current through the coil of inductance 0.15 H increases at a rate of 10 A s^{-1} . Find the induced emf across the coil.
48. Two identical circular coils are placed in the same plane side by side such that they do not touch each other. An increasing current is in the same plane and passed through one of the coils in the clockwise direction. Do the two coils attract or repel each other? Explain.
49. A bar magnet of magnetic moment M is cut into ' n ' parts along the axial line and ' m ' parts perpendicular to the axial line. Find the magnetic moment of each piece.
50. Two infinitely long wires P and Q carry currents of 2 A and 8 A, respectively, in the same direction. Find at what distance from P the resultant induction field is zero, if they are kept parallel to each other at a distance of 10 cm.
51. How will you light a bulb rated 100 W, 120 V using 240 V AC supply?
52. A magnetized rod of moment M and length ' L ' is bent in the form of an arc of a circle of radius r . If the arc length is $\frac{1}{4}$ th the circumference of the circle, then find the magnetic moment of the arc, in terms of M .

53. Explain why two magnetic field lines can never intersect.
54. A cell is connected across AD of a square loop ABCD, made of a conductor of uniform area of cross section, as shown in the figure. Find the ratio of magnetic fields at the centre produced by



- (a) sides AB and CD and
(b) sides AD and BC.
55. A bar magnet of magnetic moment M is cut into ' p ' parts along the axial line and ' q ' parts perpendicular to the axial line. Find the magnetic moment of each piece.
56. An experimentist placed two magnetic poles separated by 10 cm (in air), one having double the strength as the other and found that both repel each other with a force of $8 \times 10^{-3} \text{ N}$. Calculate the pole strength of each pole.
57. If m is the pole strength, A is the area of cross section and I is the intensity of magnetization of a given magnet, prove that $I = \frac{M}{A}$.
58. Randheer's father gave him a short bar magnet of length 5 cm and asked him to find its pole strength. He also gave him information that the earth's horizontal component of magnetic intensity is $50 \mu\text{T}$ at the given place. Experimentally Randheer found that the bar magnet produces a neutral point 15 cm away from its centre on the equatorial line and calculated its pole strength. Find the answer.
59. In a science fair, a student performed an activity with a magnet. First, he placed the magnet with its south pole pointing towards the geographic north of the earth and rotated the magnet by an angle of 180° , then calculated how the angle made by the line joining the neutral points had rotated. Find the angle.



Level 3

60. Lenz's law is in accordance with the law of conservation of energy. Explain.
61. The dipole moment of a semicircular magnet is 28 A m^2 . It is straightened to form a bar magnet, which is then cut along its axial line to give two magnets. Find the magnetic induction at a point on the equatorial line 0.2 m away from the centre of one of the magnets. If the point is along the axis same distance away from the centre of the magnet, then find the magnetic induction.
62. Explain why a current carrying conductor experiences a force when placed in a magnetic field but not when placed in an electric field.
63. Two magnetic poles of strengths ' m_1 ' and ' m_2 ' when placed in air at a distance of ' d ' from each other, a force ' F ' acts between them. If the pole strength of the poles is doubled, the distance between them is trebled and the poles are placed in some other medium, the force between them reduces by 25%. Find the relative magnetic permeability of the medium.
64. A bar magnet is suspended in a uniform magnetic field. Find the ratio of the torques when it makes an angle of 30° and 60° , respectively, with the field.

Direction for questions 65 to 69:

Select the correct alternatives from the given choices.

65. Calculate magnetic field induction B due to a straight conductor carrying current 5 A at a perpendicular distance of 10 cm from it.
66. Calculate the magnetic field induction ' B ' at the centre of a circular coil having 500 turns, radius $\pi \text{ cm}$ and carrying 5 A of current.
67. When a coil of 100 turns and resistance 0.5Ω is moved towards a stationary magnet, the magnetic flux linked with the coil changes from 5×10^{-2} weber to 0.15 weber. Find the charge flowing through the coil during its motion.
68. A rectangular coil of area 100 cm^2 is placed normal to the magnetic field. If the magnetic field changes from 0.1 T to 0.2 T in 1 ms , find the induced emf in the coil.
69. In an experiment, a physics student named Rakesh took a magnet and a coil of resistance 10Ω . He then performed an activity by moving the magnet towards the coil in such a way that the magnetic flux linked with the coil changes from 10 weber to 40 weber and he calculated the amount of charge that flowed through the coil during the motion. Find what his answer would be.



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. self-induction 9. henry 10. null point 11. force, magnetic
12. pole strength 13. Magnetic moment 14. the magnetic flux

Match the following

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

Multiple Choices questions

16. (c) 17. (d) 18. (a) 19. (b) 20. (a) 21. (d) 22. (a) 23. (b) 24. (d) 25. (c)
26. (b) 27. (b) 28. (c) 29. (b) 30. (a) 31. (a) 32. (b) 33. (a) 34. (d) 35. (d)
36. (b) 37. (c) 38. (a) 39. (b) 40. (d)

Explanation for question 31 to 40:

31. The magnetic lines of force are concentric circles, with current carrying straight conductor at the centre and perpendicular to the plane of these concentric circles. The direction of the magnetic lines of force is clockwise or anticlockwise depending on the direction of flow of current. The direction of B is obtained by drawing tangent to the concentric circles at any point on it. It is seen that different points on the concentric circle gives different directions of B and B is always perpendicular to the direction of current.
32. The retentivity of steel is high. Hence, it is used to make permanent magnet.
33. The working of a transformer is based on mutual induction. The change in the current flowing through one coil changes the flux passing through it. When this change in flux is linked to the other coil, the flux through it also changes, thereby inducing an e.m.f. In AC, the current keeps on changing and so, a transformer works with AC only.
34. Eddy currents are produced in a solid piece of metal, when magnetic flux passing through it changes. When a metallic conductor is placed in a changing magnetic field, the magnetic flux passing through it changes and so eddy currents are produced.

Also when magnetic flux around it changes, the magnetic flux passing through it changes and so eddy currents are produced.

35. The self or mutual induction takes place when magnetic flux through the coil changes.
36. The magnitude of induced emf depends on the rate of change of magnetic flux and not on the magnetic flux linked with the coil. Also, it depends on the area of cross section and number of turns of the coil.

37. Let the given data be taken as $\frac{N_1}{N_2}$ (turn-ratio),

i_1 , (input current) and P (input power) (a). Write the relation between turn-ratio and the currents as

$$\frac{N_1}{N_2} = \frac{i_2}{i_1}, \text{ where } i_2 \text{ is the current in the secondary}$$

coil (c). Substitute the given values of $\frac{N_1}{N_2}$ and i_1 , in the above formula and get the value of i_2 (b). Write the relation between input power and output power in terms of V_1, i_1, V_2, i_2 i.e. $V_1 i_1 = V_2 i_2 = P$, where V_1 and V_2 are the voltages in the primary and secondary coils, respectively (d). Substitute the values of i_2 and P in the above relation to get the value of V_2 (e).

38. Paste a sheet of white paper on a rectangular cardboard and make a small hole at its centre (b). Clamp this cardboard to a stand in the horizontal



position and sprinkle some iron filings over it (d). Pass the insulated copper wire through the small hole at the centre of the cardboard and perpendicular to it (a). Connect this wire to a battery, a switch and a variable resistance in series (c). Now, when the circuit is closed, the iron filings on the cardboard form concentric circles around the wire (e).

39. Take a copper wire and bend it in the form of a circle (c). Make two holes on a piece of cardboard covered with a sheet of white paper and pass the copper wire through the two holes of the cardboard covered with the sheet of white paper (b). Now connect the ends of the copper coil to a battery with a rheostat and a switch in series (d). Sprinkle iron filings on the cardboard and switch on the circuit (a). You observe that the iron filings arrange themselves in concentric circles (e).

40. Note the given values of i_1 , i_2 , d and x (a). Write the formula to find the magnetic field due to a long straight current carrying wire i.e $B = \frac{\mu_0 i_1}{2\pi x}$ (b). Determine the magnetic field at P due to wire A, using $B_1 = \frac{\mu_0 i}{2\pi r}$. Determine B_2 due to wire B i.e, $B_2 = \frac{\mu_0 i_2}{2\pi(d-x)}$ (f). Find the directions of the magnetic field at 'P' due to two wires A and B, using right hand thumb rule (c). If the directions of magnetic fields are same, then the resultant magnitude is equal to the sum of B_1 and B_2 (e). If the directions of the two magnetic fields are opposite, then the resultant magnitude is equal to the difference of B_1 and B_2 (g).

Level 2

41. (i) When south pole faces the geographic north, the null point is formed on the axial line. At null point, the axial field and horizontal component of earth's magnetic field are equal.

$$B_H = B_{\text{axial}} = \frac{\mu_0}{4\pi} \times \frac{2M}{d_A^3} \quad (1)$$

Where $d_A = 10 \text{ cm} = 0.1 \text{ m}$.

When the magnetic is turned through 180° , the null point is formed on the equatorial line.

$$B_H = B_e = \frac{\mu_0}{4\pi} \times \frac{M}{d_e^3} \quad (2)$$

Equating (1) and (2), find d_e .

- (ii) 8 cm

42. (i) Use $F = Bi\ell \sin\theta$.
Get the values of B , i and θ from the given data.

$$\text{Find } \frac{F}{\ell}.$$

- (ii) 1.5 N m^{-1}

43. The magnet is made concave in shape so that its magnetic field is always perpendicular to the plane of the coil when it rotates.

44. (i) Get the values of area (A) and initial magnetic induction (B_i). Find magnetic induction (B_f) and time (t) from the given data.

$$\text{Use } E = \frac{\Delta\phi}{t} \text{ and } \phi = BA.$$

Find ϕ_{final} , ϕ_{initial} and from them, find $\Delta\phi$ as well.

- (ii) 0.15 V

45. (i) Can two magnetic lines of force intersect at a point in a magnetic field?

- (ii) Magnetic field can be uniform or non - uniform. In uniform magnetic field it is possible to have same magnetic induction field at two different points.

46. Analyse the type of magnetic poles formed on either sides of two adjacent rings of a solenoid. Are the poles formed like or unlike?

47. (i) The emf induced in the coil is given by,

$$E = -L \frac{di}{dt}$$

Where L is the self inductance of the coil.

- (ii) 1.5 V

48. Recall the principles of mutual induction and Faraday's experiments.

49. (i) When the magnet is cut along axial line, its area of pole decreases. If the area of poles decreases ' n ' times, pole strength also decreases ' n ' times.

$$\text{The magnetic moment of each piece is } \frac{M}{n}$$



When each piece (obtained by cutting the magnet along the axial line) is divided into 'm' parts by cutting it perpendicular to the axial line, the length and the magnetic moment reduces to $\frac{1}{m}$ th the original value.

(ii) $\frac{M}{mn}$

50. (i) Use $B = \frac{\mu_0 i}{2r}$, for both the wires.

If the resultant field at a point is zero, then at the point B due to P it is equal in magnitude and opposite in direction to B due to Q.

(ii) 2 cm

51. Find the resistance of the bulb by using $P = \frac{V^2}{R}$

Use the resistance of the same value as resistance of the bulb and connect in series with the bulb, Another way is to connect a coil of suitable inductance in series with the bulb.

52. (i) The pole strength of the magnet (m) is

$$m = \frac{M}{L} \quad (1)$$

When the rod is bent in the form of arc, it subtends 90° at the centre.

If 'd' is the distance between the poles, then

$$d = \sqrt{r^2 + r^2}$$

$$d = r\sqrt{2} \quad (2)$$

where r is the radius of the arc.

The r is related to ℓ as

$$\ell = \pi r \quad (3)$$

Use (1), (2) and (3) and find the new magnetic moment (M_1)

M_1 = pole strength $\times$ distance between poles.

(ii) $\frac{2\sqrt{2}}{\pi} M$

53. Recall the definition of a magnetic field line.

Is it possible to have two directions for a given magnetic field at a given point in the field?

54. (i) Side AB and side CD carry equal currents. The distance of the centre from both the sides are

equal. Therefore, fields produced by both sides are equal at the centre. Side AD and BC carry different currents. If R is the resistance of each side, then current through AD (I_D) is

$$I_D = \frac{3R}{4R} \times V \quad (1)$$

Where V is the terminal PD of the cell.

The current through BC is

$$I_{BC} = \frac{R}{4R} \times V \quad (2)$$

The ratio of currents gives the ratio of fields.

(ii) 1:1, 3:1

55. When a bar magnet is cut into 'p' parts along the axial line, its area becomes (1/p)th of the total area and the pole strength becomes (1/p)th of the pole strength. With decrease in pole strength, each part will have a magnetic moment (M/p). When the magnet is cut perpendicular to axial line the magnetic moment becomes (M/p). Thus, the magnetic moment of each part is (M/p)

56. Let the pole strengths be ' m_1 ' and ' m_2 '. Let $m_1 = m$ and hence $m_2 = 2m$

Distance between them, $d = 10 \text{ cm} = 0.1 \text{ m}$

$$\text{Force of repulsion, } F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{d^2} = \frac{10^{-7} (m)(2m)}{(0.1)^2}$$

$$\text{Given } F = 8 \times 10^{-3} \text{ N}$$

$$\Rightarrow 8 \times 10^{-3} = \frac{10^{-7} (2m^2)}{0.01} \Rightarrow m = 20 \text{ Am}$$

Thus, the pole strengths are 20 A m and 40 A m.

57. The intensity of magnetization is defined as magnetic dipole moment per unit volume.

$$I = \frac{M}{V}$$

Where M = dipole moment.

V = Volume of magnet

But $M = m \times 2\ell$; $V = A \times 2\ell$

Where 2ℓ – length of magnet.

A – area of cross section.

$$\therefore I = \frac{m \times 2\ell}{A \times 2\ell}$$

$$I = \frac{m}{A}$$



58. Let B = magnetic induction due to the bar magnet.

$$B = \frac{\mu_0 M}{4\pi d^3}, \text{ on the equatorial line.}$$

Where M = magnetic moment

D = distance of a point from the center of the magnet.

At neutral point, $B = B_H$, the horizontal component of the earth's magnetic field.

$$\therefore B_H = \frac{\mu_0 M}{4\pi d^3}$$

$$m = (B_H d^3) \frac{4\pi}{\mu_0} \times \frac{1}{2\ell}$$

where 2ℓ is length of the magnet.

$$m = \frac{10^7 \times (50 \times 10^{-6}) \times (0.15)^3}{5 \times 10^{-2}} = 33.75 \text{ Am}$$

59. When the South pole of a magnet points towards the North of the earth, neutral points are obtained on the axial line. Thus, the line joining neutral points is along the axis of the magnet. When the poles are reversed the neutral points are obtained along its equatorial line. Then the line joining the neutral points is the perpendicular bisector of the magnet. Thus, the line rotates by 90° .

Level 3

60. (i) What happens if the emf is induced in such a way that it support the relative change in magnetic field associated with the coil?
- (ii) Work done by the external agent to bring the change in magnetic flux is converted into electrical energy.

61. (i) What is the expression for a magnetic moment of a semicircular magnet?

When the semicircular magnet is straightened, relate the distance between the two poles in the two cases to find the new length of the magnet.

Does the pole strength of the magnet change on straightening?

How does the pole strength change when the straight magnet is cut axially?

What is the magnetic moment of the newly formed (straightened) magnet?

$$\text{Use } B_{\text{axial}} = \frac{\mu_0 2M}{4\pi d^3} \text{ and } B_{\text{equatorial}} = \frac{\mu_0 M}{4\pi d^3}$$

$$(ii) B_{\text{equatorial}} = 0.0275 \text{ mT}$$

$$B_{\text{axial}} = 0.550 \text{ mT}$$

62. How a current carrying conductor behaves? Like a magnet or like a charged body.

63. (i) Use $F = \frac{\mu_0 m_1 m_2}{4\pi d^2}$, in both the cases.

Relate the quantities ' m_1 ', ' m_2 ', ' d ' and ' F ' in the second case with that in the first case using the given data. Then relate μ of the medium with μ_0 and find the value of μ_r of the medium.

- (ii) 3

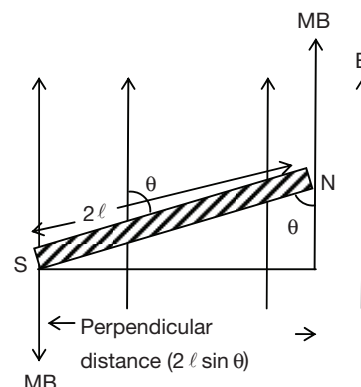
64. (i) The force on the poles of the bar magnet is mB . If the angle made by the bar magnet with the field is θ , then the perpendicular distance between the forces is $2\ell \sin\theta$ where ' 2ℓ ' is the magnetic length, as shown in the figure below. The torque is given by,

Torque = force $\times$ perpendicular distance.

$$\text{Torque} = mB \times 2\ell \sin\theta$$

$$\Rightarrow \text{Torque} \propto \sin\theta$$

- (ii) $1 : \sqrt{3}$



65. Given
- $i = 5 \text{ A}$

$$r = 10 \text{ cm} = 0.1 \text{ m}$$

$$B = \frac{\mu_0 i}{2\pi r} = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 0.1}$$

$$B = 10^{-5} \text{ T} = 10 \times 10^{-6} \text{ T} = 10 \mu\text{T}$$

66. Given
- $i = 5 \text{ A}$

$$r = \pi \text{ cm} = \pi \times 10^{-2} \text{ m}$$

$$n = 500 \text{ turns}$$

$$B = \frac{n\mu_0 i}{2r} = \frac{500 \times 4\pi \times 10^{-7} \times 5}{2 \times \pi \times 10^{-2}}$$

$$= 5 \times 10^{-2} \text{ T} = 0.05 \text{ T}$$

67. The magnitude of induced emf is given by,

$$E = N \frac{d\phi}{dt}$$

$$\text{But } E = iR$$

$$iR = N \frac{d\phi}{dt}$$

$$\text{Substitute } i = \frac{dq}{dt}$$

$$\frac{dq}{dt} \times R = N \frac{d\phi}{dt} \Rightarrow dqR = Nd\phi$$

$$dq = \frac{Nd\phi}{R}$$

$$\text{Substitute } N = 100, d\phi = 0.15 - 0.05$$

$$= 0.1 \text{ weber}, R = 0.5 \Omega$$

$$dq = \frac{100 \times 0.1}{0.5} = 20 \text{ C}$$

68. The magnetic flux passing normal through the coil is given by,

$$\phi = B \times A$$

Where A is the area of the coil.

The change in flux, $\Delta\phi$ is

$$\Delta\phi = \Delta B \times A$$

$$\text{Substitute } \Delta B = 0.2 - 0.1 = 0.1 \text{ T}$$

$$\text{And } A = 100 \text{ cm}^2 = 10^{-4} \text{ m}^2$$

$$\therefore \Delta\phi = 0.1 \times 10^{-4} = 10^{-5} \text{ weber.}$$

The rate of change of magnetic flux is induced emf

$$\text{i.e., } \frac{\Delta\phi}{dt} = E$$

Substituting $\Delta\phi = 10^{-5}$ weber and

$$\Delta t = 1 \text{ ms} = 10^{-3} \text{ s}$$

$$E = \frac{10^{-5}}{10^{-3}} = 10^{-2} \text{ volt.}$$

- 69.
- $E = \frac{d\phi}{dt} = iR \Rightarrow i = \frac{E}{R} = \frac{d\phi}{dt},$

$$dq = idt$$

$$\text{Here, } q = idt = \frac{d\phi}{R}$$

$$\text{Given } d\phi = 40 \text{ Wb} - 10 \text{ Wb} = 30 \text{ Wb and } R = 10 \Omega$$

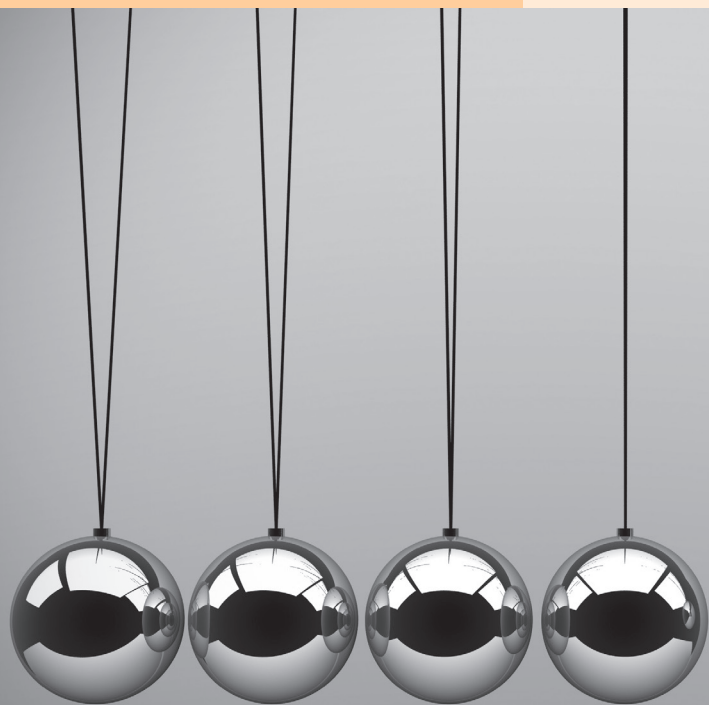
$$\therefore dq = \frac{30}{10} = 3 \text{ C}$$

Hence a charge of 3 C flows through the coil, during the motion of the magnet.



Chapter 9

Modern Physics



Remember

Before beginning this chapter, you should be able to:

- Explain the atomic structure
- Study about discharge of electricity through gases by different experiments
- Define the term radioactivity and types of radiations

Key Ideas

After completing this chapter, you should be able to:

- Learn about the discovery of different subatomic particles
- Discuss the concepts of radioactivity, types of radiations
- Study radioactive series and its properties
- Discuss the different nuclear reactions and the changes that happen inside the nucleus during these nuclear reactions

INTRODUCTION

Just as the universe at the macro level has intrigued the human mind and intellect for ages, so at the micro level, man has been continuously in search of the smallest particle and has discovered a fathomless new world of sub-atomic particles. In the process of all the research having been done in this direction, a whole new branch of physics unfolded leading to the revolutionary discoveries and inventions—radio, transistor, X-ray, photoelectric effect, computers, etc., being only a part of the endless list which opened the doors to a new modern world. This branch of physics came to be referred to as modern physics. Nuclear physics, electronics, etc., are all off-shoots of the developments in modern physics.

Cathode Rays

Gases do not conduct electricity at ordinary pressures. However, if very high potential difference (more than 30 kV) is applied between the two electrodes in the presence of air, then electric charges pass through air. As electricity passes, intense light in the form of spark is produced. The flash of lightning during rainy days is an example of conduction of electricity through gases at normal atmospheric pressure.

When the gas pressure is lowered, it is found that gases conduct electricity at sufficiently high potential which is less than the potential required at ordinary pressure. The conduction of electricity through gases is also called discharge of electricity or simply electric discharge. During electric discharge, different gases emit light of different colours. To study the electric discharge phenomenon at low pressures, a given gas is enclosed in a hard glass tube called discharge tube, as shown in the Fig. (9.1).

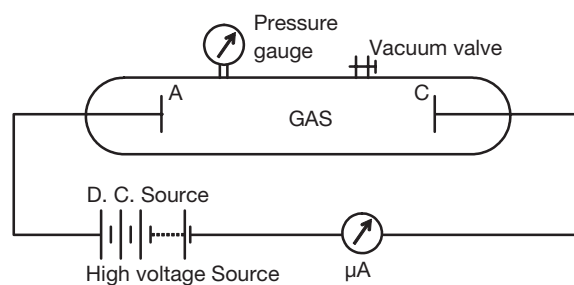


FIGURE 9.1 Discharge tube

Usually, the discharge tube is 30 cm to 40 cm long and 2 cm to 3 cm in diameter. Two aluminium dishes, called electrodes are sealed in the tube on its ends. A high potential difference can be applied across the two electrodes. The electrode connected to positive terminal (high potential) of the DC source is called anode (A) and the one connected to negative terminal (low potential) is called cathode (C). To reduce the pressure inside the discharge tube, it is provided with a side tube which is connected to the vacuum pump.

To study the electric discharge, the pressure of the gas inside the tube is gradually reduced. The electric discharge passes through various stages, as the gas pressure is gradually reduced. Finally, at a pressure of about 0.01 mm of Hg, the tube becomes dark. The wall of the tube opposite to the cathode glows with greenish fluorescence which is due to the invisible radiation given out from the cathode surface called cathode rays.

Properties of Cathode Rays

1. Cathode rays are always emitted along the normal to the surface of cathode, irrespective of the position of the anode.
2. Cathode rays travel in a straight line path.
3. Cathode rays exert mechanical force on the objects placed in their path.
4. They are deflected in electric and magnetic fields.
5. They ionize the gas through which they pass.
6. Cathode rays produce fluorescence in many substances, like Zinc Sulphide, etc.
7. They can pass through thin metal foils.
8. They affect photographic plates.
9. When cathode rays are stopped by certain objects like metals, X-rays are produced.

Nature of Cathode Rays

Cathode rays are deflected in electric and magnetic fields. This shows that they consist of charged particles. From the direction of deflection in electric and magnetic field, it is concluded that they are negatively charged particles. In 1897, J.J. Thomson measured electron-mass ratio of those particles and proved that they are the common constituents of all matter. G.J Stoney named these particles as electrons.

John Dalton in 1808, in his atomic theory had proposed that 'the atom is the smallest indivisible particle of matter.' However, discovery of electrons proved that atom itself is made up of still smaller particles and that the atom is divisible.

After the determination of e/m of electrons, the charge on it was found to be -1.6×10^{-19} C. Using $\frac{e}{m}$ ratio and charge, the mass of an electron is found to be 9.11×10^{-31} kg.

—by American Professor, R.A. Millton

Uses of Cathode Rays

1. X-rays are produced when fast moving cathode rays are stopped suddenly.
2. The screen of a cathode ray oscilloscope, a TV picture tube, the monitor of a computer, etc. are coated with fluorescent substances. When the cathode rays fall on the screen, pictures are visible on the screen.

X-RAYS

X rays were discovered in the year 1895 by Wilhelm Roentgen of Germany. While studying electric discharge phenomena, he noticed that a screen (coated with barium salt) placed near a cathode ray tube was glowing whenever the tube was working. He further observed that the screen glowed even after the tube was covered with a black paper. On further investigation, he found that the photographic plates wrapped in a black paper were fogged when kept near the tube. When he placed his hand between the tube and photographic plate, he obtained

a photograph of the bones. Roentgen concluded that some unknown, highly penetrating radiations were responsible for his observations. He named these unknown radiations as X-rays.

Production of X-rays

X rays are produced when fast moving cathode rays are stopped by a block of a metal called target. The modern device used in the production of X-ray is called the Coolidge tube, named after Dr Coolidge who designed it in the year 1913. It consists of a highly evacuated glass bulb as shown in the Fig. (9.2).

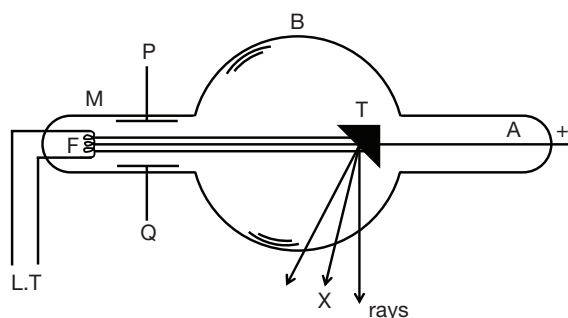
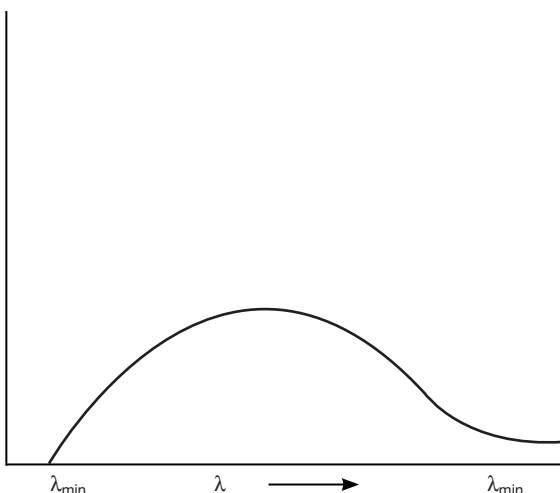


FIGURE 9.2 Coolidge tube

A filament F emits electrons when it is heated by passing a low current through it. It also acts as a cathode. It is surrounded by a molybdenum cylinder M. The cylinder M focusses the electrons as a fine beam. The target is tungsten which is embedded in a copper anode A. The anode A is inclined at 45° to the horizontal. It is cooled by circulating water around it. To produce X rays, high speed electrons are required. For this, the electrons emitted from the filament are accelerated by applying a high potential difference between the anode and the cathode. The fast moving electrons produce X-rays when they strike the target.

Properties of X-rays



1. X-rays are electromagnetic radiations. Their wavelength is very small, of the order of $1 \text{ \AA}$. They are invisible.
2. X-rays, being electromagnetic radiations, travel in a straight line with a velocity of light ($3 \times 10^8 \text{ m s}^{-1}$).
3. They affect photographic plates.
4. They produce fluorescence in certain materials.
5. They are not affected by electric and magnetic fields.
6. X-rays have a high penetrating power. However, they are stopped by bones, dead cells, etc.
7. They ionize the gases through which they pass.
8. They bring about chemical and biological changes in the substances and living beings through which they pass.
9. They are diffracted by crystals.

Uses of X-rays

X-rays are used extensively in different fields.

1. **Medicine:** In medicine, X-rays are employed to detect fracture and dislocation of the bones, presence of foreign bodies and early detection of certain diseases like tuberculosis.
2. **Industry and engineering:** X-rays are used to detect flaws in machinery parts, metal castings, metal structures, etc.
3. X-rays are used to detect goods hidden in wooden boxes and leather cases. They are also used in testing.
4. **Radiotherapy:** X-rays are used to destroy malignant tumours without surgery, especially when malignant tumours are situated deep inside. The tumours are exposed to hard X-rays which possess high penetrating power.
5. X-rays are used to study the arrangement of atoms and molecules in crystals and other matter.

EXAMPLE

In a Coolidge tube, cathode rays emitted from the cathode are accelerated through a potential difference of 20 kV. Find the minimum wavelength of the X – rays produced.

(Take Plank's constant $h = 6.6 \times 10^{-34} \text{ J s}$)

SOLUTION

When cathode rays fall through a potential difference, the work done on them equals change in their kinetic energy. When cathode rays are stopped, they lose kinetic energy which is then converted into X-rays.

Thus,

$$\text{Work done on cathode rays (W)} = V \times q = \frac{1}{2}mv^2 \quad (1)$$

The energy and frequency of X-rays (any radiation) is related as $E = h\nu$.

Where ' h ' is Plank's constant.

$$\text{But } \nu = \frac{c}{\lambda}$$

$$\therefore E = h\nu = \frac{hc}{\lambda} \quad (2)$$

Equating (1) and (2) and solving λ .

$$\frac{hc}{\lambda} = V \times q$$

$$\lambda = \frac{hc}{Vq}$$

Substituting $h = 6.6 \times 10^{-34} \text{ J s}$, we have

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

$$V = 20 \times 10^3 \text{ V}, q = 1.6 \times 10^{-19} \text{ C}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{20 \times 10^3 \times 1.6 \times 10^{-19}} = 0.625 \text{ \AA (approximately)}$$

RADIOACTIVITY

Atomic number is the number of protons present in the nucleus of an element.

Mass number is the Sum of number of protons and neutrons present in the nucleus of an element.

Natural Radioactivity

The phenomenon of radioactivity was first discovered by A.H. Becquerel and further investigations were made by Madame Marie Curie and Prof. Pierre Curie.

In 1896 Henri Becquerel, the French scientist, quite accidentally discovered radioactivity while studying the phenomenon of fluorescence. He found that the photographic plates get fogged when placed near pitchblende, an ore of uranium. It was discovered that certain substances like, uranium, radium, etc., emit some rays which were initially referred to as 'Becquerel rays'. Research work carried out by the Curies led to the discovery that these rays are emitted due to a phenomenon called radioactivity which is a nuclear phenomenon of self-disintegration.

Thus, radioactivity is the phenomenon of self-disintegration and spontaneous emission of radiation by some unstable nuclei with atomic number greater than 82. This type of

spontaneous radiation is referred to as 'natural radioactivity'. Substances which give such spontaneous emission of radiations are known as radioactive substances.

α , β and γ -radiations

The radiations emitted by radioactive substances were found to consist of three distinct constituents. They were called alpha, beta and gamma radiations. When the radiations were allowed to pass through an electric field, the constituent which deflected towards the negative plate was called the α -rays. The constituent which got deflected towards the positively charged plate was called the β -rays. The constituent which emerged undeflected was called γ -radiations.

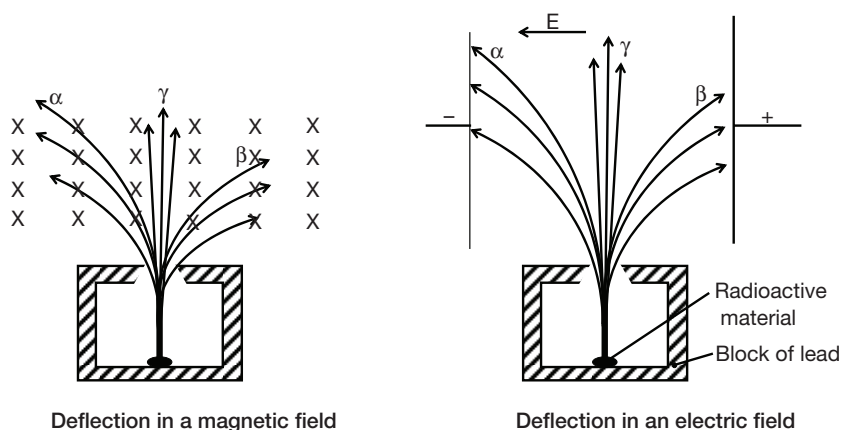


FIGURE 9.3 Deflection of alpha, beta and gamma particle in magnetic and electric field

Properties of α , β and γ radiations

Property	α -rays	β -rays	γ -rays
1. Nature	Positively charged	Negatively charged	Electrically neutral
2. Constituents	He ⁺⁺ (2 protons and 2 neutrons)	High energy electrons	Electromagnetic radiations
3. Speed	Nearly 10^7 m s ⁻¹	About 2.7×10^8 m s ⁻¹	3×10^8 m s ⁻¹
4. Rest mass	4 times the mass of a proton, i.e., 6.64×10^{-27} kg	Equal to the mass of an electron, i.e., 9.1×10^{-31} kg	No mass
5. Charge	Positive charge = $+3.2 \times 10^{-19}$ C	Negative charge = -1.6×10^{-19} C	No charge
6. Specific charge (q/m)	4.83×10^7 C kg ⁻¹	1.76×10^{11} C kg ⁻¹	—
7. Wavelength	—	—	10^{-13} m (less than the wavelength of X-rays)
8. Effect of electric field	Deflects towards the negative plate	Deflects towards the positive plate, deflection more than that for α rays	No effect

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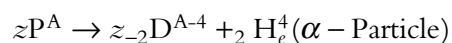
Property	α -rays	β -rays	γ -rays
9. Effect of magnetic field	Less deflected.	More deflected, direction opposite to that of α -rays	No effect
10. Ionizing power	Intense ionization (10000 times that of γ -rays)	High ionization power (100 times that of γ rays)	Little
11. Penetrating power	Small (3–8 cm in air)	Large (up to few metres in air)	Very large (up to a few hundred metres in air)
12. Stopping substance	Thin paper, human skin	About 1 mm of lead or about 3 mm of aluminium	About 30 cm of iron or few metres of concrete
13. Effect on photographic plate. Effect on a fluorescent screen.	They affect photographic plates and cause scintillations on a fluorescent screen	Affect photographic plates and cause scintillations on a fluorescent screen	Affect photographic plates and cause scintillations on a fluorescent screen
14. Biological damage	Cause damage. Harmful to being human	Cause damage. Harmful to human beings.	Passes through human body and destroy human cells. Used to kill cancer cells

Radioactive Transformation

The disintegration of an unstable nucleus resulting in the formation of another nucleus is called radioactive transformation or disintegration or radioactive decay.

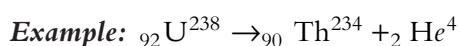
Types of Transformation

1. α -Decay or α -Emission: ‘When an α -particle is emitted from a radioactive nucleus, the atomic number (Z) decreases by 2 and the mass number (A) decreases by 4.



‘P’ is called the parent nucleus.

‘D’ is called the daughter nucleus.



Here, uranium is the parent nucleus and thorium is the daughter nucleus.

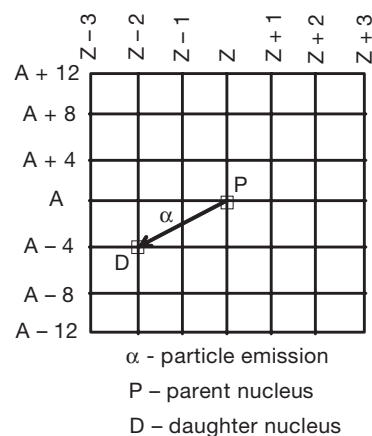


FIGURE 9.4 Graph between atomic number and mass number for an alpha particle

This is summarized as Rutherford and Soddy's law of α -emission, which states that 'whenever an α -particle is emitted from a radioactive nucleus, the atomic number decreases by 2, the mass number decreases by 4 and the position of the element shifts by two places to the left in the periodic table'.

2. β -Decay or β -Emission: The presence of excess neutrons in an unstable nucleus lead to a neutron changing into a proton by emitting an electron (for charge conservation).

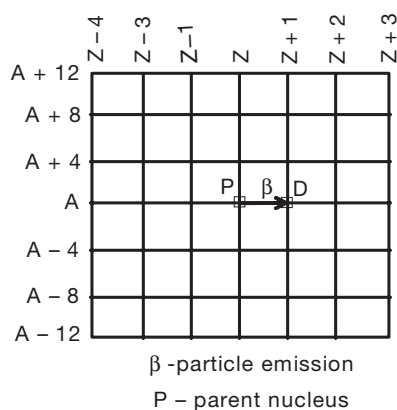
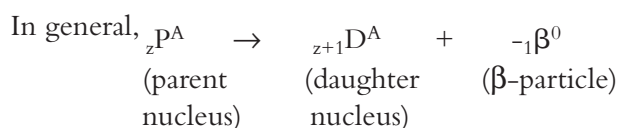
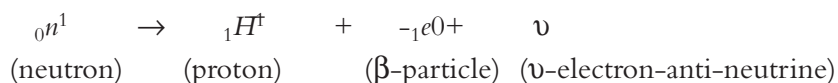
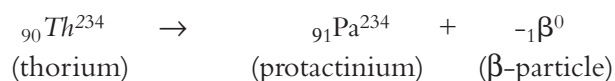


FIGURE 9.5 Graph between atomic number and mass number for a beta particle



Example:



Rutherford and Soddy's law of β -decay summarizes the above as 'Whenever a β -particle is emitted from a radioactive nucleus, the atomic number increases by 1 whereas the mass number remains the same and the position of the element shifts one place to the right in the periodic table'.

3. γ -Decay or γ -Emission: There is no change in the atomic number (Z) or in the mass number (A) of the atom which undergoes gamma decay. However, the emission of γ -rays results in a change in the energy state of the nucleus.

In a single radioactive decay, both α -decay and β -decay never take place together. There will be either an α -decay or a β -decay, which may be accompanied by a γ -emission.

Radioactive Series

An unstable parent nucleus undergoes disintegration several times producing daughter nuclei, which would also be unstable. The radioactive daughter nucleus would undergo further disintegration giving rise to a new daughter nucleus. This sequential decay of a given radioactive nucleus resulting in the production of new nuclei at each stage and giving rise to a series of elements is called radioactive decay series.

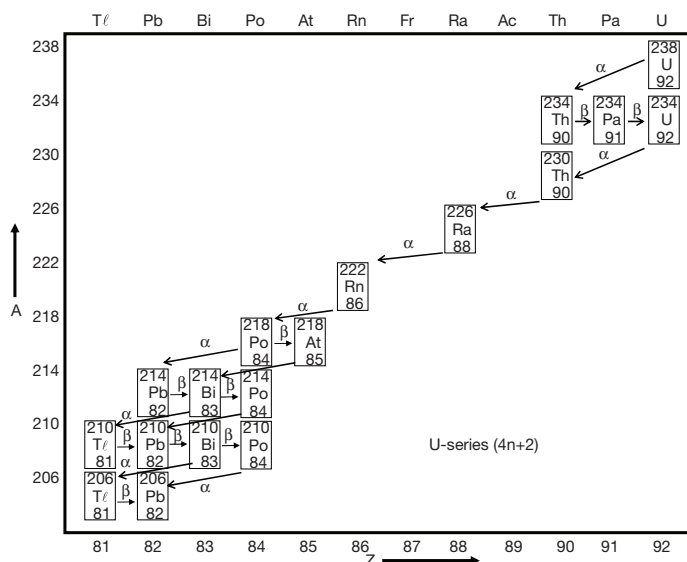


FIGURE 9.6 Uranium series

There are three radioactive series depending on the starting element naturally available on the earth.

They are

1. the uranium series ($^{238}_{92}\text{U}$ series),
2. the actino-uranium series or Actinium series (Ac-U series) and
3. the thorium series ($^{232}_{90}\text{Th}$ series).

The important features of the radioactive series are as follows:

1. The stable end-product of all the three series is an isotope of lead having an atomic number 82, but the mass number is 206 in U-series, 207 in Ac U-series and 208 in Th-series.
2. In each of the series, parent-daughter sequences exist.
3. More than one kind of decay is possible for an intermediate radioactive species.

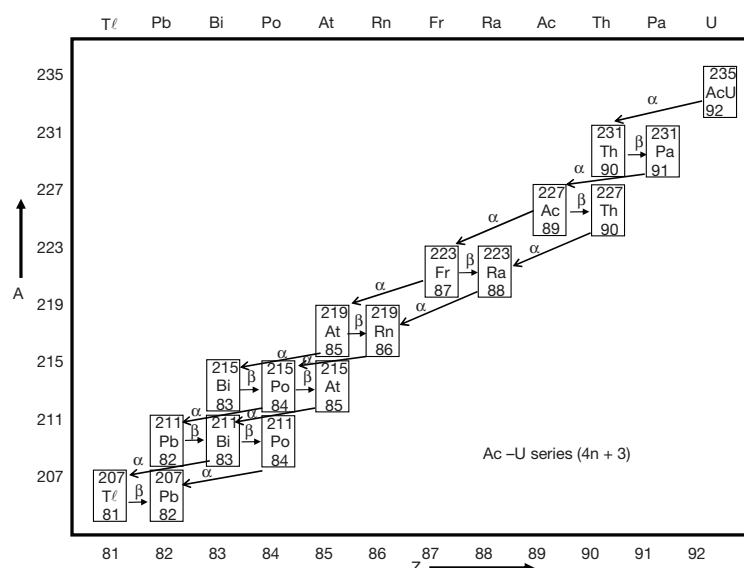


FIGURE 9.7 Actino-uranium series

4. In each of the three series, the element Radon (Rn) with atomic number 86 is present.
5. In all the three series, a change in the mass number A , [if any (due to α -decay)] is always equal to 4.
6. The thorium series is referred to as $4n$ series, since the mass numbers of all its members are multiples of 4.

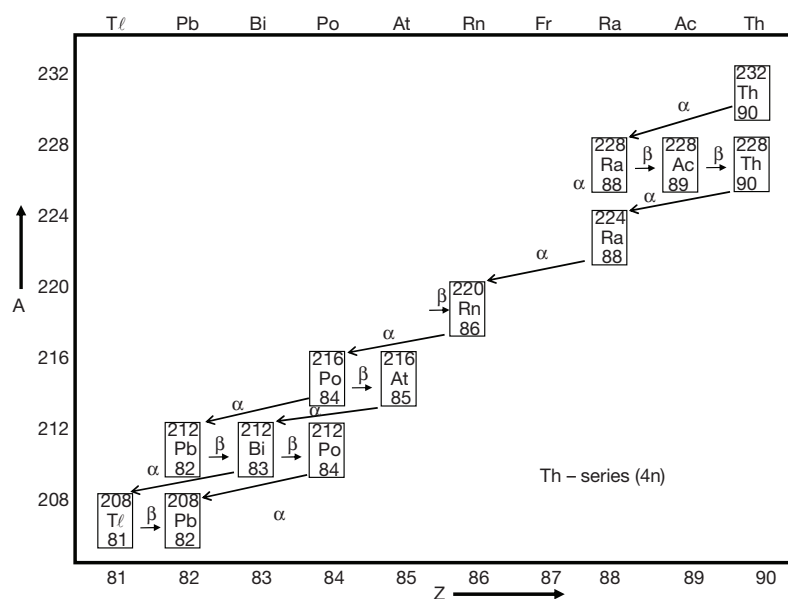


FIGURE 9.8 Thorium series

7. The uranium series is referred to as $(4n+2)$ series, since $(A-2)$ is always a multiple of 4 for each one of the elements of the series. (A is mass number of elements)
8. The actinium series is identified as $(4n+3)$ series, since $(A-3)$ is always a multiple of 4 for each one of the elements of the series. (A is mass number of elements)

9. The neptunium series (${}_{93}\text{NP}^{237}$ series) is obtained from artificially produced radioactive material. This series is also known as $(4n + 1)$ series.

It is found that during radioactive transformation due to either α -emission or β -emission, not all the nuclei undergo disintegration simultaneously. Also the rate at which the decay takes place depends on the number of parent atoms available at a given instant.

This is summarized in the law of radioactive disintegration.

Law of Radioactive Disintegration

The law of radioactive disintegration states that ‘in any radioactive substance, the number of nuclei disintegrating per second is directly proportional to the number of nuclei present’.

$$\frac{\Delta N}{\Delta t} \propto N$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

where λ , the proportionality constant, is called the decay constant. The negative sign indicates that the number of nuclei decreases with time.

Using calculus, we can show that $N = N_0 e^{-\lambda t}$ where N_0 and N are the number of nuclei of the substance at instants when time is zero and ‘ t ’ respectively and ‘ e ’ is an irrational number.

THE HALF-LIFE PERIOD

‘The half-life period (T) of a radioactive substance is defined as the time during which half the amount of the substance disintegrates.’

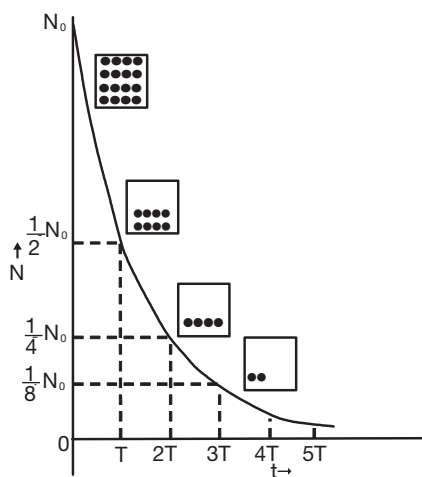


FIGURE 9.9 Graph to show a half-life period of a radioactive substance

For example, if there are 4 atoms with a half-life period of 2 seconds, it means that after 2 seconds exactly 2 atoms will disintegrate. In fact, it is just the probability of half of the atoms disintegrate (approximately).

The half-life period (T) is different for different substances. It is impossible to say exactly when a particular atom of a radioactive element would disintegrate. The fraction of the substance decaying during a given period will be the same as that during any other equal period. Smaller value of T (half-life period) indicates faster decay. Decay constant (λ) of a radioactive substance is defined as $\lambda = (0.693/T)$.

The higher value of λ indicates faster decay. Thus, the decay constant is a characteristic property of a radioactive element.

EXAMPLE

If $(7/8)$ th of the initial mass of the radioactive substance decays in 15 days, then what is the half-life period of the radioactive substance?

SOLUTION

Let the initial number of radioactive nuclei be N_0 .

Then, after a half-life period, the number of nuclei present would be $N_0 \times \frac{1}{2}$. (1)

After two half-lives, the number of nuclei present would be

$$\frac{1}{2} \times \left(N_0 \times \left(\frac{1}{2} \right) \right) = N_0 \left(\frac{1}{2} \right)^2.$$

After ' n ' half-lives, the number of nuclei present would be $N = N_0 \left(\frac{1}{2} \right)^n$

If ' t ' is the given time period and T is the half-life period of the radioactive substance, then

$$n = \frac{t}{T} \quad (2)$$

Also, if ' m_0 ' is the initial mass and ' m ' the mass of undecayed nuclei of the substance, then

$$\frac{N}{N_0} = \frac{m}{m_0} \quad (3)$$

$\therefore$ Equation (1) can be written as

$$m = m_0 \left(\frac{1}{2} \right)^n \quad (4)$$

In the given problem, undecayed mass $m = m_0 - \frac{7}{8}m_0 = \frac{1}{8}m_0$

$$t = 15 \text{ days, } T = ?$$

Substituting the values of ' m ' and ' m_0 ' in equation (4), we get

$$\begin{aligned}\frac{1}{8}m_0 &= m_0 \left(\frac{1}{2}\right)^{\frac{15}{T}} \Rightarrow \frac{1}{8} = \left(\frac{1}{2}\right)^{\frac{15}{T}} \\ \Rightarrow \frac{1}{8} &= \left(\frac{1}{2}\right)^{\frac{15}{T}} \Rightarrow \frac{15}{T} = 3 \\ T &= \frac{15}{3} \text{ days} = 5 \text{ days}\end{aligned}$$

EXAMPLE

20 g of radioactive substance decays to 10 g in 2 days. How much of the substance will remain undecayed after 10 days?

SOLUTION

As 20 g decays to 10 g, i.e., the initial mass reduces to half in 2 days, the half-life period must be 2 days. By using the formula,

$$m = m_0 \left(\frac{1}{2}\right)^n \text{ and substituting } m_0 = 20 \text{ g, } n = \frac{t}{T} = \frac{10}{2} = 5, \text{ we get}$$

$$\begin{aligned}m &= 20 \left(\frac{1}{2}\right)^5 \Rightarrow m = \frac{20}{32} \\ \Rightarrow m &= 0.625 \text{ g.}\end{aligned}$$

ISOTOPES, ISOBARS AND ISOTONES

The atoms of some elements exist in different forms depending on the variations in their atomic numbers and mass numbers but have same common factor and are referred to as isotopes, isobars or isotones.

Isotopes

'Isotopes are the atoms of the same element having the same atomic number, but different mass number due to difference in the number of neutrons in their nuclei'.

Examples of isotopes

1. ${}_1\text{H}^1$, ${}_1\text{H}^2$, ${}_1\text{H}^3$	isotopes of hydrogen
2. ${}_{17}\text{Cl}^{35}$, ${}_{17}\text{Cl}^{37}$	isotopes of chlorine
3. ${}_8\text{O}^{16}$, ${}_8\text{O}^{17}$, ${}_8\text{O}^{18}$	isotopes of oxygen
4. ${}_{92}\text{U}^{235}$, ${}_{92}\text{U}^{238}$	isotopes of uranium
5. ${}_{19}\text{K}^{39}$, ${}_{19}\text{K}^{40}$	isotopes of potassium

Isobars

‘Atoms of different elements, having the same mass number but different atomic number are called isobars’.

Examples of isobars

1. ${}_6\text{C}^{13}$, ${}_7\text{N}^{13}$
2. ${}_{19}\text{K}^{40}$, ${}_{20}\text{Ca}^{40}$
3. ${}_{18}\text{Ar}^{40}$, ${}_{20}\text{Ca}^{40}$
4. ${}_{12}\text{Mg}^{24}$, ${}_{11}\text{Na}^{24}$

Isotones

‘Atoms with their nuclei having the same number of neutrons but different number of protons are called isotones’.

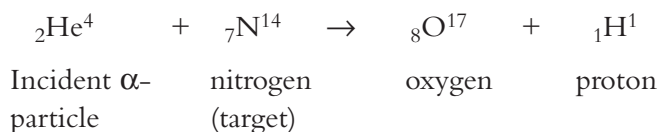
Examples of isotones: The atomic number and the mass number of ${}_{14}\text{Si}^{31}$ are 14 and 31, respectively, which give the number of neutrons as $31 - 14 = 17$. The atomic number and the mass number of ${}_{15}\text{P}^{32}$ are 15 and 32 respectively, which give the number of neutrons as $32 - 15 = 17$. Thus, ${}_{14}\text{Si}^{31}$ and ${}_{15}\text{P}^{32}$ are isotones.

ARTIFICIAL TRANSMUTATION

Unstability in the nucleus leads to a natural and spontaneous radioactive disintegration only in certain heavy elements. However, in 1919, Rutherford succeeded in producing nuclei of lighter elements which exhibit the property of radio activity.

Definition

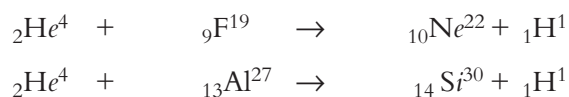
‘Artificial transmutation is the process of transformation of one element into another by artificial disintegration means of bombarding it with high energy particles’.



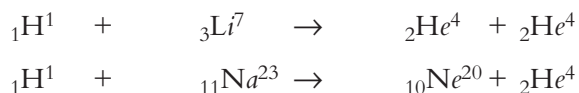
Such artificial transmutation can be achieved by employing α -particles, protons, deuterons, neutrons or small nuclei as the bombarding particles. These particles, which are used for the bombardment of target nuclei, are referred to as ‘projectiles’.

Artificial Transmutation by α -Particles

Artificial transmutation of fluorine and aluminum is possible by using the α -particles as projectiles.



Artificial Transmutation by Protons

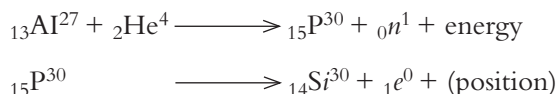


In these transmutations, a proton (nucleus of hydrogen atom) is used as a projectile to transmute the lighter elements lithium and sodium. In this type of artificial transmutation which was conducted by Cockroft and Walton in 1932, the α -particles are obtained as one of the products.

In some of the artificial transmutations, the product nucleus is found to be radioactive. It undergoes further disintegration by emitting particles like neutrons and protons. It was first discovered in 1934 by Madam Irene Curie Joliot and M. Frederic Joliot. This phenomenon came to be referred to as ‘artificial radioactivity’.

Artificial or induced radioactivity is a nuclear process in which a stable element, which is not radioactive, is converted into another element, which is radioactive in nature.

The Curies found that when the atoms of stable aluminium were bombarded by α -particles, an unstable isotope of phosphorous, ${}_{15}\text{P}^{30}$ was produced which, being radioactive, disintegrated producing stable silicon (${}_{14}\text{Si}^{30}$) and a particle whose mass was the same as that of an electron, but with a positive charge. This particle was referred to as a ‘positron’, discovered by Carl Anderson.



Thus, we see that while β -particles are emitted in natural radioactivity, positrons are emitted in the artificial radioactivity.

Instead of α -particles, energized protons, neutrons, etc., can also be used to induce radioactivity in stable atoms. These isotopes of elements which are obtained in artificial transmutation and are radioactive in nature are called ‘radio-isotopes’. About 500 radioactive isotopes have been artificially produced by the bombardment of stable elements with α -particles ?

Uses of Radio-Isotopes

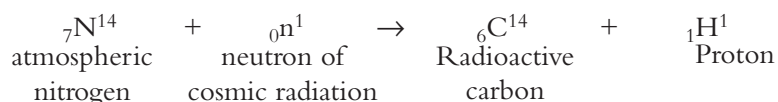
Some of the applications of radio-isotopes are as follows:

1. Sodium - 24 isotope is used to detect a clot in the blood in the human body.
2. Cobalt - 60 isotope is used to kill cancer cells since it is an intense source of γ -radiations.
3. Iodine - 131 isotope is used to test the functioning of the thyroid gland.
4. Radio-isotopes like ${}_{27}\text{Co}^{60}$ are used to detect the internal flaws in a cast-material.
5. Which are also used in agriculture in the selection of fertilizers.
6. Unnecessary mutations of plants can be prevented by irradiating seeds using radio-isotopes.

7. Perishable food items can be kept fresh for longer periods by exposing them to mild γ radiations from a radio-isotope.
8. Radioactive gases are injected into the atmosphere and by suitable detectors, the course of monsoon winds and the changes they undergo can be studied.

CARBON DATING OR RADIOACTIVE DATING

Carbon in the atmosphere is found to exist as three isotopes ${}_6\text{C}^{12}$, ${}_6\text{C}^{13}$ and ${}_6\text{C}^{14}$. ${}_6\text{C}^{14}$ (or C-14) is an unstable isotope with half-life period of 5730 years, and is continuously produced in the atmosphere by the action of cosmic rays on atmospheric nitrogen.



This C-14 is continuously absorbed by the cells of living beings. In living beings, the ratio C-14:C-12 is constant. In dead plants or animals, C-14 undergoes radioactive decay without replenishment. By determining the ratio C-14/C-12 in fossils, their age is determined. This process of estimating the age by measuring the disintegration of C-14 is known as 'Carbon dating'.

For estimating the age of earth or rocks, U-235 isotope is used. This is done by determining the present ratio of U-235 to stable lead isotope.

The III Effects of Radioactive Radiations

The α , β and γ rays emitted during radioactive disintegration of an unstable substance cause several biological effects (kill the living cells and cause radiation burns) on human beings.

The biological effects are of the following types:

1. Short term recoverable effects
2. Long term irrecoverable effects
3. Genetic effects

The first two types are limited to the affected person, whereas the third type affects the later generations.

Safety precautions for the people regularly working with radio-active substances:

1. Special lead-lined aprons, gloves, etc. should be worn and long tongs made of lead should be used while handling radioactive substances.
2. Special film badges should be worn to determine periodically the amount of radiation to which a person is exposed, and to ascertain whether any particular person is exposed to more than the permissible levels.
3. The radio-active substances should be handled with the utmost care and stored in lead containers with narrow openings to stop radiations in all directions.

Background Radiations

Background radiations are those radio-active radiations that everyone is exposed to due to the presence of natural radio-active substances on the earth as well as the cosmic radiations, and also the radio-active substances present in the body.

Internal background radiations are from the radioactive substances K-40, and C-14 present in the entire body and radium present in the bones. External background radiations are from the cosmic rays and radiations from the radioactive rocks on the earth.

Geiger Counter

Geiger counter is an instrument used for recording the rate of emission from a radioactive substance.

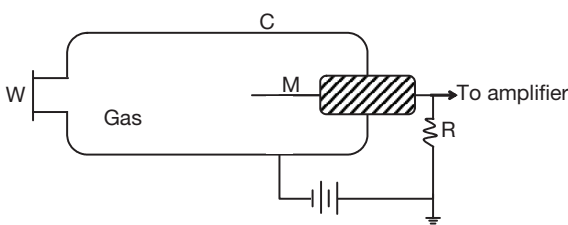


FIGURE 9.10 Geiger counter

It consists of a metallic cylinder 'C' and a metallic wire 'M' fixed along the axis of a metallic cylinder. The cylinder is filled with argon gas with traces of chlorine and the pressure inside it is maintained between 50 mm of Hg and 100 mm of Hg. A potential difference that is slightly less than the necessary potential to produce discharge in the gas is maintained between the wire and the cylinder. α -particles from a given source enter the cylinder through the thin mica window 'W' and ionize the gas molecules in the cylinder. This leads to a rapid build-up of current and a momentary change of potential across 'R'. This electric surge is amplified and given to an electronic counter.

Nuclear Energy

The experiments and the studies conducted by Rutherford in the early twentieth century, in understanding the atomic structure led to further research and the discovery of the process of artificial transmutation. This along with the discovery of neutron in 1932 by Chadwick gave a new direction to the research being carried out by the physicists in Europe. In 1939, the German scientists Otto Hahn and Fritz Strassmann conducted several experiments and showed that heavy uranium atoms could be split into lighter atoms of smaller atomic number. But what excited the scientists most was the discovery that these reactions resulted in a substantial difference in the masses of the products and reactants. And when Einstein proposed the mass-energy equivalence with his famous $E = mc^2$ equation, the foundation for the fission and fusion reactions was laid down, shifting the focus to the (nuclear) energy released in these nuclear reactions.

Before we venture into the study of these nuclear reactions in detail, we need to understand some basic concepts like mass defect, binding energy, etc.

Atomic Mass

The mass of an atom is measured in units called unified 'atomic mass unit' (u); defined as $1/12$ th of the mass of a neutral carbon atom ${}_6\text{C}^{12}$ (Carbon – 12 atom).

$$1\text{ u} = 1.6605402 \times 10^{-27}\text{ kg}.$$

Thus, the mass of a carbon atom is 12 u .

Example: Estimation of mass of helium nucleus.

Consider a helium atom ${}_2\text{He}^4$.

It has 2 electrons, 2 protons and 2 neutrons

The mass of a proton = 1.0078 u

The mass of a neutron = 1.0087 u

$$\begin{aligned}\therefore \text{The total expected mass of the nucleus} &= 2 \times 1.0078 + 2 \times 1.0087 \\ &= 4.0330\text{ u}\end{aligned}$$

But the actual mass of a helium nucleus determined experimentally is 4.0026 u . Then, what happened to the remaining mass of 0.0304 u ?

Mass Defect

The difference between the sum of the individual masses of constituents in a nucleus and the mass of the nucleus itself is called the 'mass defect'. In the above example, the mass defect is found to be 0.0304 u .

EINSTEIN'S MASS ENERGY EQUIVALENCE

According to Einstein, mass and energy are not independent, but are mutually convertible. Any body which changes its energy content ' E ' undergoes a change in its mass, ' Δm ' so that the ratio

$\frac{E}{\Delta m}$ is always constant, i.e., if the energy of a particle is increased, its mass also increases.

Thus, if m_0 is the 'rest mass' (mass of the particle at rest), then the 'moving mass' m of the particle having velocity ' v ' is given by,

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Einstein's mass-energy equivalence is given as $E = (\Delta m)c^2$, where c is the velocity of light in vacuum. Thus, the mass of $1\text{ u} = 931.5 \times 10^6\text{ eV} = 931.5\text{ MeV}$. 1 kg of mass, if completely changed into energy, would be equivalent to $9 \times 10^{10}\text{ MJ}$.

(Electron volt (eV) is unit of energy and $1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$)

What had puzzled the scientists the most was how the protons having positive charge are packed together within a distance of less than 10^{-15} m without being repelled due to the

electrostatic forces. Since the gravitational force of attraction between the protons is far less than the electrostatic force of repulsion between them, there must be some other stronger force binding the protons staying together. This force is called nuclear force.

Similarly, the role of the neutrons was also puzzling. It was thought that a neutron is formed when the electron of a hydrogen atom collapses into the nucleus under high and extreme pressure, bringing the electron very close to the proton and holding it there, by some form of nuclear energy. Thus, a neutron (a collapsed hydrogen atom) is electrically neutral.

It must be noted that these nuclear forces are much stronger than the electrostatic or electromagnetic forces. Thus, the nucleons – protons and neutrons are bound together by the nuclear energy arising out of the mass defect and the mass-energy equivalence.

Thus, here we define two quantities, binding energy and binding energy per nucleon, which play an important role in the stability of a nucleus.

BINDING ENERGY

The nucleons of a nucleus are bound together by the energy that results from the loss in the total mass of the nucleons when they are held in the nucleus, i.e. – the mass defect; this energy is called the binding energy and is measured in MeV.

$$\text{Binding energy of a nucleus} = \Delta m \times 931.5 \text{ MeV},$$

where Δm is the mass defect of the nucleus in atomic mass units ‘ u ’.

Thus, for the nucleus of a helium atom, the binding energy = $0.0304 u \times 931.5 \text{ MeV}$
= 28.32 MeV

Binding Energy Per Nucleon

It is the average energy required to extract one nucleon from the nucleus.

$$\text{Binding energy per nucleon} = \frac{\text{binding energy}}{A}$$

Binding energy per nucleon is the measure of the stability of the atom. The higher is the binding energy per nucleon, the greater is the stability of the atom.

EXAMPLE

What is the energy required to increase the mass of a system by one unified?

SOLUTION

$$\Delta m = 1 u$$

$$E = \Delta m \times c^2$$

$$E = 1u \times c^2 = 931.5 \text{ MeV}$$

EXAMPLE

What is the mass defect and binding energy of ${}_{27}\text{Co}^{59}$ which has a nucleus of mass of 58.033 u ? ($m_p = 1.0078 u$, $m_n = 1.0087 u$)

SOLUTION

In ${}_{27}\text{Co}^{59}$, number of protons = 27

Number of neutrons = $59 - 27 = 32$

$$\therefore \text{The total mass of the nucleus} = 27 \times 1.0078 \, u + 32 \times 1.0087 \, u \\ = 27.2106 \, u + 32.2784 \, u = 59.489 \, u$$

Given, The actual mass of the nucleus = $58.933 \, u$

$$\therefore \text{The mass defect} = 59.489 \, u - 58.933 \, u \\ = 0.556 \, u$$

$$\therefore \text{The binding energy} = \Delta m \times 931.5 \, \text{MeV} = 0.556 \, u \times 931.5 \, \text{MeV} = 517.914 \, \text{MeV}$$

Nuclear Reactions

Any reaction that tends to change the configuration of the nucleus of an atom can be termed as a nuclear reaction.

There are two types of nuclear reactions. They are:

1. Nuclear fission reactions
2. Nuclear fusion reactions

In electron volt MeV the energy released in a nuclear reaction is generally expressed.

$$1 \, \text{eV} = 1.602 \times 10^{-19} \, \text{J}.$$

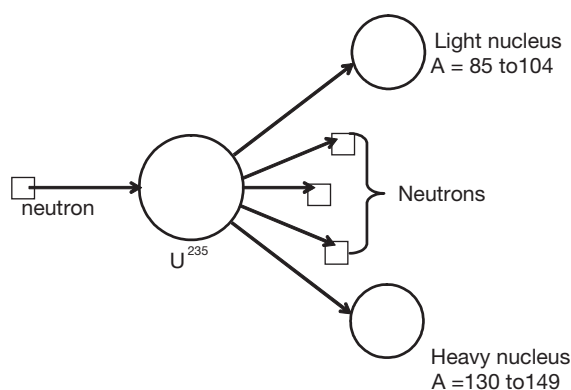
Fission Reactions

FIGURE 9.11 Fission reaction

As already studied in natural radioactivity, U^{235} and U^{238} are highly unstable and emit powerful radiations. In this process, uranium isotope ultimately ends up as 'stable lead', releasing energy of 1 MeV to 5 MeV. Thus, if it is possible to break an unstable nucleus into two or more smaller ones, this would lead to the release of a great amount of energy. This is the principle of a nuclear fission reaction.

Nuclear fission is a process in which the heavy nucleus of a radioactive substance like uranium is split into lighter nuclei by the bombardment of a low energy (slow moving) neutron, the reaction being accompanied by the release of energy and two or three or more neutrons.

The low energy neutrons used for the bombardment of the nuclei of heavier atoms of uranium are called 'thermal neutrons'. They have a kinetic energy of less than 1eV.

The salient features of a fission reaction are as follows:

1. A fission reaction takes place when the nucleus of a heavy atom such as U^{235} is bombarded with a slow moving, low energy thermal neutron.
2. Fast moving neutrons cannot produce a fission.
3. The products of a fission reaction are generally a light nucleus, a heavy nucleus and 2 or 3 neutrons. The atomic mass number of the lighter nucleus is in the range of 85 to 104, whereas the atomic mass number of the heavier nucleus is between 130 and 149.
4. On an average, about 2.5 neutrons are produced in one fission reaction.
5. There are three types of fission reactions—spontaneous, prompt and delayed reactions. In spontaneous fission reactions, fission takes place continuously and spontaneously in certain (radioactive) substances without bombardment by any projectile. In a prompt reaction, fission takes place as soon as the heavy nucleus is bombarded with a neutron, whereas in a delayed fission, the neutron enters a heavy nucleus causing instability and eventually leading to the fission.
6. Every fission reaction is accompanied by the release of enormous energy in the form of light and heat. This is due to the mass defect, i.e., the difference in the masses of the reactants and the products.
7. Another by-product of a fission reaction is γ -radiations. These radiations of very short wavelength have harmful effects on living organisms.

LIQUID DROP MODEL

After Otto Hahn and Fritz Strassmann discovered the fission reaction in 1939, Niels Bohr, Frenkel and Wheeler suggested the liquid drop model to explain the nuclear fission. According to this model, the various stages of a nuclear fission are as follows.

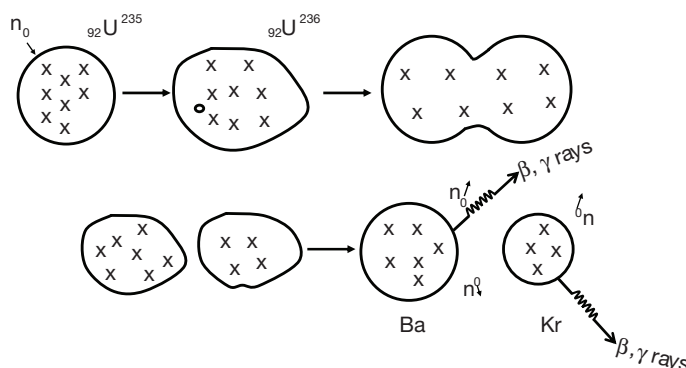


FIGURE 9.12 Pictorial representation of nuclear fission (liquid drop model)

1. A heavy nucleus can be treated as the drop of a liquid with positive charge uniformly distributed.
2. Due to the surface tension, the surface of the liquid drop would act as a stretched rubber membrane.
3. The forces acting between the nucleons inside the nucleus are different from those acting between nucleons close to the surface, just as the cohesive forces between the molecules inside the liquid are different as compared to the adhesive forces at the surface.
4. During the bombardment of a nucleus by neutrons, a neutron could be absorbed by the 'drop-like' nucleus leading to the disturbance of the internal forces and setting up oscillations.
5. These oscillations lead to the development of a thick neck forming two parts, giving the nucleus an elongated shape.
6. From this stage the repulsive forces take over causing the fission (breaking up) of the nucleus.

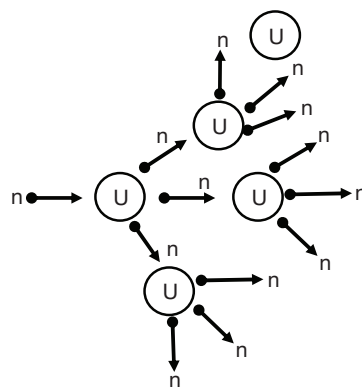
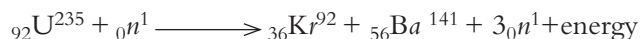


FIGURE 9.13 Stages of nuclear fission

Determination of Energy Liberated in a Nuclear Reaction

In the fission of ${}_{92}\text{U}^{235}$, the energy liberated can be calculated as follows:



The mass of ${}_{92}\text{U}^{235} = 235.124 \text{ u}$

The mass of ${}_{36}\text{Kr}^{92} = 91.944 \text{ u}$

The mass of ${}_{56}\text{Ba}^{141} = 140.948 \text{ u}$

The mass of a neutron = 1.009 u

$\therefore$ The total mass of reactants = $235.124 \text{ u} + 1.009 \text{ u} = 236.133 \text{ u}$

$\therefore$ The total mass of products = $91.944 \text{ u} + 140.948 \text{ u} + 3(1.009 \text{ u})$
 $= 235.919 \text{ u}$

The mass defect = $236.133 \text{ u} - 235.919 \text{ u} = 0.214 \text{ u}$

The mass of the products is less than that of the reactants. This loss in mass can be accounted for by the liberation of heat.

$$1 \text{ u} = 931.5 \text{ MeV}$$

$$\therefore 0.214 \text{ u} = 931.5 \times 0.214 \text{ MeV} = 199.3 \text{ MeV}$$

$$\approx 200 \text{ MeV}$$

$$= 200 \times 1.6 \times 10^{-13} \text{ J} = 3.2 \times 10^{-11} \text{ J per fission}$$

Considering the fact that 235 g of uranium contains 6.023×10^{23} atoms of uranium, if all the atoms in 1 kg of U^{235} undergo fission, it would liberate energy equal to $8.2 \times 10^{13} \text{ J}$.

Taking 30% efficiency in conversion from nuclear energy to electrical energy, 2.46×10^{13} J of electrical energy can be generated if 1 kg of U^{235} undergoes fission. If coal were to be used for the generation of this amount of energy, 2500 kg of coal would be required. Similarly, the energy liberated by 1 atom of U^{235} is two million times the energy obtained in the combustion of one molecule of methane.

Thus, harnessing nuclear energy for the generation of electrical energy has become important. Bhabha Atomic Research Centre (BARC) in Mumbai is a major research centre in India working on the atomic research. The major research reactors employed in India are APSARA (1 MW), Cirus (100 MW), Dhruva (100 MW), Purnima (zero energy fast breeder) and Zerlina (zero energy experiment research reactor).

The four nuclear power plants in India used for the generation of electricity are Tarapur Atomic Power Plant (420 MW), Rajasthan Atomic Power Plant (440 MW), Narora Atomic Power Plant (470 MW) and Chennai Power Plant (IGCAR) (470 MW). These power plants have been set up by Nuclear Power Corporation.

EXAMPLE

Find the energy released during the following nuclear reaction.



The mass of ${}_3\text{Li}^7$ is 7.0160 u, ${}_2\text{He}^4$ is 4.0026 u and proton is 1.0078 u.

SOLUTION

The mass of the reactant nuclei = $7.0160 + 1.0078 = 8.0238$ u

The mass of the product nuclei = $4.0026 + 4.0026 = 8.0052$ u

Mass defect = $\Delta m = 8.0238 - 8.0052 = 0.0186$ u

Energy released = $0.0186 \text{ u} \times 931.5 \text{ MeV} = 17.326 \text{ MeV}$

Kinds of Nuclear Fission Reactions

There are two kinds of nuclear fission reactions. They are uncontrolled fission reactions and controlled fission reactions.

The main difference between these reactions is that in the former, the amount of energy released is enormous in a short span of time and causes explosion, whereas in the latter case, there is a slow and controlled release of energy, which can be effectively utilized without causing any destructive explosion.

Uncontrolled Fission Reaction or Chain Reaction or Explosive Fission Reaction

When uranium (U-235) is bombarded by neutrons, each uranium nucleus is broken into two nearly equal fragments and along with it, huge energy is released and two or three fresh neutrons are liberated.

Under favourable conditions, these neutrons cause fission reaction in other uranium nuclei and the process continues till a stable product is obtained. However, a minimum mass of U^{235} is required to start a chain reaction. This minimum mass is known as critical mass. The probability of fission is high in U^{235} isotope.

The composition of U^{235} isotope in natural uranium is only $\sim 0.7\%$. The other isotopes are U^{234} and U^{238} . The concentration of U^{235} in natural uranium is increased by a process called 'enrichment' and the uranium thus produced is referred to as 'enriched uranium'.

CHAIN REACTION

'A chain reaction is a series of nuclear fissions whereby the neutrons produced in each fission cause additional fissions, releasing enormous amount of energy'.

It is estimated that in one minute 10^{23} uranium atoms undergo fission in an uncontrolled chain reaction and as a consequence, tremendous amount of energy is released in a very short time causing destructive explosion. The atom bombs dropped on Hiroshima and Nagasaki by the Americans in 1945 resulting in the death of about 1.5 lakh people within minutes are examples of this type of fission reaction.

Pictorial Representation of Chain Reaction Controlled Chain Reaction or Critical Fission Reaction

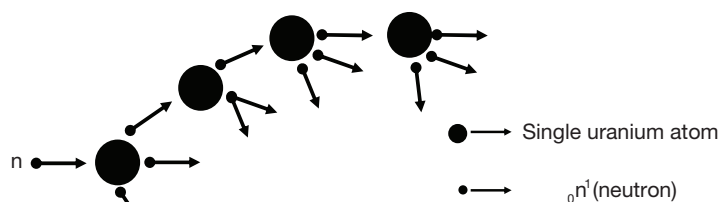


FIGURE 9.14 Critical fission reaction

The energy released in chain reaction is enormous and if this reaction is controlled, the energy can be used effectively.

The control and harnessing of the nuclear energy becomes possible if the number of neutrons in the immediate environment of uranium nuclei is limited by some means.

Pictorial Representation of a Controlled Chain Reaction

Thus, a fission reaction in which the number of neutrons participating in the fission in unit time is controlled by some means is referred to as 'controlled fission reaction'. In such a reaction, the rate of release of nuclear energy is also controlled.

A fission reaction can be controlled if

1. the neutron absorbed by a nucleus of uranium atom does not cause fission,
2. the released neutrons are stopped from being captured by other uranium nuclei or
3. the neutrons released in a fission reaction escape from the system.

NUCLEAR REACTOR

A nuclear reactor, is a device in which a self sustaining controlled chain reaction is produced in a fissionable material. It is, thus, a source of controlled energy which is utilized for many useful purposes. The first nuclear reactor was constructed by Fermi in 1942. It used U^{235} as fuel.

Generation of Electricity

A nuclear reactor used for the generation of electricity has five fundamental parts.

1. **Nuclear fuel:** It is the most important part of the reactor and is the substance used for fission. The fissionable materials like U^{235} and Pu^{239} used for the generation of heat energy in a nuclear reactor are called 'nuclear fuels'. Enriched uranium containing about 2% to 3% of U^{235} is often used as nuclear fuel.

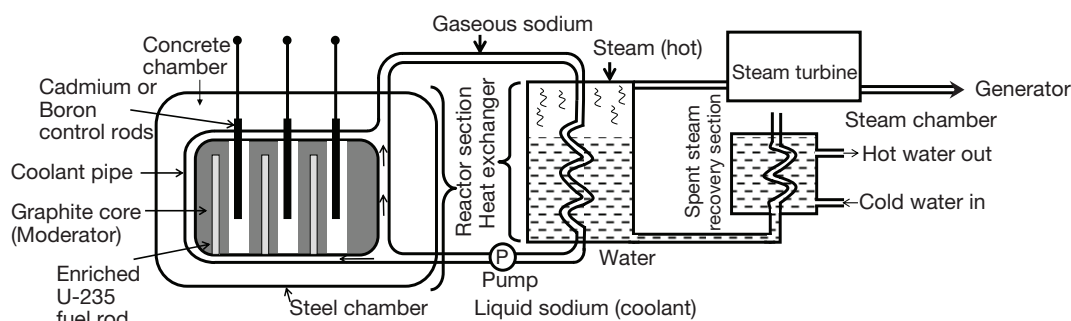


FIGURE 9.15 Nuclear Power Plant

2. **Moderator:** It is used to slow down the fast moving neutrons. Heavy water, graphite or beryllium oxide is used for this purpose. Heavy water is the best moderator available.

The neutrons produced in a fission reaction have high energy (1 MeV) and the probability of these neutrons producing fission is 500 times less than that of slow moving thermal neutrons. Thus, the moderator converts fast neutrons to thermal neutrons.

3. **Coolant:** The energy released inside the reactor in the form of heat is removed by a coolant. For this purpose, molten sodium, ice cold water or CO_2 is used in the reactor. This heat removed from the reactor is utilized for producing steam which is, then, used to drive turbines for generating electricity.

Molten sodium is the most efficient and commonly used coolant.

4. **Shield:** Various types of harmful intense rays are emitted from the reactor during fission reactions. To protect the people from these rays, the reactor is surrounded by 7 to 8 feet thick concrete and lead walls forming a shield.
5. **Control rods:** For controlled fission reaction to take place, only one of the three neutrons produced in a fission reaction should be allowed to participate in the next fission, the other two being absorbed by some other material. These materials are called 'control rods'. Cadmium rods are used to control the rate of fission in the reactor. These rods are fixed in the walls of the reactor.

During the operation of a nuclear reaction, two stages occur—shut down position and critical stage. In the shut down position, the control rods are completely inserted into the reactor so that all the neutrons emitted are absorbed, and no further fission reactions take place.

In the critical stage, the control rods are drawn out of the reactor appropriately such that the right number of neutrons is available to sustain the controlled fission reaction at the required rate.

NUCLEAR POWER PLANT

A nuclear power plant essentially consists of four units:

1. Nuclear reactor
2. Heat exchanger
3. Steam turbine
4. Electric generator or dynamo

Working

1. In order to start the nuclear reactor, the control rods are slowly lifted till the reactor goes critical.
2. The heat energy produced in a reactor vaporizes the molten sodium. The vapors of sodium pass on the heat to the water in the heat exchanger, converting water to steam.
3. The steam turns the turbine converting heat energy into mechanical energy.
4. The turbine is coupled to a generator, which, in turn, converts mechanical energy into electric energy.
5. The condensed steam in the turbine and liquefied sodium in the heat exchanger are circulated through pumps.

Nuclear Fusion

Fusion means joining together or combining together. 'A nuclear reaction in which nuclei of lighter atoms combined fuse together to form heavier nuclei resulting in the release of tremendous amount of energy is called a nuclear fusion reaction'.

It is found that this heavier nucleus has a mass less than that of the sum of the masses of the reacting nuclei. Thus, such a process results in the conversion of mass into energy.

Nuclear fusion reactions were discovered in the 1930s. In 1939, Hans Bethe suggested that the enormous amount of heat energy produced in sun and other stars are due to such fusion reactions taking place in their core. These fusion reactions which take place at high temperatures are referred to as thermo-nuclear reactions. The main advantage of a fusion reaction is that they are not accompanied by the release of harmful radiations.

Fusion Theory

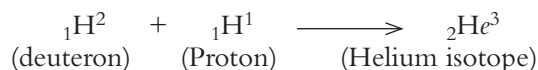
In a typical nuclear fusion reaction, four protons (nucleus of hydrogen) combine forming a helium nucleus. The other products are two positrons and two neutrinos (neutral particles of

negligible mass) and the reaction is accompanied by the release of about 27.6 MeV energy. This reaction takes place in three stages.

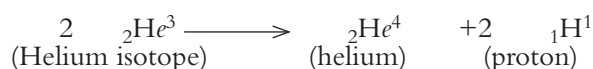
I Stage reaction



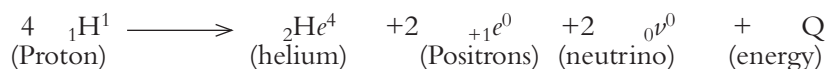
II Stage reaction



III Stage reaction



Combining the three equations, we have



This group of reactions of the three stages are called proton–proton cycle since two protons are released in the III stage reaction.

The mass–energy equivalence in a fusion reaction:

The mass of proton = 1.0078 u

The mass of helium nucleus = 4.001506 u

The masses of positrons and neutrinos being negligible, we have,

The mass of reactants = $4 \times 1.0078 \text{ u} = 4.0312 \text{ u}$ and

The mass of products = 4.001506 u

$\therefore$ The mass defect = $4.0312 \text{ u} - 4.001506 \text{ u} = 0.0297 \text{ u}$

The equivalent energy = $0.0297 \text{ u} \times 931 \text{ MeV/u} = 27.67 \text{ MeV}$

All this energy is converted into heat.

A fusion reaction can be initiated when a high energy proton (KE = 0.01 MeV) accelerated in a particle accelerator, is made to strike on a target and fuse with the nuclei of the target. The target consists of nuclei of low atomic number.

Alternately, the kinetic energy of the light nuclei (protons) can be increased by raising the temperature to as high as $4 \times 10^6 \text{ K}$ in an enclosure. At these high temperatures, the atoms are completely ionised and the electrons move at high speeds. Matter in such a state is called plasma in which the fusing nuclei easily overcome the electrostatic repulsion between them.

Hydrogen Bomb

Hydrogen bomb, like atom bomb, is a weapon of mass destruction, employing the thermo-nuclear reactions, which can release enormous energy within a few minutes. The high temperature required for the uncontrolled fusion reaction in a hydrogen bomb is produced by a fission bomb containing uranium (U^{235}) or plutonium (Pu^{239}). Thus, the hydrogen bomb is a fission–fusion bomb.

Nuclear Fusion Reactor

The energy released in a fusion reaction is much higher than the energy released in a fission reaction. Thus, there is a considerable interest in harnessing this energy for useful applications such as generation of electricity. However, fusion reactors could not be built so far for the following reasons.

1. Unlike fission reactions, fusion reactions are not chain reactions. Hence, it is not possible to sustain the reaction_____?
2. The order of the magnitude of temperature enabling a fusion reaction to take place is 10^6 K. Producing such high temperature is very difficult. Even if the temperature is produced using a fission bomb, there is no material which can withstand such a high temperature.
3. It is difficult to harness and convert the high amount of heat energy produced in a fusion reaction into mechanical energy.

Nuclear Hazards and Safety Measures

Nuclear radiations affect all living beings as well as materials including buildings. The effects due to nuclear radiations given out during the explosion of a nuclear bomb cause death of lakhs of people, plants and animals. The materials and buildings are damaged extensively. In humans, exposure to nuclear radiations causes somatic and genetic effects. Due to somatic disorders, deadly diseases like cancer develop whereas genetic effects are observed generation after generation. In genetic effect, nuclear radiations change the genes of the exposed person for the worst and pass them on to the next generation. The offsprings born to such persons have deformities. Nuclear reactors are another source of nuclear radiations. Continuous nuclear reactions in them produce a large quantity of radioactive materials. The fuel rods, after use, become highly radioactive and contain toxic elements like plutonium. The spent nuclear fuel rods should be handled carefully so that humans are not exposed to the radiations given out by them. For this, they are first stored under water in a nuclear plant and then sent to a processing plant so as to retrieve usable materials. After that, they are stored in safe places like unused deep mines. Care should be taken to ensure that there is no leakage present in moderators and cooling water used in a nuclear plant. Such a leakage, if present, can cause contamination of water bodies and soil.

NUCLEAR RESEARCH IN INDIA

In 1945, under the leadership of Dr Homi Jehangir Bhabha, the atomic research in India started. The atomic energy commission is established and Dr Bhabha was made its first Chairman.

Under his leadership, atomic reactors such as Apsara, Cirus, Zerlina and a plant to enrich Uranium were started. Indian scientists have developed the capability to prepare nuclear fuel, design and fabrication of nuclear reactors and also explosive devices like atom bomb and hydrogen bomb.

The major centre of nuclear related research and development is Bhabha Atomic Research Centre (BARC) situated at Bombay in Maharashtra. The major research nuclear reactors are

Apsara, Cirus, Dhruva, Purnima and Zerlina. The nuclear power stations are Tarapur atomic power station (Maharashtra), Rajasthan atomic power station, Narora atomic power station (Uttar Pradesh), and Chennai Power station (Tamil-Nadu). In India, Uranium occurs at Jaduguda in Jharkhand. The natural ore is processed and enriched at Nuclear Fuel Complex in Andhra Pradesh.

EXAMPLE

In a given radio-active sample, there are 10^{24} nuclei present. If its half-life period is 20 years, how many nuclei will be present after 10 years?

$$\left(\text{Take } = \frac{1}{\sqrt{2}} = 0.707\right)$$

SOLUTION

The number of nuclei (N) present after ' n ' half lives is given by,

$$N = N_0 \left(\frac{1}{2}\right)^n \quad (1)$$

$$\text{Where } n = \left(\frac{t}{T}\right)$$

In the question, we are given that $N_0 = 10^{24}$

$$n = \frac{10}{20} = \frac{1}{2}, N = ?$$

Substituting the above values in equation (1), we get

$$\begin{aligned} N &= 10^{24} \left(\frac{1}{2}\right)^{\frac{1}{2}} \\ &= 10^{24} \times 0.707 \\ &= 7.07 \times 10^{23} \end{aligned}$$

EXAMPLE

Calculate the binding energy per nucleon for Beryllium ${}^9_4\text{Be}$, its mass being 9.012 u. The masses of proton and neutron are 1.008 u and 1.009 u.

$$(\text{Take } 1 \text{ u} = 931.5 \text{ MeV})$$

SOLUTION

First, let us find the mass defect. The Beryllium nucleus contains 4 protons and 5 neutrons.
Mass of 4 protons = $4 \times 1.008 = 4.032 \text{ u}$

Mass of 5 neutrons = $5 \times 1.009 \text{ u} = 5.045 \text{ u}$

Total mass of protons (4) and neutrons (5) = $4.032 + 5.045 = 9.077 \text{ u}$

Mass defect = $9.077 - 9.012 = 0.065 \text{ u}$

The mass defect converted into equivalent energy gives binding energy.

$$1 \text{ u} = 931.5 \text{ MeV}$$

$$\therefore 0.065 \text{ u} = 0.065 \times 931.5 \text{ MeV} = 60.5475 \text{ MeV}$$

Binding energy per nucleon

$$= \frac{\text{binding energy}}{\text{No. of nucleons}} = \frac{60.5475}{9} = 6.7275 \text{ MeV}$$

EXAMPLE

Assuming 200 MeV energy is released per fission of ${}_{92}^{235}\text{U}$, calculate the energy released when 1 kg of ${}_{92}^{235}\text{U}$ undergoes complete fission. What percentage of mass of ${}_{92}^{235}\text{U}$ gets converted into energy?

SOLUTION

235 g of ${}_{92}^{235}\text{U}$ contains Avogadro number (6.023×10^{23}) of atoms.

No. of atoms of ${}_{92}^{235}\text{U}$ in 1 kg of uranium

$$= 1000 \times \frac{6.023 \times 10^{23}}{235} = 2.563 \times 10^{24}$$

Energy released = No. of atoms $\times$ energy released per fission.

$$= 2.563 \times 10^{24} \times 200 \text{ MeV}$$

$$= 5.126 \times 10^{26} \text{ MeV}$$

The mass that liberates the above energy can be calculated using $E = mc^2$ (2)

where $E = 5.126 \times 10^{26} \times 1.6 \times 10^{-13} \text{ J}$

$$= 8.2 \times 10^{13} \text{ J}$$

$$c = 3 \times 10^8 \text{ m s}^{-1}$$

Substituting in (2), we get

$$m = \frac{E}{c^2} = \frac{8.2 \times 10^{13}}{9 \times 10^{16}} = 9.11 \times 10^{-4} \text{ kg}$$

$$\% \text{ of mass} = \frac{9.11 \times 10^{-4}}{1} \times 100 = 0.0911\%$$

$$= 0.1\% \text{ approximately}$$

EXAMPLE

Two protons and two neutrons combine to form a nucleus of ${}^4_2\text{He}$. Find the energy released during the process. What type of nuclear reaction is it? Take masses of proton, neutron and helium as 1.007 u, 1.009 u, 4.002 u, respectively.

SOLUTION

The nuclear reaction is $2{}_1^1\text{P} + 2{}_0^1\text{n} \rightarrow {}^4_2\text{He}$

First, let us find mass defect and then energy.

The mass of $2p$ and $2n$ is $(2 \times 1.007 + 2 \times 1.009) = 2 \times 2.016 = 4.032$ u.

The mass of helium is = 4.002 u.

The mass defect = $4.032 - 4.002 = 0.030$ u.

1 u liberates 931.5 MeV of energy. The energy equivalent to 0.030 u = 0.03×931.5
= 27.94 MeV.

The above nuclear reaction is called fusion as lighter nuclei combine together to form a single nucleus.

EXAMPLE

The binding energy of ${}^7_3\text{Li}$ and ${}^4_2\text{He}$ are 39.2 MeV and 28.24 MeV, respectively. Which one of the two nuclei is more stable?

SOLUTION

The nucleons present in ${}^7_3\text{Li}$ is 7.

The binding energy per nucleon for lithium is = $\frac{39.2}{7} = 5.6$ MeV .

The binding per nucleon for helium is $\frac{28.24}{4} = 7.06$ MeV .

The binding energy per nucleon is the measure of stability of the nucleus. Therefore, helium is more stable than lithium.

EXAMPLE

A nuclear reactor generates 500 MW of electrical energy using the fission of ${}^{235}_{92}\text{U}$. Find the mass of ${}^{235}_{92}\text{U}$ required to produce electricity for 30 days. (0.1% of the mass of ${}^{235}_{92}\text{U}$ gets converted into energy).

SOLUTION

The electrical energy produced in one second is 500 MJ. The electrical energy generated in 30 days is

$$\begin{aligned}
 E &= 500 \times 10^6 \times 60 \times 60 \times 24 \times 30 \\
 &= 1.3 \times 10^{15} \text{ J. (approximately)}
 \end{aligned}$$

To generate above energy, the mass required can be found using the formula

$$E = mc^2$$

$$\text{or } m = \frac{E}{c^2} = \frac{1.3 \times 10^{15}}{(3 \times 10^8)^2} = 0.144 \times 10^{-1} \text{ Kg} = 1.44 \times 10^{-2} \text{ Kg}.$$

Let M be the mass of uranium required to generate energy E . Then ' m ' is 0.1% of M .

$$\text{i.e.,} \quad m = \frac{0.1}{100} \times M$$

$$\Rightarrow M = 1000 \, m = 1000 \times 1.44 \times 10^{-2} = 14.4 \text{ kg}.$$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. Define artificial transmutation.
2. Energy released in a nuclear reaction is given by _____.
3. What is a chain reaction?
4. _____ are used to absorb the neutrons in a nuclear reactor.
5. In a discharge tube, at what pressure cathode rays are produced?
6. Thorium series is also called _____.
7. If the half-life period of a radioactive substance is 0.693 years, what is its decay constant?
8. The first radioactive element discovered is _____.
9. What happens when cathode rays are suddenly stopped?
10. In a nuclear reactor, what is the function of heat exchanger?
11. What is the measure of the stability of the atom?
12. ${}_1\text{H}^3 + \text{_____} \rightarrow {}_2\text{He}^4 + {}_0n^1 + \text{Energy}$
13. How can you say that cathode rays are negatively charged particles?
14. Radioactive isotope of carbon is _____.
15. Define binding energy of a nuclear.
16. What is a fusion reaction?
17. How are X-rays produced?
18. In artificial transmutation, the bombarding particles are called _____.
19. What forces are responsible for keeping the nucleons together in a nucleus?
20. Why are nuclear fusion reactions also known as thermo-nuclear reactions?
21. Which rays among α , β and γ are deflected most in a magnetic field? Which rays remain undeflected?
22. The radioactive isotope used in the treatment of cancer is a good source of _____ radiations.
23. What is a moderator? Give one example.
24. What is radioactive transformation or radioactive decay?
25. What is the use of control rods?
26. What is the use of Geiger counter?
27. In all radioactive series, the end element formed is _____.
28. Name the three radioactive series. Which series is referred to as $4n$ Series?
29. $4n + 2$ series is called _____ series.
30. Define isotopes, isobars and isotones.

Short Answer Type Questions

31. State the laws of emissions.
32. Find the binding energy per nucleon for a lithium nucleus ${}_3\text{Li}^7$. Take mass of ${}_3\text{Li}^7 = 7u$, mass of proton $1.007825 u$ and mass of neutron $= 1.008665 u$. Take $1 u = 931.5 \text{ MeV}$.
33. Explain how the age of fossils is determined.
34. What are prompt fission and delayed fission reactions?
35. What is nuclear fusion? How many? All nine Separate.
36. Explain nuclear chain reactions.
37. Explain why the energy released during fusion cannot be used to produce electricity.
38. Mention the properties of X-rays.
39. What is a nuclear reactor? Name its different parts.
40. Give any three uses of radio-isotopes.
41. Explain nuclear fission by giving an example.
42. Mention the uses of X-rays.
43. Using $E = mc^2$, find out the energy released, when $1 u$ of mass disappears.
Take $1 u = 1.66 \times 10^{-27} \text{ kg}$.
44. What is a radioactive series? How is it formed? Explain.



Essay Type Questions

45. What is a Liquid Drop Model? How does it help in the understanding of fission reaction?
46. Explain in detail the nuclear hazards and the safety precautions to be taken while?
47. Describe in detail the process of β -decay and γ -decay.
48. Compare the properties of α , β and γ radiations.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

- High energy neutrons are used in a nuclear reactor to initiate the fission reaction.
- Cadmium rods are used as moderators in a nuclear reactor.
- Oxygen can be obtained from nitrogen by artificial nuclear transmutation.
- ${}_0n^1 + {}_7N^{14} + {}_1H^0 + {}_6C^{15}$
- X-rays have higher penetrating power as they travel with very high velocity.
- Higher the mass defect, higher will be the stability of the nucleus.
- The e/m ratio of Cathode rays is constant irrespective of the gas filled inside the discharge tube.

Direction for questions 8 to 14:

Fill in the blanks.

- If the binding energy per nucleon for ${}_3Li^7$ is 5.6 MeV, the total binding energy of a lithium nucleus is _____ MeV.
- The conversion of 1 u of mass results in _____ eV of energy.
- The common product formed in the artificial transmutation by a proton is _____.
- In plants and animals, the ratio of C^{14} to C^{12} is _____.
- The radioactive radiation which can be stopped easily is _____.
- When an α -particle is ejected, the atomic number of the atom decreases by _____.
- The cathode rays emitted from a concave cathode meet at _____.

Direction for question 15:

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

15.	Column A	Column B
A.	Coolidge tube ()	a. present in all natural radioactive series
B.	α decay ()	b. isobars
C.	Radon ()	c. isotones
D.	${}_{14}Si^{31}, {}_{15}P^{32}$ ()	d. stability of a nucleus
E.	β -decay ()	e. to slow down neutrons
F.	Binding energy per nucleon ()	f. decrease in atomic number by two
G.	Moderator ()	g. X-rays
H.	Thermonuclear reaction ()	h. $E = mc^2$
I.	Mass energy equivalence ()	i. clot of blood in human body
J.	Sodium - 24 ()	j. nuclear fusion

Direction for questions 16 to 39:

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

- The specific charge is the highest for _____.
(a) α -rays (b) β -rays
(c) protons (d) neutrons
- Which of the following is/are subatomic particles?
(a) Protons (b) Positron
(c) Neutrino (d) All the above



18. Which of the following radiations has the highest penetrating power?
 (a) α (b) β
 (c) γ (d) X-rays
19. The nuclear reaction that takes place in a nuclear reactor is _____.
 (a) controlled fission reaction
 (b) uncontrolled fission reaction
 (c) nuclear fusion reaction
 (d) None of the above
20. Identify isobars among the following.
 (a) ${}_{14}\text{Si}^{31}$, ${}_{15}\text{P}^{32}$
 (b) ${}_{6}\text{C}^{13}$, ${}_{7}\text{N}^{13}$
 (c) ${}_{7}\text{N}^{14}$, ${}_{7}\text{N}^{15}$
 (d) None of the above
21. Higher value of decay constant indicates _____.
 (a) faster decay (b) high half-life period
 (c) slower decay (d) Both (a) and (b)
22. To convert ${}_{90}\text{Th}^{232}$ into ${}_{90}\text{Th}^{228}$, the least number of α and β particles that have to be emitted are _____ and _____, respectively.
 (a) 1,1 (b) 2,1
 (c) 1,2 (d) 2,2
23. The mass number of an element in a radioactive series is 223. Then the radioactive series is _____.
 (a) $4n$ (b) $4n + 3$
 (c) $4n + 2$ (d) $4n + 1$
24. Carbon dating is used to
 (a) assess the age of fossils.
 (b) assess the amount of radioactivity.
 (c) assess the rate of radioactivity.
 (d) none of the above.
25. The kinds of force(s) that are present between two protons in a nucleus is/are _____.
 (a) electrostatic force (b) nuclear force
 (c) magnetic force (d) Both (a) and (b)
26. ${}_Z\text{X}^A$ and ${}_{Z+1}\text{Y}^A$ are two radioactive elements. X emits one α particle whereas Y emits one β particle. The daughter nuclei formed are _____.
 (a) isotopes (b) isobars
 (c) isotones (d) isomorphous
27. The e/m of three singly ionized atoms A, B and C are x , y , z , respectively. If $x > y > z$ and m_A , m_B , and m_C are their atomic weights, the correct relation among the following is _____.
 (a) $m_A > m_B > m_C$ (b) $m_C > m_B > m_A$
 (c) $m_A = m_B = m_C$ (d) $m_A > m_B = m_C$
28. A radioactive substance was reduced to $\frac{1}{4}$ of the total amount in 8 days. The time taken by this radioactive substance to get reduced to $\frac{1}{8}$ th of the remaining amount is _____.
 (a) 12 days (b) 16 days
 (c) 20 days (d) 8 days
29. ${}_1\text{H}^1 + {}_3\text{Li}^7 \rightarrow \text{_____} + {}_2\text{He}^4$
 (a) ${}_2\text{He}^4$ (b) ${}_6\text{C}^{12}$
 (c) ${}_4\text{Be}^9$ (d) ${}_4\text{Be}^8$
30. The property of cathode rays used in a monitor of a computer is _____.
 (a) high velocity
 (b) high ionization power
 (c) cause fluorescence of phosphors
 (d) rectilinear propagation
31. If the radiations from a radioactive substance, in the presence of an electric field, deflect towards the anode, the rays are
 (a) α -rays (b) β -rays
 (c) γ -rays (d) X-rays
32. A radioactive isotope of radium placed in the second group in the periodic table emits one α -particle and one β -particle. The new element formed is in the _____ group.
 (a) first (b) second
 (c) third (d) fourth
33. Which among the following statements is incorrect about visible light and X-rays?
 (a) They have same velocity in vacuum or air
 (b) They are electromagnetic radiations.
 (c) They have same wavelength in a given medium.
 (d) They are not affected by electric field.
34. Cathod rays exert _____ force on the object place in their path.
 (a) mechanical (b) electrical
 (c) magnetic (d) electromagnetic
35. Which among the following has the lowest speed when travelling through a given medium?
 (a) γ -rays (b) α -rays
 (c) β -rays (d) Cathode rays
36. Write the following steps in sequential order to calculate the binding energy per nucleon of an element ${}_Z\text{X}^A$, given the actual mass of ${}_Z\text{X}^A$, mass of proton (m_p) and mass of neutron (m_n) (All the values are given in atomic mass units)



- (a) Note the actual mass of the nucleus (M), number of nucleons in ${}_Z A^X$, m_p and m_n .
 (b) Calculate the mass defect of the given nucleus.
 (c) Find the number of protons and number of neutrons in the nucleus.
 (d) Determine the sum of the individual masses of constituents in ${}_Z A^X$.
 (e) Calculate the binding energy (B.E) of the nucleus.
 (f) Divide it with the number of nucleons present in the element to get binding energy per nucleon.
- (a) a e d c b f (b) a c d b e f
 (c) a c b d e f (d) a d c b e f
37. The process of increasing the percentage of fissionable U-235 in naturally occurring uranium is called _____
 (a) controlled fission.
 (b) artificial transmutation.
 (c) chemical process.
 (d) enrichment.
38. _____ reaction takes place in the sun.
 (a) Nuclear fission (b) Nuclear fusion
 (c) Chemical (d) both (a) and (b)
39. Write the following steps of the liquid drop model in sequential order to show the various stages of a nuclear fission reaction.
 (a) During the bombardment of a nucleus by neutrons, a neutron could be absorbed by the drop like the nucleus.
 (b) A heavy nucleus is treated as the drop of a liquid with the positive charge uniformly distributed.
 (c) This leads to the disturbance of the internal forces and sets up oscillations.
 (d) From this stage the repulsive forces take over causing the fission of the nucleus.
 (e) These oscillations lead to the development of a thick neck forming two parts, giving the nucleus an elongated shape.
- (a) b c e a d (b) a c e d b
 (c) a d c e b (d) b a c e d

Level 2

40. The binding energy per nucleon for deuterium and helium are 1.1 MeV and 7 MeV, respectively. Find how much energy is released by the fusion of 1 g of deuterium?
41. Calculate the energy equivalent of 1 μ of mass. Express the energy in MeV.
42. Show that iron ${}_{26}\text{Fe}^{56}$ is more stable than carbon ${}_6\text{C}^{12}$, given binding energy of ${}_{26}\text{Fe}^{56}$ is 492.35 MeV and that of ${}_6\text{C}^{12}$ is 89.14 MeV.
43. How many electrons, protons and neutrons are there in 12 g of ${}_6\text{C}^{12}$?
44. In Ac-U series, the decay of the parent nucleus starts with an α -particle. The decay is continued such that an α -and β -particles are emitted alternately until an unstable nucleus radium is formed. Identify the isotopes, isobars, isotones formed and the change in the number of neutrons and protons of parent and daughter nuclei.
45. How many grams of U^{235} is required to produce 8×10^{11} J of energy if 200 MeV of energy is released when one U^{235} atom undergoes fission?
46. $\frac{15}{16}$ th of a radioactive substance disintegrates in 12 days. What is the half-life period of the radioactive substance? How much more time will it take for the remaining amount of radioactive substance to reduce to $\frac{1}{32}$ of the reduced amount?
47. The half-life period of C^{14} is 5670 years. If 56 g of C^{14} was present initially, how many atoms of C^{14} is left after 22680 years?
48. Is there any force of attraction between two neutrons in a nucleus? Explain.
49. The total binding energies of ${}_1\text{H}^2$, ${}_2\text{He}^4$, ${}_{26}\text{Fe}^{56}$ and ${}_{92}\text{U}^{235}$ are 2.22 MeV, 28.3 MeV, 492 MeV and 1786 MeV, respectively. Which among the above four is the most stable nucleus? Why?
50. Complete the following nuclear reactions
 (1) ${}_{92}\text{U}^{238} + \text{_____} \rightarrow {}_{99}\text{E}^{247} + 5{}_0n^1$
 (2) ${}_{96}\text{Cm}^{244} + {}_2\text{He}^4 \rightarrow \text{_____} + {}_{97}\text{Bk}^{245} + {}_1\text{H}^1$
 (3) ${}_{94}\text{Pu}^{292} + \text{.....} \rightarrow {}_{104}\text{Ku}^{260} + 4{}_0n^1$
51. What percentage of initial amount of radioactive substance is approximately left, after 10 half lives?
52. Write down the sequence of radiations emitted in the following radioactive processes.
 (1) ${}_Z\text{P}^A \rightarrow {}_{Z-1}\text{Q}^A \rightarrow {}_Z\text{R}^A$
 (2) ${}_Z\text{K}^A \rightarrow {}_{Z-2}\text{L}^{A-4} \rightarrow {}_{Z-1}\text{M}^{A-4}$



53. How many nuclei of ${}_{92}\text{U}^{235}$ should undergo fission per second to produce a power of 10 MW if 200 MeV of energy is released per fission of ${}_{92}\text{U}^{235}$?

54. _____ radiation of a radioactive substance is electrically neutral.

Directions for questions 55 to 59:

Select the correct alternative from the given choices.

55. What is the use of control rods?

56. Sikar read that when ${}_{92}\text{U}^{235}$ undergoes fission, approximately 0.1% of its original mass changes into

energy. With this information, calculate the amount of energy released when 1 kg of ${}_{92}\text{U}^{235}$ undergoes fission.

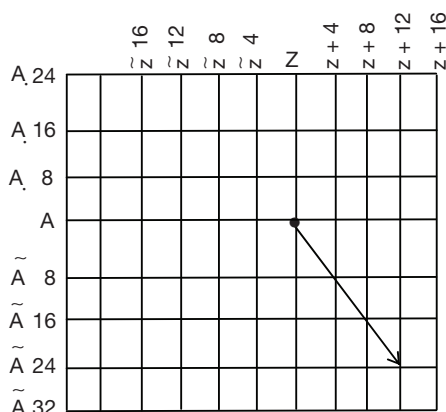
57. The mass number of an element in a radioactive series is 223. Which radioactive series is this?

58. If the binding energy per nucleon for ${}_3\text{Li}^7$ is 5.6 MeV, determine the total binding energy of a lithium nucleus.

59. A radioactive substance was reduced to $1/4$ of the total amount in 8 days. Determine the further time taken by this radioactive substance to get reduced to $1/4^{\text{th}}$ of the remaining amount.

Level 3

60. Explain how a radioactive nucleus can emit negatively charged β -particles, even though the nucleus itself is positively charged.



61. ${}_{60}\text{Nd}^{144} \rightarrow {}_{58}\text{Ce}^{140} + {}_2\text{He}^4 + 1.77 \text{ MeV}$. In the above nuclear reaction if the parent nucleus is at rest, determine the velocity of α -particle.

62. A certain radioactive isotope has a half life of 50 days. Over a period of 50 days, the average number of α -emissions per day is found to be 6.023×10^{13} from a sample of initial mass 1 μg . Assuming that only one emission of α particle takes place per atom, find the atomic weight of the radioactive isotope.

63. When the nuclear reaction started in a nuclear reactor the amount of ${}_{92}\text{U}^{235}$ and ${}_{36}\text{Kr}^{92}$ present after 2000 s is found to be 10 g and 23 g, respectively. Determine the output power of the nuclear reactor if its efficiency is 70%. Fission of one nucleus of U-235 releases 200 MeV of energy.

64. How many α and β particles are emitted when uranium ${}_{92}\text{U}^{238}$ disintegrates to form lead ${}_{82}\text{Pb}^{206}$?

Directions for questions 65 to 69:

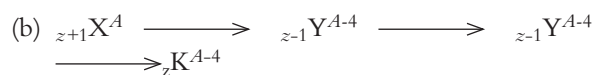
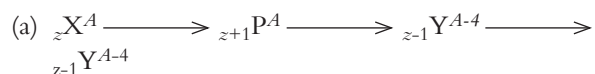
Select the correct alternative from the given choices.

65. An α particle is emitted from a heavy radioactive nucleus. Compare the momenta of the α particle and the daughter nucleus.

66. Determine the energy released during the fusion of ${}_1\text{H}^1$ to form a ${}_2\text{He}^4$ nucleus if the total mass of the products is 4.001506 u, mass of proton is 1.0078u and mass of neutron is 1.0087u.

67. Mass of ${}_{92}\text{U}^{235}$ required to produce electrical energy in a nuclear reactor for 30 days is 23.5 kg. If 40% of the energy released by the fission is converted into electrical energy, determine the power of the nuclear reactor. (Assume that 200 MeV energy is released per fission of ${}_{92}\text{U}^{235}$)

68. Write down the sequence of radiations emitted in the following radioactive processes.



69. How much energy is released when the mass of ${}_8\text{O}^{16}$ nucleus is completely converted into energy? The binding energy per nucleon of ${}_8\text{O}^{16}$ is 7.97 MeV and $m_p = 1.0078 \text{ u}$ and $m_n = 1.0087 \text{ u}$.



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. 39.2 9. 931.5×10^6 10. helium 11. a constant, i.e.,
 10. $^{-12}$ 12. α – rays 13. 2 14. centre of curvature

Match the following

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

Multiple choice questions

16. (b) 17. (d) 18. (c) 19. (a) 20. (b) 21. (a) 22. (c) 23. (b) 24. (a) 25. (d)
 26. (c) 27. (b) 28. (c) 29. (a) 30. (c) 31. (b) 32. (a) 33. (b) 34. (b) 35. (b)
 36. (b) 37. (d) 38. (b) 39. (d)

Explanation for questions 31 to 39:

31. Negatively charged particles deflect towards anode (positive electrode) in an electric field. Among the given options, β -rays are negatively charged and hence they deflect towards anode.
32. When an α particle and a β -particle are emitted from a radioactive nucleus, the atomic number decreases by 2 units and increases by one unit, respectively. And hence the new element formed will be in first group. ($\{ 2-1 = 1$ unit, effectively decreases).
33. X-rays and visible light are electromagnetic radiations and their properties are different only due to the difference in their wavelength or frequency.
34. Mechanical
35. The velocity of α -rays is less than the other rays.
36. The given values of actual mass of the nucleus (M) number of nucleons, mass of proton (m_p) and mass of neutron (m_n) are noted (a). The number of protons (Z) and neutrons ($A - Z$) are also noted (c). The sum of the individual masses is determined as ($Z \times m_p + (A - Z) m_n$) and the mass defect (Δm) is calculated (d), (b). When Δm is multiplied by 931.5 MeV, we

get binding energy (B.E) (e). Dividing B.E by the number of nucleons, i.e., its mass number (A), gives the binding energy per nucleon (f).

37. The process of increasing the percentage of fissionable U-235, in naturally occurring uranium is called enrichment.
38. A nuclear reaction combining nuclei of lighter atoms together to form heavier nuclei resulting in the release of tremendous amount of energy is called a nuclear fusion reaction. Nuclear fusion reaction takes place in the sun.
39. A heavy nucleus can be treated as the drop of a liquid with the positive charge uniformly distributed (b). Due to surface tension, the surface acts as a stretched membrane and different forces act between the nucleons inside the nucleus and between the nucleons close to the surface. During the bombardment of a nucleus by neutrons, a neutron could be absorbed by the drop like nucleus (a). This leads to the disturbance of the internal forces and sets up oscillations (c). These oscillations lead to the development of a thick neck forming two parts, giving the nucleus an elongated shape (e). From this stage, the repulsive forces take over causing the fission of the nucleus (d).



Level 2

40. 3.55×10^{24} MeV or 5.68×10^{11} J.

41. (i) $E = mc^2$

Energy equivalence of 1 kg = $1 \text{ u} \times 9 \times 10^{16}$ J

$1 \text{ u} = 1.66 \times 10^{-27}$ kg

(ii) 931.5 MeV.

42. Stability increases with binding energy per nucleon.

43. (i) 12 g of carbon consists of 6.023×10^{23} atoms.
Number of protons in one carbon atom = its atomic number = number of electrons.

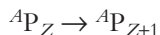
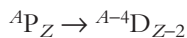
Number of neutrons in one carbon atom = $A - Z$

(ii) Number of neutrons = number of protons = 3.6138×10^{24} .

44. (i) Isobars are atoms with different atomic number and same mass number.

Isotopes are atoms having same atomic number but different mass number.

Isotones are the atoms with same number of neutrons in their nucleus.



(ii) ${}_{90}\text{Th}^{231}, {}_{91}\text{Pa}^{231}$

${}_{90}\text{Th}^{231}, {}_{90}\text{Th}^{227}$

4, 8

45. (i) $1 \text{ MeV} = 1.6 \times 10^{-13}$ J

$200 \text{ MeV} = 200 \times 1.6 \times 10^{-13} \text{ J} = \text{energy released by one } {}_{92}\text{U}^{235} \text{ atom}$

235 g of uranium contains 6.023×10^{23} atoms

From the given information, we can determine the number of uranium atoms required to produce 8×10^{11} J of energy and the mass of uranium required.

(ii) 9.8 g

46. (i) The fraction of amount of radioactive substance left = $1 - \text{fraction of radioactive substance disintegrated}$.

Use the definition of half-life period to determine the time taken to disintegrate to the given amount.

(ii) 15 days

47. (i) Nuclear forces are charge independent.

(ii) Nuclear attractive forces are between any two nucleons.

48. (i) Number of half lives = $\frac{\text{total time}}{\text{half life period}}$

Number of atoms in 14 g of $\text{C}^{14} = 6.023 \times 10^{23}$

Determine the amount of radioactive substance left in given number of half-lives.

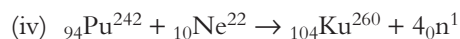
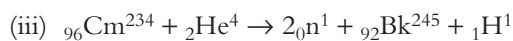
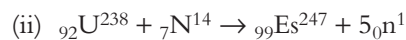
(ii) 1.50575×10^{23}

49. (i) Stability $\propto$ binding energy per nucleon.

(ii) ${}_{26}\text{Fe}^{56}$ is the most stable nucleus as its binding energy per nucleon is the largest among the given four entities.

50. (i) Balance the mass number and atomic number in the reactant side and in the product side.

Find out the difference in atomic and mass number. Identify the missing part with that atomic number and mass number.



51. (i) $N\% = \frac{1}{2^n} N_0 \times 100$ where n is the number of half lives, N_0 is the total number of atoms present initially.

(ii) Approximately 0.1%

52. (i) α decay ${}_Z\text{P}^A \rightarrow {}_{Z-2}\text{D}^{A-4}$

β^- - decay ${}_Z\text{P}^A \rightarrow {}_{Z+1}\text{D}^A$

emission of positron

$\text{P} \rightarrow \text{n} + \text{positron}$

(ii) Positron, β^- -particle

(iii) α -particle, β^- -particle

53. (i) Power = $\frac{\text{energy}}{\text{time}}$

Convert 200 MeV into MJ and calculate the number of atoms required to produce 10 MJ of energy in one second = 10 MW.

(ii) 3.125×10^{17}

54. r-rays are electrically neutral

Explanation for questions 55 to 59:

55. The materials which control the fission reaction by absorbing the two neutrons of the three produced are called control rods.

56. Out of 1 kg of uranium, 0.1%, mass of uranium is converted into energy. Now, 0.1% of 1 kg



$$\frac{0.1}{100} \times 1\text{Kg} = \frac{1}{1000} \text{Kg} = 10^{-3} \text{Kg}$$

Using the equation,

$$E = mc^2 = 10^{-3} \times (3 \times 10^8)^2 \\ = 10^{-3} \times 9 \times 10^{16} = 9 \times 10^{13} \text{J}$$

57. $223 = 220 + 3$

$$= 4 \times 55 + 3$$

Therefore the mass number of any element can be represented as $4n + 3$.

58. 39.2 MeV

$$\text{Binding energy} = 5.6 \times 7 \text{ MeV} = 39.2 \text{ MeV}$$

59. 8 days

The time taken to reduce to $\left(\frac{1}{4}\right)^{\text{th}}$ of total amount (t) 8 days.

$$\therefore n = n_0 \left(\frac{1}{4}\right)^{\frac{t}{T}}; \left(\frac{1}{4}\right)n_0 = n_0 \left(\frac{1}{2}\right)^{\frac{8}{T}}$$

$$\left(\frac{1}{2}\right)^2 - \left(\frac{1}{2}\right)^{\frac{8}{T}}; 2 = \frac{8}{T} = 4 \text{ days} = \text{half-life period}$$

$\therefore$ let 'x' be the remaining amount of substance

$$\frac{x}{4} = \left(\frac{1}{2}\right)^n$$

$$\therefore n = 2$$

$$\text{Further time} = 2 \times 4 = 8 \text{ days}$$

Level 3

60. How does the neutron form initially?

What is the change in atomic number and mass number during the emission of a ' β ' particle?

61. (i) $m_1 v_1 = m_2 v_2$

Write the velocity of one of the daughter nuclei in terms of the other.

Law of conservation of energy.

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = Q \text{ value}$$

(ii) $0.92 \times 10^7 \text{ m s}^{-1}$

62. (i) The number of atoms present in gram atom, i.e., atomic weight of the radioactive substance = 6.023×10^{23} .

Determine the number of atoms in 1 μg of the radioactive substance. Half of this gives the number of atoms disintegrated in 50 days (half-life period). Equate the number of atoms disintegrated in 50 days in both the cases to find the atomic weight.

$$\text{That is } \frac{6.023 \times 10^{23}}{\text{at. wt} \times 2} 10^{-6} = 6.023 \times 10^{13} \times 50$$

(ii) 100 g

63. (i) The amount of uranium disintegrated when 92 g of krypton is formed = 235 g.

Determine the number of uranium atoms disintegrated in a given time.

The energy released per uranium atom = 200 MeV

$$\text{Output power} = \frac{\text{output energy}}{\text{time}}$$

(ii) 1687 MW

64. (i) The mass number changes only during the emission of α particles.

Therefore, the number of α particles emitted

$$= \frac{\text{change in the mass number}}{4}$$

The atomic number of the parent nucleus decreases by two during the emission of an α particle and increases by one during the emission of a ' α ' particle.

Therefore, the number of α particles emitted = (number of α particles $\times 2$) - change in atomic number.

(ii) 8 α particles and 6 α particles are emitted.

Explanation for questions 65 to 69:

65. A daughter nucleus formed after emitting an α -particle is heavier than the α -particle. When a heavy nucleus emits an α -particle, its momentum before emission of the α -particle is equal to the sum of momenta of the α -particle and the daughter nucleus formed after the emission of the α -particles. If the parent nucleus (the nuclei emitting α particle) is at rest, then the momentum of the parent nucleus is zero. After emitting α -particle,



the total momentum of α -particle and the daughter nuclei must be zero. This implies that the momenta of α -particles and daughter nuclei are equal in magnitude but opposite in direction.



Total mass of reactants = 4×1.0078

u = 4.0312 u

Mass of ${}_2\text{He}^4$ is 4.001506 u

Mass defect $\Delta m = 4.0312 \text{ u} - 4.001506$

u = 0.0287u

The energy released = $0.0297 \times 931.5 = 27.67 \text{ MeV}$.

67. Mass = 23.5 kg

235g of ${}_{92}\text{U}^{235} = 6.023 \times 10^{23}$ atoms

$$1\text{g of uranium} \frac{6.023 \times 10^{23}}{235} \text{ atoms}$$

23.5 Kg of Uranium

$$\frac{6.023 \times 10^{23} \times 23.5 \times 1000}{235} \text{ atoms}$$

Energy released

$$\frac{6.023 \times 10^{23} \times 23.5}{235} \times 1000 \times 200 \text{ MeV}$$

$$6.023 \times 10^{25} \times 200 = 12.046 \times 10^{27} \text{ MeV}$$

$$= 12.046 \times 10^{27} \times 1.6 \times 10^{-13}$$

$$\text{J} = 19.28 \times 10^{14} \text{ J}$$

$$40\% \text{ of Energy} = \frac{19.28 \times 10^{14} \times 40}{100}$$

$$= 77.12 \times 10^{13} \text{ J}$$

$$\begin{aligned} \text{Power} &= \frac{E}{t} = \frac{77.12 \times 10^{13}}{30 \times 24 \times 60 \times 60} \\ &= \frac{77.12 \times 10^{13}}{2592 \times 10^3} = \frac{77.12 \times 10^{10}}{2592} \text{ W} \\ &= 2.97 \times 10^8 \text{ W} = 297 \text{ MW} \end{aligned}$$

68. (a) When X changes to P, the atomic number increases by 1 but mass number remains the same. So the particle emitted must be a β particle. During the change from P to Y, the atomic number decreases by two and mass number by 4. So the particle emitted must be an α particle.

In the last process, there is no change in the atomic number and atomic mass number. Therefore, the particle emitted must be γ rays. Hence, the sequence is $\beta - \alpha - \gamma$.

(b) In the first process, atomic number decreases by 2 and atomic mass number decreases by 4. So, the particle emitted is an α -particle.

In the second process, there is no change in the atomic number or atomic mass number. So, γ -rays are given out. In the last process, the atomic number increases by one and there is no change in the atomic mass number. The particle emitted must be the β -particle.

So, the sequence in which the particles are emitted is $\alpha - \gamma - \beta$.

69. Mass of 8 protons + 8 neutrons = mass of ${}_8\text{O}^{16}$ + mass defect

$\Rightarrow$ Energy equivalent of 8 protons + 8 neutrons

= energy equivalent of ${}_8\text{O}^{16}$ + energy equivalent of mass defect (1)

At the time of formation of the nucleus, the mass equivalent to mass defect gets converted into energy.

$\therefore$ Energy equivalent of mass defect is binding energy of ${}_8\text{O}^{16} = 16 \times 7.97 \text{ MeV} = 127.52 \text{ MeV}$ (2)

Energy equivalent of 8 proton + 8 neutrons

$$= 8 (m_p + m_n) \times 931.5 \text{ MeV}$$

$$= 8 (1.0078 + 1.0087) \times 931.5$$

$$= 8 \times 2.0165 \times 931.5$$

$$= 15026.958 \text{ MeV} \quad (3)$$

Substituting the values of (2) and (3) in (1).

The energy equivalent of ${}_8\text{O}^{16}$

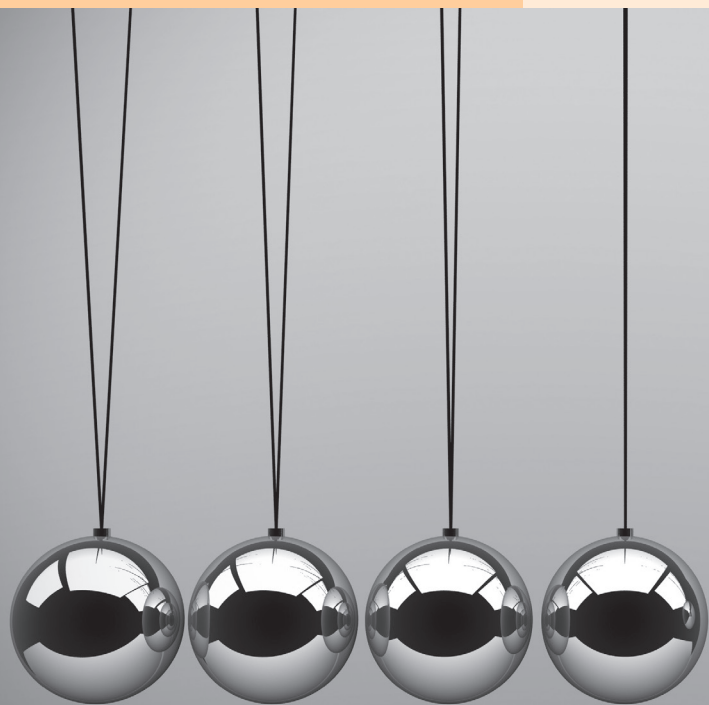
$$= 15026.958 - 127.52$$

$$= 14899.438 \text{ MeV}$$



Chapter 10

Source of Energy



Remember

Before beginning this chapter, you should be able to:

- Learn about renewable and non-renewable sources of energy
- Understand uses of different sources of energy
- Recognize causes and preventive measures of air pollution

Key Ideas

After completing this chapter, you should be able to:

- Study in detail about different sources of energy and classification of these sources into renewable and non-renewable
- Understand the advantages and disadvantages of different sources of energies like solar energy, wind energy, hydel energy, tidal energy, thermal energy, geothermal energy, etc.
- Learn about types of fuels such as solid fuels, liquid fuels, gaseous fuels and fossil fuels
- Select a good fuel, the qualities of a good fuel, the advantages and disadvantages of different fuels

INTRODUCTION

Law of conservation of energy states that energy can be neither created nor destroyed. From work-energy theorem we understand how energy spent and work done are related. Whenever certain work is done, some form of energy is always involved, that is, to do some work, energy is required. For example, if water is to be brought to a height, electrical energy supplied to a pump motor gets transformed to mechanical energy which lifts the water. But what is the source of electrical energy? It could be either hydel energy, thermal energy or nuclear energy. Again the source of hydel energy is the water stored in a reservoir, those of thermal energy and nuclear energy are coal and fissionable uranium, respectively. Thus, we find that energy is stored in nature in some substances (coal, petrol, etc.) or in some forms (winds, tides, etc.). An indepth study of these sources of energy has become an important branch of science, as we need to replenish continuously those substances or sources, which are used up during conversion to other forms. The current chapter deals with different categories of sources of energy and the related topics.

Sources of Energy

We are dependent upon various sources of energy in one way or the other for our energy requirements.

Sources of energy are mainly classified into two types. They are:

1. Renewable sources of energy and
2. Non-renewable sources of energy

Characteristics of Sources of Energy

Fuels can be classified based on the following:

1. **Net Energy Output:** The difference between the output energy and the input energy is termed as net energy output. For example, when we use a fuel, say coal or wood, we have to provide some initial heat to ignite it. This will be the input. The heat energy given by the fuel will be the output. Now, the net energy will be the difference between the two. A good fuel should have high net energy output.
2. **Availability:** The energy source should be able to provide energy over a long period of time. Sun, wind, etc. are the best examples for this.

A good fuel should be capable of providing desired quantity of energy at a steady rate over a long period of time.

3. **Safe and Convenient to Use:** This is one of the important characteristics of a fuel; a fuel has to be safe and convenient to use.

For example, nuclear energy cannot be used for cooking. Correct fuel has to be selected for the required purpose.

4. **Easy for Storage and Transportation:** Most of the sources of energy like petroleum, LPG, etc. are not found in all the places. So, they have to be transported over long distances.

Moreover, these fuels have to be safely stored so that they can be helpful during crisis of energy sources. A good fuel should be safe to store and transport.

5. **Economical:** A fuel has to be economical. A common household or an industry should not feel burdened because they have to use it.

A good fuel is one which has all the given characteristics.

Non-renewable Sources of Energy

‘Energy sources which, when once used up, cannot be replenished are called non-renewable sources of energy’.

Some non-renewable sources of energy are coal, petroleum and natural gas. These sources are related to solar energy, either directly or indirectly. The formation of these fuels have occurred over millions of years due to slow compression of plant bodies under high pressures inside the earth.

Renewable Sources of Energy

‘The energy sources that can be replenished, once they are used up, are called renewable sources of energy’. Some examples of renewable sources of energy are the sun, water, wind, earth, wood and biomass.

SOLAR ENERGY

Sunlight consists of waves called electromagnetic waves. Visible light has a wavelength of 400 nm to 700 nm. Our eyes are insensitive to radiations having wavelength beyond these values. Nearly one-third of sunlight consists of infrared rays. These rays heat up the objects that lie in their path. The heat that we feel in the sunlight is due to infrared radiation present in it. All bodies that are hot radiate energy in the form of infrared rays.

Nuclear fusion reactions in the interior of the sun continuously release enormous amounts of energy. It is estimated that the earth directly receives only 0.000000045792% of the sun’s total energy output.

The sun is the ultimate source of all the energy here on earth. All forms of energy which are available on earth owe their origin to the sun.

The solar energy reaching the periphery of the earth’s atmosphere is considered to be constant for all practical purposes, and is known as the solar constant.

$$\text{Solar constant} = 1.4 \text{ kJ m}^{-2} \text{ s}^{-1} \text{ or } 1.4 \text{ kW m}^{-2}$$

Only 47% of the solar energy that strikes the periphery of the earth reaches the surface. The remaining part of the solar energy gets reflected to space and some portion of solar energy is absorbed by the atmosphere. During this process, u - v rays get eliminated and only visible light and infrared radiation reaches the earth’s surface.

One third of sunlight consists of infrared radiation. Infrared radiation heats the substance through which they pass. Hot bodies transmit or radiate heat in the form of infrared radiation. The infrared radiation emitted by hot bodies have longer wavelength than the infrared radiation emitted by the sun.

The landmass and water bodies absorb a part of the solar energy that reaches the surface of the earth. This energy, then, manifests itself in a variety of forms through many natural processes, both biological and physical.

The various functions performed by solar energy on earth are illustrated by a flow chart as shown in Fig. 10.1.

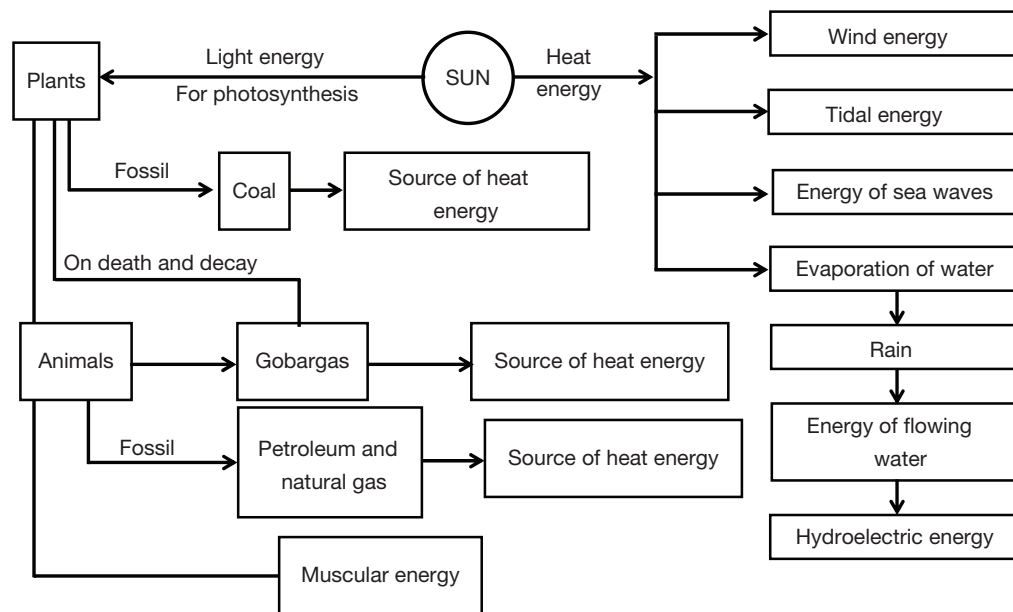


FIGURE 10.1 Functions performed by solar energy

1. Solar energy provides wind energy, tidal energy and the energy of sea waves.
2. Solar energy causes large-scale evaporation of water. Water vapours condense to form clouds, cause rain and ultimately change to flowing water. The energy of flowing water is utilised in water-mills and in the generation of hydroelectric power.
3. Light energy present in the form of solar energy is stored in plants during photosynthesis in the form of chemical energy. The chemical energy of plants remains intact when they form fossil fuels such as coal. The chemical energy of coal is, then, used as a source of heat energy from domestic fuels to thermal power plants.

If plants do not become fossil after death, they can be converted to biogas (gobar gas). In biogas, the chemical energy stored in plants changes into the heat energy on burning. Similarly, the remains of dead animals can be changed into biogas.

When animals consume plants the chemical energy of plants changes into heat energy during respiration. It is the heat energy which helps to keep animals warm and perform various activities using their muscular energy.

If animals die in large numbers and get buried under the surface of the earth, then their bodies under intense pressure and temperature for long durations change to petroleum and natural gas. These products are a source of heat energy for most of the industries.

Solar energy provides light energy which helps us to see the things around.

Direct Harnessing of Solar Energy

In this type, solar energy is directly converted into heat energy (as in the case of solar cookers, water heaters, solar concentrators, etc.) or electrical energy (as in case of solar cells).

Indirect Harnessing of Solar Energy

In nature, plants convert solar energy into chemical energy. The chemical energy of plants is used as food by animals or used as fuels to produce heat energy. Solar energy also changes into wind energy, the energy of flowing water, the energy of tides and the sea waves. This energy can be harnessed by water mills either in the form of mechanical energy or electrical energy.

Methods of Enhancing the Collection of Solar Energy

Devices working with solar energy as fuel need to enhance their solar energy collection so as to work quickly and effectively. The following are the methods to enhance the collection of solar energy.

Use of Black-painted Surface

Black bodies are good absorbers as well as good radiators of heat. Thus, the surfaces which are to collect radiant heat are painted black so that they can absorb (or radiate) more energy.

A perfect black body is one which absorbs (or radiates) all the energy (light, heat, etc.) incident on it.

Use of Insulated Box with Glass Cover

The wavelength of infrared radiation emitted by hot bodies is shorter than that of the radiation emitted by bodies of comparatively lower temperature.

It is observed that an insulated box with a glass cover prevents heat losses that occur due to conduction, convection and radiation. The glass cover allows solar energy to pass through it. It has the property of allowing radiation of shorter wavelength to pass through it. When the object with blackened surface gets hot within the box and radiates radiant heat with longer wavelength, the glass will not allow radiations to pass through, as they are of longer wavelength. Thus, the heat radiation is trapped within the insulated box, thereby raising the temperature of the objects with blackened surface.

SOLAR COOKER

Solar cooker is a device that cooks food using heat from solar energy.

Box-type Solar Cooker

This type of cooker consists of a rectangular wooden box, which is lined from inside with some insulating material such as thermocol or glass wool. The insulating material prevents heat losses that occur due to conduction, convection and radiation. The inner walls are painted black. A plane mirror is hinged on the top of the box. The mirror is adjusted in such a manner that it reflects sunlight into the box.

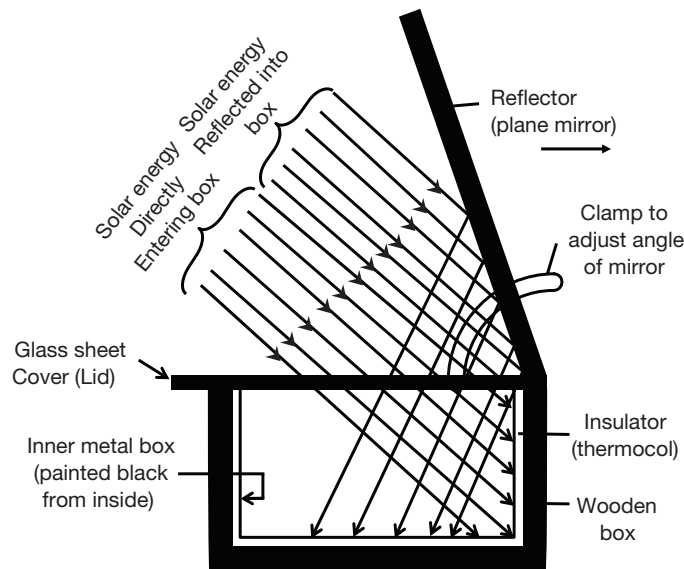


FIGURE 10.2 Solar cooker: A solar heating device for collecting maximum solar energy

Green House

Some crops require sufficient heat to grow. In cold countries, the heat required for the growth of plants is achieved by growing them in a green house.

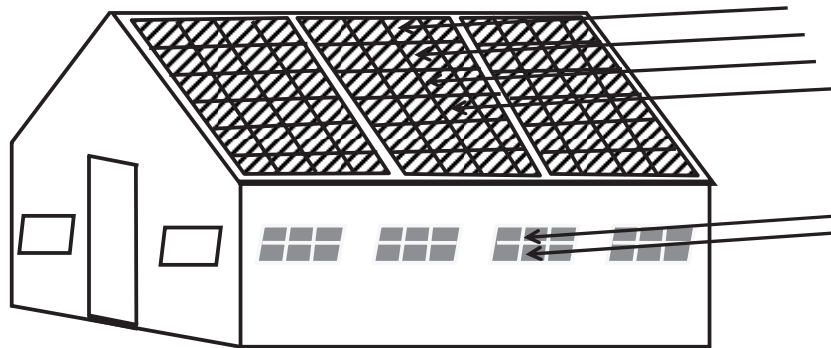


FIGURE 10.3 A green house

The principle used in this is the same as in box type solar cookers.

The glass surface on the top receives light and heat from the Sun. The walls, which are coated in black, retain the heat inside the room, thus maintaining a temperature higher than that outside of the house.

Reflector Type Solar Cooker

In this type of cooker, the solar energy received over an area is concentrated at a particular point where the cooker is kept. The surface area of the disk-like structure is coated with a reflecting material. This type of cooker can generate temperatures upto 180°C at the focus (point where it is concentrated). Thus, this is more effective than a box type cooker.

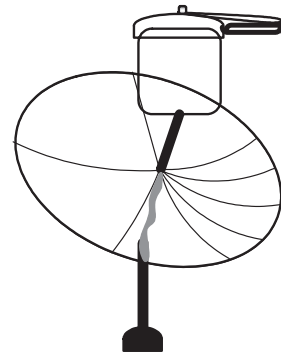


FIGURE 10.4 A reflector type solar cooker concentrates solar energy on a small area

Solar Concentrators

The principle behind reflector type solar cooker is concentration of all the received solar energy at a particular point. Thus, it can be called a solar concentrator.

Solar furnace is of reflector type design where thousands of reflectors are arranged spherically so that each and every reflector reflects the incident light in a direction so that the reflected light focuses at a particular point. In this type of design, a temperature up to 3000°C can be produced.

Solar Water Heater

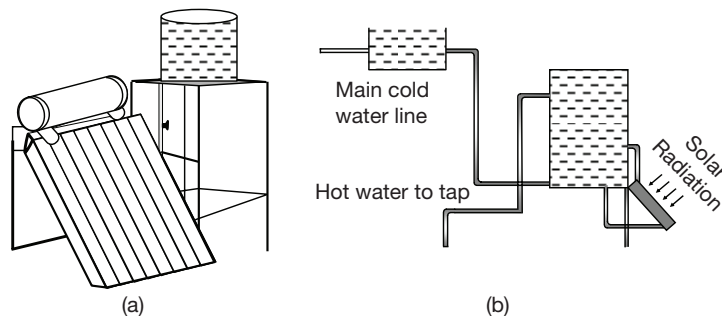


FIGURE 10.5 Schematic arrangement of a solar water heater

This is the most commonly used one among solar heating devices.

Here, a copper pipe with its outer surface painted in black, is fixed in the form of a coil in a box. Bending copper pipe as a coil helps to increase the surface area for heating. A reservoir kept at a higher level is used to store cold water, which is connected to a small tank kept slightly above the water heater. One end of the copper pipe is connected to the bottom of the small tank of water, while the other end is joined near its middle. Water in the tank continuously circulates through the copper pipe due to a small difference in pressure between its two ends.

As the water slowly moves through the pipe, it absorbs solar energy and gets heated up. The hot water again goes to the tank while the cooler water from the lower part of the tank replaces it.

Solar Cells

‘A device which can directly convert solar energy into electrical energy is called a solar cell’. Solar cell is also called photovoltaic cell.

Photoelectric Effect

The phenomenon due to which light energy directly changes into electrical energy, when light is incident on certain sensitive materials is called photoelectric effect.

First photovoltaic cell, that was invented in 1877, was only 0.6% efficient. It used selenium metal. In 1954, Bell laboratories of USA produced the first silicon solar cell, which had an efficiency of 5%.

Solar cells having multi layer silicon solar cells have been designed, which convert both visible and infrared radiation into electricity. This increases the efficiency of solar cells to a very great extent.

A large number of solar cells combined together produce large amount of current. The arrangement of large number of solar cells together is called solar panel.

Advantages of Solar Cells

1. It can be used as a source of electricity at any place.
2. It provides pollution free environment.

Disadvantages

1. High cost of installation. This is due to the technology to obtain pure silicon is expensive and due to use of silver as conducting material which is used to connect solar cells. Silver is good conductor of electricity. If other metals are used in place of silver, a fraction of electricity generated by solar cells is used to overcome the resistance of the conductor or the connectors.
2. Electricity generated by solar cells is stored in batteries which can give DC. In order to operate devices working on AC, the DC has to be converted to AC. This decreases the efficiency and further adds up to the cost.

Uses of Solar Cells

1. Solar cells are the main source of electricity in satellites and space probes.
2. They can be used for street lighting, power source to devices like TV, radio, etc.
3. Solar cells are used to provide electricity to off shore oil rigs and light houses.
4. Certain electronic calculators and wrist watches are powered by solar cells.

WIND ENERGY

Moving air is called wind. Sun's energy (solar energy) is one of the main factors responsible for the motion of air in the atmosphere. Picture are devices that convert wind energy into mechanical or electrical energy. They were used for grinding grains in many parts of the world, until a 100 years ago. Modern windmills are designed to convert wind energy into mechanical or electrical energy, on a large scale. A windmill essentially consists of a structure similar to that of a large electric fan that is erected at some height on a rigid support.

The principle of a windmill is that the blades of a windmill are designed to create a pressure difference between its different regions when wind strikes them. This pressure difference produces a turning effect to make the blades rotate.

In a water-lifting pump, the rotational motion of windmill is utilised to do mechanical work and draw underground water to the surface of the earth.

Production of Electricity Wind Energy Farm

The rotatory motion of the windmills is utilised to rotate the armature of an electric generator. However, the electricity produced by a single windmill is quite small and cannot be used for commercial purposes.

A number of windmills are erected over a large area, which is known as wind energy farm. The energy output of each windmill in a farm is coupled together to generate electricity on a commercial scale.

Limitations in Harnessing of Wind Energy

Wind energy farms can be established only at those places where wind blows for large duration of the year. The wind should be strong, steady, and should have a velocity of at least 15 kmph.

HYDEL ENERGY

Energy that comes from flowing of water is called hydel energy. Water flowing through rivers has both kinetic energy and potential energy. The energy of flowing water can be used to transport heavy logs of wood from inaccessible areas of forests in hilly regions.

Generation of electricity: Hydroelectric power plant

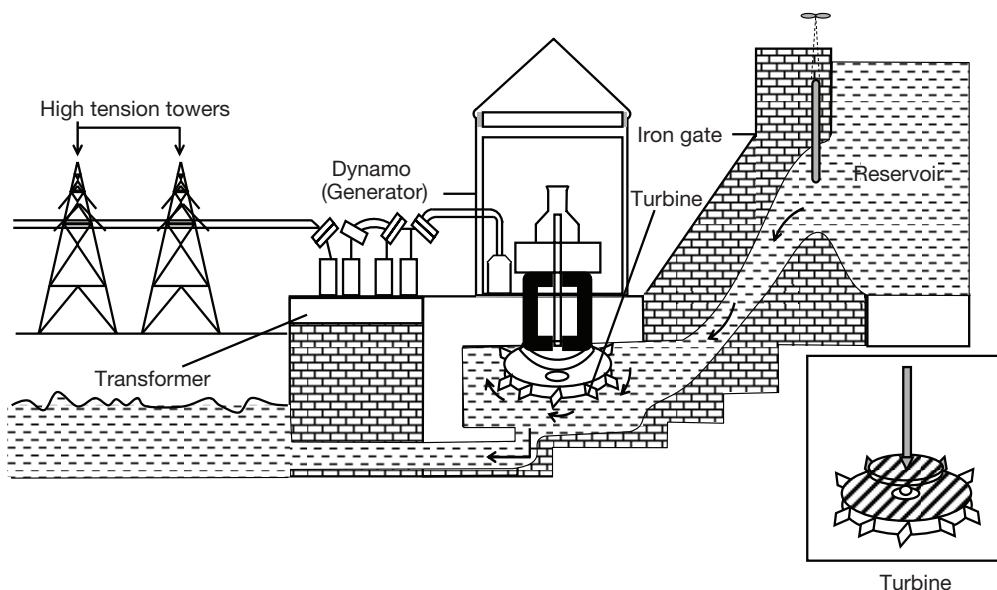


FIGURE 10.6 Hydel Power Plant

The energy of flowing water is utilised to produce electricity on a large scale at hydroelectric power plants. The water stored in dams has potential energy. When this water is released, it possesses high kinetic energy.

When the released water is made to fall on the blades of a turbine, they rotate and in turn rotate the armature of the electric generators to produce electricity.

Limitations of Hydroelectric Power Plant

1. The initial cost of the construction of a dam is very high.
2. For generation of electricity, abundant water should be available in the dam.
3. These hydroelectric power plants can be constructed only at certain places.

Advantage of Hydroelectric Power Plants

Water is a renewable source of energy and, further, these power plants do not pollute the environment.

TIDAL ENERGY

Oceans are huge reservoirs of water and energy. The oceans store energy in many forms. Tidal energy caused by the ocean tides is a renewable source of energy. The daily rise and fall of the tides can be used to drive turbines for generating electricity.

A small dam is constructed across a narrow opening of the sea. During high tide, water flows to reservoir and during the low tide, water flows out from reservoir through a pipe and this flowing water is used to rotate a turbine which in the turn generates electric current.

However, these plants can be set up at certain places only where the amount of power released by waves striking the shoreline is at least 40 MW km^{-1} .

The three most common devices that are utilised for harnessing the energy of the ocean waves are:

1. Surface-followers, using floats or pitching devices
2. Oscillating water column
3. Surge or focusing devices

Since the rise and fall of water during tides is not so high, this is not likely to be a major source of energy.

The waves that continuously hit the ocean coast possess large amount of kinetic energy. The total amount of power released by the waves striking the short lines is about 2 to 3 million mega watts, and this energy can be harnessed only in limited sites.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

The difference in temperature between warm surface waters heated by the sun and colder waters found at ocean depths is another form in which solar energy becomes available from the oceans. This is known as ocean thermal energy.

The power plants used to harness this form of energy are called OTEC power plants.

A temperature difference of 20°C or more between surface waters and water at depths upto 1000 m is required for operating OTEC systems.

In this, the warm water is used to boil a liquid like ammonia or CFC. The vapour of the liquid is used to drive the turbine of a generator. The cold water from ocean depths is pumped up to convert the vapour again into liquid.

The advantage of OTEC plant is that it can be operated for 24 hours a day through out the year.

GEO THERMAL ENERGY

Geothermal energy is the energy stored as heat in the earth. Geo means earth and thermol means heat.

The temperature inside the earth is high enough to liquify the rocks, etc. (called magma) and heat the substances in it.

In certain areas below the surface of the earth, hot magma swells up into the crust, but remains trapped below the surface of the earth. Such areas in the earth's crust are called hot spots. When these hot spots are nearer to the surface of the earth, the water which seeps through gets converted to steam and comes out of the rocks in the upper layer (crust) of the earth with great force. These are called geysers.

Generation of Electricity

This steam from geothermal sources can be directly utilised to turn turbines of the electrical generator to produce electricity. Such electricity is called geothermal electricity.

Advantages of Geothermal Energy

1. Geothermal power plants can operate round the clock.
2. It is pollution free.
3. Operating cost involved is less (but initial cost in setting up this plant will be high).
4. This type of source is free and renewable.

NUCLEAR ENERGY

Huge amount of energy can be obtained from nuclear reactions.

Nuclear reactions are of two types: nuclear fission and nuclear fusion reactions.

Nuclear fission is a process in which a heavy nucleus splits into lighter nuclei along with the release of huge amounts of energy.

Nuclear fission reaction is the principle behind a nuclear power plant.

Nuclear fusion is a reaction in which lighter nuclei (like hydrogen) combine to form a heavier nucleus at very high temperatures with evolution of enormous amounts of energy. The Sun's heat is due to the nuclear fusion reactions occurring in the interior of the sun.

Nuclear fusion reactions occur generally in stars where very high temperatures (nearly 4×10^7 K) exist. However, the energy released in fusion reactions cannot be harnessed into productive applications as these reactions cannot be controlled.

Bioenergy

A small fraction of the solar energy radiation on earth's surface is converted into chemical energy by green plants through the process of photosynthesis. This energy becomes available in the form of biomass stored in different parts of a plant. Animals, including humans, utilise a part of this energy for their food.

The excreta of living organisms and their bodies after death also contribute to biomass.

BIOGAS

Animal and plant wastes are easily degraded by anaerobic micro organisms in the presence of water, producing gases such as methane, CO_2 , H_2 and H_2S . This mixture of gases is called 'biogas'.

Fig. 10.7 (a) and (b) show the two designs of commonly used biogas plants.

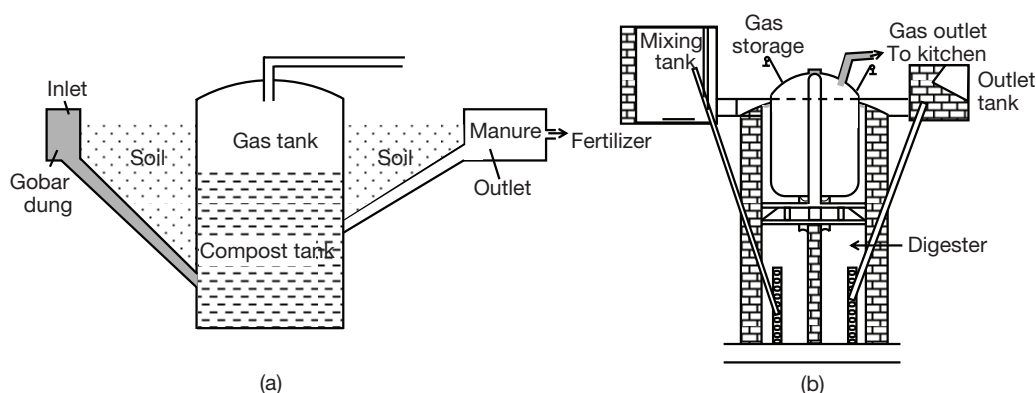


FIGURE 10.7 Schematic view of two designs of biogas plants: (a) Fixed dome type
(b) Floating gas-holder type

Floating Gas-Holder Type Biogas Plant

Floating gas-holder type biogas plant consists of a dome-like structure, usually made of steel, that floats up as the pressure of biogas evolved increases. This type of biogas plant is more frequently used where cow dung is used to obtain biogas.

Fixed Dome Type Biogas Plant

This has an advantage that the dome can be constructed by laying bricks.

Fixed dome has a longer life as compared to that of a floating dome, which reduces the cost of the biogas.

Formation of Biogas

Slurry of animal dung and water is made in the mixing tank from where it is fed into the digester tank. In the digester, the action of micro organisms breaks down or decomposes the complex compounds of the biomass in the slurry. Anaerobic micro organisms, in the presence of water, do the degradation of biomass in the digester.

Since anaerobic micro organisms do not require oxygen, the digesters are designed like a sealed chamber. This process takes a few days to complete during which gases like methane,

CO_2 , H_2 and H_2S are produced. Biogas, which is a mixture of these gases, is supplied to consumers through pipes.

Advantages of a Biogas Plant

Combustion of biogas produces no smoke but a large amount of heat as its calorific value is high. The use of biogas in villages improves the sanitary conditions and checks environmental pollution. It is convenient for domestic use. The slurry obtained as a by-product, left in the plant after the gas is used, forms a good and enriched manure, containing compounds of nitrogen and phosphorous. The use of biogas reduces the dependence on the fossil fuels and wood.

Hydrogen and Alcohol as Fuels

The reaction between hydrogen and oxygen to form water is an exothermic reaction which evolves a lot of heat. Hydrogen is the substance that releases heat more than any fuel. Hydrogen is easily produced by the electrolysis of water and is also obtained as a by product in many industrial processes. Combustion of hydrogen does not pollute the environment.

Hydrogen is used in spaceships and high temperature flames as source of energy. However, it is difficult for the common man to work with hydrogen as the amount of heat emitted is very high. Moreover, storing and transportation of hydrogen is also a difficult task. The main reason for not using hydrogen as a fuel is due to its explosive nature.

Alcohol is another fuel that is gaining significance as a fuel. It reacts with oxygen and produces carbon dioxide and water, releasing heat energy. A mixture of alcohol and petrol is being used in some countries as a fuel for automobiles.

Example: Spirit lamp used in laboratories.

FUELS

Any substance that gives out energy on burning is called a fuel. Fuels are classified into three types.

1. Solid fuels
2. Liquid fuels
3. Gaseous fuels

Calorific Value

Any fuel, on burning, gives heat energy. But the heat energy produced is not equal for all fuels. The heat energy produced by a fuel is measured in joules. And it depends on the mass and the nature of the fuel.

Thus, heat energy liberated on burning unit mass of a fuel is considered for comparison and this is called calorific value of the fuel.

Definition: 'Calorific value is the energy liberated in the form of heat by a fuel when its unit mass is burnt completely under ideal conditions'.

The SI unit of calorific value is J kg^{-1} . Calorific value is generally high for gases. Hydrogen has the highest calorific value.

Calorific values of some of the fuels are given below.

Type of fuel	Fuel	Calorific value in kJ kg^{-1}
Solid fuel	Cow-dung cake	6000–8000
	Wood	17000–22000
	Coal	25000–33000
Liquid fuel	Ethanol	30000
	Kerosene	45000
	Petrol	47000
Gaseous fuel	Biogas	35000–40000
	Butane (LPG)	55000
	Methane	55000

Fuels containing oxygen atoms have low calorific value than those of hydrocarbons but they burn readily.

Solid Fuels

Wood, charcoal, cow-dung cakes, coal, etc. are some examples of the solid fuels.

Wood is the fuel that has been used over a very long time as the main source of fuel and it is becoming scarce due to uncontrolled felling of trees.

Wood is a source of heat. When wood is burnt in a limited supply of oxygen, water and other volatile substance are removed from it and the residue left is known charcoal. The process of burning wood in limited supply of oxygen is called destructive distillation.

Hence, many nations have restricted felling of trees and have taken up afforestation as a major project.

In rural areas, cow-dung cakes, firewood and agricultural wastes are being used as a fuel for cooking. However, this increases pollution of atmosphere.

Coal is another important fuel used in industries, cities and power stations. Coal can be called as a fossil fuel.

Fossil Fuels

Fossil fuels are the fuels formed by the decay of plants and marine animals that were buried in the earth millions of years ago under extreme conditions of heat and pressure. Since these conditions do not exist any more, there is no chance of new reserves of these fuels. So, these fuels are termed as non-renewable sources of energy.

Coal is the fossilised remains of the plants that have been buried deep into the earth's crust for millions of years while petroleum and natural gas are the fossilised remains of dead bodies of marine animals and plants.

Coal

Coal is a non-renewable source of energy. It is found below the surface of the earth. The main constituent of coal is carbon. The other constituents are hydrogen and oxygen. The percentage of carbon and other constituents in a sample of coal varies from place to place. The quality of coal depends on the percentage of carbon present in it.

The following table gives the information of different types of coal and the percentage of carbon in them.

Type of coal	% of carbon
Peat	27%
Lignite	28 - 30%
Bituminous	78 - 98%
Anthracite	94 - 98%

Anthracite is found to be the best quality of coal as the percentage of carbon in it is maximum.

Coke is made from bituminous coal. High grade coke is a perfect fuel for blast furnaces.

Burning of coal creates serious air pollution. When coal is burnt, the carbon present in it reacts with oxygen to produce carbondioxide. This is an exothermic reaction which yields a lot of heat energy. Coal, on destructive distillation, gives coke. It is used as reducing agent in the extraction of some metals from their ores and in making steel.

Liquid Fuels

Fuels like petrol, diesel, kerosene, fuel oil, etc. come under the category of liquid fuels. All these fuels are liquids under normal state. They are obtained from petroleum, also called crude oil. Petroleum, and coal are fossil fuels which have been formed under the earth over thousands of years. Since these fuels are formed by natural evolutionary process of earth, their replenishment is not in our control.

Petroleum products are mixtures of hydrogen and carbon and are called hydrocarbons.

PETROLEUM

The word 'petroleum' is derived from the Greek words 'Petra' which means 'rock' and 'oleum' which means 'oil' because it is an oil derived from rocks.

Petroleum is a complex mixture of many compounds of hydrogen and carbon known as hydrocarbons. It also contains small amounts of other compounds of oxygen, nitrogen and sulphur.

Formation of Petroleum

Petroleum was formed from the dead remains of marine plants and animals, which settled in muddy sediments at the bottom of the sea millions of years ago. Due to prolonged sedimentation and accumulation of organic debris, these got buried deep below the surface of the earth. In intense heat and high pressure conditions underneath and in the presence

of natural catalysts, the remains were ultimately converted into petroleum. For this reason, petroleum is also a fossil fuel. It is a dark oily liquid, which does not burn, and is insoluble in water and floats on it.

Extraction of Petroleum

Large reservoirs of petroleum have been formed in nature for millions of years between porous rocks beneath the earth. It is pumped out by drilling holes and by digging wells. Petroleum in its natural form is a thick black liquid.

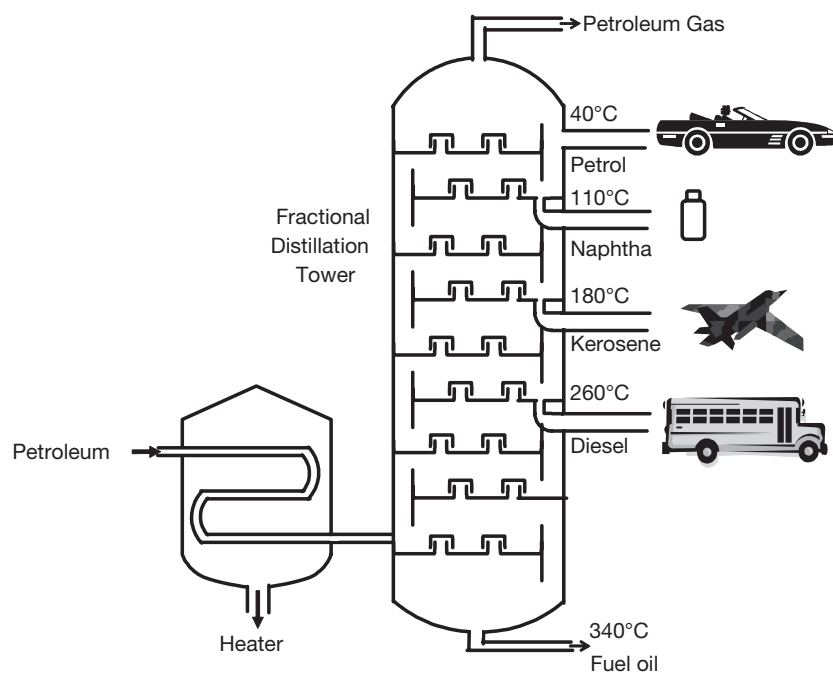


FIGURE 10.8 Distillation of petroleum

Refining of Petroleum

The crude oil extracted from deep earth is separated into its constituents by a process called ‘fractional distillation’. It is based on the principle that different fractions of petroleum boil at different temperature ranges.

In refining of petroleum, the crude oil is fed into the base of the fractionating column and heated to 650°C. The mixture of vapours of different liquid components so formed rise in the fractionating column also called distillation column. The vapours of higher boiling fraction cool first, get liquefied and finally get collected from the lower outlet of the chamber.

Fraction	Composition	Temperature Range (K)	Uses
Gaseous	$C_1 - C_4$	Below 298	As a fuel
Petroleum ether	$C_5 - C_7$	298 – 333	As solvent in dry cleaning
Petrol/gasoline	$C_7 - C_{10}$	333 – 473	Motor fuel

(Continued on following page)

Fraction	Composition	Temperature Range (K)	Uses
Kerosene	$C_{12} - C_{16}$	448 – 550	Fuel in jet engines and for domestic purposes
Fuel oil or diesel oil	$C_{15} - C_{18}$	525 – 670	In diesel engines, in industries
Lubricating oil	$C_{16} - C_{20}$	Above 623	Lubrication, vaseline, greases
Petroleum wax	C_{20} and above	Above 623	Candles, waterproofers, fabrics, fuel, electrodes
Petroleum coke			Fuel

Gaseous Fuels

Petroleum gas and natural gas are two common gaseous fuels.

Petroleum gas is obtained as a by-product in the process of refining of petroleum. It consists mainly of butane and small fractions of ethane and propane. Butane can be liquefied easily under high pressure. Cooking gas cylinders contain liquefied petroleum gas LPG. The main constituent of LPG is butane. Small quantities of ethane and propane are also present.

Biogas is another example of gaseous fuel.

Natural gas is an important fossil fuel that is found on the top of petroleum under the earth. However, some oil wells yield only natural gas. Its main component is methane.

It is compressed under high pressure to form compressed natural gas (CNG). CNG is easier for transportation than natural gas and is being used as a fuel in automobiles. Since burning of CNG evolves CO_2 and water, it is environment friendly.

Ignition Temperature

Substances begin to burn only after it has attained certain minimum temperature. This minimum temperature at which the substance begins to burn is called ignition temperature. Ignition temperature is a characteristic of a substance. Hence, a substance does not catch fire until it attains the ignition temperature.

Condition for Combustion of Fuels

Combustion is a process of burning of a fuel. During combustion, fuel combines with oxygen of the air to produce heat and light. Combustion is an oxidation and an exothermic reaction.

The conditions required for combustion of fuels are:

1. Attainment of ignition temperature of the fuel.
2. Presence of oxygen and the combustible material or the fuel.
3. Adequate supply of oxygen is necessary to maintain combustion.

Example: Burners of cooking gas and kerosene stove are designed such that to maintain adequate supply of oxygen. If stove burns with a blue flame, it indicates proper burning of the fuel. A yellow or smoky flame indicates inadequate supply of oxygen and this results in an incomplete combustion, i.e., the fuel is not completely burnt or unburnt. The partial burnt particles begins to glow due to heat which gives yellow colours to flame. For example, flame of the candle.

When fuel is burnt completely,

1. fuel is not wasted.
2. smoke will be less.
3. carbon dioxide is produced instead of carbon monoxide.
4. charcoal is not produced.

When fuel is partially burnt.

1. fuel is wasted.
2. large quantity of smoke is produced.
3. poisonous gas, carbon monoxide is produced.
4. carbon particles are expelled with smoke.

Choice of a Good Fuel

It is very important to have a knowledge of the chemical properties of different fuels so that it can be of a great help in choosing the best suitable fuel. For example, we cannot use nuclear energy for cooking or burning leaves or use of wood for producing electricity.

Some of the qualities that we should consider while choosing the most suitable fuel are:

1. easy availability, low cost,
2. no problems in storage and transport,
3. a high calorific value,
4. an ignition temperature that is well above the normal room temperature,
5. a controllable rate of combustion for different purposes,
6. low rate of evaporation at room temperature,
7. low content of non-combustibles and
8. no combustion products that are poisonous or environmental pollutants.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. What is the source of heat on the surface of the sun?
2. The S.I. unit of calorific value is _____.
3. Several solar cells when connected in series and parallel form a _____.
4. What is the chief source of energy for all natural activities?
5. Define ignition temperature.
6. The fuel used as an aviation fuel in jet aeroplanes is a special grade of _____.
7. What is the principle behind a solar power plant?
8. Name any two materials that are used for making solar cells.
9. Nearly 30% of sunlight consists of _____ rays that produce heating effect.
10. What is solar energy?
11. What are combustible and non-combustible materials?
12. A device which converts solar energy into electrical energy is _____.
13. What are the types of sources of energy?
14. What is nuclear fission?
15. _____ is left behind as a residue, when wood is burnt in a limited supply of oxygen.
16. What is combustion?
17. What is petroleum? What is natural gas?
18. The difference between the output energy and the input energy is termed as _____.
19. What is destructive distillation?
20. What are fossil fuels?
21. _____ metal is used in connecting wires that connect solar cells in a solar panel.
22. What are the types of fuels?
23. What is a hydroelectric power plant?
24. Energy sources that can be replenished, once they are used up, are called _____.
25. Between petrol and kerosene, which has a high calorific value?
26. What is a windmill?
27. The type of coal containing the lowest percentage of carbon is _____.
28. What is a solar cell?
29. The heat that we feel in the sunlight is due to _____.

Short Answer Type Questions

30. How can wind energy be converted to electrical energy?
31. Write a short note on various types of fuels (with reference to their physical presence).
32. Give the characteristics of sources of energy.
33. Explain the production of geothermal electricity.
34. Write a short note on natural gas.
35. What are the different types of sources of energy? Give two examples for each.
36. What is a calorific value? Which gaseous substance has the highest calorific value?
37. Explain the construction of a fixed dome type biogas plant.
38. What are the types of fuels? Give two examples for each.
39. Give the differences between box type and reflector type solar cookers.
40. What are the limitations of a hydroelectric power plant?
41. How is petroleum formed? How is it extracted?
42. What are the various factors to be considered in choosing a fuel?
43. What are the limitations of harnessing wind energy?
44. Explain the construction of reflector type solar cooker.



Essay Type Questions

45. What is a biogas plant? Explain the construction and working of a biogas plant.
46. Explain how various petroleum products are obtained from crude oil.
47. 'Solar energy is the chief source for all other forms of energy'. Explain.
48. How is coal formed? What are the different types of it?
49. Explain the principle, construction and working of a windmill.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

1. Tidal energy is a major source of energy due to the presence of large water bodies on the earth.
2. The amount of heat energy released when a fuel burns completely is called calorific value.
3. Sunlight contains ultraviolet radiations which make it hot.
4. Anaerobic microorganisms decompose animal and plant wastes in the presence of water and produce gases such as methane, CO_2 , H_2 and H_2S . The mixture of these gases is called biomass.
5. The calorific value of hydrogen is highest among fuels.
6. The process of burning wood in limited supply of oxygen to obtain charcoal as a resultant product is called destructive distillation.
7. Coal is the fossilised remains of dead bodies of marine animals that are buried in the earth's crust for millions of years.

Direction for questions 8 to 14:

Fill in the blanks.

8. A substance starts burning when it is exposed to air. Then, the ignition temperature of the substance is less than the _____.
9. The quality of coal depends on the percentage of _____ present in it.
10. Burning of a substance in the insufficient amount of oxygen is called _____.

11. Petroleum is a complex mixture of many compounds of _____ and _____ known as _____.
12. Solar cooker is commonly used for harnessing _____.
13. Energy harnessed from flowing water is called _____.
14. Energy sources which cannot be replenished are called _____.

Direction for question 15:

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

15.	Column A	Column B
A.	Peat ()	a. liquid fuel
B.	Alcohol ()	b. 27% of carbon
C.	Decay of biomass ()	c. difference in temperature between warm surface waters and colder waters.
D.	Rise and fall of water levels in oceans ()	d. biogas
E.	OTEC ()	e. solar cell
F.	Ultimate source of energy ()	f. tidal energy
G.	Solar energy into electrical energy ()	g. sun
H.	Stored in food grains ()	h. wind
I.	Moving air ()	i. bioenergy



Direction for questions 16 to 39:

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

16. Which of the following is a false statement?
 - (a) To overcome the energy crisis, the use of solar cooker must be increased.
 - (b) To overcome the energy crisis, more amount of non-renewable sources of energy must be used.
 - (c) The re-usage of waste material as a source of energy can be done to overcome the energy crisis.
 - (d) To overcome the energy crisis, water has to be saved.
17. The main constituent of LPG is butane. Then
 - (A) butane can be liquefied easily under high pressure.
 - (B) butane is liquefied by chemically reacting with ethane and propane.
 - (a) Only A is true
 - (b) Only B is true
 - (c) Both A and B are true
 - (d) Both A and B are false
18. Which element contained in a fuel contributes to its high calorific value?
 - (a) Carbon
 - (b) Hydrogen
 - (c) Oxygen
 - (d) Nitrogen
19. Combustion, the process of burning a fuel, is _____.
 - (a) an oxidation and an exothermic reaction.
 - (b) a reduction and an endothermic reaction.
 - (a) Only A is true
 - (b) Only B is true
 - (c) Both A and B are true
 - (d) Both A and B are false
20. _____ is used as a fuel in space ships.
 - (a) Hydrogen
 - (b) Alcohol
 - (c) Petrol
 - (d) Diesel
21. In solar water heater, a copper pipe with its outer surface painted in black is fixed in the form of a coil in a box.
 - (a) The only purpose of bending copper pipe is to increase the capacity of water storage.
 - (b) Bending copper pipe as a coil helps to increase the surface area for heating.
 - (c) Both
 - (a) and
 - (b) are true
 - (c) Both
 - (d) and (2) are false
22. In the extraction of some metals from their ores, coke can be used as a/an _____.
 - (a) oxidizing agent
 - (b) reducing agent
 - (c) catalyst
 - (d) flux
23. Find the false statement from the statements given below:
 - (a) Geothermal power plants cannot operate round the clock.
 - (b) The initial cost in setting up this plant will be high.
 - (c) This type of source is free and renewable.
 - (d) Operating cost involved in a geothermal plant is less.
24. _____ are used to produce energy in OTEC.
 - (a) Tidal energy
 - (b) Temperature difference between the different layers of water in ocean
 - (c) Ocean waves
 - (d) None of the above
25. The crude oil extracted from the earth is separated into its constituents by a process called _____.
 - (a) disintegration distillation
 - (b) compound distillation
 - (c) destructive distillation
 - (d) fractional distillation
26. The sun's energy is due to
 - (a) the nuclear fission of hydrogen.
 - (b) the nuclear fusion of hydrogen.
 - (c) the natural combustion of hydrogen.
 - (d) the nuclear fission of uranium.
27. Among the following the sources of energy for which source sun is not a chief source of energy is _____.
 - (a) Hydroelectric power plant.
 - (b) Ocean thermal energy conversion (OTEC).
 - (c) Tidal energy.
 - (d) Biomass.
28. What is the value of solar constant if the energy received by 12 m^2 area in 2 minutes is 2016 kJ?
 - (a) $1.4 \times 10^2 \text{ J s}^{-1} \text{ m}^{-2}$
 - (b) $1400 \text{ J s}^{-1} \text{ m}^{-2}$
 - (c) $84 \text{ kJ s}^{-1} \text{ m}^{-2}$
 - (d) $84 \text{ J s}^{-1} \text{ m}^{-2}$



29. A good fuel should _____.
 (a) be safe to store and transport
 (b) be able to provide desired quantity of energy at a steady rate over a long period of time
 (c) have low content of non-combustibles and no combustion products that are poisonous or environmental pollutants
 (d) All the above
30. Find the false statement from the statements given below:
 (a) Geothermal power plants cannot operate round the clock.
 (b) The initial cost in setting up this plant will be high.
 (c) This type of source is free and renewable.
 (d) Operating cost involved in a geothermal plant is less.
31. Which of the following metals is used as connecting wires that connect solar cells in a solar panel?
 (a) Copper (b) Iron
 (c) Aluminium (d) Silver
32. Quality that is not suitable for a fuel is _____.
 (a) high calorific value with ignition temperature that is well above the normal room temperature
 (b) low rate of evaporation at room temperature
 (c) carbon particles are expelled with smoke
 (d) low content of non-combustibles
33. Solar energy provides
 (a) wind energy (b) light energy
 (c) heat energy (d) All the above
34. Which one of the following can be used as a box type solar cooker?
 (a) A double walled cooker made of plastic and its inner wall is painted white.
 (b) A double walled cooker made of copper and its inner wall is painted black.
 (c) A double walled cooker made of plastic and its inner wall is painted black.
 (d) A single walled cooker made of copper and its both sides are painted white.
35. If the output energy is 1000 J and input energy is 200 J the net output is _____.
 (a) 800 (b) 1200
 (c) 10 (d) 500
36. Which one of the following sources of energy you recommend to use? A source of energy having an input energy _____ J and an output energy _____ J.
 (a) 1000, 2000 (b) 2000, 2500
 (c) 100, 12500 (d) 5000, 5250
37. The output of a given windmill
 (a) increases with an increase in wind velocity.
 (b) decreases with an increase in wind velocity
 (c) is independent of wind velocity.
 (d) Cannot be determined
38. Arrange the following steps of conversion of ocean thermal energy into electricity in a proper sequence.
 (a) The vapour of ammonia or CFC is passed over the turbines of generators.
 (b) The hot water from the ocean is used to vapourise the liquid like ammonia or CFC.
 (c) Cold water from the ocean depths is used to cool the vapour again into liquid.
 (d) This cold liquid is again vapourised and the process continues.
 (a) b a c d (b) c a b d
 (c) c b a d (d) a b c d
39. Arrange the following steps in the conversion of hydel energy to electricity in a proper sequence.
 (a) Released water is made to fall on the blades of the turbines.
 (b) Water in the dam is released.
 (c) Water is collected in the dam.
 (d) Potential energy is converted to kinetic energy.
 (e) The armature of the electric generator rotates to produce electricity.
 (a) b c d e a (b) a d b c e
 (c) e c d b a (d) c b d a e



Level 2

40. Suppose a green tree absorbs, on an average, 10^8 J of solar energy per day, incident on it and the tree could convert 1% of the solar energy incident on it to produce wood. How many days would it take to produce 50 kg of wood?
(The calorific value of wood is 15 kJ g^{-1}).
41. Water that falls from a waterfall is used to generate electricity. If the height of water fall is 100 m and 10^2 m^3 of water falls every minute, then find the hydel energy in MW h generated in one day. Assume that 60% of the energy of the flowing water is converted into electricity. (Take density of water as 1000 kg m^{-3}).
42. Among methane (CH_4) and methyl alcohol (CH_3OH), which is a better fuel and why?
43. 10 kg of water at 30°C is heated to its boiling point on a stove that uses LPG as fuel. If the efficiency of the stove is 70%, then find the mass of the fuel that is consumed. Take the calorific value of LPG (Butane) as $55,000 \text{ kJ kg}^{-1}$.
44. The combustion of 20 g of a certain fuel can melt completely 0.5 kg of ice at 0°C to form water at 0°C . Find the calorific value of the fuel.
(The latent heat of fusion of ice is 336 J g^{-1}).
45. How much time would it take for 1 litre of water to boil, initially at 0°C , if a concentrator type solar heater of area 5 m^2 is used, which can reflect 90% of energy incident on it? (Take solar constant as 1.4 kW m^{-2}).
46. Why is wood not preferred as a source of energy?
47. A power plant uses 100 tonnes of coal to produce a certain amount of electric energy. To produce the same amount of electric energy, find how much nuclear fuel U^{235} would be required by a nuclear power plant. The calorific value of coal is 30 kJ g^{-1} and a nucleus of U^{235} on fission releases about 200 MeV energy per fission. ($1\text{eV} = 1.6 \times 10^{-19} \text{ J}$). Assume that the energy conversion efficiency is 50% for coal and 25% for fission of U^{235} nucleus.
48. Find the electrical power generated in 1s by a wind mill that is erected in a location when air flows with an average speed of 54 km h^{-1} . Assume that the moving air is completely stopped by the blades of the wind turbine of area 10 m^2 , over which air flows normally and the energy conversion from wind energy to electrical energy is only 50%. (Take density of air = 1.3 kg/m^3)
49. The solar energy incident normal to the surface of the water in a container raises its temperature from 10°C to 20°C , in one minute. If the mass of water in the container is 1400 g, then find the surface area of the water in the container (solar constant = 1.4 kW m^{-2}) [Neglect the heat absorbed by the container].
50. What is the source of energy in artificial satellites? Why is this source of energy not used for meeting all our domestic electricity needs?
51. A nucleus of U^{235} on fission releases about 200 MeV energy per fission. ($1 \text{ MeV} = 1.602 \times 10^{-13} \text{ J}$). Estimate how much coal (calorific value = 33 kJ g^{-1}) has to be burnt to obtain energy equivalent to that released in the fission of 1g of U^{235} assuming that energy conversion efficiency of 30% for charcoal and 25% for fission of U^{235} nucleus.
52. An engine motor of 1 Hp power consumes 74.6 kg of a variety of biofuel to operate for one hour. If the efficiency is 100%, then find the calorific value of the fuel.
53. 1 kg of water at 0°C is taken in a vessel of water equivalent 100 g. This vessel is kept at the focal plane of a concentrator type solar heater of area 10 m^2 , which can reflect 90% of energy incident on it. Find the time taken to raise the temperature of water by 100°C . (Take solar constant as 1.4 kW m^{-2} , specific heat capacity of water as $4.2 \text{ kJ kg}^{-1} ^\circ\text{C}^{-1}$).
54. Why is it not feasible to produce hydroelectricity by spending energy in lifting a huge amount of water? Explain.

Directions for questions 55 to 59:

Select the correct alternative from the given choices.

55. What is the value of solar constant if the energy received by a portion of the outer edge of earth's atmosphere of area 12 m^2 in 2 minutes is 2016 kJ?
56. Name any two materials that are used for making solar cells.
57. Why is geothermal energy preferable over wind energy for power generation?



58. Which of the following is the best approximation of a black body?
 (a) A polished metal surface?
 (b) A black velvet cloth?
 (c) Pin hole in a blackened box. Justify your answer.
59. The wind is blowing at a speed of 36 km h^{-1} is falling on the blade of a windmill of area 0.375 m^2 and creating a pressure difference across blades of windmill. Then find the volume of air incident on the blade of windmill in a duration of 5 second.

Level 3

60. Why is geothermal energy better than wind energy for power generation?
61. 'A burning match stick can ignite a piece of paper or an incense stick but cannot burn a wooden block'. Give reasons.
62. The sun is the ultimate source of energy on earth. Is the given statement true with respect to fossil fuels?
63. Calculate the energy emitted by the sun in one second. Also estimate the mass of the sun that is converted to energy in one second.
 (Take solar constant as $1.4 \times 10^3 \text{ W m}^{-2}$, distance between the earth and the sun as $1.5 \times 10^{11} \text{ m}$ and the velocity of light as $3 \times 10^8 \text{ m s}^{-1}$).
64. Why is hydrogen not used as a fuel for domestic purposes, even though it has a high calorific value?

Directions for questions 65 to 67:

Select the correct alternative from the given choices.

65. Amount of solar energy received per unit area on the surface of earth at a location is less than the value of solar constant. (i.e., the solar energy reaching unit area at outer edge of the earth's atmosphere exposed perpendicularly to the rays of the sun at the average distance between the sun and the earth). Discuss the reasons for this variation. And also discuss the reasons for the variation in the amount of solar energy received per unit area at different locations on the surface of the earth.
66. On combustion, 250 g of cow dung cake can raise the temperature of 60 g of water through 2°C . Assuming that all the heat generated was used to heat the water, calculate the calorific value of the cow dung cake. (Take specific heat of water as $4.2 \text{ J g}^{-1} \text{ K}^{-1}$).
67. The solar energy incident on the surface of solar concentrator with an efficiency of 50% is 600 J s^{-1} . A bowl containing 1 kg of water is placed at the focal point of the concentrator. How long would it take to raise the temperature of water from 5°C to 35°C ?



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. room temperature 9. carbon 10. destructive distillation 11. hydrogen, carbon, hydrocarbons
12. Solar energy 13. hydel energy 14. non-renewable sources of energy

Match the following

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

Multiple choice questions

16. (b) 17. (a) 18. (b) 19. (a) 20. (a) 21. (b) 22. (b) 23. (a) 24. (b)
25. (d) 26. (b) 27. (c) 28. (b) 29. (d) 30. (a) 31. (d) 32. (c) 33. (d)
34. (c) 35. (a) 36. (c) 37. (a) 38. (a) 39. (d)

Explanation for questions 31 to 39:

31. Silver is the metal which is used for connecting wires that connect solar cells in a solar panel, due to its large conductivity.
32. The most suitable fuel burns completely and does not release (expel) any carbon particles with smoke.
33. Solar energy provides wind energy, light energy and heat energy.
34. In case of box-type solar cooker, more energy will be trapped by using a box, whose inner surfaces are painted black and which cannot conduct more energy to the surroundings. Now from the given options, if we choose a double wall plastic box, whose inner surfaces are painted black, then the efficiency will be more.
35. The net output = output – input = $1000 - 200 = 800$ J.
36. A good source of energy should have large, net energy output. Among the given options, a source

of energy which has input energy of 100 J and an output energy of 12500 J is the best source of energy, because the net energy output is $(12500 - 100)$ J = 12,400 J.

37. More is the velocity of wind, more will be the kinetic energy of blades of a windmill due to which more amount of electrical energy can be produced. That is, the output of a windmill increases with increase in the velocity of wind.
38. The hot water in the ocean is used to evaporate liquids like ammonia or CFC. This vapour is used to rotate the turbines of the generator and the vapour is again cooled down to a liquid by using the cold water from the ocean depth. This cooled liquid ammonia or CFC is again vapourised and the above process continues.
39. Initially water is collected in the dam. When it is released, the potential energy is converted to kinetic energy. The released water is made to fall on the blades of turbines. The armature of the electric generator rotates to produce electricity.

Level 2

40. (i) Find q , i.e., 1% of 10^8 J. This is the solar energy that is converted to wood in one day.
Find the amount of heat energy liberated on burning 50 kg of wood by using the formula,
 $Q = mS$ (1)

where S is the calorific value of wood.

Then, find the number of days required to produce 50 kg of wood by using formula,

$$Q = nq = mS \quad (2)$$

- (ii) 750 days



41. (i) Find the amount of water (m) flows in one day.
Let the volume of water that flows in every minute = V .
- (ii) Density of water (d) = $\frac{m}{V}$
- (iii) One day = 24×60 minutes
- (iv) Mass of the water that flows in one day is $m = Vd \times (60 \times 24)$
- (v) Potential energy, $PE = mgh$
- (vi) The energy of the flowing water in one day is = mgh
- (vii) 60% of the (mgh) is used to generate electricity
- (viii) 24×10^3 kW h or 24 MW h

42. (i) Which one of the given fuels—methane and methyl alcohol, has got more percentage of hydrogen?

Among the given molecules, which has got simpler molecular structure?

- (ii) CH_4 is a better fuel.

43. (i) Find the amount of heat (Q) required to boil given water by using $Q = ms(\Delta t)$.
- (ii) The above value of Q is only 70% of the amount of heat liberated by combustion of fuel (Q^1)

- (iii) Then the mass of the fuel combusted is,

$$m_{\text{fuel}} = \frac{Q^1}{S}$$

- (iv) 76 g

44. (i) Find the amount of heat energy required to melt $1/2$ kg of ice at 0°C to water at 0°C by using formula, $Q = mL$.

The amount of heat energy absorbed by ice is supplied by burning 20 g of fuel, then find the amount of heat energy produced by burning the fuel by using formula $Q = mS$.

Where S is the calorific value of the fuel.

Now, equate (10.1) and (10.2), and obtain the value of ' S '.

- (ii) 8.4 kJ g^{-1}

45. (i) Find the change in temperature of 1 litre water. Then, find the amount of heat energy absorbed by water to raise its temperature, using the formula,

$$Q = ms \Delta t. \quad (1)$$

Convert (1) in S.I system by taking $s = 4200 \text{ J kg}^{-1}^\circ\text{C}^{-1}$

Find the percentage of incident solar energy that causes rise in temperature of water.

Then, the heat absorbed by water is equal to the heat produced in solar cooker.

Then, find the heat produced in solar heater by using formula,

$$Q = (\text{Solar constant}) (\text{Area}) (\text{time}) \times \frac{90}{100} \quad (2)$$

Substitute the appropriate values in (1) and (2).

Equate (1) and (2), and find the value of time.

- (ii) 1.11 minute

46. Find the calorific value of wood with respect to the other sources of energy.

47. (i) Heat released by combustion of 100 tonnes of coal is, $Q = mS$

$$\Rightarrow Q = 100 \times 1000 \text{ kg} \times 30 \text{ kJ kg}^{-1} \rightarrow (1)$$

- (ii) Find 50% of the ' Q '.

- (iii) Let above value be Q^1 .

- (iv) The amount of heat released by fission process

$$\text{should be equal to} = \frac{100 \times Q^1}{25} \text{ J}$$

- (v) 1 fission produces $\rightarrow 200 \times 10^6 \times 1.6 \times 10^{-19} \text{ J}$

- (vi) Find the number of fissions to produce $\frac{100 \times Q^1}{25} \text{ J}$

- (vii) 235 grams of U^{235} produces 6.023×10^{23} fissions

- (viii) Find the amount of U^{235} that produces

$$\frac{100 \times Q^1}{25} \text{ J}$$

- (ix) 0.07 g

48. (i) The volume of air that makes blades to rotate = $V = \ell \times \text{area of the blade}$

- (ii) Velocity (v) = $\frac{\ell}{t}$

- (iii) Mass of the air = $m = \text{volume} \times \text{density of air}$

- (iv) Kinetic Energy (KE) of air = $\frac{1}{2} m v^2$

- (v) 50% of kinetic energy of air is converted into Electrical Energy (EE)

- (vi) The power of electrical generation is,
 $P = \frac{EE}{1s}$

- (vii) 2.53 kW

49. (i) By using formula, $Q = ms \Delta t$, find the amount of heat energy absorbed by the water. (1)



Is this heat energy absorbed by the water equal to the solar energy that is incident on the water?

Then, find the solar constant and time for which solar energy is incident on water surface.

Find the amount of solar energy incident on water by using formula,

$$Q = (\text{solar constant}) (\text{Area}) (\text{time}) \quad (2)$$

Then, substitute appropriate values and obtain the value of the area.

(ii) 0.7 m^2

50. What is the source of energy (Renewable) inouterspace?

Is it economical to harness solar energy?

Is there steady availability of the source of energy?

Then, find the efficiency of energy conversion into electrical energy.

51. (i) Find the Avogadro number.

How many atoms are contained in 235 g of uranium?

Then, find the number of atoms present in 1 g of uranium.

How many fissions are produced by 1 atom of uranium?

Find the energy of 1 eV in terms of joules.

Convert 200 MeV into joules by multiplying 200 with $(10^6 \times 1.6 \times 10^{-19})$.

Find the heat liberated by fission of 1 g of U – 235. (1)

The amount of heat liberated by burning coal is = (mass of coal) $\times$ (its calorific value) (10.2)

Find the energy conversion efficiencies of coal and uranium.

Then, equate the heat energies liberated by fission of uranium and combustion of coal.

From this, find mass of coal.

(ii) 2000 kg .

52. (i) The power of the engine = 1 Hp = 746 J $\text{s}^{-1} = \frac{Q}{3600\text{s}}$ (1)

(ii) Find the value of Q from (10.1)

(iii) We know, $Q = mS$ (2)

(iv) Equate (10.1) and (10.2) and find the value of 'S'.

(v) $S = 36,000 \text{ J kg}^{-1}$

53. (i) Solar energy incident in time 't' is = $Q = 1.4 \times 10^3 \times t \text{ J} \rightarrow$ (1)

(ii) $Q = m_w s_w (\Delta t) + (\text{water equivalent of vessel}) s_w (\Delta t)_w; \Delta t = 100^\circ\text{C}$

(iii) $\frac{90}{100} Q = 1 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1} \times 100^\circ\text{C} +$

$\frac{1}{10} \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1} \times 100^\circ\text{C} \rightarrow$ (2)

(iv) From (10.1) and (10.2), find the value of 't'.

(v) 36.6 s

54. How much energy is needed in lifting water to a certain height?

Then, this energy stored in the water is converted to produce electricity.

What is the efficiency of conversion to electrical energy?

Is it economical, if electricity produced is less than the energy spent in lifting water?

Explanation for questions 55 to 59:

55. Area of the surface which receives energy = 12 m^2 .

Time of reception (t) = 2 minute = $2 \times 60 \text{ s} = 120 \text{ s}$

The amount of energy received (E) = 2016 kJ = $2016 \times 10^3 \text{ J}$

As solar constant is the amount of energy received by a surface of unit area, per unit time from the rays which are falling normally on it.

$$K = \frac{2016 \text{ KJ}}{12 \text{ m}^2 \times 120 \text{ s}} = 1.4 \text{ KJ m}^{-2} \text{ s}^{-1}$$

56. Silicon and Selenium are used for making solar cells.

57. Geothermal energy can be harnessed for 24 hours, throughout the year. The cost of production of electricity by geothermal energy is very less than that produced by wind energy.

58. Pin hole in a blackened box, practically all radiant energy entering the pin hole is absorbed by the walls of the blackened box.



59. The speed of the wind $= 36 \text{ km h}^{-1} = 36 \times 5/18 \text{ m s}^{-1}$
 $u = 10 \text{ m s}^{-1}$

Area of cross section of the blade of the windmill A
 $= 0.375 \text{ m}^2$

time taken to create pressure difference (t) $= 5 \text{ s}$

Volume of wind falling on the blade (V) $= ?$

Length of air column falling on surface of windmill
 in 1 second $= 10 \text{ m}$

$\therefore$ Volume of air falling per second

$$= 10 \text{ m} \times 0.375 \text{ m}^2 = 3.75 \text{ m}^3$$

$\therefore$ Volume of air falling on wing in 5 second $= 5 \times 3.75 = 18.75 \text{ m}^3$.

Level 3

60. From given sources of energy, which one is available for 365 days in a year and 24 hours in a day?

61. Is the cross section of wooden block more?

Will the end of the incense stick completely covered by flame of the burning match stick.

Then, the end exposed to flame reaches ignition temperature.

In case of wooden block, is the energy supplied by match stick enough to reach ignition temperature?

62. What are fossils?

Are these impressions (or) remaining of past living creatures?

Do the living beings depend on sun for their survival?

Are these dead creatures converted into fuels?

Then which is the ultimate source of energy for the fossil fuels?

- 63 . (i) Is the energy emitted by the sun in one second equal to the energy reaching an imaginary sphere of radius equal to the distance between the sun and the earth?

Take the distance between the sun and the earth as radius of the sphere.

Then, the total surface area (T.S.A) of the sphere is $4\pi r^2$.

Then, energy received in one second (E) = (solar constant) (T.S.A).

Find the velocity of light (c) from given data.

Find the mass of the sun that is converted into energy in one second by using the formula, $E = mc^2$.

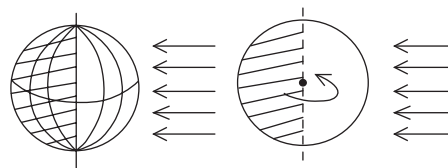
$$\text{Then, } m = \frac{E}{c^2}.$$

- (ii) $4.14 \times 10^9 \text{ kg s}^{-1}$.

64. Is it more difficult to store, handle and transport the hydrogen fuel?

Explanation for questions 65 to 67:

65. Due to the nearly spherical shape of the earth, the sun's radiations are not normal at every location on the surface of the earth. Furthermore, due to the rotation of earth on its axis, the angle of incidence of the incident radiation from the sun is changing constantly.



In addition, on an average there are only 250 – 300 days of sun shine in most of the places in India. Nearly 50% of the sun's energy entering the atmosphere is either absorbed by the atmosphere or it is reflected into space. Only infrared radiations and visible range of electro-magnetic radiations reach the surface of the earth.

66. The energy required to raise the temperature of 60 g water

$$= \text{mass} \times \text{specific heat} \times \text{rise in temp.}$$

$$= 60 \times 4.2 \times 2 = 12 \times 42 \text{ J}$$

The above energy is supplied by 250 g of cow dung

cake. Hence, its calorific value is $\frac{12 \times 42}{250}$

$$\approx 2 \text{ J g}^{-1}$$

67. Efficiency = 50%

The power of concentration = 50% of 600 J s^{-1}

$$= 300 \text{ J s}^{-1}.$$

Heat required to rise temp of water in bowl is $mc\Delta\theta$

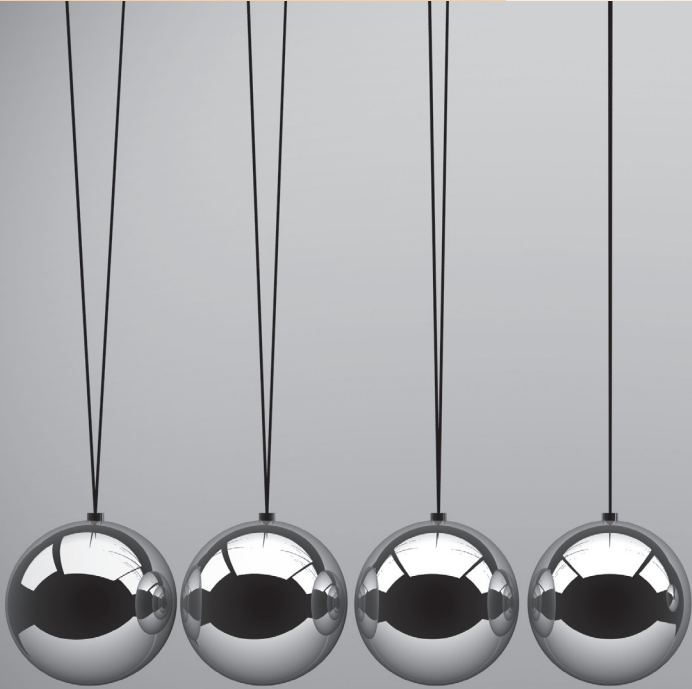
$$= 4200 \times 30 \text{ J}$$

$$\text{time taken} = \frac{4200 \times 30}{300} = 420 \text{ s} = 7 \text{ minute}$$



Chapter 11

Electronics



Remember

Before beginning this chapter, you should be able to:

- Discuss the nature of electric charges at rest
- Know the construction and working of cells
- Understand the principles of the heating effect, chemical effect and magnetic effect of electricity

KEY IDEAS

After completing this chapter, you should be able to:

- Study about the factors effecting the thermionic emission and applications of thermionic emitters
- Classify substances in electronics, study the properties and uses of the semiconductors in diode and transistors
- Study about Cathode Ray Oscilloscope (CRO)
- Learn about Radio and T.V broadcasting and reception, and study different parts of a computer

INTRODUCTION

Today computers play an important role in our everyday life. The use of computers today in many fields is the result of research and development carried out in the field of electronics, the branch of physics, that deals with the study of conduction of electrons and the related phenomena. From their primitive stage to the present stage, computers have passed through many generations. In the early stages of development, a computer was as big as a huge building. The essential components that were used in the computers in those days, were vacuum tubes, which are bulky; and that is the reason for the huge size of the computers. These computers were referred to as the first generation computers.

Later, some electronic devices called semiconductor diodes and transistors were invented and used in the circuits of these electronic devices like computers which increased their speed and efficiency. The replacement of vacuum tubes with semiconductor diodes and transistors has reduced the size of computers as well. These computers are referred to as the second generation computers. The development of semiconductor technology led to the improvisation of new devices and a large number of semiconductor diodes and transistors were arranged in a single circuit in a miniature form called integrated circuit (generally referred to as an IC or a chip). The computers which use ICs in their circuits are referred to as the third generation computers. The use of ICs in computers increased their efficiency. The fourth generation computers contain very large scale integrated circuits, i.e., large number of chips are integrated in a small circuit; and are referred to as microprocessors. Today microprocessors are used in the electronic circuits of most of the electronic devices.

In the current chapter, the fundamentals regarding electronic conduction and some of the basic components that are the building blocks of an electronic circuit are discussed in addition to the fundamentals of computers.

The term electronics comes from the word 'electron'. Electronics is a branch of applied physics which deals with controlled motion of charged particles. Electronics is a vast field and the applications of electronics are endless.

Radio, T.V. broadcast, air transport, control of rockets and space craft, electron microscope, oscilloscopes, remote controlled devices, electro radiograph and computer operated machinery are some of the devices which make use of electronics.

The branch of electronics which deals with vacuum tubes is called tube electronics.

THERMIONIC EMISSION—PRODUCTION OF ELECTRON STREAM

It is obvious that electrical conduction in solids takes place due to the drift of electrons through them. In liquids, electrical conduction takes place through motion of ions; in gases the conduction takes place only at a low pressure. A gas contained in a tube conducts electricity at a low pressure only when electrodes exist in it, similar to that in a discharge tube, and when the electrodes are connected to a source of electricity.

Thus, electrons are emitted from one electrode and pass through the gas towards another electrode, thereby conducting electricity through the gas. The electrode from which electrons are emitted is called a 'cathode' and the other electrode is called an 'anode'. Thus, electric

conduction in a gas present in a tube takes place at a low pressure from the cathode to the anode.

It is found that the movement of the electrons from the cathode to the anode takes place even in vacuum. Thus, electronic conduction is possible in a vacuum tube that contains an anode and a cathode. Such vacuum tubes were used in the circuitry of the first generation computers, mentioned earlier.

The electrons that are emitted from the surface of a cathode in a vacuum tube are called free electrons. The emission of free electrons from the surface of a cathode is an important phenomenon. The electrons, that revolve around the nucleus in the outermost orbit of an atom are valence electrons. These valence electrons are loosely bound to the nucleus and can be made free by supplying some energy.

Thus, on supplying energy to the cathode of the vacuum tube, free electrons are emitted from its surface. The energy to be supplied to the loosely bound electrons of the cathode to make them free, can be in the form of heat, light or high energy ultra violet radiation or X-ray radiation. If the energy supplied is in the form of heat, the phenomenon of electron emission is called thermionic emission.

Thus, thermionic emission is defined as ‘the phenomenon in which free electrons are emitted from a metallic surface, by the absorption of heat energy supplied to them’. The electrons thus emitted are called thermions.

The free electrons of the metallic cathode are free in the sense that they can move about from one atom to another within the metal but cannot escape from it. When heat is supplied to the cathode, the free electrons at the surface of the metal gain enough kinetic energy so that they move away from the cathode and are no more bound to the cathode surface.

The amount of heat energy to be supplied to a metallic surface for it to liberate free electrons (thermions) is different for different metals and depends on their nature. However, for a given metallic surface, there exists a minimum heat energy required for a thermion to be liberated and this minimum heat energy is called ‘**threshold energy**’ or ‘**work function**’. The threshold energy or work function is usually measured in electron-volts (eV). The corresponding temperature of the metal is known as ‘threshold temperature’.

Rate of Thermionic Emission—Factors Affecting it

Thermionic emission from a metallic surface is measured by its rate, i.e., the number of thermions emitted per unit time. This rate of thermionic emission depends on the following factors.

1. The rate of emission of thermions depends on the nature of the metallic surface. The work function of each metal is different. If the work function is less, the rate of emission of thermions is more. Thus, the rate of emission of thermions is inversely proportional to the work function of metals.
2. The rate of thermionic emission depends on the temperature of the cathode. The higher the temperature of the surface of the cathode, more is the rate of emission of thermions. Thus, the rate of thermionic emission is directly proportional to the temperature of the cathode.

3. The rate of thermionic emission depends on the surface area of the cathode. More the surface area of the cathode, more is the thermionic emission. Thus, the rate of thermionic emission is directly proportional to the surface area of the cathode.

Keeping in view the above factors on which the rate of thermionic emission depends, the characteristics of a good thermionic emitter are as follows.

1. A good thermionic emitter should have a low work function. When an emitter has a low work function, less amount of heat energy is required to liberate thermions from its surface. Thus, as more amount of heat is supplied to it, a larger number of thermions are emitted from it, increasing the rate of thermionic emission.
2. A good thermionic emitter should have a high melting point. If a thermionic emitter has a high melting point, it can be heated to a high temperature and thus the rate of thermionic emission can be increased.

Following are some of the thermionic emitters generally used.

1. **Tungsten:** It has a high melting point of 3665 K. Its work function is 4.52 electron volt (eV) and starts emitting thermions at a temperature of about 2500 K.
2. **Thoriated tungsten:** A tungsten filament on which a mixture of thorium and carbon is coated is known as thoriated tungsten. The advantage of this emitter is that heat is produced by passing electric current through tungsten filament whereas thermions are emitted from thorium. The work function of thorium is 2.6 eV corresponding to a temperature of about 2000 K. If the temperature is increased beyond 2000 K, the rate of thermionic emission also increases.
3. **Alkali metal oxides:** The work function of alkali metals is much less than that of the above-mentioned thermionic emitters. It is less than one electron-volt, and corresponds to a temperature of about 1000 K. Thus, a tungsten filament coated with alkali metal oxides like oxides of barium, strontium, caesium, etc. is an efficient thermionic emitter.

Kinds of Thermionic Emitters

Thermionic emitters can be broadly classified into two categories. They are directly heated thermionic emitters and indirectly heated thermionic emitters.

In the first category of emitters, current is passed through the emitter, thereby its temperature increases. When the temperature exceeds the temperature corresponding to the work function of the emitter, it starts emitting thermions. Tungsten filament is an example of directly heated emitters.

In the second category of emitters, heat is supplied to the emitter by a heating element like tungsten and when the temperature of the emitter crosses the temperature corresponding to its work function, i.e., its threshold temperature, it starts emitting thermions. Thoriated tungsten and alkali metal oxides fall under this category of emitters.

Applications of Thermionic Emission

The phenomenon of thermionic emission is used widely in some of the basic components used in electric circuits of electronic devices like radio, cathode ray tube (CRT) or cathode ray oscilloscope (CRO), etc. One such basic component is a diode valve.

DIODE VALVE

A diode valve is an electronic device that consists of two electrodes and is used to allow the flow of electrons in a circuit in a particular direction.

There are two types of diode valves, one that contains a directly heated thermionic emitter and the other that contains an indirectly heated thermionic emitter.

Directly Heated Diode Valve

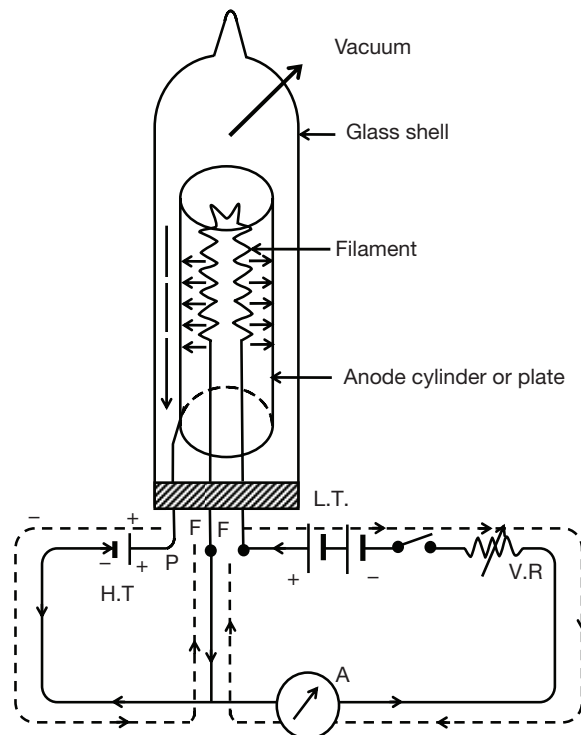


FIGURE 11.1 A directly heated diode valve

Fig. (11.1) shows the schematic representation of a directly heated diode valve used in an electric circuit. It consists of a vacuum tube in which a tungsten filament is the cathode and an aluminium cylinder that surrounds the cathode, acts like an anode. Anode is also referred to as a plate. Figure (11.2) shows the symbolic representation of a diode valve in an electric circuit. The filament (F) is connected to a low tension battery (LT) via an ammeter and a variable resistance. The current through the filament can be varied by varying the resistance and thereby the emission of thermions from the cathode can be controlled. The high-tension battery (HT) in the circuit provides the potential difference between the cathode and the anode so that the emitted thermions from the cathode move towards the plate (P) and conduct electricity in the circuit. This diode is not efficient as the work function of tungsten is high and even the number of thermions emitted is not large.

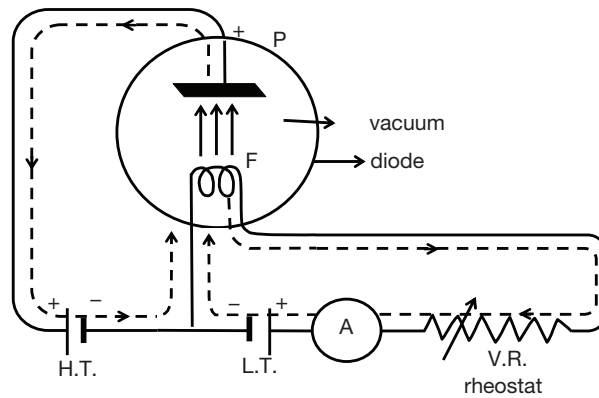


FIGURE 11.2 Symbolic representation of a directly heated diode valve and its circuit

Indirectly Heated Diode Valve

In an indirectly heated diode valve, the filament producing heat is surrounded by a cathode that emits thermions, as shown in Fig. (11.3). The terminals of the filament are connected to a low tension battery via an ammeter and a variable resistance. Adjusting the variable resistance regulates the current through the filament and thus the regulation of thermionic emission from the filament takes place. The plate and the cathode are connected to a high tension battery. The symbolic representation of an indirectly heated vacuum diode valve is shown in Fig. (11.4). As the work function and threshold temperature of the cathode is less than that of the filament, thermionic emission takes place at a comparatively lower temperature than that of the filament. As the temperature of the cathode is increased, more thermions are emitted from its surface.

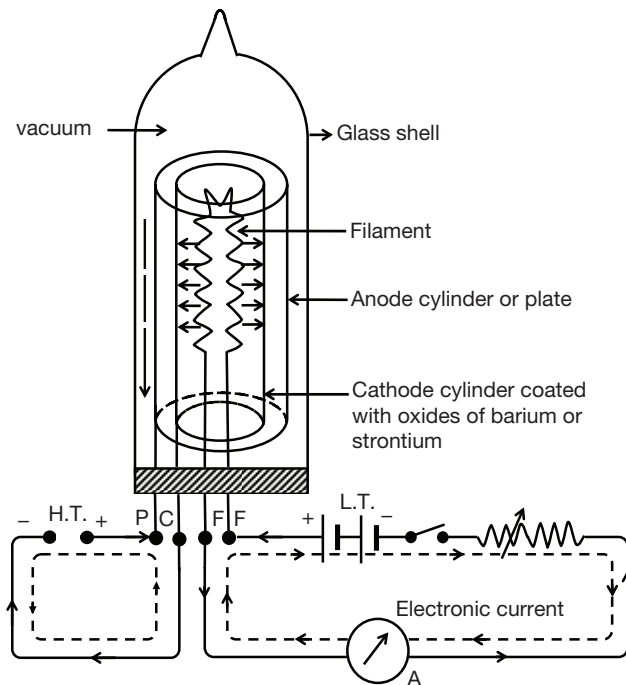


FIGURE 11.3 An indirectly heated diode valve

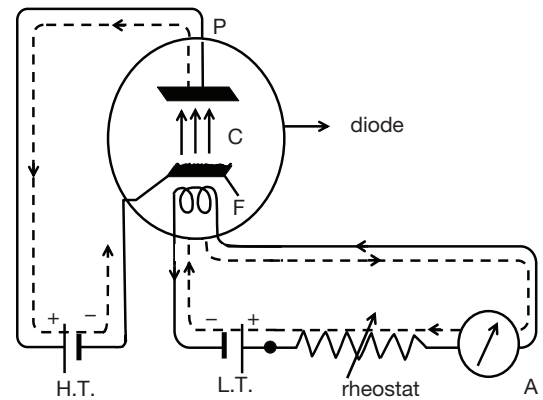


FIGURE 11.4 Symbolic representation of an indirectly heated diode valve and its circuit

Space Charge

In a diode valve, there are two circuits, one for the filament and the other for the conduction of thermions. Out of these two circuits, if only the filament circuit is switched on, the filament gets heated and produces thermions. The drift of thermions towards the plate depends on the potential difference between the plate and the cathode. If the potential difference mentioned above is zero or very less, there is no drift of thermions emitted from the cathode towards the plate and the emitted thermions are accumulated around the cathode in the form of electron cloud, called space charge. The space charge around the cathode exists as long as the rate of drift of thermions towards the anode is less than the rate of thermion production.

CATHODE RAY OSCILLOSCOPE (CRO)

A cathode ray oscilloscope (CRO) or a cathode ray tube (CRT) is a device that converts electrical signals into visual signals. The device is used to detect the nature and features of electric signals, different wave forms and also the changes in the potential difference of alternating currents.

A cathode ray oscilloscope essentially consists of an electron gun, a set of deflecting plates and a fluorescent screen. Figure (11.5) represents a cathode ray oscilloscope.

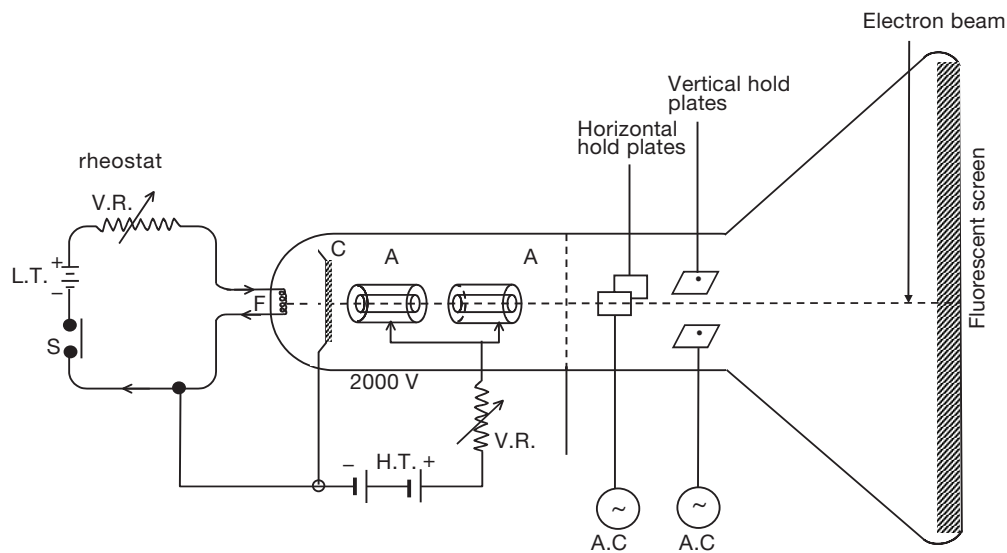


FIGURE 11.5 Cathode ray oscilloscope

The electron gun consists of a tungsten filament connected to a low tension battery via a switch and a variable resistance. In front of the filament, a cathode plate coated with barium oxide or strontium oxide is mounted and it generates thermions. To the front of the cathode, a double anode of cylindrical shape is mounted. The anode contains a fine hole in it. This is provided so as to obtain a fine beam of electrons (thermions) emitted from the cathode. In front of the anode, a control grid is mounted to which the electric signals are fed.

The fine electron beam emitted from the cathode and accelerated through the anode, passes through two pairs of deflecting plates that are connected to a high voltage source of alternating current. One pair of deflecting plates is placed in vertical position and produces deflections in the horizontal plane. The other set of deflecting plates is positioned horizontally and causes deflections in the vertical plane. Thus, the operation of these pairs of deflecting plates causes the electron beam to scan the whole screen.

The electron beam that passes between the deflecting plates impinges on the fluorescent screen and causes scintillations. Thus, the electron beam scans the screen with a bluish white glow. The intensity of the electron beam is controlled by the variable resistance in the low tension circuit. The acceleration of the emitted electrons is controlled by changing the potential difference between the cathode and the anode in the high tension circuit. The electron beam emerging through the anode is repelled after it passes through the control grid depending on the electric signal fed to the grid. Variation in the number of electrons striking the screen per second in the brightness of the light observed on the screen. If the number of electrons striking the screen is more, a white dot is observed at the place or else, a black dot is observed. This is the basic principle adopted in television picture tubes and computer monitors.

But vacuum tubes are now outdated and are replaced by semiconductor devices. The branch of electronics which deals with semiconductors is called solid state electronics. Semiconductors are preferred to vacuum tubes because of their compact size, low power consumption and economy. Based on the electrical properties, materials are classified as conductors, insulators and semi-conductors.

Semiconductors are elements whose electrical properties (conductivity or resistivity) lie between that of conductors and insulators. Examples of semiconductors are Germanium, silicon, cuprous oxide (Cu_2O), gallium arsenide, etc.

It is known that electrons in an atom revolve around the nucleus in elliptical orbits. The energy of electrons in a given orbit is fixed and thus the orbits are referred to as stationary orbits. The energy of the electrons increases as the radius of their orbits increases. The energy associated with electrons in a given orbit is referred to as their energy level. In an isolated atom, the energy levels of electrons are discrete and there exists an energy gap between two energy levels that is equivalent to the difference in the energy of the two levels. In a crystal, the atoms are not isolated. They are fixed to their positions by chemical bonds between them. The interatomic spacing in a crystal is of the order of one angstrom. In the process of forming a crystal, atoms come closer. In this process, the outermost orbits of the atoms come much closer. They superpose on one another and finally spread into a band of energy levels within a small space and this group of energy levels is called an 'energy band'. The electrons present in an energy band have no fixed energy and their energy varies continuously within the range of the energy band. Thus, an electron of an atom in a given energy band is free to move within any of the orbits of atoms present in the band.

Electrons of one atom interact with electrons of the neighbouring atom. As a result, each discrete energy level splits into as many number of separate levels as the number of interacting atoms. The split energy levels lie very close to each other and they form a continuum known as the energy band.

ENERGY BANDS IN A SILICON CRYSTAL

A silicon crystal consists entirely of silicon atoms. The atomic number of silicon is 14 and its electronic configuration is $1s^2 2s^2 2p^6 3s^2 3p^2$. In its outermost orbit, there are 4 valence electrons, whereas it can accommodate a total of 8 electrons. When many silicon atoms are brought together to form a silicon crystal, their outermost energy levels are superposed to form an energy band. As the inter-atomic distance is decreased, the energy band corresponding to 3s level is superposed on the energy bands corresponding to 3p level. In this situation, the electrons present in the 3s energy levels are free to move even in the 3p energy level. When the inter atomic spacing is still reduced and is equal to the normal interatomic spacing in a crystal shown as ' r ' in Fig. (11.6), the combined energy band is split into two with a gap called energy gap (E_g) formed between them.

Consider that there are ' n ' number of atoms in a crystal, then the 3s and 3p energy levels of all the ' n ' number of atoms are superposed to form a '3s' energy band and a '3p' energy band. Since there are ' n ' number of atoms, ' $2n$ ' number of electrons occupy the ' $2n$ ' number of available '3s' energy states and similarly ' $2n$ ' number of electrons occupy ' $6n$ ' number of available '3p' energy states. When all the '3s' and '3p' energy states are superposed, there are ' $4n$ ' number of electrons which occupy the ' $8n$ ' number of energy states. At the normal inter-atomic spacing, the total energy bands are split into two, each having ' $4n$ ' energy states in each energy band. All the ' $4n$ ' electrons in the crystal occupy the ' $4n$ ' states at the lower level and the ' $4n$ ' states in the upper level are left vacant. The energy band at the lower level which is occupied by ' $4n$ ' electrons is called **valence band (V.B)** as the electrons which occupy those states are valence electrons. When these valence electrons gain energy equivalent to the energy gap (E_g) and transit to the higher energy level, they are free to move within the crystal and conduct electricity. Thus, the energy band at the higher level is called **conduction band (C.B.)**, since no electrons exist in the energy gap (E_g), it is called **forbidden gap**.

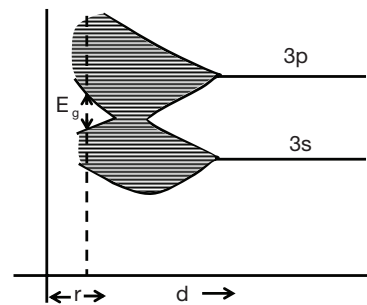


FIGURE 11.6 Energy bands in a silicon crystal

Classification of Solids Based on Band theory

Solids are classified into conductors, insulators and semiconductors based on their energy bands.

Conductors

Energy band structure of conductors are of two types.

1. The conduction band and valence band are separated by a very small gap. The conduction band is partially filled with electrons at zero kelvin. By application of a very small field, the conductor starts conducting.
2. In the second type, the valence band and the conduction band overlap. Hence, there is no forbidden energy gap. The electrical conduction takes place even when a very small electric field is applied. Hence, the resistance of these conductors is very low.

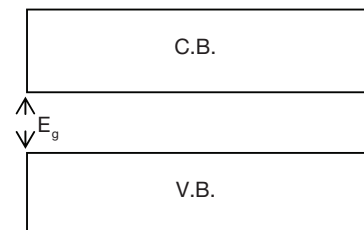


FIGURE 11.7 Conduction band & valence band separated by a small energy gap

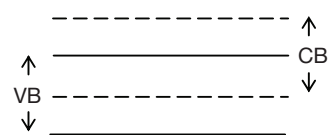


FIGURE 11.8 Overlapping of valence band & conduction band

Insulators

In insulators, the valence band and the conduction band are separated by a large energy gap (E_g). The valence band is completely filled and the conduction band is completely empty. Since there are no electrons in CB., electrical conduction does not take place. Further due to large energy gap, electrons are unable to jump to the conduction band, even if an electric field is applied. Therefore, electrical conduction is impossible in insulators.

Example: E_g of diamond is of the order of 6 eV.

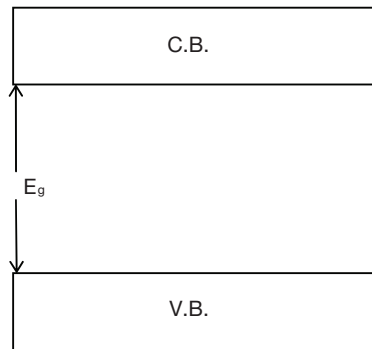


FIGURE 11.9 Large energy gap between bands of an insulator

Semiconductors

In semiconductors, the valence band and the conduction band are separated by a small forbidden energy gap. At absolute zero, the valence band is filled, the conduction band is empty and no electrons are available for conduction. Hence at zero degree kelvin, semiconductor behaves like a perfect insulator. At room temperature, some of the electrons gain thermal energy and jump to the conduction band. They are able to go from VB and CB because the forbidden energy gap is much smaller than that in insulators. They are free to move in the crystal and are available for conduction.

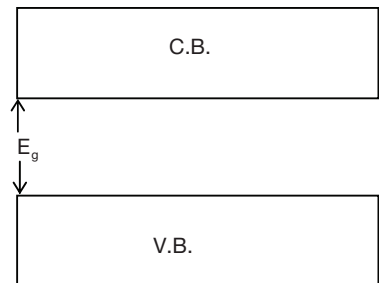


FIGURE 11.10 Small forbidden energy gap between bands of a semiconductor

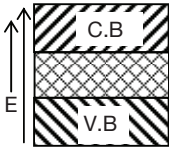
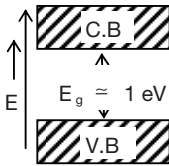
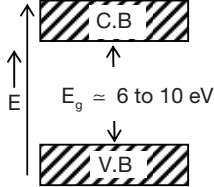
E_g of silicon = 1.1 eV

E_g of germanium = 0.75 eV

The following table compares conductors, semiconductors and insulators.

	Conductors	Semiconductors	Insulators
Number of free electrons	Of the order of 10^{28} per cm^3	Of the order of 10^{17} per cm^3	Of the order 10^7 per cm^3
Energy gap	Nil. Both the conduction band and valence band overlap.	Of the order 1 eV. For silicon, it is 1.1 eV and for germanium, it is 0.7 eV.	Of the order 6 eV to 10 eV.
Electric conductivity	Highest	Lesser	Nil or negligible

(Continued on following page)

	Conductors	Semiconductors	Insulators
Temperature coefficient of resistance	As the temperature is increased, the collisions of free electrons with positive ions increase and thus the electrical resistance increases. Thus, conductors have positive temperature coefficient of resistance.	As the temperature of a semiconductor is increased, more number of free electrons are released and so its conductivity increases. Thus, its electrical resistance decreases with increase in temperature. Hence semiconductors have negative temperature coefficient of resistance.	Similar to that of semiconductors, the resistance of an insulator is decreased, when its temperature is increased and thus also has a negative temperature coefficient of resistance.
Band diagrams			
VB → Valence band CB → Conduction band E_g → Energy gap			
Usage	For electrical conduction.	In electronic devices.	As electric shock proofers.
Examples	All metals and alloys	Silicon (Si) and germanium (Ge)	Plastics, rubber, wood, glass, ebonite, PVC, etc.

Effect of Temperature on Semiconductor

A semiconductor is a perfect insulator at absolute zero, since the conduction band of a semiconductor is completely empty. But as the temperature increases, the electrons gain energy and jump to the conduction band. Thus, the conductivity of a semiconductor increases with temperature.

In general the conductivity of a semiconductor can be increased not only by heating but also by

- 1. exposing to radiation
- 2. adding impurities to a semiconductor

Semiconductors are classified into intrinsic semiconductors or pure semiconductors and extrinsic semiconductors or impure semiconductors.

Intrinsic Semiconductor

A semiconductor in the purest form is called an intrinsic semiconductor. Examples of intrinsic semiconductors are silicon crystals and germanium crystals, i.e., every atom in the crystal is of the same type.

Silicon or germanium atom is a tetravalent element, i.e., it has four valence electrons. Each valence electron forms a covalent bond with the neighboring atom. Each silicon atom is tied down in the crystal by four covalent bonds as shown. Hence, in the pure silicon crystal, all the valence electrons are involved in bonding process and there are no free electrons available for conduction. Therefore, pure silicon or pure germanium is a perfect insulator at absolute zero.

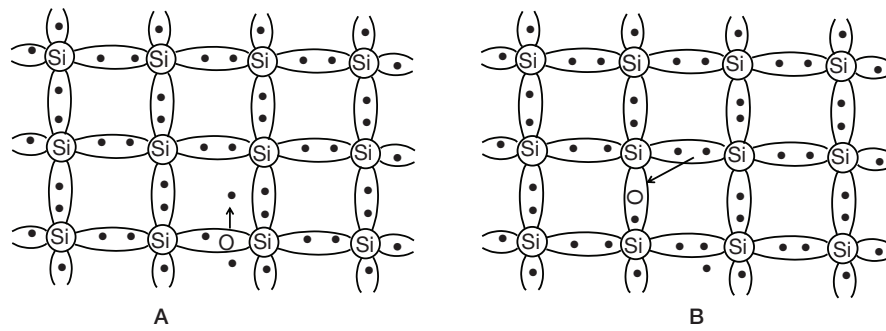


FIGURE 11.11 Bonding in an intrinsic semiconductor

As the temperature increases, it causes the atoms to vibrate with great amplitude. This vibrational energy of atoms is sufficient to break the covalent bonds and release electrons. Some of the electrons gain sufficient energy to overcome the forbidden energy gap and these electrons jump from valence band to the conduction band and are available for conduction.

When an electron moves from the valence band to the conduction band, a vacant site is created in the valence band and this vacant site behaves as net positive charge of magnitude $+e$. This vacant site is called a 'hole'. For every electron released, a hole is formed. Thus, the number of free electrons is equal to the number of holes in an intrinsic semiconductor. A hole can capture or attract an electron from the vicinity and a hole is formed at the site of the captured electron. Thus, a hole moves from one atom to another.

When potential difference is applied, the holes move in a direction opposite to that of motion of electrons. Hence, there are two types of charge carriers in a semiconductor.

Both electrons and holes contribute to the current and thus they are referred to as charge carriers. If ' I_n ' indicates the hole current and ' I_e ' indicates the electronic current, the total current in the crystal is given by, $I = I_n + I_e$. Since the electrons and the holes are equal in number, $I_n = I_e$ and thus $I = 2I_n = 2I_e$.

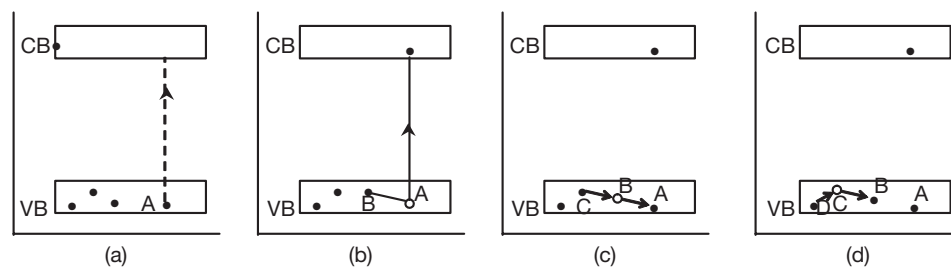


FIGURE 11.12 Formation of hole and hole movement

In an intrinsic semiconductor, the conductivity is very low because the number of charge carriers at room temperature is very small.

In order to increase the conductivity, impurities are added to a pure semiconductor crystal and the impure semiconductor is known as an extrinsic semiconductor. The process of adding impurities to a pure semiconductor is called doping and the impurities added to a pure semiconductor is called dopant. The percentage of doping depends upon the amount or concentration of impurity atoms added.

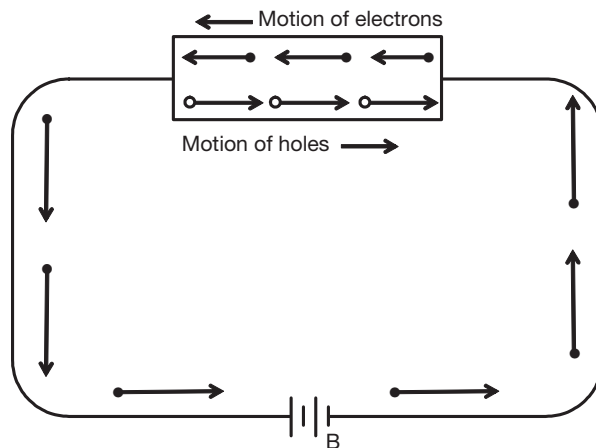


FIGURE 11.13 Electric conduction in an intrinsic semiconductor

Extrinsic semiconductors are classified into two types namely *n*-type semiconductor and *p*-type semiconductor.

N-Type Semiconductor

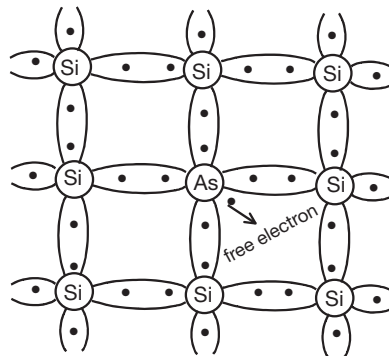


FIGURE 11.14 Bonding in an *n*-type semiconductor crystal

If a pentavalent impurity like arsenic, antimony, or phosphorus, etc. is added to molten silicon or germanium, during the process of crystal growth, an *n*-type semiconductor is obtained. Four out of the five valence electrons of the dopant atom form covalent bonds with the neighbouring silicon atoms. The fifth valence electron of the dopant is loosely bound to the parent atom and this electron can be easily set free by giving energy much less than the energy required to rupture a covalent bond. Thus, the impurity atom added donates an electron and the impurity atom is known as crystal donor impurity. Each impurity atom added to a semiconductor donates one electron without leaving a hole.

Further, free electron hole pairs are formed due to thermal agitation. So, the number of free electrons is much greater than the number of holes. So electrons are called majority carriers and holes are called minority. This type of semiconductor is called an *n*-type semiconductor. Thus, in an *n*-type semiconductor, majority charge carriers are electrons and minority charge carriers are holes.

P-Type Semiconductor

If a trivalent impurity like indium, boron or gallium is added to molten silicon or germanium, during the crystal growth, a *p*-type semiconductor is obtained.

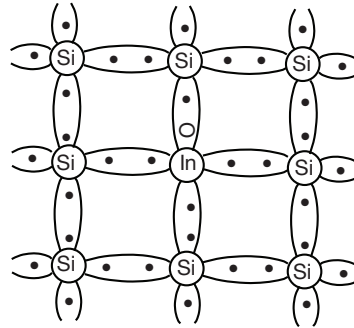


FIGURE 11.15 Bonding in an *p*-type semiconductor crystal

When a trivalent impurity atom is added to a pure silicon crystal, the three valence electrons of the impurity atom form covalent bonds with the neighbouring silicon atoms. The fourth bond is incomplete and this gives rise to a hole. This hole accepts an electron and completes the bond and hence the impurity atom in this case is known as an acceptor impurity. Every impurity atom gives rise to a hole. Further electron-hole pairs are formed due to increase in temperature. So, the number of holes now exceeds the number of free electrons. This type of semiconductor is called a *p*-type semiconductor. In *p*-type semiconductor, majority charge carriers are holes and minority charge carriers are electrons.

P-N Junction

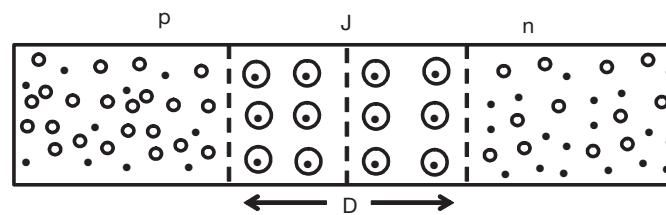


FIGURE 11.16 Electrons in a P-N junction

p-n junction is a junction between a *p*-type and *n*-type semiconductor such that it is continuous at the boundary. *p-n* junction is the basic unit for all semiconductor devices.

There are number of methods of making a *p-n* junction. In one of the methods, molten liquid of silicon or germanium is doped with pentavalent impurity and the crystal is allowed to grow upto a certain stage. This part of the crystal is *n*-type semiconductor. After that the crystal is allowed to grow in the presence of a trivalent impurity so that *p*-type semiconductor

is formed on the other side. Thus, in a single piece of a pure semiconductor, one half is doped with a pentavalent impurity and the other half of the semiconductor is doped with a trivalent impurity.

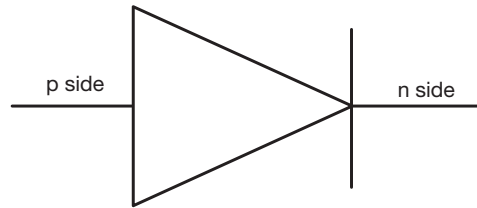


FIGURE 11.17 Symbol diagram of a p - n junction

In the p - n junction which is just formed, electrons are the majority charge carriers in the n -side and holes are the majority charge carriers in the p -side. Due to the difference in the charge concentration, electrons diffuse from n -side to p -side and holes diffuse from p -side to n -side. These electrons and holes recombine and when an electron leaves the n -side, it makes the impurity atom a positive ion and similarly when holes capture electrons it makes the trivalent atom a negative ion. Thus, the region near the junction contains immobile ions and since this region is depleted of mobile charge carriers, it is called as depletion region. The immobile ions act as a barrier for further diffusion of electrons and holes across the junction. Due to the immobile ions, an electric potential difference is developed across the junction. This potential is called the junction potential or the barrier potential. This junction potential is 0.3 V for germanium and 0.7 V for silicon at 300 K.

p - n junction is also called junction diode or a semiconducting diode. When p - n junction is not connected to an external source of electricity, it is said to be unbiased. p - n junction can be biased or connected to a battery in two ways namely, forward bias and reverse bias.

Forward Biased P - N Junction

When the p -side of a p - n junction is connected to the positive terminal of a battery and n -side is connected to the negative terminal of the battery or the applied source, then the p - n junction is said to be forward biased. (Figure 11.18)

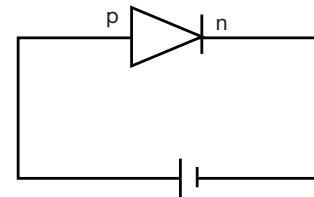


FIGURE 11.18 A forward biased P - N junction

In the forward biased p - n junction, the holes on p -side are repelled by the positive terminal of the battery and the electrons on the n -side are repelled by the negative terminal of the battery. Hence the majority charge carriers move towards the junction. The applied potential opposes the junction potential and hence the resistance or the width of the junction decreases. Once the applied voltage is greater than the barrier voltage (V_B), the majority charge carriers easily diffuse across the junction and the current flows through the diode. When the applied voltage is further increased, the current through the diode increases.

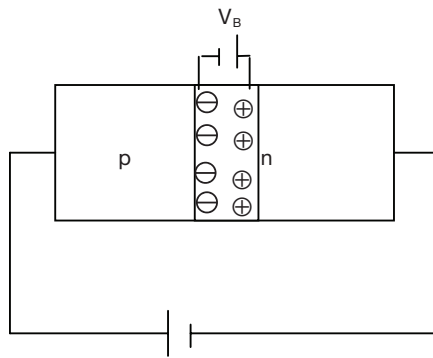


FIGURE 11.19 A forward biased P-N junction in a circuit

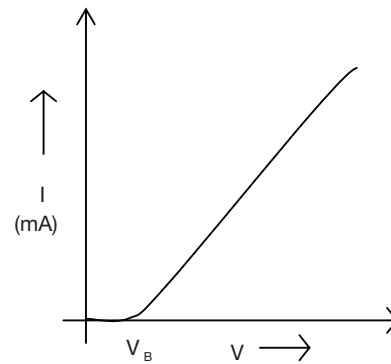


FIGURE 11.20 V-I graph for a forward biased P-N junction

Reverse Biased p - n Junction

When p -side of a p - n junction is connected to the negative terminal of a battery and n -side is connected to the positive terminal of the battery, then the p - n junction is said to be reverse biased.

In the reverse biased p - n junction, the electrons on the n -side are attracted towards the positive terminal of the battery and the holes on p -side are attracted towards the negative terminal of the battery. Thus, the majority charge carriers move away from the junction. The applied voltage supports or acts in the direction of the junction potential. As a result, the width of the depletion region and the resistance of the junction increases. There is no diffusion of majority charge carriers across the junction and hence no current flows through the p - n junction. However, there is a very small current (in μA) due to diffusion of minority charge carriers.

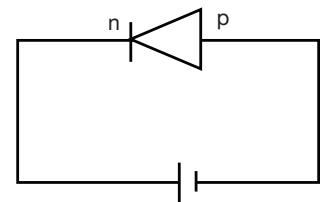


FIGURE 11.21 A Reversed biased p - n Junction

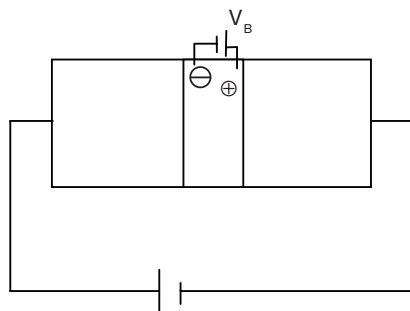


FIGURE 11.22 A reverse biased P-N junction in a circuit

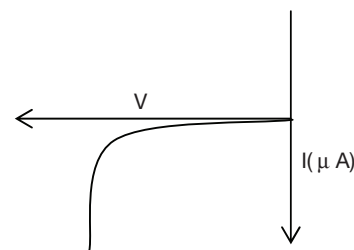


FIGURE 11.23 V-I graph for a reverse biased P-N junction

Thus, the p - n junction conducts current only if it is forward biased and practically does not conduct when it is reverse biased. This property of unidirectional current flow in a p - n junction is similar to that of a vacuum diode and thus a p - n junction is generally referred to as a p - n junction diode. This unique property of the semiconducting diode makes the diode act as a rectifier.

RECTIFIER

Rectifier is a device which converts alternating current (AC) into direct current (DC). The process of converting AC to DC is called rectification.

p-n Junction Diode as a Rectifier

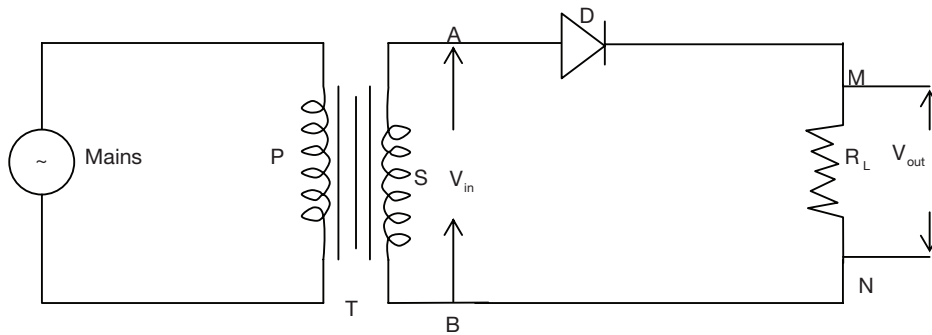


FIGURE 11.24 Circuit diagram including rectifier

D – Semiconducting diode

T – Step down transformer

R_L – Output resistor or load resistor

V_{out} – Output voltage

V_{in} – Input voltage

The circuit diagram for rectification is as shown in Fig. (11.24). The AC voltage to be rectified is applied to the primary coil of a transformer (T). The ends A and B of the secondary coil of the transformer are connected to the semiconductor diode (D) and the output resistor R_L .

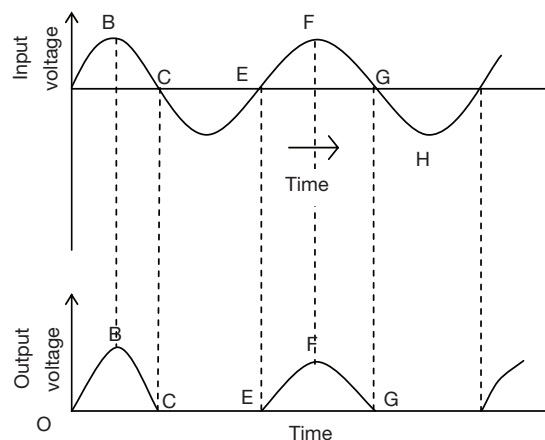


FIGURE 11.25 Graphical representation of the input and output voltages in a half wave rectifier

During the positive half cycle of the AC or the transformer output, i.e., when the end A is positive, the diode D is forward biased and current flows through R_L from M to N. The output voltage is obtained across R_L .

During the negative half cycle of the AC output, the end A is negative. As a result the diode, D is reverse biased and it does not conduct. Hence, no current flows through R_L . The cycle repeats and the output voltage is obtained only when diode is forward biased. The output voltage (V_O) is always positive, though of varying magnitude.

In the above rectification, the output voltage is obtained across the load resistor only during positive half cycle of AC input. Such type of rectification is called half-wave rectification, as only half the cycle of the input voltage is utilized. If the current flows through the output resistor (R_L) in full cycle of AC input, then it is called full-wave rectification, and the rectifier is called full wave rectifier.

There are many types of semiconducting diodes. LED or light emitting diode is one of the important semiconducting diodes. LED works on the principle of optics and electronics. LED's are p - n junction diodes which emit light when the diode is forward biased.

SCHEMATIC DIAGRAM OF LED

When the LED is forward biased, the electrons being majority charge carriers on n -side cross the junction and combine with the holes in the valence band in the p -region. Thus, the electrons fall from conduction band (higher energy level) and the difference in the energy is given out as radiation. The colours emitted depend on the nature of semiconductor used in the manufacture of LED. For example, Gallium phosphide radiates red or green colour. Silicon and germanium are not used in the preparation of LED, since they give out energy in the form of heat.

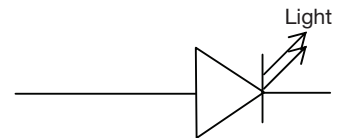


FIGURE 11.26 Symbol of a LED

Application

1. LEDs are used in display in various systems such as calculators, stereo amplifiers, digital clocks, etc.
2. LEDs emitting radiation in infrared region is used in burglar alarms, cd players, etc.

Liquid Crystal Display (LCD)

Liquid crystal is a state of matter which has property of both solid and liquid. In addition it has its own characteristic property.

Liquid crystals are very sensitive to temperature and they respond even to a very weak magnetic and electric fields. By altering or changing the temperature or the electric field, the colour of the liquid crystal can be changed. Liquid crystals are used in liquid crystal thermometer in T.V and computer monitors.

TRANSISTOR

Transistor was invented by J.Bardeen and W.H. Barttain and modern transistor was invented by William Shockley.

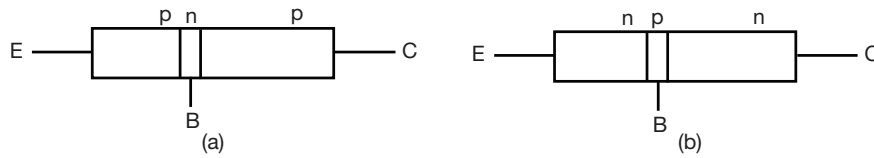


FIGURE 11.27 (a) $p-n-p$ transistor and (b) $n-p-n$ transistor E – emitter, B – base, C – Collector

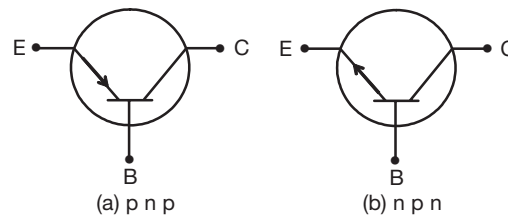


FIGURE 11.28 Symbols of (a) $p-n-p$ transistor (b) $n-p-n$ transistor

Transistor is a three terminal and two $p-n$ junction device. In this device, transfer of resistance takes place, hence this device is called as transfer resistor or transistor. Transistors are of two types namely $p-n-p$ and $n-p-n$ transistor. In $p-n-p$ transistor, n -type is sandwiched between two p -types and in $n-p-n$ transistor p -type is sandwiched between two n -types.

The central region of the transistor which is lightly doped and narrow is called the base. One of the outer regions is heavily doped and moderate in size and this region is called the emitter. Emitter emits majority charge carriers. The other outer region which is moderately doped and larger in size is called the collector. The function of the collector is to collect majority charge carriers.

Action or Working of a Transistor

In normal mode of operation of a transistor, emitter base junction is forward biased and collector base junction is reverse biased.

$V_{EB} \rightarrow$ Emitter base voltage

$V_{CB} \rightarrow$ Collector base voltage

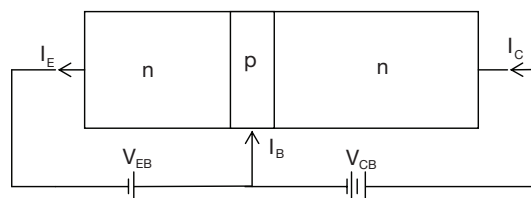


FIGURE 11.29 A $n-p-n$ transistor circuit diagram

The above circuit shows the action of $n-p-n$ transistor with base as a common terminal for both input and output. Since the emitter base junction is forward biased, electrons being the majority charge carriers in the emitter of $n-p-n$ transistor move towards the base (p-region). If applied voltage V_{EB} overcomes the barrier potential of the emitter base junction, the

electrons move to the base region. This constitutes an emitter current I_E . In the base region, few electrons combine with the holes which give rise to base current I_B . Since the base region is narrow and lightly doped and the base – collector junction is reverse biased most of the electrons cross the base collector junction and are collected in a collector. This gives rise to collector current I_C . Thus, $I_E = I_B + I_C$. By controlling the base current, the collector current can be controlled. In n-p-n transistor the conduction is mainly due to electrons.

Transistors are used as amplifiers, oscillators and in the switching circuits.

AMPLIFIER

It is a device which strengthens weak AC signals. The process of strengthening weak signal is known as amplification.

Transistor as an Amplifier

Circuit diagram for amplification using *n-p-n* transmission is as shown. The emitter base junction is forward biased with a DC source V_{BE} and the collector base junction is reverse biased with DC source V_{CE} . Emitter is made common to both input and output terminals and it is connected to earth.

The AC signal to be amplified is applied between base and the emitter, the output is obtained across the load resistor R_L .

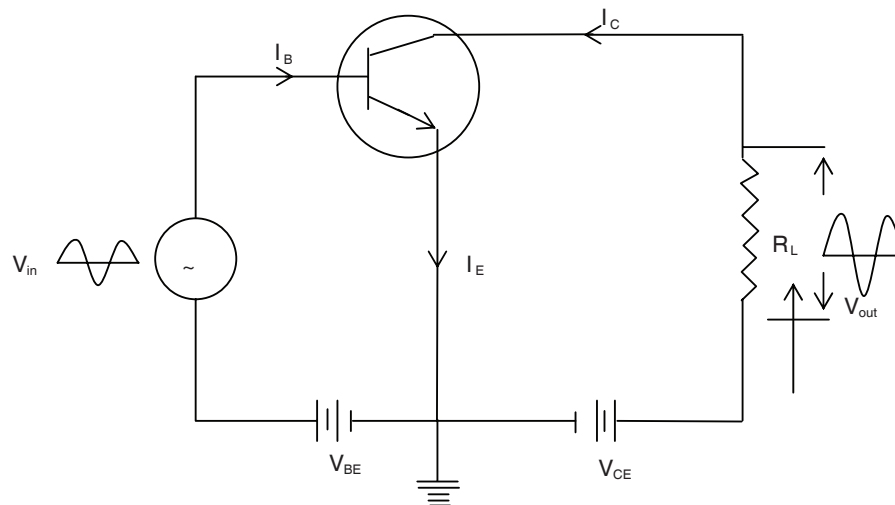


FIGURE 11.30 Circuit diagram of a transistor as an amplifier

When the input signal is applied, emitter base voltage is altered. This causes the variation in the emitter current which in turn alters the collector current to a large extent. The voltage across the load resistance R_L varies and large output voltage is obtained across R_L . Thus, the weak signal is amplified.

CAPACITORS

It is a device used to store a certain amount of electric charge. Capacitor consists of two similar parallel metal plates separated by a small distance. One of the plates is positively

charged and this induces an equal amount of negative charge on the other plate. The second plate is connected to earth. The space between the two plates is filled with insulator which is also known as dielectric. Terminals are provided to the two plates in order to connect the capacitor in the circuit.

Whenever charge is added to a conductor, its potential increases i.e., $V \propto Q$, where V is the potential and Q is the charge.

$$\therefore V \propto Q$$

i.e.,

$$Q \propto V$$

$$Q = CV$$

or

$$\frac{Q}{V} = C$$

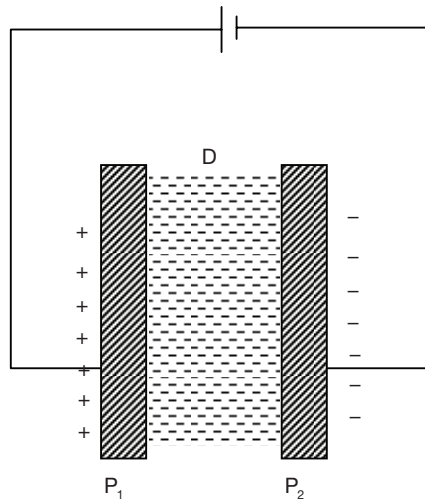


FIGURE 11.31 A parallel plate capacitor
P1, P2 Metal plates D – Dielectric

Where ‘ C ’ is called as the capacitance of a capacitor or a conductor.

Capacitance is the ability to store charge. Capacitance is measured in farad (symbol is F). Since farad is a large quantity; micro-farad and pico farad are commonly used to measure capacitance.

$$1\mu\text{F} = 10^{-6} \text{ F}$$

$$1 \text{ pF} = 10^{-12} \text{ F}$$

There are different types of capacitors. Based on the dielectric used in them, some of the types of capacitors are ceramic capacitor, paper capacitor, mica capacitor, polyester capacitor. In these capacitors, the terminals can be either connected to positive or negative, but in case of electrolytic capacitor which works on the property of chemical change of substance.

When current is passed, the terminals of this capacitor cannot be connected either to positive or negative as their poles cannot be inter changed. Hence electrolytic capacitor cannot be used in AC circuit.

*Radio and Television—Broadcasting Principles

In the broadcasting of radio and television programmes, electromagnetic waves in the frequency range of radio frequency are utilised. The fact that the induction coils detect the radio waves transmitted over long distances was discovered by Marconi in 1895, which led to the invention of radio. The fundamental stages in radio and television communication are the production of messages, the transmission of the produced messages and the reception of the transmitted messages. Initially, the messages to be transmitted are converted into electrical signals using a transducer.

Transducer is a device which converts audio or video information into electrical signal. Microphone is used as a transducer for sound transmission and photoelectric device is used as a transducer for video transmission.

These message signals are superposed over radio frequency waves, that are capable of propagating over long distances. These radio frequency waves thus are called 'radio frequency carriers'. The values of the radio frequency of the transmitting waves are different for different radio and television stations. For radio transmission, the radio frequency (R.F) is in the range of 300 kHz to 30 MHz and for television it is in the range of 30 MHz to 300 MHz. The process of superposing a message signal onto a radio frequency wave is known as 'modulation'. In modulation, there are two types, namely, 'amplitude modulation' (AM) and 'frequency modulation' (FM). At the receiving end, i.e., in the radio set or a television set, these modulated waves pass through a circuit called filter circuit and the output from the circuit is only a message signal. Thus, the message waves are separated from the modulated waves. This process of extracting message signals from a modulated radio frequency carrier waves is known as 'demodulation' or 'detection'. The following points summarize the principles of radio and television broadcasting.

1. The sound or/and the images produced during the making of a program are converted into electrical signals.
2. The electrical signals produced are amplified by using suitable amplifiers. Amplification is the process of increasing the amplitude of a given signal.
3. The amplified signal is modulated with a suitable radio frequency carrier wave, generated in an oscillator.
4. The modulated waves are fed to the transmitting antenna placed on the top of a tower of considerable height.
5. Through the transmitting antenna these modulated waves are transmitted in all possible directions in the space. This procedure is called transmission.
6. The transmitted modulated waves are received at the receiving antenna when struck with it.
7. The received radio frequency modulated waves set up alternating currents in the receiving antenna and through the antenna they are sent to the receiver, i.e., a radio or a television.
8. The tuning circuits in the radio or the television select the desired modulated wave out of the huge number of waves received at the antenna and are amplified by an amplifier.

9. The selected modulated wave is fed to the detector circuit, which consists of an electronic oscillator that separates the message signal (audio or video or both) from the radio frequency carrier wave. (This process is called demodulation or detection.)
10. The separated message signal is passed through an amplifier circuit which is fed to the corresponding devices for reception of audio/video.

*Radio Broadcasting and Reception

The following block diagram shows the basic principles discussed earlier that are involved in radio communication.

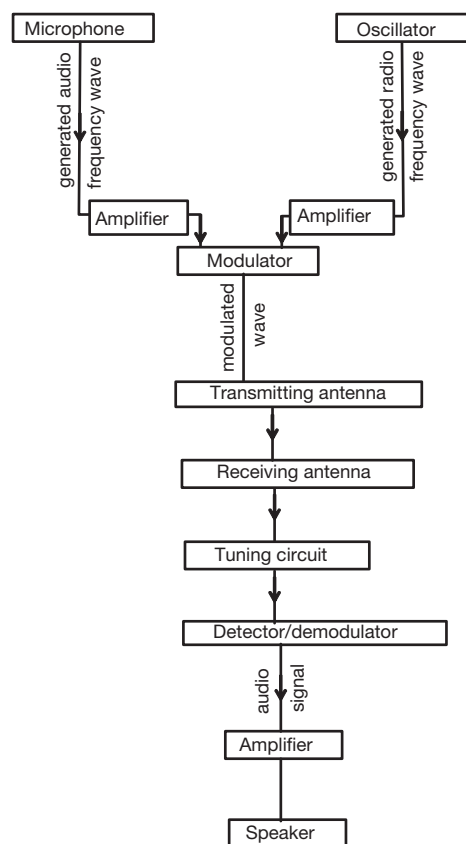


FIGURE 11.32 Block diagram for radio broadcasting

*Television Broadcasting (Telecasting) and Reception

In radio broadcasting only audio signals are involved whereas in telecasting, video signals are also involved along with audio signals. This makes the difference between radio and television broadcasting. The production of a video signal is done through the scanning of the image of an object. In the early stages of telecasting when there was no technological advancement, scanning was done using a mechanical system called 'nipkow disc'. Now-a-days, an improved system called 'iconoscope' is used for the purpose. Iconoscope is a video camera that consists of a cathode ray beam and photo electric cells. The image of an object

is focused onto a screen. The image formed on the screen is divided into a large number of small square portions.

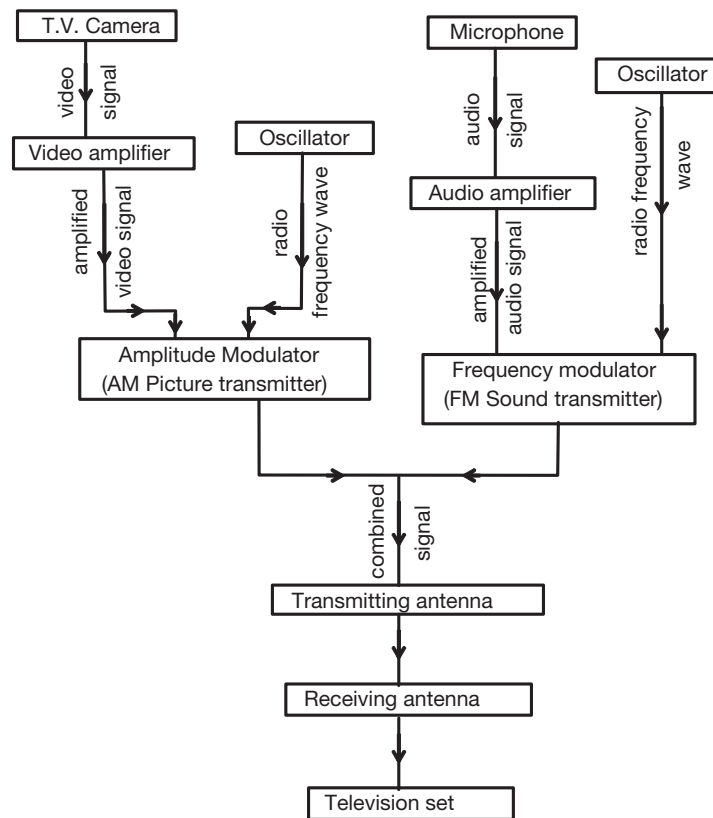


FIGURE 11.33 Block diagram for television broadcasting

The light incident on each small square portion is converted into an electric signal by photo cells present on the screen. The strength of the electric signal produced depends on the intensity of light incident on it. These electrical (video) signals are amplified further, and then used for modulation. The block diagram in Fig. (11.33) shows the telecasting and reception. The modulation done for video signal is amplitude modulation, whereas the audio signals are modulated using frequency modulation. Video signals are modulated in 'AM picture transmitter' and audio signals are modulated in 'FM sound transmitter'. Then the modulated audio and video signals are combined and fed to the transmitting antenna placed on a tower. Different television stations use different radio frequency waves for their transmission and these are referred to as 'channels'. A television antenna receives these transmitted waves and passes them to the tuning circuit of the television set, where a desired channel is selected. Then the selected modulated wave passes through detection circuit where the messages (both audio and video signals) are extracted and they are further amplified. The audio and video signals are separated. The audio signals are amplified and sent to the speaker from which the sound is heard. The video signals are fed to the picture tube where the electric signals are converted into light and the transmitted image is reconstructed. The television set is also referred to as kinescope.

The audio frequency and video signals (electrical signals) are very weak and are amplified by using suitable amplifiers.

The audio frequency signals (AF) and video signals cannot be transmitted over long distances since they have low energy. In order to propagate these electrical signals, the AF signals or the video

signals are mixed with radio waves generated by radio frequency oscillation. These radio frequency waves (RF waves) are superposed over AF waves or the video signal waves in a mixer. The process of superposing electrical message signal over RF wave is called 'modulation'. The RF wave which carries electrical signals is called a carrier wave. The carrier wave is amplified by RF amplifier.

*Assembly of a Radio

Components Required

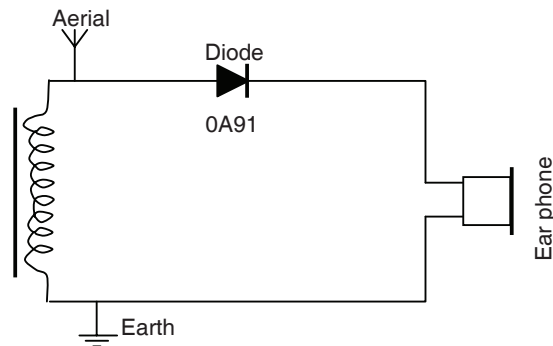


FIGURE 11.34 Circuit diagram of a radio

1. OA91 Diode, Ferrite rod, copper wire, earphone, long metal rod (aerial).
2. Variable capacitor (500 pF) and capacitor $0.01\mu\text{F}$.
3. Resistor ($100\ \Omega$) n-p-n transistor, DC source.

Procedure of Building a Circuit

Wind a copper wire around a ferrite rod and connect one end of the copper wire to *p*-type of diode and long metal rod which is the aerial. The *n*-type of diode is connected to the terminal of an earphone and the other terminal is connected to the other end of the copper wire which is connected to the ground. This circuit is a crude radio.

To increase the efficiency of the crude radio, connect a $500\ \text{pF}$ variable capacitor across the copper wire and connect a capacitor of $0.01\mu\text{F}$ in series with *n*-type of the diode and the copper wire which is connected to the earphone. The capacitor filters AC from DC.

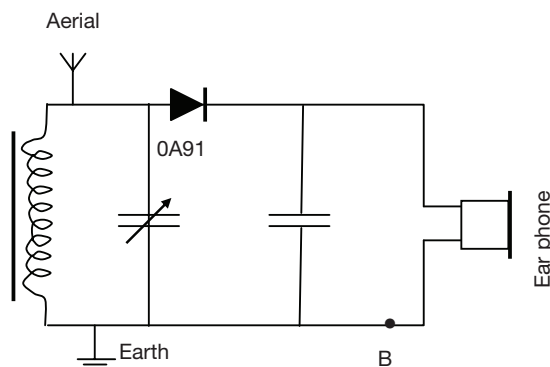


FIGURE 11.35 Circuit diagram of a crude radio

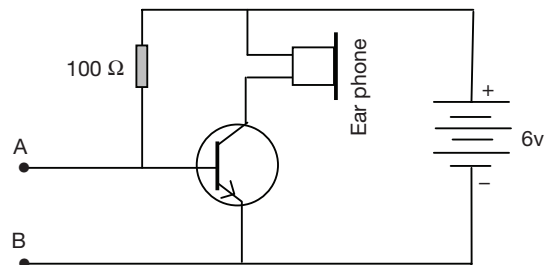


FIGURE 11.36 Circuit diagram consisting n-p-n amplifier

In order to increase the clarity and the loudness, a transistor $n-p-n$ and a resistor of $100\ \Omega$ are introduced.

Base region and the emitter of the transistor are connected across $0.01\mu\text{F}$ capacitor (as shown). One end of the $100\ \Omega$ resistor is connected to the base of the transistor and the other end of the resistor is connected to positive terminal of $6\ \text{V}$ DC source which is connected to n -type of a transistor. The negative terminal of the DC source is connected to the emitter of the transistor. The $n-p-n$ transistor amplifies the signal. Hence the sound can be heard louder.

The above circuit can work only near AM radio station.

Integrated Circuits (IC Chips)

Integrated circuit is a single semiconductor crystal or a chip which can perform the operation of resistor, capacitor, diodes and transistors in various combinations. IC chips are compact in size and are very light and very economical.

IC chips are not affected by ordinary temperature and they consume less power and the time taken to activate an IC chip is in order of nano second. Transformer and induction coil cannot be fabricated on IC chips.

Microprocessor (μp)

Combination of many ICs is called microprocessor. A microprocessor can compute data make logical decisions and store data.

The data, either numeric or non-numeric, called instructions are given to a microprocessor through a device known as input. The instruction is processed by a control unit and is sent to a decoder. The Arithmetic Logic Unit (ALU) of the micro processor does all mathematical operations and makes logical decisions. The output data is sent to a device known as output device. The output and the input data are stored in the memory unit of the micro processor.

Thus, the microprocessor which can compute data is called computer.

Computer

It is a device that helps in computing. It is a multitasking device that performs arithmetic and logical operations as well. It takes the information (data) given for doing the operations, stores them, processes the information and gives the result. It can also store the result (called output). The block diagram of a computer is as shown in Fig. (11.37).

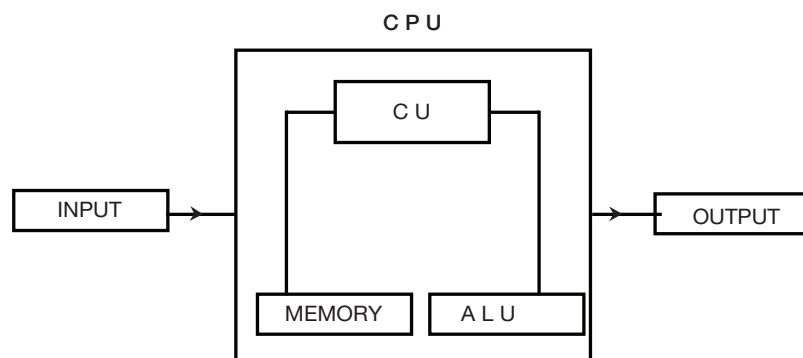


FIGURE 11.37 Block diagram of a computer

Input

The information that is fed to the computer is known as input. The devices through which information is fed are called input devices. A key board, a mouse, a floppy disc, a compact disc are the different kinds of input devices.

CPU

CPU is the central processing unit. It is the most important part of a computer and thus is generally referred to as the heart of it. This unit comprises three sub units. They are control unit (C.U), memory unit (M.U) and Arithmetic Logic Unit (ALU). Control unit controls the entire system and its related processes. The memory unit stores the information and Arithmetic Logic Unit performs the operations according to the instructions given.

Output

The processed information is the result and is given out to the user. It is called the output. The devices through which output is obtained are called the output devices. Monitor, printer, floppy, etc. are the output devices.

The CPU of a computer consists of a circuit board which is very important and is called 'mother board'. The mother board consists of the circuits related to all the components of the computer. These circuits consist of compact components called microprocessors. A micro processor consists of integrated circuits (ICs) and an integrated circuit consists of a large number of transistors, junction diodes and logic circuits.

A computer cannot perceive the information in the form that we understand, as it uses a binary system. The binary system consists of only two digits, 0 and 1, '0' refers to 'off' mode for a diode and '1' refers to 'on' mode. In the 'off' mode, the diode does not conduct electricity. In the 'on' mode, it conducts electricity. Thus, the data given to a computer is perceived by it in the binary code. The information given to a computer is in the form of either alphabet or numerals or symbols.

These put together are called 'characters'. Each character is understood by the computer in its binary code. A binary digit, i.e., either '0' or '1' is called a 'bit'. A group of eight bits is called a 'byte', and a group of one or more bytes is called a 'word'. Thus, the information is stored in the computer in the form of 'bytes' and 'words'. The digits in the decimal system, the alphabet and also the special characters in the information given to a computer are converted into a code that is understood by it before processing. One of the most commonly used codes is Binary Coded Decimal code (referred to as BCD in short). Generally the numbers, letters and symbols are represented by 8 bit codes in the BCD code. The first four bits are called 'zone bits' and the remaining four are called 'numeric bits'. Zone bits help to differentiate between a number, an alphabet and a symbol.

For example, the binary equivalents of the digit 1 and the English alphabet A, both are 0001. Thus, to differentiate between the two, zone bits are used. The zone bit of a numeral is '0101' and that of an alphabet is '1010'. Thus, the BCD code for '1' is '01010001' and for 'A' is '10100001'.

Example: Conversion of 8 into binary system

$$\begin{array}{r} 2 \overline{) 8} - 0 \\ 2 \overline{) 4} - 0 \\ 2 \overline{) 2} - 0 \\ 1 \end{array}$$

Binary equivalent of 8 is 1000 and this is also called as numeric bit zone. Bit of numerals is 0101.

∴ BCD code for 8 is 0101 1000.

Once the computer perceives the data given to it, the next stage is the processing of the data. This is done based on the instructions given to it. The instructions given to a computer in the form that we understand, however, cannot be perceived by it. So the instructions are also transformed into the BCD code. The set of instructions given to a computer is called a 'program'. The program converted into the BCD code is called 'machine language' and it depends on the CPU. Assembler is an example of a machine language. The physical components of the computer, i.e., the input and output devices and the CPU are referred to as the 'hardware' of the computer and they work on the machine languages.

But writing the program in a machine language is very tedious. Thus, the programs are written in a 'high level language' which consists of English words and symbols, thus making it easy to write a program. There are certain rules to be followed while writing the programs in a high level language, similar to the grammar rules in English. These rules are called 'syntax'.

Once a program is written in a high level language, it has to be translated into a machine language for execution. The computer takes the help of another program called 'compiler' for this translation. Thus, the compiler is a program that converts a high level language into a machine language.

The compiler and the programs written in high level language are referred to as the 'software' of the computer. BASIC, FORTRAN, COBOL, PASCAL, C, JAVA are some of the high level languages.

Applications of Computers

Computers have innumerable applications and today they are part of human life. The following are the various steps to be followed for solving a problem using a computer.

1. Identifying the problem to be solved by a computer and understanding it.
2. Scripting a suitable program for the problem to be solved by the computer.
3. Supplying data to the computer according to the written program.
4. Getting the output from the computer.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. What is the effect of temperature on conductivity of a semiconductor?
2. What are light emitting diodes?
3. What is a CPU?
4. What is an amplifier?
5. What is a forbidden gap?
6. What is a diode?
7. Define capacitance and write its unit.
8. How are conductors, semiconductors and insulators differentiated on the basis of energy bands?
9. What are thermions?
10. What are dielectrics?
11. What is an extrinsic semiconductor?
12. Define thermionic emission.
13. What is a transducer?
14. What is doping?
15. How many types of thermionic emitters are there and what are they?
16. What is an IC?
17. What is meant by a hole?
18. What is a directly heated thermionic emitter?
19. What is a microprocessor?
20. What is a p-n junction?
21. What is an indirectly heated thermionic emitter?
22. State the range of radio frequency waves used for radio transmission.
23. What is a barrier potential?
24. Define space charge.
25. What is meant by modulation?
26. What is a rectifier?
27. What is an energy band?
28. What is a computer?
29. What are liquid crystals?
30. What is a valence band?

Short Answer Type Questions

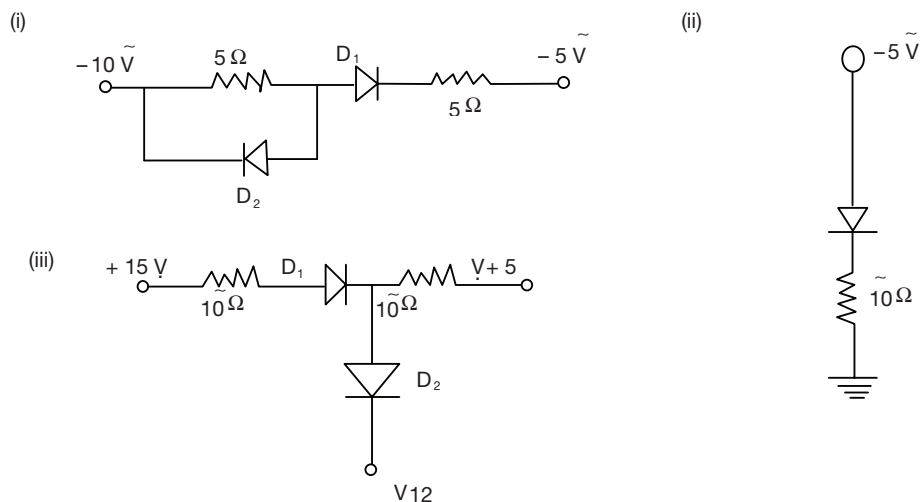
31. Explain why modulation is necessary.
32. Explain the working of a LED.
33. Explain the reason for keeping very tall TV transmission towers.
34. Explain the functioning of a p-n junction as a forward bias and reverse bias.
35. Explain how the circuit containing diodes can be used to represent '0' and '1' digits which are used in binary system.
36. How is n-type semiconductor obtained, explain with the help of diagram?
37. In an intrinsic semiconductor, the number of conduction electrons per unit volume is $7 \times 10^{18} \text{ m}^{-3}$. If the volume of a semiconductor is 1 cm^3 , find the total number of charge carriers.
38. Explain the formation of a free electron-hole pair with the help of a diagram and illustrate the motion of electrons and holes in an intrinsic semiconductor.
39. 'The p-type and n-type semiconductors have large number of electrons and holes, respectively, but still they are electrically neutral'. Explain.
40. Does a diode obey Ohm's law? Explain.
41. What are the factors that affect thermionic emission?
42. The current flowing through a diode valve for various plate voltages varies as shown below:

V (in volts)	0	60	80	150
I (in mA)	0	1	4	8

Using the above readings, show that a vacuum diode is non-ohmic conductor.
43. Write BCD for 5 and D.



44. In each of the following circuit diagrams, explain whether the diode (diodes) is (are) forward or reverse biased.



45. Are all tetravalent elements semiconductors? Explain.

Essay Type Questions

46. Explain the working of a p - n - p transistor.
47. Describe briefly about television (and radio) broadcasting with the help of neat block diagram.
48. Describe the construction and the working of a cathode ray tube with a neat diagram.
49. Explain with a neat circuit diagram the working of an npn transistor as an amplifier.
50. Explain with a neat circuit diagram the action of semiconducting diode as a half wave rectifier.

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:

State whether the following statements are true or false.

1. A high level language is independent of the hardware of a computer.
2. The process of superimposing an audio or video messages on r.f. carrier waves is called modulation.
3. Addition of either trivalent or pentavalent impurities to an intrinsic semiconductor increases its conductivity.
4. The electric current in an extrinsic semi conductor is the sum of currents due to holes and electrons.
5. The energy gap E_G of a semi conductor decreases with the rise in its temperature.
6. In an oscilloscope, the vertical deflecting plates deflect the electron beam in a vertical plane.

7. The energy bands are present only when the substance is present in the solid state.

Direction for questions 8 to 14:

Fill in the blanks.

8. The band structure determines the _____ behaviour of a solid.
9. A computer program is the group of _____ given to the computer.
10. The minimum heat energy required to emit an electron from the surface of a metal is called _____.
11. In a reverse biased p - n junction diode, the p -type semiconductor is connected to _____ terminal of the cell and n -type to the _____ terminal of the cell.
12. A group of 8-bits is called a _____.

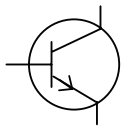
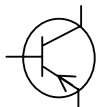


13. The depletion region in a semiconductor diode is formed at the _____.
14. The process of introducing impurities in small quantities into an intrinsic semiconductor is called _____.

Direction for question 15:

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

15.

Column A	Column B
A. Iconoscope	() a. machine language
B. Kinescope	() b. junction transistor
C. Assembler	() c. 
D. Microprocessor	() d. space charge
E. Oscillator	() e. T.V. camera
F. Extrinsic semiconductor	() f. alkali metal oxides
G. Symbol of npn transistor	() g. combination of IC's
H. Symbol of pnp transistor	() h. T.V set
I. Vacuum diode	() i. 
J. Thermion emitter	() j. p-type semiconductor

Direction for questions 16 to 44:

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

16. Compiler is a computer program that converts
- machine language instructions to high level language instructions.
 - high level language instructions into machine language instructions.
 - Basic language to Fortran language.
 - Fortran language to Basic language.
17. An oscilloscope is basically designed to convert _____.
- visual signals to electrical signals
 - sound signals to electrical signals
 - electrical signals to visual signals
 - sound signals to visual signals

18. In an intrinsic semiconductor, the number of electrons in the conduction band is _____ the number of holes in the valence band.
- equal to
 - less than
 - greater than
 - None of the above
19. A good thermionic emitter has
- high resistance.
 - high temperature coefficient of resistance.
 - high work function and high melting point.
 - low work function and high melting point
20. The characteristics which a material should possess to act as a good thermion emitter is _____.
- high work function and high melting point
 - high work function and low melting point
 - low work function and high melting point
 - low work function and low melting point
21. At absolute zero, a semiconductor is an insulator because _____.
- no electron is present in the conduction band.
 - all electrons occupy the the valence band.
 - the value of E_G is large.
 - All of the above
22. The heart, or the main component of a computer is the _____.
- key board
 - printer
 - monitor
 - central processing unit (CPU)
23. In a semiconductor, holes are present only in the _____.
- conduction band
 - valence band
 - forbidden gap
 - all of the above
24. The forbidden gap for pure silicon at room temperature is _____ eV.
- less than one
 - 1.1
 - 3
 - 9
25. For television transmission, the frequency range of carrier waves is approximately _____.
- 300 kHz to 30 MHz
 - 100 kHz to 30 MHz
 - 30 MHz to 300 MHz
 - None of the above



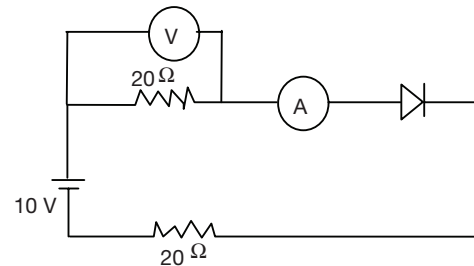
26. In an intrinsic semiconductor, if N_e is the number of electrons in the conduction band and N_p is the number of holes in the valence band, then
- $N_e > N_p$
 - $N_e = N_p$
 - $N_e < N_p$
 - None of the above
27. To make a p -type semiconductor, an intrinsic semiconductor is doped with _____.
 - gallium or indium
 - arsenic or phosphorus
 - aluminium or boron
 - Both (a) and (c)
28. The transistors are used in the _____.
 - electronic circuits called oscillators
 - stabilized power supplies
 - integrated circuits
 - All of the above
29. The arrow in the symbol of a transistor indicates _____.
 - base
 - direction of electronic current
 - direction of conventional current
 - Both (a) and (c)
30. A _____ is used as a rectifier.
 - diode
 - transistor
 - resistor
 - capacitor
31. Which among the following is an example of a semiconductor?
 - Cuprous oxide
 - Iron
 - Copper
 - Aluminium
32. In a CRO the acceleration of electrons is controlled by changing _____ between the cathode and anode.
 - Potential difference
 - Space
 - temperature
 - None of these
33. Write the following steps in a sequential order about the working of a cathode ray oscilloscope.
 - The electron beam that passes between the deflecting plates impinges on the fluorescent screen and causes scintillations.
 - When the circuit of a CRO is closed, a fine electron beam is emitted from the cathode.
 - One pair of deflecting plates is placed in vertical position and produces deflection in the horizontal plane.
 - It then gets accelerated by the double anode and passes through two pairs of deflecting plates connected to a source of alternating potential.
 - The other set positioned horizontally causes deflections in the vertical plane, thus causing the electron beam to scan the whole screen.
 - Thus, the electron beam scans the screen with a bluish white glow.
 - bdafce
 - bceadf
 - bdceaf
 - bcedaf
34. A pure germanium crystal, at absolute zero, is
 - an insulator
 - a good conductor
 - a semiconductor
 - None of the above
35. A pure semiconductor, at absolute zero, has
 - absence of electrons in the conduction band
 - all the electrons occupying the valence band
 - large E_g value
 - All of the above
36. The energy gap in glass, at room temperature, is
 - greater than that in a semiconductor
 - less than that in a good conductor
 - greater than that in a good conductor
 - Both (a) and (c) are true
37. The resistivity of an intrinsic semiconductor
 - increases with an increase in temperature
 - decreases with an increase in temperature
 - is independent of temperature
 - increases upto a certain temperature and thereafter remains constant
38. To make n -type semiconductor, an intrinsic semiconductor is doped with _____.
 - gallium
 - indium
 - boron
 - arsenic
39. A junction transistor does not have _____.
 - emitter-base junction
 - base-collector junction
 - emitter-collector junction
 - None of the above



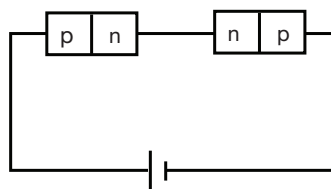
40. The conductivity of a pure or intrinsic semiconductor _____
- increases with an increase in temperature
 - decreases with an increase in temperature
 - is independent of temperature
 - increases upto a certain temperature and thereafter remains constant
41. In a *p*-type semiconductor, the electron current is _____ than the hole current.
- equal to
 - less than
 - greater than
 - None of the above
42. The energy gap in a conductor, at room temperature is _____
- greater than that in a semiconductor
 - less than that in a insulator
 - greater than that in a insulator
 - Both (a) and (c) are true
43. Phosphorus, which is used as an impurity to produce an extrinsic semiconductor, is a _____ impurity.
- trivalent
 - divalent
 - tetravalent
 - pentavalent
44. In a semiconductor, free electrons are present in _____.
- the conduction band only
 - the energy gap only
 - the valence band only
 - Both (a) and (c)

Level 2

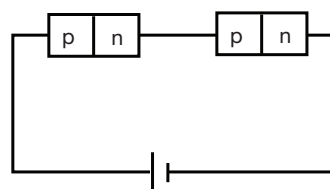
45. In the following circuit diagram, what are the values recorded by the ammeter and the voltmeter if the potential across the diode is 1 V? (Assume that ammeter and voltmeter are ideal instruments.)



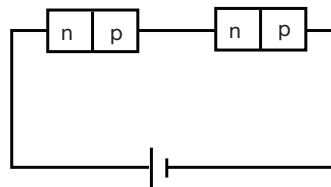
46. Two identical *p*-*n* junctions may be connected in series with a battery in three different ways as shown in the circuit diagrams. In which circuit diagram, will the potential drop across the *p*-*n* junctions be equal?



Circuit 1



Circuit 3

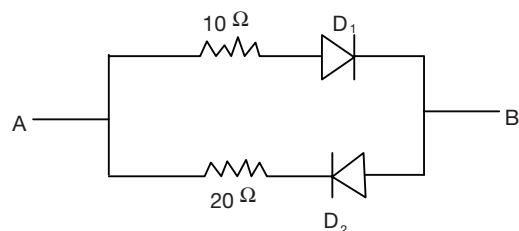


Circuit 2



47. What is the resistance offered by the following circuit if the current flows from

- (1) A to B
(2) B to A



Assume the diodes to be ideal.

What is the PD across D_1 and D_2 , when they were non-conducting, i.e., when they are reverse biased, if 7 V is applied across AB ?

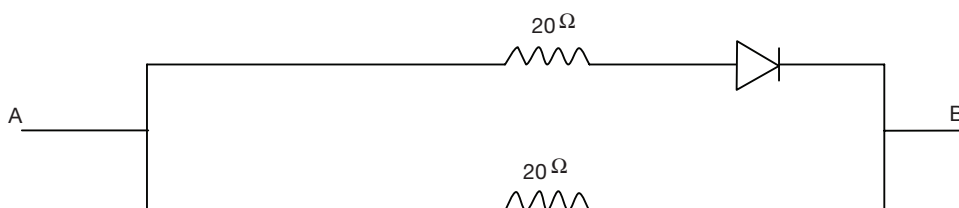
48. Find the energy dissipated in 10 minutes in the diode in the circuit shown below.

The barrier potential across a diode is 0.7 V which remains constant. (Assume the diode to be ideal)

52. What is the resistance offered by the following circuit if current flows from

- (1) A to B
(2) B to A

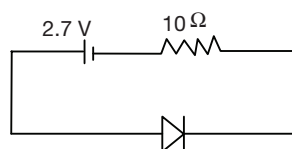
(Assume diode to be an ideal diode)



53. An electron crosses the depletion region to reach p -side from n -side. Find the speed of the electron in p -region if its speed in n -region is $3 \times 10^6 \text{ m s}^{-1}$ and potential difference across the depletion region is 0.7 V.

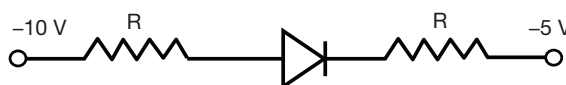
(Take the charge and mass of electron as $1.6 \times 10^{-19} \text{ C}$ and $9.1 \times 10^{-31} \text{ kg}$, respectively)

54. A certain radio station transmits the programme at 1 MHz frequency. If we can hear in the frequency range of 20 Hz to 20 kHz, then how can one hear the programme in the radio receiver?

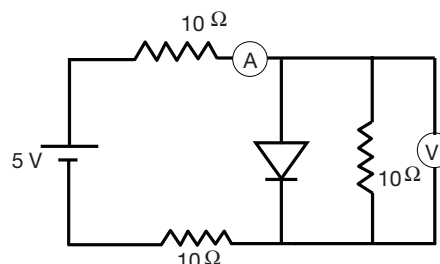


49. A diode with a barrier potential of 0.7 V is connected to a battery of 4 V in series with a resistor whose resistance is 10Ω . Find the current through the diode, if the diode is forward biased, and the forward resistance of the diode is 20Ω .

50. In each of the following circuit diagrams, explain whether the diode is forward biased or reverse biased.



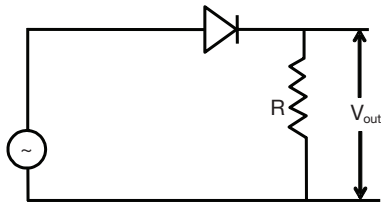
51. 1.6×10^{18} electrons, emitted from cathode, reach the plate of the diode in two seconds, if the power consumed is 1 watt, calculate the potential difference between cathode and the plate.



55. In the above said circuit diagram, if the diode is ideal, what are the values recorded by the ammeter and the voltmeter?



56. In a vacuum diode, 2×10^{19} electrons emitted from potential the cathode reach the plate of a vacuum diode in 4 seconds. Find the current and the power consumed if the potential difference between the cathode and the plate is 200 V.
57. An AC voltage is applied to the diode, as shown in the figure below. Draw the graph of output voltage versus time. Explain the action of the diode.



Is the output voltage across R a DC voltage? Explain.

Directions for questions 58 to 62:

Select the correct alternative from the given choices.

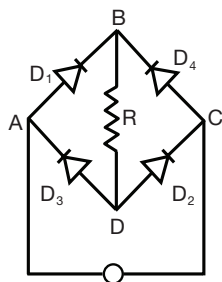
58. P and Q are oppositely charged metal plates held parallel to each other and a thermion beam passes in

the space between P and Q . If P is positively charged and Q is negatively charged, then how does the thermion beam deflect and why? Why is a tungsten filament coated with alkali metal oxides considered a good thermion emitter?

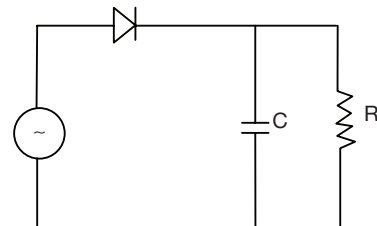
59. What is the effect on the thermion beam in a cathode ray tube if the anode voltage value is reduced but remains above zero?
60. (a) Can we use a screen coated with barium platinocyanide in a cathode ray tube?
(b) If so, what effects do we observe on the screen?
61. The diode used in the circuit shown below has a constant voltage drop of 0.6 V at all currents and a maximum power rating of 300 milli watt. What should be the value of the resistance R , if the maximum current passes through the diode?
62. Write the BCD code of the following numbers.
(a) 156 (b) 789
(c) 203 (d) 342

Level 3

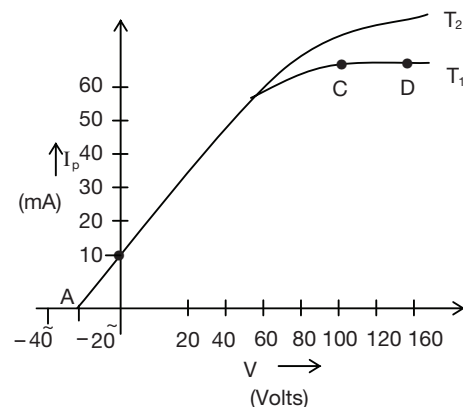
63. In an oscilloscope, the cathode emits the electrons which are accelerated by the anodes. Explain the kind of voltages to be applied to the horizontal and vertical plates so that images formed on the deflecting screen are
(1) horizontal line (2) vertical line
64. In the following circuit, explain the flow of current through resistor R . Can we use the circuit to convert AC to DC? Explain.



65. In the circuit diagram shown below, explain the voltage across R . The sinusoidal voltage has a peak value of 200 V and the capacitor used has long charging time. Assume the diode to be an ideal diode.



66. A graph of vacuum diode current I_p is plotted against the anode voltage, V_p for two different temperatures T_1 and T_2 ($T_2 > T_1$) of the cathode, as shown in the figure below.



- (1) For the same anode voltage, (called plate voltage) why is the current more when the cathode temperature changes from T_1 to T_2 ?
- (2) In the part CD of the graph, why change in V_p has no effect on I_p ?
- (3) What is the plate current when plate voltage is zero? At what plate voltage the plate current is zero?

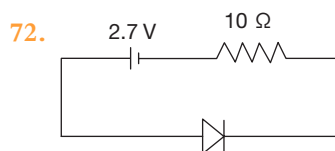
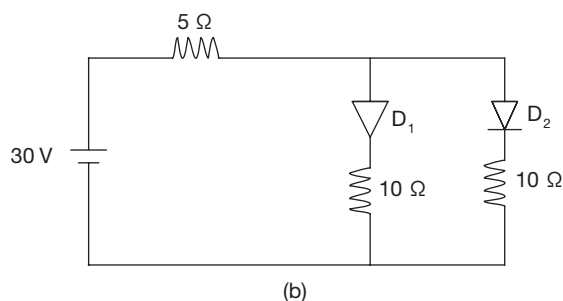
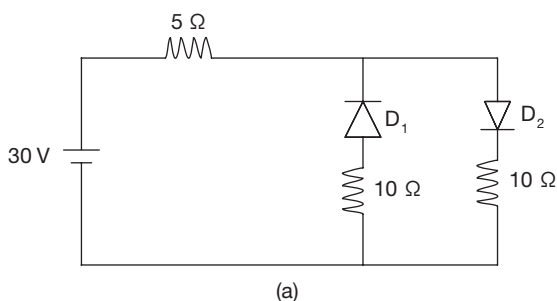
67. Electrons emitted from the surface of a cathode have sufficient kinetic energy to reach the anode even if the anode is at a negative potential. In a vacuum diode, no current flows when the anode potential is less than -5 V. Find the maximum kinetic energy of the electrons in electron volt, emitted from the cathode surface.

Directions for questions 68 to 72:

Select the correct alternative from the given choices.

68. In a vacuum diode, some of the electrons possessing sufficient kinetic energy can reach the plate even if the plate potential is negative. For a certain diode, the plate current becomes zero when plate potential is -10 V. What is the kinetic energy of the electrons in eV, if the plate potential is -4 V?
69. In an oscilloscope, the cathode emits the electrons which are accelerated by the anodes. Explain the kind of voltages to be applied to the horizontal and vertical plates so that images formed on the deflecting screen are
 - (a) horizontal line
 - (b) vertical line
70. In a $n-p-n$ transistor circuit, the collector current is 9.9 mA. If 90% of the electrons emitted reach the collector, find out the value of emitter current and base current.

71. Calculate the current through the following circuits. (The diodes are ideal)



Find the energy dissipated in 10 minutes in the diode in the circuit shown above.

The barrier potential across a diode is 0.7 V which remains constant. (Assume the diode to be ideal)



CONCEPT APPLICATION

Level 1

True or false

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

Fill in the blanks

8. electrical 9. instructions 10. work function 11. negative, positive
12. byte 13. junction 14. doping

Match the following

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

Multiple choice questions

16. (b) 17. (c) 18. (a) 19. (d) 20. (c) 21. (d) 22. (d) 23. (b) 24. (b) 25. (c)
26. (b) 27. (d) 28. (d) 29. (c) 30. (a) 31. (a) 32. (a) 33. (c) 34. (a) 35. (d)
36. (d) 37. (b) 38. (d) 39. (c) 40. (a) 41. (b) 42. (b) 43. (d) 44. (a)

Explanation for questions 31 to 44:

31. Cuprous oxide is an example of a semiconductor.
32. In a CRO, the acceleration of the electrons is changed by changing the potential difference.
33. (i) When the circuit of a CRO is closed, a fine electron beam is emitted from the cathode (b).
(ii) It then gets accelerated by the double anode and passes through two pairs of deflecting plates connected to a source of alternating current (d).
(iii) One pair of deflecting plates is placed in vertical position and produces deflections in the horizontal plane (c).
(iv) The other set positioned horizontally causes deflections in the vertical plane, thus causing the electron beam to scan the whole screen (e).
(v) The electron beam that passes between the deflecting plates impinges on the fluorescent screen and causes scintillations (a).
(vi) Thus, the electron beam scans the screen with a bluish white glow (f).
34. At absolute zero, a semiconductor is an insulator.
35. At absolute zero temperature, in a pure semiconductor, all electrons occupy the valence band and no electrons are present in the conduction band. The forbidden gap energy E_g is large.
36. Glass is an insulator. The energy gap in a glass is greater than that of semiconductor and a good conductor.
37. On increasing the temperature of a semiconductor, its resistivity decreases.
38. n -type semiconductor is made when pentavalent impurity is added. Arsenic is pentavalent.
39. A junction transistor does not have emitter collector junction.
40. The conductivity of a semiconductor increases with an increase in temperature.
41. In a p -type semiconductor, the electron current is less than the hole current.
42. Phosphorus which is used as an impurity to produce an extrinsic semiconductor is a pentavalent impurity.
43. The energy gap in a conductor, at room temperature is less than that in insulator and in semiconductor.
44. In a semiconductor free electrons are present only in conduction band.



Level 2

45. (i) A constant voltage of 1 V appears across the diode.

The remaining voltage ($10 - 1 = 9$ V) appears across the two resistors connected in series. The total resistance is $20 + 20 = 40 \Omega$ and the PD is 9 V.

Find current using Ohm's law, which is recorded by the ammeter.

Find voltage across 20Ω resistor, which is recorded by the voltmeter.

- (ii) 0.225 A, 4.5 V

46. (i) Find whether the p - n junction diodes in a given circuit is forward or reverse biased.
 (ii) If both p - n junction diodes are forward biased or both are reverse biased then the potential drop is the same across the two junctions.
 (iii) If one p - n junction diode is forward biased and the other is reverse biased then the potential drop across the two diodes is unequal.
 (iv) P.D. is equal in circuits (2) and (3).

47. (i) When current flows from A to B, diode D_1 is conducting and D_2 is non-conducting. The resistance offered is 10Ω .
 When current flows from B to A, the diode D_2 is conducting and D_1 is non conducting.
 The resistance offered equals 20Ω .
 (ii) 10Ω , 20Ω , 7 V

48. (i) The PD across the diode remains constant at 0.7 V. The remaining PD ($2.7 - 0.7 = 2$ V) appears across the resistor. Find the current using Ohm's law. Find the energy dissipated in the diode by using the formula.

$$Q = V \times I \times t$$

- (ii) 84 J

49. (i) Find the effective resistance of the circuit using the formula $R = R_D + R_1$, where R_D is the resistance offered by the diode and R is the external resistance.
 (ii) Find the current through the diode using the

$$\text{formula, } I = \frac{V - V_B}{R}$$

where V is the potential of the battery and V_B is the barrier potential.

- (iii) 0.11 A.

50. (i) 1 Find whether P end of the diode is connected to higher potential and n -end to lower potential.
 2. If the above is true, then the diode is forward biased.
 (ii) 1. What is the potential of earth?
 2. Now examine whether the P -type is connected to higher potential and n -type to lower potential.
 (iii) reverse
 (iv) reverse
 (v) forward
 (vi) forward
 (v) forward

51. (i) Power = $I^2 R$ or $V \cdot I$

$$\text{Power} = \frac{Vq}{t} \quad (1) \quad (I = q/t)$$

Where V is the potential difference.

- (ii) Find q by using $q = ne$
 where n is the number of electrons, e is the charge of an electron.
 (iii) Substitute the value of power, q and t (time) in (1) and find V .
 (iv) $\frac{125}{16}$ or 7.8125 V

52. (i) What is the resistance (R_2) of an ideal diode when the current passes from A to B?
 (ii) Find the effective resistance between A and B

$$\text{using the formula } R = \frac{R_1 \times R_2}{R_1 + R_2}.$$

- (iii) What is the resistance (R_2) of an ideal diode when the current flows in the circuit from B to A?

- (iv) Find the effective resistance using the formula

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}.$$

- (v) 10Ω , 20Ω

53. (i) Potential difference $\times$ charge = change in kinetic energy.



i.e.,

$$P.D \times q = \frac{1}{2} m(\nu_1^2 - \nu_2^2) \quad (1)$$

where q is the charge of an electron, m is the mass of an electron, ν_1 and ν_2 are speeds of an electron in the n region and p region of the semiconductor, respectively.

- (ii) Substituting the value of m , q , ν_1 and potential difference in equation (1), calculate ν_2 .
- (iii) $2.95 \times 10^6 \text{ m s}^{-1}$

54. (i) Audio signal is superposed over carrier wave.
 (ii) Is the frequency of the audio signals same as the carrier waves?
 (iii) How are the carrier wave and the message signal (audio signal) separated at the receiving end?

55. (i) What is the resistance of an ideal diode?
 (ii) Find the value of resistance R_S connected in series.

(iii) Current through the diode $I = \frac{V}{R_S}$

- (iv) What is the current (I_R) through 10Ω resistor, which is connected parallel to semiconductor diode?
- (v) Find the potential difference across the 10Ω using the formula $V = I_R R$
- (vi) Ammeter reading is 0.25 A and voltmeter reading is zero.

56. (i) The electric current can be found from

$$I = \frac{Q}{t} = \frac{ne}{t}$$

The power can be found from $P = V \times I$

- (ii) 0.8 A , 160 W

57. (i) Will the current flow through the output resistor R during the positive half cycle of AC input?
 (ii) If so, what is the nature of the current?
 (iii) Will the current flow through the output resistor R during the negative half cycle of an AC input?
 (iv) Is the current flowing through the resistor R unidirectional?

Explanation for questions 58 to 62:

58. As thermions are negatively charged particles, they will deflect towards the plate P, which is positively charged, because of attraction.

The work function of alkali metal oxides is very less (less than one eV). It starts emitting electrons at a temperature of 1000 K . Hence, tungsten coated with alkali metal oxides is considered as good thermionic emitter.

59. If the anode voltage is reduced in a cathode ray tube, the emitted electrons are less attracted and accelerated and if the rate of attraction of electrons is less than the rate of emission of electrons, then a space charge will develop around the cathode.

60. (a) Yes, it is a fluorescent material and can be coated on the screen to produce fluorescence when thermions strike it.
 (b) We observe that the screen glows with bluish white glow.

61. The resistance of the diode, R_D is

$$R_D = \frac{V^2}{P} = \frac{0.6 \times 0.6}{300 \times 10^{-3}}$$

$$= \frac{0.6 \times 0.6}{0.3} = \frac{6 \times 0.6}{3} = 1.2 \Omega$$

The current I_D through the diode is

$$I_D = \frac{P_D}{V_D} = \frac{300 \times 10^{-3}}{0.6} = \frac{0.3}{0.6} = \frac{3}{6} = 0.5 \text{ A}$$

The above current, passing through the diode is maximum

The total resistance in the circuit is

$$= \frac{V}{I} = \frac{1.6}{0.5} = \frac{16}{5} = 3.2 \Omega$$

The resistance R is $= 3.2 - R_D$

$$= 3.2 - 1.2 = 2 \Omega.$$

62. (a) 156

The zone bit of number is 0101 The numeric bit of the number is the binary equivalent of the numbers.

Therefore, the BCD code of 156

01010001010101010110

- (b) Similarly, the BCD of 789 is

010101110101100001011001

- (c) BCD code of 203 is

010100100101000001010011

- (d) BCD code of 342 is

010100110101010001010010



Level 3

63. A horizontal line can be formed on the screen if the electron beam is deflected horizontally. To move it horizontally, over the whole screen, an alternating voltage is required.

A vertical line can be formed on the screen, if the electron beam is deflected vertically. To move it vertically over the whole screen, an alternating voltage, is required.

64. (i) Identify the diodes in the circuit which conduct during the positive half cycle of an AC input.
 (ii) Does the current flow through the resistor?
 (iii) Find out the diodes which conduct during the negative cycle of an AC input.
 (iv) Find the direction of current flow through the resistor.
 (v) Is the direction of the current through R unidirectional in both positive and negative cycles of an AC input?

65. The capacitor charges to peak AC voltage during positive half cycle and discharges through load (R) during the negative half cycle when the diode is non-conducting. Thus, the voltage across R is maintained nearly at peak AC voltage.

66. (i) As the temperature of the cathode increases, it starts emitting more and more number of electrons per second which on reaching the anode increases the plate current.
 (ii) As the plate potential is increased, the plate current increases but it remains constant when the rate at which electrons are emitted from the cathode equals the rate at which they reach the anode.
67. (i) Minimum negative potential required to stop the electrons reaching the anode = kinetic energy of the electrons.
 (ii) 5eV

Explanation for questions 68 to 72:

68. The plate current is zero when the electrons are completely stopped by the negative potential on the plate. The work done to stop electrons is equal to

the change in their kinetic energy. Let the kinetic energy of the electrons when emitted from cathode is K_2 . The kinetic energy of the electrons become zero when the plate potential is -10 V.

$$\text{If } \Delta KE = v \times q$$

$$K_2 - K_1 = v \times e$$

$$K_2 = v \times e$$

$$K_2 = 10 e \quad (1)$$

Let the kinetic energy of the electrons on reaching the anode be K_1 , when the potential on anode is -4 V.

$$\therefore K_2 - K_1 = 4 \times e \quad (2)$$

Substituting K_2 from equation (1) into (2)

$$10e - K_1 = 4e \Rightarrow K_1 = 10e - 4e$$

$$K_1 = 6e \text{ Joule}$$

69. (a) To get horizontal line on the screen, an AC voltage should be applied to the vertical deflecting plate and no voltage should be applied to horizontal deflecting plates.
 (b) To get vertical line, an AC voltage should be applied to the horizontal deflecting plate and no voltage to the vertical plates.

$$70. I_c = I_b + I_e$$

Here collector current $I_c = 9.9$ mA which is 90% of emitter current I_e hence, $I_e = 11$ mA, and base current

$$I_b = I_e - I_c$$

$$I_b = 11 - 9.9 = 1.1 \text{ mA.}$$

71. (a) In the circuit, the diode D_1 is reverse biased and diode D_2 is forward biased. Current flows through the diode D_2 . So the resistors 5Ω and 10Ω are in series. The effective resistance $R = R_1 + R_2 = 10 + 5 = 15 \Omega$
 Voltage $V = 30$ V
 Current $I = \frac{V}{R} = \frac{30}{15} = 2$ A.

- (b) Here the diode D_1 and D_2 are forward biased. The current flows through D_1 and D_2 . Here the resistors 10Ω and 10Ω are in parallel, so the effective resistance



$$\frac{1}{R} = \frac{1}{10} + \frac{1}{10} = \frac{2}{10} = \frac{1}{5}, R = 5\Omega$$

This resistor is in series with $5\ \Omega$ resistor. so effective resistance

$$R = 5 + 5 = 10\ \Omega$$

$$\text{Voltage} = 30\ \text{V}$$

$$\text{Current} = I = \frac{V}{R} = \frac{30}{10} = 3\text{A.}$$

72. The PD across the diode is $0.7\ \text{V}$. The remaining voltage is $(2.7 - 0.7 = 2\ \text{V})$ and the resistance offered to the current is $10\ \Omega$. The current

$$I = \frac{V}{R} = \frac{2}{10} = 0.2\text{A}$$

Energy released in the diode = $V \times i \times t$

$$= 0.14 \times 10 \times 60 = 84\ \text{J}$$



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