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JEE
VS
YOU

MOTION

CONTENTS

INTRODUCTION

When a body does not change its position with time, we can say that the body is at **rest**, while if a body changes its position with time, it is said to be in **motion**.

- An object is said to be a **point object** if it changes its position by distances which are much greater than its size.
- A point or some stationary object with respect to which a body continuously changes its position in the state of motion is known as **origin** or **reference point**.

TYPES OF MOTION

- **According to Directions**
- **One dimensional motion** is the motion of a particle moving along a straight line.
- **Two dimensional motion** A particle moving along a curved path in a plane has 2-dimensional motion.
- **Three dimensional motion** Particle moving randomly in space has 3-dimensional motion.
- **According to state of motion**

Uniform Motion

- A body is said to be in a state of uniform motion if it travels equal distances in equal intervals of time.
- If the time distance graph is a straight line the motion is said to be uniform motion.

Non-uniform motion

- A body has a non-uniform motion if it travels unequal distances in equal intervals of time. **Ex.** a freely falling body.
- Time - distance graph for a body with non-uniform motion is a curved line.

TERMS USED TO DEFINE MOTION

(i) Distance and displacement
(ii) Speed and velocity
(iii) Acceleration

(i) Distance & Displacement

- The path length between the initial and final positions of the particle gives the **distance** covered by the particle.
- The minimum distance between the initial and final positions of a body during that time interval is called **displacement**
- Distance and displacement both are measured in *meter* in m.k.s. system.

Difference between distance and displacement

- Distance travelled is a scalar quantity while displacement is a vector quantity.
- When a body continuously moves in the same straight line and in the same direction then displacement will be equal to the distance travelled. But if the body changes its direction while moving, then the displacement is smaller than the distance travelled.

$$\boxed{\text{Displacement} \le \text{Distance}}$$

- Displacement in any interval of time may be zero, positive or negative where as distance cannot be negative..

Ex.1 A person travels a distance of 5 m towards east, then 4 m towards north and then 2 m towards west.

(i) Calculate the total distance travelled.

(ii) Calculate the resultant displacement.

Sol. (i) Total distance travelled by the person

= 5 m + 4 m + 2 m = 11 m

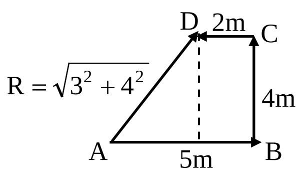
(ii) To calculate the resultant displacement, we choose a convenient scale, where 1 cm represents 1 m. We draw a 5 cm long line AB towards east and then 4 cm long line BC towards north. Finally, a 2 cm long line CD towards west. The resultant displacement is calculated by joining the initial position A to the final position D. We measure AB = 5 cm.

Since 1 cm = 1 m

$\therefore$ 5 cm = 5 m

Hence, the displacement of the person

= 5m towards AD.

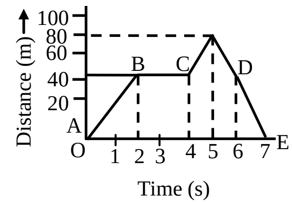


Ex.2 A body is moving in a straight line. Its distances from origin are shown with time in Fig. A, B, C, D and E represent different parts of its motion. Find the following :

(i) Displacement of the body in first 2 seconds.

(ii) Total distance travelled in 7 seconds.

(iii) Displacement in 7 seconds



Displacement-time graph

Sol. (i) Displacement of the body in first 2s = 40m

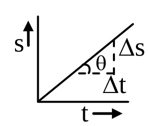
(ii) From t = 0 to t = 7 s, the body has moved a distance of 80 m from origin and it has again come back to origin. Therefore, the total distance covered = 80 × 2 = 160 m

(iii) Since the body has come back to its initial position, the displacement is zero.

(ii) Speed and Velocity

- The 'distance' travelled by a body in unit time interval is called its **speed**. When the position of a body changes in particular direction, then speed is denoted by 'velocity'. i.e. the rate of change of displacement of a body is called its **Velocity.**
- Speed is a scalar quantity while velocity is a vector quantity.
- Speed = $\dfrac{\text{distance}}{\text{time}}$
- Velocity = $\dfrac{\text{displacement}}{\text{time}}$
- Unit : In M.K.S. system = ms^{-1}
  In C.G.S. system = cm/s
- If time distance graph is given then speed can be given by the slope of the line, at given time

$$v = \frac{\Delta s}{\Delta t} = \text{slope}$$



- The area of velocity time graph gives displacement travelled.

Types of speed

(a) Average and Instantaneous speed

Average speed :

It is obtained by dividing the total distance travelled by the total time interval. i.e.

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

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

- Average speed is a scalar, while average velocity is a vector.
- For a moving body average speed can never be –ve or zero (unless $t \to \infty$), while average velocity can be i.e. $v_{av} > 0$ while $\vec{v}_{av} >=\text{ or } < 0$
- In general average speed is not equal to magnitude of average velocity. However it can be so if the motion is along a straight line without change in direction
- If a particle travels distances L_1, L_2, L_3 at speeds v_1, v_2, v_3 etc respectively, then

$$v_{av} = \frac{\Delta s}{\Delta t} = \frac{L_1 + L_2 + \ldots\ldots + L_n}{\frac{L_1}{v_1} + \frac{L_2}{v_2} + \ldots\ldots + \frac{L_n}{v_n}} = \frac{\sum Li}{\sum \frac{L_i}{v_i}}$$

- If a particle travels at speeds v_1, v_2 etc for intervals t_1, t_2 etc respectively, then

$$v_{av} = \frac{v_1 t_1 + v_2 t_2 + \ldots}{t_1 + t_2 + \ldots} = \frac{\sum v_1 t_1}{\sum t_1}$$

Instantaneous speed :

The speed of a body at a particular instant of time is called its instantaneous speed.

$$= \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

(b) Uniform and Non uniform speed

Uniform speed :

If an object covers equal distance in equal interval of time, then time speed graph of an object is a straight line parallel to time axis then body is moving with a uniform speed.

Non-uniform speed :

If the speed of a body is changing with respect to time it is moving with a non-uniform speed.

Ex.3 The distance between two points A and B is 100 m. A person moves from A to B with a speed of 20 m/s and from B to A with a speed of 25 m/s. Calculate average speed and average velocity.

Sol. (i) Distance from A to B = 100 m

Distance from B to A = 100 m

Thus, total distance = 200 m

Time taken to move from A to B, is given by

$$t_1 = \frac{\text{distance}}{\text{velocity}} = \frac{100}{20} = 5 \text{ seconds}$$

Time taken from B to A, is given by

$$t_2 = \frac{\text{distance}}{\text{velocity}} = \frac{100}{25} = 4 \text{ seconds}$$

Total time taken = $t_1 + t_2 = 5 + 4 = 9$ sec.

$\therefore$ Average speed of the person

$$= \frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{200}{9} \text{ m/s} = 22.2 \text{ m/s}$$

(ii) Since person comes back to initial position A, displacement will be zero, resulting zero average velocity.

Ex.4 A car moves with a speed of 40 km/hr for first hour, then with a speed of 60 km/hr for next half hour and finally with a speed of 30 km/hr for next $1\frac{1}{2}$ hours. Calculate the average speed of the car.

Sol. Distance travelled in first hour, is given by

s_1 = speed × time = 40 km/hr × 1 hr = 40 km

Distance travelled in next half an hour, is given by

s_2 = speed × time = 60 km/hr × $\frac{1}{2}$ hr = 30 km

Distance travelled in last $1\frac{1}{2}$ hours, is given by

s_3 = speed × time = 30 km/hr × $\frac{3}{2}$ hr = 45 km

Thus, total distance travelled = $s_1 + s_2 + s_3$

= 40 + 30 + 45 = 115 km

Total time taken = $1 + \frac{1}{2} + 1\frac{1}{2}$ = 3 hours

$\therefore$ Average speed =

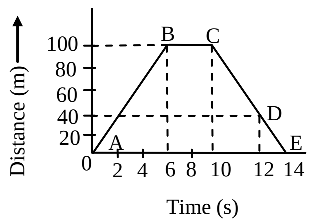
$\frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{115\text{km}}{3\text{hrs}}$ =38.33 km/hr

Ex.5 Figure shows time distance graph of an object. Calculate the following :

(i) Which part of the graph shows that the body is at rest ?

(ii) Average speed in first 10 s.

(iii) Speeds in different parts of motion.



Distance-time graph

Sol. (i) The part BC shows that the body is at rest.

(ii) In first 10 seconds, distance travelled = 100m

$\therefore$ Thus, average speed = $\frac{\text{Distance covered}}{\text{Time taken}}$

$= \frac{100}{10}$ = 10 m/s

(iii) Speed of the object in part AB is given by

slope = $\frac{100}{6}$ = 50/3 m/s

Speed of object in part BC = 0 m/s

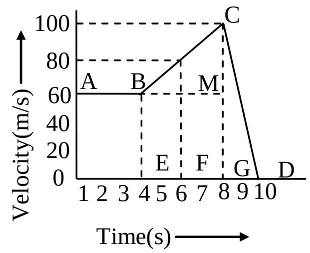
Speed of the object in part CD

$= \frac{100-40}{12-10} = \frac{60}{2}$ = 30 m/s

Speed of object in part DE

$= \frac{40-0}{14-12} = \frac{40}{2}$ = 20m/s

Ex.6 Time-velocity graph of a particle is shown in Figure. Calculate the distance travelled in first seconds.



Sol. Distance travelled in first 8s is given by area OABCG

= area of rectangle OAMG

+ area of triangle BMC

$= 8 \times 60 + \frac{1}{2} \times 4 \times 40 = 480 + 80 = 560$ m.

(iii) Acceleration

- Rate of change of velocity is called acceleration. It is a vector quantity

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

- Unit of acceleration = m/s^2 or ms^{-2}

Types of acceleration

- **Uniform & Non uniform acceleration**

Uniform acceleration

If a body travels in a straight line and its velocity increases by equal amounts in equal intervals of time then it is said to be in state of uniform acceleration.

e.g. motion of a freely falling body.

Non uniform acceleration

A body has a non-uniform acceleration if its velocity increases by unequal amounts in equal intervals of time.

Instantaneous acceleration :

The acceleration of a body at any instant is called its instantaneous acceleration.

- If the velocity of a body decreases, then it will experience a negative acceleration which is called deceleration or retardation.

- **Acceleration is determined by the slope of time-velocity graph.**

$$\tan\theta = \frac{dv}{dt}$$

(i) If the time velocity graph is a straight line, acceleration remains constants.

(ii) If the slope of the straight line is positive, positive acceleration occurs.

(iii) If the slope of the straight line is negative, negative acceleration or retardation occurs.

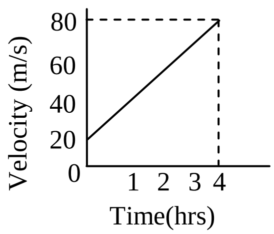
Ex.7 Time-velocity graph of a body is shown in the figure. Find its acceleration in m/s^2.

Sol. As it is clear from the figure,

At t = 0 s, v = 20 m/s

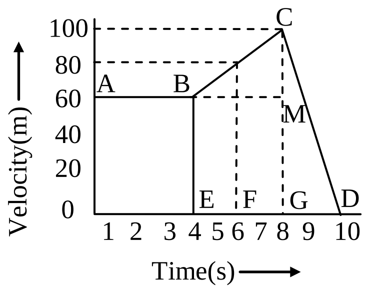
At t = 4 s, v = 80 m/s

$\therefore$ Acceleration, $a = \frac{\text{Change in velocity}}{\text{Time interval}}$



$$= \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{(80-20)\,m/s}{(4-0)} \quad 15 m/s^2$$

Ex.8 Time-velocity graph of a particle is shown in figure. Find its instantaneous acceleration at following intervals :



(i) at t = 3s

(ii) at t = 6s

(iii) at t = 9s

Sol. (i) Instantaneous acceleration at t = 3s, is given by

a = slope of line AB = zero

(ii) Instantaneous acceleration at t = 6 s, is given by a = slope of line

$$BC = \frac{CM}{BM} = \frac{100-60}{8-4} = -10 \text{ m/s}^2$$

(iii) Instantaneous acceleration at t = 9 s, is given by a = slope of line CD $= \frac{0-100}{10-8} = -50$ m/s^2

Ex.9 Starting from rest, Deepak paddles his bicycle to attain a velocity of 6 m/s in 30 seconds then he applies brakes so that the velocity of the bicycle comes down to 4 m/s in the next 5 seconds. Calculate the acceleration of the bicycle in both the cases.

Sol. (i) Initial velocity, u = 0, final velocity, v = 6 m/s, time, t = 30 s

Using the equation v = u + at, we have

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

substituting the given values of u, v and t in the above equation, we get

$$a = \frac{6-0}{30} = 0.2 \text{ m/s}^2;$$

which is positive acceleration.

(ii) Initial velocity, u = 6 m/s, final velocity, v = 4 m/s, time, t = 5 s, then

$$a = \frac{v-u}{t} = \frac{4-6}{5} = -0.4 \text{ m/s}^2;$$

which is retardation.

Note : The acceleration of the case (i) is positive and is negative in the case (ii).

EQUATIONS OF MOTION

Motion under uniform acceleration

(a) 1st Equation of motion

Consider a body having initial velocity 'u'. Suppose it is subjected to a uniform acceleration 'a' so that after time 't' its final velocity becomes 'v'. Now we know,

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{Time}}$$

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

or $\quad v = u + at \quad$ .....(i)

(b) 2nd Equation of motion

Suppose a body has an initial velocity 'u' and uniform acceleration 'a' for time 't' so that its final velocity becomes 'v'. The distance travelled by moving body in time 't' is 's' then the average velocity = (v + u)/2.

Distance travelled = Average velocity × time

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

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

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

(c) 3rd Equation of motion

Distance travelled = Average velocity x time

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

from equation (i) $\quad t = \frac{v-u}{a}$

Substituting the value of t in equation (iii), we get $s = \left(\frac{v-u}{a}\right)\left(\frac{v+u}{2}\right)$

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

$\Rightarrow 2as = v^2 - u^2$ or

$\mathbf{v^2 = u^2 + 2as}$ **....(iv)**

◆ The equations of motion under gravity can be obtained by replacing acceleration by acceleration due to gravity (g) and can be written as follows :

◆ When the body is coming towards the centre of earth

(a) $v = u + gt$ $\quad$ **(b)** $h = ut + \frac{1}{2}gt^2$

(c) $v^2 = u^2 + 2gh$

◆ When a body is thrown upwards with some initial velocity, then a retardation produced due to attraction of the earth. In equations of motion, a is replaced by (–g) and thus equations become.

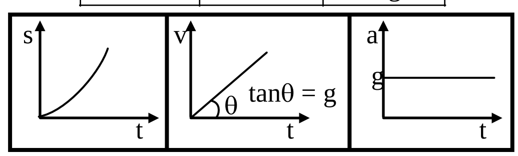
(a) $v = u - gt$ $\quad$ **(b)** $h = ut - \frac{1}{2}gt^2$

(c) $v^2 = u^2 - 2gh$

➤ BODY FALLING FREELY UNDER GRAVITY

Assuming u = 0 for a freely falling body :

t is given	h is given	v is given
$v = gt$ $h = \frac{1}{2}gt^2$	$t = \sqrt{\frac{2h}{g}}$ $v = \sqrt{2gh}$	$t = \frac{v}{g}$ $h = \frac{v^2}{2g}$



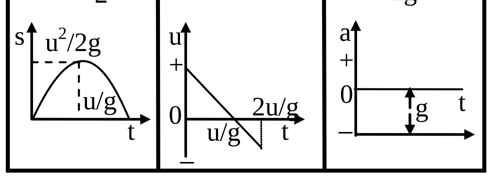
◆ Body is projected vertically up :

Taking initial position as origin and direction of motion (i.e. vertically up) as positive.

(a) At the highest point v = 0

(b) a = – g

t is given	h is given	u is given
$u = gt$ $h = \frac{1}{2}gt^2$	$t = \sqrt{2h/g}$ $u = \sqrt{2gh}$	$t = \frac{u}{g}$ $h = \frac{u^2}{2g}$



◆ It is clear that in case of motion under gravity

(a) Time taken to go up is equal to the time taken to fall down through the same distance.

(b) The speed with which a body is projected up is equal to the speed with which it comes back to the point of projection.

(c) The body returns to the starting point with the same speed with which it was thrown.

Ex.10 A body starts moving with an initial velocity 50 m/s and acceleration 20 m/s^2. How much distance it will cover in 4s ? Also, calculate its average speed during this time interval.

Sol. Given : u = 50 m/s, a = 20 m/s^2,
t = 4s, s = ?

$$s = ut + \frac{1}{2}at^2 = 50 \times 4 + \frac{1}{2} \times 20 \times (4)^2$$

$= 200 + 160 = 360$ m

Average speed during this interval,

$$\overline{V} = \frac{\text{distance travelled}}{\text{time interval}} = \frac{360}{4} = 90 \text{ m/s}$$

Ex.11 A body is moving with a speed of 20 m/s. When certain force is applied, an acceleration of 4 m/s^2 is produced. After how much time its velocity will be 80 m/s ?

Sol. Given : u = 20 m/s, a = 4 m/s^2,
v = 80 m/s, t = ?

Using equation, v = u + at, we get

$80 = 20 + 4 \times t$

or $4t = 80 - 20 = 60$

or $t = 15$ s

Therefore, after 15 seconds, the velocity of the body will be 80 m/s.

Ex.12 A body starts from rest and moves with a constant acceleration. It travels a distance s_1 in first 10 s, and a distance s_2 in next 10 s. Find the relation between s_2 and s_1.

Sol. Given : u = 0, t_1 = 10 s

∴ Distance travelled in first 10 seconds, is given by

$$s_1 = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times a \times (10)^2$$

$= 50a$ ...(1)

To calculate the distance travelled in next 10s, we first calculate distance travelled in 20 s and then subtract distance travelled in first 10 s.

$$s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times a \times (20)^2$$

$= 200a$ ...(2)

∴ Distance travelled in 10th second interval,

$s_2 = s - s_1 = 200a - 50a$ ...(3)

or $s_2 = 150a$

Now, $\frac{s_2}{s_1} = \frac{150a}{50a} = \frac{3}{1}$

or $s_2 = 3s_1$

Ex.13 A train is moving with a velocity 400 m/s. With the application of brakes a retardation of 10 m/s^2 is produced. Calculate the following :

(i) After how much time it will stop ?

(ii) How much distance will it travel before it stops?

Sol. (i) Given: u = 400 m/s, a = –10 m/s^2, v = 0, t = ?

Using equation, v = u + at, we get

$0 = 400 + (-10) \times t$

or $t = 40$ s

(ii) For calculating the distance travelled, we use equation,

$v^2 = u^2 + 2as$, we get

$(0)^2 = (400)^2 + 2 \times (-10) \times s$

or $20s = 400 \times 400$

or $s = 8000$ m = 8 km

Ex.14 A body is thrown vertically upwards with an initial velocity of 19.6 m/s. If g = –9.8 m/s^2. Calculate the following :

(i) The maximum height attained by the body.

(ii) After how much time will it come back to the ground ?

Sol.(i) Given: u = 19.6 m/s, g = –9.8 m/s^2, v = 0, h = ?

Using equation $v^2 = u^2 + 2gh$, we get

$(0)^2 = (19.6)^2 + 2(-9.8) \times h$

or $h = \frac{19.6 \times 19.6}{2 \times 9.8} = 19.6$ m

(ii) Time taken to reach the maximum height can be calculated by the equation,

$v = u + gt$

or $0 = 19.6 + (-9.8) \times t$

or $t = 2s$

In the same time, it will come back to its original position.

∴ Total time = 2 × 2 = 4s

Ex.15 From the top of a tower of height 490 m, a shell is fired horizontally with a velocity 100 m/s. At what distance from the bottom of the tower, the shell will hit the ground ?

Sol. We know that the horizontal motion and the vertical motion are independent of each other.

Now for vertical motion, we have $u = 0$, $h = 490$ m, $g = 9.8$ m/s^2, $t = ?$

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

$$490 = 0 + \frac{1}{2} \times 9.8 \times t^2$$

or $\quad t^2 = \frac{490}{4.9} = 100$

or $\quad t = 10$ s

∴ It takes 10 seconds to reach the ground.

Now, horizontal distance

= horizontal velocity × time

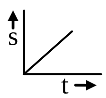
= 100 m/s × 10 s = 1000 m

∴ The shell will strike the ground at a distance of 100 m from the bottom of the tower.

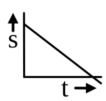
VARIOUS GRAPHS RELATED TO MOTION

Displacement- time graph :

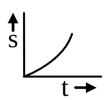
- The straight line inclined to time axis in s-t graph represents constant velocity.



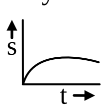
- In s-t graph the straight line inclined to time axis at angle greater than 90° shows negative velocity



- Body with accelerated motion

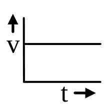


- Body with decelerated motion

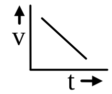


Velocity -time graph :

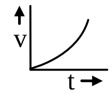
- For the body having constant velocity or zero acceleration.



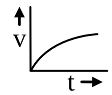
- The body is moving with constant retardation and its initial velocity is not zero.



- The body is accelerated and the initial velocity is zero.

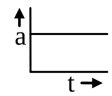


- The body is decelerated

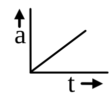


Acceleration-time graph :

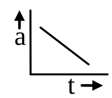
- Acceleration is constant



- Acceleration is increasing and is +ve



- Acceleration is decreasing and is –ve

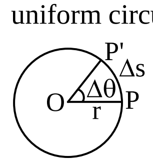


CIRCULAR MOTION

When a body moves in such a way that its distance from a fixed point always remains constant, then its motion is said to be the circular motion.

Uniform circular motion :

- If the radius vector sweeps out equal angles in equal times, then its motion is said to be uniform circular motion.



- In uniform circular motion speed remains const.
- Linear velocity, being a vector quantity, its direction changes continuously.
- The direction of velocity is along the tangent at every point.

◈ Angular velocity :

$$\omega = \frac{\Delta\theta}{\Delta t}$$

- A vector quantity
- Direction is perpendicular to plane of rotation

  Note : If the particle is revolving in the clockwise direction then the direction of angular velocity is perpendicular to the plane downwards. Whereas in case of anticlockwise direction, the direction will be upwards.
- Unit is Radian/sec.
- In uniform circular motion the direction of angular velocity is along the axis of rotation which is constant throughout.
- Angular velocity remains constant in magnitude as well as in direction.
- $v = r\omega$ where r = radius of the circle.

◈ Centripetal acceleration

- In uniform circular motion the particle experiences an acceleration called the centripetal acceleration.
- $a_c = \frac{v^2}{r}$
- The direction of centripetal acceleration is along the radius towards the centre.

◈ Centripetal force :

- Always acts towards centre.
- Centripetal force is required to move a particle in a circle.
- Because F_c is always perpendicular to velocity or displacement, hence the work done by this force will always be zero.

Note :

- Circular motion in horizontal plane is usually uniform circular motion.
- Remember that equations of motion are not applicable for circular motion.

◈ Time period :

- It is the time taken to complete one complete revolution.
- In one revolution, angle subtended is 2π and if T is time period, then the angular velocity is given by

$$\omega = \frac{2\pi}{T} \qquad \text{or} \qquad T = \frac{2\pi}{\omega}$$

◈ Frequency :

- Frequency is defined as the number of revolutions per second.

  i.e. $n = \frac{1}{T} = \frac{\omega}{2\pi}$

Ex.16 A particle moves in a circle of radius 2 m and completes 5 revolutions in 10 seconds. Calculate the following :

(i) Angular velocity and

(ii) Linear velocity.

Sol. Since, it completes 5 revolutions in 10 seconds.

$\therefore$ Time period $= \frac{10}{5} = 2s$

(i) Now angular velocity, $\omega = \frac{2\pi}{T} = \frac{2\pi}{2} = \pi$ rad/s

(ii) Linear velocity is given by

$v = r\omega = 2\pi$

$\therefore$ $v = 2\pi$ m/s

Ex.17 The length of second's needle in a watch is 1.2 cm. Calculate the following :

(i) Angular velocity and

(ii) Linear velocity of the tip of the needle.

Sol. (i) We know that the second's needle in a watch completes one revolution in 60 seconds.

$\therefore$ Time period, T = 60 s

Angular velocity,

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{60} = \frac{\pi}{30} \text{ rad/s}$$

(ii) Length of the needle = 1.2 cm = Radius of the circle

Linear velocity of the tip of the needle is given by

$$v = r\omega = 1.2 \times \frac{\pi}{30} = \frac{\pi}{25}$$

or $v = \frac{\pi}{2s} = 1.266 \times 10^{-1}$ cm/sec.

Ex.18 Earth revolves around the sun in 365 days. Calculate its angular velocity.

Sol. Time period,

$T = 365$ days

$= 365 \times 24 \times 60 \times 60$ seconds

$\therefore$ Angular velocity, $\omega = \dfrac{2\pi}{T}$

$= \dfrac{2\pi}{365 \times 24 \times 60 \times 60}$ rad/s $= 1.99 \times 10^{-7}$ rad/s.

A. Very Short Answer Type Questions

Q.1 Can the speed of a body moving with a constant velocity change ?

Q.2 Can the velocity of a body moving with a uniform speed change ?

Q.3 Can average velocity of a moving body be zero?

Q.4 Can average speed of a moving body be zero?

Q.5 Time-displacement graph is a straight line parallel to the time axis. What is its velocity and the acceleration ?

Q.6 What is the acceleration of a body moving with constant velocity ?

Q.7 A stone is thrown upwards, reaches a height h and comes back. What are the distance moved and displacement ?

Q.8 A particle moves along the circumference of a circle in half cycle. Calculate the distance travelled and displacement.

Q.9 Define uniform circular motion.

Q.10 What is the relation between linear velocity and angular velocity ?

Q.11 Does uniform circular motion has accelerated motion or no acceleration at all ?

Q.12 What is the direction of angular velocity ?

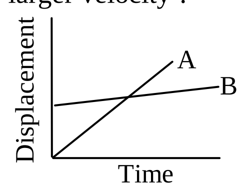
Q.13 In uniform circular motion, does the angular velocity remain constant or if changes with time.

Q.14 A car starts moving with 20 m/s and its velocity becomes 80 m/s after 6 sec. Calculate its acceleration.

Q.15 A body is thrown vertically up with a velocity 98 m/s. How much high it will rise ? (g = 9.8 m/s^2).

Q.16 A body falls from a height of 500 m. In how much time, will it strike the ground ?

Q.17 Time-displacement graphs of two bodies A and B are shown in the Figure. Which one has larger velocity ?



Q.18 The velocity of a body is 72 km/hr. Calculate its value in m/s.

B. Short Answer Type Questions

Q.19 Define state of motion.

Q.20 Differentiate between the following :

(i) speed and velocity,

(ii) distance and displacement

Q.21 Displacement of a body can be zero even when the distance travelled is not zero. Explain.

Q.22 What do you mean by negative and positive acceleration ? Explain.

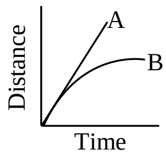
Q.23 A train is moving with a constant speed of 40 km/hr. Draw time-speed graph. From this, draw time-distance graph upto 5 hours from the start.

Q.24 Draw the graph for uniform motion.

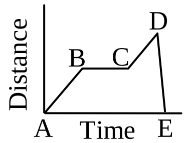
(i) Displacement - Time

(ii) Velocity - Time

Q.25 In the given figure A and B represent uniform motion or accelerated motion.

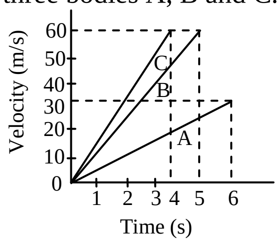


Q.26 In the given Figure. What type of motion are represented by the parts AB, BC, CD and DE.



Q.27 For a moving body distance travelled is directly proportional to the time. What do you conclude about its speed ?

Q.28 Figure shows the time velocity graphs for three bodies A, B and C.



(i) Which body has minimum acceleration ?
(ii) Which body has maximum acceleration ?

Q.29 A body starting with initial velocity u moves with a constant acceleration a. Find the expression for distance travelled in nth seconds.

Q.30 A body starting from rest moves with a constant acceleration. It moves a distance s_1 in first 5 seconds and a distance s_2 in next 5 seconds. Prove that $\Delta s_2 = 3s_1$.

Q.31 An engine is moving with a velocity 44 m/s. After applying the brakes, it stops after covering a distance of 121 m. Calculate retardation and time taken by the engine to stop.

Q.32 A body is thrown vertically up with an initial velocity of 60 m/s. If g = 10 m/s^2, at what time, it will be at a height of 100 m.

C. Long Answer Type Questions

Q.33 What do you mean by average speed ? How will you find average speed from time-distance graph ?

Q.34 What is the difference between time-speed and time-velocity graph ? In what condition, they are similar ?

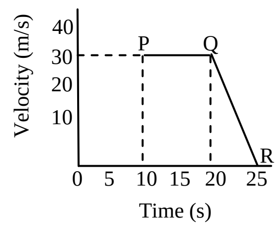
Q.35 What do you mean by acceleration ? How do you find acceleration from time-velocity graph?

Q.36 Time-velocity graph of a body is shown in figure Calculate the following :

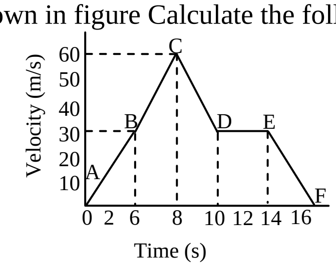
(i) Distance travelled in first 10 s

(ii) Acceleration at t = 15 s

(iii) Acceleration between t = 20 s to t = 25s.



Q.37 Time velocity graph of a moving body is shown in figure Calculate the following :



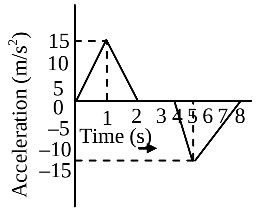
(i) Change in velocity during t = 6s to t = 8s

(ii) Average acceleration during t = 10s to t = 12s.

(iii) In which time interval acceleration will be zero.

(iv) Acceleration during t = 14 s to t = 16 s.

Q.38 Time-acceleration graph of a moving body is shown in figure Calculate the following :



(i) Time interval in which acceleration will be zero.

(ii) Acceleration at t = 5 s.

(iii) Change in velocity during time interval t = 4s and t = 8 s.

Q.39 An artificial satellite is moving in a circular orbit of radius 42, 250 km. Find its speed if it takes 24 hours to revolve round the earth.

Q.40 On 120 km track, a train travels the first 30 km with a uniform speed of 30 km/h. How fast must the train travel the next 90 km so as to average 60 km/hr for entire trip ?

EXERCISE-2

Single Correct Answer Type Questions

Q.1 A body whose position with respect to surrounding does not change, is said to be in a state of -
(A) Rest (B) Motion
(C) Vibration (D) Oscillation

Q.2 In case of a moving body-
(A) Displacement > Distance
(B) Displacement < Distance
(C) Displacement ≥ Distance
(D) Displacement ≤ Distance

Q.3 Vector quantities are those which have :
(A) Only direction
(B) Only Magnitude
(C) Magnitude and direction both
(D) None of these

Q.4 What is true about scalar quantities ?
(A) Scalars quantities have direction also.
(B) Scalars can be added arithmetically.
(C) There are special laws for scalar addition.
(D) Scalars have special method to represent.

Q.5 A body is said to be in motion if -
(A) Its position with respect to surrounding objects remains same
(B) Its position with respect to surrounding objects keep on changing
(C) both (A) and (B)
(D) Neither (A) nor (B)

Q.6 A distance is always-
(A) shortest length between two points
(B) path covered by an object between two points
(C) product of length and time
(D) none of the above

Q.7 A displacement-
(A) is always positive
(B) is always negative
(C) may be positive as well as negative
(D) is neither positive nor negative

Q.8 Examples of vector quantities are:
(A) velocity, length and mass
(B) speed, length and mass
(C) time, displacement and mass
(D) velocity, displacement and force

Q.9 Which of the following is not characteristic of displacement ?
(A) It is always positive.
(B) It has both magnitude and direction.
(C) It can be zero.
(D) Its magnitude is less than or equal to the actual path length of the object.

Q.10 S.I. unit of displacement is-
(A) m (b) ms^{-1}
(C) ms^{-2} (D) none of these

Q.11 Which of the following is not a vector?
(A) Speed (B) Velocity
(C) Weight (D) Acceleration

Q.12 Time is an example of:-
(A) Scalar
(B) Vector
(C) Scalar or vector
(D) Neither scalar nor vector

Q.13 In five minutes distance between a pole and a car changes progressively. What is true about the car ?
(A) Car is at rest
(B) Car is in motion
(C) Nothing can be said with this information
(D) None of the above

Q.14 A distance -
(A) Is always positive
(B) Is always negative
(C) May be positive as well as negative
(D) Is neither positive nor negative

Q.15 When a body covers equal distance in equal intervals of time, its motion is said to be :
(A) Non-uniform
(B) Uniform
(C) Accelerated
(D) Back and forth

Q.16 The motion along a straight line is called:
(A) Vibratory (B) Stationary
(C) Circular (D) Linear

Q.17 A particle is traveling with a constant speed. This means-
(A) Its position remains constant as time passes
(B) It covers equal distances in equal interval of time
(C) Its acceleration is zero
(D) It does not change its direction of motion

Q.18 The rate of change of displacement is -
(A) Speed (B) Velocity
(C) Acceleration (D) Retardation

Q.19 Speed is never -
(A) Zero (B) Fraction
(C) Negative (D) Positive

Q.20 The motion of a body covering different distances in same intervals of time is said to be -
(A) Zig-Zag (B) Fast
(C) Slow (D) Variable

Q.21 Unit of velocity is :
(A) ms (B) ms^{-1}
(C) ms^{-2} (D) none of these

Q.22 Metre per second is not the unit of -
(A) Displacement (B) Velocity
(C) Speed (D) None of them

Q.23 A particle moves with a uniform velocity -
(A) The particle must be at rest
(B) The particle moves along a curved path
(C) The particle moves along a circle
(D) The particle moves along a straight line

Q.24 A quantity has value of $-6.0\ ms^{-1}$. It may be the-
(A) Speed of a particle
(B) Velocity of a particle
(C) Position of a particle
(D) Displacement of a particle

Q.25 In 10 minutes, a car with speed of 60 kmh^{-1} travels a distance of -
(A) 6 km (B) 600 km
(C) 10 km (D) 7 km

Q.26 A particle covers equal distances in equal intervals of time, it is said to be moving with uniform-
(A) Speed (B) Velocity
(C) Acceleration (D) Retardation

Q.27 The SI unit of the average velocity is -
(A) m/s (B) km/s
(C) cm/s (D) mm/s

Q.28 A car accelerates uniformly from 18 km/h to 36km/ h in 5 s. The acceleration in ms^{-2} is -
(A) 1 (B) 2
(C) 3 (D) 4

Q.29 Out of energy and acceleration which is vector ?
(A) Acceleration (B) Energy
(C) Both (D) None of these

Q.30 C.G.S. unit of acceleration is -
(A) ms^{-2} (B) $cm\ s^{-2}$
(C) ms^{-2} (D) $cm\ s^{2}$

Q.31 A train starting from a railway station and moving with uniform acceleration, attains a speed of 40 kmh^{-1} in 10 minutes. Its acceleration is -

(A) 18.5 ms^{-2} (B) 1.85 cm s^{-2}

(C) 18.5 cms^{-2} (D) 1.85 m s^{-2}

Q.32 The brakes applied to a car produce a negative acceleration of $6ms^{-2}$. If the car stops after 2 seconds, the initial velocity of the car is -

(A) 6 ms^{-1} (B) 12 ms^{-1}

(C) 24 ms^{-1} (D) Zero

Q.33 A body is moving with uniform velocity of 10 ms^{-1}. The velocity of the body after 10 s is -

(A) 100 ms^{-1} (B) 50 ms^{-1}

(C) 10 ms^{-1} (D) 5 ms^{-1}

Q.34 In 12 minutes a car whose speed is 35 kmh^{-1} travels a distance of -

(A) 7 km (B) 3.5 km

(C) 14 km (D) 28 km

Q.35 A body is moving along a straight line at 20 ms^{-1} undergoes an acceleration of 4 ms^{-2}. After 2 s, its speed will be-

(A) 8 ms^{-1} (B) 12 ms^{-1}

(C) 16 ms^{-1} (D) 28 ms^{-1}

Q.36 A car increase its speed from 20 kmh^{-1} to 50 kmh^{-1} in 10 s., its acceleration is -

(A) 30 ms^{-2} (B)3 ms^{-1}

(C) 18 ms^{-2} (D) 0.83 ms^{-2}

Q.37 When the distance travelled by an object is directly proportional to the time, it is said to travel with-

(A) zero velocity
(B) constant speed
(C) constant acceleration
(D) uniform velocity

Q.38 A body freely falling from rest has a velocity v after it falls through a height h. The distance it has to fall further for its velocity to become double is -

(A) 3 h (B) 6 h

(C) 8 h (D) 10 h

Q.39 The velocity of a bullet is reduced from 200 m/s to 100 m/s while travelling through a wooden block of thickness 10 cm. The retardation, assuming it to be uniform, will be

(A) 10×10^4 m/s^2 (B) 1.2 x 10^4 m/s^2

(C) 13.5×10^4 m/s^2 (D) 15 x 10^4 m/s^2

Q.40 A body starts falling from height 'h' and travels distance h/2 during the last second of motion. The time of travel (in sec.) is-

(A) $\sqrt{2}-1$ (B) $2+\sqrt{2}$

(C) $\sqrt{2}+\sqrt{3}$ (D) $\sqrt{3}+2$

Q.41 Area between speed-time graph and time axis gives-

(A) Distance (B) Velocity

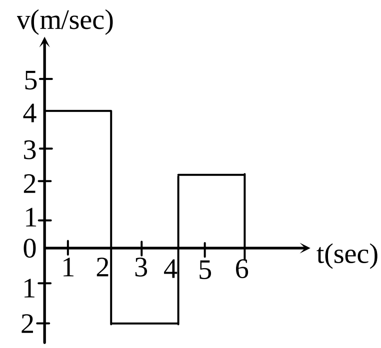
(C) Speed (D) None of these

Q.42 An object undergoes an acceleration of $8ms^{-2}$ starting from rest. Distance travelled in 1 sec. is-

(A) 2 m (B) 4 m

(C) 6 m (D) 8 m

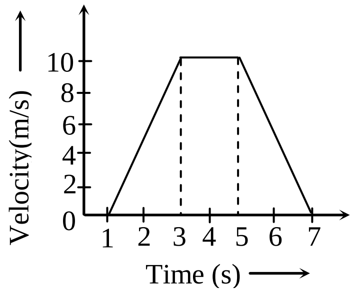
Q.43 The velocity-time graph of a body moving in a straight line is shown in figure. The displacement and distance travelled by the body in 6 second are respectively-



(A) 8m , 16m (B) 16m, 8m

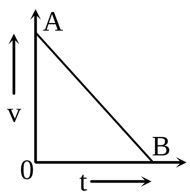
(C) 16m, 16m (D) 8m, 8m

Q.44 For the velocity time graph shown in figure, the distance covered by the body in the last two seconds of its motion is what fraction of the total distance covered in all the seven seconds ?



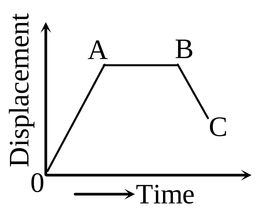
(A) 1/2 (B) 1/4
(C) 1/3 (D) 2/3

Q.45 Velocity-time graph AB (Figure) shows that the body has-



(A) A uniform acceleration
(B) A non uniform retardation
(C) Uniform speed
(D) Initial velocity OA and is moving with uniform retardation

Q.46 In figure BC represents a body moving-



(A) Backwards with uniform velocity
(B) Forward with uniform velocity
(C) Backward with non-uniform velocity
(D) Forward with non-uniform velocity

Q.47 1^C is equal to-
(A) 57.3° (B) 573°
(C) 180° (D) 360°

Q.48 An athlete complete one round of a circular track of diameter 200 m in 40 s. What will be the displacement at the end of 2 minutes 40 s. ?
(A) 2200 m (B) 220 m
(C) 22 m (D) Zero

Q.49 What will be the distance in the above question?
(A) 2512 m (B) 2500 m
(C) 2200 m (D) Zero

Q.50 The distance travelled by a body is directly proportional to the time, then the body is said to have -
(A) Zero speed (B) Zero velocity
(C) Constant speed (D) None of these

Q.51 An athlete runs along a circular track of diameter 28 m. The displacement of the athlete after he completes one circle is -
(A) 28 m (B) 88 m
(C) 44 m (D) Zero

Q.52 A boy is running along a circular track of radius 7 m. He completes one circle in 10 second. The average velocity of the boy is -
(A) 4.4 ms^{-1} (B) 0.7 ms^{-1}
(C) Zero (D) 70 ms^{-1}

Q.53 A body is moving with a uniform speed of 5 ms^{-1} in a circular path of radius 5 m. The acceleration of the body is:
(A) 25 ms^{-2} (B) 15 ms^{-2}
(C) 5 ms^{-2} (D) 1 ms^{-2}

Q.54 Unit of angular velocity is –
(A) rad (B) m/s
(C) rad/s^2 (D) rad/s

Q.55 Two bodies in circular paths of radii 1 : 2 take same time to complete their circles. The ratio of their linear speeds is-
(A) 1 : 2 (C) 2 : 1
(C) 1: 3 (D) 3 : 1

Q.56 In a circular path of radius 1 m, a mass of 2 kg moves with a constant speed of 10 ms^{-1}. The angular speed in radian/sec. is -
(A) 5 (B) 10
(C) 15 (D) 20

Q.57 The relation among v, ω and r is -
(A) $\omega = \frac{v}{r}$ (B) $v = \frac{\omega}{r}$
(C) $\omega = \frac{r}{v}$ (D) None of these

Q.58 Uniform circular motion is an example of :
(A) Constant acceleration
(B) Variable acceleration
(C) A and B both
(D) None of these

Q.59 Rate of change of angular velocity refer to :
(A) angular speed
(B) angular displacement
(C) angular acceleration
(D) None of these

Q.60 A car travels $\left(\frac{1}{4}\right)^{th}$ of a circle with radius r. The ratio of the distance to its displacement is-
(A) $1:\frac{\pi}{2\sqrt{2}}$ (B) $\frac{\pi}{2\sqrt{2}}:1$
(C) $2\sqrt{2}:\pi$ (D) $\pi 2\sqrt{2}:1$

ANSWER KEY

EXERCISE - 1

1. no **2.**yes **3.** yes
4. no **5.** 0, 0 **6.** 0
7. 2h, 0 **8.** πr, 2r **10.** v = rω
11. accelerated motion **12.** along the axis of rotation **13.** remains constant
14. 10m/sec^2 **15.** 490 m **16.** 10s
17. A **18.** 20 m/sec
27.A$\rightarrow$uniform motion, B$\rightarrow$accelerated motion **28.** (i) A, (ii) C
31. 8 m/sec^2, 5.5s **32.** 2s, 10s **36. (**i) 300 m (ii) 0 m/s^2, (iii) –6 m/s^2
37. (i) 30 m/s, (ii) 0, (iii) 10 to 14 s, (iv) – 15 m/s^2 **38.** (i) 2 to 4s, (ii) – 15 m/s^2 (iii) 30 m/s
39. 3.1 km/sec **40.** 90 km/h

EXERCISE - 2

Ques	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Ans	A	D	C	B	B	B	C	D	A	A	A	A	B	A	B
Ques	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Ans	D	B	B	C	D	B	A	D	B	C	A	A	A	A	B
Ques	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
Ans	B	B	C	A	D	D	B	A	D	B	A	B	A	B	D
Ques	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
Ans	A	A	D	A	C	D	C	C	D	A	B	A	B	C	B

NCERT QUESTIONS

Exercises

1. An athlete completes one round of a circular track of diameter 200 m in 40 *s*. What will be the distance covered and the displacement at the end of 2 minutes 20 s?
2. Joseph jogs from one end A to the other end B of a straight 300 m road in 2 minutes 50 seconds and then turns around and jogs 100 m back to point C in another 1 minute. What are Joseph's average speeds and velocities in jogging (a) from A to B and (b) from A to C?
3. Abdul, while driving to school, computes the average speed for his trip to be 20 km h^{-1}. On his return trip along the same route, there is less traffic and the average speed is 40 km h^{-1}. What is the average speed for Abdul's trip?
4. A motorboat starting from rest on a lake accelerates in a straight line at a constant rate of 3.0 m s^{-2} for 8.0 s. How far does the boat travel during this time?
5. A driver of a car travelling at 52 km h^{-1} applies the brakes and accelerates uniformly in the opposite direction. The car stops in 5 s. Another driver going at 3 km h^{-1} in another car applies his brakes slowly and stops in 10 s. On the same graph paper, plot the speed versus time graphs for the two cars. Which of the two cars travelled farther after the brakes were applied?
6. Fig 8.11 shows the distance-time graph of three objects A,B and C. Study the graph and answer the following questions:

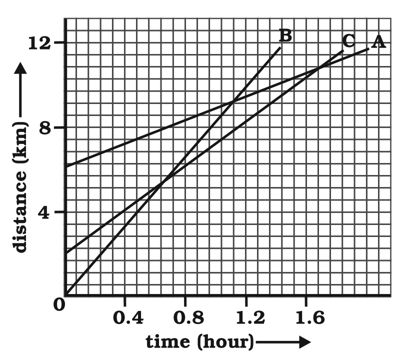


Fig. 8.11

(a) Which of the three is travelling the fastest?

(b) Are all three ever at the same point on the road?

(c) How far has C travelled when B passes A?

(d) How far has B travelled by the time it passes C?

7. A ball is gently dropped from a height of 20 m. If its velocity increases uniformly at the rate of 10 m s^{-2}, with what velocity will it strike the ground? After what time will it strike the ground?

8. The speed-time graph for a car is shown is Fig. 8.12.

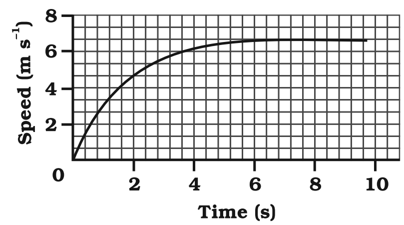


Fig. 8.12

(a) Find how far does the car travel in the first 4 seconds. Shade the area on the graph that represents the distance travelled by the car during the period.

(b) Which part of the graph represents uniform motion of the car?

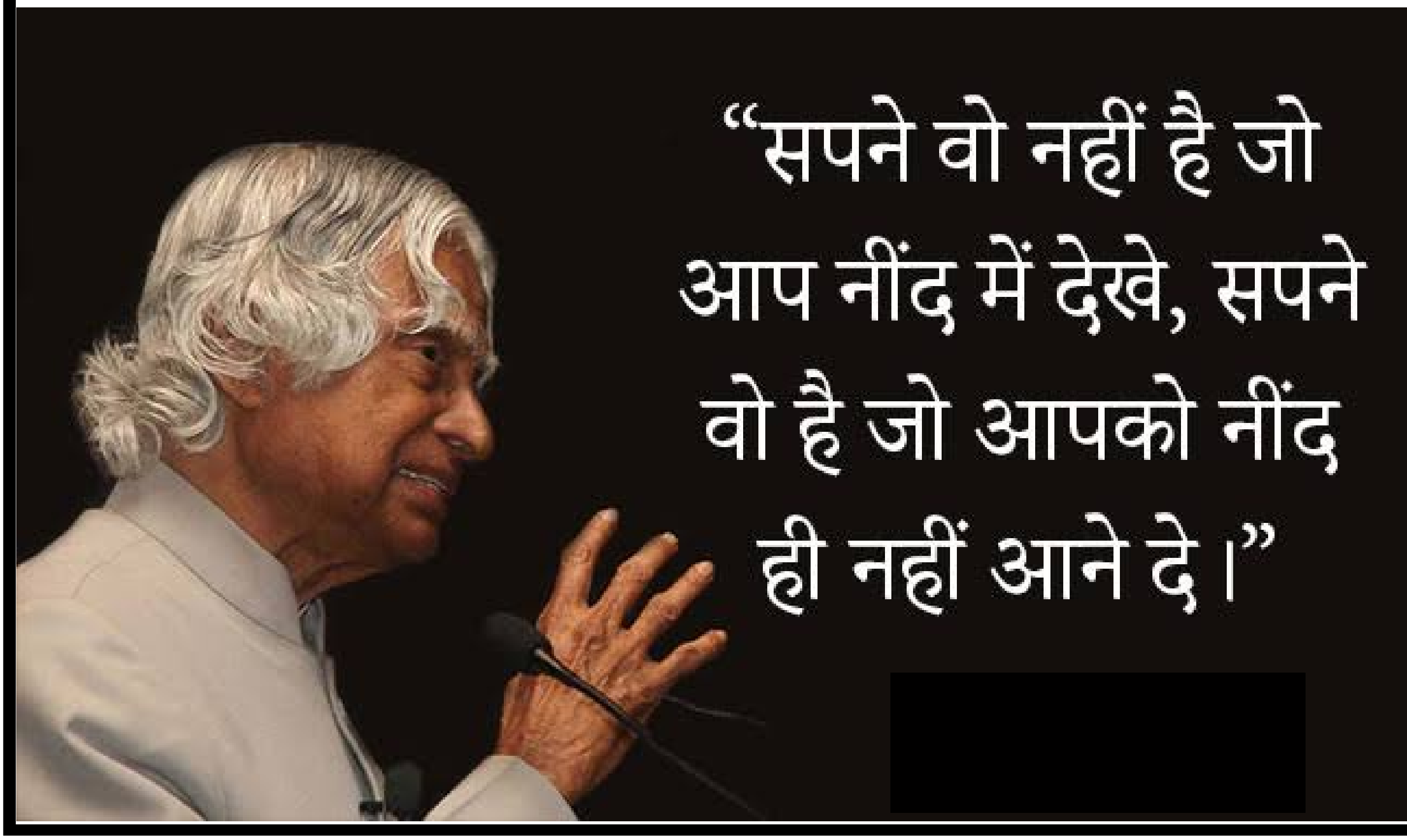
9. State which of the following situations are possible and give an example for each of these:

(a) an object with a constant acceleration but with zero velocity

(b) an object moving in a certain direction with an acceleration in the perpendicular direction.

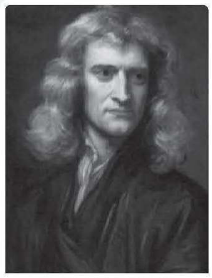
10. An artificial satellite is moving in a circular orbit of radius 42250 km. Calculate its speed if it takes 24 hours to revolve around the earth.

Newtons Law of Motion



BRAIN MAP

LAWS OF MOTION



SIR ISSAC NEWTON
(1643-1727)

LAWS OF MOTION AND THEIR CONSEQUENCES

Newton's 1st Law
A body continues its state of rest or motion until unless an external force is acted on it.

Inertia of Rest
The property of a body due to which it cannot change its state of rest by itself.

Inertia of Direction
The property due to which a body cannot change its direction of motion by itself.

Inertia of Motion
The tendency of a body to remain in a state of uniform motion in a straight line.

Newton's 2nd Law
The rate of change of linear momentum of a body is directly proportional to the external force applied on the body in the direction of force.

Introduces the Concept of Force

Force = mass × acceleration
$F = ma$, SI unit ≡ N

Newton's 3rd Law
To every action there is always an equal and opposite reaction
$\vec{F}_{AB} = -\vec{F}_{BA}$

Impulse
A large force acts for a very short duration of time producing a finite change in momentum.
$J = F \times t = \Delta p$

Conservation of Linear Momentum
Total momentum of an isolated system of interacting particles is conserved if there is no external force acting on it. $P_{\text{initial}} = P_{\text{final}}$

Friction
Resistance offered to the relative motion between the surface of the two bodies in contact.

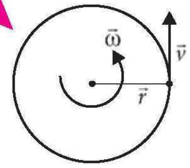
- Acceleration of a body sliding down a rough inclined plane, $a = g(\sin\theta - \mu\cos\theta)$
- Angle of friction, $\theta = \tan^{-1}(\mu_s)$.
- Angle of repose, $\alpha = \tan^{-1}(\mu_s)$.
- Numerically, $\alpha = \theta$

Types of Friction
(a) Static friction : acts when a body is at rest on application of a force, $f_s = F_{\text{ext}}$
(b) Limiting friction : acts when a body is just at the verge of movement, $f_l = \mu_s N$
(c) Kinetic friction : acts when a body is actually sliding, $f_l = \mu_s N$

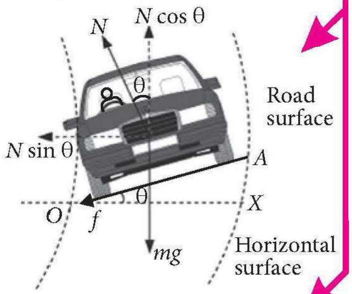
CIRCULAR MOTION IN HORIZONTAL PLANE

Circular Motion
A body moving in a circular path is called circular motion.
Centripetal force $F_e = \dfrac{mv^2}{r}$

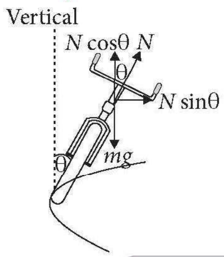
Non-uniform circular motion
Acceleration, $\vec{a} = \vec{a}_T + \vec{a}_C = \vec{\alpha}\times\vec{r} + \vec{\omega}\times\vec{v}$
$a = \sqrt{a_T^2 + a_C^T}$



Motion of a Car on Banked Road
- Maximum velocity on banked road to avoid skidding
$v_{\max} = \sqrt{\dfrac{rg(\mu_s + \tan\theta)}{(1-\mu_s\tan\theta)}}$
- Optimum speed on a smooth banked road
$v_0 = \sqrt{rg\tan\theta}$



Bending of a Cyclist on a circular turn
Angle of bending
$\theta = \tan^{-1}\left(\dfrac{v^2}{rg}\right)$



Motion of a Car on Level Road
Maximum velocity on a curved road to avoid skidding
$v_{\max} = \sqrt{\mu_s rg}$

Problem Solving Techniques in Mechanics
- Make free body diagram of each element showing all external forces acting on it.
- Analyse the magnitude and direction of pseudo forces if there is any.
- For equilibrium of concurrent forces use
$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ... + \vec{F}_n = 0$
$\dfrac{F_1}{\sin\alpha} = \dfrac{F_2}{\sin\beta} = \dfrac{F_3}{\sin\gamma}$ (Lami's theorem)
- For horse cart type system
$a = \dfrac{F_x - f}{M_H + M_{\text{cart}}}$ F_x = horizontal component of reaction, f = frictional force

BRAIN MAP

NEWTON'S LAWS OF MOTION

Problem Solving Strategies

- *Identify the unknown forces and accelerations.*
- *Draw FBD of bodies in the system.*
- *Resolve forces into their components.*
- *Apply $\Sigma\vec{F} = M\vec{a}$ in the direction of motion.*
- *Apply $\Sigma\vec{F} = 0$ in the direction of equilibrium.*
- *Write constraint relation if exists.*
- *Solve equations $\Sigma\vec{F} = M\vec{a}$ and $\Sigma\vec{F} = 0$.*

LAWS OF MOTION AND THEIR CONSEQUENCES

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- Inertia of rest
- Inertia of motion
- Inertia of direction

Newton's 2nd Law

The rate of change of linear momentum of a body is directly proportional to the external force applied on the body in the direction of force.

$$F = \frac{dp}{dt} = ma$$

Newton's 3rd Law

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

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

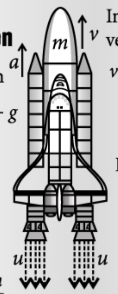
Pseudo Force

For non-inertial frame of reference

$$\vec{F}_{ext} + \vec{F}_{Pseudo} = M\vec{a}$$

$$\vec{F}_{pseudo} = -M\vec{a}_{frame}$$

Rocket Propulsion



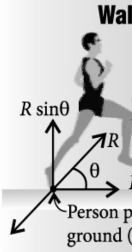
Acceleration $a = \frac{u}{m}\frac{dm}{dt} - g$

Instantaneous velocity $v = u\log_e\left(\frac{m_0}{m_r}\right) - gt$

Burn out speed $v_{max} = u\log_e\left(\frac{m_0}{m_r}\right)$

Thrust $F = -u\frac{dm}{dt}$

Walking



Ground pushes the person (reaction)

Person presses the ground (action)

Horse Cart Type System

For horse cart type system

$$a = \frac{F_x - f}{M_H + M_{cart}}$$

F_x = horizontal component of reaction force

f = frictional force

FRICTION

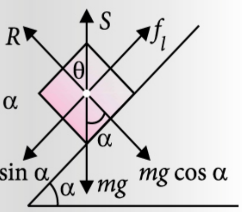
The motion resisted by a bonding between the body and the surface in contact represented by single force called

Angle of Friction (θ) and Angle of Repose (α)

$$S = \sqrt{R^2 + f_l^2}$$

$$\tan\theta = \frac{f_l}{R} = \mu_s = \tan\alpha$$

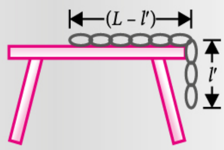
∴ Numerically, $\theta = \alpha$



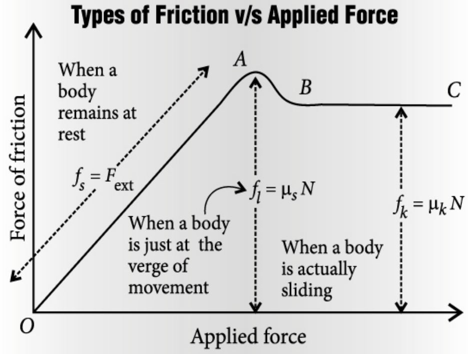
Maximum Length of Hanging Chain

Length of a chain hanging in air

$$l' = \frac{\mu L}{1+\mu}$$

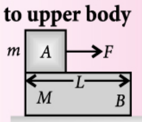


Types of Friction v/s Applied Force

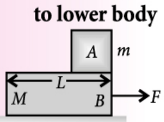


Motion of Two Bodies One Resting on the Other

Force F applied to upper body



Force F applied to lower body



Force applied to upper body:

- **When there is no friction**
  - $a_A = F/m$; $a_B = 0$
  - A will fall from B after time $t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2mL}{F}}$
- **Friction present between A and B ($F < f_l$)**
  - Combined system will move together with $a = F/(M+m)$
- **Friction present between A and B ($F > f_l$)**
  - Relative acceleration $a = a_A - a_B = \frac{MF - \mu_k mg(m+M)}{mM}$
  - A will fall from B after time $t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2mML}{MF - \mu_k mg(m+M)}}$

Force applied to lower body:

- **When there is no friction**
  - $a_B = F/M$ and $a_A = 0$
  - A will fall from B (backward) after time t
  - ∴ $t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2ML}{F}}$
- **Friction present between A and B ($F < f_l$)**
  - Both the bodies will move together $a = \frac{F}{M+m}$ and $f_l = \mu_s mg$
  - Pseudo force on the body A, $F' = ma = \frac{mF}{m+M}$
- **Friction present between A and B ($F > f_l$)**
  - Relative acceleration $a = a_A - a_B = -\left[\frac{F - \mu_k g(m+M)}{M}\right]$
  - A will fall from B (backward) after time $t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2ML}{F - \mu_k g(m+M)}}$

CONTENTS

- Force
- Newton´s Laws of Motion
- Law of Conservation of Momentum
- Friction
- Thrust and Pressure
- Buoyancy
- Density

FORCE

The external agent which tends to set a body in motion or which changes the speed and direction of motion of a body or which can change the shape of a body is called force. SI unit of force is newton.

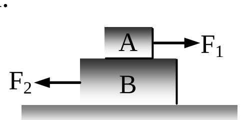
Types of forces :

(a) non contact :

These are the forces in which contact between two objects is not necessary. Gravitational force between two bodies and electrostatic force between two charges are two examples of field forces.

(b) Contact forces :

Two bodies in contact exert equal and opposite forces on each other. If the contact is frictionless the contact force is perpendicular to the common surface and known as normal reaction.



If, however, the objects are in rough contact and move (or have a tendency to move) relative to each other without losing contact then frictional force arise which oppose such motion. Again each object exerts a frictional force on the other and the two forces are equal and opposite. This force is perpendicular to normal reaction. Thus, the contact force (F) between two objects is made up of two forces.

(i) Normal reaction (N) (ii) Force of friction (f) and since these two forces are mutually perpendicular.

$$F = \sqrt{N^2 + f^2}$$

NEWTON'S LAWS OF MOTION

(A) Newton´s Ist law :

A body can not change its state of motion by itself. If the object is at rest it will remain at rest and if it is in uniform motion, it continues to be in motion unless some external force is applied on it.

Inertia :

- There is an inherent property of an object by virtue of which it cannot change its state of motion or rest by itself. This property is called 'inertia'.
- Inertia is of two types– inertia of rest and inertia of motion.

(a) Inertia of rest:

If the body is at rest, it will continue to be at rest unless some external force is applied on it. Examples are following.

Ex. When a train at rest starts moving suddenly, a passenger standing inside the compartment tends to fall backward.

Ex. When a carpet is beaten up with a stick, the dust particles are detached.

Ex. When a bullet is fired into a glass pane, it pierces a hole only at the pt where the bullet hits the glass without breaking the entire glass pane into pieces.

(b) Inertia of motion :

When a body is in uniform motion, it will continue to remain in its uniform motion, i.e. it resists any change in its state of motion due to inertia of motion.

Ex. when a person jumps out of a moving bus, he should run in the direction in which bus is moving otherwise he will fall down.

Ex. A train moving with a uniform speed and if a ball is thrown upwards inside the train by a passenger, then the ball comes back to his hand.

◆ **Relation between mass and inertia :**

Larger the mass of the body, larger is the inertia.

Ex. eg : it is more difficult to stop a cricket ball than a tennis ball.

(B) Newton's second law of motion

Momentum : The product of mass and velocity is called 'momentum'. i.e. $p = m\vec{v}$

(a) Unit : SI unit of momentum is kg-m/s.

(b) It is a vector quantity.

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

(a) i.e. $F = \frac{P_2 - P_1}{t}$ or $F = m\left(\frac{v-u}{t}\right) = m\vec{a}$

where p_1 = initial momentum = mu

p_2 = final momentum = mv

(b) Unit of force in SI system is newton.

(c) 1N is equivalent to that force which can produce an acceleration of $1 m/s^2$ in a body of mass 1 kg.

(d) Unit of force in CGS system is dyne.

1 dyne = 1 gm - cm/s^2

1 N = 10^5 dynes

Ex.1 Calculate the force required to produce an acceleration of 5 m/s^2 in a body of mass 2.4 kg.

Sol. We know that force = mass × acceleration

= 2.4 kg × 5 m/s^2

= 12.0N

Ex.2 A body of mass 2.5 kg is moving with a velocity of 20 m/s. Calculate its momentum.

Sol. Momentum, p = mass × velocity

Here, mass m = 2.5 kg

Velocity, v = 20 m/s

∴ Momentum, p = mv = 2.5 × 20 kg-m/s

= 50 kg-m/s

◈Impulse :

◆ If a force F is applied on a body of mass m for a time interval Δt and if the change in velocity is Δv then

∴ Impulse = F dt = m Δ v

Impulse = change in momentum

◆ Unit of impulse is newton × second,

Examples of impulse

Ex. While catching a cricket ball a player moves his hands backwards. Cricket ball coming towards fielder has a large momentum. By doing so he increases the time interval to reduce the momentum of the ball. Rate of change of momentum becomes slow.

Ex.3 A force acts for 0.2 s on a body of mass 2.5 kg initially at rest. The force then ceases to act and the body moves through 4m in the next one second. Calculate the magnitude of force.

Sol. When the force ceases to act, the body will move with a constant velocity. Since it moves a distance of 4 m in 1 s, therefore, its uniform velocity = 4m/s.

Now, initial velocity, u = 0

Final velocity, v = 4 m/s

Time interval Δt = 0.2 s

∴ Acceleration, $a = \frac{v-u}{\Delta t} = \frac{4-0}{0.2} = 20 m/s^2$

Force, F = 2.5 × 20 = 50 N

Ex.4 A ball of mass 20 gm is initially moving with a velocity of 100 m/s. On applying a constant force on the ball for 0.5s, it acquires a velocity of 150 m/s. Calculate the following :

(i) Initial momentum of the ball

(ii) Final momentum of the ball

(iii) Rate of change of momentum

(iv) Acceleration of the ball

(v) Magnitude of the force applied

Sol. Given, m = 20 gm = $\frac{20}{1000}$ kg = 0.02 kg

Initial velocity, u = 100 m/s

Time interval, t = 0.5 s

Final velocity, v = 150 m/s

(i) Initial momentum of the ball

= mass × initial velocity

or $P_1 = mu = 0.02 \text{ kg} \times 100 \text{ m/s}$

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

(ii) Final momentum of the ball

= mass × final velocity

or $P_2 = mv = 0.02 \text{ kg} \times 150 \text{ m/s}$

$= 3 \text{ kg-ms}^{-1}$

(iii) Rate of change of momentum

$= \frac{\text{Final momentum} - \text{Initial momentum}}{\text{Time}}$

or $\frac{\Delta P}{\Delta t} = \frac{3-2}{0.5} = \frac{1}{0.5} = 2.0 \text{ kg-ms}^{-1} = 2.0\text{N}$

(iv) Acceleration, $a = \frac{v-u}{t} = \frac{150-100}{0.5}$

$= 100\text{ms}^{-2}$

(v) Force, F = mass × acceleration

= 0.02 × 100 = 2.0 N

Ex.5 A cricket ball of mass 200 gm moving with a speed of 40 m/s is brought to rest by a player in 0.04s. Calculate the following :

(i) change in momentum of the ball,

(ii) average force applied by the player.

Sol. Mass, m = 200 gm = $\frac{200}{1000}$ kg = 0.2 kg

Initial velocity, u = 40 m/s

Final velocity, v = 0

Time, t = 0.04 s

(i) Initial momentum, $p_1 = mu = 0.2 \text{ kg} \times 40 \text{ m/s}$

$= 8.0 \text{ kg-ms}^{-1}$

Final momentum, $p_2 = m \times v = 0.2 \times 0$

$= 0 \text{ kg-ms}^{-1}$

Change in momentum, $\Delta p = p_2 - p_1$

$= 0 - 8.0 \text{ kg ms}^{-1} = -8.0 \text{ kg-ms}^{-1}$

(ii) Average force = $\frac{\text{Change in momentum}}{\text{Time}}$

$= \frac{-8.0-0}{0.04} = -200$ N

(The negative sign shows that the force is applied in a direction opposite to the direction of motion of the ball).

Ex. 6 A motorcycle is moving with a velocity of 108 km/hr and it takes 5 s to stop it after the brakes are applied. Calculate the force exerted by the brakes on the motorcycle if its mass along with the rider is 250 kg.

Sol. Given that initial velocity of the motorcycle = 108 km/hr = 30 m/s

Final velocity = 0 m/s

Time taken to stop = 5s, the mass of the motorcycle with rider = 250 kg.

The change in the velocity of the motorcycle in 5s = 0 – 30 = –30 m/s

Therefore, the acceleration of the motorcycle,

$a = \frac{-30}{5} = -6 \text{ m/s}^2$

The magnitude of the force applied by the brakes is given by the equation,

F = mass × acceleration

$= 250 \text{ kg} \times (6)\text{m/s}^2 = 1500$ N

(C) Newton's third law of motion

Newton's first law of motion gives a qualitative idea of force, while the second law provides us an idea to measure the force.

- **Newton's third law of motion states that** " if a body A exerts a force on the body B, the body B will also exert an equal and opposite force on A."

  The force exerted by A on B is called action while the force exerted by B on A is called the reaction.
- Newton's third law is also stated as "to every action there is an equal and opposite reaction."
- Forces always occur in pairs.
- Action and reaction always act on different bodies.

Ex. by hitting a table with palm we apply a force. The table also exerts a force on palm on hitting it.

❖ Applications of Newtons III law :

- Recoil of a gun – when the bullet is fired from a gun, an equal and opposite force is applied on the gun, due to which the gun recoils in backward direction.

- Application in walking : while moving in forward direction we push the ground backwards that is the action. An equal and opposite force is applied by the ground on the man, thus the reaction due to which man moves forward.
- Rowing a boat in river : when we push the water backward with the help of oars (applying a force backward), an equal and opposite force acts on the boat. This is the reaction which moves the boat forward.
- Launching Rocket : In rocket, gases are produced in large amount. Due to internal combustion they come out and move backwards with an equal and opposite force which in turn acts on the rocket and moves it forward.

➢ LAW OF CONSERVATION OF MOMENTUM

- According to law of conservation of momentum "if there is no force acting on a system, the momentum of the system remains unchanged."
- Generalizing the situation " if a group of bodies are exerting force on each other, their total momentum remains conserved before and after the interaction provided there is no external force acting on them."

  i.e. $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Ex.7 A rifle of mass 5 kg fires a bullet of mass 40 gm. The bullet leaves the barrel of the rifle with a velocity 200 m/s. If the bullet takes 0.004 s to move through the barrel, calculate the following:

(i) recoil velocity of the rifle and

(ii) the force experienced by the rifle due to its recoil.

Sol. (i) Given mass of the rifle, $m_1 = 5$ kg

Mass of the bullet, $m_2 = 40$ gm $= 0.04$ kg

Initial velocities, $u_1 = 0$, $u_2 = 0$

After firing velocity of the bullet, $v_2 = 200$ m/s

Velocity of the rifle, $v_1 = ?$

Applying the law of conservation of momentum, we get

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

or $\quad 0 + 0 = 5 \times v_1 + 0.04 \times 200$

or $\quad v_1 = -\dfrac{0.04 \times 200}{5} = -1.6$ m/s

(ii) Initial momentum of the rifle = 0

Final momentum of the rifle $= 5$ kg $\times(-1.6)$

$= -B$ kg-m/s

Time interval = 0.004 s

$\therefore$ Force $= \dfrac{\text{Change in momentum}}{\text{Time interval}}$

$= \dfrac{-8\text{kg}-\text{ms}^{-1}}{0.004} = -2000$ N

Ex.8 A bullet of mass 20 gm moving with a velocity 200 m/s gets embedded into a wooden block of mass 980 gm suspended by a string. Calculate velocity acquired by the combined system.

Sol. Mass of the bullet, $m_1 = 20$ gm

$= \dfrac{20}{1000}$ kg $= 0.02$ kg

Velocity of the bullet, $u_1 = 200$ m/s

Momentum of the bullet $= m_1u_1$

$= 0.02 \times 200$ kg-m/s $= 4$ kg-m/s

Now, the bullet gets embedded into a wooden block of mass 980 gm. The mass of the block and bullet = 980 + 20

= 1000 gm = 1kg

Let the velocity of the combined system = v

$\therefore$ Momentum of the combined system

$= 1 \times v$ kg-m/s $= v$ kg-m/s

Now, applying the law of conservation of momentum,

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

or $\quad 4 = v \qquad \therefore v = 4$ m/s = 4 kg m/s

Ex.9 A rifle man, who together with his rifle has a mass of 100 kg, stands on a smooth surface fires 10 shots horizontally. Each bullet has a mass 10 gm a muzzle velocity of 800 m/s. What velocity does rifle man acquire at the end of 10 shots?

Sol Let m_1 and m_2 be the masses of bullet and the rifleman and v_1 and v_2 their respective velocities after the first shot. Initially the rifleman and bullet are at rest, therefore initial momentum of system = 0.

As external force is zero, momentum of system is constant i.e. initial momentum = final momentum

$= m_1v_1 + m_2v_2$

or $v_2 = \dfrac{m_1v_1}{m_2} = -\dfrac{(10\times10^{-3}\,kg)(800\,m/s)}{100kg}$

$= -0.08$ m/s

Velocity acquired after 10 shots

$= 10\ v_2 = 10 \text{ x } (-0.08)$

$= -0.8$ m/s.

i.e, the velocity of rifle man is 0.8 m/s in a direction opposite to that of bullet.

Ex.10 A body of mass 1 kg strikes elastically with another body at rest and continues to move in the same direction with one fourth of the initial velocity. What will be the mass of the other body ?

Sol . Given that,

Initial velocity = u

Final velocity = $\dfrac{u}{4}$

So by conservation of momentum, we have

$1 \text{ x } u + 0 = 1 \times \dfrac{u}{4} + m \text{ x } v_2$

$\Rightarrow\ mv_2 = \dfrac{3u}{4}$ ...(1)

and by conservation of energy, we have

$\dfrac{1}{2} \times 1 \times u^2 + 0 = \dfrac{1}{2} \text{ x } 1 \left(\dfrac{u}{4}\right)^2 + \dfrac{1}{2}\ mv_2^{\,2}$

or $mv_2^{\,2} = \dfrac{15}{16}\ u^2$ ...(2)

from equation (1) and (2),

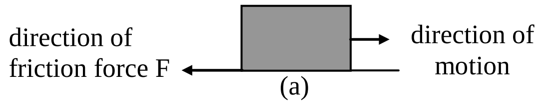
$= \dfrac{(mv_2)^2}{mv_2^2} = \dfrac{(9/16)u^2}{(15/16)u^2}$

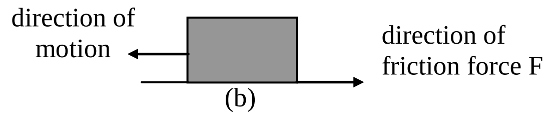
or m = 0.6 kg

FRICTION

If the switch off the engine of car it will stop after moving a certain distance. It means that some retarding force is acting on the car which stops it. The force opposing the motion of the car is called "force of friction".

- The frictional force is tangential to the surface in contact and always in a direction opposite to the direction of motion of the object.





- Frictional force is a force opposing the relative motion between two surfaces which are in contact with each other.

Reducing friction

Frictional force can be reduced in the following ways:

- **Use of lubricants :** In machines, friction can be reduced by applying lubricants between the contact surfaces to fill the fine pores or depressions in the surfaces and make them smooth thereby reducing friction.
- **Polishing :** unevenness of the surfaces can be reduced by polishing, thereby reducing the friction.
- **Use of ball bearings :** In rotating machines, shafts are mounted on ball bearings. By doing so, rolling friction occurs lesser than sliding friction, thereby reducing the friction.
- **By streamlining :** Air friction is reduced by designing streamlined bodies of cars or aeroplanes. Similarly, if the bodies of boats and ships are streamlined, friction of water can be reduced.

Disadvantages of friction :

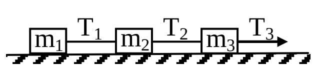
- Wear and Tear : In machine parts like gears, brakes when they come in contact with each other continuously, they wear out gradually, which should be replaced time to time.
- Friction reduces efficiency of the machine.

- Friction in machine produces heat and undesirable noise which damages the machine. To avoid excessive heating, water is circulated in machines generally.

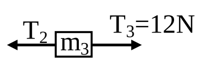
Applications of frictional forces

- We would not be able to walk if there had been no friction between the soles of our shoes and the ground.
- If there had been no friction, the wheels of a car will slip instead of rotating and stop moving. For that we have to increase the friction by making the tyres corrugated to get better grip of tyres on the road. Also, the friction is increased.
- When brakes are applied, the vehicle stops due to the force of friction between the brake lining and the drum.
- In the absence of friction, we cannot write on a blackboard with a chalk stick because the chalk stick will slide off the board without leaving any mark on the board.

Ex.11 Three blocks are tied together with strings as shown. They are lying on a horizontal frictionless table. These are pulled to the right with T_3 = 12N force. If m_1 = 1 kg, m_2 = 2kg, and m_3 = 3 kg, calculate the tension T_1.



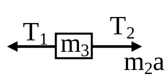
Sol.



$\longrightarrow m_3a$

$m_3a = T_3 - T_2$

$\Rightarrow 3a = 12 - T_2$ ...(1)



$m_2a = T_2 - T_1$

$\Rightarrow 2a = T_2 - T_1$ ...(2)

from (1) & (2)

$5a = 12 - T_1$ ...(3)

$m_1a = T_1 \Rightarrow a = T_1$ ...(4)

from (3) & (4)

$5T_1 = 12 - T_1 \Rightarrow T_1 = 2N$

THRUST AND PRESSURE

(A) Thrust :

- The force acting normally on surface is called 'thrust'.
- This is a vector quantity.
- It is measured in newton (N).

(B) Pressures :

- The thrust on an unit area of a surface is called 'pressure'.
- Pressure = $\frac{\text{Thrust}}{\text{Area}}$ or P = $\frac{F}{A}$
- Unit : The SI unit of pressure is newton per meter square or N/m^2, other units of pressure are pascal and bar.
- One Pascal : One pascal is defined as the pressure exerted on a surface area of $1m^2$ by a thrust of 1 newton.

  i.e. 1 Pascal = 1 N/m^2

Some examples based on pressure

Ex. Inserting a pointed nail in a wooden block is an easier task than to insert a rod inside a wooden block with the same force because the nail has a smaller area and thus it will experience more pressure even with the same force.

Ex. A sharp knife cuts better than a blunt knife.

Ex. While walking, a man exerts more pressure on the ground in comparison to when he is standing.

Pressure in fluids

- A substance that can flow is called a 'fluid'.

  liquid and gases are considered as fluids

Laws of pressure

- Pressure exerted by the liquid is the same in all directions about a point.
- Pressure exerted is the same at all points in a horizontal plane as well as in a stationary liquid.
- Pressure at a particular depth is P = hdg

  where,h = height of the column of liquid.

  d = density of the liquid

  g = acceleration due to gravity

Different types of Pressure :

(A) Hydrostatic Pressure :

The normal force (or thrust) exerted by a liquid at rest per unit area of the surface in contact with it is called "pressure of liquid or hydrostatic pressure."

(B) Atmospheric Pressure :

- The pressure exerted by atmosphere is called atmospheric pressure.
- At sea level, atmospheric pressure is the pressure exerted by 0.76 m of mercury column i.e. h = 0.76 m equal to 10 pascal
- 1 atm = 10^5 Pascal

Ex.12 What will be the pressure in N/m^2 at a depth of 1.5 m in brine of density 120 kg/cm^3 ?

Sol. P = hdg

$=15 \times 120 \times 10$

$= 1800\ N/m^2$

Ex.13 Calculate the density of a liquid if the pressure at a point 30 m below its surface is $32 \times 10^4\ N/m^2$.

Sol. P = hdg

$$\Rightarrow \quad d = \frac{P}{hg} = \frac{32 \times 10^4}{30 \times 10} = 1066.6\ kg/m^3$$

Ex.14 A force of 150 N is applied on an area of 1.5 m^2. Calculate the pressure exerted.

Sol. Force, F = 150 N; area, A = 1.5 m^2

Now, $\quad \text{Pressure} = \frac{\text{Force}}{\text{Area}}$

or $\quad P = \frac{F}{A} = \frac{150N}{1.5m^2} = 100\ N/m^2$

Ex.15 A force of 500 dynes is applied on an area of 20 cm^2. Calculate the pressure exerted.

Sol. Force, F = 500 dynes = 500×10^{-5} newton

Area, A = 20 cm^2 = $20 \times 10^{-4}\ m^2$

$$\text{Pressure, } P = \frac{F}{A} = \frac{500 \times 10^{-5} N}{20 \times 10^{-4} m^2} = 2.5\ N/m^2$$

BUOYANCY

When a body is immersed in a liquid, the liquid exerts an upward force on the body called as the 'upthrust' or 'buoyant force.'

Factors affecting upthrust :

- Larger the volume of the body submerged in the liquid, greater is the upthrust.
- Larger the density of the liquid, greater is the upthrust.

Archimedes principle :

'Archimedes' principle states that when a body is immersed in liquid partially or completely, it experiences an upthrust equal to the weight of the liquid displaced."

or

The loss in weight of the block, i.e. buoyant force acting on the block is equal to the weight of the liquid displaced.

i.e. $\quad F = Vdg$

where $\quad$ V = volume of the body

d = density of the liquid

g = acceleration due to gravity

Ex.16 A body weighs 300 gmf in air and 260 gmf when completely immersed in water. Calculate the following :

(i) loss in weight of the body

(ii) upthrust on the body.

Sol. Given : Weight of body in air = 300 gmf

Weight of the body in water = 260 gmf

$\therefore$ Loss in weight of the body

= 300 – 260 = 40 gmf

$\therefore$ Upthrust of the body = Loss in weight

= 40 gmf

Ex.17 A solid block of volume 2 litres has a weight of 80 N. What will be its weight when immersed completely in water ?

Sol. In order to calculate the weight of the block in water, first calculate the upthrust, i.e. the loss in weight of the body in water, then

Volume of the block = 2 litres = 2000 cc

$\therefore$ Volume of water displaced = 2000 cc

Weight of water displaced = 2000 gm

$= 2.0$ kgf

(Density of water = 1 gm/cc)

$= 2.0 \times 9.8$ N = 19.6 N

$\therefore$ Upthrust of water = 19.6 N

Hence, weight of the body fully immersed in water = 80 N – 19.6 N = 60.4 N

Ex.18 A solid block of density D has a weight W in air is fully immersed in a liquid of density d. Calculate its apparent weight when fully immersed in liquid.

Sol. Weight of the block = W

Density of block = D

$\therefore$ Volume of the block = $\frac{W}{D} \cdot d$

$\therefore$ Upthrust on the block = $\frac{W}{D} . d$

$\therefore$ Loss in weight of the block inside liquid

$$= \frac{W}{D} . d$$

Hence, apparent weight of the block when fully immersed in water

$$= W - \frac{W}{D} d = W\left(1 - \frac{d}{D}\right)$$

DENSITY

- Density = $\frac{\text{Mass}}{\text{Volume}}$ or $d = \frac{M}{V}$

  SI unit of density is kg/m^3 and CGS unit of density is g /cm^3
- 1 gm/cm^3 = 1000 kg/m^3
- Different substances have different densities which gets affected by temperature.
- Respective density of a substance decreases on heating due to the expansion of the substance.
- Water has anomalous expansion. When water is cooled at 4ºC, its volume decreases but on further cooling its volume starts increasing.

  $\Rightarrow$ the density of water is maximum at 4ºC.

Relative density

Relative density of a substance

$$= \frac{\text{density of substance}}{\text{density of water at } 4°C}$$

$$= \frac{\text{mass of unit volume of substance}}{\text{mass of unit volume of water at } 4°C}$$

$$= \frac{\text{mass of certain volume of substance}}{\text{mass of same volume of water at } 4°C}$$

$$= \frac{\text{weight of certain volume of substance}}{\text{weight of same volume of water at } 4°C}$$

Unit of Relative Density

It has no units.

Note : density of water in CGS system is 1 gm/cm^3.

Relative Density for solids

i.e. $R.D = \frac{W_1}{W_1 - W_2}$

Where W_1 = weight of solid body in air

W_2 = weight of solid body in water

Relative Density for liquids

i.e R.D. = $\frac{W - W''}{W - W'}$

Where.

W' = weight of the body fully immersed in water

W'' = weight of the body fully immersed in liquid.

W = weight of the body in air

Ex.19 A body weighs 30 N in air and 26 N when fully immersed in water. Calculate its relative density.

Sol. Given : Weight of body in air, W_1 = 30 N

Weight of body in water, W_2 = 26 N

$\therefore$ Relative density = $\frac{W_1}{W_1 - W_2}$

$$= \frac{30}{30 - 26} = 7.5$$

Ex.20 Relative density of copper is 8.8. What is its density in SI system ?

Sol. R.D. = $\frac{\text{density of copper}}{\text{density of water}}$

$\therefore$ Density of copper = R.D. × density of water

= 8.8×10^3 kg/m^3

Ex.21 A solid weighs 60 gmf in air and 52 gmf when completely immersed in water. Calculate the following :

(i) upthrust,

(ii) volume of the solid,

(iii) relative density of the solid

Sol. Given:

Weight of solid in air = 60 gmf

Weight of solid in water = 52 gmf

$\therefore$ Loss of weight in water = 60 – 52 = 8 gmf

(i) $\therefore$ Upthrust = loss of weight in water = 8 gmf

(ii) Since density of water is 1 gm/cm^3, and weight of equal volume of water = 8 gmf

$\therefore$ Volume of solid = 8 cm^3

(iii) Relative density of solid = $\frac{W_1}{W_1 - W_2}$

$= \frac{60}{60-52} = 7.5$

A. Very Short Answer Type Questions

Q.1 State Newton's third law.

Q.2 What is the unit of momentum ?

Q.3 Name and state the action and reaction in the following cases :

(i) Firing a bullet from a gun.
(ii) Hammering a nail.
(iii) A book lying on a table.
(iv) A moving rocket.
(v) A person walking on the floor.
(vi) A moving train colliding with a stationary train.

Q.4 Why a gun recoils when a bullet is fired ?

Q.5 Define the term force.

Q.6 What do you mean by inertia ?

Q.7 Why are tyres made rough ?

Q.8 Why does a glass filled with water feel lighter inside a water containing tank ?

Q.9 Explain the term friction.

Q.10 Define thrust. Give the S.I. unit of thrust.

Q.11 Define pressure. Give the S.I. unit of pressure.

Q.12 Calculate the pressure when a force of 50 N is applied on an area of 0.5 m^2.

Q.13 Do the liquids exert pressure ?

Q.14 Why does a sharp knife cuts objects more easily than a blunt knife ?

Q.15 In what direction the buoyant force of a liquid acts ?

Q.16 What is the relation between the buoyant force on a body and the liquid displaced by it ?

Q.17 A feather and a stone of same mass fall with different rates in the air. Why ?

Q.18 State Archimedes' Principle.

B. Short Answer Type Questions

Q.19 Enunciate the Newton's first law of motion.

Q.20 State and explain the law of inertia.

Q.21 Why it is advised to tie the luggage with a rope on the roof of the buses ?

Q.22 Why it is difficult for a fireman to hold a hose, which ejects water at a high velocity ?

Q.23 State Newton's third law of motion. Give two examples.

Q.24 When a shot is fired from a gun, the gun recoils. Explain.

Q.25 Discuss the law of conservation of momentum.

Q.26 A bullet of mass 20 gm moving with a velocity of 100 m/s strikes a wooden block of mass 800 gm and gets embedded into it. Calculate velocity of the combined system.

Q.27 Explain why it is easier to stop a tennis ball in comparison to a cricket ball moving with the same speed ?

Q.28 A force of 20 N acts on a body of mass 4 kg for 5 s initially at rest. Calculate the velocity acquired by the body and change in momentum of the body.

Q.29 A cricket ball of mass 100 gm moving with a speed of 40 ms^{-1} is brought to rest by a player in 0.02s. Find the average force applied by the player.

Q.30 Describe the laws of liquid pressure.

Q.31 Explain the term fluid.

Q.32 Explain the term buoyancy.

Q.33 While drawing water with the help of a bucket from a well, the bucket appears to be heavy when comes out of water. Why ?

Q.34 A body weighs 8.6 N in air and 6.8 N when fully immersed in water. Calculate the buoyant force.

Q.35 A metal object when fully immersed in water, displaces 2 litres of water. What is the loss in its weight in water ? Also, calculate the buoyant force.

Q.36 Define the term density. Give its units in SI and in CGS systems.

Q.37 Define the term relative density. Calculate the relative density of a substance if its density is 8.2 gm/cm^3.

C. Long Answer Type Questions

Q.38 A piece of wood or cork immersed into water and left, comes back to the surface. Explain why ?

Q.39 A piece of metal weighs 48.5 gmf in air, 42.0 gmf in water and 44.5 gmf in a liquid. Determine relative densities of metal and liquid.

Q.40 Why the accidents occurred due to high speeds have worst result than the accidents occurred at low speeds ?

EXERCISE-2

Single Correct Answer Type Questions

Q.1 If A and B are two objects with masses 10 kg and 30 kg respectively then :
(A) A has more inertia than B
(B) B has more inertia than A
(C) A and B have the same inertia
(D) none of the two have inertia

Q.2 First law of motion defines-
(A) inertia
(B) force
(C) both inertia and force
(D) neither inertia nor force

Q.3 Newton's first law of motion is -
(A) qualitative
(B) quantitative
(C) both qualitative and quantitative
(D) neither qualitative nor quantitative

Q.4 Inertia depends upon -
(A) acceleration of the body
(B) velocity of the body
(C) shape of the body
(D) mass of the body

Q.5 Which of the following has largest inertia?
(A) A pin
(B) An ink pot
(C) Your physics book
(D) Your body

Q.6 When a bus starts suddenly the passengers standing on it, lean backwards in the bus. This is an example of -
(A) Newton's first law
(B) Newton's second law
(C) Newton's third law
(D) none of Newton's law

Q.7 The law which defines force is -
(A) Newton's third law
(B) Newton's first law
(C) Newton's second law
(D) none of these

Q.8 Inertia of rest is the property by virtue of which the body is unable to change by itself:
(A) the state of rest only
(B) the state of uniform linear motion
(C) the direction of motion only
(D) the steady state of rest

Q.9 An iron ball and aluminium ball has same mass:
(A) inertia of iron is greater than aluminium
(B) both the ball have same inertia
(C) inertia of iron is less than that of Aluminium
(D) none of these

Q.10 Mass measures amount of ....in a body-
(A) inertia (B) motion
(C) velocity (D) acceleration

Q.11 Newton's second law of motion-
(A) defines force
(B) defines inertia
(C) gives measure of force
(D) none of these

Q.12 Newton's second law of motion is -
(A) qualitative
(B) quantitative
(C) both qualitative and quantitative
(D) neither qualitative nor quantitative

Q.13 Momentum measures amount of .... in a body-
(A) inertia (B) motion
(C) velocity (D) acceleration

Q.14 Force measures rate of change of .... a body
(A) mass (B) inertia
(C) velocity (D) momentum

Q.15 C.G.S. unit of force is -
(A) m/s (B) s/m
(C) dyne (D) Newton

Q.16 Momentum has same unit as -
(A) impulse (B) torque
(C) moment of force (D) couple

Q.17. When force of 1 N acts on mass of 1 kg, which is able to move freely, the object moves with a/an -

(A) speed of 1 ms^{-1}

(B) speed of 1 kms^{-1}

(C) acceleration of 10 ms^{-2}

(D) acceleration of 1 ms^{-2}

Q.18 The net force acting on a body of mass of 1 kg moving with a uniform velocity of 5 ms^{-1} is -

(A) 5 N (B) 0.2 N

(C) 0 N (D) None of these

Q.19 A body of mass 20 kg moves with an acceleration of 2ms^{-2}. The rate of change of momentum in S.I. unit is -

(A) 40 (B) 10

(C) 4 (D) 1

Q.20 A body of mass M strikes against wall with a velocity v and rebounds with the same velocity. Its change in momentum is -

(A) zero (B) Mv

(C) –Mv (D) –2 Mv

Q.21 Gram weight is a unit of-

(A) mass (B) weight

(C) A and B both (D) neither A nor B

Q.22 9.8 N is equal to-

(A) 1 kgf (B) 1 kgwt

(C) A and B both (D) Neither A nor B

Q.23 A body of mass 5 kg undergoes a change in speed from 20 m/s to 0.20 m/s. The momentum-

(A) increases by 99 kgm/s

(B) decreases by 99 kgm/s

(C) increases by 101 kgm/s

(D) decreases by 101 kgm/s

Q.24 The combined effect of mass and velocity is taken into account by a physical quantity called

(A) torque (B) moment of force

(C) momentum (D) all of them

Q.25 How many dynes are equal to 1 N ?

(A) 10^6 (B) 10^4

(C) 10^5 (D) 10^3

Q.26 Choose correct relation :

(A) a = F/m (B)aF = m

(C) m = F × a (D) none of these

Q.27 If a moving ball A collides with another moving ball B, then

(A) momentum of A = momentum of B

(B) (momentum A + momentum of B) before collision = (momentum A + momentum of B) after collision

(C) neither A nor B

(D) A or B both are possible

Q.28. When a bullet is fired from a gun. The gun recoils to -

(A) conserve mass

(B) conserve momentum

(C) conserve K.E

(D) none of these

Q.29 A bullet in motion hits and gets embedded in a solid resting on a frictionless table. What is conserved ?

(A) Momentum and K.E.

(B) Momentum alone

(C) K.E. alone

(D) None of these

Q.30 A bullet of mass 0.01 kg is fired from a gun weighing 5.0 kg. If the initial speed of the bullet is 250 m/s, calculate the speed with which the gun recoils-

(A) – 0.50 m/s (B) – 0.25 m/s

(C) + 0.05 m/s (D) + 0.25 m/s

Q.31 Forces of action and reaction are:

(A) equal and in same direction

(B) equal and in opposite direction

(C) unequal and in same direction

(D) unequal and opposite.

Q.32 Forces of action and reaction -

(A) one after the other on same body

(B) simultaneously on same body

(C) one after the other on different bodies

(D) simultaneously on different bodies

Q.33 A man is standing on a boat in still water. If he walks towards the shore the boat will -

(A) move away from the shore

(B) remain stationary

(C) move towards the shore

(D) sink

Q.34 If the action and reaction were to act on the same body-

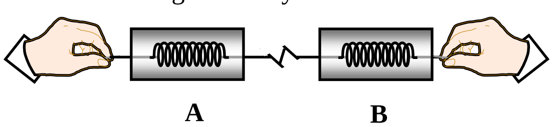
(A) the resultant would be zero

(B) the body would not move at all

(C) both A and B are correct

(D) neither A nor B is correct

Q.35 Consider two spring balances hooked as shown in the figure. We pull them in opposite directions. If the reading shown by A is 1.5 N, the reading shown by B will be -



(A) 1.5 N (B) 2.5 N

(C) 3.0 N (D) zero

Q.36 Newton used, 'quantity of motion' for-

(A) momentum

(B) force

(C) acceleration due to gravity

(D) none of these

Q.37 A cannon after firing recoils due to -

(A) conservation of energy

(B) backward thrust of gases produced

(C) Newton's first law of motion

(D) Newton's third law of motion

Q.38 A Diwali rocket is ejecting 0.05 kg of gases per second at a velocity of 400 ms^{-1}. The accelerating force on the rocket is:

(A) 20 dyne

(B) 20 Newton

(C) 20 kg wt.

(D) sufficient data not given

Q.39 The forces of action and reaction have .... magnitude but .... direction-

(A) same, same (B) same, opposite

(C) opposite, same (D) opposite, opposite

Q.40 Choose correct statement-

(A) Action and reaction forces act on same object.

(B) Action and reaction forces act on different objects.

(C) A and B both are possible.

(D) Neither A nor B is correct.

ANSWER KEY

EXERCISE - 1

12. 100 N/m^2 m/sec **13.** Yes **26.** 2.43 m/sec **28.** 25m/s, 100kg

29. 200 N **34.** 1.B N

EXERCISE - 2

Ques	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Ans	B	C	A	D	D	A	B	D	B	A	C	B	B	D	C
Ques	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Ans	A	D	C	A	D	B	C	B	C	C	A	B	B	B	A
Ques	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**					
Ans	B	D	A	C	A	A	D	B	B	B					

NCERT QUESTIONS

1. An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with a non-zero velocity? If yes, state the conditions that must be placed on the magnitude and direction of the velocity. If no, provide a reason.
2. When a carpet is beaten with a stick, dust comes out of it. Explain.
3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?
4. A batsman hits a cricket ball which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows to a stop because
   (a) the batsman did not hit the ball hard enough.
   (b) velocity is proportional to the force exerted on the ball.
   (c) there is a force on the ball opposing the motion.
   (d) there is no unbalanced force on the ball, so the ball would want to come to rest.
5. A truck starts from rest and rolls down a hill with a constant acceleration. It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it if its mass is 7 metric tonnes (*Hint*: 1 metric tonne = 1000 kg.)
6. A stone of 1 kg is thrown with a velocity of 20 m s^{-1} across the frozen surface of a lake and comes to rest after travelling a distance of 50 m. What is the force of friction between the stone and the ice?
7. A 8000 kg engine pulls a train of 5 wagons, each of 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a friction force of 5000 N, then calculate:
   (a) the net accelerating force;
   (b) the acceleration of the train; and
   (c) the force of wagon 1 on wagon 2.
8. An automobile vehicle has a mass of 1500 kg. What must be the force between the vehicle and road if the vehicle is to be stopped with a negative acceleration of 1.7 m s^{-2}?
9. What is the momentum of an object of mass m, moving with a velocity v?
   (a) $(mv)^2$ (b) mv^2 (c) ½ mv^2 (d) mv
10. Using a horizontal force of 200 N, we intend to move a wooden cabinet across a floor at a constant velocity. What is the friction force that will be exerted on the cabinet?
11. Two objects, each of mass 1.5 kg, are moving in the same straight line but in opposite directions. The velocity of each

object is 2.5 m s^{-1} before the collision during which they stick together. What will be the velocity of the combined object after collision?

12. According to the third law of motion when we push on an object, the object pushes back on us with an equal and opposite force. If the object is a massive truck parked along the roadside, it will probably not move. A student justifies this by answering that the two opposite and equal forces cancel each other. Comment on this logic and explain why the truck does not move.

13. A hockey ball of mass 200 g travelling at 10 m s^{-1} is struck by a hockey stick so as to return it along its original path with a velocity at 5 m s^{-1}. Calculate the change of momentum occurred in the motion of the hockey ball by the force applied by the hockey stick.

14. A bullet of mass 10 g travelling horizontally with a velocity of 150 m s^{-1} strikes a stationary wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of the bullet into the block. Also calculate the magnitude of the force exerted by the wooden block on the bullet.

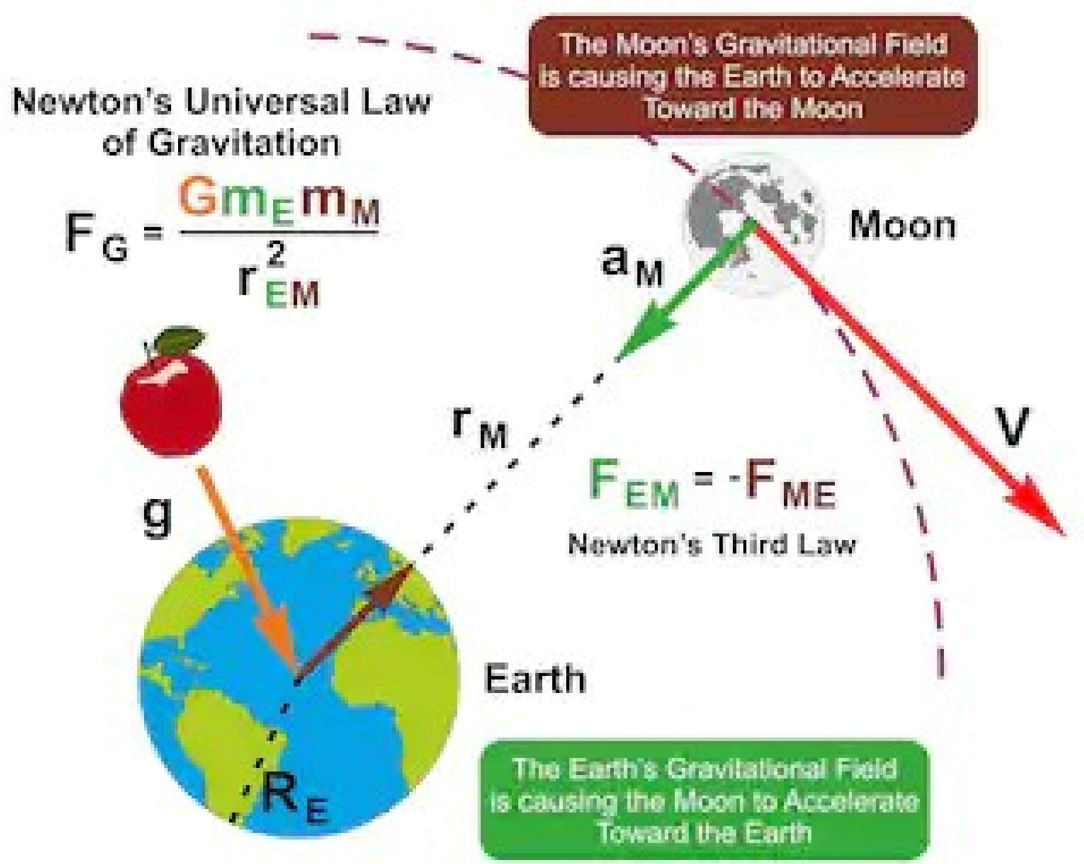
15. An object of mass 1 kg travelling in a straight line with a velocity of 10 m s^{-1} collides with, and sticks to, a stationary wooden block of mass 5 kg. Then they both move off together in the same straight line. Calculate the total momentum just before the impact and just after the impact. Also, calculate the velocity of the combined object.

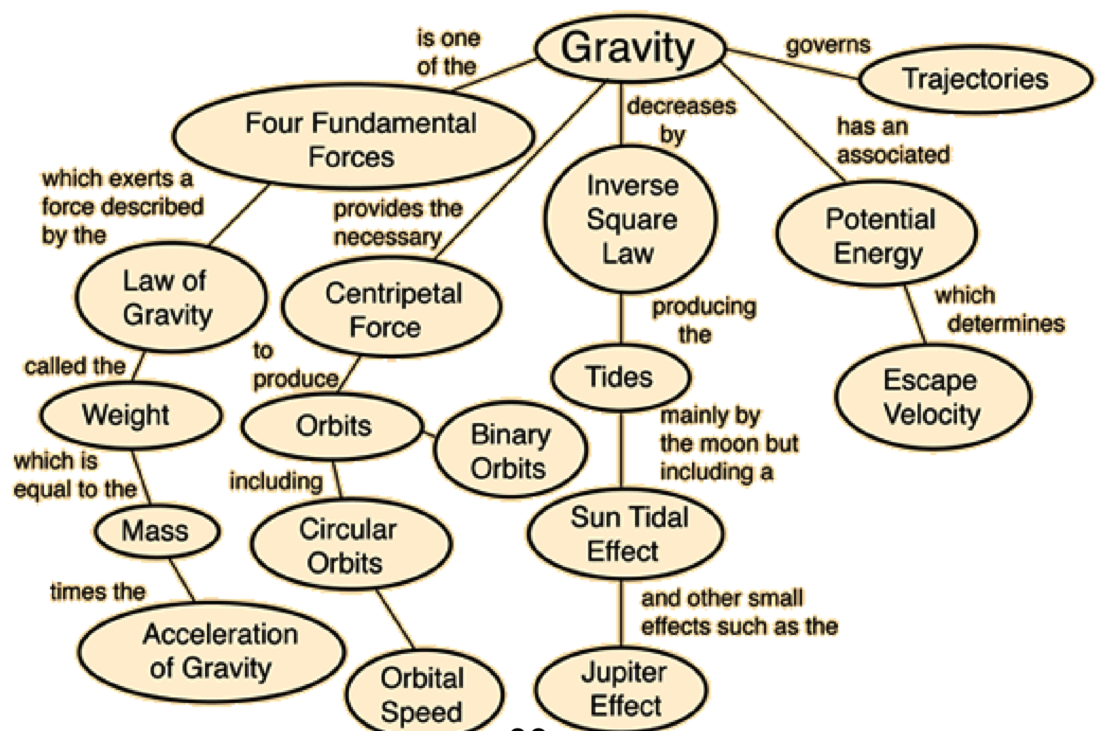
16. An object of mass 100 kg is accelerated uniformly from a velocity of 5 m s^{-1} to 8 m s^{-1} in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.

17. Akhtar, Kiran and Rahul were riding in a motorcar that was moving with a high velocity on an expressway when an insect hit the windshield and got stuck on the windscreen. Akhtar and Kiran started pondering over the situation. Kiran suggested that the insect suffered a greater change in momentum as compared to the change in momentum of the motorcar (because the change in the velocity of the insect was much more than that of the motorcar). Akhtar said that since the motorcar was moving with a larger velocity, it exerted a larger force on the insect. And as a result the insect died. Rahul while putting an entirely new explanation said that both the motorcar and the insect experienced the same force and a change in their momentum. Comment on these suggestions.

18. How much momentum will a dumb-bell of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Take its downward acceleration to be 10 m s^{-2}.

GRAVITATION





CONTENTS

➢ FORCE OF GRAVITATION

Any two particles in the universe attract each other. This force is called the force of gravitation.

This concept was given by **Newton**.

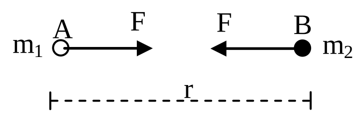
➢ NEWTON'S LAW OF GRAVITATION

According to newton, "Any two bodies in universe attract each other with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them."

◆ **Mathematical expression**

Lat A and B be two particle of mass m_1 and m_2 respectively. Let the distance AB = r.

By the law of gravitational, the particle A attracts the particle B with a force F such that.



$F \propto m_1 m_2$ (for a given pair of particles)

$F \propto \frac{1}{r^2}$ (for a given separation between the particles)

So $F \propto \frac{m_1 m_2}{r^2}$

or $F = G\frac{m_1 m_2}{r^2}$

Here G is a constant known as the universal constant of gravitation. $G = 6.67 \times 10^{-11}$ Nm^2/kg^2

- ◆ G is independent of the masses of the bodies and the distance between them.
- ◆ Newton's law of gravitation is applicable for everybody in the universe.

Note : The force between any two bodies in the universe is called the force of gravitation while the force with which earth attracts a body is called the force of gravity.

◈ **Some Scientific Phenomenon Based on Gravitational Force :**

- ◆ The gravitational force between the sun and the earth keeps the earth moving around the sun.
- ◆ The gravitational force b/w the earth and the moon keeps the moon moving around the earth.
- ◆ Existence of our solar system is due to gravitational force.

- Gravitation force of the sun and the moon on the earth's water surface is responsible for the tides in sea.
- Atmosphere above the earth is held due to gravitational force of the earth.
- Gravitational force between the sun and planet keeps the planet moving around the sun.
- Gravitational force is responsible for providing the centripetal force required by the planets.
- The attractive force of the earth is responsible for providing the centripetal force required by moon.

Newton's Third Law of Motion and Law of Gravitation :

- Newton's third law of motion is applicable to gravitation also.
  Ex. if the earth exerts a force of attraction on a body, the body also exerts an equal and opposite force of attraction on the earth.
- As a = F/m
  mass of the body is larger, acceleration produced will be smaller and vice versa.

Ex. 1 Calculate the force between two masses of 100 kg and 1000 kg separated by a distance of 10 m ($G = 6.67 \times 10^{-11}$ Nm²/kg²).

Sol. According to Newton's law of gravitation, force of attraction between two bodies is

$$F = \frac{Gm_1m_2}{r^2}$$

Here, $m_1 = 100$ kg; $m_2 = 1000$ kg ;
r = 10 m ; $G = 6.67 \times 10^{-11}$ Nm²/kg²

$$\therefore \quad F = \frac{6.67\times10^{-11}\times100\times1000}{(10)^2}$$

$$= 6.67 \times 10^{-8} \text{ N}$$

Ex. 2 Given mass of earth = 6×10^{24} kg, radius of earth = 6.4×10^6 m. Calculate the force of attraction experienced by a man of mass 50 kg.

Sol. Force of gravitation is given by the expression, $F = \dfrac{Gm_1m_2}{r^2}$

Here, mass of earth, $m_1 = 6 \times 10^{24}$ kg;
mass of man, $m_2 = 50$ kg

Distance between them is to be taken equal to the radius of earth.

$\therefore \quad r = 6.4 \times 10^6$ m

Substituting these values, we get

$$F = \frac{6.67\times10^{-11}\times6\times10^{24}\times50}{(6.4\times10^6)^2} = 488.5 \text{ N}$$

Ex. 3 Compare the gravitational forces exerted by the sun and the moon on earth. Which exerts a greater force on earth ?
(Given : mass of sun, $M_S = 4 \times 10^{31}$ kg; mass of moon, $M_m = 6.3 \times 10^{22}$ kg; distance between sun and earth, $r_{se} = 1.3 \times 10^{12}$ m and the distance between moon and earth, $r_{me} = 4.5 \times 10^8$ m)

Sol. If mass of sun is M_S and mass of earth is M_e and distance between the sun and earth is r_{se}, then force exerted by the sun on earth is

$$F_S = \frac{GM_sM_e}{(r_{se})^2} \quad ...(1)$$

Similarly, if mass of moon is M_m, mass of earth is M_e, the distance between moon and earth is r_{me}, then force exerted by moon on the earth is

$$F_m = \frac{GM_mM_e}{(r_{me})^2} \quad ...(2)$$

Dividing equation (1) by equation (2), we get

$$\frac{F_s}{F_m} = \frac{GM_sM_e}{(r_{se})^2} \times \frac{r_{me}^2}{GM_mM_e}$$

$$= \frac{M_s}{M_m} \times \frac{(r_{me})^2}{(r_{se})^2}$$

$$= \frac{4\times10^{31}}{6.3\times10^{22}} \times \left(\frac{4.5\times10^8}{1.3\times10^{12}}\right)^2 = 76.07$$

$\therefore$ The force exerted by the sun on earth is about 76 times the force exerted by the moon on earth.

Ex. 4 If mass and radius of earth is 6.0×10^{24} kg and 6.4×10^6 m respectively, calculate the force exerted by earth on a body of mass 1 kg. Also, calculate :

(i) acceleration produced in the body of mass 1 kg, and

(ii) acceleration produced in the earth

Sol. From Newton's law of gravitation, we know that the force of attraction between two bodies is given by

$$F = \frac{Gm_1m_2}{r^2}$$

Here, m_1 = mass of earth = 6.0×10^{24} kg;

m_2 = mass of body = 1 kg

r = distance between the two bodies

= radius of earth = 6.4×10^6 m

$G = 6.67 \times 10^{-11}$ Nm^2/kg^2

$$\therefore \quad F = \frac{6.67\times10^{-11}\times6.0\times10^{24}\times1}{(6.4\times10^6)^2} = 9.8 \text{ N}$$

This shows that earth exerts a force of 9.8 N on a body of mass of 1 kg. The body will exert an equal force of attraction of 9.8 N on earth.

(i) Acceleration produced in the body of mass 1kg

Force = mass × acceleration

$$\therefore \quad \text{Acceleration, } a = \frac{F}{m} = \frac{9.8}{1} = 9.8 \text{ m/s}^2$$

Thus, the acceleration produced in a body of mass 1 kg due to attraction of earth is 9.8 m/s^2, which is quite large. Thus, when a body is released, it falls towards the earth with an acceleration of 9.8 m/s^2, which can be easily observed.

(ii) Acceleration produced in the earth

Similarly, acceleration of earth is given by

$$= \frac{\text{Force}}{\text{Mass of earth}} = \frac{9.8}{6.0\times10^{24}}$$

$= 1.63 \times 10^{-24}$ m/s^2

This shows that the acceleration produced in the earth by a body of mass 1 kg is 1.63×10^{-24} m/s^2 which is very small and cannot be observed.

EARTH'S GRAVITATIONAL FORCE

- The force which earth exerts on a body is called 'force of gravity'. i.e. $F = \frac{GMm}{R^2}$

Where M = mass of the earth, R = radius of the earth.

- Due to this force, a body released from some height on the earth's surface falls towards the earth with its velocity increasing at a constant rate.

Acceleration due to Gravity :

- The acceleration produced in a body due to attraction of earth is called the acceleration due to gravity and is denoted by 'g'.

$$g = \frac{GM}{R^2} = 9.8 \text{ m/s}^2$$

near the earth surface

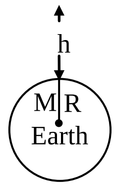
$$g \text{ on moon } \approx \frac{g_e}{6} = \frac{9.8}{6} \text{ m/s}^2$$

- A body moving upwards with some initial velocity, experiences a retardation of 9.8 m/s^2 & its velocity decreases continuously unless it becomes zero.
- After this, it again starts falling towards the earth with the same acceleration of 9.8 m/s^2.
- The value of g is minimum at equator and maximum at poles.
- The value of g does not depend upon the mass of the body falling towards the earth.

VARIATION IN THE VALUE OF GRAVITATIONAL ACCELERATION (g)

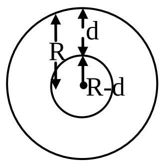
(A) Variation with altitude or height :

- When a body moves above the earth's surface the distance of the body from the centre of earth increases there by decreasing the force of attraction.
- $g = \frac{GM}{R^2}$; at the earth's surface.
- $g = \frac{GM}{(R+h)^2}$; at a height h above the earth's surface.
- As we go above the earth's surface the value of g goes on decreasing.



(B) Variation with depth d :

- As we go deeper inside the earth, the body gets attracted by the core of the earth which is smaller in mass.



- As we go inside the earth, the value of g decreases.
- Force of attraction decreases and thus decreasing the value of g and becoming zero at the centre.

(C) Variation due to rotation of the earth :

- Due to the rotation of the earth, the weight of a body is maximum at the poles and minimum at the equator.

➤ MASS & WEIGHT

	Mass	Weight
1.	Mass of a body is defined as the quantity of matter contained in it.	Weight of a body is the force with which it is attracted towards the centre of the earth. $W = mg$
2.	Mass of a body remains constant and does not change from place to place.	Weight of a body changes from place to place. It depends upon the value of *g*. Weight of a body on another planet will be different.
3.	Mass is measured by a pan balance.	Weight is measured by a spring balance.
4.	Unit of mass is kg.	Unit of weight is newton or kg-wt.
5.	Mass of a body cannot be zero.	Weight of a body can be zero. Ex. astronauts experience weightlessness in spaceships.
6.	Mass is a scalar quantity.	Weight is a vector quantity.

Ex. 5 Given mass of earth is 6×10^{24} kg and mean radius of earth is 6.4×10^6 m. Calculate the value of acceleration due to gravity (g) on the surface of the earth.

Sol. The formula for the acceleration due to gravity is given by

$$g = \frac{GM}{R^2}$$

Here, $G = 6.67 \times 10^{-11}\ Nm^2/kg^2$;
M = mass of earth $= 6 \times 10^{24}$ kg;
R = radius of earth $= 6.4 \times 10^6$ m

$$g = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^6)^2} = 9.8\ m/s^2$$

Ex. 6 Calculate the value of acceleration due to gravity on a planet whose mass is 4 times as that of the earth and radius is 3 times as that of the earth.

Sol. If M is the mass of the earth and R is the radius of earth, the value of acceleration due to gravity on the earth (g_e) is given by

$$g_e = \frac{GM}{R^2} \quad ...(1)$$

Let us consider a planet such that mass of the planet is equal to 4 times the mass of earth.

$$M_p = 4M$$

Radius of the planet is equal to 3 times the radius of earth.

$$R_e = 3R$$

Then, acceleration due to gravity on this planet(g_p) is

$$g_p = \frac{G \times (4M)}{(3R)^2} = \frac{4}{9} \cdot \frac{GM}{R^2} \quad ...(2)$$

Dividing equation (2) by equation (1), we get

$$\frac{g_p}{g_e} = \frac{\frac{4}{9} \times \frac{GM}{R^2}}{\frac{GM}{R^2}} \text{ or } \frac{g_p}{g_e} = \frac{4}{9}$$

or $g_p = \frac{4}{9}(g_e)$

Since $g_e = 9.8\ m/s^2$

$\therefore$ $g_p = \frac{4}{5} \times 9.8 = 4.35\ m/s^2$

Thus, acceleration due to gravity on the given planet is 4.35 m/s^2.

Ex. 7 Given the mass of the moon = 7.35×10^{22} kg and the radius of the moon = 1740 km. Calculate the acceleration experienced by a particle on the surface of the moon due to the gravitational force of the moon. Find the ratio of this acceleration to that experienced by the same particle on the surface of the earth.

Sol. If M_m is the mass of the moon and R_m is its radius, then the acceleration experienced by a body on its surface is given by

$$a = \frac{GM_m}{R_m^2}$$

Here, $M_m = 7.3 \times 10^{22}$ kg;
$R_m = 1740 \text{ km} = 1.74 \times 10^6$ m

$$\therefore \quad a = \frac{6.67\times10^{-11}\times7.3\times10^{22}}{(1.74\times10^6)^2} = 1.57 \text{ m/s}^2$$

While the acceleration due to gravity on the surface of the earth, is given by

$$g_e = \frac{GM_e}{R_e^2} = \frac{6.67\times10^{-11}\times6\times10^{24}}{(6.4\times10^6)^2} = 9.8 \text{ m/s}^2$$

Comparing acceleration due to gravity on moon to that on the earth is

$$\frac{a}{g} = \frac{1.57}{9.8} = 0.16$$

Ex. 8 At what height above the earth's surface the value of g will be half of that on the earth's surface ?

Sol. We know that the value of g at earth's surface is

$$g = \frac{GM}{R^2} \qquad ...(1)$$

While the value of g at a height h above the earth's surface is given by

$$g' = \frac{GM}{(R+h)^2} \qquad ...(2)$$

Dividing equation (2) by equation (1), we get

$$\frac{g'}{g} = \left(\frac{R}{R+h}\right)^2 \text{ or } g' = g\left(\frac{R}{R+h}\right)^2$$

Here, $g' = \frac{g}{2}$

$$\therefore \quad \frac{g}{2} = g\left(\frac{R}{R+h}\right)^2$$

or $\frac{R+h}{R} = \sqrt{2}$

or $R + h = \sqrt{2}R$

or $h = (\sqrt{2} - 1)R$

or $h = (1.41 - 1) \times 6400 = 0.41 \times 6400$
$= 2624$ km

Ex. 9 Given mass of the planet Mars is 6×10^{23} kg and radius is 4.3×10^6 m. Calculate the weight of a man whose weight on earth is 600 N. (Given g on earth = 10 m/s^2)

Sol. Weight of the man on earth, W = mg
or $600 = m \times 10$ or $m = 60$ kg
So the mass of the man is 60 kg which will remain the same everywhere.
Now acceleration due to gravity on Mars,

$$g_m = \frac{GM_m}{R_m^2}$$

Here, $M_m = 6 \times 10^{23}$ kg; $R_m = 4.3 \times 10^6$m

$$\therefore \quad g_m = \frac{6.67\times10^{-11}\times6\times10^{23}}{(4.3\times10^6)^2} = 2.17 \text{ m/s}^2$$

Now, weight of the man on Mars will be
$W_m = m \times g_m = 60 \times 2.17 = 130.2$ N

EQUATIONS OF MOTION FOR FREELY FALLING OBJECT

Since the freely falling bodies fall with uniformly accelerated motion, the three equations of motion derived earlier for bodies under uniform acceleration can be applied to the motion of freely falling bodies. For freely falling bodies, the acceleration due to gravity is 'g', so we replace the acceleration 'a' of the equations by 'g' and since the vertical distance of the freely falling bodies is known as height 'h', we replace the distance 's' in our equations by the height 'h'. This gives us the following modified equations for the motion of freely falling bodies.

General equation of motion	Equations of motion for freely falling bodies
(i) $v = u + at$ changes to	$v = u + gt$
(ii) $s = ut + \frac{1}{2}at^2$ changes to	$h = ut + \frac{1}{2}gt^2$
(iii) $v^2 = u^2 + 2as$ changes to	$v^2 = u^2 + 2gh$

We shall use these modified equations to solve numerical problems. Before we do that, we should remember the following important points for the motion of freely falling bodies.

(i) When a body is dropped freely from a height, its initial velocity 'u' becomes zero

(ii) When a body is thrown vertically upwards, its final velocity 'v' becomes zero

(iii) The time taken by body to rise to the highest point is equal to the time it takes to fall from the same height.

(iv) The distance travelled by a freely falling body is directly proportional to the square of time of fall.

A. Very Short Answer Type Questions

Q.1 Give the formula to calculate the gravitational force of attraction.

Q.2 What is the value of gravitational constant ?

Q.3 What is the unit of gravitational constant ?

Q.4 Does the gravitational force between two bodies change, if some other material body is placed between them ?

Q.5 What is the approximate value of acceleration due to gravity on the surface of earth ?

Q.6 What is the unit of acceleration due to gravity?

Q.7 State the relation between g and G on earth.

Q.8 What is the effect of altitude on the value of g ?

Q.9 What is the weight of a body at a height equal to the radius of earth above the earth's surface ?

Q.10 Is the weight of body more at the equator or at poles ?

Q.11 Which force is responsible for the earth revolving round the sun ?

Q.12 A stone is released from some height, it moves towards the earth. Does the earth also move towards the stone ?

Q.13 A light and a heavy body, both are dropped simultaneously from the same height. Which will strike the ground earlier ?

Q.14 As we go inside the earth, what is the effect on the value of g ?

Q.15 What is the value of g at the centre of earth?

B. Short Answer Type Questions

Q.16 How does the gravitational force change between two objects when the distance between them is doubled ?

Q.17 Why two stones do not come closer, even if there is gravitational force of attraction between them ?

Q.18 Under what conditions our weight becomes zero? Give examples.

Q.19 An astronaut inside a spaceship orbiting round the earth feels weightlessness. Explain.

Q.20 The weight of a body is less inside the earth than on the surface. Why?

Q.21 For two bodies of different masses, acceleration due to gravity is same or different? Explain.

Q.22 Newton's law of gravitation states that there is a force of attraction between two bodies. Why do we not observe the motion of two stones lying on the floor moving towards each other ?

Q.23 Calculate the force of attraction between two bodies of masses 100 kg and 60 kg respectively separated by a distance of 5 m from each other.

Q.24 If the distance between two bodies is decreased by a factor of 4, by what factor the force of attraction will change ?

Q.25 Calculate force of attraction on a body of mass 50 kg lying on the surface of earth. Given that the mass of earth = 6×10^{24} kg radius of the earth = 6.4×10^{6} m and $G = 6.67 \times 10^{-11} Nm^2/kg^2$.

Q.26 What happens to the weight of a body when it is falling freely under gravity ?

Q.27 Although, the value of G is very small, but all the objects near the surface of earth fall towards the earth. Why ?

Q.28 Calculate the force of gravitation between two bodies each of mass 80 kg and placed 16 cm apart. (Take $G = 6.67 \times 10^{-11}$ Nm^2/kg^2)

Q.29 The mass of Mars is $\frac{1}{10}$ th and its radius is half of that of the earth. Calculate value of g on the surface of Mars.

Q.30 What is the weight of a body whose mass is 25 kg ?

C. Long Answer Type Questions

Q.31 Discuss the terms gravitation and gravity with suitable examples.

Q.32 State Newton's law of gravitation. State the unit and value of gravitational constant.

Q.33 Discuss the various factors on which the value of g depends.

Q.34 Compare the gravitational attraction on the earth due to the attraction of sun due to attraction of moon. Given mass of sun = 2×10^{30} kg, mass of moon = 7.35×10^{22} kg, distance of sun from earth = 1.5×10^{11} m, distance of moon from earth = 3.84×10^{8}m.

Q.35 A body weighs 160 N on the surface of the earth. Calculate his weight at a height of 3.6×10^{6} m from the surface of the earth. Radius of earth = 6.4×10^{6} m.

EXERCISE # 2

Single correct answer type questions

Q.1 When an apple falls from a tree:
(A) only earth attracts the apple
(B) only apple attracts the earth
(C) both the earth and the apple attract each other
(D) none attracts each other

Q.2 Force of attraction between two bodies does not depend upon :
(A) the shape of bodies
(B) the distance between their centres
(C) the magnitude of their masses
(D) the gravitational constant

Q.3 When the medium between two bodies changes, force of gravitation between them :
(A) will increase
(B) will decrease
(C) will change according to the environment
(D) remains same

Q.4 S.I. unit of G is :
(A) $Nm^2\ kg^{-2}$ (B) $Nm\ kg^{-2}$
(C) $N\ kg^2M^{-2}$ (D) $Nkg\ m^{-2}$

Q.5 The value of universal gravitational constant:
(A) changes with change of place
(B) does not change from place to place
(C) becomes more at night
(D) becomes more during the day

Q.6 The value of G in S.I. unit is :
(A) 6.67×10^{-9} (B) 6.67×10^{-10}
(C) 6.67×10^{-11} (D) $6.67 \text{ x } 10^{-12}$

Q.7 The gravitational force between two bodies varies with distance *r* as :
(A) $1/r$ (B) $1/r^2$
(C) r (D) r^2

Q.8. The value of G in year 1900 was $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$, The value of G in the year 2007 will be :
(A) $6.673 \times 10^{-9}\ Nm^2\ kg^{-2}$
(B) $6.673 \times 10^{-10}\ Nm^2\ kg^{-2}$
(C) $6.673 \times 10^{-2}\ Nm^2\ kg^{-2}$
(D) $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$

Q.9 Value of G on surface of earth is $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$, then value of G on surface of Jupiter is :
(A) $12 \times 6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$
(B) $\frac{6.673}{12} \times 1\ 0^{-11}\ Nm^2\ kg^{-2}$
(C) $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$
(D) $\frac{6.673}{6} \times 10^{-11}\ Nm^2\ kg^{-2}$

Q.10 The earth attracts the moon with a gravitational force of 10^{20} N. Then the moon attracts the earth with a gravitational force of:
(A) 10^{-20} N (B) 10^2 N

(C) 10^{20} N (D) 10^{10} N

Q.11 The orbits of planets around the sun are:
(A) circular (B) parabolic
(C) elliptical (C) straight

Q.12 Law of gravitation is applicable for:
(A) heavy bodies only
(B) medium sized bodies only
(C) small sized bodies only
(D) bodies of any size

Q.13 The universal law of gravitation was proposed by :
(A) Copernicus (B) Newton
(C) Galileo (D) Archimedes

Q.14 Choose the correct statement :
(A) All bodies repel each other in the universe.
(B) Our earth does not behave like a magnet.
(C) Acceleration due to gravity is 8.9 ms^{-2}
(D) All bodies fall at the same rate in vacuum.

Q.15 The value of acceleration due to gravity (g) on earth's surface is :
(A) 6.67×10^{-11} Nm^2 kg^2
(B) 8.9 m/sec^2
(C) 9.8 m/sec^2
(D) none of these

Q.16 The acceleration due to gravity:
(A) has the same value everywhere in space
(B) has the same value everywhere on the earth
(C) varies with the latitude on the earth
(D) is greater on moon because it has smaller diameter

Q.17 When a space ship is at a distance of two earths radius from the centre of the earth, the gravitational acceleration is :
(A) 19.6 ms^{-2} (B) 9.8 m/s^{-2}
(C) 4.9 m/s^2 (D) 2.45 ms^{-2}

Q.18 If planet existed whose mass and radius were both half of the earth, the acceleration due to gravity at the surface would be :
(A) 19.6 m/sec^2 (B) 9.8 m/s^2
(C) 4.9 ms^{-2} (D) 2.45 m/s^2

Q.19 A stone is dropped from the top of a tower. Its velocity after it has fallen 20 m is [Take g = 10 ms^{-2}] :
(A) 5 ms^{-1} (B) 10 m s^{-1}
(C) 15 m s^{-1} (D) 20 m s^{-1}

Q.20 A ball is thrown vertically upwards. The acceleration due to gravity:
(A) is in the direction opposite to the direction of its motion
(B) is in the same direction as the direction of its motion
(C) increases as it comes down
(D) become zero at the highest point.

Q.21 The acceleration due to gravity on the moon's surface is:
(A) approximately equal to that near the earth's surface
(B) approximately six times that near the earth's surface
(C) approximately one-sixth of that near the earth's surface
(D) slightly greater than that near the earth's surface

Q.22 The force acting on a ball due to earth has a magnitude F_b and that acting on the earth due to the ball has a magnitude F_e Then :
(A) $F_b = F_e$ (B) $F_b > F_e$
(C) $F_b < F_e$ (D) $F_e = 0$

Q.23 Force of gravitation between two bodies of mass 1 kg each kept at a distance of 1 m is :
(A) 6.67 N (B) 6.67×10^{-9} N

(C) 6.67×10^{-11} N (D) 6.67×10^{-7} N

Q.24 The force of gravitation between two bodies does not depend on:
(A) their separation
(B) the product of their masses
(C) the sum of their masses
(D) the gravitational constant

Q.25 The ratio of the value of g on the surface of moon to that on the earth's surface is :
(A) 6 (B) $\sqrt{6}$
(C) $\frac{1}{6}$ (D) $\frac{1}{\sqrt{6}}$

Q.26 Order of magnitude of G in S.I. unit is :
(A) 10^{-11} (B) 10^{11}
(C) 10^{-7} (D) 10^{7}

Q.27 The S.I. unit of g is :
(A) m^2/s (B) m/s^2
(C) s/m^2 (D) m/s

Q.28 If the distance between two masses be doubled then the force between them will become :
(A) $\frac{1}{4}$ times (B) 4 times
(C) $\frac{1}{2}$ times (D) 2 times

Q.29 The type of force which exists between charged bodies is
(A) only gravitational
(B) neither gravitational nor electrical
(C) only electrical
(D) both electrical and gravitational

Q.30 The acceleration due to gravity is 9.8 m/s^2
(A) Much above the earth's surface
(B) Near the earth's surface
(C) Deep inside the earth
(D) At the centre of the earth

Q.31 A particle is taken to a height R above the earth's surface, where R is the radius of the earth. The acceleration due to gravity there is -
(A) 2.45 m/s^2 (B) 4.9 m/s^2
(C) 9.8 m/s^2 (D) 19.6 m/s^2

Q.32 When a body is thrown up, the force of gravity is :
(A) in upward direction
(B) in downward direction
(C) zero
(D) in horizontal direction

Q. 33 Mass of an object is :
(A) amount of matter present in the object
(B) same as weight of an object
(C) measure of gravitational pull
(D) none of these

Q.34 The weight of an object is :
(A) the quantity of matter it contains
(B) refers to its inertia
(C) same as its mass but is expressed in different units
(D) the force with which it is attracted towards the earth

Q.35 Weight of an object depends on :
(A) temperature of the place
(B) atmosphere of the place
(C) mass of an object
(D) none of these

Q.36 The mass of body is measured to be 12 kg on the earth. Its mass on moon will be :
(A) 12 kg (B) 6 kg
(C) 2 kg (D) 72 kg

Q.37 A heavy stone falls:
(A) faster than a light stone
(B) slower than a light stone

(C) with same acceleration as light stone
(D) none of these

Q.38 A stone is dropped from the roof of a building takes 4s to reach the ground. The height of the building is :
(A) 19.6m (B) 39.2 m
(C) 156.8 m (D) 78.4 m

Q.39 A ball is thrown up and attains a maximum height of 19.6 m. Its initial speed was:
(A) 9.8 ms^{-1} (B) 44.3 ms^{-1}
(C) 19.6 ms^{-1} (D) 98 ms^{-1}

Q.40 The value of *g* at pole is :
(A) greater than the value at the equator
(B) less than the value at the equator
(C) equal to the value at the equator
(D) none of these

Q.41 Two bodies A and B of mass 500 g and 200 g respectively are dropped near the earth's surface. Let the acceleration of A and B be a_A and a_B respectively, then:
(A) $a_A = a_B$ (B) $a_A > a_B$
(C) $a_A < a_B$ (D) $a_A \neq a_B$

Q.42 A body is thrown up with a velocity of 20 m/s. The maximum height attained by it is approximately:
(A) 80 m (B) 60 m
(C) 40 m (D) 20 m

Q.43 The weight of a body is 120 N on the earth. If it is taken to the moon, its weight will be about:
(A) 120 N (B) 60 N
(C) 20 N (D) 720 N

Q.44 Two iron and wooden balls identical in size are released from the same height in vacuum. The time taken by them to reach the ground are-
(A) not equal (B) exactly equal
(C) regularly equal (D) zero

ANSWER KEY

EXERCISE-1

1. $F = G\, m_1\, m_2 /r^2$	**2.** 6.67×10^{-11} Nm^2/kg^2	**3.** Nm^2/kg^2	
4. No	**5.** 9.8 m/s^2	**6.** m/s^2	**7.** $g = \frac{GM}{R^2}$
8. Decreases		**9.** mg/4	**10.** poles
11. Gravitational force	**13.** Both	**14.** decreases	**15.** zero
23. 1.6×10^{-8} N	**24.** 16 times	**25.** 490 N	**28.** 1. 6675 × 10^{-5}N
29. 3.92 m/s^2	**30.** 245 N	**34.** 1800 : 1	**35.** 81.9 N

EXERCISE-2

Ques	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans	C	A	D	A	B	C	B	D	C	C	C	D	B	D	C
Ques	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ans	C	D	A	D	A	C	A	C	C	C	A	B	A	D	B
Ques	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
Ans	A	B	A	D	C	A	C	D	C	A	A	D	C	B	

NCERT QUESTIONS

Exercises

1. How does the force of gravitation between two objects change when the distance between them is reduced to half ?
2. Gravitational force acts on all objects in proportion to their masses. Why then, a heavy object does not fall faster than a light object?
3. What is the magnitude of the gravitational force between the earth and a 1 kg object on its surface? (Mass of the earth is 6×10^{24} kg and radius of the earth is 6.4×10^{6} m.)
4. The earth and the moon are attracted to each other by gravitational force. Does the earth attract the moon with a force that is greater or smaller or the same as the force with which the moon attracts the earth? Why?
5. If the moon attracts the earth, why does the earth not move towards the moon?

6. What happens to the force between two objects, if
   (i) the mass of one object is doubled?
   (ii) the distance between the objects is doubled and tripled?
   (iii) the masses of both objects are doubled?
7. What is the importance of universal law of gravitation?
8. What is the acceleration of free fall?
9. What do we call the gravitational force between the earth and an object?
10. Amit buys few grams of gold at the poles as per the instruction of one of his friends. He hands over the same when he meets him at the equator. Will the friend agree with the weight of gold bought? If not, why? [*Hint*: The value of g is greater at the poles than at the equator.]
11. Why will a sheet of paper fall slower than one that is crumpled into a ball?
12. Gravitational force on the surface of the moon is only $\frac{1}{6}$ as strong as gravitational force on the earth. What is the weight in newtons of a 10 kg object on the moon and on the earth?
13. A ball is thrown vertically upwards with a velocity of 49 m/s. Calculate
   (i) the maximum height to which it rises,
   (ii) the total time it takes to return to the surface of the earth.
14. A stone is released from the top of a tower of height 19.6 m. Calculate its final velocity.
15. A stone is thrown vertically upward with an initial velocity of 40 m/s. Taking g = 10 m/s^2, find the maximum height reached by the stone. What is the net displacement and the total distance covered by the stone?
16. Calculate the force of gravitation between the earth and the Sun, given that the mass of the earth = 6×10^{24} kg and of the Sun = 2×10^{30} kg. The average distance between the two is 1.5×10^{11} m.
17. A stone is allowed to fall from the top of a tower 100 m high and at the same time another stone is projected vertically upwards from the ground with a velocity of 25 m/s. Calculate when and where the two stones will meet.
18. A ball thrown up vertically returns to the thrower after 6 s. Find
   (a) the velocity with which it was thrown up,
   (b) the maximum height it reaches, and
   (c) its position after 4 s.

BRAIN MAP

WORK, ENERGY AND POWER

WORK

Work is said to be done whenever a force acts on a body and the body moves through some distance.

$W = \vec{F} \cdot \vec{S} = FS\cos\theta$ (where θ is the angle between force applied $\vec{F}$ and displacement vector $\vec{S}$.)

The SI unit of work is joule (J).

Nature of Work Done

If $\theta = 0°$, $W = FS$ *i.e.*, work done is maximum.

If $\theta = 90°$, $W = 0$ *i.e.*, work done is zero.

Work Done by a Variable Force

The work done by a variable force in changing the displacement from S_1 to S_2 is $W = \int_{S_1}^{S_2} \vec{F} \cdot d\vec{S}$ = Area under the force-displacement graph

ENERGY

It is defined as the ability of a body to do work. It is measured by the amount of work that a body can do. The unit of energy used at the atomic level is electron volt (eV) and SI unit is J.

Kinetic Energy

It is the energy possessed by a body by virtue of its motion. The K.E. of a body of mass m moving with speed v is

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

Potential Energy

It is the energy possessed by a body by virtue of its position (in a field) or configuration (shape or size). For a conservative force in one dimension, the potential energy function $U(x)$ may be defined as

$$F(x) = -\frac{dU(x)}{dx} \text{ or } \Delta U = U_f - U_i = -\int_{x_i}^{x_f} F(x)dx$$

Power

The rate of doing work is called power.

Average Power:

It is defined as the ratio of the small amount of work done W to the time taken t to perform the work.

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

The SI unit of power is watt (W).

Work Energy Theorem

The work done by the net force acting on a body is equal to the change in kinetic energy of the body.

W = Change in kinetic energy

$$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \Rightarrow W = \Delta\text{K.E.}$$

The work energy theorem may be regarded as the scalar form of Newton's second law of motion.

Potential Energy of a Spring

According to Hooke's law, when a spring is stretched through a distance x, the restoring force F is such that

$F \propto x$ (where k is the spring constant or $F = -kx$ and its unit is N m^{-1}.)

The work done is stored as potential energy U of the spring.

$$W = \int_0^x kx dx = \frac{1}{2}kx^2 \Rightarrow U = \frac{1}{2}kx^2$$

COLLISION

A collision between two bodies is said to occur if either they physically collide against each other or the path of the motion of one body is influenced by the other.

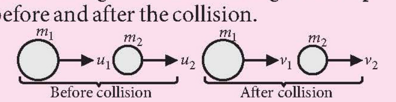
Types of Collision

Elastic collision : Both the momentum and kinetic energy of the system remain conserved.

Inelastic collision : Only the momentum of the system is conserved but kinetic energy is not conserved.

Head-on Collision or One-Dimensional Collision

It is a collision in which the colliding bodies move along the same straight line path before and after the collision.



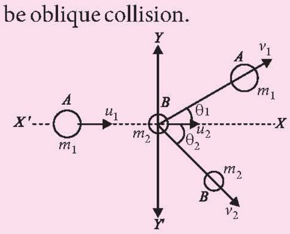
Velocity of approach = Velocity of separation or $u_1 - u_2 = v_2 - v_1$

Also, $v_1 = \frac{m_1 - m_2}{m_1 + m_2} \cdot u_1 + \frac{2m_2}{m_1 + m_2} \cdot u_2$ and

$$v_2 = \frac{2m_1}{m_1 + m_2} \cdot u_1 + \frac{m_2 - m_1}{m_1 + m_2} \cdot u_2$$

Oblique Collision

If the two bodies do not move along the same straight line path before and after the collision, the collision is said to be oblique collision.



CONTENTS

WORK

◈ **Definition :** In our daily life "work" implies an activity resulting in muscular or mental exertion. However, in physics the term 'work' is used in a specific sense involves the displacement of a particle or body under the action of a force. "work is said to be done when the point of application of a force moves.

Work done in moving a body is equal to the product of force exerted on the body and the distance moved by the body in the direction of force.

Work = Force × Distance moved in the direction of force.

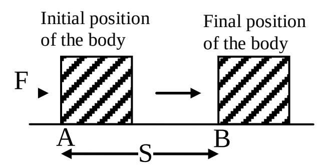
◆ The work done by a force on a body depends on two factors :

(i) Magnitude of the force, and

(ii) Distance through which the body moves (in the direction of force)

◈ **Unit of Work**

When a force of 1 newton moves a body through a distance of 1 metre in its own direction, then the work done is known as 1 joule.



Work = Force × Displacement

1 joule = 1 N × 1 m

or 1 J = 1 Nm (In SI unit)

Ex.1 How much work is done by a force of 10N in moving an object through a distance of 1 m in the direction of the force ?

Sol. The work done is calculated by using the formula:

W = F × S

Here, Force, F = 10 N

And, Distance, S = 1 m

So, Work done, W = 10 × 1 J

= 10 J

Thus, the work done is 10 joules

Ex.2 Find the work done by a force of 10 N in moving an object through a distance of 2 m.

Sol. Work done = Force × Distance moved

Here, Force = 10 N

Distance moved = 2 m

Work done, W = 10 N × 2 m

= 20 Joule = 20 J

WORK DONE ANALYSIS

- **Work done when force and displacement are along same line.**
  - **Work done by a force :** Work is said to be done by a force if the direction of displacement is the same as the direction of the applied force.
  - **Work done against the force :** Work is said to be done against a force if the direction of the displacement is opposite to that of the force.
  - **Work done against Gravity :** To lift an object, an applied force has to be equal and opposite to the force of gravity acting on the object. If 'm' is the mass of the object and 'h' is the height through which it is raised, then the upward force

    (F) = force of gravity = mg

    If 'W' stands for work done, then

    W = F . h = mg . h

    Thus W = mgh

    Therefore we can say that, "The amount of work done is equal to the product of weight of the body and the vertical distance through which the body is lifted.

Ex.3 Calculate the work done in pushing a cart, through a distance of 100 m against the force of friction equal to 120 N.

Sol. Force, F = 120 N; Distance, s = 100 m

Using the formula, we have

$W = Fs = 120\text{ N} \times 100\text{ m} = 12,000\text{ J}$

Ex.4 A body of mass 5 kg is displaced through a distance of 4m under an acceleration of 3 m/s^2. Calculate the work done.

Sol. Given :mass, m = 5 kg

acceleration, a = 3 m/s^2

Force acting on the body is given by

$F = ma = 5 \times 3 = 15\text{ N}$

Now, work done is given by

$W = Fs = 15\text{ N} \times 4\text{ m} = 60\text{ J}$

Ex.5 Calculate the work done in raising a bucket full of water and weighing 200 kg through a height of 5 m. (Take g = 9.8 ms^{-2}).

Sol. Force of gravity

$mg = 200 \times 9.8 = 1960.0\text{ N}$

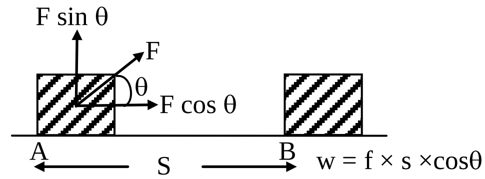
$h = 5\text{ m}$

Work done, W = mgh

or $W = 1960 \times 5 = 9800\text{ J}$

- **Work done when force and displacement are inclined (Oblique case)**

  Consider a force 'F' acting at angle θ to the direction of displacement 's' as shown in fig.



  - **Work done when force is perpendicular to Displacement**

    $\theta = 90^\circ$

    $W = F.S \times \cos 90^\circ = F.S \times 0 = 0$

    Thus no work is done when a force acts at right angle to the displacement.

- **Special Examples :**
  - When a bob attached to a string is whirled along a circular horizontal path, the force acting on the bob acts towards the centre of the circle and is called as the centripetal force. Since the bob is always displaced perpendicular to this force, thus no work is done in this case.
  - Earth revolves around the sun. A satellite moves around the earth. In all these cases, the direction of displacement is always perpendicular to the direction of force (centripetal force) and hence no work is done.
  - A person walking on a road with a load on his head actually does no work because the weight of the load (force of gravity) acts vertically downwards, while the motion is horizontal that is perpendicular to the direction of force resulting in no work done. Here, one can ask that if no work is done, then why the person gets tired. It is because the person has to do work in moving his muscles or to work against friction and air resistance.

Ex.6 A boy pulls a toy cart with a force of 100 N by a string which makes an angle of 60º with the horizontal so as to move the toy cart by a distance horizontally. Calculate the work done.

Sol. Given F = 100 N, s = 3 m, $\theta = 60^o$.

Work done is given by

$W = Fs \cos\theta = 100 \times 2 \times \cos 60^o$

$= 100 \times 3 \times \frac{1}{2} = 150 \text{ J } (\because \cos 60^o = \frac{1}{2})$

Ex.7 An engine does 64,000 J of work by exerting a force of 8,000 N. Calculate the displacement in the direction of force.

Sol. Given W = 64,000 J; F = 8,000 N

Work done is given by W = Fs

or 64000 = 8000 × s

or s = 8 m

POWER

- **Definition :** Power is defined as the rate of doing work

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} \Rightarrow P = \frac{W}{t}$$

In other words, power is the work done per unit time, power is a scalar quantity.

Since W = F.S therefore

$$P = \frac{W}{t} = \frac{FS}{t} = F \times V = \text{force} \times \text{velocity}$$

- **Unit of power :** The S.I. unit of power is watt and it is the rate of doing work at 1 joule per second.

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

1 kilowatt = 1 kW = 1000 W

1 Horse power = 1 H.P. = 746 W

Ex.8 A machine raises a load of 750 N through a height of 15 m in 5s. Calculate :

(i) the work done by the machine.

(ii) the power at which the machine works.

Sol. (i) Work done is given by W = F.s

Here F = 750 N; s = 15 m

$\therefore$ W = 750 × 15 = 11250 J

= 11.250 kJ

(ii) Now, power of the machine is given by

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

Here, W = 11250 J; t = 5 s

$$\therefore \text{ Power } P = \frac{11250\text{J}}{5\text{s}} = 2250 \text{ W} = 2.250 \text{ kW}$$

Ex.9 A weight lifter lifted a load of 100 kg to a height of 3 m in 10 s. Calculate the following:

(i) amount of work done

(ii) power developed by him

Sol. (i) Work done is given by

W = F . s

Here, F = mg = 100 × 10 = 1000 N

W = 1000 N × 3 m = 3000 joule

(ii) Now, $P = \frac{W}{t}$, where W = 3000 J and t = 10 s

$$\therefore P = \frac{3000\text{ J}}{10\text{ s}} = 300 \text{ W}$$

Ex.10 A water pump raises 60 liters of water through a height of 20 m in 5 s. Calculate the power of the pump. (Given: g = 10 m/s^2, density of water = 1000 kg/m^3)

Sol. Work done, W = F.s ...(1)

Here, F = mg ...(2)

But,Mass = volume × density

Volume = 60 liters = 60 × 10^{-3} m^3

Density = 1000 kg/m^3

$\therefore$ Mass , m = (60 × 10^{-3} m^3) × (1000 kg/m^3)

= 60 kg

$\therefore$ Equation (2) becomes

F = 60 kg × 10 m/s^2 = 600 N

Now, W = F . s = 600 N × 20 m = 12000 J $\therefore$

$$\text{Power} = \frac{W}{t} = \frac{12000\text{J}}{5\text{s}} = 2400 \text{ W}$$

Ex.11 A woman pulls a bucket of water of total mass 5 kg from a well which is 10 m deep in 10 s. Calculate the power used by her.

Sol. Given that m = 5 kg; h = 10 m; t = 10 s

g = 10 m/s^2

$$\text{Now,} P = \frac{W}{t} = \frac{mgh}{t} = \frac{5 \times 10 \times 10}{10} = 50\text{W}$$

ENERGY

- **Definition :** Energy is the ability to do work. The amount of energy possessed by a body is equal to the amount of work it can do when its energy is released. Thus, energy is defined as the capacity of doing work. Energy is a scalar quantity and it exists in various forms.

◈ **Units of energy :** The units of energy are the same as that of work. In SI system, the unit of energy is joule (J). In CGS system, the unit of energy is erg.

1 Joule = 10^7 ergs

Other units of energy in common use are watt-hour and kilowatt hour.

1 watt-hour = 1 watt × 1 hour

= 1 watt × 60 × 60 sec

= 3600 J

1 kilowatt-hour (kWh) = 3.6×10^6 Joule

Heat energy is usually measured in calorie or kilocalorie such that

1 calorie = 4.18 J

A very small unit of energy is electron volt(eV).

1 eV = 1.6×10^{-19} J

➤ MECHANICAL ENERGY

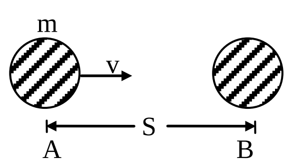
The energy possessed by a body due to its state of rest or state of motion is called mechanical energy.

Mechanical energy is of two types–

(A) Kinetic Energy (B) Potential Energy.

◈ **Kinetic Energy :** The energy of a body due to its motion is called kinetic energy. In other words. The ability of a body to do work by virtue of its motion is called its kinetic energy.

Expression for Kinetic Energy : The kinetic energy of a body is measured in terms of the amount of work done by an opposing force that brings the body to rest from its present state of motion.



Suppose a body of mass m is moving with a velocity v and is brought to rest by an opposing force F.

Now retarding force is given by

$$F = ma \quad ...(1)$$

Now using the equation of motion,

$v^2 - u^2 = 2as$, we get

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

$$\therefore \quad s = \frac{v^2}{2a} \quad ...(2)$$

Kinetic energy of the body = work done by the retarding force

or Kinetic energy = force × displacement

= F . s ...(3)

Substituting the value of F from equation (1) and the value of s from equation (2) in equation (3), we get

$$K.E. = ma \times \frac{v^2}{2a} = \frac{1}{2} mv^2$$

Thus, a body of mass m and moving with a velocity v has the capacity of doing work equal to $\frac{1}{2}mv^2$ before it stops.

Ex.12 A bullet of mass 100 gm is fired with a velocity 50 m/s from a gun. Calculate the kinetic energy of the bullet.

Sol. Kinetic energy is given by

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

Here m = 100 gm = 0.1 kg; v = 500 m/s

$$K.E. = \frac{1}{2} \times 0.1 \times (50)^2$$

$$= \frac{1}{2} \times 0.1 \times 50 \times 50 = 125 \text{ J}$$

Ex.13 A 4 kg body is dropped from the top of a building of height 2.5 m. With what velocity will it strike the ground ? What is its kinetic energy when it strikes the ground ?

(Takes g = 9.8 m/s^2)

Sol. Velocity of the body with which it strikes the ground can be calculated by using the equation, $v^2 = u^2 + 2gh$

Here u = 0; g = 9.8 m/s^2 ; h = 2.5 m

Substituting these values, we get

$v^2 = 0^2 + 2 \times 9.8 \times 2.5 = 49$

or $v = 7$ m/s

Thus, the speed of the body with which it strikes the ground = 7 m/s.

Ex.14 Calculate the velocity of 4 kg mass with kinetic energy of 128 J.

Sol. The formula for kinetic energy is given by

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

Here K.E. = 128 J; m = 4 kg

$$\therefore \quad 128 = \frac{1}{2} \times 4 \times v^2$$

or $v^2 = 64$; or $v = 8$ m/s

Ex.15 Which would have a greater effect on the kinetic energy of an object, doubling the mass or doubling the velocity ?

Sol. (i) The kinetic energy of a body is directly proportional to its "mass" (m). So, if we double the mass (so that it becomes 2m), then the kinetic energy will also get doubled.

(ii) On the other hand, kinetic energy of a body is directly proportional to the "square of its velocity" (v^2). So, if we double the velocity (so that it becomes 2v), then the kinetic energy will become four times. This is because : $(2v)^2 = 4v^2$.

It is clear from the above discussion that doubling the velocity has a greater effect on the kinetic energy of an object.

◈ Potential Energy

Thus the energy possessed by a body by virtue of its position or change in shape is known as potential energy. It is obvious that a body may possess energy even when it is not in motion.

◆ Expression for Potential Energy :

Suppose a body of mass m be lifted from the ground to a vertical height h, then the minimum force required to lift the body is equal to the force of gravity, i.e.

$$F = mg$$

This force of gravity acts on the body vertically downwards.

Now, work done in lifting the body to a height h will be

$$\text{Work} = \text{force} \times \text{distance} = mgh$$

This work done is stored as potential energy in the body such that

Potential energy, U = mgh, i.e. gain in potential energy of the body and the earth.

Ex.16 What will be the potential energy of a body of mass 2 kg kept at a height of 10 m ?

Sol. The potential energy is given by

$$U = mgh$$

Here,m = 2 kg; g = 10 m/s^2; h = 10 m

$$\therefore \quad U = 2 \times 10 \times 10 = 200 \text{ J}$$

Ex.17 In lifting a mass of 25 kg to a certain height 1250 J energy is utilized. Calculate to what height it has been lifted ? (Take g = 10 m/s^2)

Sol. In lifting a mass through a height h the work done is given by

$$U = mgh$$

Here, U = 1250 J; g = 10 m/s^2; m = 25 kg

$$\therefore \quad 1250 = 25 \times 10 \times h$$

or $h = 5$ m

➤ LAW OF CONSERVATION OF ENERGY

Energy can neither be created nor be destroyed, it can only be changed from one form to another. Appearing amount of energy in one form is always equal to the disappearing amount of energy in some other form. The total energy thus remains constant.

➢ INTER CONVERSION OF POTENTIAL AND KINETIC ENERGY

Mechanical Energy of a Freely Falling Body :

Assume, a body of mass m is at rest at a height h from the earth's surface, as it starts falling, its velocity after travelling a distance x (point B) becomes v and its velocity on the earth's surface is v'.

Mechanical energy of the body at point A :

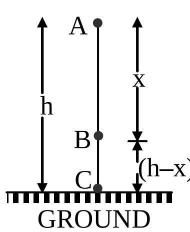
E_A = Kinetic energy + Potential energy

$E_A = m(0)^2 + mgh$

$E_A = mgh$ .... (i)

Mechanical energy of the body at point B :

$E_B = \frac{1}{2} mv^2 + mg(h - x)$ ....(ii)



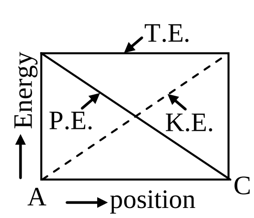
Mechanical energy of the body at point C :

$E_C = \frac{1}{2} m(v')^2 + mg \times 0$

$E_C = \frac{1}{2} m(v')^2$ ....(iv)

Use : $E_A = E_B = E_c$

Hence, when a body falls freely, its mechanical energy will be constant. That means, the total energy of the body during free fall, remains constant at all positions. However, the form of energy keeps on changing at all points during the motion.



➢ TRANSFORMATION OF ENERGY

◈ **Definition :** The change of one form of energy into another form of energy is known as transformation of energy.

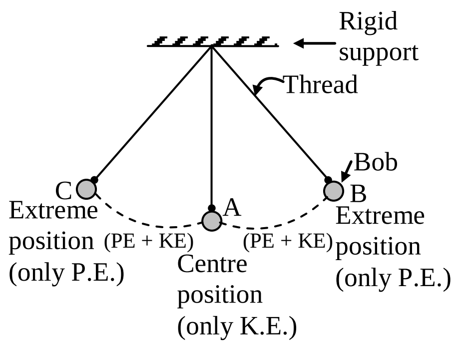
◈ **Different Forms of Energy**

- **Heat energy :** Burning of fuels like diesel or petrol in vehicles provides heat energy to do work.
- **Electrical energy :** Electric motors are used in home, industry and even for driving electric trains.
- **Light energy :** When light energy falls on light-meter used in photography, it causes its pointer to move across a scale.
- **Sound energy :** Sound energy causes a thin plate of microphone diaphragm to vibrate.
- **Chemical energy :** Chemical energy is the source of energy in our food and it provides us energy to move the various objects.
- **Nuclear Energy :** The energy in the nucleus of an atom is used to produce heat energy which in turn is used to generate electrical power.

Device used	Energy tranformation	
	Form	**to**
Steam engine	Heat	Mechanical
Electric fan	Electrical	Mechanical
Electric lamp	Electrical	Light and Heat
Electric heater	Electrical	Heat
Microphone	Sound	Electrical
Solar cell	Solar heat	Electrical
Photo-cell	Light	Electrical
Car engine	Chemical	Heat, Mechanical
Electric cell/batteries	Chemical	Electrical

◈ **A swinging simple pendulum is an example of conservation of energy :**

This is because a swinging simple pendulum is a body whose energy can either be potential or kinetic, or a mixture of potential and kinetic, but its total energy at any instant of time remains the same.



- When the pendulum bob is at position B, it has only potential energy (but no kinetic energy).
- As the bob starts moving down from position B to position A, its potential energy goes on decreasing but its kinetic energy goes on increasing.
- When the bob reaches the centre position A, it has only kinetic energy (but no potential energy).
- As the bob goes from position A towards position C, its kinetic energy goes on decreasing but its potential energy goes on increasing.
- On reaching the extreme position C, the bob stops for a very small instant of time. So at position C, the bob has only potential energy (but no kinetic energy).

Miscellaneous Examples :

Ex.18 A car weighing 1200 kg and travelling at a speed of 20 m/s stops at a distance of 40 m retarding uniformly. Calculate the force exerted by the brakes. Also calculate the work done by the brakes.

Sol. In order to calculate the force applied by the brakes, we first calculate the retardation.

Initial speed, u = 20 m/s; final speed,

v = 0, distance covered, s = 90 m

Using the equation, $v^2 = u^2 + 2as$, we get

$0^2 = (20)^2 + 2 \times a \times 40$

or $80a = -400$

or $a = -5 \text{ m/s}^2$

Force exerted by the brakes is given by

$F = ma$

Herem = 1200 kg; $a = -5 \text{ m/s}^2$

$\therefore$ $F = 1200 \times (-5) = -6000$ N

The negative sign shows that it is a retarding force. Now, the work done by the brakes is given by

$W = Fs$

Here F = 6000 N; s = 40 m

$\therefore$ $W = 6000 \times 40 \text{ J} = 240000 \text{ J}$

$= 2.4 \times 10^5$ J

$\therefore$ Work done by the brakes = 2.4×10^5 J

Ex.19 A horse applying a force of 800 N in pulling a cart with a constant speed of 20 m/s. Calculate the power at which horse is working.

Sol. Power, P is given by force × velocity, i.e.

$P = F \,.\, v$

Here F = 800 N; v = 20 m/s

$\therefore$ $P = 800 \times 20 = 16000$ watt

= 16 kW

Ex.20 A boy keeps on his palm a mass of 0.5 kg. He lifts the palm vertically by a distance of 0.5 m. Calculate the amount of work done.

Use $g = 9.8 \text{ m/s}^2$.

Sol. Work done, $W = F \,.\, s$

Here, force F of gravity applied to lift the mass, is given by

$F = mg$

$= (0.5 \text{ kg}) \times (9.8 \text{ m/s}^2)$

$= 4.9$ N

and s = 0.5 m

Therefore, W = (4.9) . (0.5m) = 2.45 J.

Ex.21 A truck of mass 2500 kg is stopped by a force of 1000 N. It stops at a distance of 320 m. What is the amount of work done ? Is the work done by the force or against the force?

Sol. Here the force, F = 1000 N

Displacement, s = 320 m

$\therefore$ Work done, W = F . s

= (1000N) . (320 m)

= 320000 J

In this case, the force acts opposite to the direction of displacement. So the work is done against the force.

Ex.22 Two bodies of equal masses move with uniform velocity v and 3v respectively. Find the ratio of their kinetic energies.

Sol. In this problem, the masses of the bodies are equal, so let the mass of each body be m. We will now write down the expression for the kinetic energies of both the bodies separately.

(i) Mass of first body = m

Velocity of first body = v

So, K.E. of first body = $\frac{1}{2}$ mv^2 ...(1)

(ii) Mass of second body = m

Velocity of second body = 3v

So, K.E. of second body $= \frac{1}{2}$ m(3v)^2

$= \frac{1}{2}$ m × 9v^2

$= \frac{9}{2}$mv^2 ...(2)

Now, to find out the ratio of kinetic energies of the two bodies, we should divide equation (1) by equation (2), so that :

$$\frac{\text{K.E. of first body}}{\text{K.E. of second body}} = \frac{\frac{1}{2}mv^2}{\frac{9}{2}mv^2}$$

or $\frac{\text{K.E. of first body}}{\text{K.E. of second body}} = \frac{1}{9}$ …. (3)

Thus, the ratio of the kinetic energies is 1 : 9. We can also write down the equation (3) as follows:

K.E. of second body = 9 × K.E. of first body

That is, the kinetic energy of second body is 9 times the kinetic energy of the first body. It is clear from this example that when the velocity (or speed) of a body is "tripled" (from v to 3v), then its kinetic energy becomes "nine times".

A Very Short Answer Type Questions

Q.1 Is work a scalar or a vector quantity ?

Q.2 What name is given to the product of force and distance ?

Q.3 Give the units of work in SI system and in CGS system.

Q.4 What is the work done, when the displacement of a body is perpendicular to the direction of force acting on it ?

Q.5 Give the SI unit of power.

Q.6 What is the relationship between watt and horse power ?

Q.7 What are the units of work and energy ?

Q.8 A cell converts one form of energy into another. Name the two forms.

Q.9 Name the device which converts electrical energy into mechanical energy.

Q.10 Is energy a scalar quantity or a vector quantity ?

Q.11 What are the two different forms of mechanical energy ?

Q.12 How much work is done when a body of mass m is raised to a height h above the ground ?

Q.13 How much work is done when a force of 1 N moves a body through a distance of 1 m in its own direction ?

Q.14 What is the power of a body which is doing work at the rate of one joule per second ?

B Short Answer Type Questions

Q.15 Write the formula for the work done on a body when the force is applied at an angle θ with the direction of motion of the body.

Q.16 A satellite revolves around the earth in a circular orbit. Calculate the work done by the force of gravity ?

Q.17 In which of the following case the work done by a force will be maximum : when the angle between the direction of force and direction of motion is 0^o or 90^o ?

Q.18 State two situations in which a body moves with uniform speed and force acts on the body but work done on the body by the force acting is zero.

Q.19 What do you understand by the kinetic energy of a body ? Deduce the formula for kinetic energy.

Q.20 On what factors does the kinetic energy of a body depend ?

Q.21 What is the difference between potential energy and kinetic energy ?

Q.22 When a ball is thrown vertically upwards, its velocity goes on decreasing. What happens to its potential energy as its velocity becomes zero ?

Q.23 State whether the following objects possess potential energy, kinetic energy or both ?

(i) A flying aeroplane
(ii) A stretched spring
(iii) A rotating ceiling fan
(iv) A man climbing upstairs
(v) A stone placed on the roof
(vi) A running car
(vii) Water stored in a dam

Q.24 What do you understand by the term "transformation of energy" ? Explain with an example.

Q.25 A car of mass 1000 kg moving with a speed of 10 m/s stops after moving a distance of 8 m after applying the brakes. Calculate the force applied by the brakes and work done by the brakes.

Q.26 A car is being driven by a force of 2.5×10^{10}N. Travelling at a constant speed of 5 m/s, it takes 2 minutes to reach a certain place. Calculate the work done.

Q.27 How much is the mass of a man if he has to do 2500 joules of work in climbing a tree 5 m tall ?

Q.28 A man weighing 500 N carried a load of 100 N up a flight of stairs 4 m high in 5 seconds. What is the power ?

Q.29 An athlete weighing 60 kg makes a high jump of 1.8 m. Determine the following :
(i) kinetic energy at the highest point.
(ii) potential energy at the highest point.

Q.30 If an electric bulb of 100 W is light up for 2 hrs, how much electrical energy will be consumed ?

Q.31 A person weighing 800 N carries a packet from the base camp B to point A of a hill at a height of 1200 m. The weight of the packet is 200 N. Calculate the following :
(i) How much work he does against gravity ?
(ii) What is the potential energy of the packet at A if it assumed to be zero at B ?

Q.32 A man weighing 600 N carries a load of 100 N up a flight of stairs 4 m high in 5 s. Calculate the power.

Q.33 Water is falling on the blades of a turbine at the rate of 6×10^3 kg/min. The height of the fall is 10 m. Calculate the power of the motor to be used.

Q.34 An electric motor drives a machine which lifts a mass of 2 kg through a height of 6 m, in 4 s at a constant speed. Assume g = 9.8 N kg^{-1} and calculate (i) the amount of work done and (ii) the power of the machine to lift the mass of 2 kg.

C Long Answer Type Questions

Q.35 Define the term work. What are the quantities on which the amount of work done depends ? How are they related to work ? What is the condition for a force to do work on a body?

Q.36 Write the formula for work done on a body when the body moves at an angle to the direction of force. Give the meaning of each symbol used. What will happen to the work done if angle θ between the direction of force and motion of the body is increased gradually? Will it increase, decrease or remain constant ?

Q.37 Write an expression for the kinetic energy of a body of mass m moving with a velocity v. Explain by an example what is meant by potential energy. Write down the expression for gravitational potential energy of a body of mass m placed at a height h above the surface of the earth.

Q.38 How can you explain the oscillation of a simple pendulum on the basis of conservation of energy ?

EXERCISE - 2

Single Correct Answer Type Questions

Q.1 Work done upon a body is-
(A) a vector quantity
(B) a scalar quantity
(C) (A) and (B) both are correct
(D) none of these

Q.2 Work done -
(A) is always positive
(B) is always nagative
(C) can be positive, negative or zero
(D) none of these

Q.3 No work is done when -
(A) a nail is plugged in a wooden board
(B) a box is pushed along a horizontal floor
(C) there is no component of force parallel to the direction of motion
(D) there is no component of force perpendicular to the direction of motion

Q.4 A body at rest can have :
(A) speed (B) velocity
(C) momentum (D) energy

Q.5 Types of mechanical energy are:
(A) kinetic energy only
(B) potential energy only
(C) kinetic energy and potential energy both
(D) neither kinetic energy nor potential energy

Q.6 Work means:
(A) effort (B) interview
(C) achievement (D) get-together

Q.7 Work is done on a body when :
(A) force acts on the body but the body is not displaced
(B) force does not act on the body but it is displaced
(C) force acts on the body in a direction perpendicular to the direction of the displacement of the body
(D) force acts on the body and the body is either displaced in the direction of force or opposite to the direction of force

Q.8 Force F acts on a body such that force F makes an angle θ with the horizontal direction and the body is also displaced through a distance S in the horizontal direction, then the work done by the force is -
(A) FS (B) FS cos θ
(C) FS sin θ (D) zero

Q.9 In tug of war work done by winning team is :
(A) zero (B) positive
(C) negative (D) none of these

Q.10 In tug of war work done by loosing team is :
(A) zero (B) positive
(C) negative (D) none of these

Q.11 Work done by the force of gravity, when a body is lifted to height h above the ground is :
(A) zero (B) positive
(C) negative (D) none of these

Q.12 When work is done on a body:
(A) it gains energy
(B) it looses energy
(C) its energy remains constant
(D) none of these

Q.13 Choose correct relation :
(A) 1 J = 10^5 erg
(B) 1 J = 10^7 erg
(C) 1 J = 10^3 erg
(D) none of these

Q.14 The kinetic energy of an object is K. If its velocity is doubled than its kinetic energy will be –

(A) K (B) 2K

(C) $\frac{K}{2}$ (D) 4K

Q.15 Two bodies of mass 1 kg and 4 kg possess equal momentum. The ratio of their K.E.

(A) 4 : 1 (B) 1 : 4

(C) 2 : 1 (D) 1 : 2

Q.16 Which one is not the unit of energy?

(A) kilocalorie (B) kWh

(C) erg (D) watt

Q.17 1 kg mass has K.E. of 1 J when its speed is-

(A) 0.45 ms^{-1} (B) 1 ms^{-1}

(C) 1.4 ms^{-1} (D) 4.4 ms^{-1}

Q.18 When you compress a spring you do work on it. The elastic potential energy of the spring-

(A) increases (B) decreases

(C) disappears (D) remains constant

Q.19 When a ball is thrown upward, its total energy-

(A) increases (B) decreases

(C) remains same (D) none of these

Q.20 If a stone of mass 'm' falls a vertical distance 'd' the decrease in gravitational potential energy is-

(A) $\frac{Mg}{d}$ (B) $\frac{Mg^2}{2}$

(C) mgd (D) $\frac{Mg}{d^2}$

Q.21 An object of mass 10 kg falls from height 10 m.. Kinetic energy gained by the body will be approximately equal to-

(A) 1000 J (B) 500 J

(C) 100 J (D) None of these

Q.22 A spring is stretched. The potential energy in stretching the spring-

(A) remains the same (B) increases

(C) decreases (D) becomes zero

Q.23 The potential energy of a boy is maximum when he is-

(A) standing

(B) sleeping on the ground

(C) sitting on the ground

(D) sitting on chair

Q.24 The potential energy of a freely falling object decreases continuously. What happens to the loss of potential energy ?

(A) It is continuously converted into sound energy

(B) it is continuously converted into kinetic energy

(C) it is continuously destroyed

(D) None of these

Q.25 A device which converts mechanical energy into electrical energy is known as-

(A) electric motor (B) lever

(C) generator (D) microphone

Q.26 The value of g on moon is $1/6^{th}$ of the value of g on the earth. A man can jump 1.5 m high on the earth. On moon he can jump up to a height of-

(A) 9 m (B) 7.5 m

(C) 6 m (D) 4.5 m

Q.27 A raised hammer possess-

(A) kinetic energy only

(B) gravitational potential energy

(C) electrical energy

(D) sound energy

Q.28 An object of mass 1 kg has a P.E. of 1 J relative to the ground when it is at a height of : (g = 9.8 m/s^2).

(A) 0.10 m (B) 10 m

(C) 9.8 m (D) 32 m

Q.29 To lift a 5 kg mass to a certain height, amount of energy spent is 245 J. The mass was raised to a height of-

(A) 15 m (B) 10 m
(C) 7.5 m (D) 5 m

Q.30 Chlorophyll in the plants convert the light energy into-

(A) heat energy (B) chemical energy
(C) mechanical energy(D) electrical energy

Q.31 Kilowatt is the unit of-

(A) energy (B) power
(C) force (D) momentum

Q.32 Work is product of time and-

(A) energy (B) power
(C) force (D) distance

Q.33 A young son work quickly for two hours and prepares 16 items in a day. His old father works slowly for eight hours and prepare 24 items a day.

(A) son has more power
(B) son has more energy
(C) both have equal power
(D) both have equal energy

Q.34 One horse power is

(A) 746 W (B) 550 W
(C) 980 W (D) 32 W

Q.35 Power of a moving body is stored in the form of-

(A) Work and distance
(B) force and distance
(C) force and velocity
(D) force and time

Q.36 A weight lifter lifts 240 kg from the ground to a height of 2.5 m in 3 second his power is-

(A) 1960 W (B) 19.6 W
(C) 1.96 W (D) 196 W

Q.37 Which of the following is not the unit of power ?

(A) J/s (B) Watt
(C) kJ/h (D) kWh

ANSWER KEY

EXERCISE - 1

6. 1 watt = 746 H.P

12. mgh

13. 1 Joule

14. 1 watt

25. 6250 N, 5×10^6 J

26. 15×10^{14} J

27. 50 kg

28. 480 W

29. (i) zero, (ii) 1080 J

30. 0.2 kWh

31. (i) 12×10^5 J, (ii) 2.4×10^5 J

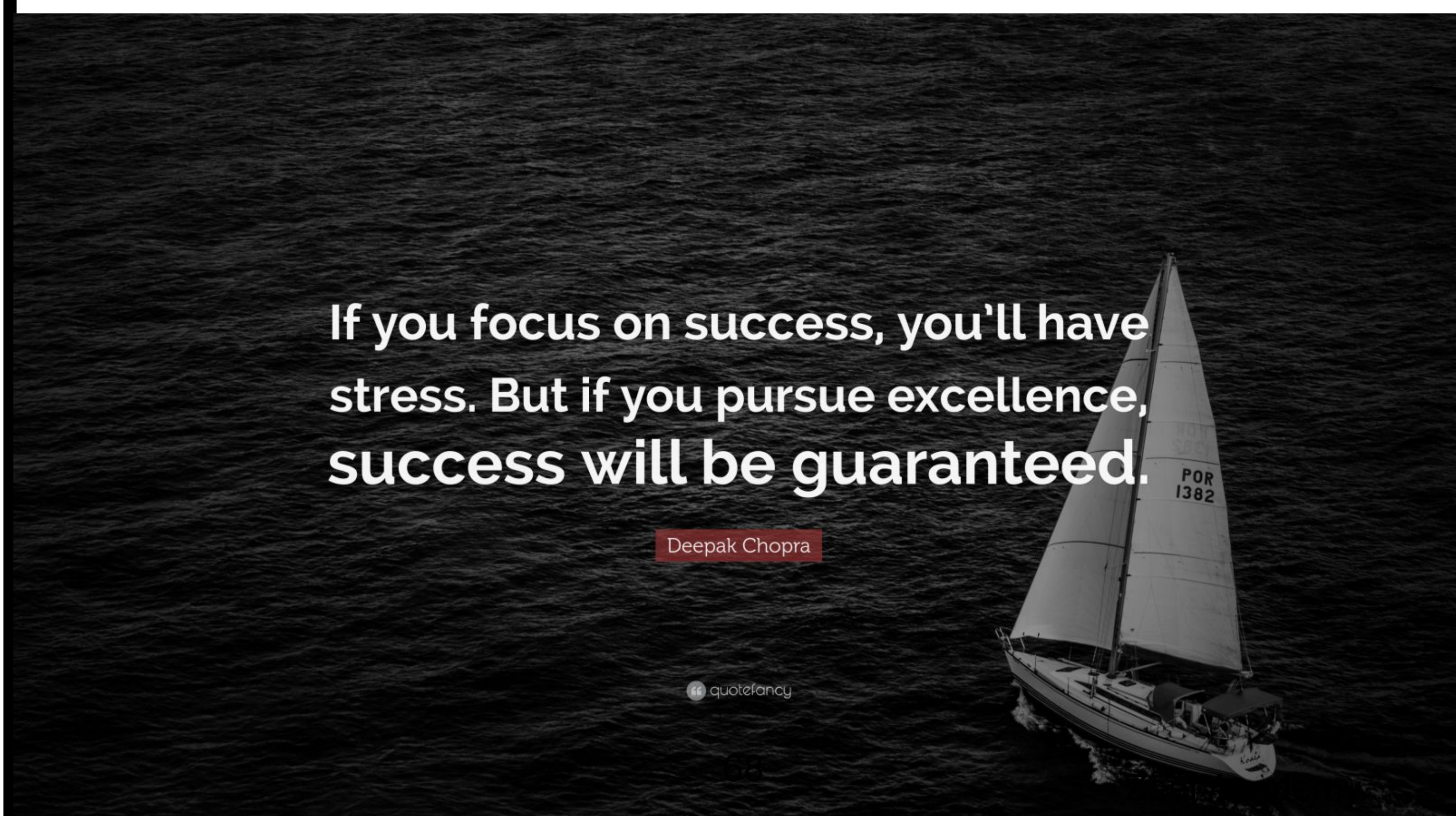
32. 560 W

33. 10 kW

34. (i) 117.6 J (ii) 29.4 W

EXERCISE - 2

Ques	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Ans	B	C	C	D	C	C	D	B	B	C	C	A	B	D	A
Ques	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Ans	D	C	A	C	C	A	B	A	B	C	A	B	A	D	B
Ques	**31**	**32**	**33**	**34**	**35**	**36**	**37**								
Ans	B	B	A	A	C	A	D								




SOUND CHAPTER
THIK SE PADHO!

CONTENTS

➢ PERIODIC MOTION

(i) When a body repeats its motion continuously on a definite path in a definite interval of time then its motion is called **periodic motion.**

(ii) The constant interval of time after which the motion is repeated is called the **'Time period of motion.' (T)**

Example : Time period of hour hand is 12 hours.

➢ OSCILLATORY MOTION

(i) If a body in periodic motion moves along the same path to and fro about a definite point (equilibrium position), then the motion of the body is a vibratory motion or oscillatory motion

Note: Resultant force acting on the particle is zero in equilibrium condition.

(ii) It is to be noted here that every oscillatory motion is periodic but every periodic motion is not oscillatory

➢ INTRODUCTION TO WAVE MOTION

Most of us have seen the formation of ripples when a small stone (pebble) is dropped into a pond. The disturbances created by the stone in the water produces ripples which move outwards towards the shore of the pond.

If you examine the motion of a leaf floating near the disturbance for a short while on a steady day, you would see that the leaf moves up and down about its original position, but does not move away or towards the source of disturbance. This indicates that the disturbance (such as a water wave) moves from one place to another, but the water is not carried with it. The water particles simply move up and down their mean positions.

The formation of ripples on the surface of water is an example of wave motion.

◆ **Wave Motion :** The movement of a disturbance produced in one part of a medium to another involving the transfer of energy but not the transfer of matter is called wave motion.

Examples :

(i) Formation of ripples on the water surface.

(ii) Propagation of sound waves through air or any other material medium.

➤ CHARACTERISTICS OF WAVE MOTION

The main characteristics of wave motion are described below :

- In wave motion, the particles of the medium vibrate about their mean positions. The particles of the medium do not move from one place to another.
- A wave motion travels at the same speed in all directions in the given medium. The speed of a wave depends upon the nature of the medium through which it travels.
- During a wave motion, energy is transferred from one point of the medium to another. There is no transfer of matter through the medium.

➤ CLASSIFICATION OF WAVE MOTION

(A) On the Bases of Necessity of Medium Required

◈ MECHANICAL WAVES :

The wave which propagates only in a material medium are called elastic or mechanical waves.

Example : Sound waves, Water waves (ripples), Waves on stretched strings, Earthquake waves and the Shock waves produced by a supersonic aircraft are mechanical (or elastic) waves.

◈ ELECTROMAGNETIC WAVES :

Wave which do not require any material medium for their propagation are called. electromagnetic waves.

Example : Light waves, Radio waves, Television waves, and X-rays are electromagnetic waves. Thus, Light waves, Radio and Television waves, and X-rays can also travel through vaccum.

Difference between Mechanical waves & electromagnetic waves

	Mechanical waves	**Electromagnetic waves**
1.	Mechanical waves need a material medium for their propagation. These waves cannot travel through vacuum.	Electromagnetic waves do not need any material medium for their propagation. These waves can travel through vacuum.
2.	Speed of mechanical waves are low and depends upon the source and the medium through which they travel.	(EMW) a electromagnetic waves travel with the speed of light (3×10^8 m/s) in vaccum. The speed of an electromagnetic wave in any material medium is less than that in vaccum.
3.	Mechanical waves are due to the vibrations of the particles of the medium.	(EMW) a electromagnetic waves are not due to vibration of medium particles
4.	Mechanical waves may be longitudinal or transverse waves.	Electromagnetic are transverse waves.
5.	Example : Sound waves, water waves, string waves are mechanical waves.	Examples : Light waves, radio and TV waves, and X-rays are electromagnetic

(B) On the Basis of mode of Vibration of the Particle

◈ TRANSVERSE WAVES

A wave in which the particles of the medium oscillate about their mean position in a direction perpendicular to the direction of propagation of the wave is called a transverse wave.

Transverse waves can travel through solids and over the surface of liquids, but not through gases.

Examples : Following are the examples of transverse waves :

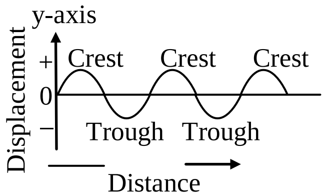
(i) The water waves (ripples) produced on the surface of water is transverse waves. In water waves, the molecules of water move up and down from their mean positions.

(ii) A pulse on a slinky when it is given a jerk is a transverse wave.

(iii) All electromagnetic waves, e.g., light waves, radio waves etc., are transverse waves.

(iv) The waves produced in a stretched string when plucked are transverse waves. When a string of sitar (a musical instrument) or guitar is plucked, transverse waves are produced in the string.

◆ **Graphical Representation :**



Displacement-distance graph for a transverse waves

(a) **Crest :** The highest point on the hump in a transverse wave is called a crest. Thus, the point of maximum positive displacement on a transverse wave is called a crest.

(b) **Trough :** The lowest point on the depression in a transverse wave is called a trough. Thus, the point of maximum negative displacement on a transverse wave is called a trough.

◈ LONGITUDINAL WAVES :

A wave in which the particle of the medium oscillate (vibrate) to and fro about their mean position in the direction of propagation of the wave is called a longitudinal wave.

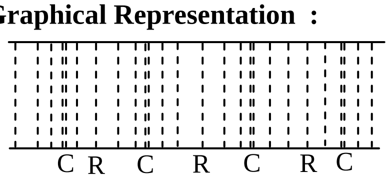
Longitudinal waves can be produced in any medium, viz., in solids, liquids and in gases.

Example :

(i) Sound waves are longitudinal waves.

(ii) The waves produced in a spring (slinky) by compressing a small portion of it and releasing are longitudinal waves.

◆ **Graphical Representation :**



(a) **Compression :** The part of a longitudinal wave in which the density of the particles of the medium is higher than the normal density is called a compression.

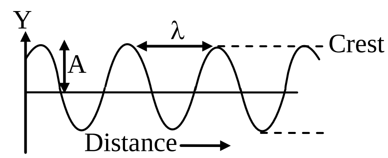
(b) **Rarefaction :** The part of a longitudinal wave in which the density of the particles of the medium is lesser than the normal density is called a rarefaction.

◈ Difference between Transverse & Longitudinal Wave

	Longitudinal	Transverse waves
1	In a longitudinal wave the particles of the medium oscillate along the direction of propagation of the wave.	In a transverse wave, the particles of the medium oscillate in a direction perpendicular to the direction of propagation of the wave
2	Longitudinal waves can propagate through solids, liquids, as well as gases.	Transverse waves can propagate through solids, and over the surface of liquids, but not through gases.
3	Longitudinal waves consist of compression and rarefactions.	Transverse waves consist of crests and troughs.

➢ TERMS USED FOR DEFINING WAVE MOTION

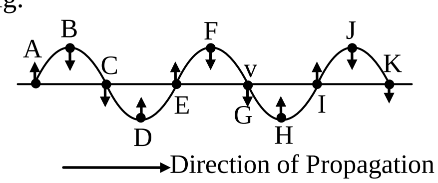
◆ **Wave Length :** The distance between two nearest points in a wave which are in the same phase of vibration is called the wave length. In simple words it is the length of one complete wave. It is denoted by lambda, λ.



◆ **Amplitude :** The amplitude of a wave is the magnitude of maximum displacement of the vibrating particles on the either side of their mean position. It is denoted by the letter A and its SI unit is metre (m).

- **Time-Period :** The time required to produce one complete wave (or cycle) is called time-period of the wave.

- **Frequency :** The frequency of an oscillating particle is the number of oscillations completed in one second. The unit of frequency is hertz (or Hz). The frequency of the wave is 1\T. It is generally represented by ν (nu)
- **Wave Velocity :** The distance travelled by the wave in one second is called the wave velocity. It is represented by 'v' and its unit is ms^{-1}.
- **Phase :** All the points on a wave which are in the same state of vibration are said to be in the same phase. Thus, in the wave shown in fig.



(a) Points B, F and J are in the same phase – all lie on the crests.
(b) Points D and H are in the same phase – both lie on the troughs.
(c) Points A, E and I are in the same phase. All these points are just about to start their vibration in the upward direction from their mean positions.
(d) Points C, G and K are in the same phase. All these points are just about to start their vibration in the downward direction from their mean positions.

RELATION BETWEEN WAVE VELOCITY, FREQUENCY AND WAVELENGTH FOR A PERIODIC WAVE.

$$\text{wave velocity} = \frac{\text{distance covered}}{\text{Time taken}}$$

$$= \frac{\text{wavelength}}{\text{Time taken}}$$

or $\quad v = \dfrac{\lambda}{T} \qquad ...(1)$

since $\nu = \dfrac{1}{T}$, equation (1) can also be written as

$v = \nu\lambda \qquad ...(2)$

wave velocity = Frequency × wave length

Ex. 1 If 50 waves are produced in 2 seconds, what is its frequency ?

Sol. Frequency, $\nu = \dfrac{\text{Number of wave produced}}{\text{Time taken}}$

$$= \frac{50}{2} = 25 \text{ Hz}$$

Ex. 2 A source produce 50 crests and 50 troughs in 0.5 second. Find the frequency.

Sol. 1 crest and 1 trough = 1 wave

$\therefore$ 50 crests and 50 troughs = 50 waves

Now, Frequency, $\nu = \dfrac{\text{Number of wave}}{\text{Time}}$

$$= \frac{50}{0.5} = 100 \text{ Hz}$$

Ex. 3 Sound waves travel with a speed of 330 m/s. What is the wavelength of sound waves whose frequency is 550 Hz ?

Sol. Given velocity, v = 330 m/s,

Frequency, ν = 550 Hz

$\therefore$ wavelength, $\lambda = \dfrac{v}{\upsilon} = \dfrac{330}{550} = 0.6$ m

Ex. 4 The wave length of sound emitted by a source is 1.7×10^{-2} m. Calculate frequency of the sound, if its velocity is $343.4\ ms^{-1}$.

Sol. The relation ship between velocity, frequency and wave length of a wave is given by the formula $v = \nu \times \lambda$

Here, velocity, $v = 343.4\ ms^{-1}$

frequency ν = ?

and wavelength, $\lambda = 1.7 \times 10^{-2}$ m

So, putting these values in the above formula, we get :

$$343.4 = \nu \times 1.7 \times 10^{-2}$$

$$\nu = \frac{343.4}{1.7 \times 10^{-2}}$$

$$= \frac{343.4 \times 10^{2}}{1.7} = 2.02 \times 10^{4} \text{ Hz}$$

Thus, the frequency of sound is 2.02×10^4 hertz.

Ex. 5 A wave pulse on a string moves a distance of 8m in 0.05 s.

(i) Calculate the velocity of the pulse.

(ii) What would be the wavelength of the wave on the same string, if its frequency is 200 Hz ?

Sol. (i) Velocity of the wave,

$$v = \frac{\text{Distance covered}}{\text{Time taken}} = \frac{8\text{m}}{0.05\text{s}} = 160 \text{ m/s}$$

(ii) Periodic wave has the same velocity as that of the wave pulse on the same string.

$\therefore$ Wavelength, $\lambda = \dfrac{v}{\nu} = \dfrac{160\,m/s}{200\,Hz} = 0.8$ m

Thus, the wavelength of the wave is 0.8 m.

Ex. 6 A person has a hearing range of 20 Hz to 20 kHz. What are the typical wavelengths of sound waves in air corresponding to these two frequencies ? Take the speed of sound in air as 340 m/s.

Sol. Given : v_1 = 20 Hz, V = 340 m/s

$\therefore\ \lambda_1 = \dfrac{v}{\nu_1} = \dfrac{340}{20} = 17$ m

v_2 = 20 kHz = 20,000 Hz, v = 340 m/s

$\therefore\ \lambda_2 = \dfrac{v}{\nu_2} = \dfrac{340}{20{,}000} = 1.7 \times 10^{-2}$ m = 1.7cm

$\therefore$ The typical wavelengths are 17 m and 1.7 cm.

Ex. 7 A longitudinal wave is produced on a toy string. The wave travels at a speed of 30 cm/s and the frequency of the wave is 20 Hz. What is the minimum separation between the consecutive compressions of the string ?

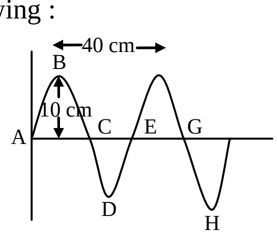
Sol. Given, Velocity, v = 30 cm/s

Frequency, ν = 20 Hz

Minimum separation between the two consecutive compressions is equal to one wavelength λ and

$$\lambda = \frac{v}{\nu} = \frac{30\,cm/s}{20\,Hz} = 1.5 \text{ cm}$$

Ex.8 Wave of frequency 200 Hz produced in a string is represented in figure. Find out the following :



(i) amplitude

(ii) wavelength

(iii) wave velocity

Sol.(i) Amplitude = Maximum displacement = 10 cm

(ii) Wavelength λ = Distance between two successive crests = 40 cm

(iii) Now, frequency, n = 2 Hz

Wavelength, λ = 40cm = 0.4 m

$\therefore$ Wave velocity, $v = \nu\lambda = 200 \times 0.4$ m/s = 80m/s

Ex. 9 A stone is dropped into a well 44.1 m deep. The sound of splash is heard 3.13 seconds after the stone is dropped. Calculate the velocity of sound in air.

Sol. First we calculate the time taken by the stone to reach the water level by using the relation:

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

Here s = 44.1 m, u = 0, g = 9.8 m/s^2

$\therefore\ 44.1 = 0 \times t + \dfrac{1}{2} \times 9.8 \times t^2$

or $t^2 = \dfrac{44.1 \times 2}{9.8} = 9$

or t = 3 s

Time taken by the sound to reach the top of the well

t_2 = 3.13 – 3 = 0.13 s

Now, speed of sound

$$= \frac{\text{Distance}}{\text{Time}} = \frac{44.1\text{m}}{0.13\text{s}} = 339.2 \text{ m/s}$$

INTRODUCTION TO SOUND

- **Sound** is a form of energy that produces the sensation of hearing in our ears.
  Frequency range of audible sound for human is between 20Hz to 20 KHz
- **Sound need Material to Travel :** You have learnt in previous section that vibrations produce sound. To produce vibrations, we need a material body. Therefore, we can say that a medium is needed for sound to travel. Sound can travel through air (or gases), liquids and solids, but not through vacuum.
- **Speed of Sound :** The speed of sound is the rate at which sound travels from the sound

producing body of our ears. The speed of sound depends on the

(i) **Nature of Material** (or medium) through which it travels. Speed of sound in air is 344 m/s.

(ii) **Temperature :** As the temperature increases the speed of sound in air increases.

(iii) **Humidity of Air :** Sound travel first in humid air.

- **The Time Gap between 'Seeing' and 'Hearing'** is due to the difference between the time taken by the light and the sound to travel from the source to the observer.

  The speed of light high 3×10^8 meters per second (30 crore metres per second) and the speed of sound in the air under normal conditions is 344 metres per second. So, the light travels almost instantaneously, whereas sound takes some time.

- **Sound Wave are Longitudinal Waves :** Sound travels through air in the form of longitudinal waves.

PRODUCTION & PROPAGATION OF SOUND

- **Production of sound**

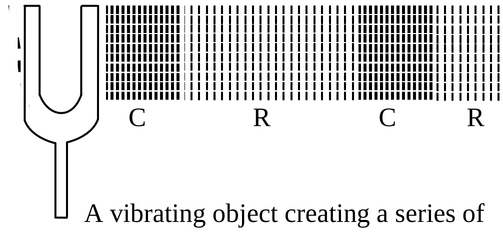
  Sound is produced when an object vibrates (moves back and forth rapidly). In other word, sound is produced by vibrations of objects.

- **Propagation of sound**

  When an object vibrates (and makes sound), then the air layers around it also start vibrating in exactly in the same way and carry sound waves from the sound producing object to our ears. Transmission of sound requires a material medium so it cannot travel through vacuum.

  In laboratory a vibrating tuning fork is used for producing sound. During vibration, the prong of the tuning fork moves from one extreme position to another about its mean position (the position when it is at rest).

  Let us now see what happens in the air near a vibrating prong of a tuning fork.



A vibrating object creating a series of compression (C) and rarefactions (R) in the medium

SOUND AS A LONGITUDINAL WAVE

When a sound wave travels through the air, the molecules in the air oscillate to and fro about their mean positions in the direction of propagation of the sound wave. Therefore, *Sound waves are called longitudinal waves.*

The sound waves propagate in any material medium as a series of compressions or rarefactions.

SOUND WAVE CAN BE STUDIED IN TERMS OF PRESSURE AND DENSITY WITH DISTANCE AND TIME.

Pressure & density is high for the particle whose amplitude is less, i.e. at compression state.

CHARACTERISTIC OF SOUND

(A) LOUDNESS

Loudness of a sound depends on the amplitude of the vibration producing that sound. Greater is the amplitude of vibration, louder is the sound produced by it.

The loudness of a sound also depends on the quantity of air that is made to vibrate. Loudness of sound is measured in decibel (dB) unit.

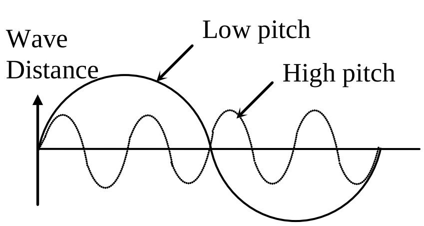
Sound	dB	Loudness
Rocket at take off	200	Dangerously loud
Aircraft engine	100–200	Painfully loud
Pneumatic drill	100	Very loud
Heavy traffic	90	Very loud
Loud music	90	Very loud
Ordinary coversation	40-60	Moderate
Whisper	20	Faint
Rustling of leaves	10	Very faint

(B) PITCH

The shrillness of a sound is called its pitch. The pitch of a sound depends upon its frequency. Higher the frequency of a sound, higher is its pitch.

The voice of a child or a woman has higher frequency than the voice of a man.

- The faster is the vibration of the source object, higher is the frequency and therefore higher is the pitch.
- Higher pitch of any sound corresponds to larger number of compressions and rarefactions passing a point per unit time.



Wave shape

The stretched membrane of a tabla or mridangam produces sound of a higher frequency (or of higher pitch).

(C) QUALITY

Quality of a sound is also called timbre. *The quality of sound is the characteristic which enable us to distinguish between the sounds produced by different sources.*

The more pleasant sound is said to be of rich quality.

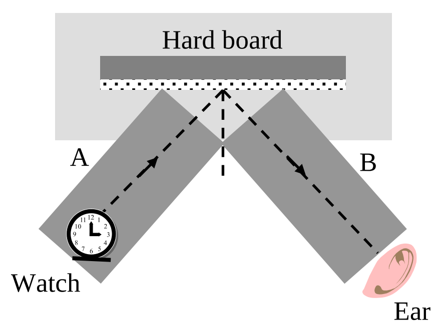
A sound of single frequency (called pure sound) is called a tone.

A tuning fork produces the sound of a single frequency. The sound which is a mixture of several frequencies is called an impure sound (or note) is pleasant to listen.

Different instruments, depending on their shape and size, produce different number of harmonics of different relative loudness. As a result, the sound produced by an instrument can be distinguished from that produced by other instruments.

REFLECTION OF SOUND

Sound waves like light waves also get reflected from plane and spherical surfaces. During reflection, sound waves obey the laws of reflections. The reflection of sound from a hard surface can be observed by performing a simple experiment on the equipment as shown in fig.



Reflection of sound from a hard surface

- Sound waves have much longer wavelength than the light waves. Therefore unlike light waves, sound waves do not need smooth surfaces for suffering reflection. That is why, a brick wall, a wooden board, a row of trees, a hill etc. serve as the reflectors of sound waves.
- *To have an appreciable reflection of sound waves from any surface, it should have dimensions equal or larger than the wavelength of the sound waves falling on it.*

That is, a smaller object will not reflect the sound waves of larger wavelength.

ECHO

The sound returning back towards the source after suffering reflection from a distance obstacle (a wall, a row of building etc.) is called an echo.

When the sound is reflected repeatedly from a number of obstacles, more than one echoes, called multiple echoes are heard. Multiple echoes may be heard one after the other when sound gets repeatedly reflected from distant high rise buildings or hills. The rolling of thunder is an example of multiple echo formation.

The two sounds–one direct and the other echo, can be heard distinctly provided the distance between the observer and the reflecting surface is large enough to allow the reflected sound to reach him without interfering with the direct sound. Since the sensation of sound persists for 1/10 second after it is produced, the echo can be heard distinctly only if it reaches at least 1/10 second after the original sound is produced.

- **Minimum distance between the observer and the obstacle for echo to be heard :**

Let

Distance between the observer and the obstacle = d

Speed of sound (in the medium) = v

Time after which echo is heard = t

Then, $t = \frac{2d}{v}$ or $d = \frac{vt}{2}$

We know

Speed of sound in air at 25ºC = 343 ms^{-1}

For an echo to be heard distinctly,

$t \geq 0.1$ s

Then $d \geq \frac{343 ms^{-1} \times 0.1 s}{2}$

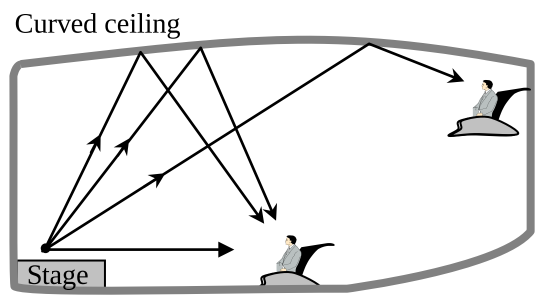
or $d \geq 17.2$ m

Thus, *the minimum distance (in air at 25ºC) between the observer and the obstacle for the echo to be heard clearly should be 17.2 m.*

The speed of sound increases with a rise in temperature. Therefore, the minimum distance in air between the observer and the obstacle for an echo to be heard clearly at temperatures higher than 25ºC is more than 17.2 m. In rooms having walls less than 17.2 m away from each other, no echo can be heard.

REVERBERATION

The repeated reflection that results in the persistence of sound in a large hall is called reverberation.



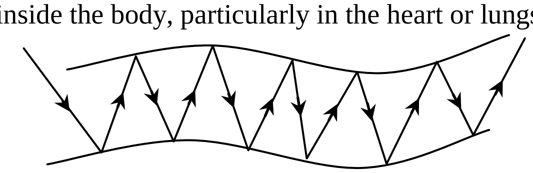
Excessive reverberation in any auditorium/hall is not desirable because the sound becomes blurred and distorted. The reverberation can be minimised/reduced by covering the ceiling and walls with sound absorbing materials, such as, fiber-board, rough plaster, draperies, perforted cardboard sheets etc.

PRACTICAL APPLICATIONS OF MULTIPLE REFLECTION OF SOUND

Some simple devices based on multiple reflection of sound are,

- Stethoscope
- Megaphone, Loudhailer, Horns
- Trumpet, Shehanais
- Curved ceiling of concert hall/conference hall/cinema hall
- Soundboards

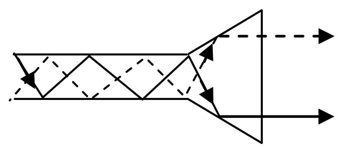
Stethoscope : Stethoscope is a medical diagnostic instrument based on multiple reflection of sound waves. This is used by doctors for listening to the sounds produced inside the body, particularly in the heart or lungs.



◆ **Megaphone :** Megaphone is a horn-shaped tube. Megaphones are used for addressing a small group of people.

Speaking tube is a hollow tube– one end is the speaker's end, whereas the other one is the listener's end.

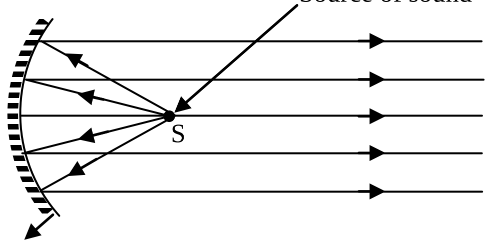
In these devices, the sound waves suffer reflection repeatedly and the energy of the waves remains confined to the tube. The sound waves are prevented from spreading out.



It is for this very reason that loudspeakers also have horn-shaped opening.

◆ **Ear Trumpet (or Hearing Aid) :** Ear trumpet or hearing aid is used by the persons who are hard of hearing. The sound waves received by the wide end of the trumpet are reflected into a much narrower area, leading it to the ear. This increases amplitude of the vibrating air inside the ear and helps in improving hearing.

◆ **Sound Boards and Curved Ceiling and Walls in Large Halls :** The arched ceiling and walls of large halls or auditorium often reflect the sound waves. These reflected sound waves interfere with the words of the speaker. This problem is solved by hanging curtains, putting up screens or by using sound boards. A sound board is often a concave rigid surface. The speaker is located at the focus of the sound board placed behind the speaker. The sound board the reflected sound waves parallel. This enable the sound to reach large distances.



The sound board prevents the spreading out of the sound waves in different directions.

Ex. 10 A girl hears the echo of his own voice from a distance hill after 3 second. The speed of sound in air is 340 m/s. What is the distance of the hill from the girl ?

Sol. Let d be the distance of the hill from the girl.
Total distance travelled by the sound in going and coming back = 2d
Now,

$$v = \frac{\text{Total distance travelled}}{\text{Time taken}} = \frac{2d}{t}$$

$$\Rightarrow 340 = \frac{2 \times d}{3}$$

$$\Rightarrow d = 510 \text{ m}$$

➢ AUDIBLE, ULTRASONIC AND INFRASONIC WAVES

(a) Audible Wave :

The human ear is sensitive to sound waves of frequency between **20 Hz to 20 kHz**. This range is known as audible range and these waves are known as audible waves.

Ex. Waves produced by vibrating sitar, guitar, organ pipes, flutes, shehnai etc.

(b) Ultrasonic waves :

A longitudinal wave whose frequency is above the upper limit of audible range i.e. **20 kHz,** is called ultrasonic wave. It is generated by very small sources.

Ex. Quartz crystal

(c) Infrasonic wave :

A longitudinal elastic wave whose frequency is below the audible range i.e. **20 Hz,** is called an infrasonic wave. It is generally generated by a large source.

Ex. Earthquake.

➢ ULTRA SOUND

◈ The sound waves having frequency higher than 20,000 Hz is called ultrasonic waves or ultrasound. Human beings cannot hear ultrasound. Dogs, bats and dolphins can hear ultrasound. For example bats and dolphins can hear sound waves having frequencies of about 150,000 Hz. Bats and dolphins detect the presence of any obstacle by hearing the echo of the sound produced by them.

Ultrasound finds many technological applications.

Characteristics of Ultra Sound :

Ultrasound (or ultrasonic waves) are found very useful due to the following reasons :

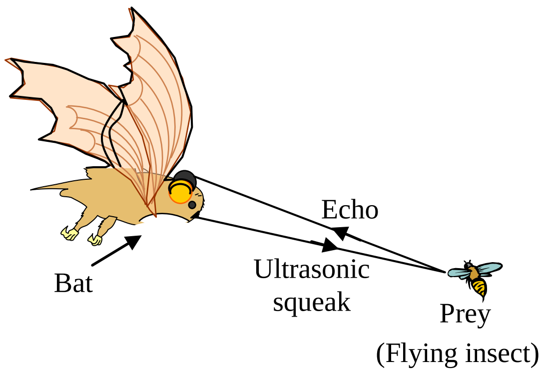
- Ultrasound (or ultrasonic) waves are high frequency sound waves. So these waves have short wavelength. These short wavelength sound waves can be reflected back from the smaller objects. Thus, ultrasound can detect smaller objects (< 1 cm size). The sound waves in the audible range cannot detect or 'see' objects smaller than having size ranging from a few tens of centimeters to a few metres.
- Ultrasound beam is more directional and can be aimed towards any target just like a torch. These waves remain undeviated over long distances.

APPLICATIONS OF ULTRASOUND

Some important applications of ultrasound are described below :

- **In ultrasonic spectacles for blind people :** Such a spectacle is fitted with a transmitter and a receiver. The receiver produces a high or low sound in the person's ear depending upon whether the object causing the echo is near or far.
- **For medical use :** Ultrasound is used to detect any infirmity / deformity in the unborn baby (X-rays cannot be used for this purpose because X-rays may harm the unborn baby). In this method, an ultrasonic transmitter / receiver is moved across the mother's stomach. Different tissues (skin, muscles, bones) reflect the sound waves differently to produce many echoes. The machine uses these echoes to construct a picture on the screen. Any deformity / infirmity in the baby can be detected and proper treatment could be prescribed.

  This technology has been misused for knowing the sex of the unborn baby. It has been noticed that many people force the would-be mother to have an abortion if the unborn baby is identified to be a female baby. This practice is unethical and a social crime. Our Government has banned such practices. We all should work together to eradicate this social menace.
- **In echocardiography :** In this medical diagnostic technique, ultrasonic waves are used to construct the image of the heart.
- **For determining the depth of sea :** Ships use ultrasound to determine the depth of the sea by echo-sounding method. A transmitter on the ship sends ultrasound towards the sea-bed and the receiver receives the echo. From the time gap between the two signals, the depth of the sea can be estimated. This is illustrated below.
- **For clearing hard to reach places :** Ultrasonic waves are also used for clearing hard to reach places, such as spiral tube, odd shaped machine parts / components, electronic components etc. The object to be cleaned is kept in the 'cleaning solution' and the solution is subjected to the ultrasonic waves. The high frequency (ultrasonic) waves stir up the dust / dirt particles. These particles get detached and the object is thoroughly cleaned.
- Bats fly in the darkness of night without colliding with other objects by the method of echolocation. Bats emit high frequency ultrasonic squeaks while flying and listen to the echoes produced by the reflection of their squeaks from the objects in their path. From the time taken by the echo to be heard, bats can judge the distance of the objects in their path and hence avoid it by changing the direction. Bats search their prey at night by the method of echolocation.

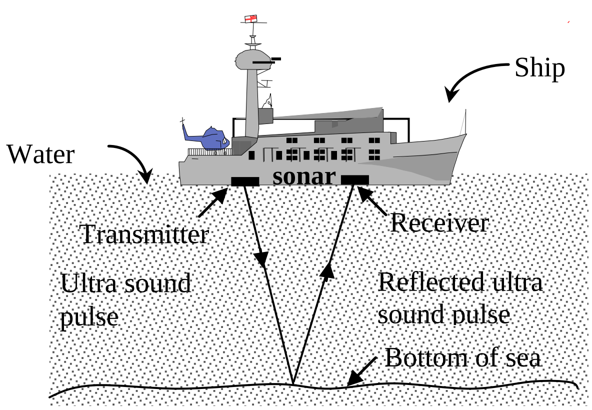


◈ SONAR :

The word 'SONAR' stands for
Sound Navigation and Ranging.

(A) Principle of Sonar : Sonar is an apparatus which is used to find the depth of a sea or to locate the under water things like shoals of fish, enemy submarines etc. Sonar works by sending short bursts of ultrasonic sound from a ship down into sea water and then gets echo produced by the reflection of ultrasonic sound from under-water objects like bottom of sea, shoal of fish, a submarine.

(B) Working of Sonar :



(i) A transmitter (for emitting ultrasonic waves) and (ii) a receiver (for detecting ultrasonic waves). Now suppose a sonar device is attached to the under-side of a ship and we want to measure the depth of sea (below the ship). To do this the transmitter of sonar is made to emit a pulse of ultrasonic sound with a very high frequency of about 50,000 hertz. This pulse of ultrasonic sound travels down in the sea-water towards the bottom of the sea. When the ultrasonic sound pulse strikes the bottom of the sea, it is reflected back to the ship in the form of an echo. This echo produces and electrical signal in the receiver part of the sonar device. The sonar device measures the time taken by the ultrasonic sound pulse to travel from the ship to the bottom of the sea and back to the ship. Half of this time gives the time taken by the ultrasonic to travel from the ship to the bottom of the sea.

d = Depth of sea

v = Velocity of sound in sea water

t = time recorded by the recorder

$$v = \frac{2d}{t}$$

Ex.11 The ultrasonic waves take 4 seconds to travel from the ship to the bottom of the sea and back to the ship. What is the depth of the sea ? (Speed of sound in water = 1500 m/s.)

Sol. The time taken by the ultrasonic sound waves to travel from the ship to the sea-bed and back to the ship is 4 seconds. So, the time taken by the ultrasonic sound to travel from the ship to sea-bed will be half of this time, which is $\frac{4}{2} = 2$ seconds. This means that the sound takes 2 seconds to travel from the ship to the bottom of the sea

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

So, $1500 = \frac{\text{Distance}}{2}$

And, Distance = $1500 \times 2\text{m} = 3000\text{m}$

Ex.12 A submarine emits a sonar pulse which returns from the underwater cliff in 1.02 s. If the speed of sound in salt water is 1531 ms^{-1}, how far away is the cliff ?

Sol. Given : Speed of sonar pulse, V = 1531 ms^{-1},
Time interval of return journey of the pulse, t = 1.02s

Let the distance of the underwater cliff be S.

For distance S of the cliff, the pulse travels a total distance of 2S in return journey.

From relation, distance = speed × time

$$2S = vt$$

We have, $S = \frac{vt}{2}$

$$S = \frac{1531ms^{-1} \times 1.02s}{2}$$

$$S = 780.8 \text{ m}$$

❖ REASON FOR USING ULTRASONIC WAVES IN SONAR

(i) Ultrasonic waves have a very high frequency due to which they can penetrate deep in sea water without being absorbed.

(ii) Ultra sonic waves cannot be confused with the noise, such as the voice of engines of ship. It is because the ultrasonic waves are not perceived by human ear.

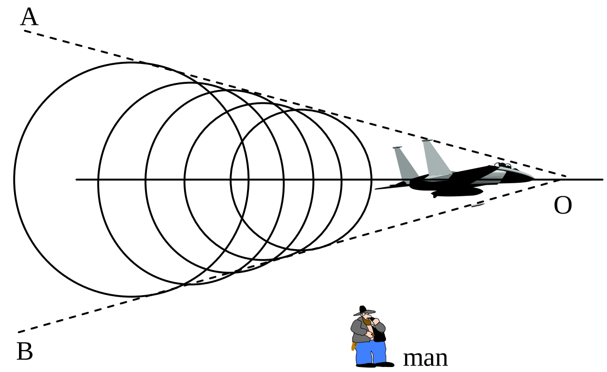
➢ SONIC BOOM

When a body moves with a speed which is greater than the speed of sound in air, it is said to be travelling at supersonic speed jet fighters, bullets, etc, often travel at supersonic speed, and when they do so, they produce a sharp, loud sound called a sonic boom.

The source moves at a speed greater than that of sound, sound waves travelling at the speed of sound, are left behind. The high-pressure layers due to sound waves originating at different points bunch together as shown in figure. Actually, these layers fall on the surface of an imaginary cone of which OA, OB is a part. The total pressure on the surface of this cone is very high. The source is at the apex of this cone. As the source moves ahead, it drags the cone together with it. when the surface of the cone reaches a person, the ears experience a sudden increase in pressure. After the surface crosses him, the pressure is suddenly reduced. This causes the person to hear a sharp, loud sound-the sonic boom.

A region consisting of a very-high-pressure layer followed by a lower-pressure layer travels through the space together with the cone. This is called a shock wave. This shock wave gives rise to the sonic boom when it reaches a person.

The shock waves produced by supersonic aircraft have enough energy to shatter glass and even damage weak structure.

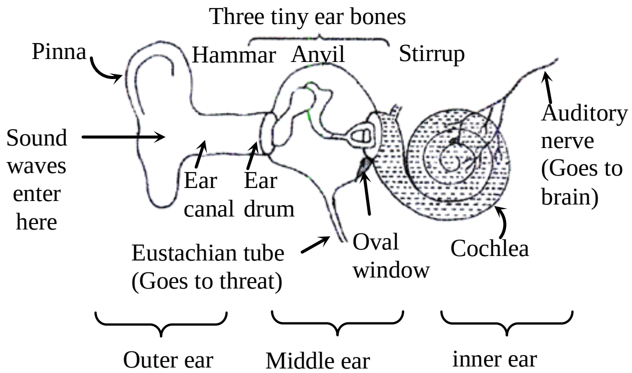


➢ THE HUMAN EAR

(a) Structure of human ear :

The ear consists of three compartments : outer ear, middle ear and inner ear.

The part of ear which we see outside the head is called outer ear. The outer ears consists of broad part called pinna and about 2 to 3 centimeters long passage called ear canal. At the end of ear canal there is a thin, elastic and circular membrane called ear-drum. The ear-drum is also called tympanum. The outer ear contains air. The middle ear contains three small and delicate bones called hammer, anvil and stirrup. These ear bones are linked to one another. One end of the bone called hammer is touching the ear-drum and its other end is connected to the second bone called anvil. The other end of anvil is connected to the third bone called stirrup and the free end of stirrup is held against the membrane over the oval window of inner ear. The middle ear also contains air. The lower part of middle ear has narrow tube called 'eustachian tube' going to the throat. Eustachian tube connects the middle ear to throats and ensures that the air pressure inside the middle ear is the same as that on the outside



The inner ear has a coiled tube called cochlea. One side of cochlea is connected to the middle ear through the elastic membrane over the oval window. The cochlea is filled with a liquid. The liquid present in cochlea contains nerve cells which are sensitive to sound. The other side of cochlea is connected to auditory nerve which goes into the brain.

(b) Working of human ear :

Sound waves from outside are collected by the outer ear (called pinna) and reach the eardrum through the auditory canal. When the sound waves strike the eardrum, (tympanic membrane) it starts vibrating. These vibrations are passed on to the oval window by three bones (called the hammer, anvil and stirrup) which act as a lever with the pivot at point P. They magnify the force of the vibrations.

The oval window has a smaller area than the eardrum. So, this increase pressure on the oval window and on the liquid in the cochlea.

The vibrations of the liquid in the cochlea affect thousands of auditory nerves which send message to the brain.

Our ears are very delicate and fragile organs. Proper care must be taken to keep them in healthy state.

Some suggestions to keep the ears healthy are given below :

- Never insert any pointed object into the ear. It can damage the eardrum and make a person deaf.
- Never shout loudly into someone's ear.
- Never hit anyone hard on his / her ear.

A Very Short Answer Type Questions

Q.1 At what position the velocity of the bob of an oscillating simple pendulum is maximum and where is it minimum ?

Q.2 What is transferred by wave motion from one point to the other– matter or energy ?

Q.3 What are the SI units of wavelength and frequency of a wave ?

Q.4 Define velocity of a wave.

Q.5 What is the separation between tw successive crests and troughs ?

Q.6 What is the speed of electromagnetic waves?

Q.7 A simple pendulum completes 20 oscillation in 10 seconds. Calculate its time period.

Q.8 If the distance between the two extrem positions of a simple pendulum is 3 cm, wha is its amplitude ?

Q.9 When a wire of sitar is plucked, what type of waves are produced in (i) the wire and (ii) air ?

Q.10 What is the relation between time period and frequency.

B Short Answer Type Questions

Q.11 Why does the motion of a simple pendulum stop?

Q.12 Can two persons hear each other on moon ? Explain with reason.

Q.13 A ship sends a signal and receives it back from a submarine after 5s. Speed of sound in water is 1450 m/s. Calculate distance of submarine from the ship.

Q.14 What are ultrasonic waves and infrasonic waves?

Q.15 Explain working of a sonar.

Q.16 Explain industrial uses of ultrasonic waves.

Q.17 On what principle does a megaphone works?

Q.18 What type of scans are used these days to see the developing baby in the uterus ?

Q.19 A worker lives at a distance of 1.32 km from the factory. If the speed of sound in air be 330 m/s, how much time will the sound of factory siren take to reach the worker ?

Q.20 The flash of a gun is seen by man 3 seconds before the sound is heard. Calculate the distance of the gun from the man (speed of sound in air is 332 m/s).

Q.21 State the general name of the waves in which the particles of the medium vibrate :
(i) in the same direction as wave.
(ii) at right angles to the direction of wave.

Q.22 Calculate the wavelength of an ultrasonic wave of frequency 10^5 Hz. The velocity of sound is 330 m/s.

Q.23 Two sound waves in air have wavelengths ratio 1 : 3. Find their frequency ratio.

Q.24 The wavelength of a sound wave is 66 m. Calculate the frequency of the wave if the velocity of sound is 330 m/s, would this sound be audible to the human ear ?

Q.25 If the period of small ripples on water is 0.1 s and their wavelength is 5 cm, what is the speed of the waves ?

Q.26 Longitudinal waves travel in a coiled spring at a rate of 4 ms^{-1}. The distance between two consecutive compressions is 20 cm. Find (i) the wave length and (ii) frequency of the wave.

C Long Answer Type Questions

Q.27 Define transverse waves and longitudinal waves. State the main difference between them.

Q.28 What is sound ? What is the cause of every sound ? Give some examples of sources producing sound.

Q.29 What do you mean by reflection of sound ? Briefly explain some applications of reflection of sound.

Q.30 Define the following terms : wavelength, time period, frequency and velocity of a wave.

EXERCISE # 2

Single correct answer type questions

Q.1 A sound wave travels from east to west, in which direction do the particles of air move–
(A) East-west (B) North-south
(C) Up and down (D) None of these

Q.2 In which medium sound travels faster–
(A) solid (B) liquid
(C) gas (D) none of these

Q.3 What is the name of short duration wave–
(A) Pulse (B) Frequency
(C) Time period (D) Velocity

Q.4 What is the velocity of sound in water at room temperature–
(A) 1500 m/s (B) 330 m/s
(C) 1500 km/s (D) 330 km/s

Q.5 The unit of quantity on which pitch of the sound depends is–
(A) Hertz (B) metre
(C) metre/second (D) second

Q.6 The unit of quantity on which loudness of sound depends is–
(A) metre (B) Hertz
(C) metre/second (D) second

Q.7 Nature of sound wave is–
(A) transverse (B) longitudinal
(C) electromagnetic (D) seismve

Q.8 Pitch of high frequency sound is–
(A) high (B) low
(C) zero (D) infinite

Q.9 Voice of a friend is recognised by its–
(A) pitch (B) quality
(C) intensity (D) velocity

Q.10 Sound waves in air are–
(A) longitudinal waves
(B) Radio waves
(C) Transverse waves
(D) Electromagnetic waves

Q.11 Sound waves can not pass through–
(A) A solid liquid mixture
(B) A liquid gas mixture
(C) An ideal gas
(D) A perfect vaccum

Q.12 A periodic wave is characterized by–
(A) Phase only (B) Wavelength only
(C) Frequency only (D) All the above

Q.13 The speed of sound is maximum in–
(A) Air (B) Hydrogen
(C) Water (D) Iron

Q.14 When sound waves travelling in air enter into the medium of water, the quantity which remains unchanged is–
(A) Wavelength (B) Velocity
(C) Frequency (D) None

Q.15 For the echo of the last syllable of the speech to be heard the least distance of the reflector must be (approximately)–
(A) 22 metre (B) 32 metre
(C) 110 metre (D) 340 metre

Q.16 During summer, an echo is heard–
(A) Sooner than during winter
(B) Later than during winter
(C) After same time as in winter
(D) Rarely

Q.17 The velocity of sound in air at 30°C is approximately–
(A) 332 ms^{-1} (B) 350 ms^{-1}
(C) 530 ms^{-1} (D) 332 kms^{-1}

Q.18 With the rise of temperature, the velocity of sound–
(A) Decreases
(B) Increases
(C) Remains the same
(D) Is independent of temperature

Q.19 Infrasonic frequency range is–
(A) below 20 Hz (B) 20 Hz to 20 kHz
(C) Above 20 kHz (D) No limit

Q.20 Ultrasonic frequency range is–
(A) below 20 Hz (B) 20 Hz to 20 kHz
(C) Above 20 kHz (D) No limit

Q.21 The speed of sound in air at constant temperature–
(A) Decreases with increase of pressure
(B) Increases with increase of pressure
(C) Remains the same with the increase in pressure
(D) None of these

Q.22 The frequency of sound waves in water is –
(A) Same as that of frequency of source
(B) Less than frequency of source
(C) More than frequency of source
(D) None

Q.23 The equipment (device) used for locating the position and distance of an object inside sea, using ultrasound is called–
(A) Pukar (B) Upkar
(C) Radar (D) Sonar

Q.24 Human ear can hear–
(A) audible sound (B) infra sound
(C) ultra sound (D) all the above

Q.25 A sonar echo takes 4.4s to return from a submarine. If the speed of sound in water is 1500 ms^{-1}, then the distance of submarine from the sonar is-
(A) 1500 m (B) 3000 m
(C) 3300 m (D) 3600 m

Q.26 The eardrum is a–
(A) bone (B) coiled tube
(C) stretched membrane (D) fluid

Q.27 The part of the ear, that is filled with a liquid is the –
(A) cochlea (B) ear canal
(C) anril (D) hammer

Q.28 A fishing boat sonar detects a shoal of fish 190 m below it. How much time elapsed between sending the ultra sonic signal which detected the fish and receiving the signals echo ? (speed of sound in sea water is 1519 ms^{-1})–
(A) 0.25 s (B) 0.50 s
(C) 0.75 s (D) 1.0 s

ANSWER KEY

EXERCISE-2

Ques	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans	A	A	A	A	A	A	B	A	B	A	D	D	D	C	A
Ques	16	17	18	19	20	21	22	23	24	25	26	27	28		
Ans	A	B	B	A	C	C	A	D	A	C	C	A	A