

Class-XI

MHT-CET

Study Material

PHYSICS

Booklet-1

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Motion in a Plane



TOPIC 1.1 : RECTILINEAR MOTION, MOTION IN A PLANE

RECTILINEAR MOTION

Displacement

Displacement is the change in position. Let x_1 and x_2 be the positions of an object at time t_1 and t_2 . Then its displacement, denoted by Δx is given by the difference between the final and initial positions :

$$\Delta x = x_2 - x_1$$

Delta (Δ) denote change in a quantity.

Path Length or Distance

The length of the actual path between initial and final positions of a particle in a given interval of time is called distance covered by the particle. Distance is the actual length of the path. It is the characteristic property of any path i.e. path is always associated when we consider distance between two positions.

Speed

Speed of an object is defined as the rate of change of position of the object in any direction. It is measured by the distance travelled by the object in unit time in any direction.

$$\text{i.e., Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

Average speed for the given motion is defined as the ratio of the total distance travelled by the object to the total time taken

$$\text{i.e., Average speed } \bar{V} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

The speed of the body at any instant of time or at a particular position is called instantaneous speed.

$$\therefore \text{ Instantaneous speed} = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Velocity

The rate of change of displacement of a particle with time is called the velocity of the particle.

$$\text{i.e., Velocity} = \frac{\text{Displacement}}{\text{Time interval}}$$

Average Velocity

The average velocity of an object is equal to the ratio of the displacement to the time interval for which the motion takes place

$$\text{i.e., Average velocity} = \frac{\text{Displacement}}{\text{Time taken}}$$

Instantaneous Velocity

The velocity of the object at a given instant of time or at a given position during motion is called instantaneous velocity.

Acceleration

The rate of change of velocity of an object is called acceleration of the object.

Let v and v' be the velocity of the object at time t and t' respectively, then acceleration of the body is given by

$$\text{Acceleration } (\vec{a}) = \frac{\text{Change in velocity}}{\text{Time interval}} = \frac{\vec{v}' - \vec{v}}{t' - t}$$

Uniform Acceleration

An object is said to be moving with a uniform acceleration if its velocity changes by equal amounts in equal intervals of time.

Variable or Non-Uniform Acceleration

An object is said to be moving with a variable acceleration if its velocity changes by unequal amounts in equal intervals of time.

Average Acceleration

When an object is moving with a variable acceleration, then the average acceleration of the object for the given motion is defined as the ratio of the total change in velocity of the object during motion to the total time taken.

i.e., Average acceleration

$$= \frac{\text{Total change in velocity}}{\text{Total time taken}}$$

Kinematic Equations for Uniformly Accelerated Motion

Motion under uniform acceleration is described by the following equations.

$$v = u + at; s = ut + \frac{1}{2}at^2; v^2 = u^2 + 2as \text{ and } s_{nth} = u + \frac{a}{2}(2n-1)$$

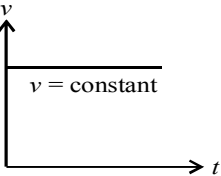
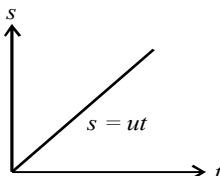
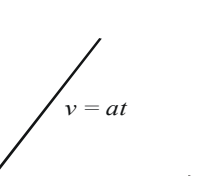
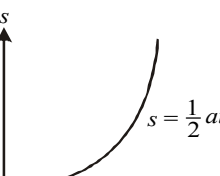
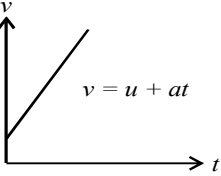
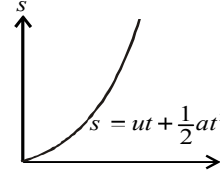
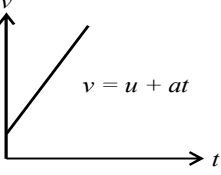
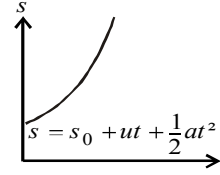
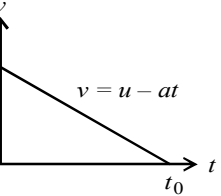
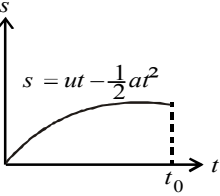
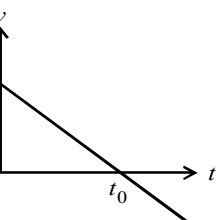
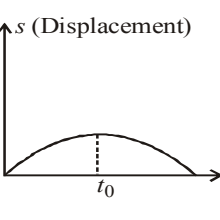
Motion Under Gravity

The most important example of motion in a straight line with constant acceleration is motion under gravity. In case of motion under gravity,

- the acceleration is constant, i.e., $a = g = 9.8 \text{ m/s}^2$ and directed vertically downwards.
- in vacuum, viscous force or thrust of the medium has no effect on the motion.

Graphical Study of Motion

All the following graphs are drawn for one-dimensional motion with uniform velocity or with constant acceleration.

Different case	v-t graph	s-t graph	Important points
1. Uniform motion			- Slope of s-t graph = $v = \text{constant}$ - In s-t graph $s = 0$ at $t = 0$
2. Uniformly accelerated motion with $u = 0$ and $s = 0$ at $t = 0$			$u = 0$, i.e., $v = 0$ at $t = 0$ $u = 0$, i.e., slope of s-t graph at $t = 0$, should be zero a or slope of v-t graph is constant
3. Uniformly accelerated motion with $u \neq 0$ but $s = 0$ at $t = 0$			$u \neq 0$, i.e., v or slope of s-t graph at $t = 0$ is not zero v or slope of s-t graph gradually goes on increasing
4. Uniformly accelerated motion with $u \neq 0$ and $s = s_0$ at $t = 0$			$s = s_0$ at $t = 0$
5. Uniformly retarded motion till velocity becomes zero			- Slope of s-t graph at $t = 0$ gives u - Slope of s-t graph at $t = t_0$ becomes zero - In this case u can't be zero
6. Uniformly retarded then accelerated in opposite direction			- At time $t = t_0$, $v = 0$ or slope of s-t graph is zero - In s-t graph slope or velocity first increases then decreases

Relative Velocity

Relative velocity of an object A with respect to another object B, when both are in motion is the time rate at which object A changes its position with respect to object B.

If $\vec{v}_A$ and $\vec{v}_B$ be the respective velocities of object A and B, then relative velocity of A w.r.t. B is

$$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$$

Similarly, relative velocity of B w.r.t. A is

$$\vec{v}_{BA} = \vec{v}_B - \vec{v}_A$$

Relative Velocity of Rain

The relative velocity of rain w.r.t. man $\vec{v}_{rm} = \vec{v}_r - \vec{v}_m$, will be

represented by diagonal $\vec{OD}$ of rectangle OBDC.

$$\therefore v_{rm} = \sqrt{v_r^2 + v_m^2 + 2v_r v_m \cos 90^\circ} = \sqrt{v_r^2 + v_m^2}$$

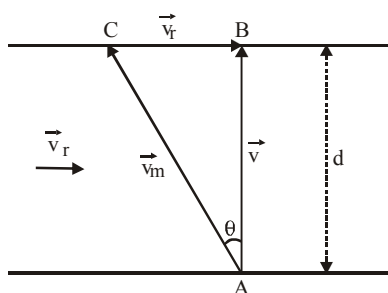
If θ is the angle which $\vec{v}_{rm}$ makes with the vertical direction

$$\text{then, } \tan \theta = \frac{BD}{OB} = \frac{v_m}{v_r} \text{ or } \theta = \tan^{-1} \left(\frac{v_m}{v_r} \right)$$

Here angle θ is from vertical towards west and is written as θ , west of vertical.

Relative Velocity of the Swimmer

Minimum distance of approach



Let d = width of river, v_r = velocity of river water,
 v_m = velocity of swimmer

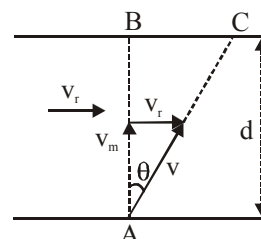
The swimmer should swim in a direction such that resultant

$\vec{v}$ of $\vec{v}_m$ and $\vec{v}_r$ is along AB which is the shortest path.

$$\sin \theta = \frac{v_r}{v_m}; \quad v = \sqrt{v_m^2 - v_r^2}; \quad t = \frac{d}{\sqrt{v_m^2 - v_r^2}}$$

$$\text{or, } d = t \sqrt{v_m^2 - v_r^2}$$

Minimum time of approach



$$\text{Time of crossing the river } t = \frac{d}{v_m \cos \theta}$$

$$t = t_{\min}; \text{ when } \cos \theta = +1 = \cos 0^\circ \text{ i.e. } \theta = 0^\circ$$

$$t_{\min} = \frac{d}{v_m}$$

To cross the river in shortest time man should swim perpendicular to direction of flow.

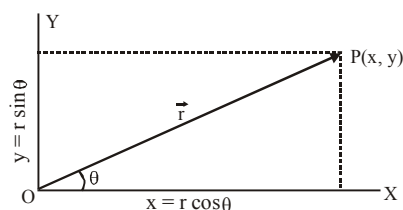
Man will reach C instead of B

$$\text{If } BC = x \text{ then, } \tan \theta = \frac{v_r}{v_m} = \frac{x}{d} \text{ so, } x = \frac{v_r}{v_m} \cdot d$$

MOTION IN A PLANE OR MOTION IN TWO DIMENSIONS

Position Vector

An object moving in a plane is said to have two dimensional motion. The two dimensional motion is equal to vector sum of two one dimensional motions along mutually perpendicular direction.

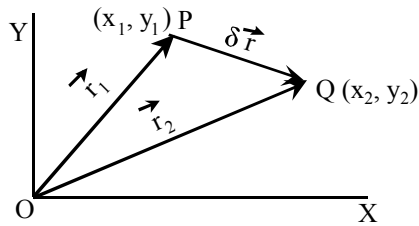


Let the position of point P at any time t be given by position vector

$$\begin{aligned} \vec{OP} = \vec{r} &= \hat{i} r \cos \theta + \hat{j} r \sin \theta \\ &= \hat{i} x + \hat{j} y \end{aligned}$$

Displacement Vector

Suppose at time t a particle is at P,



Position vector of P, $\vec{OP} = \vec{r}_1 = x_1 \hat{i} + y_1 \hat{j}$

Point P move to Q

Position vector of Q, $\vec{OQ} = \vec{r}_2 = x_2 \hat{i} + y_2 \hat{j}$

Displacement vector = difference of two positions

$$\vec{\delta r} = \vec{r}_2 - \vec{r}_1$$

Velocity

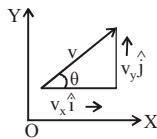
The ratio of the displacement and the corresponding time interval is called the **average velocity**.

$$\text{Average velocity } \vec{v} = \frac{\Delta \vec{r}}{\Delta t} = \hat{i} \frac{\Delta x}{\Delta t} + \hat{j} \frac{\Delta y}{\Delta t} = \vec{v}_x \hat{i} + \vec{v}_y \hat{j}$$

$$\text{Instantaneous velocity } v_{\text{inst}} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{r}}{\Delta t}$$

The magnitude of velocity

$$v = \sqrt{v_x^2 + v_y^2}$$



$$\text{The direction of the velocity, } \tan \theta = \frac{v_y}{v_x} \therefore \theta = \tan^{-1} \frac{v_y}{v_x}$$

Acceleration

The average acceleration in a x-y plane in time interval Δt is the change in velocity divided by the time interval.

$$\text{Average acceleration } \vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\Delta v_x}{\Delta t} \hat{i} + \frac{\Delta v_y}{\Delta t} \hat{j}$$

Instantaneous acceleration

$$a_{\text{inst}} = \frac{\Delta \vec{v}}{\lim_{\Delta t \rightarrow 0} \Delta t} = \lim_{\Delta t \rightarrow 0} \frac{\Delta v_x}{\Delta t} \hat{i} + \lim_{\Delta t \rightarrow 0} \frac{\Delta v_y}{\Delta t} \hat{j}$$

In two or three dimensions, the velocity and acceleration vectors may have any angle between 0° and 180° between them.

So, $v_x = u_x + a_x t$ and $v_y = u_y + a_y t$

And similarly component of displacement are

$$s_x = u_x t + \frac{1}{2} a_x t^2 \text{ and } s_y = u_y t + \frac{1}{2} a_y t^2$$

$$\text{Hence, } s_x \hat{i} + s_y \hat{j} = (u_x \hat{i} + u_y \hat{j}) + \frac{1}{2} (a_x \hat{i} + a_y \hat{j}) t^2$$

$$\text{or, } \vec{s} = \vec{u} t + \frac{1}{2} \vec{a} t^2$$

Relative Velocity in Two Dimensions

If two objects A and B moving with velocities $\vec{V}_A$ and $\vec{V}_B$ with respect to some common frame of reference, then

(i) relative velocity of A w.r.t B

$$\vec{v}_{AB} = \vec{V}_A - \vec{V}_B$$

(ii) relative velocity of B w.r.t. A

$$\vec{v}_{BA} = \vec{V}_B - \vec{V}_A$$

$$\text{Therefore, } \vec{v}_{AB} = -\vec{v}_{BA} \text{ and } |\vec{v}_{AB}| = |\vec{v}_{BA}|$$

TOPIC 1.2 : PROJECTILE MOTION—OBLIQUE AND HORIZONTAL

PROJECTILE MOTION

A body which is in flight through the atmosphere after being thrown or projected is called a **projectile**. In projectile motion, a body or particle moving in atmosphere under the effect of gravity only. Motion of projectile is two dimensional motion in a vertical plane.

OBLIQUE PROJECTILE MOTION

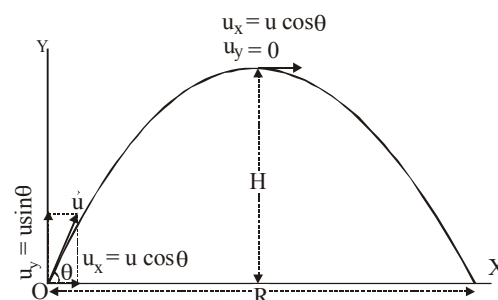
Consider the motion of a body which is projected with initial velocity $\vec{u}$ making an angle θ with the horizontal direction. Let us take X-axis along ground and Y-axis along vertical. $\vec{u}$ can be resolved as

$$u_x = u \cos \theta \text{ (along horizontal)}$$

$$\text{and } u_y = u \sin \theta \text{ (along vertical)}$$

At highest point of projectile motion, there is no vertical component of velocity.

$$\therefore \text{Velocity at highest point} = u \cos \theta$$



The motion in the vertical direction is the same as that of a body thrown upward with an initial velocity $u_y = u \sin \theta$ (vertical component) and acceleration $a_y = -g$ (downward).

Velocity at time t

$$\vec{v}_t = v_{xt} \hat{i} + v_{yt} \hat{j} = (u \cos \theta) \hat{i} + (u \sin \theta - gt) \hat{j}$$

$$v = \sqrt{u^2 \cos^2 \theta + (u \sin \theta - gt)^2}$$

If $\vec{v}$ makes angle α with horizontal, then

$$\tan \alpha = \frac{v_{yt}}{v_{xt}} = \frac{u \sin \theta - gt}{u \cos \theta}$$

Equation of Motion for a Projectile

we get, $y = (u \sin \theta) \left(\frac{x}{u \cos \theta} \right) - \frac{1}{2} g \left(\frac{x}{u \cos \theta} \right)^2$

$$\text{or } y = x \tan \theta - \frac{g}{2u^2 \cos^2 \theta} x^2$$

$$= ax - bx^2$$

Range, $R = \frac{u^2 \sin 2\theta}{g}$

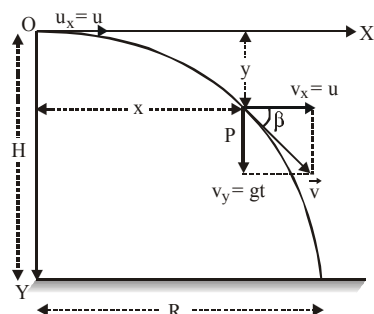
Total time of flight, $T = \frac{2u \sin \theta}{g}$

Maximum height, $H = \frac{u^2 \sin^2 \theta}{2g}$

HORIZONTAL PROJECTILE MOTION

Suppose a body is thrown horizontally from point O, with velocity u . Height of O from ground = H .

Let X-axis be along horizontal and Y-axis be vertically downwards and origin O is at point of projection as shown in figure.



$$\text{or, } y = -kx^2 \text{ or } k = \frac{g}{2u^2}$$

(k is constant)

This is the eqn. of a parabola

A body thrown horizontally from a certain height above the ground follows a parabolic trajectory till it hits the ground.

(i) Time of flight $T = \sqrt{\frac{2H}{g}}$

$$[\because y = \frac{1}{2} gt^2]$$

(ii) Range (horizontal distance covered)

$$R = u \times \text{time of flight}$$

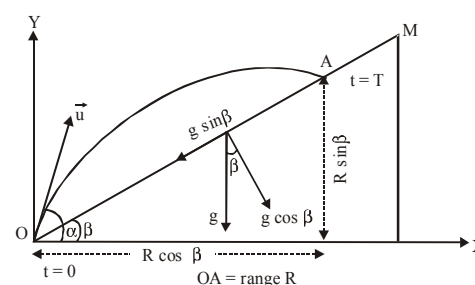
$$R = u \cdot \sqrt{\frac{2H}{g}}$$

$$[\because H = \frac{g}{2u^2} R^2]$$

(iii) Velocity when it hits the ground

$$v_g = \sqrt{u^2 + 2gH}$$

Projectile Motion on an Inclined Plane



$$a_x = -g \sin \beta ;$$

$$a_y = -g \cos \beta$$

$$u_x = u \cos (\alpha - \beta),$$

$$u_y = u \sin (\alpha - \beta)$$

$$\text{Time of flight, } T = \frac{2u \sin (\alpha - \beta)}{g \cos \beta}$$

CHAPTER AT A GLANCE

- ☛ Displacement is the change in position.

- ☛ The length of the actual path between initial and final positions of a particle in a given interval of time is called distance covered by the particle. Distance is the actual length of the path.

- ☛ Speed of an object is defined as the rate of change of position of the object in any direction.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

- ☛ The rate of change of displacement of a particle with time is called the velocity of the particle.

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

- ☛ The rate of change of velocity of an object is called acceleration of the object.

$$\text{Acceleration } (\vec{a}) = \frac{\text{Change in velocity}}{\text{Time interval}} = \frac{\vec{v}' - \vec{v}}{t' - t}$$

- ☛ Motion under uniform acceleration is described by the following equations.

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

$$v^2 = u^2 + 2as \text{ and } s_{\text{nth}} = u + \frac{a}{2}(2n-1)$$

- ☛ Relative velocity of A w.r.t. B, $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$

- ☛ Position vector of Q, $\vec{OQ} = \vec{r}_2 = x_2 \hat{i} + y_2 \hat{j}$

Displacement vector = difference of two positions

$$\vec{\delta r} = \vec{r}_2 - \vec{r}_1$$

- ☛ The ratio of the displacement and the corresponding time interval is called the **average velocity**.

$$\text{Average velocity } \vec{v} = \frac{\Delta \vec{r}}{\Delta t} = \hat{i} \frac{\Delta x}{\Delta t} + \hat{j} \frac{\Delta y}{\Delta t} = \vec{v}_x \hat{i} + \vec{v}_y \hat{j}$$

- ☛ The average acceleration in a x-y plane in time interval Δt is the change in velocity divided by the time interval.

$$\text{Average acceleration } \vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\Delta v_x}{\Delta t} \hat{i} + \frac{\Delta v_y}{\Delta t} \hat{j}$$

- ☛ A body which is in flight through the atmosphere after being thrown or projected is called a **projectile**.

- ☛ Equation of trajectory is $y = x \tan \theta - \frac{gx^2}{2u^2 \cos^2 \theta}$, which is a parabola.

- ☛ $\text{Range, } R = \frac{u^2 \sin 2\theta}{g}$

- ☛ $\text{Total time of flight, } T = \frac{2u \sin \theta}{g}$

- ☛ $\text{Maximum height, } H = \frac{u^2 \sin^2 \theta}{2g}$

Exercise 1 :

WARM-UP
Topic-wise MCQs

1.1 Rectilinear Motion, Motion in a Plane

- The location of a particle has changed. What can we say about the displacement and the distance covered by the particle?
(a) Neither can be zero (b) One may be zero
(c) Both may be zero (d) One is +ve, other is -ve
- The displacement of a body is zero. The distance covered
(a) is zero
(b) is not zero
(c) may or may not be zero
(d) depends upon the acceleration
- The numerical ratio of displacement to distance for a moving object is
(a) always less than 1 (b) always equal to 1
(c) always more than 1 (d) equal to or less than 1
- Which of the following can be zero, when a particle is in motion for some time?
(a) Distance (b) Displacement
(c) Speed (d) None of these
- An athlete completes one round of a circular track of radius R in 40 sec. What will be his displacement at the end of 3 min. 20 sec?
(a) Zero (b) $2R$ (c) $2\pi R$ (d) $7\pi R$
- A particle moves from $(2,3)$ m to $(4,1)$ m. The magnitude of displacement is
(a) 2 m (b) $2\sqrt{3}$ m (c) $2\sqrt{2}$ m (d) $3\sqrt{2}$ m
- A body moves in straight line with velocity v_1 for $1/3^{\text{rd}}$ time and for remaining time with v_2 . Find average velocity.
(a) $\frac{v_1}{3} + \frac{2v_2}{3}$ (b) $\frac{v_1}{3} + \frac{v_2}{3}$
(c) $\frac{2v_1}{3} + \frac{v_2}{3}$ (d) $v_1 + \frac{2v_2}{3}$
- A particle moves in straight line with velocity 6 m/s and 3 m/s for time intervals which are in ratio 1:2. Find average velocity.
(a) 2 m/s (b) 3 m/s (c) 4 m/s (d) 5 m/s
- The velocity of a particle having magnitude of 10 ms^{-1} in the direction of 60° with positive X-axis is
(a) $5\hat{i} - 5\sqrt{3}\hat{j}$ (b) $5\sqrt{3}\hat{i} - 5\hat{j}$
(c) $5\sqrt{3}\hat{i} + 5\hat{j}$ (d) $5\hat{i} + 5\sqrt{3}\hat{j}$
- The distance travelled by a body is directly proportional to the time taken. Its speed
(a) increases (b) decreases
(c) becomes zero (d) remains constant
- The slope of velocity-time graph for motion with uniform velocity is equal to
(a) final velocity (b) initial velocity
(c) zero (d) none of these
- The ratio of the numerical values of the average velocity and average speed of a body is
(a) unity (b) unity or less
(c) unity or more (d) less than unity
- The slope of the tangent drawn on position-time graph at any instant is equal to the instantaneous
(a) acceleration (b) force
(c) velocity (d) momentum
- The displacement-time graphs of two particles A and B are straight lines making angles of 30° and 60° respectively with the time axis. If the velocity of A is v_A and that of B is v_B , the value of v_A/v_B is
(a) $1/2$ (b) $1/\sqrt{3}$ (c) $\sqrt{3}$ (d) $1/3$
- Choose the wrong statement from the following.
(a) The motion of an object along a straight line is a rectilinear motion.
(b) The speed in general is less than the magnitude of the velocity.
(c) The slope of the displacement-time graph gives the velocity of the body.
(d) The area under the velocity-time graph gives the displacement of the body.
- Choose the correct equation to determine distance in a straight line for a body with uniform motion.
(a) $s = \frac{v}{t}$ (b) $s = v^2 t$
(c) $s = ut + \frac{1}{2}at^2$ (d) $s = v \times t^2$
- What is the rate of change of velocity of an object in uniform motion?
(a) Always equal to zero
(b) Always less than one
(c) Always greater than one
(d) Either less than or equal to one.
- What determines the nature of the path followed by the particle?
(a) Speed (b) Velocity
(c) Acceleration (d) Both (b) and (c)
- The acceleration of a moving body can be found from
(a) area under velocity - time graph
(b) area under distance - time graph
(c) slope of the velocity- time graph
(d) slope of distance-time graph

20. Acceleration of a particle changes when
 (a) direction of velocity changes
 (b) magnitude of velocity changes
 (c) speed changes
 (d) Both (a) and (b)
21. The area under acceleration time graph gives
 (a) distance travelled (b) change in acceleration
 (c) force acting (d) change in velocity
22. Which of the following is the correct expression of instantaneous acceleration?
 (a) $a = \frac{\Delta v}{(\Delta t)^2}$ (b) $a = \frac{dv}{dt}$
 (c) $a = \frac{d^2 v}{dt^2}$ (d) $a = \left(\frac{\Delta v}{\Delta t}\right)^2$
23. The graph between displacement and time for a particle moving with uniform acceleration is a/an
 (a) straight line with a positive slope
 (b) parabola
 (c) ellipse
 (d) straight line parallel to time axis
24. Velocity time curve for a body projected vertically upwards is
 (a) parabola (b) ellipse
 (c) hyperbola (d) straight line
25. A bus starts moving with acceleration 2 m/s^2 . A cyclist 96 m behind the bus starts simultaneously towards the bus at 20 m/s . After what time will he be able to overtake the bus?
 (a) 4 sec (b) 8 sec (c) 18 sec (d) 16 sec
26. Stopping distance of a moving vehicle is directly proportional to
 (a) square of the initial velocity
 (b) square of the initial acceleration
 (c) the initial velocity
 (d) the initial acceleration
27. A body is thrown vertically upwards. If air resistance is to be taken into account, then the time during which the body rises is
 (a) equal to the time of fall
 (b) less than the time of fall
 (c) greater than the time of fall
 (d) twice the time of fall
28. A body is thrown upwards and reaches half of its maximum height. At that position
 (a) its acceleration is minimum
 (b) its velocity is maximum
 (c) its velocity is zero
 (d) its acceleration is constant
29. Velocity-time curve for a body projected vertically upwards is
 (a) parabola (b) ellipse
 (c) hyperbola (d) straight line
30. An object accelerated downward under the influence of force of gravity. The motion of object is said to be
 (a) uniform motion
 (b) free fall
 (c) non uniformly accelerated motion
 (d) None of these
31. Free fall of an object (in vacuum) is a case of motion with
 (a) uniform velocity (b) uniform acceleration
 (c) variable acceleration (d) constant momentum
32. Simultaneously, from the top of a tower, when ball-1 is thrown horizontally and ball-2 is just dropped, in the absence of air resistance which among the following options is correct?
 (a) Ball-1 reaches the ground first.
 (b) Ball-2 reaches the ground first.
 (c) Both will reach the ground simultaneously.
 (d) Either ball-1 or ball-2 reach the ground first depending on which ever is heavier.
33. Consider the motion of a particle described by $x = a \cos t$, $y = a \sin t$ and $z = t$. The trajectory traced by the particle as a function of time is
 (a) helix (b) circular
 (c) elliptical (d) straight line
34. A bird flies from $(-2 \text{ m}, 4 \text{ m}, -3 \text{ m})$ to $(5 \text{ m}, -2 \text{ m}, -3 \text{ m})$ in the xyz-coordinates. The bird's displacement vector and magnitude are
 (a) $(4\hat{i} + 2\hat{j} - 6\hat{k})$, 6.2 m (b) $(10\hat{i} - 6\hat{j})$, 9.2 m
 (c) $(7\hat{i} - 6\hat{j})$, 9.2 m (d) $(10\hat{i} + 6\hat{j} - 6\hat{k})$, 6.2 m
35. The position of a particle is given by $\vec{r} = 3t\hat{i} + 2t^2\hat{j} + 5\hat{k}$, then the direction of $\vec{v}(t)$ at $t = 1 \text{ s}$ in
 (a) 45° with X-axis (b) 63° with Y-axis
 (c) 30° with Y-axis (d) 53° with X-axis
36. The position of particle is given by $\vec{r} = 2t^2\hat{i} + 3t\hat{j} + 4\hat{k}$, where t is in second and the coefficients have proper units for $\vec{r}$ to be in metre. The $\vec{a}(t)$ of the particle at $t = 1 \text{ s}$ is
 (a) 4 m s^{-2} along y-direction
 (b) 3 m s^{-2} along x-direction
 (c) 4 m s^{-2} along x-direction
 (d) 2 m s^{-2} along z-direction
37. A body moves in X-Y plane under the action of acceleration given by $\frac{1}{3}(6t\hat{i} + 4t\hat{j})$. Assuming that the body is at rest at time $t = 0$, the velocity of body at $t = 3 \text{ sec}$ is
 (a) $9\hat{i} + 6\hat{j}$ (b) $18\hat{i} + 6\hat{j}$
 (c) $18\hat{i} + 12\hat{j}$ (d) $12\hat{i} + 68\hat{j}$
38. A particle moves in the X-Y plane with a constant acceleration 1.5 m/s^2 in the direction making an angle of 37° with the X-axis. At $t = 0$ the particle is at the origin and its velocity is 8.0 m/s along the X-axis. Find the position of the particle at $t = 4.0 \text{ s}$.

- (a) (41.6m, 7.2 m) (b) (50.3 m, 8.2 m)
(c) (60.2m, 8.2 m) (d) (11.2 m, 8 m)
39. For motion in two or three dimensions, the angle between velocity and acceleration is
(a) 0° (b) 90° (c) 180°
(d) Any angle between 0° & 180°
40. A particle moving with velocity $\vec{v} = k(\hat{y}\hat{i} + \hat{x}\hat{j})$, where $k = \text{constant}$. The general equation for its path is [C = constant]
(a) $y = x^2 + C$ (b) $y^2 = x + C$
(c) $xy = C$ (d) $y^2 = x^2 + C$
41. The coordinates of a particle moving in x-y plane at any instant of time t are $x = 4t^2$; $y = 3t^2$. The speed of the particle at that instant is
(a) $10t$ (b) $5t$ (c) $3t$ (d) $2t$
42. The shape of trajectory of the motion of an object is determined by
(a) acceleration (b) initial position
(c) initial velocity (d) All of these
43. A particle has an initial velocity $3\hat{i} + 4\hat{j}$ and an acceleration of $0.4\hat{i} + 0.3\hat{j}$. Its speed after 10 sec is
(a) $7\sqrt{2}$ units (b) 7 units
(c) 8.5 units (d) 10 units
44. A moves with 65 km/h while B is coming back of A with 80 km/h. The relative velocity of B with respect to A is
(a) 80 km/h (b) 60 km/h
(c) 15 km/h (d) 145 km/h
45. If t_m is the time taken by a projectile to achieve the maximum height, then the total time of flight T_f related to t_m as
(a) $t_m = 2T_f$ (b) $T_f = t_m$
(c) $T_f = 2t_m$ (d) None of these
46. If u is the initial velocity of a projectile and v is the velocity at any instant, then the maximum horizontal range R_m is equal to
(a) $R_m = \frac{u^2 \sin 2\theta}{g}$ (b) $R_m = \frac{v^2}{g}$
(c) $R_m = \frac{v^2 \sin 2\theta}{g}$ (d) $R_m = \frac{u^2}{g}$
47. In the projectile motion, if air resistance is ignored, the horizontal motion is at
(a) constant acceleration (b) constant velocity
(c) variable acceleration (d) constant retardation
48. The time of flight of a projectile on an upward inclined plane depends upon
(a) angle of inclination of the plane
(b) angle of projection
(c) the value of acceleration due to gravity
(d) all of the above.
49. For angle ...X..., the projectile has maximum range and it is equal to ...X.... Here, X and Y refer to
(a) $\frac{\pi}{4}$ and $\frac{v_0^2}{2g}$ (b) $\frac{\pi}{2}$ and $\frac{v_0}{g}$
(c) $\frac{\pi}{4}$ and $\frac{v_0^2}{g}$ (d) $\frac{\pi}{2}$ and $\frac{v_0^2}{g}$
50. At the top of the trajectory of a projectile, the acceleration is
(a) maximum (b) minimum
(c) zero (d) constant (g)
51. A stone is projected horizontally with a 5 m/s from the top of a plane inclined at an angle 45° with the horizontal. How far from the point of projection will the particle strike the plane?
(a) $5\sqrt{2}$ m (b) $11\sqrt{2}$ m
(c) $12\sqrt{2}$ m (d) $15\sqrt{2}$ m
52. A body is projected horizontally with velocity 3 m/s from a height 5m. Its horizontal range is
(a) 3m (b) 5m (c) 10m (d) 12m
53. Two balls are projected at an angle θ and $(90^\circ - \theta)$ to the horizontal with the same speed. The ratio of their maximum vertical heights is
(a) 1 : 1 (b) $\tan \theta : 1$ (c) $1 : \tan \theta$ (d) $\tan^2 \theta : 1$
54. The velocity of projection of a body is increased by 2%. Other factors remaining unchanged, what will be the percentage change in the maximum height attained?
(a) 1% (b) 2% (c) 4% (d) 8%
55. A cricket ball is hit with a velocity 25 ms^{-1} , 60° above the horizontal. How far above the ground, ball passes over a fielder 50 m from the bat (consider the ball is struck very close to the ground)?
Take $\sqrt{3} = 1.7$ and $g = 10 \text{ ms}^{-2}$
(a) 6.8m (b) 7m (c) 5m (d) 10m
56. A missile is fired for maximum range with an initial velocity of 20 m/s. If $g = 10 \text{ m/s}^2$, the range of the missile is
(a) 40m (b) 50m (c) 60m (d) 20m
57. A projectile can have the same range R for two angles of projection. If t_1 and t_2 be the times of flight in two cases, then what is the product of two times of flight?
(a) $t_1 t_2 \propto R$ (b) $t_1 t_2 \propto R^2$
(c) $t_1 t_2 \propto 1/R$ (d) $t_1 t_2 \propto 1/R^2$
58. Two particles are projected from the same point with the same speed u such that they have the same range R , but different maximum heights, h_1 and h_2 . Which of the following is correct?
(a) $R^2 = 4 h_1 h_2$ (b) $R^2 = 16 h_1 h_2$
(c) $R^2 = 2 h_1 h_2$ (d) $R^2 = h_1 h_2$

1.2 Projectile Motion-Oblique and Horizontal

59. Two guns A and B can fire bullets at speeds 1 km/s and 2 km/s respectively. From a point on a horizontal ground, they are fired in all possible directions. The ratio of maximum areas covered by the bullets fired by the two guns, on the ground is:
 (a) 1 : 16 (b) 1 : 2
 (c) 1 : 4 (d) 1 : 8
60. The maximum vertical height to which a man can throw a ball is 136 m. The maximum horizontal distance upto which he can throw the same ball is
 (a) 192 m (b) 136 m
 (c) 272 m (d) 68 m
61. Two projectiles P_1 and P_2 thrown with speed in the ratio $\sqrt{3} : \sqrt{2}$, attain the same height during their motion. If P_2 is thrown at an angle of 60° with the horizontal, the angle of projection of P_1 with horizontal will be:
 (a) 15° (b) 30° (c) 45° (d) 60°
62. A boy throws a ball with a velocity ' V_0 ' at an angle ' α ' to the ground. At the same time he starts running with uniform velocity to catch the ball before it hits the ground. To achieve this, he should run with a velocity of
 (a) $V_0 \cos \alpha$ (b) $V_0 \sin \alpha$
 (c) $V_0 \tan \alpha$ (d) $\sqrt{V_0^2 \tan \alpha}$
63. The maximum height attained by projectile is increased by 10% by keeping the angle of projection constant. What is the percentage increase in the time of flight?
 (a) 5% (b) 10% (c) 20% (d) 40%
64. The horizontal range of a projectile projected at an angle of 45° with the horizontal is 50 m. The height of the projectile when its horizontal displacement is 20 m is
 (a) 18 m (b) 36 m (c) 12 m (d) 24 m
65. If two stones are projected at angle ' θ ' and $(90 - \theta)$ respectively with horizontal with a speed of 20 ms^{-1} . If second stone rises 10 m higher than the first stone, then the angle of projection ' θ ' is (acceleration due to gravity = 10 ms^{-2})
 (a) 45° (b) 30° (c) 60° (d) 20°
66. A projectile can have the same range (R) for two angles of projection. Their initial velocities are same. If T_1 and T_2 are times of flight in two cases, then the product of two times of flight is directly proportional to
 (a) $\frac{1}{R}$ (b) R^3 (c) R^2 (d) R
67. A 2 kg ball thrown vertically upward and another 3 kg ball projected with certain angle ($\theta \neq 90^\circ$) both will have same time of flight. Then the ratio of their maximum heights is
 (a) 2 : 3 (b) 3 : 2
 (c) $\sqrt{3} : 2$ (d) 1 : 1
68. In a sport event a disc is thrown such that it reaches its maximum range of 80m, the distance travelled in first 3 s is ($g = 10 \text{ ms}^{-2}$)
 (a) 80 m (b) 60 m
 (c) 72 m (d) 74 m
69. An object is projected such that it has to attain maximum range. Another body is projected to reach maximum height. If both the objects reached the same maximum height, then the ratio initial velocities
 (a) 2 : 1 (b) $\sqrt{2} : 1$
 (c) $1 : \sqrt{2}$ (d) 1 : 2
70. The maximum horizontal range of a ball projected from the ground is 32 m. If the ball is thrown with the same speed horizontally from the top of a tower of height 25 m, the maximum horizontal distance covered by the ball is (Acceleration due to gravity = 10 ms^{-2})
 (a) 40 m (b) 57 m
 (c) 60 m (d) 75 m
71. A body P is projected at an angle of 30° with the horizontal and another body Q is projected at angle of 30° with the vertical. If the ratio of the horizontal ranges of the bodies P and Q is 1 : 2, then the ratio of the maximum heights reached by the bodies P and Q is
 (a) 1 : 4 (b) 1 : 6
 (c) 2 : 3 (d) 1 : 1
72. At any instant ' t ' the vertical distance ' Y ' and horizontal distance ' X ' of a projectile are given by $2Y = 6t - gt^2$ and $X = 4t$. The initial velocity of projectile is (X and Y are in metre and t is in second)
 (a) 3 ms^{-1} (b) 4 ms^{-1}
 (c) 5 ms^{-1} (d) 6 ms^{-1}
73. The time of flight of a vertically projected stone is 8 s. The position of the stone after 6 s from the ground is (Acceleration due to gravity = 10 ms^{-2})
 (a) 20 m (b) 60 m
 (c) 75 m (d) 40 m
74. A particle moves in a plane with a constant acceleration in a direction different from the initial velocity. The path of the particle is a/an
 (a) straight line (b) arc of a circle
 (c) parabola (d) ellipse
75. A particle of mass m is projected with a velocity v making an angle of 30° with the horizontal. The magnitude of ($V_h \times h$) of the projectile when the particle is at its maximum height h

- (a) $\frac{\sqrt{3}}{2} \frac{v^2}{g}$ (b) zero
- (c) $\frac{v^3}{\sqrt{2}g}$ (d) $\frac{\sqrt{3}}{16} \frac{v^3}{g}$
76. Two pegs A and B thrown with speeds in the ratio 1 : 3 acquired the same heights. If A is thrown at an angle of 30° with the horizontal, the angle of projection of B will be
- (a) 0° (b) $\sin^{-1}\left(\frac{1}{8}\right)$
- (c) $\sin^{-1}\left(\frac{1}{6}\right)$ (d) $\sin^{-1}\left(\frac{1}{2}\right)$
77. A body projected at an angle with the horizontal has a range 300 m. If the time of flight is 6 s, then the horizontal component of velocity is
- (a) 30 m s^{-1} (b) 50 m s^{-1}
- (c) 40 m s^{-1} (d) 45 m s^{-1}
78. The range of a projectile is R when the angle of projection is 40° . For the same velocity of projection and range, the other possible angle of projection is
- (a) 45° (b) 50°
- (c) 60° (d) 40°
79. If the angles of projection of a projectile with same initial velocity exceed or fall short of 45° by equal amounts, then the ratio of horizontal ranges is
- (a) 1 : 2 (b) 1 : 3 (c) 1 : 4 (d) 1 : 1
80. A projectile is projected at 30° from horizontal with initial velocity 40 ms^{-1} . The velocity of the projectile at $t = 2 \text{ s}$ from the start will be:
- (Given $g = 10 \text{ m/s}^2$)
- (a) $20\sqrt{3} \text{ ms}^{-1}$ (b) $40\sqrt{3} \text{ ms}^{-1}$
- (c) 20 ms^{-1} (d) Zero
81. The equation of trajectory of projectile is given by
- $$y = \frac{x}{\sqrt{3}} - \frac{gx^2}{20}, \text{ where } x \text{ and } y \text{ are in metre.}$$
- The maximum range of the projectile is
- (a) $\frac{8}{3} \text{ m}$ (b) $\frac{4}{3} \text{ m}$
- (c) $\frac{3}{4} \text{ m}$ (d) $\frac{3}{8} \text{ m}$
82. A stone is just released from the window of a moving train moving along a horizontal straight track. The stone will hit the ground following a
- (a) straight line path (b) circular path
- (c) parabolic path (d) hyperbolic path
83. A stone is projected horizontally with velocity u from a height H . Its time of flight is:
- (a) $\sqrt{2H/g}$ (b) $2\sqrt{H/gu}$
- (c) $\sqrt{H/2gu}$ (d) $4\sqrt{H/g}$
84. A body of mass 10 kg is projected at an angle of 45° with the horizontal. The trajectory of the body is observed to pass through a point (20, 10). If T is the time of flight, then its momentum vector, at time $t = \frac{T}{\sqrt{2}}$, is _____
- [Take $g = 10 \text{ m/s}^2$]
- (a) $100\hat{i} + (100\sqrt{2} - 200)\hat{j}$
- (b) $100\sqrt{2}\hat{i} + (100 - 200\sqrt{2})\hat{j}$
- (c) $100\hat{i} + (100 - 200\sqrt{2})\hat{j}$
- (d) $100\sqrt{2}\hat{i} + (100\sqrt{2} - 200)\hat{j}$
85. The trajectory of projectile, projected from the ground is given by $y = x - \frac{x^2}{20}$. Where x and y are measured in meter. The maximum height attained by the projectile will be.
- (a) 5m (b) $10\sqrt{2}\text{m}$
- (c) 200m (d) 10m
86. A bullet is fired with a speed of 1500 m/s in order to hit a target 100 m away. If $g = 10 \text{ m/s}^2$. The gun should be aimed
- (a) 15 cm above the target
- (b) 10 cm above the target
- (c) 2.2 cm above the target
- (d) directly towards the target
87. A projectile is thrown in the upward direction making an angle of 60° with the horizontal direction with a velocity of 147 ms^{-1} . Then the time after which its inclination with the horizontal is 45° , is
- (a) 15 s (b) 10.98 s
- (c) 5.49 s (d) 2.745 s
88. A particle is projected with a velocity v such that its range on the horizontal plane is twice the greatest height attained by it. The range of the projectile is (where g is acceleration due to gravity)
- (a) $\frac{4v^2}{5g}$ (b) $\frac{4g}{5v^2}$ (c) $\frac{v^2}{g}$ (d) $\frac{4v^2}{\sqrt{5}g}$
89. Two balls with same mass and initial velocity, are projected at different angles in such a way that maximum height reached by first ball is 8 times higher than that of the second ball. T_1 and T_2 are the total flying times of first and second ball, respectively, then the ratio of T_1 and T_2 is :
- (a) $2\sqrt{2} : 1$ (b) 2 : 1
- (c) $\sqrt{2} : 1$ (d) 4 : 1

90. Two projectiles are fired from ground with same initial speeds from same point at angles $(45^\circ + \alpha)$ and $(45^\circ - \alpha)$ with horizontal direction. The ratio of their times of flights is

- (a) 1 (b) $\frac{1 - \tan \alpha}{1 + \tan \alpha}$
(c) $\frac{1 + \sin 2\alpha}{1 - \sin 2\alpha}$ (d) $\frac{1 + \tan \alpha}{1 - \tan \alpha}$

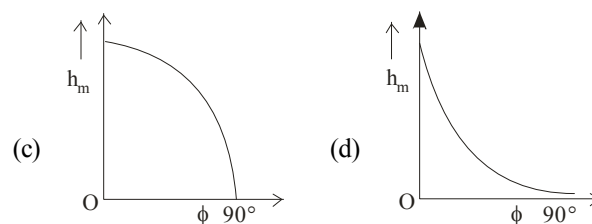
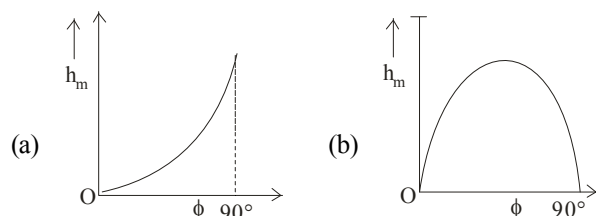
91. A particle is projected with velocity u so that its horizontal range is three times the maximum height attained by it.

The horizontal range of the projectile is given as $\frac{nu^2}{25g}$, where value of n is :

(Given 'g' is the acceleration due to gravity).

- (a) 6 (b) 18
(c) 12 (d) 24

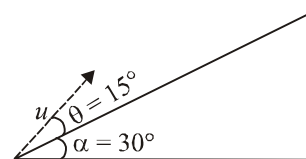
92. The angle of projection of a particle is measured from the vertical axis as ϕ and the maximum height reached by the particle is h_m . Here h_m as function of ϕ can be presented as



93. Two projectiles are fired with same initial speed from same point on ground at angles of $(45^\circ - \alpha)$ and $(45^\circ + \alpha)$, respectively, with the horizontal direction. The ratio of their maximum heights attained is :

- (a) $\frac{1 - \tan \alpha}{1 + \tan \alpha}$ (b) $\frac{1 + \sin \alpha}{1 - \sin \alpha}$
(c) $\frac{1 - \sin 2\alpha}{1 + \sin 2\alpha}$ (d) $\frac{1 + \sin 2\alpha}{1 - \sin 2\alpha}$

94. A plane is inclined at an angle $\alpha = 30^\circ$ with respect to the horizontal. A particle is projected with a speed $u = 2 \text{ ms}^{-1}$, from the base of the plane, as shown in figure. The distance from the base, at which the particle hits the plane is close to: (Take $g = 10 \text{ ms}^{-2}$)



- (a) 20 cm (b) 18 cm (c) 26 cm (d) 14 cm
95. A projectile is given an initial velocity of $(\hat{i} + 2\hat{j}) \text{ m/s}$, where $\hat{i}$ is along the ground and $\hat{j}$ is along the vertical. If $g = 10 \text{ m/s}^2$, the equation of its trajectory is :
(a) $y = x - 5x^2$ (b) $y = 2x - 5x^2$
(c) $4y = 2x - 5x^2$ (d) $4y = 2x - 25x^2$

Exercise 2 :

ACCELERATOR Topic-wise MCQs

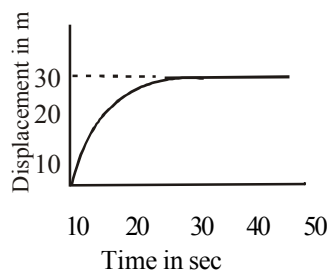
1.1 Rectilinear Motion, Motion in a Plane

1. A man leaves his house for a cycle ride. He comes back to his house after half-an-hour after covering a distance of one km. What is his average velocity for the ride?
(a) zero (b) 2 km h^{-1}
(c) 10 km s^{-1} (d) $\frac{1}{2} \text{ km s}^{-1}$
2. A point traversed half of the distance with a velocity v_0 . The half of remaining part of the distance was covered with velocity v_1 & second half of remaining part by v_2

velocity. The mean velocity of the point, averaged over the whole time of motion is

- (a) $\frac{v_0 + v_1 + v_2}{3}$ (b) $\frac{2v_0 + v_1 + v_2}{3}$
(c) $\frac{v_0 + 2v_1 + 2v_2}{3}$ (d) $\frac{2v_0(v_1 + v_2)}{(2v_0 + v_1 + v_2)}$
3. The dependence of velocity of a body with time is given by the equation $v = 20 + 0.1t^2$. The body is in
(a) uniform retardation
(b) uniform acceleration
(c) non-uniform acceleration
(d) zero acceleration.

4. The displacement of a particle as a function of time is shown in figure. It indicates that

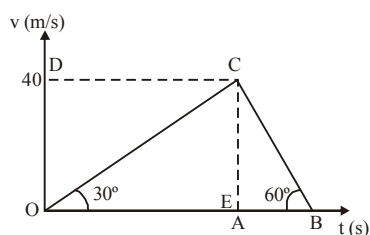


- (a) the velocity of the particle is constant throughout
 (b) the acceleration of the particle is constant throughout
 (c) the particle starts with a constant velocity and is accelerated
 (d) the motion is retarded and finally the particle stops
5. The position of a particle along the x -axis at certain times is given below

$t(s)$	0	1	2	3
$x(m)$	-2	0	6	16

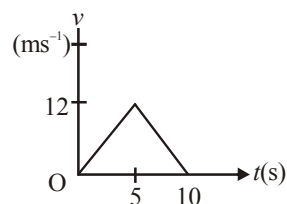
Which of the following describes the motion correctly?

- (a) uniform acceleration
 (b) uniform retardation
 (c) non-uniform acceleration
 (d) there is not enough data for generalization
6. A body covers 26, 28, 30, 32 meters in 10th, 11th, 12th and 13th seconds respectively. The body starts
- (a) from rest and moves with uniform velocity
 (b) from rest and moves with uniform acceleration
 (c) with an initial velocity and moves with uniform acceleration
 (d) with an initial velocity and moves with uniform velocity
7. Two trains, each 40 m long are travelling in opposite direction with equal velocity 20 m/s. The time of crossing is
- (a) 1s (b) 2s (c) 3s (d) Zero
8. The displacement of a particle is represented by the following equation: $S = 3t^3 + 7t^2 + 5t + 8$ where S is in meter and t in second. The acceleration of the particle at $t = 15$ is
- (a) 14 m/s^2 (b) 18 m/s^2 (c) 32 m/s^2 (d) zero
9. The velocity-time graph of a body is shown in fig. The ratio of average acceleration during the intervals OA and AB is

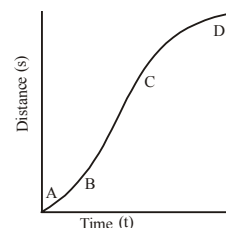


- (a) 1
 (b) $\frac{1}{2}$
 (c) $\frac{1}{3}$
 (d) 3

10. The speed-time graph of a particle moving along a fixed direction is shown in the figure. The distance traversed by the particle between $t = 0 \text{ s}$ to $t = 10 \text{ s}$ is

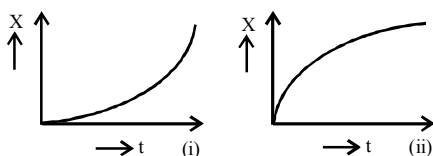


- (a) 20m (b) 40m
 (c) 60m (d) 80m
11. Which of the following statements is not correct regarding the motion of a particle in a straight line?
- (a) $x-t$ graph is a parabola, if motion is uniformly accelerated.
 (b) $v-t$ is a straight line inclined to the time axis, if motion is uniformly accelerated.
 (c) $x-t$ graph is a straight line inclined to the time axis of motion is uniform and acceleration is zero.
 (d) $v-t$ graph is a parabola if motion is uniform and acceleration is zero.
12. A body moves with speed 10 m/s for 10 sec, then with a speed of 20 m/s for distance 300m. Its average speed may be
- (a) 4 m/s (b) 8 m/s
 (c) 16 m/s (d) None of these
13. The three initial and final positions of a man on the x -axis are given as
- (i) $(-3 \text{ m}, 7 \text{ m})$
 (ii) $(7 \text{ m}, -3 \text{ m})$
 (iii) $(-7 \text{ m}, 3 \text{ m})$
- Which pair gives the negative displacement?
- (a) (i) (b) (ii)
 (c) (iii) (d) (i) and (iii)
14. A particle shows distance - time curve as given in this figure. The maximum instantaneous velocity of the particle is around the point:



- (a) B (b) C (c) D (d) A
15. The acceleration of a moving body can be found from
- (a) area under velocity-time graph
 (b) area under distance-time graph
 (c) slope of the velocity-time graph
 (d) slope of distance-time graph

16. Figures (i) and (ii) below show the displacement-time graphs of two particles moving along the x-axis. We can say that

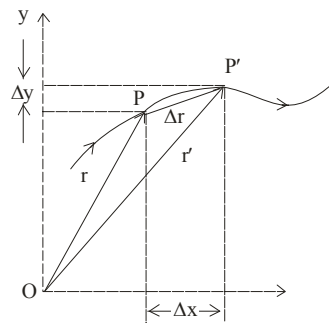


- (a) Both the particles are having a uniformly accelerated motion
 (b) Both the particles are having a uniformly retarded motion
 (c) Particle (i) is having a uniformly accelerated motion while particle (ii) is having a uniformly retarded motion
 (d) Particle (i) is having a uniformly retarded motion while particle (ii) is having a uniformly accelerated motion
17. A person walks in such a way that he covers equal distance in each step. The person takes 2 steps forward towards east, then takes a right turn and walks 4 steps towards south, then takes a right turn and walks 6 steps towards west and then takes a right turn and walks further. The direction of his final position after a total of 20 steps walk with respect to his initial position is
 (a) North-West (b) 60° West of South
 (c) 60° South of West (d) South-East
18. A particle is moving in xy-plane as

$$\vec{x} = (4t + t^2)\hat{i}, \vec{y} = \left(2t + \frac{t^2}{2}\right)\hat{j} \text{ where } \vec{x} \text{ \& } \vec{y} \text{ are}$$

displacements measured along x and y axes respectively in meters and t in seconds. What is the velocity of the particle?

- (a) $\vec{v} = (4+t)\hat{i} + (2+t)\hat{j}$ (b) $\vec{v} = (4+2t)\hat{i} + (2+t)\hat{j}$
 (c) $\vec{v} = (4+2t)\hat{i} + \left(2 + \frac{t}{2}\right)\hat{j}$ (d) $\vec{v} = (4+t)\hat{i} + \left(2 + \frac{t}{2}\right)\hat{j}$
19. A body is moving with an initial velocity of $10\sqrt{2} \text{ ms}^{-1}$ in the north-east direction. If it is subjected to an acceleration of 2 ms^{-2} directed towards the south, then velocity of the body after 5s is
 (a) 10 ms^{-1} , towards east
 (b) 10 ms^{-1} , towards north
 (c) 10 ms^{-1} , towards south
 (d) 10 ms^{-1} , towards north-east
20. Suppose a particle moves along a curve shown by the thick line and the positions of particle are represented by P at t and P' at t'.



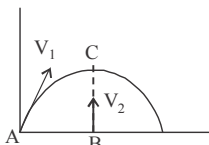
where, coordinates of P is (2, 3) and P' is (5, 6). Net displacement of the particle will be

- (a) zero (b) $7\hat{i} + 9\hat{j}$ (c) $10\hat{i} + 18\hat{j}$ (d) $3\hat{i} + 3\hat{j}$
21. Position of an ant (S in metres) moving in Y-Z plane is given by $S = 2t^2\hat{j} + 5\hat{k}$ (where t is in second). The magnitude and direction of velocity of the ant at $t = 1$ s will be :
 (a) 16 m/s in y-direction (b) 4 m/s in x-direction
 (c) 9 m/s in z-direction (d) 4 m/s in y-direction
22. A particle starts from origin at $t = 0$ with a velocity $5\hat{i} \text{ m/s}$ and moves in x-y plane under action of a force which produces a constant acceleration of $(3\hat{i} + 2\hat{j}) \text{ m/s}^2$. If the x-coordinate of the particle at that instant is 84 m, then the speed of the particle at this time is $\sqrt{\alpha} \text{ m/s}$. The value of α is
 (a) 261 (b) 572
 (c) 673 (d) 841
23. A particle crossing the origin of co-ordinates at time $t = 0$, moves in the xy-plane with a constant acceleration a in the y-direction. If its equation of motion is $y = bx^2$ (b is a constant), its velocity component in the x-direction is
 (a) $\sqrt{\frac{2b}{a}}$ (b) $\sqrt{\frac{a}{2b}}$
 (c) $\sqrt{\frac{a}{b}}$ (d) $\sqrt{\frac{b}{a}}$
24. A particle starting from the origin (0, 0) moves in a straight line in the (x, y) plane. Its coordinates at a later time are $(\sqrt{3}, 3)$. The path of the particle makes with the x-axis an angle of
 (a) 45° (b) 60° (c) 0° (d) 30°
25. At time $t = 0$ a particle starts travelling from a height $7 \hat{z} \text{ cm}$ in a plane keeping z coordinate constant. At any instant of time it's position along the $\hat{x}$ and $\hat{y}$ directions are defined as $3t$ and $5t^3$ respectively. At $t = 1$ s acceleration of the particle will be
 (a) $-30\hat{y}$ (b) $30\hat{y}$
 (c) $3\hat{x} + 15\hat{y}$ (d) $3\hat{x} + 15\hat{y} + 7\hat{z}$

1.2 Projectile Motion-Oblique and Horizontal

26. When air resistance is taken into account while dealing with the motion of the properties which of the following properties of the projectile, shows an increase ?
 (a) range
 (b) maximum height
 (c) speed at which it strikes the ground
 (d) the angle at which the projectile strikes the ground.
27. At the top of the trajectory of a projectile, the acceleration is
 (a) maximum (b) minimum
 (c) zero (d) g
28. In projectile motion, velocity at maximum height is
 (a) $\frac{u \cos \theta}{2}$ (b) $u \cos \theta$
 (c) $\frac{u \sin \theta}{2}$ (d) None of these
29. Neglecting the air resistance, the time of flight of a projectile is determined by
 (a) u_{vertical}
 (b) $u_{\text{horizontal}}$
 (c) $u = u_{\text{vertical}}^2 + u_{\text{horizontal}}^2$
 (d) $u = u (u_{\text{vertical}}^2 + u_{\text{horizontal}}^2)^{1/2}$
30. At the top of the trajectory of a projectile, the directions of its velocity and acceleration are
 (a) perpendicular to each other
 (b) parallel to each other
 (c) inclined to each other at an angle of 45°
 (d) antiparallel to each other
31. In case of a projectile motion, what is the angle between the velocity and acceleration at the highest point ?
 (a) 0° (b) 45° (c) 90° (d) 180°
32. A particle (A) is dropped from a height and another particle (B) is thrown in horizontal direction with speed of 5 m/sec from the same height. The correct statement is
 (a) both particles will reach the ground simultaneously
 (b) both particles will reach the ground with same speed
 (c) particle (A) will reach the ground first with respect to particle (B)
 (d) Particle (B) will reach the ground first with respect to particle (A)
33. An object is thrown along a direction inclined at an angle of 45° with the horizontal direction. The horizontal range of the particle is equal to
 (a) vertical height
 (b) twice the vertical height
 (c) thrice the vertical height
 (d) four times the vertical height
34. A cricket ball is hit at 30° with the horizontal with kinetic energy K . The kinetic energy at the highest point is
 (a) Zero (b) $K/4$
 (c) $K/2$ (d) $3K/4$
35. A particle is projected with a velocity v so that its horizontal range twice the greatest height attained. The horizontal range is
 (a) $\frac{2v^2}{3g}$ (b) $\frac{v^2}{2g}$
 (c) $\frac{v^2}{g}$ (d) $\frac{4v^2}{5g}$
36. A projectile is given an initial velocity of $(i + 2j)$ m/s where $\hat{i}$ is along the ground and $\hat{j}$ is along the vertical. If $g = 10 \text{ m/s}^2$ the equation of its trajectory is
 (a) $y = 2x - 5x^2$ (b) $y = x - 5x^2$
 (c) $2y = 2x - 5x^2$ (d) $4y = 2x - 25x^2$
37. A plane flying horizontally at a height of 1500 m with a velocity of 200 ms^{-1} passes directly overhead on anti-aircraft gun. Then the angle with the horizontal at which the gun should be fired from the shell with a muzzle velocity of 400 ms^{-1} to hit the plane, is
 (a) 90° (b) 60° (c) 30° (d) 45°
38. A projectile is fired from the surface of the earth with a velocity of 5 ms^{-1} and angle θ with the horizontal. Another projectile fired from another planet with a velocity of 3 ms^{-1} at the same angle follows a trajectory which is identical with the trajectory of the projectile fired from the earth. The value of the acceleration due to gravity on the planet is (in ms^{-2}) given $g = 9.8 \text{ m/s}^2$
 (a) 3.5 (b) 5.9 (c) 16.3 (d) 110.8
39. The horizontal range and the maximum height of a projectile are equal. The angle of projection of the projectiles is :
 (a) $\theta = \tan^{-1} \left(\frac{1}{4} \right)$ (b) $\theta = \tan^{-1} (4)$
 (c) $\theta = \tan^{-1} (2)$ (d) $\theta = 45^\circ$
40. If a body A of mass M is thrown with velocity v at an angle of 30° to the horizontal and another body B of the same mass is thrown with the same speed at an angle of 60° to the horizontal, the ratio of horizontal range of A to B will be
 (a) 1 : 3 (b) 1 : 1
 (c) 1 : $\sqrt{3}$ (d) $\sqrt{3} : 1$

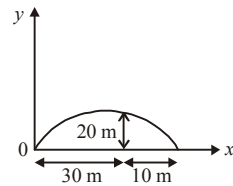
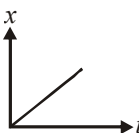
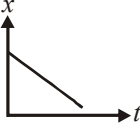
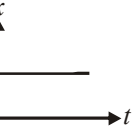
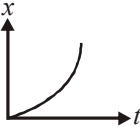
41. A projectile is fired at an angle of 45° with the horizontal. Elevation angle of the projectile at its highest point as seen from the point of projection is
- (a) 60° (b) $\tan^{-1}\left(\frac{1}{2}\right)$
- (c) $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$ (d) 45°
42. A projectile thrown with velocity v making angle θ with vertical gains maximum height 20m in the time for which the projectile remains in air, the time period is
- (a) 15 s (b) 25 s (c) 9 s (d) 4 s
43. A boy playing on the roof of a 20 m high tower throws a ball with a speed of 20m/s at an angle of 45° with the horizontal. How far from the throwing point will the ball be at the height of 20 m from the ground ?
- [$g = 10 \text{ m/s}^2$]
- (a) 20m (b) 4.33m
- (c) 2.60m (d) 40m
44. The range of the projectile projected at an angle of 15° with horizontal is 50 m. If the projectile is projected with same velocity at an angle of 45° with horizontal, then its range will be :
- (a) 50m (b) $50\sqrt{2}$ m
- (c) 100m (d) $100\sqrt{2}$ m
45. A bomber plane moves horizontally with a speed of 500 m/s and a bomb released from it, strikes the ground in 10 sec. Angle with the ground at which it strikes the ground will be ($g = 10 \text{ m/s}^2$)
- (a) $\tan^{-1}\left(\frac{1}{5}\right)$ (b) $\tan\left(\frac{1}{5}\right)$
- (c) $\tan^{-1}(1)$ (d) $\tan^{-1}(5)$
46. A bomb is dropped by fighter plane flying horizontally. To an observer sitting in the plane, the trajectory of the bomb is a :
- (a) hyperbola
- (b) parabola in the direction of motion of plane
- (c) straight line vertically down the plane
- (d) parabola in a direction opposite to the motion of plane
47. An artillery piece which consistently shoots its shells with the same muzzle speed has a maximum range R . To hit a target which is $R/2$ from the gun and on the same level, the elevation angle of the gun should be
- (a) 15° (b) 45° (c) 30° (d) 60°
48. A ball is projected with velocity 10 ms^{-1} in a direction making an angle 30° with the horizontal, what is the position coordinate (in metres) of the ball after 1s?
- (a) (8.66, 0.1) (b) (9.8, 1.0)
- (c) (4.26, 5.29) (d) (0.4, 8.66)
49. The trajectory of a projectile near the surface of the earth is given as $y = 2x - 9x^2$. If it were launched at an angle θ_0 with speed v_0 then ($g = 10 \text{ ms}^{-2}$):
- (a) $\theta_0 = \sin^{-1} \frac{1}{\sqrt{5}}$ and $v_0 = \frac{5}{3} \text{ ms}^{-1}$
- (b) $\theta_0 = \cos^{-1} \left(\frac{2}{\sqrt{5}} \right)$ and $v_0 = \frac{3}{5} \text{ ms}^{-1}$
- (c) $\theta_0 = \cos^{-1} \left(\frac{1}{\sqrt{5}} \right)$ and $v_0 = \frac{5}{3} \text{ ms}^{-1}$
- (d) $\theta_0 = \sin^{-1} \left(\frac{2}{\sqrt{5}} \right)$ and $v_0 = \frac{3}{5} \text{ ms}^{-1}$
50. A bowling machine placed at a height h above the earth surface releases different balls with different angles but with same velocity $10\sqrt{3} \text{ ms}^{-1}$. All these balls landing velocities make angles 30° or more with horizontal. Then the height ' h ' (in meters) (acceleration due to gravity = 10 ms^{-2})
- (a) 15 (b) 12
- (c) 10 (d) 5
51. The relation between the horizontal displacement x (in metre) and the vertical displacement y (in metre) of a projectile is $y = 3x - 0.8x^2$. The time of flight of the projectile is (Acceleration due to gravity = 10 ms^{-2}).
- (a) 1.5 s (b) 3 s
- (c) 2 s (d) 2.5 s
52. A ball is projected at an angle of 45° with the horizontal. It passes through a wall of height ' h ' at a horizontal distance d_1 from the point of projection and strikes the ground at a distance $d_1 + d_2$ from the point of projection, then ' h ' is
- (a) $h = \frac{2d_1d_2}{d_1 + d_2}$ (b) $h = \frac{d_1d_2}{d_1 + d_2}$
- (c) $h = \frac{\sqrt{2}d_1d_2}{d_1 + d_2}$ (d) $h = \frac{d_1d_2}{2(d_1 + d_2)}$
53. One second after projection, a projectile is travelling in a direction inclined at 45° to horizontal. After two more seconds it is travelling horizontally. Then the magnitude of velocity of the projectile is ($g = 10 \text{ ms}^{-2}$)

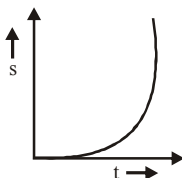
- (a) $10\sqrt{13} \text{ ms}^{-1}$ (b) 11 ms^{-1}
 (c) $10\sqrt{2} \text{ ms}^{-1}$ (d) 20 ms^{-1}
54. From a height of 'h' above the ground, a ball is projected up at an angle 30° with the horizontal. If the ball strikes the ground with a speed of 1.25 times its initial speed of 40 ms^{-1} , the value of 'h' is (acceleration due to gravity = 10 ms^{-2})
 (a) 75 m (b) 60 m (c) 30 m (d) 45 m
55. A body is projected from the ground at an angle of $\tan^{-1}(\sqrt{7})$ with the horizontal. At half of the maximum height, the speed of the body is 'n' times the speed of projection. The value of 'n' is
 (a) 2 (b) $\frac{1}{2}$
 (c) $\frac{4}{3}$ (d) $\frac{3}{4}$
56. A cannon placed on a cliff at a height of 375 m fires a cannon ball with a velocity of 100 ms^{-1} at an angle of 30° above the horizontal. The horizontal distance between the cannon and the target is (Acceleration due to gravity = 10 ms^{-2})
 (a) $750\sqrt{3} \text{ m}$ (b) $500\sqrt{3} \text{ m}$
 (c) $250\sqrt{3} \text{ m}$ (d) 750 m
57. A projectile is projected with velocity of 25 m/s at an angle θ with the horizontal. After t seconds its inclination with horizontal becomes zero. If R represents horizontal range of the projectile, the value of θ will be : [use $g = 10 \text{ m/s}^2$]
 (a) $\frac{1}{2} \sin^{-1} \left(\frac{5t^2}{4R} \right)$ (b) $\frac{1}{2} \sin^{-1} \left(\frac{4R}{5t^2} \right)$
 (c) $\tan^{-1} \left(\frac{4t^2}{5R} \right)$ (d) $\cot^{-1} \left(\frac{R}{20t^2} \right)$
58. If V_1 is velocity of a body projected from the point A and V_2 is the velocity of a body projected from point B which is vertically below the highest point C. If both the bodies collide, then
 (a) $V_1 = \frac{1}{2} V_2$
 (b) $V_2 = \frac{1}{2} V_1$
 (c) $V_1 = V_2$
 (d) Two bodies can't collide.
- 
59. A ball is thrown from rear end of the compartment of train to the front end which is moving at a constant horizontal velocity. An observer A sitting in the compartment and another observer B standing on the ground draw the trajectory. They will have
 (a) equal horizontal and equal vertical ranges
 (b) equal vertical ranges but different horizontal ranges
 (c) different vertical ranges but equal horizontal ranges
 (d) different vertical and different horizontal ranges
60. A stone is thrown from a point with a speed 5 m/s at an elevation angle of θ . From the same point and at the same instant, a person starts running with a constant speed 2.5 m/s to catch the stone. If the person will be able to catch the ball then, what should be the angle of projection θ ?
 (a) 75° (b) 30°
 (c) 60° (d) 45°
61. Projectiles A and B are thrown at angles of 45° and 60° with vertical respectively from top of a 400 m high tower. If their ranges and times of flight are same, the ratio of their speeds of projection $v_A : v_B$ is:
 [Take $g = 10 \text{ ms}^{-2}$]
 (a) $1 : \sqrt{3}$ (b) $\sqrt{2} : 1$
 (c) $1 : 2$ (d) $1 : \sqrt{2}$
62. A particle moving in a circle of radius R with uniform speed takes time T to complete one revolution. If this particle is projected with the same speed at an angle θ to the horizontal, the maximum height attained by it is equal to 4R. The angle of projection θ is then given by:
 (a) $\sin^{-1} \left[\frac{2gT^2}{\pi^2 R} \right]^{\frac{1}{2}}$ (b) $\sin^{-1} \left[\frac{\pi^2 R}{2gT^2} \right]^{\frac{1}{2}}$
 (c) $\cos^{-1} \left[\frac{2gT^2}{\pi^2 R} \right]^{\frac{1}{2}}$ (d) $\cos^{-1} \left[\frac{\pi R}{2gT^2} \right]^{\frac{1}{2}}$
63. Two objects are projected at an angle θ° and $(90 - \theta)^\circ$, to the horizontal with the same speed. The ratio of their maximum vertical heights is
 (a) $1 : \tan \theta$ (b) $1 : 1$
 (c) $\tan^2 \theta : 1$ (d) $\tan \theta : 1$
64. A body of mass 10 kg is projected at an angle of 45° with the horizontal. The trajectory of the body is observed to pass through a point (20, 10). If T is the time of flight, then its momentum vector, at time $t = \frac{T}{\sqrt{2}}$, is
 [Take $g = 10 \text{ m/s}^2$]

- (a) $100\hat{i} + (100\sqrt{2} - 200)\hat{j}$
 (b) $100\sqrt{2}\hat{i} + (100 - 200\sqrt{2})\hat{j}$
 (c) $100\hat{i} + (100 - 200\sqrt{2})\hat{j}$
 (d) $100\sqrt{2}\hat{i} + (100\sqrt{2} - 200)\hat{j}$
65. A projectile is launched at an angle ' α ' with the horizontal with a velocity 20 ms^{-1} . After 10 s, its inclination with horizontal is ' β '. The value of $\tan \beta$ will be: ($g = 10 \text{ ms}^{-2}$)
 (a) $\tan \alpha + 5 \sec \alpha$ (b) $\tan \alpha - 5 \sec \alpha$
 (c) $2 \tan \alpha - 5 \sec \alpha$ (d) $2 \tan \alpha + 5 \sec \alpha$
66. The initial speed of a projectile fired from ground is u . At the highest point during its motion, the speed of projectile is $\frac{\sqrt{3}}{2}u$. The time of flight of the projectile is:
 (a) $\frac{u}{2g}$ (b) $\frac{u}{g}$
 (c) $\frac{2u}{g}$ (d) $\frac{\sqrt{3}u}{g}$
67. A projectile fired at 30° to the ground is observed to be at same height at time 3s and 5s after projection, during its flight. The speed of projection of the projectile is (Given $g = 10 \text{ m s}^{-2}$)
 (a) 40 m/s (b) 80 m/s
 (c) 120 m/s (d) 160 m/s
68. The trajectory of a projectile in a vertical plane is $y = \alpha x - \beta x^2$, where α and β are constants and x & y are respectively the horizontal and vertical distances of the projectile from the point of projection. The angle of projection θ and the maximum height attained H are respectively given by
 (a) $\tan^{-1} \alpha, \frac{4\alpha^2}{\beta}$ (b) $\tan^{-1} \beta, \frac{\alpha^2}{2\beta}$
 (c) $\tan^{-1} \left(\frac{\beta}{\alpha} \right), \frac{\alpha^2}{\beta}$ (d) $\tan^{-1} \alpha, \frac{\alpha^2}{4\beta}$
69. A ball is projected from the ground at a speed of 10 ms^{-1} making an angle of 30° with the horizontal. Another ball is simultaneously released from a point on the vertical line along the maximum height of the projectile. Both the balls collide at the maximum height of first ball. The initial height of the second ball is ($g = 10 \text{ ms}^{-2}$)
 (a) 6.25 m (b) 2.5 m
 (c) 3.75 m (d) 5 m
70. A projectile moves from the ground such that its horizontal displacement is $x = Kt$ and vertical displacement is $y = Kt(1 - \alpha t)$, where K and α are constants and t is time. Find out total time of flight (T) and maximum height attained ($Y_{\max}$) is
 (a) $T = \alpha, Y_{\max} = \frac{K}{2\alpha}$
 (b) $T = \frac{1}{\alpha}, Y_{\max} = \frac{2K}{\alpha}$
 (c) $T = \frac{1}{\alpha}, Y_{\max} = \frac{K}{6\alpha}$
 (d) $T = \frac{1}{\alpha}, Y_{\max} = \frac{K}{4\alpha}$
71. Ratio between maximum range and square of time of flight in projectile motion is
 (a) 10 : 49 (b) 49 : 10
 (c) 98 : 10 (d) 10 : 98
72. A height y and the distance x along the horizontal plane of a projectile on a certain planet (with no surrounding atmosphere) are given by $y = (8t - 5t^2) \text{ m}$ and $x = 6t \text{ m}$, where t is in second. The velocity with which the projectile is projected is
 (a) 8 m/sec
 (b) 6 m/sec
 (c) 10 m/sec
 (d) Not obtainable from the data
73. Two particles are projected in air with speed u at angles θ_1 and θ_2 (both acute) to the horizontal, respectively. If the height reached by the first particle is greater than that of the second, then which one of the following is correct?
 (a) $\theta_1 > \theta_2$ (b) $\theta_1 = \theta_2$
 (c) $T_1 < T_2$ (d) $T_1 = T_2$
 where T_1 and T_2 are the time of flight.
74. A body of mass 0.5 kg is projected under gravity with a speed of 98 m/s at an angle of 30° with the horizontal. The change in momentum (in magnitude) of the body is
 (a) 24.5 N-s
 (b) 49.0 N-s
 (c) 98.0 N-s
 (d) 50.0 N-s
75. A body is thrown horizontally from the top of a tower of height 5 m. It touches the ground at a distance of 10 m from the foot of the tower. The initial velocity of the body is ($g = 10 \text{ ms}^{-2}$)
 (a) 2.5 ms^{-1} (b) 5 ms^{-1}
 (c) 10 ms^{-1} (d) 20 ms^{-1}

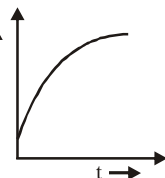
Exercise 3 :

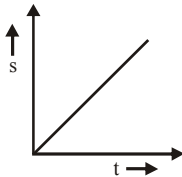
PREVIOUS YEARS MCQs

- Two bodies of same mass are projected with the same velocity at an angle 30° and 60° respectively. The ratio of their horizontal ranges will be [2025]
 - 1 : 1
 - 1 : 2
 - 1 : 3
 - $2 : \sqrt{2}$
- If the range of a body projected with a velocity of 60 ms^{-1} is $180\sqrt{3} \text{ m}$, then the angle of projection of the body is (Acceleration due to gravity = 10 ms^{-2}) [2024]
 - 30° or 60°
 - 37° or 53°
 - 20° or 70°
 - 15° or 75°
- A man travels along a straight road for the first half time with a velocity v_1 and the next half time with a velocity v_2 . The mean velocity V of the man is [2024]
 - $V = \frac{1}{v_1} + \frac{1}{v_2}$
 - $V = \frac{v_1 + v_2}{2}$
 - $V = \sqrt{v_1 v_2}$
 - $V = \sqrt{\frac{v_1}{v_2}}$
- The position vector of a moving body at any instant of time is given as $\vec{r} = (5t^2\hat{i} - 5t\hat{j}) \text{ m}$. The magnitude and direction of velocity at $t = 2 \text{ s}$ is [2023]
 - $5\sqrt{15} \text{ m/s}$, making an angle of $\tan^{-1} 4$ with $-ve$ Y axis
 - $5\sqrt{15} \text{ m/s}$, making an angle of $\tan^{-1} 4$ with $+ve$ X axis
 - $5\sqrt{17} \text{ m/s}$, making an angle of $\tan^{-1} 4$ with $-ve$ Y axis
 - $5\sqrt{17} \text{ m/s}$, making an angle of $\tan^{-1} 4$ with $+ve$ X axis
- If two bodies A and B are projected with same velocity but with different angles θ_1 and θ_2 respectively with the horizontal such that both will have same range, then the ratio of times of flight of the bodies A and B is [2022]
 - $\sin \theta_2$
 - $\sin \theta_1$
 - $\tan \theta_2$
 - $\tan \theta_1$
- If the horizontal range of a body projected with a velocity ' u ' is 3 times the maximum height reached by it, then the range of the body is [2021] (g-acceleration due to gravity)
 - $\frac{2u^2}{3g}$
 - $\frac{4u^2}{5g}$
 - $\frac{12u^2}{13g}$
 - $\frac{24u^2}{25g}$
- If the velocity at the maximum height of a projectile projected at an angle of 45° is 20 m s^{-1} , then the maximum height reached by the projectile is [2020] (Acceleration due to gravity = 10 m s^{-2})
 - m
 - 20m
 - 30m
 - 40m
- Which of the following statements is incorrect ? [2020]
 - Displacement is independent of the choice of origin of the axis.
 - Displacement may or may not be equal to the distance travelled.
 - When a particle returns to its starting point, its displacement is not zero.
 - Displacement does not tell the nature of the actual motion of a particle between the points.
- If the height of a projectile at a time of 2 s from the beginning of motion is 60 m, then the time of flight of the projectile is [2019] (Acceleration due to gravity = 10 ms^{-2})
 - 12 s
 - 4 s
 - 6 s
 - 8 s
- The angle of projection of a projectile whose path is shown in the given figure is [2018]
 
 - $\tan^{-1}(1)$
 - $\tan^{-1}\left(\frac{8}{3}\right)$
 - $\tan^{-1}\left(\frac{4}{3}\right)$
 - $\tan^{-1}\left(\frac{5}{3}\right)$
- Which of the following graphs represents the position-time graph of a particle moving with negative velocity. [2018]
 - 
 - 
 - 
 - 
- If the equation of motion of a projectile is $y = Ax - Bx^2$, then the ratio of the maximum height reached and the range of the projectile is [2017]
 - $\frac{A}{4}$
 - $\frac{A}{B}$
 - $\frac{B}{4}$
 - $\frac{A^2}{B}$

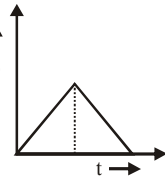
13. The height of ceiling in an auditorium is 30 m. A ball is thrown with a speed of 30 ms^{-1} from the entrance such that it just moves very near to the ceiling without touching it and then it reaches the ground at the end of the auditorium. Then the length of auditorium is [Acceleration due to gravity = 10 ms^{-2}] [2016]
 (a) $60\sqrt{2} \text{ m}$ (b) $30\sqrt{2} \text{ m}$
 (c) $70\sqrt{2} \text{ m}$ (d) $1000\sqrt{2} \text{ m}$
14. If a particle moves with an acceleration, then which of the following can remain constant [2015]
 (a) Both speed and velocity
 (b) Neither speed nor velocity
 (c) Only the velocity
 (d) Only the speed
15. A body covers 20 m, 22 m, 24 m, in 8th, 9th and 10th seconds respectively. The body starts [2014]
 (a) from rest and moves with uniform velocity.
 (b) from rest and moves with uniform acceleration.
 (c) with an initial velocity and moves with uniform acceleration.
 (d) with an initial velocity and moves with uniform velocity.
16. Which of the following equations does not represent the kinematic equations of motion ? [2013]
 (a) $v = u + at$ (b) $S = ut + \frac{1}{2}at^2$
 (c) $S = vt + \frac{1}{2}at^2$ (d) $v^2 - u^2 = 2as$
17. Which graph represents the uniform acceleration [2012]
- 

(a)



(b)
- 

(c)



(d)
18. If bullets are fired in all possible directions from same point with equal velocity of 10 ms^{-1} and with an angle of projection 45° , then the area covered by the bullets on the ground is nearly [2011]
 (Acceleration due to gravity 10 ms^{-2})
 (a) 628 m^2 (b) 314 m^2
 (c) 157 m^2 (d) 79 m^2
19. A ball is projected from a point with a speed V_0 at certain angle with the horizontal. From the same point and at the same instant, a person starts running with a constant speed $0.5V_0$ to catch the ball. If the person catches the ball after some time, then the angle of projection of the ball is [2010]
 (a) 60° (b) 30° (c) 45° (d) 53°
20. The vertical displacement (y in metre) of a projectile in terms of its horizontal displacement (x in metre) is given by $y = (\sqrt{3}x - 0.2x^2)$. The time of flight of the projectile is (Acceleration due to gravity = 10 ms^{-2}) [2009]
 (a) $5\sqrt{3} \text{ s}$ (b) $\sqrt{3} \text{ s}$ (c) 0.2 s (d) $0.2\sqrt{3} \text{ s}$
21. A body projected at certain angle ($\neq 90^\circ$) from the ground crosses a point in its path at a time of 2.3 s and from there it reaches the ground after a time of 5.7 s. The maximum height reached by the body is [2008]
 (Acceleration due to gravity = 10 ms^{-2})
 (a) 80 m (b) 120 m (c) 40 m (d) 160 m
22. A ball projected at an angle of 45° with the horizontal crosses two points at equal heights separated by a distance at times 2 s and 8 s respectively. The horizontal distance between the two points is [2007]
 (Acceleration due to gravity = 10 ms^{-2})
 (a) 300 m (b) 400 m (c) 500 m (d) 600 m
23. If a body projected with a velocity of 19.6 ms^{-1} reaches a maximum height of 9.8 m, then the range of the projectile is (Neglect air resistance) [2006]
 (a) 19.6 m (b) 39.2 m (c) 78.4 m (d) 9.8 m
24. Two bodies are projected from the same point with the same initial velocity ' u ' making angles ' θ ' and $(90^\circ - \theta)$ with the horizontal in opposite directions. The horizontal distance between their positions when the bodies are at their maximum heights is [2006]
 (a) $\frac{u^2}{2g}(\sin^2 \theta - \cos^2 \theta)$ (b) $\frac{u^2 \sin 2\theta}{2g}$
 (c) $\frac{u^2}{g}$ (d) $\frac{u^2 \sin 2(90^\circ - \theta)}{g}$
25. The angle of projection for a projectile to have same horizontal range and maximum height is : [2005]
 (a) $\tan^{-1}(2)$ (b) $\tan^{-1}(4)$
 (c) $\tan^{-1}\left(\frac{1}{4}\right)$ (d) $\tan^{-1}\left(\frac{1}{2}\right)$
26. A body moves from rest with a constant acceleration of 5 m/s^2 . Its instantaneous speed (in m/s) at the end of 10 sec is [2005]
 (a) 50 (b) 5 (c) 2 (d) 0.5

ANSWER KEYS

Exercise 1 : WARM-UP Topic-wise MCQs

1	(a)	12	(b)	23	(b)	34	(c)	45	(c)	56	(a)	67	(d)	78	(b)	89	(a)		
2	(c)	13	(c)	24	(d)	35	(d)	46	(d)	57	(a)	68	(b)	79	(d)	90	(d)		
3	(d)	14	(d)	25	(b)	36	(c)	47	(b)	58	(b)	69	(b)	80	(a)	91	(d)		
4	(b)	15	(b)	26	(a)	37	(a)	48	(d)	59	(a)	70	(a)	81	(b)	92	(c)		
5	(a)	16	(c)	27	(b)	38	(a)	49	(c)	60	(c)	71	(b)	82	(c)	93	(c)		
6	(c)	17	(a)	28	(d)	39	(d)	50	(d)	61	(c)	72	(c)	83	(a)	94	(a)		
7	(a)	18	(d)	29	(d)	40	(d)	51	(a)	62	(a)	73	(b)	84	(d)	95	(b)		
8	(c)	19	(c)	30	(b)	41	(a)	52	(a)	63	(a)	74	(c)	85	(a)				
9	(d)	20	(c)	31	(b)	42	(d)	53	(d)	64	(c)	75	(d)	86	(c)				
10	(d)	21	(d)	32	(c)	43	(a)	54	(c)	65	(b)	76	(c)	87	(c)				
11	(c)	22	(b)	33	(a)	44	(c)	55	(c)	66	(d)	77	(b)	88	(a)				

Exercise 2 : ACCELERATOR Topic-wise MCQs

1	(a)	9	(c)	17	(a)	25	(b)	33	(d)	41	(b)	49	(c)	57	(d)	65	(b)	73	(a)
2	(d)	10	(c)	18	(b)	26	(d)	34	(d)	42	(d)	50	(d)	58	(b)	66	(b)	74	(b)
3	(c)	11	(d)	19	(a)	27	(d)	35	(c)	43	(d)	51	(a)	59	(b)	67	(b)	75	(c)
4	(d)	12	(c)	20	(d)	28	(b)	36	(a)	44	(c)	52	(b)	60	(c)	68	(d)		
5	(a)	13	(b)	21	(d)	29	(a)	37	(b)	45	(a)	53	(a)	61	(d)	69	(b)		
6	(c)	14	(b)	22	(c)	30	(a)	38	(a)	46	(c)	54	(d)	62	(a)	70	(d)		
7	(a)	15	(c)	23	(b)	31	(c)	39	(b)	47	(a)	55	(d)	63	(c)	71	(b)		
8	(c)	16	(c)	24	(b)	32	(a)	40	(b)	48	(a)	56	(a)	64	(d)	72	(c)		

Exercise 3 : PREVIOUS YEARS MCQs

1	(a)	4	(c)	7	(b)	10	(b)	13	(a)	16	(c)	19	(a)	22	(c)	25	(b)		
2	(a)	5	(d)	8	(c)	11	(b)	14	(d)	17	(a)	20	(b)	23	(b)	26	(a)		
3	(b)	6	(d)	9	(d)	12	(a)	15	(c)	18	(b)	21	(a)	24	(d)				



Laws of Motion



TOPIC 2.1 : ARISTOTLE'S FALLACY, NEWTON'S LAW OF MOTION, FRAME OF REFERENCE, TYPES OF FORCES

ARISTOTLE'S FALLACY

According to Aristotelian law an external force is required to keep a body in motion. However an external force is required to overcome the frictional forces in case of solids and viscous forces in fluids which are always present in nature.

NEWTON'S LAW OF MOTION

Newton's first law of motion

Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by an external force to change its state. This fundamental property of the body is called **inertia**.

Inertia

Inertia is the property of a body due to which it opposes the change in its state. Inertia of a body is measured by mass of the body. It is directly proportional to the mass of the body

$$\text{i.e., Inertia} \propto \text{mass}$$

Momentum

The linear momentum of a body ($\vec{p}$) is defined as the product of the mass of the body (m) and its velocity ($\vec{v}$). i.e., $\vec{p} = m\vec{v}$.

The **S.I. unit** of momentum is kg m s^{-1}

and its **dimensions** $[\text{MLT}^{-1}]$

The concept of momentum was introduced by Newton to measure the quantitative effect of force.

Newton's Second law of motion

The rate of change of momentum of a body is directly proportional to unbalanced external force applied on it.

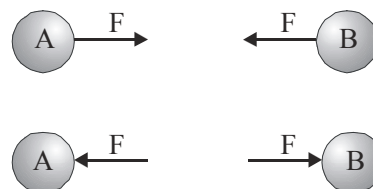
$$\text{i.e., } \vec{F} \propto \frac{d\vec{p}}{dt}$$

$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{d}{dt}(m\vec{v})$$

$$\text{or } \vec{F} = m \frac{d\vec{v}}{dt} + \vec{v} \frac{dm}{dt}$$

Newton's third law of motion

According to newton's third law of motion every action has equal and opposite reaction. Action and reaction act on two different bodies and they are simultaneous. There can be no reaction without action.



Let force on 1st object due to 2nd object

$$\vec{F}_{12} = \frac{d\vec{p}_1}{dt} \quad \dots\dots (i)$$

And force on 2nd object due to 1st object $\vec{F}_{21} = \frac{d\vec{p}_2}{dt} \quad \dots\dots (ii)$

Adding the two equations, we have

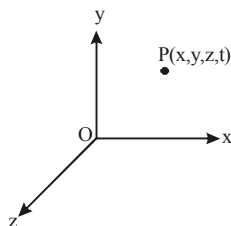
$$\vec{F}_{12} + \vec{F}_{21} = \frac{d\vec{p}_1}{dt} + \frac{d\vec{p}_2}{dt} = \frac{d}{dt}(\vec{p}_1 + \vec{p}_2)$$

Since no external force ($\vec{F}_{12} + \vec{F}_{21} = \vec{0}$) acts on the system, the total momentum of the system must be constant.

FRAME OF REFERENCE

- The position or location which defines a body or system w.r.t. a fixed point on a frame is called a frame of reference.

A Cartesian coordinate system is used as a simplest frame of reference in which three mutually perpendicular axes names as x-axis, y-axis and z-axis, intersect at a common point known as origin O.



Types of Frame of Reference

- (a) **Inertial frame of reference** : A reference frame which is at rest or in uniform motion along the straight line. A non-accelerating frame of reference is called an inertial frame of reference.

- (1) All the fundamental laws of physics have been formulated in the respect of inertial frame of reference.
- (2) All the fundamental laws of physics can be expressed as to have the same mathematical form in all the inertial frames of reference.

- (3) The mechanical and optical experiments performed in an inertial frame in any direction will always yield the same results. It is called **isotropic property** of the inertial frame of reference.

- Ex.**
1. A frame of reference remains fixed w.r.t. distance. Star is an inertial frame of reference.
 2. A space-ship moving in outer space without spinning and with its engine cut-off is also inertial frame of reference.
 3. For practical purposes, a frame of reference fixed to the earth can be considered as an inertial frame. Strictly speaking, such a frame of reference is not an inertial frame of reference, because the motion of earth around the sun is accelerated motion due to its orbital and rotational motion. However, due to negligibly small effects of rotation and orbital motion, the motion of earth may be assumed to be uniform and hence a frame of reference fixed to it may be regarded as inertial frame of reference.

- (b) **Non-inertial frame of reference** : An accelerating frame of reference is called a non-inertial frame of reference.

TYPES OF FORCES

Fundamental Force	Relative Strength	Range	Operates among
Gravitational force	10^{-39}	Infinite	All objects universe.
Weak nuclear force	10^{-39}	Very short, Sub nuclear	Some elementary particles, particles, particularly electrons and neutrino.
Electromagnetic force	10^{-2}	Infinite	Charged particles.
Strong nuclear force	1	Short nuclear size (10^{-15})	Nucleons, heavier elementary particles.

Contact force arises when one body is in physical contact with another.

Ex. : Force exerted by ropes or springs, the force involved in collisions, the force of friction between two surfaces, and the force exerted by a fluid on its container.

Non-Contact Force Forces resulting without any physical contact. e.g. Gravitational force, electrostatic force etc.

Real Force It arises from physical interaction between objects.

Pseudo Force It does not arise from any physical interaction. It appears when observing motion from a non-inertial frame of reference.

TOPIC 2.2 : CONSERVATIVE AND NON CONSERVATIVE FORCE, CONCEPT OF POTENTIAL ENERGY, WORK DONE BY A VARIABLE FORCE, WORK ENERGY THEOREM, LAW OF CONSERVATION OF LINEAR MOMENTUM, FREE BODY DIAGRAM, COLLISIONS, IMPULSE

CONSERVATIVE FORCE

A force is said to be conservative, if the work done, by or against the force

- (a) is independent of path and depends only on initial and final positions.

- (b) does not depend on the nature of path followed between the initial and final positions.

The potential energy is equal to negative of work done in shifting an object from some reference position to a given position for conservative force.

NON-CONSERVATIVE FORCE

A force is said to be non-conservative, if work done, by or against the force in moving a body depends upon the path between the initial and final positions.

The work done in a closed path is not zero in a non-conservative force field.

The frictional forces are non-conservative forces.

CONCEPT OF POTENTIAL ENERGY

$$\text{Therefore, } \Delta U = -\int_i^f \vec{F} \cdot d\vec{r} \text{ or } U_f - U_i = -\int_i^f \vec{F} \cdot d\vec{r}$$

Potential energy of a compressed or stretched spring

$$U = \frac{1}{2} kx^2$$

KE of a particle can be expressed as

$$E = \frac{1}{2} mv^2 = \frac{mv^2}{2} = \frac{p^2}{2m}$$

WORK DONE BY A VARIABLE FORCE

Work done by a variable force

$$W = \int_{x_1}^{x_2} F dx = \text{area under } F\text{-}x \text{ curve with proper algebraic sign.}$$

THE WORK-ENERGY THEOREM

As we know, the relation for rectilinear motion under constant acceleration a ,

$$v^2 - u^2 = 2as \quad \dots(i)$$

where u and v are the initial and final speeds and s is the distance traversed.

Multiplying both sides of eq (i) by $m/2$

$$\frac{m}{2} v^2 - \frac{m}{2} u^2 = \frac{m}{2} 2as$$

$$\text{or, } \frac{1}{2} mv^2 - \frac{1}{2} mu^2 = mas$$

$$\text{or, } \frac{1}{2} mv^2 - \frac{1}{2} mu^2 = F.s \quad \dots(ii)$$

$$\text{or, } \Delta K.E. = W$$

i.e., The change in kinetic energy of a particle is equal to the work done on it by the net force. This is the **Work-energy (W-E) theorem**.

Power

We define power as the rate at which work is being done.

$$\begin{aligned} \text{Average power, } P_{av} &= \frac{\text{Work done}}{\text{Time taken to do work}} = \frac{\Delta W}{\Delta t} \\ &= \frac{\text{Total change in kinetic energy}}{\text{Total change in time}} \end{aligned}$$

If ΔW is the amount of work done in the time interval Δt then,

$$\text{Instantaneous power, } P = \frac{dW}{dt}$$

LAW OF CONSERVATION OF LINEAR MOMENTUM

If the total external force acting on a system is equal to zero, then the final value of the total momentum of the system is equal to the initial value of the total momentum of the system.

$$\vec{F}_{\text{ext}} = \frac{d\vec{p}}{dt}$$

$$\text{If } \vec{F}_{\text{ext}} = 0, \text{ i.e., } \frac{d\vec{p}}{dt} = 0 \text{ then}$$

$$\vec{p} = \text{constant or } \vec{p}_f = \vec{p}_i$$

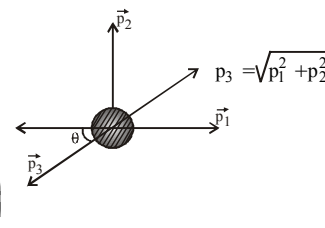
(a) Explosion of a Bomb

Conserving momentum

$$\vec{p}_1 + \vec{p}_2 + \vec{p}_3 = 0$$

$$\text{or } \vec{p}_3 = -(\vec{p}_1 + \vec{p}_2)$$

$$p_3 = \sqrt{p_1^2 + p_2^2} \left(\theta = \frac{\pi}{2} \right)$$



Angle made by $\vec{p}_3$ from $\vec{p}_1 = \pi + \theta$; angle made by $\vec{p}_3$ from

$$\vec{p}_2 = \frac{\pi}{2} + \theta$$

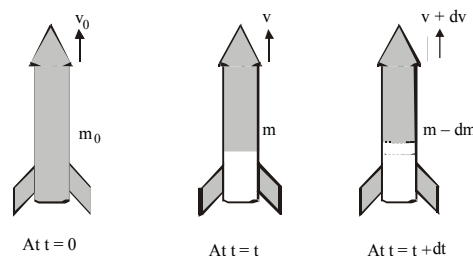
Energy released in explosion = $K_f - K_i$

$$K_f = \frac{p_1^2}{2m_1} + \frac{p_2^2}{2m_2} + \frac{p_3^2}{2m_3}; K_i = 0$$

(b) Rocket Propulsion :

u = velocity of ejected gases w.r.t rocket

$$\frac{dm}{dt} = \text{mass of gases ejected per unit time}$$



m_0 = initial mass of (rocket + fuel) system

Resultant force on the rocket

= upward thrust on the rocket - weight of rocket

$$ma = u \frac{dm}{dt} - mg \quad \dots(1)$$

$$\text{or } m \frac{dv}{dt} = u \frac{dm}{dt} - mg \quad \left(\because a = \frac{dv}{dt} \right)$$

$$\text{or } dv = u \frac{dm}{m} - g dt$$

Integrate on both the sides

$$\int_{v_0}^v dv = -u \int_{m_0}^m \frac{dm}{m} - g \int_0^t dt$$

(negative sign shows reduction in mass)

$$v - v_0 = -u \log_e \frac{m}{m_0} - gt \text{ or } v = v_0 + u \log_e \frac{m_0}{m} - gt$$

$$\text{at } t = 0 \quad v_0 = 0$$

$$\text{so } v = u \log_e \frac{m_0}{m} - gt \quad \dots\dots\dots(2)$$

Acceleration of the rocket

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

$$\text{or } a = \frac{u}{m} \frac{dm}{dt} - g \quad \dots\dots\dots(3)$$

In free space, $g = 0$ So from eqⁿ. (2)

$$v = u \log_e \frac{m_0}{m} = 2.3026 u \log \frac{m_0}{m}$$

$$\text{Thrust on rocket } F = m \frac{dv}{dt} \text{ (since } F = ma)$$

$$\text{or } F = u \frac{dm}{dt} \quad [\text{from eq}^n. (1)]$$

$$\text{Acceleration of rocket } a = \frac{u}{m} \frac{dm}{dt} \text{ in free space.}$$

FREE BODY DIAGRAM (FBD)

A free body diagram is a diagram showing the chosen body by itself, “free” of its surroundings, with vectors drawn to show the magnitude and directions of all the forces applied to the body by the various other bodies that interact with it.

Pulley

- Ideal pulley is considered weightless and frictionless.
- Ideal string is massless and inextensible.
- The pulley may change the direction of force in the string but not the tension.

Some cases of pulley

Case I : When $m_1 = m_2 = m$

Tension in the string

$$T = mg$$

Acceleration $a = \text{zero}$

Reaction at the suspension of the pulley

$$R = 2T = 2mg$$

$$\text{Acceleration} = \frac{\text{Net pulling force}}{\text{Total mass to be pulled}}$$

$$\text{Tension} = \frac{2 \times \text{Product of masses}}{\text{Sum of two masses}} g$$

Case II : When $m_1 > m_2$

Now for mass m_1 ,

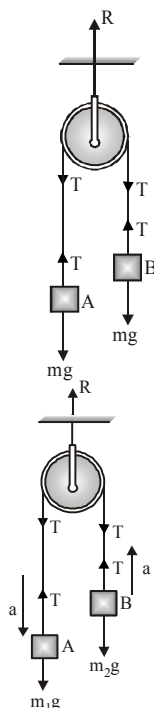
$$m_1 g - T = m_1 a \quad \dots\dots (i)$$

For mass m_2 ,

$$T - m_2 g = m_2 a \quad \dots\dots (ii)$$

By eqs. (i) and (ii)

$$a = \left(\frac{m_1 - m_2}{m_1 + m_2} \right) g$$



$$\text{and } T = \frac{(2m_1 m_2) g}{(m_1 + m_2)}$$

Reaction at the suspension of pulley,

$$R = 2T = \frac{4m_1 m_2 g}{(m_1 + m_2)}$$

Apparent weight of a man in an elevator or lift.

- $R = m(g + a)$ when lift moves upward with acceleration a .
- $R = m(g - a)$ when lift moves downward with acceleration a .
- $R = mg$ when lift is at rest or moving with uniform velocity.
- $R = m(g - g) = 0$ when lift falls freely i.e. case of weight less mass.

COLLISIONS

When exchange of momentum takes place between two physical bodies only due to their mutual interaction force. It is defined as **collision** between two bodies.

Coefficient of restitution,

$$e = \frac{\vec{v}_2 - \vec{v}_1}{\vec{u}_1 - \vec{u}_2} = \frac{(\text{relative velocity of separation after collision})}{(\text{relative velocity of approach before collision})}$$

Newton distinguished these three classes of collisions in terms of coefficient of restitution.

- $e = 1$, the collision is perfectly elastic.
- $e = 0$, the collision is perfectly inelastic.
- $0 < e < 1$, the collision is inelastic.

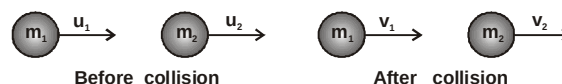
Collision between two bodies is said to be elastic if both the bodies come to their original shape and size after the collision,

The total kinetic energy of the bodies involved before collision is equal to the total kinetic energy after collision.

Perfectly Elastic or Head on Collision (Collision in One Dimension)

Collision of two elastic bodies moving in a straight line, known as head-on collision.

Before and after collision particles move along a straight line.



$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2} \right) u_1 + 2 \left(\frac{m_2}{m_1 + m_2} \right) u_2 \quad \dots\dots\dots(1)$$

$$v_2 = \left(\frac{2m_1}{m_1 + m_2} \right) u_1 + \left(\frac{m_2 - m_1}{m_1 + m_2} \right) u_2 \quad \dots\dots\dots(2)$$

Case-1 : If, $m_1 = m_2$ when both the colliding bodies are of the same mass.

From eqns. (1) and (2) we get, $v_1 = u_2$ and $v_2 = u_1$.

Thus, if masses of two bodies are equal, velocities after collision are interchanged. If the second particle is at rest, after collision

first comes to rest and second moves with the velocity of the first.
If target body m_2 is at rest i.e. $u_2 = 0$

then $v_1 = 0$ and $v_2 = u_1$

When a body suffers an elastic collision with another body of the same mass at rest, it is stopped dead whereas the second body starts moving with the same velocity as that of the first.

Case-2 : If, $m_1 \gg m_2$, and m_1 is moving with velocity u_1 and m_2 is at rest, $u_2 = 0$

Neglecting m_2 in comparison with m_1 , $m_1 + m_2 \approx m_1$ and $m_1 - m_2 \approx m_1$.

From eqⁿ. (1) $v_1 \approx \frac{m_1}{m_1} u_1$ or $v_1 = u_1$

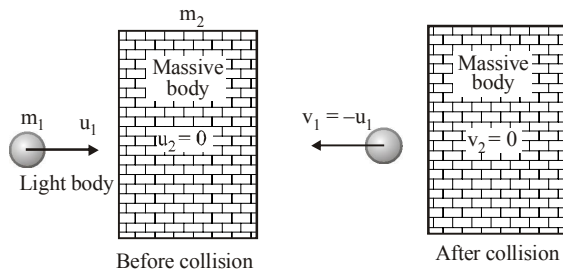
From eqⁿ. (2), $v_2 = \frac{2m_1}{m_1} u_1 - u_2$ or $v_2 = 2u_1 - u_2$

$[\because u_2 = 0]$ or, $v_2 = 2u_1$

When a massive body suffers an elastic collision with a stationary light body, there is practically no change in the velocity of the massive body but the light body acquires a velocity which is nearly double the initial velocity of massive body.

Case-3 : If, $m_2 \gg m_1$, and m_1 is moving with velocity u_1 and m_2 is at rest, $u_2 = 0$

Neglecting m_1 in comparison with m_2 , $m_1 + m_2 \approx m_2$ and $m_1 - m_2 \approx -m_2$.



From eqⁿ. (1) $v_1 = \frac{-m_2}{m_2} u_1 + \frac{2m_2}{m_2} u_2$ or $v_1 = -u_1 + 2u_2$ $[\because u_2 = 0]$

From eqⁿ. (2) $v_2 \approx \frac{2m_1}{m_2} u_1 + \frac{m_2}{m_2} u_2$

So, the velocity of the massive body after collision is very small.

or $v_2 \approx u_2 = 0$ $(\because \frac{2m_1}{m_2} \approx 0)$

So, the velocity of the light body after collision is nearly equal (in magnitude) and opposite to its velocity before collision. In other words, the light body transfers only a small fraction of its kinetic energy to the massive body.

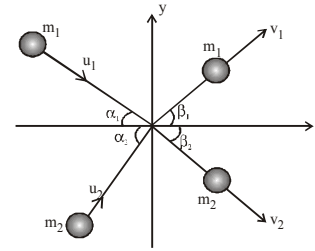
When a light body suffers an elastic collision with a stationary massive body, the velocity of the light body is reversed and the massive body remains practically at rest.

Ex. A rubber ball thrown against a wall.

Elastic Collision in Two Dimensions

(Oblique Collision)

If the colliding bodies do not move along the same straight line path, then the collision is said to be an oblique collision.



Particles move before and after collision in a plane.

Conserving momentum along

X-axis, $m_1 u_1 \cos \alpha_1 + m_2 u_2 \cos \alpha_2 = m_1 v_1 \cos \beta_1 + m_2 v_2 \cos \beta_2$ (1)

Y-axis, $-m_1 u_1 \sin \alpha_1 + m_2 u_2 \sin \alpha_2 = m_1 v_1 \sin \beta_1 - m_2 v_2 \sin \beta_2$ (2)

For elastic collision

$$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \quad \text{.....(3)}$$

With the help of these three eqⁿs. we can determine unknown quantity.

Perfectly Inelastic Collision

It is also known as **absolutely non-elastic collision**.

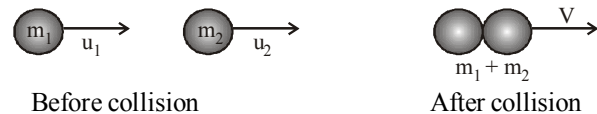
An inelastic impact means an encounter between two bodies whereby these two bodies stick together after collision.

Inelastic Collision

In an inelastic collision, the colliding bodies do not return to their original shape and size completely after collision.

Perfectly Inelastic Collision (Particles Stick After Collision)

Collision is said to be perfectly inelastic if both the particles stick together after collision and move with same velocity, say V .



Let two bodies of masses m_1 and m_2 are moving with velocities u_1 and u_2 before collision.

Total momentum before collision = $m_1 u_1 + m_2 u_2$.

After collision the two bodies stick together and have a common mass $(m_1 + m_2)$.

Total momentum after collision = $(m_1 + m_2) \cdot V$

Applying law of conservation of momentum,

$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) \cdot V$$

$$\text{or} \quad V = \frac{m_1 u_1 + m_2 u_2}{m_1 + m_2}$$

An inelastic collision is accompanied by a transformation of energy.

Kinetic energy of the system before collision is

$$K_i = \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$$

Kinetic energy of the system after collision is

$$K_f = \frac{1}{2} (m_1 + m_2) V^2$$

Loss of kinetic energy during collision is $\Delta K = K_i - K_f$

$$= \frac{1}{2} \left[m_1 u_1^2 + m_2 u_2^2 - \frac{(m_1 u_1 + m_2 u_2)^2}{(m_1 + m_2)} \right]$$

$$\text{or } \Delta K = \frac{1}{2} \left[\frac{m_1 m_2}{(m_1 + m_2)} (u_1 - u_2)^2 \right]$$

Since $(u_1 - u_2)^2$ is +ive, so ΔK is also positive.

Special Cases :

If the target is initially at rest, i.e., $u_2 = 0$, then

$$\text{Loss of kinetic energy, } \Delta K = \frac{1}{2} \left[\frac{m_1 m_2}{m_1 + m_2} \cdot u_1^2 \right]$$

$$\text{But as } K_i = \frac{1}{2} m_1 u_1^2 \text{ So, } \frac{\Delta K}{K_i} = \frac{m_2}{(m_1 + m_2)}$$

Now if the target is massive, that is, $m_2 > m_1$.

$$\frac{\Delta K}{K_i} = 1 \quad \text{or} \quad \Delta K = K_i$$

If a light moving body strikes a heavy target at rest and sticks to it, practically all its kinetic energy is lost.

Inelastic Collision (Head on) Particles do not Stick After Collision

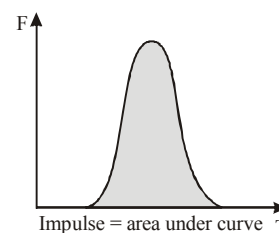
Loss in kinetic energy, $\Delta K = K_i - K_f$

$$= \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 - \frac{1}{2} m_1 v_1^2 - \frac{1}{2} m_2 v_2^2$$

$$\Rightarrow \Delta K = \frac{m_1 m_2}{2(m_1 + m_2)} (u_1 - u_2)^2 (1 - e^2)$$

IMPULSE

When a large force acts for an extremely short duration, neither the magnitude of the force nor the time for which it acts is important. In such a case, the total effect of force is measured. The total effect of force is called impulse (measure of the action of force).



This type of force is generally variable in magnitude and is sometimes called impulsive force.

If a large force acts on a body or particle for a smaller time, then Impulse = product of force and time = total change in momentum

Suppose a force $\vec{F}$ acts for a short time dt then impulse = $\vec{F} dt$

For a finite interval of time t_1 to t_2 the impulse = $\int_{t_1}^{t_2} \vec{F} dt$

If constant force acts for an interval Δt then

$$\text{Impulse} = \vec{F} \Delta t$$

Impulse = Force $\times$ time duration

= Change in momentum

Change in Momentum = Area of F-t graph

TOPIC 2.3 : TORQUE, MECHANICAL EQUILIBRIUM, CENTRE OF MASS

TORQUE (OR MOMENT OF FORCE)

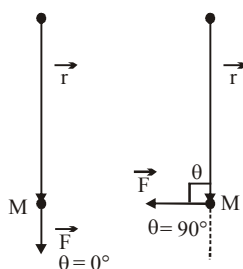
If a pivoted, hinged or suspended body tends to change in state of rotation under the action of a force, it is said to be acted on by a torque.

Torque, $\vec{\tau} = \vec{r} \times \vec{F}$

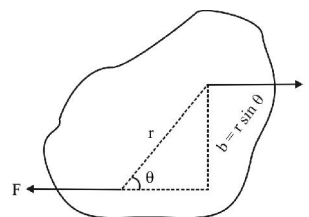
The magnitude of torque :

Torque = force $\times$ perpendicular distance of line of action of force from the axis of rotation.

$$\tau = r F \sin \theta = F (r \sin \theta) = Fb$$



Couple of forces : When two forces of equal magnitude act on different points and in opposite direction, these forces form a couple. This couple tries to rotate the body.



$$\text{Moment of couple } \tau = F r \sin \theta = Fb$$

MECHANICAL EQUILIBRIUM

➤ The equilibrium of a body needs both translatory as well as rotatory equilibrium.

Rotatory equilibrium : In this case net external torque acting on a body is zero i.e., $\Sigma \tau = 0$

Translatory equilibrium : When concurrent and coplanar forces act on a body or on a system then to be in equilibrium

$$\Sigma \vec{F} = 0$$

$$\text{or } \Sigma \vec{F}_x = 0 \text{ and } \Sigma \vec{F}_y = 0$$

Comparative study of stable, unstable and neutral equilibrium.

S.No.	Stable equilibrium	Unstable equilibrium	Neutral equilibrium
1.	Net force is zero. $\vec{F}_{\text{net}} = 0$	Net force is zero. $\vec{F}_{\text{net}} = 0$	Net force is zero. $\vec{F}_{\text{net}} = 0$
2.	$\frac{dU}{dr} = 0$ or slope of U-r graph is zero	$\frac{dU}{dr} = 0$ or slope of U-r graph is zero.	$\frac{dU}{dr} = 0$ or slope of U-r graph is zero
3.	When displaced slightly, from its equilibrium position a net restoring force starts acting on the body which has a tendency to bring the body back to its equilibrium position.	When displaced slightly from its equilibrium position, a net force starts acting on the body which moves the body in the direction of displacement or away from the equilibrium position.	When displaced slightly from its equilibrium position the body has neither the tendency to come back to original position nor to move away from the original position.
4.	Potential energy in equilibrium position is minimum as compared to its neighbouring points. $\frac{d^2U}{dr^2} = \text{positive}$	Potential energy in equilibrium position is maximum as compared to its neighbouring points. $\frac{d^2U}{dr^2} = \text{negative}$	Potential energy remains constant even if the body is displaced from its equilibrium position. $\frac{d^2U}{dr^2} = 0$
5.	When displaced from equilibrium position the centre of gravity of the body goes up.	When displaced from equilibrium position the centre of gravity of the body comes down.	When displaced from equilibrium position the centre of gravity of the body remains at the same level.

CENTRE OF MASS

For a system of particles, **centre of mass** is that point at which its total mass is supposed to be concentrated.

$$x_{\text{cm}} = \left(\frac{m_1 x_1 + m_2 x_2 + \dots}{m_1 + m_2 + m_3 + \dots} \right) = \frac{1}{M} \sum_{i=1}^n m_i x_i$$

$$y_{\text{cm}} = \left(\frac{m_1 y_1 + m_2 y_2 + \dots}{m_1 + m_2 + m_3 + \dots} \right) = \frac{1}{M} \sum_{i=1}^n m_i y_i$$

$$z_{\text{cm}} = \left(\frac{m_1 z_1 + m_2 z_2 + \dots}{m_1 + m_2 + m_3 + \dots} \right) = \frac{1}{M} \sum_{i=1}^n m_i z_i$$

If the system has continuous distribution of mass, treating the mass element dm at position $\vec{r}$ as a point mass and replacing summation by integration

$$\vec{r}_{\text{CM}} = \frac{1}{M} \int \vec{r} \, dm$$

$$\text{So that } \bar{x}_{\text{CM}} = \frac{1}{M} \int \bar{x} \, dm, \quad \bar{y}_{\text{CM}} = \frac{1}{M} \int \bar{y} \, dm$$

According to Aristotelian law an external force is required to keep a body in motion.

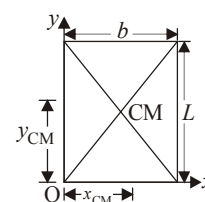
$$\text{and } \bar{z}_{\text{CM}} = \frac{1}{M} \int \bar{z} \, dm$$

Centre of Mass of Some Symmetric/Uniform Bodies

Rectangular plate
(By symmetry)

$$x_{\text{CM}} = \frac{b}{2}$$

$$y_{\text{CM}} = \frac{L}{2}$$



Triangular plate At the centroid, $y_{CM} = \frac{h}{3}$ $x_{CM} = 0$	
Semi-circular ring $y_{CM} = \frac{2R}{\pi}, x_{CM} = 0$	
Semi-circular disc $y_{CM} = \frac{4R}{3\pi}, x_{CM} = 0$	
Hemispherical shell $y_{CM} = \frac{R}{2}, x_{CM} = 0$	
Solid hemisphere $y_{CM} = \frac{3R}{8}, x_{CM} = 0$	
Circular cone (solid) $y_{CM} = \frac{h}{4}, x_{CM} = 0$	
Circular cone (hollow) $y_{CM} = \frac{h}{3}, x_{CM} = 0$	

Points to Remember

- There may or may not be any mass present physically at centre of mass (Fig. A, B, C, D)



- It may be inside or outside of the body (Fig. A, B, C, D)
- Its position depends on the shape of the body. (Fig. A, B, C, D)
- For a given shape it depends on the distribution of mass within the body and is closer to massive part.
- For symmetrical bodies having homogeneous distribution of mass it coincides with centre of symmetry of geometrical centre. (Fig. A, C, D).
- If we know the centre of mass of parts of the system and their masses, we can get the combined centre of mass by treating the parts as point particles placed at their respective centre of masses.
- It is independent of the co-ordinate system, e.g., the centre of mass of a ring is at its centre whatever be the co-ordinate system.
- If the origin of co-ordinate system is at centre of mass, i.e., $\vec{r}_{CM} = 0$, then by definition

$$\frac{1}{M} \sum_{i=1}^n m_i \vec{r}_i = 0 \Rightarrow \sum m_i \vec{r}_i = 0$$

i.e., the sum of the moments of the masses of a system about its centre of mass is always zero.

Motion of Centre of Mass

As for a system of particles, **position of centre of mass** is

$$\vec{r}_{CM} = \frac{m_1 \vec{r}_1 + m_2 \vec{r}_2 + m_3 \vec{r}_3 + \dots}{m_1 + m_2 + m_3 + \dots}$$

$$\text{So, } \frac{d}{dt}(\vec{r}_{CM}) = \frac{m_1 \frac{d\vec{r}_1}{dt} + m_2 \frac{d\vec{r}_2}{dt} + m_3 \frac{d\vec{r}_3}{dt} + \dots}{m_1 + m_2 + m_3 + \dots}$$

Velocity of CM

$$\vec{v}_{CM} = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2 + \dots}{m_1 + m_2 + \dots} = \frac{1}{M} \sum_{i=1}^n m_i \vec{v}_i \quad \left[\because \frac{d\vec{r}}{dt} = \vec{v} \right]$$

$$\text{Similarly, acceleration of CM } \vec{a}_{CM} = \frac{d}{dt} \vec{v}_{CM}$$

$$\Rightarrow \vec{a}_{CM} = \frac{m_1 \vec{a}_1 + m_2 \vec{a}_2 + \dots}{m_1 + m_2 + \dots} = \frac{1}{M} \sum_{i=1}^n m_i \vec{a}_i \quad \left[\because \vec{a} = \frac{d\vec{v}}{dt} \right]$$

Centre of gravity of a body : It is a point where whole weight of a body may be assumed to be act. Where there is no gravity or uniform gravity, the centre of gravity of the body coincides with the centre of mass.

CHAPTER AT A GLANCE

- ☛ According to Aristotelian law an external force is required to keep a body in motion.
- ☛ According to Newton's first law of motion, every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by an external force to change its state.
- ☛ The linear momentum of a body ($\vec{p}$) is defined as the product of the mass of the body (m) and its velocity ($\vec{v}$).
- ☛ *According to Newton's second law of motion, The rate of change of momentum of a body is directly proportional to unbalanced external force applied on it.*
- ☛ *According to Newton's third law of motion every action has equal and opposite reaction.*
- ☛ The position or location which defines a body or system w.r.t. a fixed point on a frame is called a frame of reference.
- ☛ A non-accelerating frame of reference is called an inertial frame of reference.
- ☛ An accelerating frame of reference is called a non-inertial frame of reference.
- ☛ **Non-Contact Force** Forces resulting without any physical contact. e.g. Gravitational force, electrostatic force etc.
- ☛ **Real Force** It arises from physical interaction between objects.
- ☛ **Pseudo Force** It does not arise from any physical interaction. It appears when observing motion from a non-inertial frame of reference.
- ☛ A force is said to be conservative, if the work done, by or against the force
 - (a) is independent of path and depends only on initial and final positions.
- ☛ A force is said to be non-conservative, if work done, by or against the force in moving a body depends upon the path between the initial and final positions.
- ☛ Work done by a variable force

$$W = \int_{x_1}^{x_2} F dx = \text{area under } F\text{-}x \text{ curve with proper algebraic}$$

sign.

- ☛ The change in kinetic energy of a particle is equal to the work done on it by the net force. This is the **Work-energy (W-E) theorem**. or, $\Delta K.E. = W$

- ☛ According to law of conservation of linear momentum. If the total external force acting on a system is equal to zero, then the final value of the total momentum of the system is equal to the initial value of the total momentum of the system.

$$\text{If } \vec{F}_{\text{ext}} = 0, \text{ i.e., } \frac{d\vec{p}}{dt} = 0 \text{ then}$$

$$\vec{p} = \text{constant} \text{ or } \vec{p}_f = \vec{p}_i$$

- ☛ A free body diagram is a diagram showing the chosen body by itself, "free" of its surroundings, with vectors drawn to show the magnitude and directions of all the forces applied to the body by the various other bodies that interact with it.

- ☛ *When exchange of momentum takes place between two physical bodies only due to their mutual interaction force. It is defined as **collision** between two bodies.* Velocities of two bodies after collision

$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2} \right) u_1 + 2 \left(\frac{m_2}{m_1 + m_2} \right) u_2$$

$$v_2 = \left(\frac{2m_1}{m_1 + m_2} \right) u_1 + \left(\frac{m_2 - m_1}{m_1 + m_2} \right) u_2$$

Loss of kinetic energy during inelastic collision is $\Delta K = K_i - K_f$

$$= \frac{1}{2} \left[m_1 u_1^2 + m_2 u_2^2 - \frac{(m_1 u_1 + m_2 u_2)^2}{(m_1 + m_2)} \right]$$

$$\text{or } \Delta K = \frac{1}{2} \left[\frac{m_1 m_2}{(m_1 + m_2)} (u_1 - u_2)^2 \right]$$

- ☛ For a finite interval of time t_1 to t_2 the *impulse* = $\int_{t_1}^{t_2} \vec{F} dt$

If constant force acts for an interval Δt then

$$\text{Impulse} = \vec{F} \Delta t$$

$$\begin{aligned} \text{Impulse} &= \text{Force} \times \text{time duration} \\ &= \text{Change in momentum} \end{aligned}$$

Change in Momentum = Area of F-t graph

- ☛ Torque = force $\times$ perpendicular distance of line of action of force from the axis of rotation.
- ☛ When two forces of equal magnitude act on different points and in opposite direction, these forces form a couple.

- ☛ In stable equilibrium When displaced slightly, from its equilibrium position a net restoring force starts acting on the body which has a tendency to bring the body back to its equilibrium position.
 - ☛ In unstable equilibrium When displaced slightly from its equilibrium position, a net force starts acting on the body which moves the body in the direction of displacement or away from the equilibrium position.
 - ☛ In neutral equilibrium When displaced slightly from its equilibrium position the body has neither the tendency to come back to original position nor to move away from the original position.
 - ☛ For a system of particles, **centre of mass** is that point at which its total mass is supposed to be concentrated.
- $$x_{cm} = \left(\frac{m_1 x_1 + m_2 x_2 + \dots}{m_1 + m_2 + m_3 + \dots} \right) = \frac{1}{M} \sum_{i=1}^n m_i x_i$$
- ☛ **Centre of gravity of a body** : It is a point where whole weight of a body may be assumed to be act. Where there is no gravity or uniform gravity, the centre of gravity of the body coincides with the centre of mass.

Exercise 1 :

WARM-UP Topic-wise MCQs

2.1

Aristotle's Fallacy, Newton's Law of Motion, Frame of Reference, Types of Forces

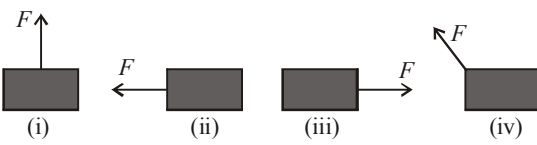
- No force is required for
 - an object moving in straight line with constant velocity
 - an object moving in circular motion
 - an object moving with constant acceleration
 - an object moving in elliptical path.
- When a body is stationary
 - there is no force acting on it
 - the force acting on it is not in contact with it
 - the combination of forces acting on it balances each other
 - the body is in vacuum
- Inertia is the property of a body linked to tendency of a body
 - to change its position
 - to change its direction
 - to change the momentum
 - to resist any change in its state
- Newton's first law of motion describes the
 - energy
 - work
 - inertia
 - moment of inertia
- Physical independence of force is a consequence of
 - third law of motion
 - second law of motion
 - first law of motion
 - all of these
- A truck accelerates on a horizontal road due to the force exerted by the
 - road
 - engine
 - earth
 - driver
- A body of mass 1000 kg is moving horizontally with a velocity 6 m/s. If 200 kg extra mass is added, the final velocity (in m/s) is:
 - 6
 - 2
 - 3
 - 5
- The magnitude of the external force acting on moving bodies can be known directly by
 - Law of conservation of angular momentum
 - Newton's first law of motion.
 - Newton's second law of motion.
 - Law of conservation of energy.
- The force required to stop a body of mass 10 kg moving along a straight line path with a velocity of 10 ms⁻¹ in a time of 10 s is
 - 10 N
 - 1000 N
 - 100 N
 - 1 N
- Force is the mutual interaction between the bodies is according to
 - Newton's first law of motion
 - Newton's second law of motion
 - Newton's third law of motion
 - Newton's law of gravitation
- When a bullet is fired from a rifle its momentum becomes 20 kg ms⁻¹. If the velocity of the bullet is 1000 ms⁻¹, then what is its mass
 - 30 g
 - 5 kg
 - 20 g
 - 500 g
- The force required to stop a car of mass 800 kg, moving at a speed of 20 ms⁻¹ over a distance of 25 m in 2.5 sec is
 - 1200 N
 - 6400 N
 - 1600 N
 - 1800 N

13. We can derive Newton's
 (a) second and third laws from the first law
 (b) first and second laws from the third law
 (c) third and first laws from the second law
 (d) All the three laws are independent of each other
14. A cannon after firing recoils due to
 (a) conservation of energy
 (b) backward thrust of gases produced
 (c) Newton's third law of motion
 (d) Newton's first law of motion
15. A force $\vec{F} = 8\hat{i} - 6\hat{j} - 10\hat{k}$ newton produces an acceleration of 1 ms^{-2} in a body. The mass of the body is
 (a) 10 kg (b) $10\sqrt{2}$ kg (c) $10\sqrt{3}$ kg (d) 200 kg
16. Force acts for 20 s on a body of mass 20 kg, starting from rest, after which the force ceases and then body describes 50 m in the next 10 s. The value of force will be :
 (a) 40 N (b) 5 N (c) 20 N (d) 10 N
17. If n bullets each of mass m are fired with a velocity v per second from a machine gun, the force required to hold the gun in position is
 (a) $(n+1)mv$ (b) $\frac{mv}{n^2}$
 (c) $\frac{mv}{n}$ (d) mnv
18. Two bodies of masses 1 kg and 2 kg moving with same velocities are stopped by the same force. Then the ratio of their stopping distances is
 (a) 1:2 (b) 2:1 (c) $\sqrt{2}:1$ (d) $1:\sqrt{2}$
19. The motion of a particle of mass m is described by $y = ut + gt^2$. Find the force acting on the particle.
 (a) Zero (b) mg (c) $2mg$ (d) $3mg$
20. Which of the following statement is incorrect regarding Newton's third law of motion?
 (a) To every action, there is always an equal and opposite reaction.
 (b) Action and reaction act on the same body.
 (c) There is no cause-effect relation between action and reaction
 (d) Action and reaction forces are simultaneous.
21. Every action has an equal and opposite reaction, which suggests that
 (a) action and reaction always act on different bodies
 (b) the forces of action and reaction cancel to each other
 (c) the forces of action and reaction cannot cancel to each other
 (d) Both (a) and (c)
22. A stone of mass 2 kg is lying on the floor of a train which is accelerating with 4 ms^{-2} . The net force acting on the stone is
 (a) 2 N (b) 4 N (c) 6 N (d) 8 N
23. A force of 10 N acts on a body of mass 0.5 kg for 0.25s starting from rest. What is its momentum now?
 (a) 0.25 N-s (b) 2.5 N-s
 (c) 0.5 N-s (d) 0.75 N-s
24. Which of the following quantities measured from different inertial reference frames are same
 (a) Force (b) Velocity
 (c) Displacement (d) Kinetic energy

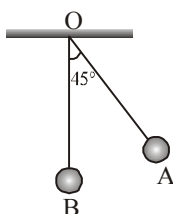
2.2

Conservative and Non Conservative Force, Concept of Potential Energy, Work done by a Variable Force, Work Energy Theorem, Law of Conservation of Linear Momentum, Free Body Diagram, Collisions, Impulse

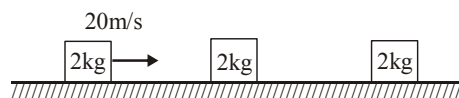
25. When the force retards the motion of body, the work done is
 (a) zero
 (b) negative
 (c) positive
 (d) Positive or negative depending upon the magnitude of force and displacement
26. A man pushes a wall and fails to displace it, he does
 (a) negative work
 (b) positive but not maximum work
 (c) no work at all
 (d) maximum positive work
27. A boy carrying a box on his head is walking on a level road from one place to another is doing no work. This statement is
 (a) correct (b) incorrect
 (c) partly correct (d) cannot say
28. No work is done if
 (a) displacement is zero
 (b) force is zero
 (c) force and displacement are mutually perpendicular
 (d) All of these
29. A particle is taken round a circle by application of force. The work done by the force is
 (a) positive non-zero (b) negative non-zero
 (c) Zero (d) None of these
30. A porter lifts a heavy suitcase of mass 80 kg and at the destination lowers it down by a distance of 80 cm with a constant velocity. Calculate the work done by the porter in lowering the suitcase. (take $g = 9.8 \text{ ms}^{-2}$)
 (a) -62720.0 J (b) -627.2 J
 (c) $+627.2 \text{ J}$ (d) 784.0 J
31. A ball moves in a frictionless inclined table without slipping. The work done by the table surface on the ball is
 (a) positive (b) negative
 (c) zero (d) None of these

32. A uniform force of $(3\hat{i} + \hat{j})$ newton acts on a particle of mass 2 kg. The particle is displaced from position $(2\hat{i} + \hat{k})$ meter to position $(4\hat{i} + 3\hat{j} - \hat{k})$ meter. The work done by the force on the particle is
 (a) 6 J (b) 13 J (c) 15 J (d) 9 J
33. A boy pushes a toy box 2.0 m along the floor by means of a force of 10 N directed downward at an angle of 60° to the horizontal. The work done by the boy is
 (a) 6 J (b) 8 J (c) 10 J (d) 12 J
34. A body moves a distance of 10 m along a straight line under the action of a force of 5 newtons. If the work done is 25 joules, the angle which the force makes with the direction of motion of body is
 (a) 0° (b) 30°
 (c) 60° (d) 90°
35. For a conservative force in one dimension, potential energy function $V(x)$ is related to the force $F(x)$ as
 (a) $F(x) = \frac{-dV(x)}{dx}$ (b) $F(x) = \frac{dV(x)}{dx}$
 (c) $F(x) = V(x) dx$ (d) $F(x) = \int \frac{-dV(x)}{dx}$
36. Which one of the following statements is true?
 (a) Momentum is conserved in elastic collisions but not in inelastic collisions
 (b) Total kinetic energy is conserved in elastic collisions but momentum is not conserved in elastic collisions
 (c) Total kinetic energy is not conserved but momentum is conserved in inelastic collisions
 (d) Kinetic energy and momentum both are conserved in all types of collisions
37. When after collision the deformation is not relived and the two bodies move together after the collision, it is called
 (a) elastic collision
 (b) inelastic collision
 (c) perfectly inelastic collision
 (d) perfectly elastic collision
38. In an inelastic collision, which of the following does not remain conserved?
 (a) Momentum
 (b) kinetic energy
 (c) Total energy
 (d) Neither momentum nor kinetic energy
39. In case of elastic collision, at the time of impact.
 (a) total K.E. of colliding bodies is conserved.
 (b) total K.E. of colliding bodies increases
 (c) total K.E. of colliding bodies decreases
 (d) total momentum of colliding bodies decreases.
40. In elastic collision, 100% energy transfer takes place when
 (a) $m_1 = m_2$ (b) $m_1 > m_2$
 (c) $m_1 < m_2$ (d) $m_1 = 2m_2$
41. If two equal masses ($m_1 = m_2$) collide elastically in one dimension, where m_2 is at rest and m_1 moves with a velocity u_1 , then the final velocities of two masses are
 (a) $V_1 = 0; V_2 = u_1$ (b) $V_1 = V_2 = 0$
 (c) $V_1 = 0$ and $V_2 = -u_1$ (d) $V_1 = -u_1; V_2 = 0$
42. A particle A suffers an oblique elastic collision with a particle B that is at rest initially. If their masses are the same, then after collision
 (a) they will move in opposite directions
 (b) A continues to move in the original direction while B remains at rest
 (c) they will move in mutually perpendicular directions
 (d) A comes to rest and B starts moving in the direction of the original motion of A
43. A metal ball of mass 2 kg moving with a velocity of 36 km/h has a head on collision with a stationary ball of mass 3 kg. If after the collision, the two balls move together, the loss in kinetic energy due to collision is
 (a) 140 J (b) 100 J (c) 60 J (d) 40 J
44. A body of mass 10 kg is dropped to the ground from a height of 10 metre. The work done by the gravitational force is ($g = 9.8 \text{ m/sec}^2$)
 (a) -490 Joule (b) +490 Joule
 (c) -980 Joule (d) +980 Joule
45. Figure shows four situations in which a force is applied to a block. In all four cases, the force has the same magnitude, and the displacement of the block is to the right and of the same magnitude. Which of the following cases work done by the applied force on the block is zero?
- 
- (i) (ii) (iii) (iv)
- (a) (i) (b) (ii) (c) (iii) (d) (iv)
46. A body of mass 5 kg is placed at the origin, and can move only on the x -axis. A force of 10 N is acting on it in a direction making an angle of 60° with the x -axis and displaces it along the x -axis by 4 metres. The work done by the force is
 (a) 2.5 J (b) 7.25 J (c) 40 J (d) 20 J
47. The work done in pulling up a block of wood weighing 2 kN for a length of 10 m on a smooth plane inclined at an angle of 15° with the horizontal is [$\sin 15^\circ = 0.2588$]
 (a) 4.36 kJ (b) 5.17 kJ (c) 8.91 kJ (d) 9.82 kJ
48. A force $F = 5 + 10y$ acts on a particle in y -direction where F is in newton and y in meter. Work done by this force to move the particle from $y = 0$ to $y = 1$ m is :
 (a) 30 J (b) 5 J (c) 10 J (d) 20 J
49. Which one of the following is not a conservative force?
 (a) Gravitational force
 (b) Electrostatic force between two charges
 (c) Magnetic force between two magnetic dipoles
 (d) Frictional force

50. Two identical balls A and B moving with velocities $+0.5 \text{ m/s}$ and -0.3 m/s respectively, collide head on elastically. The velocities of the balls A and B after collision, will be, respectively
- $+0.5 \text{ m/s}$ and $+0.3 \text{ m/s}$
 - -0.3 m/s and $+0.5 \text{ m/s}$
 - $+0.3 \text{ m/s}$ and 0.5 m/s
 - -0.5 m/s and $+0.3 \text{ m/s}$
51. The bob A of a simple pendulum is released when the string makes an angle of 45° with the vertical. It hits another bob B of the same material and same mass kept at rest on the table. If the collision is elastic

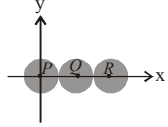
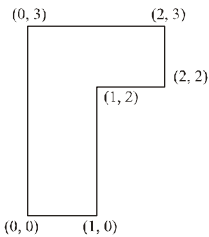


- both A and B rise to the same height
 - both A and B come to rest at B
 - both A and B move with the same velocity of A
 - A comes to rest and B moves with the velocity of A
52. Four smooth steel balls of equal mass at rest are free to move along a straight line without friction. The first ball is given a velocity of 0.4 m/s . It collides head on with the second elastically, the second one similarly with the third and so on. The velocity of the last ball is
- 0.4 m/s
 - 0.2 m/s
 - 0.1 m/s
 - 0.05 m/s
53. Consider elastic collision of a particle of mass m moving with a velocity u with another particle of the same mass at rest. After the collision the projectile and the struck particle move in directions making angles θ_1 and θ_2 respectively with the initial direction of motion. The sum of the angles $\theta_1 + \theta_2$, is :
- 45°
 - 90°
 - 135°
 - 180°
54. A particle of mass m moving in the x direction with speed $2v$ is hit by another particle of mass $2m$ moving in the y direction with speed v . If the collision is perfectly inelastic, the percentage loss in the energy during the collision is close to :
- 56%
 - 62%
 - 44%
 - 50%
55. A block of mass 2 kg collide with identical stationary block head on elastically with velocity of 20 m/s . After collision second block collide with the third block of mass 2 kg initially at rest. If they collide head on perfectly inelastically then the velocity of their combination will be



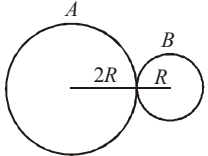
- 5 m/s
- 4 m/s
- 10 m/s
- 20 m/s

56. A ball projected from ground at a certain angle collides a smooth inclined plane at the highest point of its trajectory. If the collision is perfectly inelastic then after the collision, ball will
- come to rest
 - move along the incline
 - retrace its path.
 - bounce back but will strike the ground at a point other than point of projection.
57. The co-efficient of restitution e for a perfectly elastic collision is
- 1
 - 0
 - ∞
 - 1
58. A particle of mass m moving with velocity v collides with a stationary particle of mass $2m$. After collision, they stick together and continue to move together with velocity
- v
 - $\frac{v}{2}$
 - $\frac{v}{3}$
 - $\frac{v}{4}$
59. A stationary particle explodes into two particles of masses m_1 and m_2 which move in opposite directions with velocities v_1 and v_2 . The ratio of their kinetic energies E_1/E_2 is
- $m_1 v_2 / m_2 v_1$
 - m_2 / m_1
 - m_1 / m_2
 - 1
60. A ball moving with velocity 2 m/s collides head on with another stationary ball of double the mass. If the coefficient of restitution is 0.5 , then their velocities (in m/s) after collision will be
- 0, 1
 - 1, 1
 - 1, 0.5
 - 0, 2
61. A 100 kg gun fires a ball of 1 kg horizontally from a cliff of height 500 m . It falls on the ground at a distance of 400 m from the bottom of the cliff. The recoil velocity of the gun is (Take $g: 10 \text{ ms}^{-2}$)
- 0.2 ms^{-1}
 - 0.4 s^{-1}
 - 0.6 ms^{-1}
 - 0.8 ms^{-1}
62. A particle of mass m is moving with velocity v_1 , it is given an impulse such that the velocity becomes v_2 . Then magnitude of impulse is equal to
- $m(\vec{v}_2 - \vec{v}_1)$
 - $m(\vec{v}_1 - \vec{v}_2)$
 - $m \times (\vec{v}_2 - \vec{v}_1)$
 - $0.5m(\vec{v}_2 - \vec{v}_1)$
63. A large force is acting on a body for a short time. The impulse imparted is equal to the change in
- acceleration
 - momentum
 - energy
 - velocity
64. China wares are wrapped in straw of paper before packing. This is the application of concept of
- impulse
 - momentum
 - acceleration
 - force
65. A hammer weighing 3 kg strikes the head of a nail with a speed of 2 ms^{-1} drives it by 1 cm into the wall. The impulse imparted to the wall is
- 6 Ns
 - 3 Ns
 - 2 Ns
 - 12 Ns

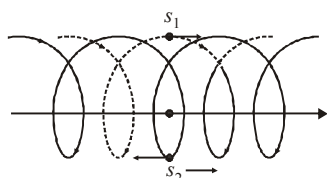
66. Law of conservation of momentum follows from
 (a) Newton's first law of motion
 (b) Newton's second law of motion
 (c) Newton's third law of motion
 (d) Both (b) & (c)
67. A body whose momentum is constant must have constant
 (a) velocity (b) force
 (c) acceleration (d) All of these
68. In an isolated system (i.e. a system with no external force), total momentum of interacting particles is conserved. It follows
 (a) Newton's first law (b) Newton's second law
 (c) Newton's third law (d) Both (b) and (c)
69. A ball of mass 150 g, moving with an acceleration 20 m/s^2 , is hit by a force which acts on it for 0.1 sec. The impulsive force is
 (a) 0.5 N (b) 0.1 N
 (c) 0.3 N (d) 1.2 N
70. The direction of impulse is
 (a) same as that of the net force
 (b) opposite to that of the net force
 (c) same as that of the final speed
 (d) same as that of the initial speed
71. A force of 10 Newton acts on a body of mass 20 kg for 10 seconds. Change in its momentum is
 (a) 5 kg m/s (b) 100 kg m/s
 (c) 200 kg m/s (d) 1000 kg m/s
72. A shell of mass 10 kg is moving with a velocity of 10 ms^{-1} when it blasts and forms two parts of mass 9 kg and 1 kg respectively. If the 9 kg mass is stationary, the velocity of the 2nd is
 (a) 1 m/s (b) 10 m/s
 (c) 100 m/s (d) 1000 m/s
73. In an explosion, a body breaks up into two pieces of unequal masses. In this
 (a) both parts will have numerically equal momentum
 (b) lighter part will have more momentum
 (c) heavier part will have more momentum
 (d) both parts will have equal kinetic energy
- (a) $\hat{i} - 2\hat{j} + \hat{k}$ (b) $-3\hat{i} - 2\hat{j} + \hat{k}$
 (c) $-2\hat{i} + 2\hat{k}$ (d) $-2\hat{i} - \hat{j} + 2\hat{k}$
76. The position of centre of mass of a system of particles does not depend upon the
 (a) mass of particles
 (b) symmetry of the body
 (c) position of the particles
 (d) relative distance between the particles
77. The mass per unit length of a non-uniform rod of length L varies as $m = \lambda x$ where λ is constant. The centre of mass of the rod will be at ;
 (a) $\frac{2}{3}L$ (b) $\frac{3}{2}L$ (c) $\frac{1}{2}L$ (d) $\frac{4}{3}L$
78. The motion of the centre of mass depends on
 (a) total external forces (b) total internal forces
 (c) sum of (a) and (b) (d) None of these
79. The centre of mass of two particles lies on the line
 (a) joining the particles
 (b) perpendicular to the line joining the particles
 (c) at any angle to this line
 (d) None of these
80. Three identical spheres, each of mass 1 kg are kept as shown in figure, touching each other, with their centres on a straight line. If their centres are marked P, Q, R respectively, the distance of centre of mass of the system from P is

 (a) $\frac{PQ + PR + QR}{3}$ (b) $\frac{PQ + PR}{3}$
 (c) $\frac{PQ + QR}{3}$ (d) $\frac{PR + QR}{3}$
81. The coordinates of centre of mass of a uniform flag shaped lamina (thin flat plate) of mass 4 kg. (The coordinates of the same are shown in figure) are:

 (a) (1.25 m, 1.50 m)
 (b) (0.75 m, 1.75 m)
 (c) (0.75 m, 0.75 m)
 (d) (1 m, 1.75 m)

2.3

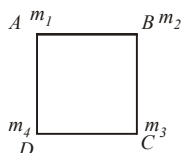
Torque, Mechanical Equilibrium, Centre of Mass

74. The centre of mass of a body
 (a) lies always outside the body
 (b) may lie within, outside on the surface of the body
 (c) lies always inside the body
 (d) lies always on the surface of the body
75. Two bodies of mass 1 kg and 3 kg have position vectors $\hat{i} + 2\hat{j} + \hat{k}$ and $-3\hat{i} - 2\hat{j} + \hat{k}$ respectively. The magnitude of position vector of centre of mass of this system will be similar to the magnitude of vector:
 (a) inside A
 (b) inside B
 (c) at the point of contact
 (d) None of these
82. Two spheres A and B of masses m and $2m$ and radii $2R$ and R respectively are placed in contact as shown. The COM of the system lies

83. Centre of mass of the earth and the moon system lies
 (a) closer to the earth
 (b) closer to the moon
 (c) at the mid-point of line joining the earth and the moon
 (d) cannot be predicted

84. A stick is thrown in the air and lands on the ground at some distance from the thrower. The centre of mass of the stick will move along a parabolic path
- in all cases
 - only if the stick is uniform
 - only if the stick has linear motion but no rotational motion
 - only if the stick has a shape such that its centre of mass is located at some point on it and not outside it
85. The motion of binary stars, S_1 and S_2 is the combination of X.... and Y.... Here, X and Y refer to



- motion of the CM and motion about the CM
 - motion about the CM and motion of one star
 - position of the CM and motion of the CM
 - motion about CM and position of one star
86. Consider a system of two particles having masses m_1 and m_2 . If the particle of mass m_1 is pushed towards the centre of mass particles through a distance d , by what distance would the particle of mass m_2 move so as to keep the mass centre of particles at the original position?
- $\frac{m_2}{m_1}d$
 - $\frac{m_1}{m_1 + m_2}d$
 - $\frac{m_1}{m_2}d$
 - d
87. Three masses are placed on the x -axis : 300 g at origin, 500 g at $x = 40$ cm and 400 g at $x = 70$ cm. The distance of the centre of mass from the origin is
- 40 cm
 - 45 cm
 - 50 cm
 - 30 cm
88. A system consists of three particles, each of mass m and located at $(1, 1)$, $(2, 2)$ and $(3, 3)$. The co-ordinates of the centre of mass are
- $(1, 1)$
 - $(2, 2)$
 - $(3, 3)$
 - $(6, 6)$
89. Four particles of masses m_1, m_2, m_3 and m_4 are placed at the vertices A, B, C and D as respectively of a square shown. The COM of the system will lie at diagonal AC if

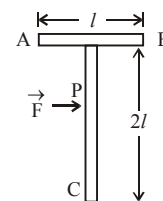


- $m_1 = m_3$
 - $m_2 = m_4$
 - $m_1 = m_2$
 - $m_3 = m_4$
90. A shell following a parabolic path explodes somewhere in its flight. The centre of mass of fragments will continue to move in
- vertical direction
 - any direction
 - horizontal direction
 - same parabolic path

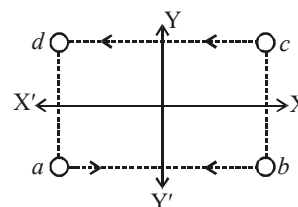
91. A man stands at one end of a boat which is stationary in water. Neglect water resistance. The man now moves to the other end of the boat and again becomes stationary. The centre of mass of the 'man plus boat' system will remain stationary with respect to water
- in all cases
 - only when the man is stationary initially and finally
 - only if the man moves without acceleration on the boat
 - only if the man and the boat have equal masses
92. Two bodies of masses 2 kg and 4 kg are moving with velocities 2 m/s and 10 m/s respectively along same direction. Then the velocity of their centre of mass will be
- 8.1 m/s
 - 7.3 m/s
 - 6.4 m/s
 - 5.3 m/s
93. A large number of particles are placed around the origin, each at a distance R from the origin. The distance of the center of mass of the system from the origin is
- $= R$
 - $\geq R$
 - $> R$
 - $\leq R$
94. A cricket bat is cut at the location of its centre of mass as shown. Then



- The two pieces will have the same mass
 - The bottom piece will have larger mass
 - The handle piece will have larger mass
 - Mass of handle piece is double the mass of bottom piece
95. A 'T' shaped object with dimensions shown in the figure, is lying on a smooth floor. A force 'F' is applied at the point P parallel to AB, such that the object has only the translational motion without rotation. Find the location of P with respect to C.



- $\frac{4}{3}l$
 - l
 - $\frac{2}{3}l$
 - $\frac{3}{2}l$
96. Four bodies of equal mass start moving with same speed as shown in the figure. In which of the following combination the centre of mass will remain at origin



- (a) c and d (b) a and b (c) a and c (d) b and d
97. Four point masses P, Q, R and S with respective masses 1 kg, 1 kg, 2 kg and 2 kg form the corners of a square of side a. The centre of mass of the system will be farthest from
- (a) P only (b) R and S (c) R only (d) P and Q
98. The centre of mass of a solid hemisphere of radius 8 cm is x cm from the centre of the flat surface. Then value of x is
- (a) 3 (b) 5 (c) 11 (d) 16
99. The position of the centre of mass of a uniform semi-circular wire of radius 'R' placed in x-y plane with its centre at the origin and the line joining its ends as x-axis is given by $\left(0, \frac{xR}{\pi}\right)$. Then, the value of $|x|$ is
- (a) 3 (b) 2 (c) 22 (d) $\frac{2R}{\pi}$
100. Let $\vec{F}$ be the force acting on a particle having position vector $\vec{r}$ and $\vec{\tau}$ be the torque of this force about the origin. Then
- (a) $\vec{r} \cdot \vec{\tau} = 0$ and $\vec{F} \cdot \vec{\tau} = 0$
 (b) $\vec{r} \cdot \vec{\tau} = 0$ and $\vec{F} \cdot \vec{\tau} \neq 0$
 (c) $\vec{r} \cdot \vec{\tau} \neq 0$ and $\vec{F} \cdot \vec{\tau} = 0$
 (d) $\vec{r} \cdot \vec{\tau} \neq 0$ and $\vec{F} \cdot \vec{\tau} \neq 0$

Exercise 2 :

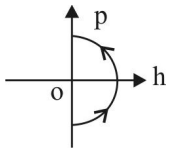
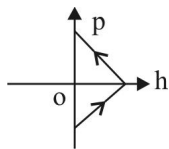
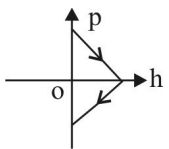
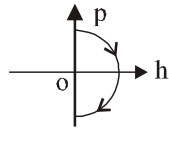
ACCELERATOR

Topic-wise MCQs

2.1

Aristotle's Fallacy, Newton's Law of Motion, Frame of Reference, Types of Forces

1. In which of the following cases the net of force acting on the body is not zero?
- (a) A drop of rain falling down with a constant speed.
 (b) A cork of mass 10g floating on the surface of water.
 (c) A car moving with a constant speed of 20 km h^{-1} on a rough road.
 (d) A pebble of mass 0.05 kg is thrown vertically upwards.
2. A body of mass 0.4 kg starting at origin at $t = 0$ with a speed of 10 m s^{-1} in the positive x-axis direction is subjected to a constant $F = 8 \text{ N}$ towards negative x-axis. The position of the body after 25 s is
- (a) -6000 m (b) -8000 m
 (c) $+4000 \text{ m}$ (d) $+7000 \text{ m}$
3. A body of mass 4 kg is at rest. If a force $F = (4t^2 \hat{i} + 2t \hat{j}) \text{ N}$ is applied on the object, then the velocity (in m/s) of the object at $t = 3 \text{ s}$ is
- (a) $9\hat{i} + 4\hat{j}$ (b) $4\hat{i} + 9\hat{j}$
 (c) $9\hat{i} + 2.25\hat{j}$ (d) $9\hat{i} + \hat{j}$
4. A body of mass 1 kg starting from origin with initial velocity of $(3\hat{i} + 4\hat{j}) \text{ ms}^{-1}$. If a constant force of $(2\hat{i} - 3\hat{j}) \text{ N}$ acts on it, find the coordinate of point it reaches in 3 s.
- (a) $(18, -1.5)$ (b) $(9, 1.5)$
 (c) $(18, 1.5)$ (d) $(9, -1.5)$
5. A wooden block, initially at rest on the ground, is pushed by a force which increases linearly with time t . Which of the following curve best describes acceleration of the block with time:
- (a) (b)
 (c) (d)
6. A cricket player catches a ball of mass 120g moving with 25 m/s speed. If the catching process is completed in 0.1 s then the magnitude of force exerted by the ball on the hand of player will be (in SI unit):
- (a) 30 (b) 24 (c) 12 (d) 25
7. An object with mass 5 kg is acted upon by a force, $\vec{F} = (-3\hat{i} + 4\hat{j}) \text{ N}$. If its initial velocity at $t = 0$ is $\vec{v} = (6\hat{i} - 12\hat{j}) \text{ m s}^{-1}$, the time at which it will just have a velocity along y-axis is
- (a) 2 s (b) 5 s (c) 15 s (d) 10 s

8. A stone of mass 0.05 kg is thrown vertically upwards. What is the direction and magnitude of net force on the stone during its upward motion?
 (a) 0.49 N vertically downwards.
 (b) 9.8 N vertically downwards.
 (c) 0.49 N vertically upwards.
 (d) 0.98 N vertically downwards.
9. A bullet of mass 20 g moving with 500 ms^{-1} is pierced 1 cm into a wooden block, then the retarding force experienced by the bullet is
 (a) $125 \times 10^3 \text{ N}$ (b) $750 \times 10^3 \text{ N}$
 (c) $500 \times 10^3 \text{ N}$ (d) $250 \times 10^3 \text{ N}$
10. A body of mass 6 kg is moving with a uniform velocity 4 ms^{-1} . Its velocity changes to 6 ms^{-1} when a force of 12 N acts on it. Then its displacement is
 (a) 3m (b) 5m (c) 8m (d) 12m
11. A motor car moving with velocity 7 m/s stops in 10 m distance when brakes are applied. What is the relation between the resistance force (R) and the weight (W) of the car?
 (Take value of $g = 9.8 \text{ m/s}^2$)
 (a) $R = W$ (b) $R = -W$
 (c) $R = -\frac{W}{2}$ (d) $R = -\frac{W}{4}$
12. A body of mass 1.5 kg is moving towards south with a uniform velocity of 8 ms^{-1} . A force of 6 N is applied to the body towards east. The displacement of the body 3 seconds after the application of the force is
 (a) 24m (b) 30m (c) 18m (d) 42m
13. A ball is thrown vertically up (taken as + z-axis) from the ground. The correct momentum-height (p-h) diagram is:
 (a)  (b) 
 (c)  (d) 
14. A particle of mass 0.3 kg subject to a force $F = -kx$ with $k = 15 \text{ N/m}$. What will be its initial acceleration if it is released from a point 20 cm away from the origin?
 (a) 15 m/s^2 (b) 3 m/s^2 (c) 10 m/s^2 (d) 5 m/s^2
15. An object of mass 10 kg moves at a constant speed of 10 ms^{-1} . A constant force, that acts for 4 sec on the object, gives it a speed of 2 ms^{-1} in opposite direction. The force acting on the object is
 (a) -3 N (b) -30 N
 (c) 3 N (d) 30 N

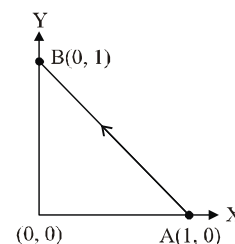
16. A player stops a football weighting 0.5 kg which comes flying towards him with a velocity of 10 m/s . If the impact lasts for $1/50$ th sec. and the ball bounces back with a velocity of 15 m/s , then the average force involved is
 (a) 250 N (b) 1250 N
 (c) 500 N (d) 625 N

2.2

Conservative and Non Conservative Force, Concept of Potential Energy, Work done by a Variable Force, Work Energy Theorem, Law of Conservation of Linear Momentum, Free Body Diagram, Collisions, Impulse

17. Consider a force $\vec{F} = -x\hat{i} + y\hat{j}$. The work done by this force in moving a particle from point A(1, 0) to B(0, 1) along the line segment is: (all quantities are in SI units)

- (a) 2J
 (b) $\frac{1}{2} \text{ J}$
 (c) 1J
 (d) $\frac{3}{2} \text{ J}$

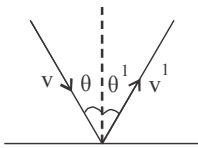


18. If W represents the work done, then match the two columns:

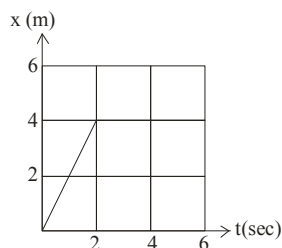
Column I

Column II

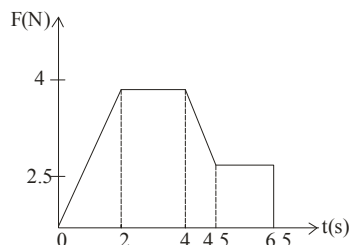
- (A) Force is always along the velocity (1) $W = 0$
 (B) Force is always perpendicular to velocity (2) $W < 0$
 (C) Force is always perpendicular to acceleration (3) $W > 0$
 (D) The object is stationary but the point of application of the force moves on the object
- (a) (A)→(1); (B)→(2); (C)→(3); (D)→(2)
 (b) (A)→(3); (B)→(1); (C)→(2,3); (D)→(1)
 (c) (A)→(2); (B)→(3); (C)→(1); (D)→(2)
 (d) (A)→(1); (B)→(2); (C)→(3); (D)→(1)
19. A particle moving in the xy plane undergoes a displacement of $\vec{s} = (2\hat{i} + 3\hat{j})$ while a constant force $\vec{F} = (5\hat{i} + 2\hat{j}) \text{ N}$ acts on the particle. The work done by the force F is
 (a) 17 joule (b) 18 joule
 (c) 16 joule (d) 15 joule
20. A particle describe a horizontal circle of radius 0.5 m with uniform speed. The centripetal force acting is 10 N. The work done in describing a semicircle is
 (a) zero (b) 5 J (c) $5\pi \text{ J}$ (d) $10\pi \text{ J}$
21. A force acts on a 30 g particle in such a way that the position of the particle as a function of time is given by $x = 3t - 4t^2 + t^3$, where x is in metres and t is in seconds. The work done

- during the first 4 seconds is
 (a) 576mJ (b) 450mJ
 (c) 490mJ (d) 530mJ
22. A cord is used to lower vertically a block of mass M , a distance d at a constant downward acceleration of $g/4$. The work done by the cord on the block is
 (a) $Mg \frac{d}{4}$ (b) $3Mg \frac{d}{4}$ (c) $-3Mg \frac{d}{4}$ (d) $Mg d$
23. If a motorcyclist skids and stops after covering a distance of 15 m. The stopping force acting on the motorcycle by the road is 100 N, then the work done by the motorcycle on the road is
 (a) 1500 J (b) -1500 J (c) 750 J (d) Zero
24. A particle moves under the effect of a force $F = cx$ from $x = 0$ to $x = x_1$, the work done in the process is
 (a) cx_1^2 (b) $\frac{1}{2}cx_1^2$ (c) $2cx_1^2$ (d) zero
25. A body of mass 0.5 kg travels on straight line path with velocity $v = (3x^2 + 4)$ m/s. The net workdone by the force during its displacement from $x = 0$ to $x = 2$ m is :
 (a) 64 J (b) 60 J (c) 120 J (d) 128 J
26. The potential energy of a system increases if work is done
 (a) upon the system by a non conservative force
 (b) by the system against a conservative force
 (c) by the system against a non conservative force
 (d) upon the system by a conservative force
27. Two particles having the position $\vec{r}_1 = (3\hat{i} + 5\hat{j})$ m and $\vec{r}_2 = (-5\hat{i} - 3\hat{j})$ m move with velocities $\vec{v}_1 = (4\hat{i} + 3\hat{j})$ m/s and $\vec{v}_2 = (a\hat{i} + 7\hat{j})$ m/s. If the particles collide, then value of a must be
 (a) 8 (b) 6 (c) 4 (d) 2
28. A mass of 20 kg moving with a speed of 10m/s collides with another stationary mass of 5 kg. As a result of the collision, the two masses stick together. The kinetic energy of the composite mass will be
 (a) 600 (b) 800 (c) 1000 (d) 1200
29. A mass m moving horizontally (along the x -axis) with velocity v collides and sticks to mass of $3m$ moving vertically upward (along the y -axis) with velocity $2v$. The final velocity of the combination is
 (a) $\frac{1}{4}v\hat{i} + \frac{3}{2}v\hat{j}$ (b) $\frac{1}{3}v\hat{i} + \frac{2}{3}v\hat{j}$
 (c) $\frac{2}{3}v\hat{i} + \frac{1}{3}v\hat{j}$ (d) $\frac{3}{2}v\hat{i} + \frac{1}{4}v\hat{j}$
30. A body of mass m moving with velocity v collides head on with another body of mass $2m$ which is initially at rest. The ratio of K. E. of colliding body before and after collision will be
 (a) 1 : 1 (b) 2 : 1 (c) 4 : 1 (d) 9 : 1
31. An object of mass 2.0 kg makes an elastic collision with another object of mass M at rest and continues to move in the original direction but with one-fourth of its original speed. What is the value of M ?
 (a) 0.75 kg (b) 1.0 kg
 (c) 1.2 kg (d) None of these
32. A bullet of mass 20g and moving with 600 m/s collides with a block of mass 4 kg hanging with the string. What is velocity of bullet when it comes out of block, if block rises to height 0.2 m after collision?
 (a) 200m/s (b) 150m/s
 (c) 400m/s (d) 300m/s
33. A block of mass 0.50 kg is moving with a speed of 2.00 ms^{-1} on a smooth surface. It strikes another mass of 1.00 kg and then they move together as a single body. The energy loss during the collision is
 (a) 0.16 J (b) 1.00 J (c) 0.67 J (d) 0.34 J
34. If a shell fired from a cannon, explodes in mid air, then
 (a) its total kinetic energy increases
 (b) its total momentum increases
 (c) its total momentum decreases
 (d) None of these
35. A ball of mass m hits the floor making an angle θ as shown in the figure. If e is the coefficient of restitution, then which relation is true, for the velocity component before and after collision?
- 
- (a) $V^1 \sin \theta = V \sin \theta$ (b) $V^1 \sin \theta' = -\sin \theta$
 (c) $V^1 \cos \theta' = V \cos \theta$ (d) $V^1 \cos \theta' = -V \cos \theta$
36. Before a rubber ball bounces off from the floor, the ball is in contact with the floor for a fraction of second. Which of the following statements is correct?
 (a) Conservation of energy is not valid during this period
 (b) Conservation of energy is valid during this period
 (c) As ball is compressed, kinetic energy is converted to compressed potential energy
 (d) None of these
37. A bag of sand of mass 9.8 kg is suspended by a rope. A bullet of 200 g travelling with speed 10 ms^{-1} gets embedded in it, then loss of kinetic energy will be
 (a) 4.9 J (b) 9.8 J (c) 14.7 (d) 19.6 J
38. A object of mass m_1 collides with another object of mass m_2 , which is at rest. After the collision the objects move with equal speeds in opposite direction. The ratio of the masses $m_2 : m_1$ is:
 (a) 2 : 1 (b) 3 : 1 (c) 1 : 2 (d) 1 : 1
39. Two billiard balls of mass 0.05 kg each moving in opposite directions with 10 ms^{-1} collide and rebound with the same speed. If the time duration of contact is $t = 0.005 \text{ s}$, then what is the force exerted on the ball due to each other?
 (a) 100 N (b) 200 N (c) 300 N (d) 4000 N

40. A bullet is fired from a gun. The force on the bullet is given by $F = 600 - 2 \times 10^5 t$, where F is in newton's and t in seconds. The force on the bullet becomes zero as soon as it leaves the barrel. What is the average impulse imparted to the bullet?
 (a) 9 Ns (b) Zero (c) 0.9 Ns (d) 1.8 Ns
41. In the figure given below, the position–time graph of a particle of mass 0.1 kg is shown. The impulse at $t = 2$ sec is



- (a) $0.2 \text{ kg m sec}^{-1}$ (b) $-0.2 \text{ kg m sec}^{-1}$
 (c) $0.1 \text{ kg m sec}^{-1}$ (d) $-0.4 \text{ kg m sec}^{-1}$
42. A body of 2 kg has an initial speed 5 ms^{-1} . A force acts on it for some time in the direction of motion. The force time graph is shown in figure. The final speed of the body is



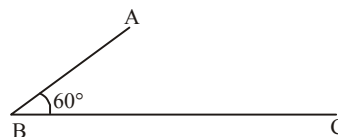
- (a) 9.25 ms^{-1} (b) 5 ms^{-1}
 (c) 14.25 ms^{-1} (d) 4.25 ms^{-1}
43. A 100 kg gun fires a ball of 1 kg horizontally from a cliff of height 500 m. It falls on the ground at a distance of 400 m from the bottom of the cliff. The recoil velocity of the gun is (Acceleration due to gravity = 10 ms^{-2}).
 (a) 0.6 ms^{-1} (b) 0.8 ms^{-1} (c) 0.2 ms^{-1} (d) 0.4 ms^{-1}
44. A spacecraft of mass 100 kg breaks into two when its velocity is 10^4 m s^{-1} . After the break, a mass of 10 kg of the space craft is left stationary. The velocity of the remaining part is
 (a) 10^3 m s^{-1} (b) $11.11 \times 10^3 \text{ m s}^{-1}$
 (c) $11.11 \times 10^2 \text{ m s}^{-1}$ (d) 10^4 m s^{-1}
45. A moving block having mass m , collides with another stationary block having mass $4m$. The lighter block comes to rest after collision. When the initial velocity of the lighter block is v , then the value of coefficient of restitution (e) will be
 (a) 0.5 (b) 0.25 (c) 0.4 (d) 0.8
46. Two bodies A and B of same mass undergo completely inelastic one dimensional collision. The body A moves with velocity v_1 while body B is at rest before collision. The velocity of the system after collision is v_2 . The ratio $v_1 : v_2$ is
 (a) 1 : 2 (b) 2 : 1 (c) 4 : 1 (d) 1 : 4

47. A block of mass 10 kg, moving in x direction with a constant speed of 10 ms^{-1} , is subject to a retarding force $F = 0.1x \text{ J/m}$ during its travel from $x = 20 \text{ m}$ to 30 m . Its final KE will be:
 (a) 450 J (b) 275 J
 (c) 250 J (d) 475 J
48. Consider a drop of rain water having mass 1 g falling from a height of 1 km. It hits the ground with a speed of 50 m/s. Take 'g' constant with a value 10 m/s^2 . The work done by the (i) gravitational force and the (ii) resistive force of air is
 (a) (i) 1.25 J (ii) -8.25 J
 (b) (i) 100 J (ii) 8.75 J
 (c) (i) 10 J (ii) -8.75 J
 (d) (i) -10 J (ii) -8.25 J

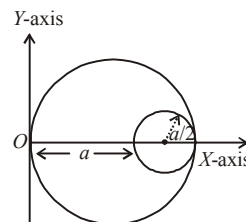
2.3

Torque, Mechanical Equilibrium, Centre of Mass

49. In the figure shown ABC is a uniform wire. If centre of mass of wire lies vertically below point A, then $\frac{BC}{AB}$ is close to :



- (a) 1.85 (b) 1.5 (c) 1.37 (d) 3
50. A circular hole of radius $\left(\frac{a}{2}\right)$ is cut out of a circular disc of radius ' a ' as shown in figure. The centroid of the remaining circular portion with respect to point ' O ' will be:



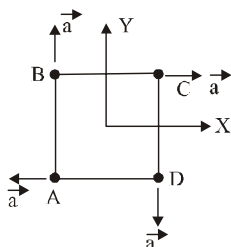
- (a) $\frac{1}{6}a$ (b) $\frac{10}{11}a$ (c) $\frac{5}{6}a$ (d) $\frac{2}{3}a$
51. The centre of mass of three bodies each of mass 1 kg located at the points (0, 0), (3, 0) and (0, 4) in the XY plane is

- (a) $\left(\frac{4}{3}, 1\right)$ (b) $\left(\frac{1}{3}, \frac{2}{3}\right)$
 (c) $\left(\frac{1}{2}, \frac{1}{2}\right)$ (d) $\left(1, \frac{4}{3}\right)$

52. A uniform thin rod AB of length L has linear mass density $\mu(x) = a + \frac{bx}{L}$, where x is measured from A. If

the CM of the rod lies at a distance of $\left(\frac{7}{12}\right)L$ from A, then a and b are related as :

- (a) $a = 2b$ (b) $2a = b$
 (c) $a = b$ (d) $3a = 2b$
53. If the resultant of all external forces is zero, then velocity of centre of mass will be
 (a) zero (b) constant
 (c) either (a) or (b) (d) neither (a) nor (b)
54. Four particles A, B, C and D with masses $m_A = m$, $m_B = 2m$, $m_C = 3m$ and $m_D = 4m$ are at the corners of a square. They have accelerations of equal magnitude with directions as shown. The acceleration of the centre of mass of the particles is :



- (a) $\frac{a}{5}(\hat{i} - \hat{j})$ (b) a
 (c) Zero (d) $\frac{a}{5}(\hat{i} + \hat{j})$
55. There are some passengers inside a stationary railway compartment. The centre of mass of the compartment itself (without the passengers) is C_1 , while the centre of mass of the 'compartment plus passengers' system is C_2 . If the passengers move about inside the compartment then
 (a) both C_1 and C_2 will move with respect to the ground
 (b) neither C_1 nor C_2 will be stationary with respect to the ground
 (c) C_1 will move but C_2 will be stationary with respect to the ground
 (d) C_2 will move but C_1 will be stationary with respect to the ground
56. A body A of mass M while falling vertically downwards under gravity breaks into two parts; a body B of mass $\frac{1}{3}M$ and a body C of mass $\frac{2}{3}M$. The centre of mass of bodies B and C taken together shifts compared to that of body A
 (a) does not shift
 (b) depends on height of breaking
 (c) towards body B
 (d) towards body C

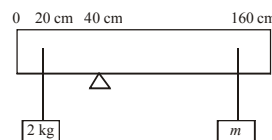
57. Two particles of mass m_1 and m_2 ($m_1 > m_2$) attract each other with a force inversely proportional to the square of the distance between them. If the particles are initially held at rest and then released, the centre of mass will

- (a) move towards m_1 (b) move towards m_2
 (c) remains at rest (d) None of these
58. A rod of weight W is supported by two parallel knife edges A and B and is in equilibrium in a horizontal position. The knives are at a distance d from each other. The centre of mass of the rod is at distance x from A. The normal reaction on A is

- (a) $\frac{Wd}{x}$ (b) $\frac{W(d-x)}{x}$
 (c) $\frac{W(d-x)}{d}$ (d) $\frac{Wx}{d}m$

59. Find the torque about the origin when a force of $3\hat{j}$ N acts on a particle whose position vector is $2\hat{k}$ m.

- (a) $6\hat{j}$ Nm (b) $-6\hat{i}$ Nm (c) $6\hat{k}$ Nm (d) $6\hat{i}$ Nm
60. Two particles of mass 5 kg and 10 kg respectively are attached to the two ends of a rigid rod of length 1 m with negligible mass. The centre of mass of the system from the 5 kg particle is nearly at a distance of :
 (a) 50 cm (b) 67 cm
 (c) 80 cm (d) 33 cm
61. A uniform rod of length 200 cm and mass 500 g is balanced on a wedge placed at 40 cm mark. A mass of 2 kg is suspended from the rod at 20 cm and another unknown mass ' m ' is suspended from the rod at 160 cm mark as shown in the figure. Find the value of ' m ' such that the rod is in equilibrium. ($g = 10 \text{ m/s}^2$)



- (a) $\frac{1}{12}$ kg (b) $\frac{1}{2}$ kg
 (c) $\frac{1}{3}$ kg (d) $\frac{1}{6}$ kg
62. Two objects of mass 10 kg and 20 kg respectively are connected to the two ends of a rigid rod of length 10 m with negligible mass. The distance of the center of mass of the system from the 10 kg mass is:
 (a) $\frac{20}{3}$ m (b) 10 m
 (c) 5 m (d) $\frac{10}{3}$ m

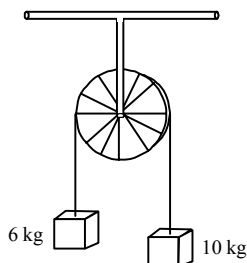
Exercise 3 :

PREVIOUS YEARS MCQs

- A body of mass 2 kg moving with a speed of 4 m/s. makes an elastic collision with another body at rest and continues to move in the original direction but with one fourth of its initial speed. The speed of the two body centre of mass is
(a) 2.5 m/s (b) 5 m/s (c) 7.5 m/s (d) 10 m/s [2025]
- Hail storms are observed to strike the surface of the frozen lake at 30° with the vertical and rebound at 60° with the vertical. Assume contact to be smooth, the coefficient of restitution is :
(a) $e = \frac{1}{\sqrt{3}}$ (b) $e = \frac{1}{3}$ (c) $e = \sqrt{3}$ (d) $e = 3$ [2025]
- Find the torque about the origin when a force of $3\hat{j}$ N acts on a particle whose position vector is $2\hat{k}$ m. [2025]
(a) $6\hat{j}$ Nm (b) $-6\hat{i}$ Nm (c) $6\hat{k}$ Nm (d) $6\hat{i}$ Nm
- If a force of $(6x^2 - 4x)$ N acts on a body of mass 10 kg, then work to be done by the force in displacing the body from $x = 2$ m to $x = 4$ m is [2024]
(a) 22 J (b) 44 J (c) 66 J (d) 88 J
- If the potential energy of a particle of mass 0.1 kg moving along x-axis is $5x(x - 4)$ J, then the speed of the particle is maximum at a position of [2023]
(a) $x = 2$ m (b) $x = 3$ m (c) $x = 0.5$ m (d) $x = 5$ m
- A body of mass 'm' moving along a straight line collides with a stationary body of mass '2m'. After collision if the two bodies move together with the same velocity, then the fraction of kinetic energy lost in the process is [2022]
(a) $\frac{1}{2}$ (b) $\frac{2}{3}$ (c) $\frac{3}{4}$ (d) $\frac{1}{3}$
- A body of mass 2 kg is moving towards north with a velocity of 20 m s^{-1} and another body of mass 3 kg is moving towards east with a velocity of 10 m s^{-1} . The magnitude of the velocity of the centre of mass of the system of the two bodies is [2021]
(a) 20 m s^{-1} (b) 10 m s^{-1} (c) 15 m s^{-1} (d) $2\sqrt{5} \text{ m s}^{-1}$
- If two bodies of masses 2 kg and 3 kg are moving at right angles with velocities 20 ms^{-1} and 10 ms^{-1} respectively, then the velocity of the centre of mass of the system of the two bodies is [2020]
(a) 5 ms^{-1} (b) 30 ms^{-1} (c) 10 ms^{-1} (d) 14 ms^{-1}
- In the case of non-conservative forces, the following statement is correct. [2019]
(a) The work done by non-conservative force in a closed path is zero.
(b) The work done by non-conservative forces does not depend on the path.
(c) The work done by non-conservative forces depend on the path.
(d) There is no energy loss in case of non-conservative forces.
- In an inelastic collision, after collision the kinetic energy [2018]
(a) increases by 2 times
(b) is less than before collision
(c) is more than before collision
(d) remains same
- When two bodies collide elastically, then [2017]
(a) kinetic energy of the system along is conserved
(b) only momentum is conserved
(c) both kinetic energy and momentum is conserved
(d) Neither kinetic energy nor momentum is conserved
- A particle of mass m moving with velocity v collides with a stationary particle of mass 2m. After collision, they stick together and continue to move together with velocity [2015]
(a) v (b) $\frac{v}{2}$ (c) $\frac{v}{3}$ (d) $\frac{v}{4}$
- A body of mass M moving at speed V_0 collides elastically with a mass 'm' at rest. After the collision, the two masses move at angles θ_1 and θ_2 with respect to the initial direction of motion of the body of mass M. The largest possible value of the ratio M/m , for which the angles θ_1 and θ_2 will be equal, is : [2014]
(a) 4 (b) 1 (c) 3 (d) 2
- Newton's third law of motion leads to the law of conservation of [2013]
(a) Angular momentum (b) Energy (c) Mass (d) Momentum
- A batsman hits back a ball of mass 0.4 kg straight in the direction of the bowler without changing its initial speed of 15 ms^{-1} . The impulse imparted to the ball is [2012]
(a) 12 Ns (b) 16 Ns (c) 24 Ns (d) 48 Ns

16. A light string passes over a frictionless pulley. To one of its ends a mass of 6 kg is attached. To its other end a mass of 10 kg is attached. The tension in the thread will be

[2011]



- (a) 24.5 N (b) 2.45 N (c) 79 N (d) 73.5 N
17. A body of mass m is at rest. Another body of same mass moving with velocity V makes head on elastic collision with the first body. After collision the first body starts to move with velocity
- (a) V (b) $2V$
(c) Remain at rest (d) No predictable
18. Two masses m_A and m_B moving with velocities v_A and v_B in opposite directions collide elastically. After that the masses m_A and m_B move with velocity v_B and v_A respectively. The ratio (m_A/m_B) is

[2009]

- (a) 1 (b) $\frac{v_A - v_B}{v_A + v_B}$
(c) $(m_A + m_B)/m_A$ (d) v_A/v_B

19. Three particles of masses 1 kg, $\frac{3}{2}$ kg, and 2 kg are located at the vertices of an equilateral triangle of side a . The x, y coordinates of the centre of mass are

[2008]

- (a) $\left(\frac{5a}{9}, \frac{2a}{3\sqrt{3}}\right)$ (b) $\left(\frac{2a}{3\sqrt{3}}, \frac{5a}{9}\right)$
(c) $\left(\frac{5a}{9}, \frac{2a}{\sqrt{3}}\right)$ (d) $\left(\frac{2a}{\sqrt{3}}, \frac{5a}{9}\right)$

20. The potential energy of particle in a force field is

$$U = \frac{A}{r^2} - \frac{B}{r}, \text{ where } A \text{ and } B \text{ are positive constants and } r$$

is the distance of particle from the centre of the field. For stable equilibrium, the distance of the particle is :

[2007]

- (a) $B/2A$ (b) $2A/B$ (c) A/B (d) B/A
21. An explosion blows a rock into three parts. Two parts go off at right angles to each other. These two are, 1 kg first part moving with a velocity of 12 ms^{-1} and 2 kg second part moving with a velocity of 8 ms^{-1} . If the third part flies off with a velocity of 4 ms^{-1} , its mass would be

[2006]

- (a) 5 kg (b) 7 kg (c) 17 kg (d) 3 kg
22. A shell at rest at the origin explodes into three fragments of masses 1 kg, 2 kg and m kg. The 1 kg and 2 kg pieces fly off with speeds of 5 ms^{-1} along x -axis and 6 ms^{-1} along y -axis respectively. If the m kg piece flies off with a speed of 6.5 ms^{-1} , the total mass of the shell must be

[2005]

- (a) 4 kg (b) 5 kg (c) 3.5 kg (d) 4.5 kg

ANSWER KEYS

Exercise 1 : WARM-UP Topic-wise MCQs

1	(a)	11	(c)	21	(d)	31	(c)	41	(a)	51	(d)	61	(b)	71	(b)	81	(b)	91	(a)
2	(c)	12	(b)	22	(d)	32	(d)	42	(c)	52	(a)	62	(a)	72	(c)	82	(c)	92	(b)
3	(d)	13	(c)	23	(b)	33	(c)	43	(c)	53	(b)	63	(b)	73	(a)	83	(a)	93	(d)
4	(c)	14	(c)	24	(a)	34	(c)	44	(d)	54	(a)	64	(a)	74	(b)	84	(a)	94	(b)
5	(c)	15	(b)	25	(b)	35	(a)	45	(a)	55	(c)	65	(a)	75	(a)	85	(a)	95	(a)
6	(a)	16	(b)	26	(c)	36	(c)	46	(d)	56	(b)	66	(d)	76	(d)	86	(c)	96	(c)
7	(d)	17	(d)	27	(a)	37	(c)	47	(b)	57	(a)	67	(a)	77	(a)	87	(a)	97	(d)
8	(c)	18	(a)	28	(d)	38	(b)	48	(c)	58	(c)	68	(d)	78	(a)	88	(b)	98	(a)
9	(a)	19	(c)	29	(c)	39	(c)	49	(d)	59	(b)	69	(c)	79	(a)	89	(b)	99	(b)
10	(c)	20	(b)	30	(b)	40	(a)	50	(b)	60	(a)	70	(a)	80	(b)	90	(d)	100	(a)

Exercise 2 : ACCELERATOR Topic-wise MCQs

1	(d)	8	(a)	15	(b)	22	(c)	29	(a)	36	(b)	43	(d)	50	(c)	57	(c)		
2	(a)	9	(d)	16	(d)	23	(d)	30	(d)	37	(b)	44	(b)	51	(d)	58	(c)		
3	(c)	10	(b)	17	(c)	24	(b)	31	(d)	38	(b)	45	(b)	52	(b)	59	(b)		
4	(a)	11	(d)	18	(b)	25	(b)	32	(a)	39	(b)	46	(b)	53	(c)	60	(b)		
5	(b)	12	(b)	19	(c)	26	(d)	33	(c)	40	(c)	47	(d)	54	(a)	61	(a)		
6	(a)	13	(d)	20	(a)	27	(a)	34	(a)	41	(b)	48	(c)	55	(c)	62	(a)		
7	(d)	14	(c)	21	(a)	28	(b)	35	(a)	42	(c)	49	(c)	56	(a)				

Exercise 3 : PREVIOUS YEARS MCQs

1	(a)	4	(d)	7	(b)	10	(b)	13	(c)	16	(d)	19	(a)	22	(b)				
2	(b)	5	(a)	8	(c)	11	(c)	14	(d)	17	(a)	20	(b)						
3	(b)	6	(b)	9	(c)	12	(c)	15	(a)	18	(a)	21	(a)						

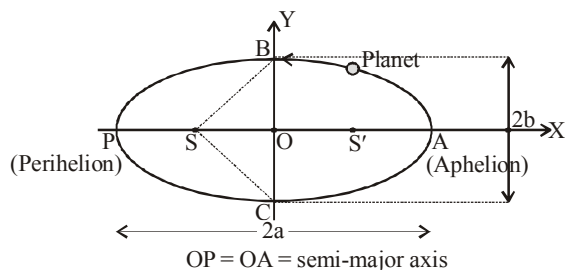


Gravitation

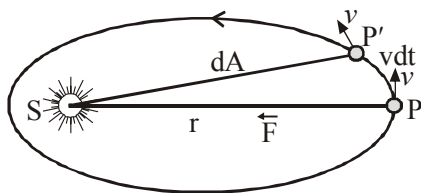
TOPIC 3.1 : KEPLER'S LAWS OF PLANETARY MOTION, NEWTON'S LAW OF GRAVITATION

KEPLER'S LAWS OF PLANETARY MOTION

- Law of orbits (first law) :** *All planets revolve in elliptical orbits around the sun and the sun is situated at one of the two foci of the elliptical path.*



- Law of areas (second law) :** *The areal velocity $\left(\frac{dA}{dt}\right)$ of a planet remains constant, i.e. the line joining the sun to planet covers equal areas in same intervals of time.*

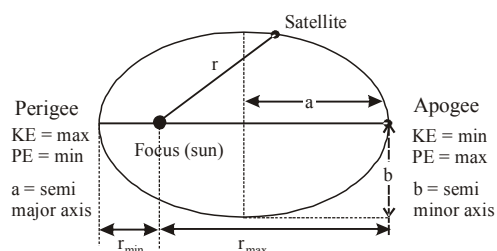


$$\text{i.e., } \frac{dA}{dt} = \text{constant}$$

$$= \frac{1}{2} \frac{r(v dt)}{dt} = \frac{1}{2} r v = \frac{L}{2m} \quad [\text{since } L = mvr]$$

- Law of periods (third law) :** *The square of the period of revolution of the planet is directly proportional to the cube of semi major axis of its orbit.*

$$\text{i.e., } T^2 \propto a^3 \quad \text{or, } \frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3}$$

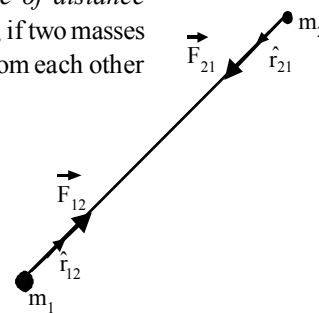


NEWTON'S LAW OF GRAVITATION

Every two objects in the universe attract each other and the force of attraction between the two bodies is directly proportional to the product of their masses and inversely proportional to the square of distance between the two masses i.e., if two masses m_1 and m_2 are separated from each other by a distance r then

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

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



where G = **universal gravitational constant**

The numerical value of G determined by scientists Henry cavendish in 1798,

$$G = 6.67 \times 10^{-11} \text{ N-m}^2 \text{ kg}^{-2} \text{ in SI system}$$

$$= 6.67 \times 10^{-8} \text{ dyne cm}^2 \text{ gm}^{-2} \text{ in CGS system}$$

Its **dimensions** : $[M^{-1} L^3 T^{-2}]$

In vector form, gravitational force $\vec{F} = \frac{Gm_1 m_2}{r^3} \vec{r}$

Gravitation force is a mutual force hence, it is action - reaction force.

$$\text{i.e. } \vec{F}_{12} = -\vec{F}_{21}$$

TOPIC 3.2 : ACCELERATION DUE TO GRAVITY OF THE EARTH AND VARIATIONS IN ACCELERATION DUE TO GRAVITY

ACCELERATION DUE TO GRAVITY OF THE EARTH

The acceleration produced in a body due to earth's gravitational force is called **acceleration due to gravity**.

$$g = \frac{GM_e}{R_e^2} \text{ m/s}^2$$

By putting the value of $M_E = 6 \times 10^{24} \text{ kg}$

$$R_e = 6.4 \times 10^6 \text{ m and } G = 6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2}$$

we get, $g = 9.8 \text{ ms}^{-2}$.

It is a vector quantity. If a body falling under the gravity alone then the motion is called **free fall**.

Weight : The gravitational force that a body experiences is called its weight. If a body of mass m experiences an acceleration due to gravity g , then weight of the body

$$W = mg$$

where g = acc. due to gravity at the point P

VARIATIONS IN ACCELERATION DUE TO GRAVITY

Acceleration due to gravity (g) varies with :

- (a) **Height (altitude) above the earth's surface -**

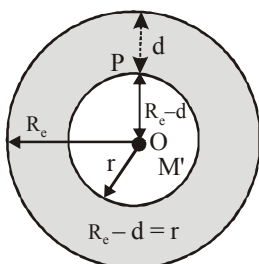
$$g' = \frac{g}{\left(1 + \frac{h}{R_e}\right)^2}$$

$$\text{or, } g' = g \left(1 - \frac{2h}{R_e}\right) \text{ (if } h \ll R_e\text{)}$$

i.e., The decrease in the value of g on going up a height ' h '

above the surface of earth by a factor $\left(1 - \frac{2h}{R_e}\right)$

- (b) **Depth below the earth surface -** If the value of acceleration due to gravity at the surface of earth is g and at a depth h from the earth's surface is g' then,



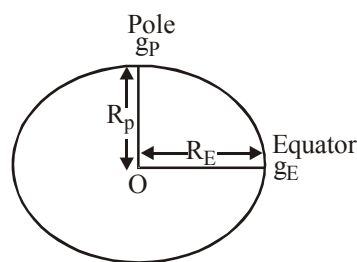
$$g' = g \left(1 - \frac{d}{R_e}\right)$$

Thus the value of g decreases by a factor $\left(1 - \frac{d}{R_e}\right)$ as we go down below the surface of the earth.

- (c) **Shape of the earth** - The earth is elliptical in shape. It is flatter at the poles and bulged out at the equator. Now, we know that $g \propto 1/R^2$,

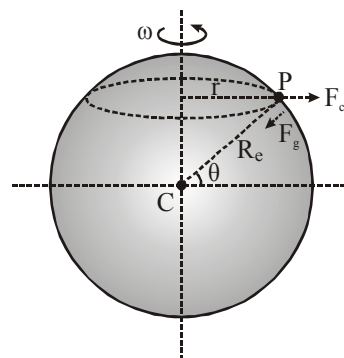
$$R_p < R_e$$

$$\therefore g_E < g_p$$



Therefore the value of g at the equator is minimum and the value of g at the poles is maximum.

- (d) **Axial rotation (latitude) of the earth** - If the observed value of g at the latitude λ is represented by g_λ , then



$$g_\lambda = g_e - R_e \omega^2 \cos^2 \lambda$$

where ω is the angular velocity of the earth.

At equator, $\lambda = 0^\circ$; $\cos \lambda = 1$

$$\therefore g_\lambda = g_e - R_e \omega^2$$

At poles, $\lambda = 90^\circ$; $\cos \lambda = 0$

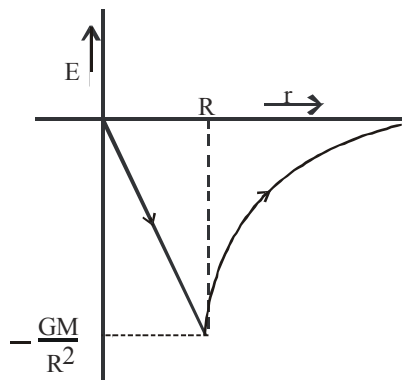
$$\therefore g_\lambda = g_e$$

i.e., $g_p > g_e$

TOPIC 3.3 : INTENSITY OF GRAVITATIONAL FIELD, GRAVITATIONAL POTENTIAL AND GRAVITATIONAL POTENTIAL ENERGY

INTENSITY OF GRAVITATIONAL FIELD

It is defined as the force experience by unit mass placed at any point in the gravitational field of a given mass.



Intensity of gravitational field due to a body of mass m

$$\vec{E}_g = \frac{\vec{F}}{m} \quad \text{or} \quad \vec{E}_g = \frac{GM_e}{r^2} (-\hat{r})$$

The gravitational field is a vector quantity. Its **SI unit** is N/kg . At the earth's surface the gravitational field is given by

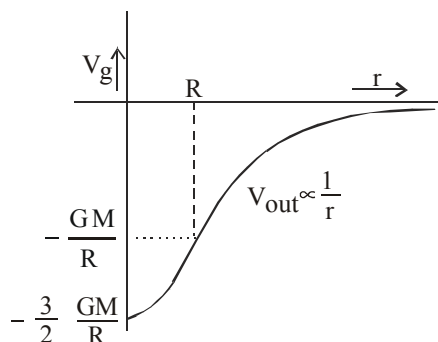
$$E_g = \frac{GM_e}{r_e^2} = g = 9.8 \text{ m/s}^2.$$

GRAVITATIONAL POTENTIAL

The work done in bringing a unit mass from infinity to a certain point against the gravitational force of earth, is called gravitational potential at that point.

It is a scalar quantity. Its **SI unit** is joule/kg and its **dimensions** are $[M^0 L^2 T^{-2}]$.

Gravitational potential



$$V_g = -\frac{GM}{r}$$

$$V_g = -\int_{\infty}^r \vec{E}_g \cdot d\vec{r}$$

For a solid spherical body, like earth :

- (a) For points outside it ($r > R$), $V_g = -\frac{GM}{R}$
- (b) For points on the surface ($r = R$), $V_g = -\frac{GM}{R}$
- (c) For points inside it ($r < R$), $V_g = -GM \frac{(3R^2 - r^2)}{2R^3}$

V_g is constant inside a hollow spherical shell whereas E_g is zero there.

GRAVITATIONAL POTENTIAL ENERGY

The work done against the field in bringing a body from infinity to a point in the gravitational field is called its gravitational potential energy. It is a scalar quantity. Its **SI unit** is joule.

The gravitational potential energy of a particle of mass ' m ' at a point distant ' r ' from the centre of earth is

$$U_g = -\frac{GM_e m}{r} = -\frac{GM_e m}{(R_e + h)} \quad (\text{if } r > R_e)$$

$$U_g = -\frac{GM_e m (3R_e^2 - r^2)}{2R_e^3} \quad (\text{if } r < R_e)$$

$$U_g = -\frac{GM_e m}{R_e} = -mg R_e \quad (\text{if } r = R_e)$$

Increase in potential energy on going to a height h above the surface

$$\Delta U_g = \frac{mgh}{(1 + h/R_e)} = mgh, \quad (\text{if } h \ll R_e)$$

Force between two particles, if their potential energy is U ,

$$F = -\frac{dU}{dr} = -\frac{d}{dr} \left(-\frac{GMm}{r} \right) = -\frac{GMm}{r^2}$$

Relation between gravitational potential energy and gravitational potential.

Gravitational potential energy = gravitational potential $\times$ mass

TOPIC 3.4 : ESCAPE SPEED, EARTH'S SATELLITES AND WEIGHTLESSNESS

ESCAPE SPEED

Escape speed is the minimum speed that should be given to the body to enable it to escape away from the gravitational field of earth.

$$V_e = \sqrt{(2GM/R)}$$

$$\text{or } V_e = \sqrt{(2gR)} \quad [\text{since } GM = gR^2]$$

Escape speed from the surface of earth is **11.2 km/sec**.

Escape velocity of a satellite orbiting at height h :

$$V_e = R \sqrt{\frac{g}{R+h}}$$

EARTH'S SATELLITES

The objects which revolve round the earth is called earth's satellite.

- (a) **Orbital velocity of a satellite (v_o)** : It is the velocity required to put the satellite into the orbit around the earth.

$$\text{or, } v_o = \sqrt{\frac{GM_e}{r}} = \sqrt{\frac{GM_e}{R_e + h}}$$

For a satellite near the surface of the earth ($h \ll R_e$), neglecting h in comparison to R_e

$$v_o = \sqrt{gR_e}$$

By putting the value of g and R_e we get, $v_o = 7.92 \text{ km/s}$.

Relation between escape velocity (v_e) and orbital velocity (v_o)

$$v_e = \sqrt{2gR} = \sqrt{2}v_o$$

- (b) **Period of revolution of a satellite (T)** :

For a satellite revolving very close to the surface of earth ($h \ll R_e$)

$$\therefore T = 2\pi \sqrt{\frac{R_e}{g}} = 84.6 \text{ min.}$$

- (c) **Energy of a satellite :**

- (i) Potential energy of satellite

$$U = mv = -\frac{GM_em}{r} = \frac{-L^2}{2mr^2}$$

- (ii) Kinetic energy of satellite

$$K = \frac{1}{2} mV_o^2 = \frac{GM_em}{2r} = \frac{L^2}{2mr^2}$$

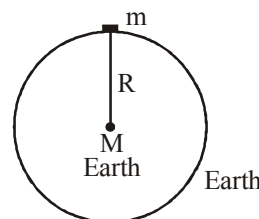
- (iii) Total energy of satellite

$$T.E. = K + U = -\frac{GM_em}{2r} = \frac{-L^2}{2mr^2}$$

- (iv) Binding energy of satellite (B.E.)

- (d) **Binding energy :**

- (i) **For a body at rest on the earth's surface**



PE of the body

$$\text{Binding energy } E_b = -E = \frac{GMm}{R}$$

$$\text{But } GM = gR^2$$

$$\text{So } E = -mgR, E_b = +mgR$$

- (ii) **For a body at rest at height h**

Binding energy is the energy given to satellite in order that the satellite escape away from its orbit.

$$B.E. = -\text{total energy} = \frac{1}{2} \frac{GM_em}{r}$$

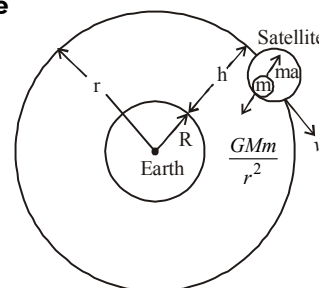
WEIGHTLESSNESS

The weight of a body is the force with which it is attracted towards the centre of earth. When a body is stationary with respect to the earth, its weight equals the gravity. This weight of the body is known as its static or true weight.

Weightlessness in a Satellite

A satellite, which does not produce its own gravity moves around the earth in a circular orbit under the action of gravity. The acceleration of

satellite is $\frac{GM}{r^2}$ towards the centre of earth.



If a body of mass m placed on a surface inside a satellite moving around the earth. Then force on the body are

- (i) The gravitational pull of earth = $\frac{GMm}{r^2}$

- (ii) The reaction by the surface = R

$$\text{By Newton's law } \frac{GMm}{r^2} - R = ma$$

$$\frac{GMm}{r^2} - R = m \left(\frac{GM}{r^2} \right) \quad \therefore R = 0$$

Thus the surface does not exert any force on the body and hence its apparent weight is zero.

Geostationary or Parking Satellites

If an artificial satellite revolves around the earth in an equatorial plane with a time period of 24 hrs. in the same time as that of earth, then it will appear stationary to the observer on earth. Such a satellite is known as **Geostationary satellite or Parking satellite**. In India all INSAT group of satellites are Geostationary satellite.

It is widely used for telecommunication.

- Time period of Geostationary satellite is 24 hrs.
- The radius of orbit of Geostationary satellite is 42,400 km and its height above the surface of earth is 36000 Km.
- The relative angular velocity of the Geostationary satellite is zero.
- The orbital velocity of a Geostationary satellite is 3.08 km s^{-1} .

CHAPTER AT A GLANCE**Kepler's laws of planetary motion**

(i) **Law of orbits (first law) :** All planets revolve in elliptical orbits around the sun and the sun is situated at one of the two foci of the elliptical path.

(ii) **Law of areas (second law) :** The areal velocity $\left(\frac{dA}{dt}\right)$ of a planet remains constant, i.e. the line joining the sun to planet covers equal areas in same intervals of time.

$$\frac{dA}{dt} = \text{constant} = \frac{1}{2} \frac{r(v dt)}{dt} = \frac{1}{2} r v = \frac{L}{2m}$$

[since $L = mvr$]

(iii) **Law of periods (third law) :** The square of the period of revolution of the planet is directly proportional to the cube of semi major axis of its orbit.

Gravitational Force, $F = \frac{Gm_1m_2}{r^2}$

Acceleration due to gravity:

$$g = \frac{GM_e}{R_e^2} \text{ m/s}^2$$

Variations in acceleration due to gravity :

(i) **At a height h from earth's surface**

$$g' = \frac{g}{\left(1 + \frac{h}{R_e}\right)^2} \quad \text{or,} \quad g' = g \left(1 - \frac{2h}{R_e}\right) \quad (\text{if } h \ll R_e)$$

(ii) **Below depth d from earth's surface**

$$g' = g \frac{R_e - d}{R_e} \quad \text{or,} \quad g' = g \left(1 - \frac{d}{R_e}\right)$$

(iii) **Axial rotation (latitude) of the earth**

$$g_\lambda = g_e - R_e \omega^2 \cos^2 \lambda$$

At equator, $\lambda = 0^\circ$; $\cos \lambda = 1$

$$\therefore g_\lambda = g_e - R_e \omega^2$$

At poles, $\lambda = 90^\circ$; $\cos \lambda = 0$

$$\therefore g_\lambda = g_e \quad \text{i.e.,} \quad g_p > g_e$$

Gravitational potential energy :

$$U_g = - \frac{GM_e m}{R_e} = -mg R_e$$

Escape Speed :

$$V_e = \sqrt{(2GM / R)}$$

$$\text{or } V_e = \sqrt{(2gR)} \quad [\text{since } GM = gR^2]$$

Escape speed from the surface of earth is 11.2 km/sec.

Orbital velocity of a satellite (v_o) :

$$v_o = \sqrt{gR_e}$$

Period of revolution of a satellite (T) :

$$T = 2\pi \sqrt{\frac{R_e}{g}} = 84.6 \text{ min.}$$

Energy of a satellite :

$$T.E. = K + U = - \frac{GM_e m}{2r} - \frac{L^2}{2mr^2}$$

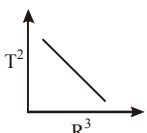
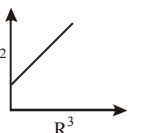
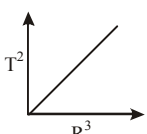
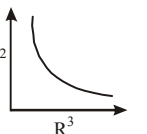
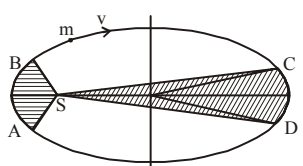
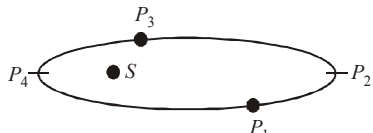
Binding energy of satellite (B.E.)

$$B.E. = - \text{total energy} = \frac{1}{2} \frac{GM_e m}{r}$$

Exercise 1 :

WARM-UP Topic-wise MCQs

3.1 Kepler's Laws of Planetary Motion, Newton's Law of Gravitation

- The time period of revolution of a satellite close to planet's surface is 80 minutes. The time period of another satellite which is at a height of 3 times the radius of the planet from surface is
(a) 64 minutes (b) 640 minutes
(c) 320 minutes (d) 240 minutes
- When a planet revolves around the Sun, in general, for the planet
(a) linear momentum and aerial velocity are constant.
(b) kinetic and potential energy of the planet are constant.
(c) angular momentum about the Sun and aerial velocity of the planet are constant.
(d) linear momentum and linear velocity are constant.
- Which of the following graphs represents the motion of a planet moving about the sun?
(a)  (b) 
(c)  (d) 
- The figure shows elliptical orbit of a planet m about the sun S . The shaded area SCD is twice the shaded area SAB . If t_1 is the time for the planet to move from C to D and t_2 is the time to move from A to B then

(a) $t_1 = 4t_2$ (b) $t_1 = 2t_2$
(c) $t_1 = t_2$ (d) $t_1 > t_2$
- If the distance of earth is halved from the sun, then the no. of days in a year will be
(a) 365 (b) 182.5
(c) 730 (d) 129
- A satellite A of mass m is at a distance r from the centre of the earth. Another satellite B of mass $2m$ is at a distance $2r$ from the earth's centre. Their time periods are in the ratio of
(a) 1 : 2 (b) 1 : 16 (c) 1 : 32 (d) 1 : $2\sqrt{2}$
- A satellite of mass ' m ', moving around the earth in a circular orbit of radius R , has angular momentum L . The areal velocity of satellite is (M_e = mass of earth)
(a) $L/2m$ (b) L/m (c) $2L/m$ (d) $2L/M_e$
- Which of the following astronomers proposed a definitive model in which the planets moved in circles around a fixed central sun?
(a) Copernicus (b) Kepler
(c) Galileo (d) None of these
- For elliptical orbits, in the equation $T^2 = \left(\frac{4\pi^2}{GM_s} \right) R^3$
 R refers to
(a) radius of orbit (b) major axis
(c) semi-minor axis (d) semi-major axis
- In planetary motion
(a) the angular speed remains constant
(b) the total angular momentum remains constant
(c) the linear speed remains constant
(d) neither the angular momentum nor angular speed remains constant
- Kepler's second law may be stated as "under the influence of central force, in equal interval of time, position vector sweeps out equal
(a) distance (b) area
(c) displacement (d) volume
- The figure shows a planet in elliptical orbit around the sun S . Where is the kinetic energy of the planet maximum?
(a) P_1 (b) P_2
(c) P_3 (d) P_4

- A planet revolves about the sun in elliptical orbit. The areal velocity $\left(\frac{dA}{dt} \right)$ of the planet is $4.0 \times 10^{16} \text{ m}^2/\text{s}$. The least distance between planet and the sun is $2 \times 10^{12} \text{ m}$. Then the maximum speed of the planet in km/s is
(a) 10 (b) 20 (c) 30 (d) 40
- In planetary motion the areal velocity of position vector of a planet depends on angular velocity (ω) and the distance of the planet from sun (r). If so, the correct relation for areal velocity is
(a) $\frac{dA}{dt} \propto \omega r$ (b) $\frac{dA}{dt} \propto \omega^2 r$
(c) $\frac{dA}{dt} \propto \omega r^2$ (d) $\frac{dA}{dt} \propto \sqrt{\omega r}$

15. A planet goes round the sun three times as fast as the earth. If r_p and r_e are the radii of orbit of the planet and the earth respectively then
 (a) $r_e^3 = 8r_p^3$ (b) $r_e^3 = 3r_p^3$ (c) $r_e^3 = 9r_p^3$ (d) $r_e^3 = \frac{1}{3}r_p^3$
16. The period of moon's rotation around the earth is nearly 29 days. If moon's mass were 2 fold its present value and all other things remain unchanged, the period of moon's rotation would be nearly
 (a) $29\sqrt{2}$ days (b) $29/\sqrt{2}$ days
 (c) 29×2 days (d) 29 days
17. The distance of two planets from the sun are 10^{13} and 10^{12} metres respectively. The ratio of time periods of these two planets is
 (a) $\frac{1}{\sqrt{10}}$ (b) 100 (c) $10\sqrt{10}$ (d) $\sqrt{10}$
18. According to Kepler, the period of revolution of a planet (T) and its mean distance from the sun (r) are related by the equation
 (a) $T^3r^3 = \text{constant}$ (b) $T^2r^{-3} = \text{constant}$
 (c) $Tr^3 = \text{constant}$ (d) $T^2r = \text{constant}$
19. The maximum and minimum distances of a comet from the sun are 8×10^{12} m and 1.6×10^{12} m. If its velocity when nearest to the sun is 60 m/s, what will be its velocity in m/s when it is farthest
 (a) 12 (b) 60 (c) 112 (d) 6
20. Two planets at mean distance d_1 and d_2 from the sun and their frequencies are n_1 and n_2 respectively then
 (a) $n_1^2 d_1^2 = n_2^2 d_2^2$ (b) $n_2^2 d_2^3 = n_1^2 d_1^3$
 (c) $n_1 d_1^2 = n_2 d_2^2$ (d) $n_1^2 d_1 = n_2^2 d_2$
21. A satellite is launched into a circular orbit of radius R around the earth. A second satellite is launched into an orbit of radius 4R. The ratio of their respective periods is
 (a) 4 : 1 (b) 1 : 8 (c) 8 : 1 (d) 1 : 4
22. Kepler's second law regarding constancy of aerial velocity of a planet is a consequence of the law of conservation of
 (a) Energy (b) Angular momentum
 (c) Linear momentum (d) None of these
23. What does not change in the field of central force
 (a) Potential energy (b) Kinetic energy
 (c) Linear momentum (d) Angular momentum
24. If r denotes the distance between the sun and the earth, then the angular momentum of the earth around the sun is proportional to
 (a) $r^{3/2}$ (b) r (c) $\sqrt{r}$ (d) r^2
25. If the earth is at one-fourth of its present distance from the sun, the duration of the year will be
 (a) Half the present year
 (b) One-eighth the present year
 (c) One-fourth the present year
 (d) One-sixth the present year
26. Two point masses m_1 and m_2 having masses in the ratio of 4 : 3 are separated by a distance of 1 m. If another point mass M is placed in between m_1 and m_2 , the force between m_1 and m_3 is $\left(\frac{1}{3}\right)$ rd of the force between m_2 and m_3 . Then, the distance between m_1 and m_3 is
 (a) $\frac{2}{7}m$ (b) $\frac{1}{4}m$ (c) $\frac{2}{3}m$ (d) $\frac{1}{3}m$
27. Two equal point masses are separated by a distance d_1 . The force of gravitation acting between them is F_1 . If the separation is decreased to d_2 , then the new force of gravitation F_2 is given by
 (a) $F_2 = F_1$ (b) $F_2 = F_1 \left(\frac{d_1}{d_2}\right)^2$
 (c) $F_2 = F_1 \left(\frac{d_2}{d_1}\right)^2$ (d) $F_2 = F_1 \left(\frac{d_1}{d_2}\right)$
28. Which of the following statements is correct regarding the gravitational force?
 (a) The gravitational force is dependent on the intervening medium.
 (b) The gravitational force is a non-conservative force.
 (c) The gravitational force forms action-reaction pair.
 (d) The gravitational force is a non-central force.
29. Three identical point masses, each of mass 1 kg lie in the x-y plane at points (0, 0), (0, 0.2m) and (0.2m, 0). The net gravitational force on the mass at the origin is
 (a) $1.67 \times 10^{-9} (\hat{i} + \hat{j})N$ (b) $3.34 \times 10^{-10} (\hat{i} + \hat{j})N$
 (c) $1.67 \times 10^{-9} (\hat{i} - \hat{j})N$ (d) $3.34 \times 10^{-10} (\hat{i} + \hat{j})N$
30. Four particles of masses m , $2m$, $3m$ and $4m$ are kept in sequence at the corners of a square of side a . The magnitude of gravitational force acting on a particle of mass m placed at the centre of the square will be
 (a) $\frac{24m^2G}{a^2}$ (b) $\frac{6m^2G}{a^2}$
 (c) $\frac{4\sqrt{2}Gm^2}{a^2}$ (d) Zero
31. The value of G varies with
 (a) height above the earth's surface
 (b) depth below the ground
 (c) radius of the planet
 (d) None of these
32. Two spheres of masses m and M are situated in air and the gravitational force between them is F . The space around the masses is now filled with a liquid of specific gravity 3. The gravitational force will now be
 (a) 3 F (b) F (c) $\frac{F}{3}$ (d) $\frac{F}{9}$

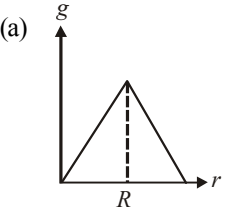
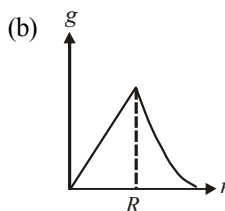
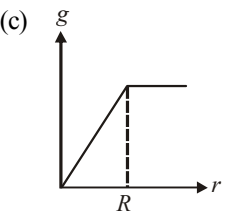
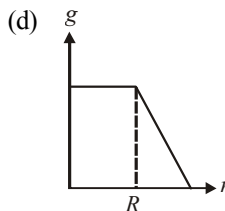
33. Mass M is divided into two parts xM and $(1-x)M$. For a given separation, the value of x for which the gravitational attraction between the two pieces becomes maximum is
- (a) $\frac{1}{2}$ (b) $\frac{3}{5}$ (c) 1 (d) 2
34. The distance of the centres of moon and earth is D . The mass of earth is 81 times the mass of the moon. At what distance from the centre of the earth, the gravitational force will be zero?
- (a) $\frac{D}{2}$ (b) $\frac{2D}{3}$ (c) $\frac{4D}{3}$ (d) $\frac{9D}{10}$
35. Two stars of mass m_1 and m_2 are parts of a binary system. The radii of their orbits are r_1 and r_2 respectively, measured from the C.M. of the system. The magnitude of gravitational force m_1 exerts on m_2 is
- (a) $\frac{m_1 m_2 G}{(r_1 + r_2)^2}$ (b) $\frac{m_1 G}{(r_1 + r_2)^2}$
- (c) $\frac{m_2 G}{(r_1 + r_2)^2}$ (d) $\frac{(m_1 + m_2)}{(r_1 + r_2)^2}$
36. Three masses, each equal to M , are placed at the three corners of a square of side a . The force of attraction on unit mass at the fourth corner will be
- (a) $\frac{GM}{3a^2}$ (b) $\frac{GM}{a^2}\sqrt{3}$
- (c) $\frac{3GM}{a^2}$ (d) $\frac{GM}{a^2}\left[\frac{1}{2} + \sqrt{2}\right]$
37. Two identical spheres of radii R are kept touching each other. How gravitational force of attraction between them depends on R ?
- (a) $\frac{1}{R^2}$ (b) $\frac{1}{R^2}$ (c) R^3 (d) R^4
38. If the law of gravitation instead of being inverse square law, becomes an inverse cube law, then
- (a) planets will have elliptical orbits.
 (b) Kepler's law of areas does not hold good.
 (c) projectile motion of a stone thrown by hand on the surface of the earth will be approximately parabolic.
 (d) there will be no gravitational force inside a spherical shell of uniform density.
- (a) $9.0 \times 10^6 \text{ m}$ (b) $2.6 \times 10^6 \text{ m}$
 (c) $6.4 \times 10^6 \text{ m}$ (d) $1.6 \times 10^6 \text{ m}$
40. A body weighs w at the surface of the earth. Its weight at a height equals to half the radius of the earth will be
- (a) $\frac{w}{2}$ (b) $\frac{2w}{3}$ (c) $\frac{4w}{9}$ (d) $\frac{8w}{27}$
41. At what height h above the surface of the earth, the value of g becomes $\left(\frac{g}{2}\right)$?
- (Take, g = acceleration due to gravity at the surface of the earth and R = radius of the earth)
- (a) $3R$ (b) $\sqrt{2}R$
 (c) $(\sqrt{2}-1)R$ (d) $\frac{1}{\sqrt{2}}R$
42. A body weighs 200 N on the surface of the earth. How much will it weigh half-way down to the centre of the earth?
- (a) 200 N (b) 250 N (c) 100 N (d) 150 N
43. The height at which the weight of a body becomes $(1/16)$ th of its weight on the surface of the earth (radius R), is
- (a) $5R$ (b) $15R$
 (c) $3R$ (d) $4R$
44. The mass of the moon is $\frac{1}{81}$ of the earth but the gravitational pull is $\frac{1}{6}$ of the earth. It is due to the fact that
- (a) The radius of the moon is $\frac{81}{6}$ of the earth
 (b) The radius of the earth is $\frac{9}{\sqrt{6}}$ of the moon
 (c) Moon is the satellite of the earth
 (d) None of the above
45. Consider earth to be a homogenous sphere. Scientist A goes deep down in a mine and scientist B goes high up in a balloon. The value of g measured by
- (a) A goes on decreasing and that by B goes on increasing.
 (b) B goes on decreasing and that by A goes on increasing
 (c) Each decreases at the same rate
 (d) Each decreases at different rates
46. The height of the point vertically above the earth's surface, which acceleration due to gravity becomes 1% of its value at the surface is (Radius of the earth = R)
- (a) $8R$ (b) $9R$
 (c) $10R$ (d) $20R$



3.2

Acceleration due to Gravity of the Earth and Variations in Acceleration due to Gravity

39. The value of acceleration due to gravity at earth's surface is 9.8 ms^{-2} . The altitude above its surface at which the acceleration due to gravity decreases to 4.9 ms^{-2} , is close to (Take, radius of earth = $6.4 \times 10^6 \text{ m}$)

47. The depth at which the effective value of acceleration due to gravity is $\frac{g}{4}$ is (R = radius of the earth)
- (a) R (b) $\frac{3R}{4}$ (c) $\frac{R}{2}$ (d) $\frac{R}{4}$
48. A planet has mass $1/10$ of that of earth, while radius is $1/3$ that of earth. If a person can throw a stone on earth surface to a height of 90 m, then he will be able to throw the stone on that planet to a height
- (a) 90m (b) 40m (c) 100m (d) 45m
49. At surface of earth weight of a person is 72 N then his weight at height $R/2$ from surface of earth is (R = radius of earth)
- (a) 28 N (b) 16 N
(c) 32 N (d) 72 N
50. Assuming the earth to be a sphere of uniform mass density, a body weighed 300 N on the surface of earth. How much it would weigh at $R/4$ depth under surface of earth?
- (a) 75 N (b) 375 N (c) 300 N (d) 225 N
51. A 90 kg body placed at $2R$ distance from surface of earth experiences gravitational pull of:
(R = Radius of earth, $g = 10 \text{ ms}^{-2}$)
- (a) 300 N (b) 225 N (c) 120 N (d) 100 N
52. At what distance above and below the surface of the earth a body will have same weight (take radius of earth as R .)
- (a) $\frac{R}{2}$ (b) $\sqrt{5} R - R$
(c) $\frac{\sqrt{3} R - R}{2}$ (d) $\frac{\sqrt{5} R - R}{2}$
53. The acceleration due to gravity on the surface of earth is g . If the diameter of earth reduces to half of its original value and mass remains constant, then acceleration due to gravity on the surface of earth would be:
- (a) $g/4$ (b) $2g$
(c) $g/2$ (d) $4g$
54. What is the height from the surface of earth, where acceleration due to gravity will be $\frac{1}{4}$ of that of the earth?
($R_E = 6400 \text{ km}$)
- (a) 6400km (b) 3200km (c) 1600km (d) 640km
55. The ratio of the radii of a planet and the earth is $1 : 2$, the ratio of their mean densities is $4 : 1$. If the acceleration due to gravity on the surface of the earth is 9.8 ms^{-2} , then the acceleration due to gravity on the surface of the planet is
- (a) 4.9 ms^{-2} (b) 8.9 ms^{-2}
(c) 29.4 ms^{-2} (d) 19.6 ms^{-2}
56. The ratio of the accelerations due to gravity at heights 1280 km and 3200 km above the surface of the earth is (Radius of the earth = 6400 km)
- (a) 25 : 16 (b) 5 : 2 (c) 1 : 1 (d) 25 : 4
57. What is the value of acceleration due to gravity at a height equal to half the radius of the Earth, from its surface?
- (a) 4.4 ms^{-2} (b) 6.5 ms^{-2}
(c) zero (d) 9.8 ms^{-2}
58. The value of acceleration due to gravity at a height of 10 km from the surface of earth is x . At what depth inside the earth is the value of the acceleration due to gravity has the same value x ?
- (a) 10km (b) 15km (c) 5km (d) 20km
59. Which of the following graphs correctly represents the variation of g on the Earth?
- (a)  (b) 
- (c)  (d) 
60. The weight of a body on the surface of the earth is 100 N. The gravitational force on it when taken at a height, from the surface of earth, equal to one-fourth the radius of the earth is:
- (a) 100 N (b) 64 N (c) 50 N (d) 25 N

3.3

Intensity of Gravitational Field, Gravitational Potential and Gravitational Potential Energy

61. The intensity of gravitational field at a point situated at a distance of 8000 km from the centre of the earth is 6 N/kg . The gravitational potential at that point is – (in Joule/kg)
- (a) 8×10^6 (b) 2.4×10^3
(c) 4.8×10^7 (d) 6.4×10^{14}
62. A particle of mass m is placed at the centre of a uniform spherical shell of mass $3m$ and radius R . The gravitational potential on the surface of the shell is
- (a) $-\frac{Gm}{R}$ (b) $-\frac{3Gm}{R}$ (c) $-\frac{4Gm}{R}$ (d) $-\frac{2Gm}{R}$
63. Three particles each of mass m are kept at vertices of an equilateral triangle of side L . The gravitational potential at the centre due to these particles is
- (a) $-\frac{3Gm}{L}$ (b) $-\frac{8Gm}{\sqrt{3}L}$
(c) $-\frac{3\sqrt{3}Gm}{L}$ (d) $-\frac{4Gm}{\sqrt{3}L}$

64. The gravitational potential energy of a body on the surface of the earth is E . If the body is taken from the surface of the earth to a height equal to 150% of the radius of the earth, its gravitational potential energy is
 (a) $0.4E$ (b) $0.2E$ (c) $0.6E$ (d) $0.3E$
65. Four particles each of mass M , are located at the vertices of a square with side L . The gravitational potential due to this at the centre of the square is
 (a) $-\sqrt{32} \frac{GM}{L}$ (b) $-\sqrt{64} \frac{GM}{L^2}$
 (c) zero (d) $\sqrt{32} \frac{GM}{L}$
66. Assuming the radius of the earth as R , the change in gravitational potential energy of a body of mass m , when it is taken from the earth's surface to a height $3R$ above its surface, is
 (a) $3mgR$ (b) $\frac{3}{4}mgR$
 (c) $1mgR$ (d) $\frac{3}{2}mgR$
67. A particle of mass M is situated at the centre of a spherical shell of same mass and radius a . The gravitational potential at a point situated at $\frac{a}{2}$ distance from the centre, will be
 (a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$
 (c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$
68. The energy required to move a satellite of mass m from an orbit of radius $2R$ to $3R$ around earth of mass M is
 (a) $\frac{GMm}{12R}$ (b) $\frac{GMm}{R}$ (c) $\frac{GMm}{8R}$ (d) $\frac{GMm}{2R}$
69. If mass of earth is M , radius is R and gravitational constant is G , then work done to take 1 kg mass from earth surface to infinity will be
 (a) $\sqrt{\frac{GM}{2R}}$ (b) $\frac{GM}{R}$ (c) $\sqrt{\frac{2GM}{R}}$ (d) $\frac{GM}{2R}$
70. The gravitational potential energy of a body on the surface of the earth is E . If the body is taken from the surface of the earth to a height equal to 150% of the radius of the earth, its gravitational potential energy is
 (a) positive and negative (b) negative and positive
 (c) positive and positive (d) negative and negative
72. A body is orbiting very close to the earth surface with kinetic energy KE . The Energy required to completely escape from it is
 (a) $\sqrt{2}KE$ (b) KE
 (c) $KE/\sqrt{2}$ (d) None of these
73. Two satellites A and B move round the earth in the same orbit. The mass of A is twice the mass of B. The quantity which is same for the two satellites will be :
 (a) Potential energy (b) Total energy
 (c) Kinetic energy (d) Speed
74. A body of mass m kg starts falling from a point $2R$ above the Earth's surface. Its kinetic energy when it has fallen to a point ' R ' above the Earth's surface [R -radius of Earth, M -mass of Earth. G -gravitational constant.]
 (a) $\sqrt{2}KE$ (b) KE
 (c) $KE/\sqrt{2}$ (d) None of these
75. Radius of orbit of satellite of earth is R . Its kinetic energy is proportional to
 (a) $\frac{1}{R}$ (b) $\frac{1}{\sqrt{R}}$ (c) R (d) $\frac{1}{R^{3/2}}$
76. The orbital velocity of a satellite close to the surface of the earth is v . If this satellite starts orbiting at an altitude of half the earth's radius, the orbital velocity will be
 (a) $\sqrt{\frac{2}{3}}v$ (b) $\sqrt{\frac{2}{5}}v$ (c) $\sqrt{\frac{2}{7}}v$ (d) $\sqrt{\frac{2}{9}}v$
77. Which one of the following statements is correct?
 (a) The kinetic energy of an orbiting satellite is half of its total energy.
 (b) The potential energy of an orbiting satellite increases with increases in radius of the orbit.
 (c) Total energy of an orbiting satellite is positive.
 (d) The potential energy of an orbiting satellite is half of its total energy.
78. The kinetic energy of the satellite in a circular orbit with speed v is given as
 (a) $KE = \frac{-GmM_E}{2(R_E + h)}$ (b) $KE = \frac{GmM_E}{(R_E + h)}$
 (c) $KE = \frac{GmM_E}{2(R_E + h)}$ (d) $KE = -\frac{1}{2}mv^2$
79. Two satellites A and B move round the earth in the same orbit. The mass of A is twice the mass of B. The quantity which is same for the two satellites will be :
 (a) Potential energy (b) Total energy
 (c) Kinetic energy (d) Speed



3.4

Escape Speed, Earth's Satellites and Weightlessness

70. An artificial satellite moving in a circular at a distance h from the centre of the earth a total energy E_0 . Its potential energy is
 (a) $-E_0$ (b) $1.5E_0$ (c) E_0 (d) $2E_0$
71. The total energy and kinetic energy of an Earth's satellite are respectively

80. The potential energy of a satellite is given as

$$PE = \lambda (KE)$$

where, PE = potential energy of the satellite and KE = kinetic energy of the satellite.

The value of the constant λ is

- (a) -2 (b) 2 (c) $-1/2$ (d) $+1/2$
81. If the time period of revolution of a satellite is T , then its kinetic energy is proportional to
(a) T^{-1} (b) T^{-2} (c) T^{-3} (d) $T^{-2/3}$
82. Maximum height reached by a rocket fired with a speed equal to 50% of the escape speed from the surface of the earth is (R - Radius of the earth)
(a) $\frac{R}{2}$ (b) $\frac{16R}{9}$ (c) $\frac{R}{3}$ (d) $\frac{R}{8}$
83. Correct formula for height of a satellite from earth's surface is :
(a) $\left(\frac{T^2 R^2 g}{4\pi}\right)^{1/2} - R$ (b) $\left(\frac{T^2 R^2 g}{4\pi^2}\right)^{1/3} - R$
(c) $\left(\frac{T^2 R^2}{4\pi^2 g}\right)^{1/3} - R$ (d) $\left(\frac{T^2 R^2}{4\pi^2}\right)^{-1/3} + R$
84. The mass of the moon is $1/144$ times the mass of a planet and its diameter $1/16$ times the diameter of a planet. If the escape velocity on the planet is v , the escape velocity on the moon will be:
(a) $\frac{v}{3}$ (b) $\frac{v}{4}$ (c) $\frac{v}{12}$ (d) $\frac{v}{6}$
85. To project a body of mass m from earth's surface to infinity, the required kinetic energy is (assume, the radius of earth is R_E , g = acceleration due to gravity on the surface of earth) :
(a) $2mgR_E$ (b) mgR_E
(c) $\frac{1}{2}mgR_E$ (d) $4mgR_E$
86. If the height of a satellite from the earth is negligible in comparison to the radius of the earth R , the orbital velocity of the satellite is
(a) gR (b) $gR/2$ (c) $\sqrt{g/R}$ (d) $\sqrt{gR}$
87. A planet has twice the radius but the mean density is $\frac{1}{4}$ th as compared to earth. What is the ratio of escape velocity from earth to that from the planet ?
(a) $3:1$ (b) $1:2$ (c) $1:1$ (d) $2:1$
88. For a satellite moving in an orbit around the earth, the ratio of kinetic energy to potential energy is
(a) $\frac{1}{2}$ (b) $\frac{1}{\sqrt{2}}$ (c) 2 (d) $\sqrt{2}$
89. A planet having mass $9M_e$ and radius $4R_e$, where M_e and R_e are mass and radius of earth respectively, has escape

velocity in km/s given by: (Given escape velocity on earth $V_e = 11.2 \times 10^3$ m/s)

- (a) 67.2 (b) 16.8 (c) 33.6 (d) 11.2
90. Two satellites of masses m and $3m$ revolve around the earth in circular orbits of radii r & $3r$ respectively. The ratio of orbital speeds of the satellites respectively is :
(a) $1:1$ (b) $3:1$ (c) $\sqrt{3}:1$ (d) $9:1$
91. For a satellite escape velocity is 11 km/s. If the satellite is launched at an angle of 60° with the vertical, then escape velocity will be
(a) 11 km/s (b) $11\sqrt{3}$ km/s
(c) $\frac{11}{\sqrt{3}}$ km/s (d) 33 km/s
92. A ball is dropped from a satellite revolving round the earth at a height of 120 km. The ball will
(a) continue to move with same speed along a straight line tangentially to the satellite at that time.
(b) continue to move with the same speed along the original orbit of satellite.
(c) fall down to earth gradually
(d) go far away in space
93. The escape velocity of a sphere of mass m is given by (G = Universal gravitational constant; M = Mass of the earth and R_e = Radius of the earth)
(a) $\sqrt{\frac{GM}{R_e}}$ (b) $\sqrt{\frac{2GM}{R_e}}$
(c) $\sqrt{\frac{2GMm}{R_e}}$ (d) $\sqrt{\frac{2GM + R_e}{R_e}}$
94. If suddenly the gravitational force of attraction between the earth and a satellite revolving around it becomes zero, then the satellite will
(a) continue to move in its orbit with same speed
(b) move tangentially to the original orbit with same speed
(c) become stationary in its orbit
(d) move towards the earth
95. The escape velocity of a body depends upon its mass as
(a) m^0 (b) m^1 (c) m^2 (d) m^3
96. The escape velocity from the surface of earth is v_e . The escape velocity from the surface of a planet whose mass and radius are 3 times those of the earth will be
(a) v_e (b) $3v_e$ (c) $9v_e$ (d) $27v_e$
97. Which one of the following statements regarding artificial satellite of the earth is incorrect ?
(a) The orbital velocity depends on the mass of the satellite
(b) A minimum velocity of 8 km/sec is required by a satellite to orbit quite close to the earth
(c) The period of revolution is large if the radius of its orbit is large
(d) The height of a geostationary satellite is about 36000 km from earth

98. If v_e is escape velocity and v_0 is orbital velocity of a satellite for orbit close to the earth's surface, then these are related by :

- (a) $v_0 = \sqrt{2}v_e$
 (b) $v_0 = v_e$
 (c) $v_e = \sqrt{2}v_0$
 (d) $v_e = \sqrt{2}v_0$

99. The escape velocity for an object from the surface of Earth (radius R) is

- (a) $\sqrt{gR}$ (b) gR
 (c) $\sqrt{gR^2}$ (d) $\sqrt{2gR}$

100. An astronaut orbiting the earth in a circular orbit 120 km above the surface of earth, gently drops a spoon out of space-ship. The spoon will
 (a) Fall vertically down to the earth
 (b) Move towards the moon
 (c) Will move in an irregular way then fall down to earth
 (d) Will move in an irregular way then fall down to earth

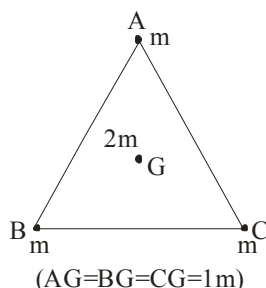
Exercise 2 :

ACCELERATOR Topic-wise MCQs

3.1

Kepler's Laws of Planetary Motion, Newton's Law of Gravitation

1. Three equal masses of m kg each are fixed at the vertices of an equilateral triangle ABC and a mass $2m$ is placed at centroid G of the triangle as shown below.



The force acting on a mass $2m$ placed at the centroid G of the triangle is

- (a) $\frac{2Gm^2}{\sqrt{2}}$ (b) $2Gm^2$ (c) $6Gm^2$ (d) zero

2. Three uniform spheres of mass M and radius R each are kept in such a way that each touches the other two. The magnitude of the gravitational force on any of the spheres due to the other two is

- (a) $\frac{\sqrt{3}}{4} \frac{GM^2}{R^2}$ (b) $\frac{3}{2} \frac{GM^2}{R^2}$
 (c) $\frac{\sqrt{3}}{2} \frac{GM^2}{R^2}$ (d) $\frac{\sqrt{3}}{2} \frac{GM^2}{R^2}$

3. A planet is revolving around the sun in a circular orbit with a radius r and the time period is T . If the force between the planet and star is proportional to $r^{-3/2}$, then the square of time period is proportional to

- (a) $r^{3/2}$ (b) r^2 (c) r (d) $r^{5/2}$

4. Two satellites of masses m and $1.5m$ are revolving around the earth with different speeds in two circular orbits of heights R_E and $2R_E$ respectively, where R_E is the radius of the earth. The ratio of the minimum and maximum gravitational forces on the earth due to the two satellites is
 (a) 2 : 5 (b) 2 : 3 (c) 1 : 2 (d) 1 : 5

5. Two stars of masses ' M ' and ' $2M$ ' that are at a distance ' d ' apart, are revolving one around another. The angular velocity of the system of two stars is (G -Universal gravitational constant)

- (a) $\sqrt{\frac{4GM}{d^3}}$ (b) $\sqrt{\frac{2GM}{d^3}}$ (c) $\sqrt{\frac{9GM}{d^3}}$ (d) $\sqrt{\frac{3GM}{d^3}}$

6. Two bodies of masses 4 kg and 9 kg are separated by a distance of 60 cm. A 1 kg mass is placed in between these two masses. If the net force on 1 kg is zero, then its distance from 4 kg mass is

- (a) 26 cm (b) 30 cm
 (c) 28 cm (d) 24 cm

7. If masses of two point objects is doubled and distance between them is tripled, then gravitational force of attraction between them will nearly

- (a) increase by 225% (b) decrease by 44%
 (c) decrease by 56% (d) increase by 125%

8. Two particles of equal mass ' m ' go around a circle of radius R under the action of their mutual gravitational attraction. The speed of each particle with respect to their centre of mass is

- (a) $\sqrt{\frac{Gm}{4R}}$ (b) $\sqrt{\frac{Gm}{3R}}$
 (c) $\sqrt{\frac{Gm}{2R}}$ (d) $\sqrt{\frac{Gm}{R}}$

9. The vector form of universal law of gravitation

- (a) $\vec{F} = G \frac{m_1 m_2}{r} \vec{r}$ (b) $\vec{F} = G \frac{m_1 m_2}{r^3} \hat{r}$
 (c) $\vec{F} = G \frac{m_1 m_2}{r^2} \vec{r}$ (d) $\vec{F} = G \frac{m_1 m_2}{r^3} \vec{r}$

10. Newton's universal law of gravitation applies to

(a) small bodies only
(b) planets only
(c) both small and big bodies
(d) only valid for solar system

11. For a particle inside a uniform spherical shell, the gravitational force on the particle is

(a) infinite (b) zero
(c) $\frac{-Gm_1m_2}{r^2}$ (d) $\frac{Gm_1m_2}{r^2}$

12. Force of gravitational attraction is least

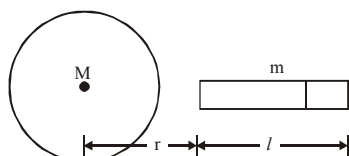
(a) at the equator
(b) at the poles
(c) at a point in between equator and any pole
(d) None of these

13. Six stars of equal mass are moving about the centre of mass of the system such that they are always on the vertices of a regular hexagon of side length a . Their common time period will be

(a) $4\pi\sqrt{\frac{a^3}{Gm}}$ (b) $2\pi\sqrt{\frac{4\sqrt{3}a^3}{Gm(5\sqrt{3}+4)}}$
(c) $4\pi\sqrt{\frac{3a^3}{Gm}}$ (d) None of these

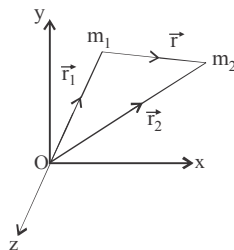
14. The gravitational force of attraction between a uniform sphere of mass M and a uniform rod of length l and mass m oriented as shown is

(a) $\frac{GMm}{r(r+l)}$
(b) $\frac{GM}{r^2}$
(c) $Mmr^2 + l$
(d) $(r^2 + l)mM$



15. In the figure, the direction of gravitational force on m_1 due to m_2 is along

(a) $\vec{i}_1$
(b) $\vec{i}_2$
(c) $\vec{r}$
(d) $-\vec{r}$



16. The gravitational force between two point masses m_1 and m_2 at separation r is given by $F = k \frac{m_1m_2}{r^2}$

The constant k

(a) depends on system of units only
(b) depends on medium between masses only
(c) depends on both (a) and (b)
(d) is independent of both (a) and (b)

17. Two identical solid copper spheres of radius R placed in contact with each other. The gravitational attraction between them is proportional to

(a) R^2 (b) R^3
(c) R^4 (d) R^{-4}

18. Two masses m_1 and m_2 ($m_1 < m_2$) are released from rest from a finite distance. They start under their mutual gravitational attraction –

(a) acceleration of m_1 is more than that of m_2 .
(b) acceleration of m_2 is more than that of m_1 .
(c) centre of mass of system will remain at rest in all the reference frame
(d) total energy of system does not remain constant

19. If the distance between two masses is doubled, the gravitational attraction between them

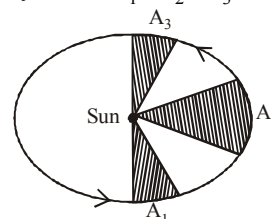
(a) is doubled (b) becomes four times
(c) is reduced to half (d) is reduced to a quarter

20. Who among the following gave first the experimental value of G ?

(a) Cavendish (b) Copernicus
(c) Brook Taylor (d) None of these

21. A planet moving around sun sweeps area A_1 in 2 days, A_2 in 3 days and A_3 in 6 days, then $A_1 : A_2 : A_3$ is

(a) 3 : 2 : 6
(b) 6 : 2 : 3
(c) 2 : 3 : 6
(d) 3 : 6 : 2



22. Average distance of the earth from the sun is L_1 . If one year of the earth = D days, one year of another planet whose average distance is L_2 from the sun, will be

(a) $D\left(\frac{L_2}{L_1}\right)^{1/2}$ days (b) $D\left(\frac{L_2}{L_1}\right)^{3/2}$ days
(c) $D\left(\frac{L_2}{L_1}\right)^{2/3}$ days (d) $D\left(\frac{L_2}{L_1}\right)$ days

23. The time period of revolution T of planet in years (yr) is 84. The semi-major axis a in units of 10^{10} m is 287. The quotient (T^2/a^3) in units of $10^{-34} \text{ yr}^2 \text{ m}^{-3}$ is approximately

(a) 3 units (b) 4 units (c) 2 units (d) 1 units

24. According to Kepler's law of planetary motion, if T represents time period and r is orbital radius, then for two planets, these are related as

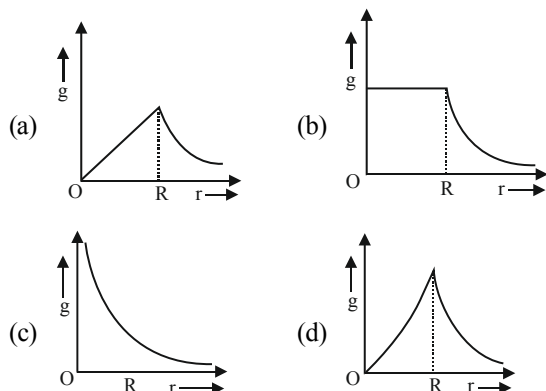
(a) $\left(\frac{T_1}{T_2}\right)^3 = \left(\frac{r_1}{r_2}\right)^2$ (b) $\left(\frac{T_1}{T_2}\right)^{3/2} = \left(\frac{r_1}{r_2}\right)$
(c) $\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{r_1}{r_2}\right)^3$ (d) $\left(\frac{T_1}{T_2}\right) = \left(\frac{r_1}{r_2}\right)^{2/3}$

25. Assuming that earth and the mars move in circular orbits around the sun, with the martian orbit being 1.52 times the orbital radius of the earth. The length of the martian year (in days) is
 (a) $(1.52)^{2/3} \times 365$ (b) $(1.52)^{3/2} \times 365$
 (c) $(1.52)^2 \times 365$ (d) $(1.52)^3 \times 365$
26. A planet moves around the sun. At a given point P , it is closed from the sun at a distance d_1 and has a speed v_1 . At another point Q , when it is farthest from the sun at a distance d_2 , its speed will be
 (a) $\frac{d_1^2 v_1}{d_2^2}$ (b) $\frac{d_2 v_1}{d_1}$ (c) $\frac{d_1 v_1}{d_2}$ (d) $\frac{d_2^2 v_1}{d_1^2}$
27. A planet takes 200 days to complete one revolution around the Sun. If the distance of the planet from Sun is reduced to one fourth of the original distance, how many days will it take to complete one revolution :
 (a) 20 (b) 25 (c) 50 (d) 100

3.2 Acceleration due to Gravity of the Earth and Variations in Acceleration due to Gravity

28. The value of acceleration due to gravity at a depth of 1600 km is equal to [Radius of earth = 6400 km]
 (a) 9.8 m s^{-2} (b) 4.9 m s^{-2}
 (c) 7.35 m s^{-2} (d) 19.6 m s^{-2}
29. If the mass of a body is M on the surface of the earth, the mass of the same body on the surface of the moon is
 (a) M (b) zero (c) $M/6$ (d) $6M$
30. The radii of two planets are respectively R_1 and R_2 and their densities are respectively ρ_1 and ρ_2 . The ratio of the accelerations due to gravity at their surfaces is
 (a) $g_1 : g_2 = \frac{\rho_1}{R_1^2} : \frac{\rho_2}{R_2^2}$ (b) $g_1 : g_2 = R_1 R_2 : \rho_1 \rho_2$
 (c) $g_1 : g_2 = R_1 R_2 : R_2 \rho_1$ (d) $g_1 : g_2 = R_1 \rho_1 : R_2 \rho_2$
31. A body weight W , is projected vertically upwards from earth's surface to reach a height above the earth which is equal to nine times the radius of earth. The weight of the body at that height will be:
 (a) $\frac{W}{91}$ (b) $\frac{W}{100}$ (c) $\frac{W}{9}$ (d) $\frac{W}{3}$
32. If the density of a small planet is the same as that of earth, while the radius of the planet is 0.2 times that of the earth, the gravitational acceleration on the surface of the planet is
 (a) $0.2 g$ (b) $0.4 g$
 (c) $2 g$ (d) $4 g$
33. If the radius of the earth were to shrink by 1%, with its mass remaining the same, the acceleration due to gravity on the earth's surface would
 (a) decrease by 1% (b) decrease by 2%
 (c) increase by 1% (d) increase by 2%
34. As we go down below the earth's surface, the acceleration due to gravity decreases by a factor
 ($d \rightarrow$ distance, $R \rightarrow$ radius of earth)
 (a) $1 + \frac{d}{R}$ (b) $1 - \frac{R}{d}$
 (c) $1 - \frac{d}{R}$ (d) remains constant
35. Acceleration due to gravity
 (a) increases with altitude
 (b) decreases with altitude
 (c) is independent of altitude
 (d) first decrease and then increase with altitude
36. At what height from the ground will the value of g be the same as that in 10 km deep mine below the surface of earth?
 (a) 20 km (b) 10 km
 (c) 15 km (d) 5 km
37. If a person goes to height equal to the radius of the earth, from its surface, then his weight (W') relative to the weight on earth (W) will be
 (a) $W' = \frac{W}{4}$ (b) $W' = 2W$
 (c) $W' = \frac{W}{2}$ (d) $W' = W$
38. If value of acceleration due to gravity is ' g ' at a height 50 km above the surface of earth, then at what depth inside the earth will the acceleration due to gravity be same as ' g '?
 (a) 100 km (b) 50 km
 (c) 25 km (d) 75 km
39. The value of acceleration due to gravity on moving from equator to poles will
 (a) decrease (b) increase
 (c) remain same (d) become half
40. Which of the following is the correct relation between acceleration due to gravity ' g ' and universal gravitational constant (G).
 (a) $g = \frac{G}{MR_E^2}$ (b) $g = \frac{GM_E}{R_E^2}$
 (c) $g = G$ (d) $g = \frac{GM_E}{R_E}$
41. An object is taken to a height above the surface of earth at a distance $\frac{5}{4}R$ from the centre of the earth. Where radius of earth, $R = 6400 \text{ km}$. The percentage decrease in the weight of the object will be
 (a) 36% (b) 50%
 (c) 64% (d) 25%

42. The weight of a body at the centre of the earth is
 (a) zero
 (b) infinite
 (c) same as on the surface of earth
 (d) None of these
43. The variation of acceleration due to gravity (g) with distance (r) from the center of the earth is correctly represented by:
 (Given R = radius of earth)



3.3 Intensity of Gravitational Field, Gravitational Potential and Gravitational Potential Energy

44. If ' g ' is the acceleration due to gravity on the earth's surface, the gain in the potential energy of an object of mass ' m ' raised from the surface of the earth to a height equal to the radius ' R ' of the earth is
 (a) $\frac{1}{4}mgR$ (b) $\frac{1}{2}mgR$ (c) $2mgR$ (d) mgR
45. The diagram showing the variation of gravitational potential of earth with distance from the centre of earth is
 (a) (b) (c) (d)
46. If an object of mass m is taken from the surface of earth (radius R) to a height $2R$, then the work done is
 (a) $2mgR$ (b) mgR (c) $\frac{2}{3}mgR$ (d) $\frac{3}{2}mgR$
47. Two bodies of masses m and $4m$ are placed at a distance r . The gravitational potential at a point on the line joining them where the gravitational field is zero is:
 (a) $-\frac{4Gm}{r}$ (b) $-\frac{6Gm}{r}$ (c) $-\frac{9Gm}{r}$ (d) zero

48. If the radius of the earth were to shrink by 1%, with its mass remaining the same, the acceleration due to gravity on the earth's surface would
 (a) decrease by 1% (b) decrease by 2%
 (c) increase by 1% (d) increase by 2%
49. As we go down below the earth's surface, the acceleration due to gravity decreases by a factor ($d \rightarrow$ distance, $R \rightarrow$ radius of earth)
 (a) $1 + \frac{d}{R}$ (b) $1 - \frac{R}{d}$
 (c) $1 - \frac{d}{R}$ (d) remains constant

3.4 Escape Speed, Earth's Satellites and Weightlessness

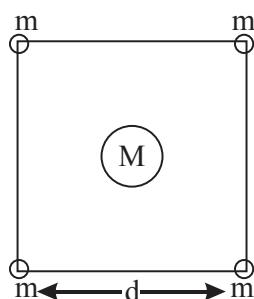
50. If escape velocity on earth's surface is 11.1 km/h, then find the escape velocity on moon's surface. Mass of the moon is $\left(\frac{1}{81}\right)$ times of the mass of earth and radius of the moon is $\left(\frac{1}{4}\right)$ times radius of the earth.
 (a) 2.46 km/h (b) 3.46 km/h
 (c) 4.4 km/h (d) None of these
51. A satellite with kinetic energy E_k is revolving round the earth in a circular orbit. How much more kinetic energy should be given to it so that it may just escape into outer space
 (a) E_k (b) $2E_k$ (c) $\frac{1}{2}E_k$ (d) $3E_k$
52. A planet in a distant solar system is 10 times more massive than the earth and its radius is 10 times smaller. Given that the escape velocity from the earth is 11 km s^{-1} , the escape velocity from the surface of the planet would be
 (a) 1.1 km s^{-1} (b) 11 km s^{-1}
 (c) 110 km s^{-1} (d) 0.11 km s^{-1}
53. A geostationary satellite is orbiting the earth at a height of $5R$ above that surface of the earth, R being the radius of the earth. The time period of another satellite in hours at a height of $2R$ from the surface of the earth is
 (a) 5 (b) 10 (c) $6\sqrt{2}$ (d) $\frac{6}{\sqrt{2}}$
54. For any rocket on earth the escape velocity is 11.2 km/sec. The value of the escape velocity at the planet where acceleration due to gravity is two times that of the earth and the diameter is two times that of the earth will be
 (a) 33.6 km/s (b) 22.4 km/s
 (c) 11.2 km/s (d) 5.6 km/s
55. If the escape velocity of a planet is 3 times that of the earth and its radius is 4 times that of the earth, then the mass of the planet is
 (a) $1.62 \times 10^{22} \text{ kg}$ (b) $0.72 \times 10^{22} \text{ kg}$
 (c) $2.16 \times 10^{26} \text{ kg}$ (d) $1.22 \times 10^{22} \text{ kg}$
56. The time period T of the moon of planet Mars (mass M_m) is related to its orbital radius R (G = Gravitational constant) as

- (a) $T^2 = \frac{4\pi^2 R^3}{GM_m}$ (b) $T^2 = \frac{4\pi^2 GR^3}{M_m}$
- (c) $T^2 = \frac{2\pi R^3 G}{M_m}$ (d) $T^2 = 4\pi M_m GR^3$
57. For a satellite moving in an orbit around the earth, the ratio of kinetic energy to potential energy is
 (a) 2 (b) 1/2
 (c) $1/\sqrt{2}$ (d) $\sqrt{2}$
58. Two identical satellites are at R and $7R$ away from earth surface, the wrong statement is (R = Radius of earth)
 (a) Ratio of total energy will be 4
 (b) Ratio of kinetic energies will be 4
 (c) Ratio of potential energies will be 4
 (d) Ratio of total energy will be 4 but ratio of potential and kinetic energies will be 2
59. A geostationary satellite is revolving around the earth. To make it escape from gravitational field of earth, its velocity must be increased.
 (a) 100% (b) 41.4%
 (c) 50% (d) 59.6%
60. The value of escape velocity on a certain planet is 2 km/s. Then the value of orbital speed for a satellite orbiting close to its surface is
 (a) 12 km/s (b) 1 km/s
 (c) $\sqrt{2}$ km/s (d) $2\sqrt{2}$ km/s
61. The mean radius of the earth is R , its angular speed on its own axis is ω and the acceleration due to gravity at earth's surface is g . The cube of the radius of the orbit of a geostationary satellite will be
 (a) $R^2 g / \omega$ (b) $R^2 \omega^2 / g$
 (c) Rg / ω^2 (d) $R^2 g / \omega^2$
62. The orbital speed of an artificial satellite very close to the surface of the earth is V_o . Then the orbital speed of another artificial satellite at a height equal to three times the radius of the earth is
 (a) $1 V_o$ (b) $2 V_o$
 (c) $0.5 V_o$ (d) $4 V_o$
63. The distance of a geostationary satellite from the centre of the earth ($R = 6400$ km) is nearest to
 (a) $5R$ (b) $7R$
 (c) $10R$ (d) $18R$
64. Where can a geostationary satellite be installed
 (a) Over any city on the equator
 (b) Over the north or south pole
 (c) At height R above earth
 (d) At the surface of earth

Exercise 3 :

PREVIOUS YEARS MCQs

1. The value of acceleration due to gravity at Earth's surface is 9.8 ms^{-2} . The altitude above its surface at which the acceleration due to gravity decreases to 4.9 ms^{-2} , is close to : (Radius of earth = $6.4 \times 10^6 \text{ m}$) [2025]
 (a) $2.6 \times 10^6 \text{ m}$ (b) $6.4 \times 10^6 \text{ m}$
 (c) $9.0 \times 10^6 \text{ m}$ (d) $1.6 \times 10^6 \text{ m}$
2. Two identical particles each of mass 'm' go round a circle of radius a under the action of their mutual gravitational attraction. The angular speed of each particle will be: [2024]
 (a) $\sqrt{\frac{Gm}{2a^3}}$ (b) $\sqrt{\frac{Gm}{8a^3}}$
 (c) $\sqrt{\frac{Gm}{4a^3}}$ (d) $\sqrt{\frac{Gm}{a^3}}$
3. A planet having mass $9 M_e$ and radius $4R_e$, where M_e and R_e are mass and radius of earth respectively, has escape velocity in km/s given by: [2023]
 (Given escape velocity on earth $V_e = 11.2 \times 10^3 \text{ m/s}$)
 (a) 67.2 (b) 16.8
 (c) 33.6 (d) 11.2
4. The potential energy of a satellite, having mass m and rotating at a height of $6.4 \times 10^6 \text{ m}$ from the earth surface, is [2023]
 (a) $-mgR_e$
 (b) $-0.67 mgR_e$
 (c) $-0.5 mgR_e$
 (d) $-0.33 mgR_e$
5. Two planets A and B of equal mass are having their period of revolutions T_A and T_B such that $T_A = 2T_B$. These planets are revolving in the circular orbits of radii r_A and r_B respectively. Which out of the following would be the correct relationship of their orbits? [2022]
 (a) $2r_A^2 = r_B^2$
 (b) $r_A^3 = 2r_B^3$
 (c) $r_A^3 = 4r_B^3$
 (d) $T_A^2 - T_B^2 = \frac{\pi^2}{GM}(r_B^3 - 4r_A^3)$
6. Four spheres each of mass m form a square of side d (as shown in figure). A fifth sphere of mass M is situated at the centre of square. The total gravitational potential energy of the system is : [2022]



- (a) $-\frac{Gm}{d}[(4+\sqrt{2})m+4\sqrt{2}M]$
 (b) $-\frac{Gm}{d}[(4+\sqrt{2})M+4\sqrt{2}m]$
 (c) $-\frac{Gm}{d}[3m^2+4\sqrt{2}M]$
 (d) $-\frac{Gm}{d}[6m^2+4\sqrt{2}M]$

7. A central particle M is surrounded by a square array of other particles, separated by either distance d or distance $d/2$ along the perimeter of the square. The magnitude of the gravitational force on the central particle due to the other particles is [2021]

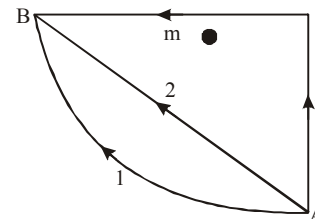
- (a) $\frac{9GMm}{d^2}$
 (b) $\frac{5GMm}{d^2}$
 (c) $\frac{3GMm}{d^2}$
 (d) $\frac{GMm}{d^2}$

8. Newton's universal law of gravitation applies to
 (a) small bodies only [2020, 2006]
 (b) planets only
 (c) both small and big bodies
 (d) only valid for solar system
9. If three equal masses m are placed at the three vertices of an equilateral triangle of side $1/m$ then what force acts on a particle of mass $2m$ placed at the centroid? [2019, 2010]
 (a) Gm^2 (b) $2Gm^2$ (c) Zero (d) $-Gm^2$
10. A particle of mass M is situated at the centre of a spherical shell of same mass and radius a . The gravitational potential at a point situated at $\frac{a}{2}$ distance from the centre, will be: [2018]
 (a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$ (c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$
11. The radius of the earth and the radius of orbit around the sun are 6371 km and 149×10^6 km respectively. The order of magnitude of the diameter of the orbit is greater than that of earth by [2016, 2008]

- (a) 10^3 (b) 10^2
 (c) 10^4 (d) 10^5

12. If W_1 , W_2 and W_3 represent the work done in moving a particle from A to B along three different paths 1, 2 and 3 (as shown in fig.) in the gravitational field of the point mass ' m '. Find the correct relation between ' W_1 ', ' W_2 ' and ' W_3 '. [2015]

- (a) $W_1 < W_3 < W_2$
 (b) $W_1 < W_2 < W_3$
 (c) $W_1 = W_2 = W_3$
 (d) $W_1 > W_3 > W_2$



13. A body is projected vertically from the surface of the earth of radius ' R ' with velocity equal to half of the escape velocity. The maximum height reached by the body is [2013]

- (a) $\frac{R}{5}$ (b) $\frac{R}{3}$ (c) $\frac{R}{2}$ (d) $\frac{R}{4}$

14. A satellite is revolving in a circular orbit at a height ' h ' above the surface of the earth of radius ' R '. The speed of the satellite in its orbit is one-fourth the escape velocity from the surface of the earth. The relation between ' h ' and ' R ' is [2011]

- (a) $h = 2R$ (b) $h = 3R$
 (c) $h = 5R$ (d) $h = 7R$

15. The ratio of binding energy of a satellite at rest on earth's surface to the binding energy of a satellite of same mass revolving around the earth at a height h above the earth's surface is [2009]
 (R = radius of the earth).

- (a) $\frac{2(R+h)}{R}$ (b) $\frac{R+h}{2}$
 (c) $\frac{R+h}{R}$ (d) $\frac{R}{R+h}$

16. The depth ' d ' at which the value of acceleration due to gravity becomes $\frac{1}{n}$ times the value at the earth's surface is (R = radius of earth) [2007]

- (a) $d = R \left(\frac{n}{n-1} \right)$ (b) $d = R \left(\frac{n-1}{2n} \right)$
 (c) $d = R \left(\frac{n-1}{n} \right)$ (d) $d = R^2 \left(\frac{n-1}{n} \right)$

17. The value of gravitational acceleration g at a height h above the earth's surface is $\frac{g}{4}$, then (R = radius of earth)

- (a) $h = R$ (b) $h = \frac{R}{2}$ [2005]
 (c) $h = \frac{R}{3}$ (d) $h = \frac{R}{4}$

ANSWER KEYS

Exercise 1 : WARM-UP Topic-wise MCQs

1	(b)	11	(b)	21	(b)	31	(d)	41	(c)	51	(d)	61	(c)	71	(b)	81	(d)	91	(a)
2	(c)	12	(d)	22	(b)	32	(b)	42	(c)	52	(d)	62	(c)	72	(b)	82	(c)	92	(b)
3	(c)	13	(d)	23	(d)	33	(a)	43	(c)	53	(d)	63	(c)	73	(d)	83	(b)	93	(b)
4	(b)	14	(c)	24	(c)	34	(d)	44	(b)	54	(a)	64	(a)	74	(b)	84	(a)	94	(b)
5	(d)	15	(c)	25	(b)	35	(a)	45	(d)	55	(d)	65	(a)	75	(a)	85	(b)	95	(a)
6	(d)	16	(d)	26	(c)	36	(d)	46	(b)	56	(a)	66	(b)	76	(a)	86	(d)	96	(a)
7	(a)	17	(c)	27	(b)	37	(d)	47	(b)	57	(a)	67	(a)	77	(b)	87	(c)	97	(a)
8	(a)	18	(b)	28	(c)	38	(c)	48	(c)	58	(d)	68	(a)	78	(c)	88	(a)	98	(d)
9	(d)	19	(a)	29	(a)	39	(b)	49	(c)	59	(b)	69	(b)	79	(d)	89	(b)	99	(d)
10	(b)	20	(b)	30	(c)	40	(c)	50	(d)	60	(b)	70	(d)	80	(a)	90	(c)	100	(c)

Exercise 2 : ACCELERATOR Topic-wise MCQs

1	(d)	8	(a)	15	(c)	22	(b)	29	(a)	36	(d)	43	(a)	50	(a)	57	(b)	64	(a)
2	(a)	9	(d)	16	(a)	23	(a)	30	(d)	37	(a)	44	(b)	51	(a)	58	(d)		
3	(d)	10	(c)	17	(c)	24	(c)	31	(b)	38	(a)	45	(c)	52	(c)	59	(b)		
4	(d)	11	(b)	18	(a)	25	(b)	32	(a)	39	(b)	46	(c)	53	(c)	60	(c)		
5	(d)	12	(a)	19	(d)	26	(c)	33	(d)	40	(b)	47	(c)	54	(b)	61	(d)		
6	(d)	13	(b)	20	(a)	27	(b)	34	(c)	41	(a)	48	(d)	55	(c)	62	(c)		
7	(c)	14	(a)	21	(c)	28	(c)	35	(b)	42	(a)	49	(c)	56	(a)	63	(b)		

Exercise 3 : PREVIOUS YEARS MCQs

1	(a)	3	(b)	5	(c)	7	(c)	9	(c)	11	(c)	13	(b)	15	(a)	17	(a)		
2	(c)	4	(c)	6	(a)	8	(c)	10	(a)	12	(c)	14	(d)	16	(c)				

4

Thermal Properties of Matter



TOPIC 4.1 : TEMPERATURE & HEAT, MEASUREMENT OF TEMPERATURE, ABSOLUTE TEMPERATURE AND IDEAL GAS EQUATION, THERMAL EXPANSION

TEMPERATURE AND HEAT

Temperature is defined as the degree of hotness or coldness of a body.

Heat is a form of energy which causes sensation of hotness or coldness.

No heat flows from one body to other, when both the bodies are at the same temperature i.e. in **thermal equilibrium**.

The **SI unit** of heat is **joule**. Its **CGS unit** is **calorie**, $1 \text{ cal} = 4.2 \text{ joule}$

MEASUREMENT OF TEMPERATURE

Thermometer is a device used to measure the temperature. Thermometer used for measuring very high temperatures are called **pyrometer**.

Relationship Between Different Scales of Temperature

$$\frac{C - 0}{100} = \frac{F - 32}{212 - 32} = \frac{K - 273.16}{373.16 - 273.16}$$

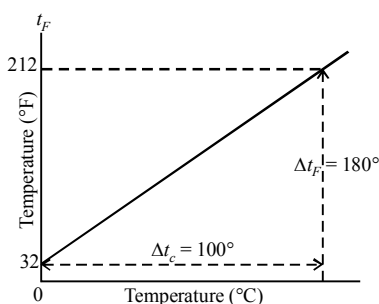
$$= \frac{R - 0}{80 - 0} = \frac{Ra - 460}{672 - 460}$$

$$T(K) = (t^{\circ}\text{C} + 273.16)$$

Normal temperature of human body is 310.15 K

$(37^{\circ}\text{C} = 98.6^{\circ}\text{F})$

STP or NTP implies 273.15 K ($0^{\circ}\text{C} = 32^{\circ}\text{F}$)



Types of Thermometers

Thermometry deals with the measurement of temperature of a substance.

- (1) A platinum resistance thermometer is used to measure temperatures between -250°C and 1200°C .
- (2) **Liquid thermometers** : Mercury thermometers, Alcohol thermometers. Mercury has high thermal conductivity and low specific heat.
- (3) **Gas thermometers** are of two types :
 - (i) In **constant volume gas thermometers**, we find the variation of pressure (P) of a gas with temperature (t) at constant volume.

$$\text{Formula : } t = \left(\frac{P - P_0}{P_{100} - P_0} \right) \times 100^{\circ}\text{C}$$

- (ii) In constant pressure gas thermometer, we find the variation in V with temperature at constant P.

Formula for unknown temperature,

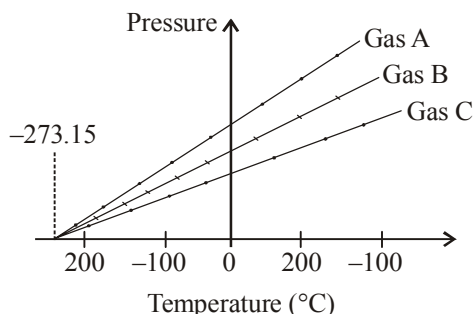
$$t = \left(\frac{V - V_0}{V_{100} - V_0} \right) \times 100^{\circ}\text{C}$$

We use hydrogen, helium and nitrogen gas thermometers.

(Temperature range - 200°C to about 600°C)

- (4) Thermoelectric thermometers using thermocouples. (Based on Seebeck effect.)
- (5) **Pyrometers** : They are used for measuring very high temperatures. [From 600°C to 6000°C . They are based on Stefan's law of radiation $Q \propto T^4$.]
- (6) Vapour pressure thermometers are used to measure very low temperatures.

ABSOLUTE TEMPERATURE AND IDEAL GAS EQUATION



In the graph of pressure versus temperature, the temperature at which the pressure of a gas would be zero is -273.15°C .

Absolute zero temperature = $-273.15^\circ = 0\text{ K}$

The relation between three properties of gas i.e., pressure, volume and temperature is called ideal gas equation.

Charle's law pressure is constant $\rightarrow \frac{V}{T} = \text{constant}$.

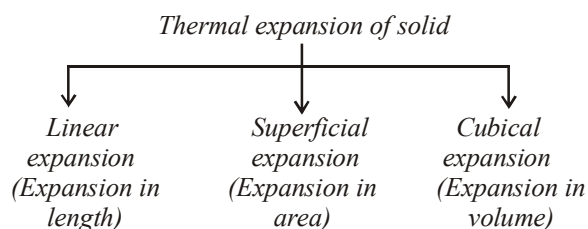
Boyle's law temperature is constant $\rightarrow pV = \text{constant}$.

Gay Lussac's law volume is constant $\rightarrow \frac{p}{T} = \text{constant}$.

THERMAL EXPANSION

The increase in the dimensions of a body due to the increase in its temperature is called thermal expansion.

The thermal expansion of solid is classified as follows:



Linear Expansion

The increase in length of a metal rod on heating is called linear expansion.

The fractional increase in length per $^\circ\text{C}$ rise in temperature is called **coefficient of linear expansion**. If ℓ is the length of the rod at a temperature $T\text{ K}$ and as the temperature is increased to $T + \Delta T$ its length becomes $\ell + \Delta\ell$, so coefficient of linear expansion α is

$$\text{Coefficient of linear expansion, } \alpha = \frac{\left(\frac{\Delta\ell}{\ell}\right)}{\Delta T} = \frac{d\ell}{\ell \cdot dT}$$

It is positive for metals except carbon. The value of α is negative for plastic because in plastic when the temperature increases, length decreases. The numerical value of α is same in both the units i.e. in per K or per $^\circ\text{C}$

If α is coefficient of linear expansion at $t_1^\circ\text{C}$ then,

$$\ell_1 = \text{length of the rod at } t_1^\circ\text{C}$$

$$\ell_2 = \text{length of the rod at } t_2^\circ\text{C}$$

$$\text{then, } \ell_2 = \ell_1 [1 + \alpha(t_2 - t_1)]$$

Superficial Expansion

On increasing the temperature of a metal sheet, its area increases. This increase in area is referred as **superficial or areal expansion**. If the area of solid at temperature $t_1^\circ\text{C}$ is A_1 and on heating the rod, the area becomes A_2 at $t_2^\circ\text{C}$ then,

$$A_2 = A_1 [1 + \beta(t_2 - t_1)]$$

where β is called coefficient of superficial expansion.

Coefficient of superficial expansion is defined as the fractional increase in area per $^\circ\text{C}$ rise in temperature.

i.e., Coefficient of areal expansion

$$\beta = \frac{\Delta A / A}{\Delta T} = \frac{dA}{A \cdot dT}$$

Cubical Expansion

On increasing the temperature of a solid, its volume increases. This increase in volume with increase in temperature is called cubical or volume expansion.

If V_1 is the volume of a solid at temperature $t_1^\circ\text{C}$ and on increasing the temperature to $t_2^\circ\text{C}$ the volume becomes V_2 then,

$$V_2 = V_1 [1 + \gamma(t_2 - t_1)]$$

where γ is coefficient of volume expansion.

Coefficient of volume expansion is defined as the fractional increase in volume per $^\circ\text{C}$ rise in temperature.

i.e., Coefficient of volume expansion,

$$\gamma = \frac{\Delta V / V}{\Delta T} = \frac{dV}{V \cdot dT}$$

Relation between coefficient of linear expansion (α), superficial expansion (β) and cubical expansion (γ)

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}$$

$$\Rightarrow \alpha : \beta : \gamma = 1 : 2 : 3$$

Thermal stress in a rigidly fixed rod : When a rod is heated or cooled, it expands or contracts.

If the ends of the rods are rigidly fixed so as to prevent it from expansion or contraction then stress is produced in the rod.

Thermal stress developed $= \gamma \propto \Delta T$

Expansion of Liquid

When a liquid is heated, its container also expands. The observed expansion of the liquid is called apparent expansion which is different from the real expansion of the liquid.

Coefficient of apparent expansion. It is defined as the apparent increases in volume per unit original volume for 1°C rise in temperature. The coefficient of apparent expansion of the liquid is given by

$$\gamma_a = \frac{\text{Apparent increase in volume}}{\text{Original volume} \times \text{rise in temperature}}$$

Coefficient of real expansion. It is defined as the real increase in volume per unit original volume for 1°C rise in temperature. The coefficient of real expansion of the liquid is given by

$$\gamma_r = \frac{\text{Real increase in volume}}{\text{Original volume} \times \text{rise in temperature}}$$

It can be proved that $\gamma_r = \gamma_a + \gamma_g$

where γ_g is coefficient of cubical expansion of glass (material) of the container.

Change in Density with Temperature

Suppose m is the mass of a solid which is at a given temperature occupies a volume V so that density at 0°C is $d_0 = \frac{m}{V}$

Now, if the temperature is increased by $t^\circ\text{C}$, mass will remain unchanged but due to thermal expansion volume increases so that, $V' = V(1 + \gamma\Delta t)$

Now density, $d_t = \frac{m}{V'} = \frac{m}{V(1 + \gamma\Delta t)}$ or, d_t

$$= \frac{d_0}{(1 + \gamma\Delta t)} = d_0(1 + \gamma\Delta t)^{-1}$$

$$\text{or } d_t = d_0(1 - \gamma\Delta t)$$

Thus the density of a solid or a liquid (except water) decreases with the increase in temperature.

Here γ is coefficient of cubical expansion of the substance.

Anomalous expansion of water

Water exhibits an anomalous behaviour; it contracts on heating between 0°C and 4°C . The volume of a given amount of water decreases as it is cooled from room temperature, until its temperature reaches 4°C . Below 4°C , the volume increases, and therefore, the density decreases. This means that water has the maximum density at 4°C .

TOPIC 4.2 : SPECIFIC HEAT CAPACITY, CALORIMETRY AND CHANGE OF STATE

SPECIFIC HEAT CAPACITY

Specific heat capacity : It is the amount of heat energy needed to raise the temperature of unit mass of substance by 1°C (or 1K).

It is denoted by s or c .

$$c = \frac{1}{m} \frac{dQ}{dT}$$

Unit of specific heat capacity :

CGS unit of specific heat capacity is $\text{cal/g } ^\circ\text{C}$

SI unit of specific heat capacity is joule/kg K

For example, the specific heat capacity of water is:

$$\begin{aligned} c_{\text{water}} &= 1 \text{ cal/g } ^\circ\text{C} = 1 \text{ cal/g K} \\ &= 1 \text{ kcal/kg K} = 4200 \text{ joule/kg K} \end{aligned}$$

Molar specific heat capacity "C" : The molar heat capacity C is the heat required to raise the temperature of 1 mole of a substance by 1°C (or 1K). Heat required to raise the

temperature of n -moles of a substance by $\Delta T^\circ\text{C}$, $C = \frac{\Delta Q}{n\Delta T}$

Its **SI unit** is $\text{J mol}^{-1} \text{K}^{-1}$ and **CGS unit** $\text{cal mol}^{-1} \text{C}^{-1}$

For a gas the value of C depends on the process through which its temperature is raised.

For example, in an isothermal process $\Delta T = 0$ or $C_{\text{iso}} = \infty$.

In an adiabatic process $\Delta Q = 0$. Hence, $C_{\text{adi}} = 0$.

Thus, molar specific heat of a gas varies from 0 to ∞ depending on the process.

Thermal or heat capacity : It is the quantity of heat required to raise the temperature of the whole substance by 1°C . The thermal capacity of mass m of the whole of substance of specific heat capacity s is equal to (ms) kilocalorie.

i.e., Thermal capacity = mass $\times$ specific heat capacity

CALORIMETRY

The branch of physics that deals with the measurement of heat is called **calorimetry**. A device in which heat measurement can be done is called **calorimeter**.

Principle of Calorimetry or Law of Mixture

When two bodies (one being solid and other liquid or both being liquid) at different temperatures are mixed, heat will be transferred from body at higher temperature to a body at lower temperature till both acquire same temperature. The body at higher temperature released heat while body at lower temperature absorbs it. Then according to the principle of calorimetry, Heat lost = heat gained

Heat lost or gained by a body is given by,

$$Q = m \times c \times (\theta_2 - \theta_1)$$

Principle of calorimetry represents the law of conservation of heat energy. Temperature of mixture (T) is always $\geq$ lower temperature (T_L) and $\leq$ higher temperature (T_H), $T_L \leq T \leq T_H$

Latent Heat or Hidden Heat

The amount of heat required to change the state of unit mass of a substance at a constant temperature is called the latent heat.

$$Q = mL$$

where L is latent heat.

The **SI unit** of latent heat is J/kg

Latent heat of fusion : The quantity of heat (in kilocalorie) required to change unit mass from solid to liquid state at its melting point is called latent heat of fusion.

For ice latent heat of fusion = 80 kilocal/kg .

Latent heat of vaporisation : It is the quantity of heat required to change unit mass from liquid to vapour state at its boiling point. For water latent heat of vaporisation = 536 kilocal/kg .

Water equivalent of a body : The thermal capacity of a body (ms) also represents its water equivalent, since the specific heat of water is unity.

The *water equivalent of a body is the amount of water that absorbs or gives out the same amount of heat as is done by the body when heated or cooled through 1°C.*

Mass of water having the same thermal capacity as the body is called the water equivalent of the body

$$W = \text{mass} \times \text{specific heat capacity}$$

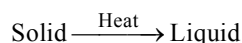
Its **SI unit** is Kg and **CGS unit** g.

CHANGE OF STATE

The transition of a substance from one state to another is called a change of state.

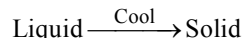
Some common changes of states :

- (i) **Melting :** When heat is supplied, solid substance changes into liquid, this change of state of substance is called melting.

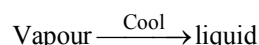


The temperature at which the solid and the liquid states of a substance coexist in thermal equilibrium with each other is called its **melting point**.

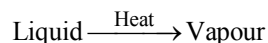
- (ii) **Freezing :** When heat is released, liquid changes into solid, this change of state of substance is called freezing.



- (iii) **Condensation :** When vapour is cooled, it changes into liquid, this change of state is called condensation



- (iv) **Vaporisation :** Conversion of liquid into gaseous state at all the temperatures is called vaporisation.

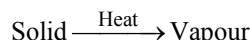


There are two types of vaporisation : Evaporation and Boiling.

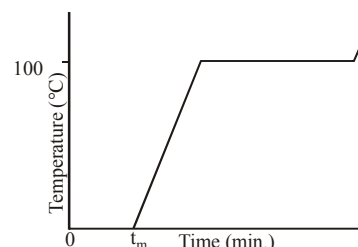
The temperature at which the liquid and vapour states of a substance coexist in thermal equilibrium with each other is called its **boiling point** and the process is called boiling.

Evaporation is a phenomenon that occurs at the top surface of liquids. The rate of evaporation increases with rise in temperature. Heat required to change unit mass of liquid into vapour at a given temperature is called heat of evaporation at that temperature.

- (v) **Sublimation :** It is the conversion of a solid directly into vapours.

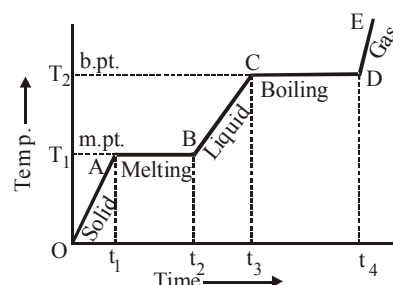


After the whole of ice gets converted into water and as we continue further heating, we shall see that temperature begins to rise. The temperature keeps on rising till it reaches nearly 100°C when it again becomes steady. The heat supplied is now being utilised to change water from liquid state to vapour or gaseous state.

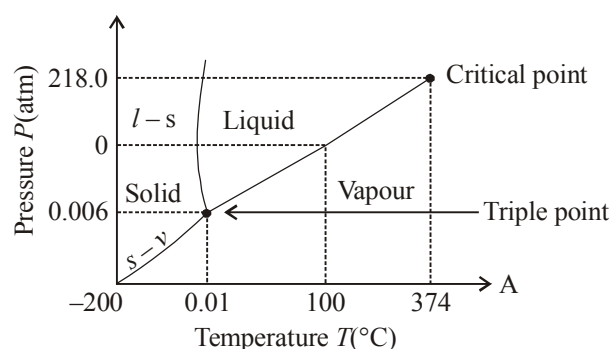


Heating Curve

For a given mass (m) of a solid, heat is supplied at constant rate and a graph is plotted between temperature and time and the graph is called heating curve.



Regelation : The phenomenon in which ice-melts when pressure is increased and again freezes when pressure is removed is called regelation.



TOPIC 4.3 : HEAT TRANSFER, CONDUCTION, CONVECTION, RADIATION, NEWTON'S LAW OF COOLING

HEAT TRANSFER

Heat can be transferred from one place to another by three different methods. They are conduction, convection and radiation.

CONDUCTION

Conduction is that mode of transmission of heat in which heat is transferred from a region of higher temperature to a region of lower temperature by the aid of particles of the body without their actual migration. Conduction requires material medium.

In metals the conduction of heat takes place by means of free electrons present in the metal.

The rate of flow of heat through a metal rod will remain same, if the ends are maintained at same temperature difference.

Temperature gradient : The rate of change of temperature with distance between two isothermal surfaces is called temperature gradient.

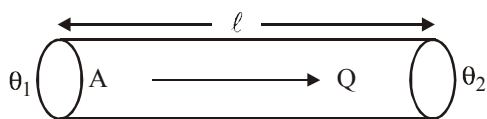
If the temperature of the isothermal surfaces be θ and $\theta - \Delta\theta$ and perpendicular distance between them is Δx then, Temperature gradient between them

$$= \frac{\text{Change in temperature}}{\text{Distance between two surfaces}}$$

$$= \frac{(\theta - \Delta\theta) - \theta}{\Delta x} = -\frac{\Delta\theta}{\Delta x}$$

The negative sign show that temperature θ decreases as the distance x increases in the direction of heat flow.

Unit: In SI System $^{\circ}\text{C}/\text{metre}$



$$\frac{Q}{t} \propto \frac{A(\theta_1 - \theta_2)}{l} \quad \text{or} \quad H = \frac{K A (\theta_1 - \theta_2)}{l}$$

where K is a constant of proportionality called the **thermal conductivity of the substance**. It is a measure of how quickly heat energy can conduct (flow) through the substance.

Coefficient of thermal conductivity (K) : The coefficient of thermal conductivity, K , of a material is defined as the quantity of heat that flows per unit time through a unit area of the material when its opposite faces are kept at a temperature difference of one degree.

Unit of coefficient of thermal conductivity in SI system is watt/m-K. **Dimensions :** $[\text{ML}^{-1}\text{T}^{-3}\theta^{-1}]$

For a perfect conductor thermal conductivity K is infinite and for a perfect insulator K is zero.

In general, solids are better conductors than liquids and liquids are better conductors than gases. Metals are much better conductors than non-metals.

The conduction of both heat and electricity is due to the movement of free electrons.

Thermal Resistance : It is defined as the ratio of temperature difference to the heat current (= rate of flow of heat)

Now, if temperature difference = $(\theta_1 - \theta_2)$

l = length of rod

Heat current, $H = \frac{Q}{t}$; A = area of cross section of rod

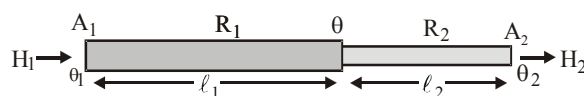
$$\therefore R_{Th} = \frac{\theta_1 - \theta_2}{H} = \frac{\theta_1 - \theta_2}{(Q/t)} = \frac{\theta_1 - \theta_2}{KA(\theta_1 - \theta_2)/l} = \frac{l}{KA}$$

$$\text{or } R_{Th} = \frac{\Delta\theta}{H} = \frac{l}{KA}$$

Unit in SI system : kelvin sec/joule

Combination of Metallic Conductors

Series combination of conductors



$$R = R_1 + R_2 \quad R_1 = \frac{l_1}{K_1 A_1} \quad \text{and} \quad R_2 = \frac{l_2}{K_2 A_2}$$

$$\text{so that, } \frac{l_{eq.}}{K_{eq.} A_{eq.}} = \frac{l_1}{K_1 A_1} + \frac{l_2}{K_2 A_2}$$

$$\text{If } A_1 = A_2 = A$$

$$\therefore \frac{l_1 + l_2}{K_{eq.}} = \frac{l_1}{K_1} + \frac{l_2}{K_2} \quad \text{or} \quad K_{eq.} = \frac{l_1 + l_2}{\frac{l_1}{K_1} + \frac{l_2}{K_2}}$$

$$\text{If } l_1 = l_2 = l; \quad K_{eq.} = \frac{2K_1 K_2}{K_1 + K_2}$$

If we have more than two slabs in the compound slab. Then the total thermal resistance of the slabs connected in series

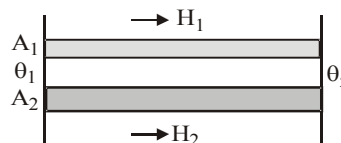
$$R_{eq.} = R_1 + R_2 + R_3 + \dots + R_n$$

Parallel combination of conductors

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

For more than two slabs, we have

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$



Suppose two conductors each of length l but with areas of cross-section A_1 and A_2 are connected in parallel. Let the temperatures of the first and second faces be θ_1 and θ_2 . The total heat current H_p is the sum of heat currents H_1 and H_2 in the first and second conductors respectively,

$$\text{i.e., } H_p = H_1 + H_2.$$

$$\text{Now, } H_1 = \frac{K_1 A_1 (\theta_1 - \theta_2)}{l} \quad \text{and} \quad H_2 = \frac{K_2 A_2 (\theta_1 - \theta_2)}{l}$$

$$\text{and } H_p = \frac{K_p (A_1 + A_2) (\theta_1 - \theta_2)}{l}$$

$$\text{As } H_p = H_1 + H_2, \text{ hence,}$$

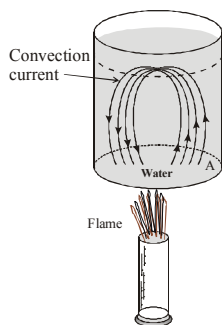
$$\frac{K_{eq} (A_1 + A_2) (\theta_1 - \theta_2)}{l} = \frac{K_1 A_1 (\theta_1 - \theta_2)}{l} + \frac{K_2 A_2 (\theta_1 - \theta_2)}{l}$$

$$\text{or } K_{eq} (A_1 + A_2) = K_1 A_1 + K_2 A_2 \quad \text{or} \quad K_{eq} = \frac{K_1 A_1 + K_2 A_2}{A_1 + A_2}$$

$$\text{If, } A_1 = A_2, \text{ then } K_{eq} = \frac{K_1 + K_2}{2}$$

CONVECTION

Convection like conduction requires a material medium. *It is the process in which heat is transferred from one place to other by actual movement of heated material particles.* It is possible only in fluids. The type of convection which results from difference in densities is called **natural convection**.



1. Natural convection takes place from bottom to top while forced convection in any direction.
2. In case of natural convection, convection currents move warm air upwards and cool air downwards. This is why heating is done from base, while cooling from the top.
3. Natural convection is not possible in a gravity free region such as in a freely falling lift or an orbiting satellite.
4. Natural convection plays an important role in ventilation, in changing climate and weather and in forming **land** and **sea breezes** and **trade winds**.
5. The forced convection of blood in our body by a pump (heart) helps in keeping the temperature of body constant.

RADIATION

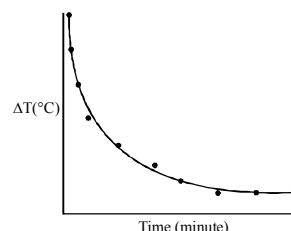
When a body is heated and placed in vacuum, it loses heat even when there is no medium surrounding it. The heat cannot go out from the body by the process of conduction or convection since

both of these process require the presence of a material medium between source and surrounding objects. The process by which heat is lost in this case is called radiation. This does not require the presence of any material medium. It is by radiation that the heat from the sun reaches the earth.

Radiation has the following properties :

- (a) Radiant energy travels in straight line and when some object is placed in the path, its shadow is formed at the detector.
- (b) It is reflected and refracted or can be made to interfere. The reflection or refraction are exactly as in case of light.
- (c) It can travel through vacuum.
- (d) Intensity of radiation follows the law of inverse square.
- (e) Thermal radiation can be polarised in the same way as light by transmission through a nicol prisms.

NEWTON'S LAW OF COOLING



According to Newton's law of cooling, the rate of loss of heat, $-dQ/dt$ of the body is directly proportional to the difference of temperature $\Delta T = (T_2 - T_1)$ of the body and the surroundings. The law holds good only for small difference of temperature.

From Newton's law of cooling

$$-\frac{dQ}{dt} = k(T_2 - T_1) \quad \dots(i)$$

where k is a positive constant depending upon the area and nature of the surface of the body.

CHAPTER AT A GLANCE

☛ **Temperature** is defined as the degree of hotness or coldness of a body.

☛ **Heat** is a form of energy which causes sensation of hotness or coldness.

☛ Conversion of temperature from one scale to another

$$\frac{T_C}{5} = \frac{T_F - 32}{9} = \frac{T_{Reu}}{4} = \frac{T_K - 273.15}{5}$$

☛ Temperature at which Fahrenheit and Celsius thermometers show the same reading is -40°C .

☛ Coefficient of linear, superficial and cubical expansion

$$\alpha = \frac{\Delta \ell}{\ell_0 \Delta T} \quad \beta = \frac{\Delta s}{s_0 \Delta T} \quad \text{and} \quad \gamma = \frac{\Delta v}{v_0 \Delta T}$$

☛ Relation between α , β and γ : $\beta = 2\alpha$ and $\gamma = 3\alpha \Rightarrow \alpha : \beta : \gamma = 1 : 2 : 3$

☛ Final volume $v = v_0 (1 + \gamma \Delta T)$; Final density $p = p_0 (1 - \gamma \Delta T)$

☛ Specific heat of the substance, $C = \frac{\Delta Q}{M \times \Delta T} \text{ J kg}^{-1} \text{ K}^{-1}$

☛ Heat capacity or thermal capacity $S = \text{Mass} \times \text{Specific heat (mc)}$

☛ Water equivalent (w) = Mass $\times$ Specific heat (mc)

☛ Latent heat of vapourisation or fusion, $Q = mL$

☛ Principle of calorimetry, heat lost = heat gained = $mc\Delta T$

☛ Mixing of two substances when temperature changes

$$\text{only, } \theta_{\text{mix}} = \frac{m_1 c_1 \theta_1 + m_2 c_2 \theta_2}{m_1 c_1 + m_2 c_2}$$

☛ **Conduction** is that mode of transmission of heat in which heat is transferred from a region of higher temperature to a region of lower temperature by the aid of particles of the body without their actual migration. Conduction requires material medium.

- ☛ Rate of flow of heat $\frac{dQ}{dt} = -KA \frac{dT}{dx}$ Where, k = thermal conductivity of the substance and $\frac{dT}{dx}$ = temperature gradient
- ☛ Convection like conduction requires a material medium. *It is the process in which heat is transferred from one place to other by actual movement of heated material particles*
- ☛ When a body is heated and placed in vacuum, it loses heat even when there is no medium surrounding it. The heat

cannot go out from the body by the process of conduction or convection since both of these process require the presence of a material medium between source and surrounding objects. The process by which heat is lost in this case is called radiation.

- ☛ According to Newton's law of cooling, rate of loss of heat from a body is

$$mc \frac{(T_1 - T_2)}{t} = k(T - T_0) = k \left(\frac{T_1 + T_2}{2} - T_0 \right)$$

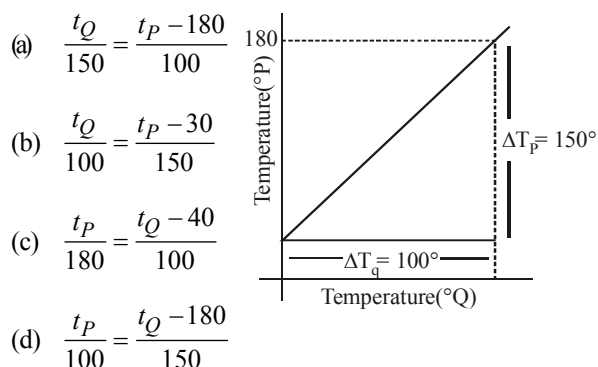
Exercise 1 :

WARM-UP Topic-wise MCQs

4.1 Temperature & Heat, Measurement of Temperature, Absolute Temperature and Ideal Gas Equation, Thermal Expansion

- Heat is associated with
 - kinetic energy of random motion of molecules
 - kinetic energy of orderly motion of molecules
 - total kinetic energy of random and orderly motion of molecules
 - None of these
- Choose the correct equation for interconversion of temperature scales.
 - $\frac{T_C - 0}{100} = \frac{T_F - 32}{180}$
 - $\frac{T_F - 32}{180} = \frac{T_K + 273.15}{100}$
 - $\frac{T_F - 32}{180} = \frac{T_K - 273.15}{180}$
 - $\frac{T_C - 0}{180} = \frac{T_F - 32}{100}$
- If α , β and γ are coefficient of linear, area and volume expansion respectively, then
 - $\gamma = 3\alpha$
 - $\alpha = 3\gamma$
 - $\beta = 3\alpha$
 - $\gamma = 3\beta$
- The temperature on a Fahrenheit temperature scale that is twice the temperature on a Celsius temperature scale is
 - 160°F
 - 240°F
 - 320°F
 - 480°F
- On a new temperature scale, the melting point of ice is 20 °X and the boiling point of water is 110 °X. A temperature of 40 °C would be indicated on this new temperature scale as
 - 60 °X
 - 56 °X
 - 70 °X
 - 54 °X
- In a thermometer, the level of mercury rises to $\left(\frac{3}{5}\right)^{th}$ of the total distance when taken from the melting ice to warm liquid. The temperature of liquid (in K) is
 - 313.15
 - 330
 - 333.15
 - 217.15
- A faulty thermometer has its fixed points at 5°C and 95°C. What is the correct temperature when the thermometer reads 64°C?
 - 60°C
 - 75.5°C
 - 60.5°C
 - 65.5°C
- On an X temperature scale, water freezes at -250.0° X and boils at 375.0° X. On a Y temperature scale, water freezes at -70.0° Y and boils at -30.0° Y. The value of temperature on X-scale equal to the temperature of 50.0° Y on Y-scale is:
 - 455.0° X
 - 125.0° X
 - 1375.0° X
 - 1500.0° X
- Temperature at which Fahrenheit and kelvin pair of scales give the same reading will be:
 - $\theta = -40$
 - $\theta = 40$
 - $\theta = 574.25$
 - 512.45
- The T_F versus T_C graph will be a
 - straight line parallel to x-axis
 - straight line parallel to y-axis
 - straight line inclined to x-axis
 - parabolic curve
- A thermometer graduated according to a linear scale reads a value x_0 when in contact with boiling water, and $x_0/3$ when in contact with ice. What is the temperature of an object in °C, if this thermometer in the contact with the object reads $x_0/2$?
 - 25
 - 60
 - 40
 - 35

12. On a new scale of temperature (which is linear) and called the W scale, the freezing and boiling points of water are 39°W and 239°W respectively. What will be the temperature on the new scale, corresponding to a temperature of 39°C on the Celsius scale?
- (a) 78°W (b) 117°W
(c) 200°W (d) 139°W
13. Mercury thermometer can be used to measure temperature upto
- (a) 260°C (b) 100°C (c) 357°C (d) 500°C
14. The reading of Centigrade thermometer coincides with that of Fahrenheit thermometer in a liquid. The temperature of the liquid is
- (a) -40°C (b) 313°C
(c) 0°C (d) 100°C
15. The graph between two temperature scales P and Q is shown in the figure. Between upper fixed point and lower fixed point there are 150 equal divisions of scale P and 100 divisions on scale Q. The relationship for conversion between the two scales is given by :



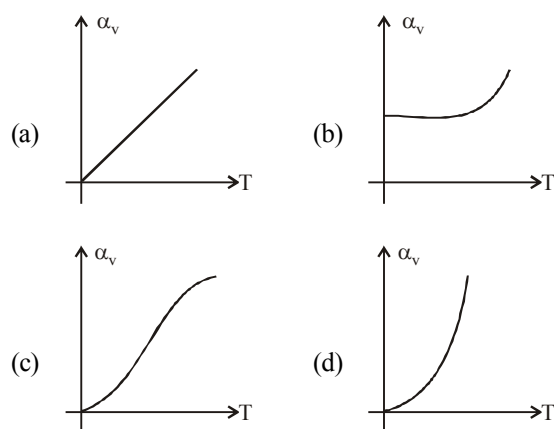
16. The lengths of two metallic rods at temperatures θ and L_A and L_B and their linear coefficient of expansion are α_A and α_B respectively. If the difference in their lengths is to remain constant at any temperature then
- (a) $L_A/L_B = \alpha_A/\alpha_B$ (b) $L_A/L_B = \alpha_B/\alpha_A$
(c) $\alpha_A = \alpha_B$ (d) $\alpha_A \alpha_B = 1$
17. A steel rod of length 1m is heated from 25°C to 75°C keeping its length constant. The longitudinal strain developed in the rod is (Given: Coefficient of linear expansion of steel = $12 \times 10^{-6}/^\circ \text{C}$)
- (a) -6×10^{-6} (b) -6×10^{-5}
(c) -6×10^{-4} (d) zero
18. A brass rod of length 50 cm and diameter 3.0 cm is joined to a steel rod of the length and diameter. What is the change in length of the combined rod at 250°C , if the original lengths are at 40.0°C ?
(Coefficient of linear expansion of brass = $2.0 \times 10^{-5}/^\circ \text{C}$, steel = $1.2 \times 10^{-5}/^\circ \text{C}$)
- (a) 0.27 cm (b) 0.34 cm
(c) 0.21 cm (d) 0.18 cm

19. A brass wire 1.8 m long at 27°C is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of -39°C , what is the tension developed in the wire, if its diameter is 2.0 mm? Coefficient of linear expansion of brass = $2.0 \times 10^{-5}/^\circ \text{C}$, Young's modulus of brass = $0.91 \times 10^{11} \text{ Pa}$.
- (a) $2.4 \times 10^2 \text{ N}$ (b) $3.8 \times 10^2 \text{ N}$
(c) $1.8 \times 10^2 \text{ N}$ (d) $4.8 \times 10^2 \text{ N}$
20. A steel tape 1 m long is correctly calibrated for a temperature of 27.0°C . The length of a steel rod measured by this tape is found to be 63.0 cm of a hot day when the temperature is 45°C . Coefficient of linear expansion of steel = $1.20 \times 10^{-5}/\text{K}$. What is the actual length of the steel rod on that day?
- (a) 63.0136 cm (b) 63.2134 cm
(c) 63.1526 cm (d) 63.3136 cm
21. Calculate the stress developed inside a tooth cavity filled with copper when hot tea at temperature of 57°C is drunk. You can take body (tooth) temperature to be 37°C and $\alpha_{\text{Cu}} = 1.7 \times 10^{-5}/^\circ \text{C}$ bulk modulus for copper $B_{\text{Cu}} = 140 \times 10^9/\text{N/m}^2$.
- (a) $42 \times 10^6 \text{ N/m}^2$ (b) $22 \times 10^6 \text{ N/m}^2$
(c) $36 \times 10^6 \text{ N/m}^2$ (d) $18 \times 10^6 \text{ N/m}^2$
22. Thermal coefficient of volume expansion at constant pressure for an ideal gas sample of n moles having pressure P_0 , volume V_0 and temperature T_0 is
- (a) $\frac{R}{P_0 V_0}$ (b) $\frac{P_0 V_0}{R}$ (c) $\frac{1}{T_0}$ (d) $\frac{1}{n T_0}$
23. A surveyor's 30 m steel tape is correct at a temperature of 20°C . The distance between the two points, as measured by this tape on a day when the temperature is 35°C is 26m. The true distance between the points is [α_1 (steel) = $1.2 \times 10^{-5}/^\circ \text{C}$]
- (a) 25.9953 m (b) 26.0046 m
(c) 27.995 m (d) 24.0046 m
24. A copper rod of 88 cm and an aluminium rod of unknown length have their increase in length is independent of increase in temperature. The length of aluminium rod is ($\alpha_{\text{cu}} = 1.7 \times 10^{-5} \text{ K}^{-1}$ and $\alpha_{\text{Al}} = 2.2 \times 10^{-5} \text{ K}^{-1}$)
- (a) 113.9 cm (b) 88 cm
(c) 68 cm (d) 6.8 cm
25. How much should the temperature of a brass rod be increased so as to increase its length by 1%?
(Given, α for brass is $0.00002^\circ \text{C}^{-1}$)
- (a) 300°C (b) 400°C
(c) 500°C (d) 550°C
26. Two rods, one of aluminium and the other made of steel, having initial length l_1 and l_2 are connected together to form a single rod of length $l_1 + l_2$.

The coefficients of linear expansion for aluminium and steel are α_a and α_s , respectively. If the length of each rod increases by the same amount when their temperatures are raised by $t^\circ\text{C}$, then find the ratio of l_1 with $l_1 + l_2$.

- (a) $\frac{\alpha_s}{\alpha_a}$ (b) $\frac{\alpha_a}{\alpha_s}$
 (c) $\frac{\alpha_s}{\alpha_a + \alpha_s}$ (d) $\frac{\alpha_a}{\alpha_a + \alpha_s}$

27. Coefficient of volumetric expansion α_v is not a constant. It depends on temperature. Variation of α_v with temperature T for metals is



28. A brass wire 1.8 m long at 27°C is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of -39°C , what is the tension developed in the wire, if its diameter is 2.0 mm? Coefficient of linear expansion of brass $= 2.0 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ and Young's modulus of brass $= 0.91 \times 10^{11} \text{ Nm}^{-2}$.

- (a) $3.77 \times 10^2 \text{ N}$ (b) $5.3 \times 10^2 \text{ N}$
 (c) $2.5 \times 10^2 \text{ N}$ (d) $4.3 \times 10^2 \text{ N}$

29. A wire 3 m in length and 1 mm in diameter at 30°C is kept in a low temperature -170°C and is stretched by hanging a weight of 10 kg at one end, so the change in length of the wire is

($Y = 2 \times 10^{11} \text{ Nm}^{-2}$, $g = 10 \text{ ms}^{-2}$ and $\alpha = 1.2 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$)

- (a) -5.3 mm (b) -2.5 mm
 (c) -52 mm (d) -25 mm

30. A liquid is heated to the temperature of 353 K, due to heating the mass expelled is $\left(\frac{1}{50}\right)th$ of mass still remaining, the coefficient of expansion of liquid is

- (a) $1.6 \times 10^{-5} \text{ }^\circ\text{C}$ (b) $2.5 \times 10^{-4} \text{ }^\circ\text{C}$
 (c) $29 \times 10^{-5} \text{ }^\circ\text{C}$ (d) $3.2 \times 10^{-4} \text{ }^\circ\text{C}$

31. A pendulum clock loses 10.8 seconds a day when the temperature is 38°C and gains 10.8 seconds a day when the temperature is 18°C . The coefficient of linear expansion of the metal of the pendulum clock is

- (a) $7 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ (b) $1.25 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$
 (c) $5 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ (d) $2.5 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$

32. A uniform metal solid sphere is rotating with angular speed ω_0 about diameter. If the temperature is raised by 50°C , the angular speed will be [given a metal, $\alpha = 20 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$]

- (a) $0.95 \omega_0$
 (b) $0.96 \omega_0$
 (c) $0.98 \omega_0$
 (d) ω_0 (Angular velocity is same)

33. A steel tape of 300 cm length is graduated at 27°C . The length of a steel rod measured using the tape is found to be 110 cm at 50°C . The actual length of steel rod at 50°C is

($\alpha_{\text{steel}} = 1.2 \times 10^{-5} \text{ K}^{-1}$)

- (a) 110.03 cm (b) 110.10 cm
 (c) 110.07 cm (d) 110.62 cm

34. A rod is found to be 0.05 cm longer at 40°C than it is at 10°C . The length of the rod at 0°C is

(Coefficient of linear expansion of the material of the rod $= 1.5 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$)

- (a) 101.1 cm (b) 120.2 cm
 (c) 105.1 cm (d) 111.1 cm

35. The length of a metal rod at 30°C is 30 cm. If its temperature is raised to 105°C , its length is increased by 0.027 cm. Then the coefficient of linear expansion of the metal is

- (a) $12 \times 10^{-4} \text{ }^\circ\text{C}$ (b) $12 \times 10^{-5} \text{ }^\circ\text{C}$
 (c) $12 \times 10^{-6} \text{ }^\circ\text{C}$ (d) $12 \times 10^{-7} \text{ }^\circ\text{C}$

36. For an ideal gas at a temperature of 27°C and at constant pressure, the coefficient of volume expansion is nearly

- (a) $33 \times 10^{-5} \text{ K}^{-1}$ (b) $22 \times 10^{-4} \text{ K}^{-1}$
 (c) $37 \times 10^{-5} \text{ K}^{-1}$ (d) $33 \times 10^{-4} \text{ K}^{-1}$

37. The change in density of mercury, when it is heated from 10°C to 60°C is (The coefficient of volume expansion of mercury is $18.2 \times 10^{-5} \text{ K}^{-1}$)

- (a) 1.82% (b) 0.91%
 (c) 9.1% (d) 0.45%

38. Two metal rods A and B each of length 50 cm and diameter 4.0 mm are joined together at temperature 30°C . What is the change in length of the combined rod at 230°C ?

[Given linear expansion coefficients of rods A and B are respectively, $2.0 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ and $1.0 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$]

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

39. A hole of diameter 5 cm is drilled in a metal sheet at 30°C . The linear expansion of metal is $2 \times 10^{-5} \text{ K}^{-1}$. The diameter of the hole when the temperature is raised to 230°C , is equal to

- (a) 5.01 cm (b) 5.02 cm
 (c) 5.03 cm (d) 5.04 cm

40. Find the ratio of the length of a steel rod and a copper rod if the steel rod is 4 cm longer than the copper rod at any temperature.

[The coefficient of linear expansion for steel and copper are $1.1 \times 10^{-5}/^{\circ}\text{C}$ and $1.7 \times 10^{-5}/^{\circ}\text{C}$ respectively]

- (a) $\frac{17}{11}$ (b) $\frac{11}{17}$ (c) $\frac{11}{4}$ (d) $\frac{17}{4}$

41. A bar of iron is 10 cm at 20°C . At 19°C it will be (α of iron = $11 \times 10^{-6}/^{\circ}\text{C}$)
 (a) 11×10^{-6} cm longer (b) 11×10^{-6} cm shorter
 (c) 11×10^{-35} cm shorter (d) 11×10^{-5} cm longer
42. A pendulum clock loses 12 s a day if the temperature is 40°C and gains 4 s a day if the temperature is 20°C . The temperature at which the clock will show correct time, and the co-efficient of linear expansion (α) of the metal of the pendulum shaft are respectively :
 (a) 30°C ; $\alpha = 1.85 \times 10^{-3}/^{\circ}\text{C}$
 (b) 55°C ; $\alpha = 1.85 \times 10^{-2}/^{\circ}\text{C}$
 (c) 25°C ; $\alpha = 1.85 \times 10^{-5}/^{\circ}\text{C}$
 (d) 60°C ; $\alpha = 1.85 \times 10^{-4}/^{\circ}\text{C}$
43. The coefficient of linear expansion of crystal in one direction is α_1 and that in every direction perpendicular to it is α_2 . The coefficient of cubical expansion is
 (a) $\alpha_1 + \alpha_2$ (b) $\alpha_1 + 2\alpha_2$
 (c) $2\alpha_1 + \alpha_2$ (d) $\alpha_1 + \alpha_2/2$
44. A solid metallic cube having total surface area 24 m^2 is uniformly heated. If its temperature is increased by 10°C , calculate the increase in volume of the cube.
 (Given : $\alpha = 5.0 \times 10^{-4} /^{\circ}\text{C}^{-1}$)
 (a) $2.4 \times 10^6 \text{ cm}^3$ (b) $1.2 \times 10^5 \text{ cm}^3$
 (c) $6.0 \times 10^4 \text{ cm}^3$ (d) $4.8 \times 10^5 \text{ cm}^3$
45. The coefficient of apparent expansion of mercury in a glass vessel is $153 \times 10^{-6}/^{\circ}\text{C}$ and in a steel vessel is $144 \times 10^{-6}/^{\circ}\text{C}$. If α for steel is $12 \times 10^{-6}/^{\circ}\text{C}$, then that of glass is
 (a) $9 \times 10^{-6}/^{\circ}\text{C}$ (b) $6 \times 10^{-6}/^{\circ}\text{C}$
 (c) $36 \times 10^{-6}/^{\circ}\text{C}$ (d) $27 \times 10^{-6}/^{\circ}\text{C}$
46. The value of coefficient of volume expansion of glycerine is $5 \times 10^{-4} \text{ K}^{-1}$. The fractional change in the density of glycerine for a rise of 40°C in its temperature, is:
 (a) 0.020 (b) 0.025
 (c) 0.010 (d) 0.015
47. The table gives the initial length L , change in temperature ΔT and change in length ΔL of four rods. The rod, which has greatest coefficient of expansion?

Rod	$L(\text{m})$	$\Delta T(^{\circ}\text{C})$	$\Delta L(\text{m})$
a	2	10	4×10^{-4}
b	1	20	4×10^{-4}
c	2	10	8×10^{-4}
d	4	5	4×10^{-4}

- (a) a (b) b (c) c (d) d

48. Two different wires having lengths L_1 and L_2 , and respective temperature coefficient of linear expansion α_1 and α_2 are joined end-to-end. Then the effective temperature coefficient of linear expansion is :

- (a) $\frac{\alpha_1 L_1 + \alpha_2 L_2}{L_1 + L_2}$ (b) $2\sqrt{\alpha_1 \alpha_2}$
 (c) $\frac{\alpha_1 + \alpha_2}{2}$ (d) $4 \frac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2} \frac{L_2 L_1}{(L_2 + L_1)^2}$

49. Expansion during heating

- (a) occurs only in solids
 (b) increases the weight of a material
 (c) generally decreases the density of a material
 (d) occurs at the same rate for all liquids and solids

50. Which of the following will expand the most for same rise in temperature?

- (a) Aluminium
 (b) Glass
 (c) Wood
 (d) All will expand same

51. On heating a liquid of coefficient of cubical expansion γ in a container having coefficient of linear expansion $\gamma/3$, the level of liquid in the container will

- (a) rise
 (b) fall
 (c) remain almost stationary
 (d) It is difficult to say

52. An iron tyre is to be fitted on to a wooden wheel 1 m in diameter. The diameter of tyre is 6 mm smaller than that of wheel. The tyre should be heated so that its temperature increases by a minimum of (the coefficient of cubical expansion of iron is $3.6 \times 10^{-5} /^{\circ}\text{C}$)

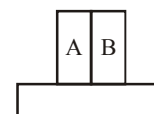
- (a) 167°C (b) 334°C
 (c) 500°C (d) 1000°C

53. A metal sheet with a circular hole is heated. The hole

- (a) gets larger
 (b) gets smaller
 (c) remains of the same size
 (d) gets deformed

54. A bimetallic strip consists of metals A and B. It is mounted rigidly as shown. The metal A has higher coefficient of expansion compared to that of metal B. When the bimetallic strip is placed in a cold bath, it will:

- (a) Bend towards the left
 (b) Bend towards the right
 (c) Not bend but shrink
 (d) Neither bend nor shrink



55. A glass flask is filled up to a mark with 50 cc of mercury at 18°C . If the flask and contents are heated to 38°C , how much mercury will be above the mark? (α for glass is $9 \times 10^{-6}/^\circ\text{C}$ and coefficient of real expansion of mercury is $180 \times 10^{-6}/^\circ\text{C}$)
- (a) 0.85 cc (b) 0.46 cc (c) 0.153 cc (d) 0.05 cc



4.2

Specific Heat Capacity, Calorimetry and Change of State

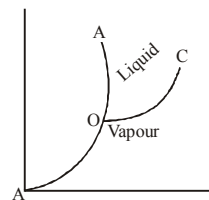
56. A quantity of heat required to change the unit mass of a solid substance, from solid state to liquid state, while the temperature remains constant, is known as
- (a) latent heat (b) sublimation
(c) hoar frost (d) latent heat of fusion
57. The latent heat of vaporization of a substance is always
- (a) greater than its latent heat of fusion
(b) greater than its latent heat of sublimation
(c) equal to its latent heat of sublimation
(d) less than its latent heat of fusion
58. 37 g of ice at 0°C temperature is mixed with 74 g of water at 70°C temperature. The resultant temperature is (Specific heat capacity of water = $1 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$ and latent heat of fusion of ice = 80 cal g^{-1})
- (a) 45°C (b) 70°C (c) 20°C (d) 35°C
59. When 54 g of ice at -20°C is mixed with 25 g of steam at 100°C , then the final mixture at thermal equilibrium contains
- (a) 20 g water at 100°C
(b) 73 g water at 100°C and 6 g steam at 100°C
(c) 8 g steam at 100°C and 12 g water at 0°C
(d) 20 g water at 50°C
60. The change in internal energy when 20 g of a gas is heated from 25°C to 35°C at constant volume is (Specific heat capacity of the gas at constant volume = $0.2 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$ and $J = 4200 \text{ J/kcal}$).
- (a) 74 J (b) 336 J
(c) 136 J (d) 168 J
61. A 50 g ice cube at -10°C is added to 200 g of water at 30°C . The final temperature of the mixture is (Specific heat of water = $1 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$, latent heat of fusion of ice = 80 cal g^{-1} specific heat of ice = $0.5 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$)
- (a) 20°C (b) 7°C
(c) 12°C (d) 10°C
62. The heat energy released by water of mass 2 kg when it is cooled by 10°C is (Specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$)
- (a) 42000 J (b) 21000 J
(c) 63000 J (d) 84000 J

63. The height of victoria falls is 63 m. What is the difference in temperature of water at the top and at the bottom of fall? [Given $1 \text{ cal} = 4.2 \text{ J}$ and specific heat of water = $1 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$]

- (a) 0.147°C (b) 14.76°C
(c) 1.476°C (d) 0.014°C

64. In the given triple point curve as shown in fig. the curves AO, BO, CO represents

- (a) AO = Sublimation curve,
BO = fusion curve,
CO = Vaporization curve
(b) AO = Fusion curve,
BO = Sublimation curve,
CO = Vaporization curve
(c) AO = Fusion curve,
BO = Vaporization curve,
CO = Sublimation curve
(d) AO = Vaporization curve,
BO = fusion curve,
CO = Sublimation curve



65. The specific heat capacity of a copper block of mass M is ' s '. If the mass of the copper block is doubled, the specific heat capacity will be

- (a) $2s$ (b) $\frac{s}{2}$ (c) s (d) $\sqrt{\frac{3}{2}}s$

66. Steam at 100°C is added to 150 g water to increase its temperature from 20°C to 40°C . The total mass of the water at 40°C is

(Specific heat capacity of water = $1 \text{ cal g}^{-1} ^\circ\text{C}^{-1}$ and latent heat of steam = 540 cal g^{-1})

- (a) 155 g (b) 150 g (c) 145 g (d) 5 g

67. The heat energy required convert 10 kg of ice at -10°C into water at 0°C is (specific heat capacity of ice = 0.5 cal g^{-1} and latent heat of fusion of ice = 80 cal g^{-1})

- (a) $357 \times 10^4 \text{ J}$ (b) $357 \times 10^3 \text{ J}$
(c) $357 \times 10^2 \text{ J}$ (d) $357 \times 10^5 \text{ J}$

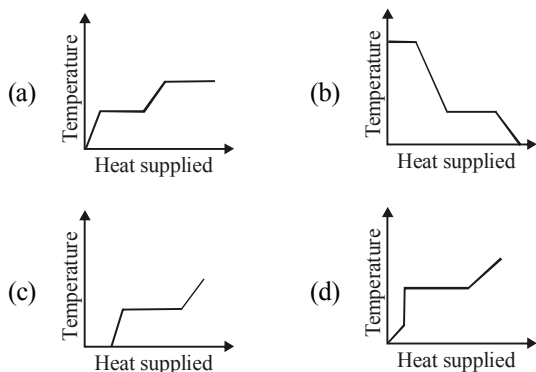
68. The temperature of 100 g of water is to be raised from 24°C to 90°C by adding steam at 100°C to it. The mass of the steam required in this process is (latent heat of steam is 540 cal g^{-1})

- (a) 2 g (b) 4 g (c) 10 g (d) 12 g

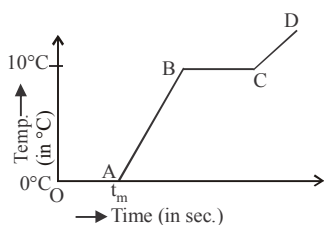
69. The amount of heat needed to heat 200 grams of ice at -10°C to convert it into water at 30°C is

Specific heat capacity of ice = $2100 \text{ J kg}^{-1} \text{ K}^{-1}$
Specific heat capacity of water = $4186 \text{ J kg}^{-1} \text{ K}^{-1}$
Latent heat of fusion of ice = $3.35 \times 10^5 \text{ J kg}^{-1}$

- (a) 96316 J (b) 67000 J
(c) 92116 J (d) 71200 J
70. 176 grams of CO_2 can change its temperature from 0°C to 30°C by absorbing 3600 joules of thermal energy. Molar specific heat of CO_2 in $\text{J. mol}^{-1} \text{K}^{-1}$ is
(a) 30 (b) 40 (c) 50 (d) 60
71. A solution consists of ether and 5.0 g of water at 0°C . If the ether evaporates completely to freeze the water, then the mass of the ether in the solution is
(a) 5 g (b) 4 g (c) 4.5 g (d) 6 g
72. A metal cube absorbs 2100.0 J of heat when its temperature is raised by 2°C . If the specific heat of the metal is $900 \text{ J kg}^{-1} \text{K}^{-1}$, then the mass of the cube is
(a) 1.116 kg (b) 2.33 kg
(c) 1.66 kg (d) 1.33 kg
73. Two objects made of the same material have masses ' m ' and ' $2m$ ' and are at temperatures ' $2T$ ' and ' T ' respectively. When heat ' Q ' is supplied to the object of mass ' $2m$ ', its temperature raises to ' $2T$ '. If the same heat is supplied to the object of mass ' m ', its temperature raises to
(a) $2T$ (b) $\frac{3T}{2}$ (c) $4T$ (d) $3T$
74. 300 gm of water at 25°C is added to 100 g of ice at 0°C . The final temperature of the mixture is
(a) $-\frac{5}{3}^\circ\text{C}$ (b) $-\frac{5}{2}^\circ\text{C}$
(c) 5°C (d) 0°C
75. A block of ice at -10°C is slowly heated and converted to steam at 100°C . Which of the following curves represents the phenomenon qualitatively



76. In the plot of temperature versus time showing changes in the state of ice on heating, which part represents constant temperature?



- (a) OA (b) AB
(c) CD (d) All of these
77. Assuming no heat losses, the heat released by the condensation of x g of steam at 100°C can be used to convert y g of ice at 0°C into water at 100°C , the ratio $x : y$ is :
(a) 1 : 1 (b) 1 : 2 (c) 1 : 3 (d) 3 : 1
78. In an energy recycling process, 100 g of steam at 100°C becomes water at 100°C which converts y g of ice at 0°C into water at 100°C . The numeric value of y is
(a) 100 (b) 200 (c) 300 (d) 400
79. A 2 kg copper block is heated to 500°C and then it is placed on a large block of ice at 0°C . If the specific heat capacity of copper is $400 \text{ J/kg}^\circ\text{C}$ and latent heat of fusion of water is $3.5 \times 10^5 \text{ J/kg}$, the amount of ice that can melt is
(a) $(7/8) \text{ kg}$ (b) $(7/5) \text{ kg}$
(c) $(8/7) \text{ kg}$ (d) $(5/7) \text{ kg}$
80. Mass of water which absorbs or emits the same amount of heat as is done by the body for the same rise or fall in temperature is known as
(a) thermal capacity of the body
(b) specific heat capacity of the body
(c) latent heat capacity of the body
(d) water equivalent of the body
81. 4200 J of work is required for
(a) increasing the temperature of 10 g of water through 10°C
(b) increasing the temperature of 100 g of water through 10°C
(c) increasing the temperature of 1 kg of water through 10°C
(d) increasing the temperature of 500 g of water through 10°C
82. A lead bullet strikes against a steel plate with a velocity 200 m s^{-1} . If the impact is perfectly inelastic and the heat produced is equally shared between the bullet and the target, then the rise in temperature of the bullet is (specific heat capacity of lead = $125 \text{ J kg}^{-1} \text{K}^{-1}$)
(a) 80°C (b) 60°C
(c) 160°C (d) 40°C
83. A hammer of mass 1 kg having speed of 50 m/s, hit a iron nail of mass 200 gm. If specific heat of iron is $0.105 \text{ cal/gm}^\circ\text{C}$ and half the energy is converted into heat. the raise in temperature of nail is
(a) 7.1°C (b) 9.2°C
(c) 10.5°C (d) 12.1°C
84. In a water-fall the water falls from a height of 100 m. If the entire K.E. of water is converted into heat, the rise in temperature of water will be
(a) 0.23°C (b) 0.46°C
(c) 2.3°C (d) 0.023°C

85. A beaker contains 200 gm of water. The heat capacity of the beaker is equal to that of 20 gm of water. The initial temperature of water in the beaker is 20°C . If 440 gm of hot water at 92°C is poured in it, the final temperature, neglecting radiation loss, will be nearest to

(a) 58°C (b) 68°C (c) 73°C (d) 78°C



4.3

Heat Transfer, Conduction, Convection, Radiation, Newton's Law of Cooling

86. A slab consists of two identical plates of copper and brass. The free face of the brass is at 0°C and that of copper at 100°C . If the thermal conductivities of brass and copper are in the ratio 1 : 4, then the temperature of interface is

(a) 20°C (b) 40°C
(c) 60°C (d) 80°C

87. Two rods of thermal conductivities K_1 and K_2 , cross-sections A_1 and A_2 and specific heats S_1 and S_2 are of equal lengths. The temperatures of two ends of each rod are T_1 and T_2 . The rate of flow of heat at the steady state will be equal if

(a) $\frac{K_1}{A_1 S_1} = \frac{K_2}{A_2 S_2}$ (b) $K_1 A_1 = K_2 A_2$
(c) $K_1 S_1 = K_2 S_2$ (d) $A_1 S_1 = A_2 S_2$

88. Two identical metal wires of thermal conductivities K_1 and K_2 respectively are connected in series. The effective thermal conductivity of the combination is:

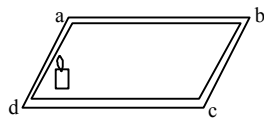
(a) $\frac{2K_1 K_2}{K_1 + K_2}$ (b) $\frac{K_1 K_2}{2K_1 K_2}$ (c) $\frac{K_1 + K_2}{K_1 K_2}$ (d) $\frac{K_1 K_2}{K_1 + K_2}$

89. Heat is transmitted from higher to lower temperature through actual mass motion of the molecules in

(a) conduction (b) convection
(c) radiation (d) None of these

90. A tube shaped like a parallelogram is filled with liquid is kept in a vertical plane. Tube is heated at mid point of ad. The heat flows only by convection. Then

(a) $T_d = T_a > T_b = T_c$
(b) $T_a > T_b > T_c > T_d$
(c) $T_a > T_b > T_d = T_c$
(d) $T_d > T_a > T_b > T_c$



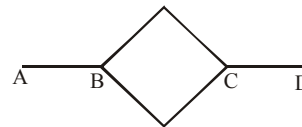
91. A cylindrical rod of aluminium is of length 20 cms and radius 2 cms. The two ends are maintained at temperatures of 0°C and 50°C the coefficient of thermal conductivity is

$\frac{0.5 \text{ cal}}{\text{cm} \times \text{sec} \times ^{\circ}\text{C}}$. Then the thermal resistance of the rod in $\frac{\text{cal}}{\text{sec} \times ^{\circ}\text{C}}$ is

(a) 318 (b) 31.8
(c) 3.18 (d) 0.318

92. Six identical conducting rods are joined as shown in figure. Points A and D are maintained at 200°C and 20°C respectively. The temperature of junction B will be

(a) 120°C
(b) 100°C
(c) 140°C
(d) 80°C



93. Which of the following is used as a coolant in automobile radiator as well as a heater in hot water bags?

(a) Ice (b) Sand
(c) Water (d) All of these

94. 500 g of water and 100 g of ice at 0°C are in a calorimeter whose water equivalent is 40 g. 10 g of steam at 100°C is added to it. Then water in the calorimeter is : (Latent heat of ice = 80 cal/g, Latent heat of steam = 540 cal/g)

(a) 580 g (b) 590 g (c) 600 g (d) 610 g

95. Which of the following circular rods, (given radius r and length l) each made of the same material and whose ends are maintained at the same temperature will conduct most heat?

(a) $r = 2r_0; l = 2l_0$ (b) $r = 2r_0; l = l_0$
(c) $r = r_0; l = 2l_0$ (d) $r = r_0; l = l_0$

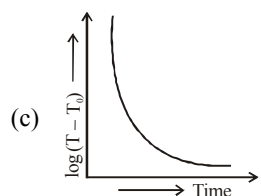
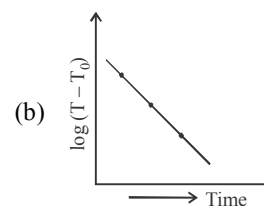
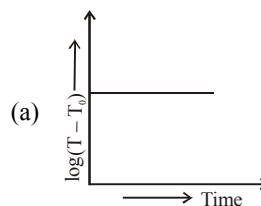
96. If two rods A and B of equal length L , and different areas of cross-section A_1 and A_2 have one end each at temperature T_1 and T_2 , have equal rates of flow of heat, then

(a) $A_1 = A_2$ (b) $\frac{A_1}{A_2} = \frac{K_1}{K_2}$
(c) $\frac{A_1}{A_2} = \frac{K_2}{K_1}$ (d) $K_1 = K_2$

97. Newton's law of cooling is applicable for

(a) any excess of temperature over the surrounding
(b) small excess of temperature over the surrounding
(c) large excess of temperature over the surrounding
(d) very large excess of temperature over the surrounding

98. Which of the given graphs proves Newton's law of cooling?



(d) None of these

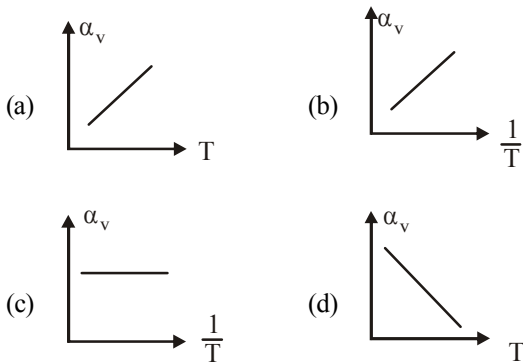
99. A body cools in a surrounding of constant temperature 30°C . Its heat capacity is $2\text{J/kg } ^\circ\text{C}$. Initial temperature of the body is 40°C . Assume Newton's law of cooling is valid. The body cools to 38°C in 10 minutes. In further 10 minutes it will cool from 38°C to
 (a) 36°C (b) 36.4°C (c) 37°C (d) 37.5°C
100. Rate of cooling of a spherical body is directly proportional to [where T = body temperature T_0 = surrounding temperature]
 (a) $(T - T_0)$ (b) $(T^2 - T_0^2)$
 (c) T/T_0 (d) T_0/T

Exercise 2 :

ACCELERATOR

Topic-wise MCQs

4.1 Temperature & Heat, Measurement of Temperature, Absolute Temperature and Ideal Gas Equation, Thermal Expansion

- If two rods of length L and $2L$, having coefficients of linear expansion α and 2α respectively are connected end-to-end, then find the average coefficient of linear expansion of the composite rod.
 (a) $\frac{3\alpha}{2}$ (b) $\frac{5\alpha}{2}$ (c) $\frac{5\alpha}{4}$ (d) $\frac{5\alpha}{3}$
- Which of the following curves represent the variation of coefficient of volume expansion of an ideal gas at constant pressure?

- A steel rod of length 1 m and cross-sectional area 10^{-4}m^2 is heated from 0°C to 200°C without being allowed to extend or bend. The compressive tension produced in the rod is
 (Given Young's modulus of steel = $2 \times 10^{11}\text{Nm}^{-2}$, coefficient of linear expansion = 10^{-5}K^{-1}).
 (a) $2 \times 10^4\text{N}$ (b) $4 \times 10^4\text{N}$
 (c) $8 \times 10^4\text{N}$ (d) $16 \times 10^4\text{N}$
- The length of a metal rod at 30°C is 30 cm. If its temperature is raised to 105°C , its length is increased by 0.027 cm. Then the coefficient of linear expansion of the metal is
 (a) $12 \times 10^{-4}/^\circ\text{C}$ (b) $12 \times 10^{-5}/^\circ\text{C}$
 (c) $12 \times 10^{-6}/^\circ\text{C}$ (d) $12 \times 10^{-7}/^\circ\text{C}$
- The density of water at 20°C is 998kg/m^3 and at 40°C 992kg/m^3 . The coefficient of volume expansion of water is
 (a) $10^{-4}/^\circ\text{C}$ (b) $3 \times 10^{-4}/^\circ\text{C}$
 (c) $2 \times 10^{-4}/^\circ\text{C}$ (d) $6 \times 10^{-4}/^\circ\text{C}$
- For an ideal gas at a temperature of 27°C and at constant pressure, the coefficient of volume expansion is nearly
 (a) $33 \times 10^{-5}\text{K}^{-1}$ (b) $22 \times 10^{-4}\text{K}^{-1}$
 (c) $37 \times 10^{-5}\text{K}^{-1}$ (d) $33 \times 10^{-4}\text{K}^{-1}$
- A steel tape of 300 cm length is graduated at 27°C . The length of a steel rod measured using the tape is found to be 110 cm at 50°C . The actual length of steel rod at 50°C is
 ($\alpha_{\text{steel}} = 1.2 \times 10^{-5}\text{K}^{-1}$)
 (a) 110.03 cm (b) 110.10 cm
 (c) 110.07 cm (d) 110.62 cm
- A rod is found to be 0.05 cm longer at 40°C than it is at 10°C . The length of the rod at 0°C is
 (coefficient of linear expansion of the material of the rod = $1.5 \times 10^{-5}/^\circ\text{C}$)
 (a) 101.1 cm (b) 120.2 cm
 (c) 105.1 cm (d) 111.1 cm
- On a new temperature scale, the melting point of ice is 20°X and the boiling point of water is 110°X . A temperature of 40°C would be indicated on this new temperature scale as
 (a) 60°X (b) 56°X (c) 70°X (d) 54°X
- Two rods A and B of identical dimensions are at temperature 30°C . If A is heated upto 180°C and B upto $T^\circ\text{C}$, then the new lengths are the same. If the ratio of the coefficients of linear expansion of A and B is 4 : 3, then the value of T is :
 (a) 230°C (b) 270°C (c) 200°C (d) 250°C
- A thermometer graduated according to a linear scale reads a value x_0 when in contact with boiling water, and $x_0/3$ when in contact with ice. What is the temperature of an object in $^\circ\text{C}$, if this thermometer in the contact with the object reads $x_0/2$?
 (a) 25 (b) 60 (c) 40 (d) 35

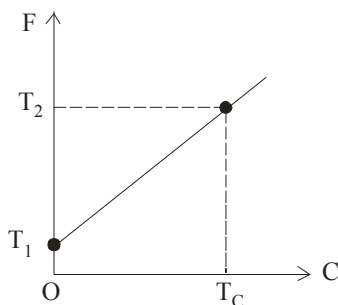
12. The graph of Fahrenheit temperature (F) versus Celsius temperature (C) is shown below. The correct relation between F and C which can be deduced from graph, is

(a) $\frac{F - 32}{T_2 - T_1} = \frac{T_C}{C}$

(b) $\frac{F - T_1}{T_2 - T_1} = \frac{C}{T_C}$

(c) $\frac{F - 32}{T_2 - T_1} = \frac{C}{T_C}$

(d) $\frac{C}{T_1 - T_2} = \frac{F - 32}{T_C}$



13. A metallic rod ℓ cm long, A cm² in cross-section is heated through $t^\circ\text{C}$. If Young's modulus of elasticity of the metal is E and the mean coefficient of linear expansion is α per degree celsius, then the compressional force required to prevent the rod from expanding along its length is
 (a) $E A \alpha t$ (b) $E A \alpha t/(1 + \alpha t)$
 (c) $E A \alpha t/(1 - \alpha t)$ (d) $E \ell \alpha t$
14. A glass flask of volume one litre at 0°C is filled full with mercury at this temperature. The flask and mercury are now heated to 100°C . How much mercury will spill out, if coefficient of volume expansion of mercury is $1.82 \times 10^{-4}/^\circ\text{C}$ and linear expansion of glass is $0.1 \times 10^{-4}/^\circ\text{C}$ respectively?
 (a) 21.2 cc (b) 15.2 cc
 (c) 1.52 cc (d) 2.12 cc
15. The radius of a metal sphere at room temperature T is R and the coefficient of linear expansion of the metal is α . The sphere heated a little by a temperature ΔT so that its new temperature is $T + \Delta T$. The increase in the volume of the sphere is approximately.
 (a) $2\pi R \alpha \Delta T$ (b) $\pi R^2 \alpha \Delta T$
 (c) $4\pi R^3 \alpha \Delta T / 3$ (d) $4\pi R^3 \alpha \Delta T$
16. The temperature of equal masses of three different liquids x, y and z are 10°C , 20°C and 30°C respectively. The temperature of mixture when x is mixed with y is 16°C and that when y is mixed with z is 26°C . The temperature of mixture when x and z are mixed will be :
 (a) 28.32°C (b) 25.62°C
 (c) 23.84°C (d) 20.28°C
17. A piece of metal weight 46 gm in air, when it is immersed in the liquid of specific gravity 1.24 at 27°C it weighs 30 gm. When the temperature of liquid is raised to 42°C the metal piece weight 30.5 gm, specific gravity of the liquid at 42°C is 1.20, then the linear expansion of the metal will be
 (a) $3.316 \times 10^{-5}/^\circ\text{C}$ (b) $2.316 \times 10^{-5}/^\circ\text{C}$
 (c) $4.316 \times 10^{-5}/^\circ\text{C}$ (d) None of these

18. A 30.0 cm long metal rod expands by 0.0650 cm when its temperature is raised from 0°C to 100°C . A second rod of different metal and of the same length expands by 0.0350 cm for the same rise in temperature. A third composite rod, also 30.0 cm long, is made-up of pieces of each of the above metals placed end to end and expands by 0.0580 cm when temperature is increased from 0°C to 100°C . The length of the longer portion of the composite bar in cm at 0°C is

(a) 23 cm (b) 16 cm (c) 18 cm (d) 20 cm

19. A blacksmith fixes circular iron frame on the wooden wheel of a bullock cart. The diameter of wooden wheel and circular iron frame are 5.012 m and 5 m respectively at 27°C . The temperature (in $^\circ\text{C}$) to which the iron ring must be heated so as to fit the wooden wheel is (Coefficient of linear expansion of iron = $1.2 \times 10^{-5}/^\circ\text{C}$)

(a) 200 (b) 227
 (c) 254 (d) 300

20. A circular copper ring at 30°C has a hole with an area of 9.98 cm^2 . It is made to slip onto a steel rod of cross-sectional area of 10 cm^2 , by raising the temperature of both ring and rod simultaneously by an amount ΔT . If the coefficient of linear expansion of copper and steel are $17 \times 10^{-6}/^\circ\text{C}$ and $11 \times 10^{-6}/^\circ\text{C}$, then minimum value of ΔT should be

(a) 167.6°C (b) 133.3°C
 (c) 83.3°C (d) 249.9°C

21. A piece of metal has a weight of 49 gm in air and 39 gm in a liquid of density $1.2 \times 10^3 \text{ kg/m}^3$ kept at 32°C . When the temperature of the liquid is raised to 45°C the metal piece has a weight of 40 gm. If the density of the liquid at 42°C is $1.0 \times 10^3 \text{ kg/m}^3$, then the coefficient of linear expansion of the metal is

(a) $\frac{8}{3} \times 10^{-3}/^\circ\text{C}$ (b) $\frac{11}{3} \times 10^{-3}/^\circ\text{C}$
 (c) $\frac{1}{3} \times 10^{-4}/^\circ\text{C}$ (d) $\frac{4}{3} \times 10^{-3}/^\circ\text{C}$

22. Two marks on a glass rod 10 cm apart are found to increase their distance by 0.08 mm when the rod is heated from 0°C to 100°C . A flask made of the same glass as that of rod measures a volume of 1000 cc at 0°C . The volume it measures at 100°C in cc is

(a) 1002.4 (b) 1004.2
 (c) 1006.4 (d) 1008.2

23. The ratio of the coefficient of volume expansion of a glass container to that of a viscous liquid kept inside the container is 1 : 4. What fraction of the inner volume of the container should the liquid occupy so that the volume of the remaining vacant space will be same at all temperatures?

(a) 2 : 5 (b) 1 : 4 (c) 1 : 64 (d) 1 : 8

24. The coefficient of linear expansion for a certain metal varies with temperature as $\alpha(T)$. If L_0 is the initial length of the metal and the temperature of metal is changed from T_0 to T ($T_0 > T$), then

$$(a) \quad L = L_0 \int_{T_0}^T \alpha(T) dT$$

$$(b) \quad L = L_0 \left[1 + \int_{T_0}^T \alpha(T) dT \right]$$

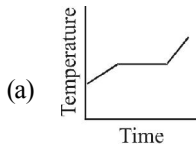
$$(c) \quad L = L_0 \left[1 - \int_{T_0}^T \alpha(T) dT \right]$$

$$(d) \quad L > L_0$$

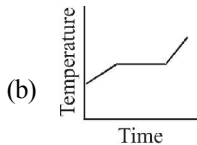
25. A rod PQ of length l is pivoted at an end P and freely rotated in a horizontal plane at an angular speed ω about a vertical axis passing through P . Coefficient of linear expansion of material of rod is α . Find the percentage change in its angular velocity if temperature of system is increased by ΔT is

- (a) $(\alpha \Delta T \times 100)\%$ (b) $(2\alpha \Delta T \times 100)\%$
 (c) $(3\alpha \Delta T \times 100) \times 100\%$ (d) $(4\alpha \Delta T \times 100)\%$

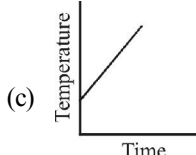
4.2 Specific Heat Capacity, Calorimetry and Change of State

26. A heating element of mass 100 g and having specific heat of 1 J/(g°C) is exposed to surrounding air at 27°C. The element attains a steady state temperature of 127°C while absorbing 100W of electric power. if the power is switched Off, then approximate time taken by the element to cool down to 126°C will be (neglect radiation)
 (a) 0.1 s (b) 1.0 s (c) 5.0 s (d) 10.0 s
27. A solid cube of mass m at a temperature θ_0 is heated at a constant rate. It becomes liquid at temperature θ_1 and vapour at temperature θ_2 . Let s_1 and s_2 be specific heats in its solid and liquid states respectively. If L_f and L_v are latent heats of fusion and vaporisation respectively, then the minimum heat energy supplied to the cube until it vaporises is
 (a) $ms_1(\theta_1 - \theta_0) + ms_2(\theta_2 - \theta_1)$
 (b) $mL_f + ms_2(\theta_2 - \theta_1) + mL_v$
 (c) $ms_1(\theta_1 - \theta_0) + mL_f + ms_2(\theta_2 - \theta_1) + mL_v$
 (d) $ms_1(\theta_1 - \theta_0) + mL_f + ms_2(\theta_2 - \theta_0) + mL_v$
28. One ends of a conducting rod is maintained at temperature 50°C and at the other end ice is melting at 0°C. The rate of melting of ice is doubled if
 (a) the temperature is made 200°C and the area of cross-section of the rod is doubled
 (b) the temperature is made 100°C and length of the rod is made four times.
 (c) area of cross-section of the rod is halved and length is doubled.
 (d) the temperature is made 100°C and area of cross-section of rod and length both are doubled.
29. An ice cube of dimensions 60 cm × 50 cm × 20 cm is placed in an insulation box of wall thickness 1 cm. The box keeping the ice cube at 0°C of temperature is brought to a room of temperature 40°C. The rate of melting of ice is approximately: (Latent heat of fusion of ice is 3.4×10^5 J kg⁻¹ and thermal conducting of insulation wall is 0.05 Wm⁻¹ °C⁻¹)
 (a) 61×10^{-1} kg s⁻¹ (b) 61×10^{-5} kg s⁻¹
 (c) 208 kg s⁻¹ (d) 30×10^{-5} kg s⁻¹
30. Liquid oxygen at 50 K is heated to 300 K at constant pressure of 1 atm. The rate of heating is constant. Which one of the following graphs represents the variation of temperature with time?
- 

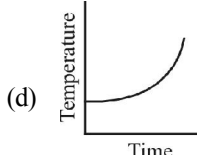
(a)



(b)



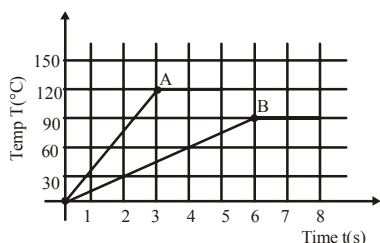
(c)



(d)
31. Steam of mass 60 g at a temperature 100°C is mixed with water of mass 360 g at a temperature 40°C. The ratio of the masses of steam and water in equilibrium is (Latent heat of steam is 540 cal g⁻¹ and specific heat capacity of water is 1 cal g⁻¹ °C⁻¹)
 (a) 1 : 20 (b) 1 : 10 (c) 1 : 5 (d) 1 : 3
32. Ice at -20°C is added to 50 g of water at 40°C. When the temperature of the mixture reaches 0°C, it is found that 20 g of ice is still unmelted. The amount of ice added to the water was close to
 (Specific heat of water = 4.2 J/g°C
 Specific heat of Ice = 2.1 J/g°C
 Heat of fusion of water at 0°C = 334 J/g)
 (a) 50 g (b) 100 g (c) 60 g (d) 40 g
33. Steam at 100°C is added to 150 g water to increase its temperature from 20°C to 40°C. The total mass of the water at 40°C is
 (specific heat capacity of water = 1 cal g⁻¹ °C⁻¹ and latent heat of steam = 540 cal g⁻¹)
 (a) 155 g (b) 150 g (c) 145 g (d) 5 g
34. When M_1 gram of ice at -10 °C (Specific heat = 0.5 cal g⁻¹ °C⁻¹) is added to M_2 gram of water at 50°C, finally no ice is left and the water is at 0°C. The value of latent heat of ice, in cal g⁻¹ is:

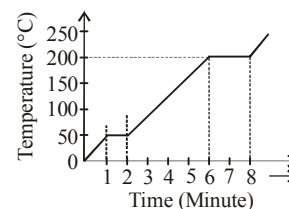
- (a) $\frac{50M_2}{M_1} - 5$ (b) $\frac{5M_1}{M_2} - 50$
 (c) $\frac{50M_2}{M_1}$ (d) $\frac{5M_2}{M_1} - 5$

35. When 100 g of a liquid A at 100°C is added to 50 g of a liquid B at temperature 75°C , the temperature of the mixture becomes 90°C . The temperature of the mixture, if 100 g of liquid A at 100°C is added to 50 g of liquid B at 50°C , will be:
 (a) 85°C (b) 60°C (c) 80°C (d) 70°C
36. A metal ball of mass 0.1 kg is heated upto 500°C and dropped into a vessel of heat capacity 800 J K^{-1} and containing 0.5 kg water. The initial temperature of water and vessel is 30°C . What is the approximate percentage increment in the temperature of the water? [Specific Heat Capacities of water and metal are, respectively, $4200 \text{ J kg}^{-1} \text{ K}^{-1}$ and $400 \text{ J kg}^{-1} \text{ K}^{-1}$]
 (a) 15% (b) 30% (c) 25% (d) 20%
37. A metal block is made from a mixture of 2.4 kg of aluminium, 1.6 kg of brass and 0.8 kg of copper. The metal block is initially at 20°C . If the heat supplied to the metal block is 44.4 calories, find the final temperature of the block if specific heats of aluminium, brass and copper are 0.216, 0.0917, 0.0931 cal. $\text{kg}^{-1} \text{ }^\circ\text{C}^{-1}$ respectively.
 (a) 100°C (b) 60°C (c) 40°C (d) 80°C
38. A steel ball of mass 200 g falls freely from a height of 20 m and bounces to a height of 10.8 m from the ground. If the energy lost in this process is absorbed by the ball, the rise in its temperature is
 ($g = 10 \text{ ms}^{-2}$, specific heat capacity of steel is $460 \text{ J kg}^{-1} \text{ K}^{-1}$)
 (a) 0.1°C (b) 1°C (c) 0.2°C (d) 2°C
39. The temperature of equal masses of three different liquids A, B and C are 12°C , 19°C and 28°C respectively. The temperature when A and B are mixed is 16°C and when B and C are mixed is 23°C . The temperature when A and C are mixed is
 (a) 18.2°C (b) 22°C (c) 20.2°C (d) 25.2°C
40. Two different metal bodies A and B of equal mass are heated at a uniform rate under similar conditions. The variation of temperature of the bodies is graphically represented as shown in the figure. The ratio of specific heat capacities is :



- (a) $\frac{8}{3}$ (b) $\frac{3}{8}$ (c) $\frac{3}{4}$ (d) $\frac{4}{3}$
41. A student takes 50gm wax (specific heat = $0.6 \text{ kcal/kg}^\circ\text{C}$) and heats it till it boils. The graph between temperature and time is as follows. Heat supplied to the wax per minute and boiling

point are respectively

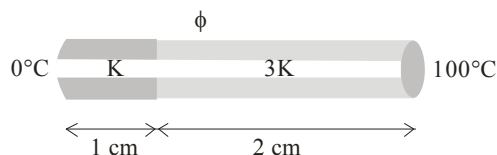


- (a) 500 cal, 50°C (b) 1000 cal, 100°C
 (c) 1500 cal, 200°C (d) 1000 cal, 200°C

4.3

Heat Transfer, Conduction, Convection, Radiation, Newton's Law of Cooling

42. A composite slab is prepared with two different materials A and B. The relation between their coefficient of thermal conductivity and thickness is given as $K_A = \frac{K_B}{2}$ and $X_A = 2X_B$, respectively. If the temperature of faces of A and B are 75°C and 50°C respectively, what will be the temperature of common surface?
 (a) 75°C (b) 50°C
 (c) 55°C (d) 125°C
43. Two bars of thermal conductivities K and 3K and lengths 1 cm and 2 cm respectively have equal cross-sectional area, they are joined lengths wise as shown in the figure. If the temperature at the ends of this composite bar is 0°C and $K^2/1$ respectively (see figure), then the temperature ϕ of the interface is



- (a) 50°C (b) $\frac{100}{3}^\circ\text{C}$ (c) 60°C (d) $\frac{200}{3}^\circ\text{C}$
44. Ice has formed on a shallow pond, and a steady state has been reached, with the air above the ice at -5.0°C and the bottom of the pond at 4.0°C . If the total depth of ice + water is 1.4 m, (Assume that the thermal conductivities of ice and water are 0.40 and 0.12 cal/m $^\circ\text{C}$ s, respectively.) The thickness of ice layer is
 (a) 1.1m (b) 0.4m (c) 2.1m (d) 3.6m
45. Two sphere of a different material one with double the radius and one-fourth wall thickness of the other are filled with ice. If the time taken for complete melting of ice in the larger sphere is 25 minutes and for smaller one is 16 minutes, the ratio of thermal conductivities of the materials of larger sphere to that of smaller sphere is:
 (a) 4 : 5 (b) 5 : 4
 (c) 25 : 8 (d) 8 : 25

46. A wall has two layers A and B each made of different materials. The thickness of both the layers is the same. The thermal conductivity of A, $K_A = 3K_B$. The temperature difference across the wall is 20°C in thermal equilibrium.

(a) The temperature differences across A is 15°C
 (b) Rate of heat transfer across A is more than across B.
 (c) Rate of heat transfer across both is same.
 (d) Temperature difference across A is 5°C .

47. A cylinder of radius R made of a material of thermal conductivity K_1 is surrounded by a cylindrical shell of inner radius R and outer radius $2R$ made of a material of thermal conductivity K_2 . The two ends of a combined system are maintained at two different temperatures. There is no loss of heat across the cylindrical surface and the system is in steady state. The effective thermal conductivity of the system is:

(a) $K_1 + K_2$ (b) $\frac{K_1 + 3K_2}{4}$
 (c) $\frac{K_1 K_2}{K_1 + K_2}$ (d) $\frac{3K_1 + K_2}{4}$

48. A wall is made up of two layers A and B. The thickness of the two layers is the same, but materials are different. The thermal conductivity of A is double than that of B. In the two ends is 36°C . Then the difference of temperature at the two surfaces of A will be

(a) 6°C (b) 12°C (c) 18°C (d) 24°C

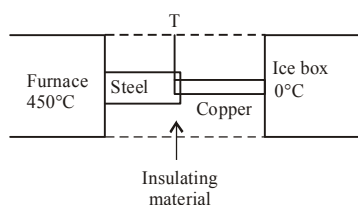
49. A cylindrical metallic rod in thermal contact with two reservoirs of heat at its two ends conducts an amount of heat Q in time t . The metallic rod is melted and the material is formed into a rod of half the radius of the original rod. What is the amount of heat conducted by the new rod, when placed in thermal contact with the two reservoirs in time t ?

(a) $\frac{Q}{4}$ (b) $\frac{Q}{16}$ (c) $2Q$ (d) $\frac{Q}{2}$

50. If K_1 and K_2 are the thermal conductivities, L_1 and L_2 are the lengths, A_1 and A_2 are the cross sectional areas of steel and copper rods respectively such that

$\frac{K_2}{K_1} = 9, \frac{A_1}{A_2} = 2, \frac{L_1}{L_2} = 2$. Then, for the arrangement as

shown in the figure, the value of temperature T of the steel – copper junction in the steady state will be :



(a) 18°C (b) 14°C (c) 45°C (d) 150°C

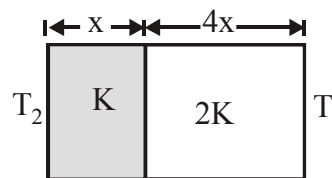
51. Two thin metallic spherical shells of radii r_1 and r_2 ($r_1 < r_2$) are placed with their centres coinciding. A material

of thermal conductivity K is filled in the space between the shells. The inner shell is maintained at temperature θ_1 and the outer shell at temperature θ_2 ($\theta_1 < \theta_2$). The rate at which heat flows radially through the material is :-

(a) $\frac{4\pi K r_1 r_2 (\theta_2 - \theta_1)}{r_2 - r_1}$ (b) $\frac{\pi r_1 r_2 (\theta_2 - \theta_1)}{r_2 - r_1}$
 (c) $\frac{K (\theta_2 - \theta_1)}{r_2 - r_1}$ (d) $\frac{K (\theta_2 - \theta_1) (r_2 - r_1)}{4\pi r_1 r_2}$

52. The temperature of the two outer surfaces of a composite slab, consisting of two materials having coefficient of thermal conductivity K and $2K$ and thickness x and $4x$ respectively are T_2 and T_1 ($T_2 > T_1$). The rate of heat transfer through the slab,

in a steady state is $\left(\frac{A(T_2 - T_1)K}{x} \right)$ with f equal to



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

53. Two spheres of different materials one with double the radius and one-fourth wall thickness of the other are filled with ice. If the time taken for complete melting of ice in the larger sphere is 25 minute and for smaller one is 16 minute, the ratio of thermal conductivities of the materials of larger spheres to that of smaller sphere is

(a) 4 : 5 (b) 5 : 4 (c) 25 : 8 (d) 8 : 25

54. A large cylindrical rod of length L is made by joining two identical rods of copper and steel of length $\left(\frac{L}{2} \right)$ each.

The rods are completely insulated from the surroundings. If the free end of copper rod is maintained at 100°C and that of steel at 0°C then the temperature of junction is (Thermal conductivity of copper is 9 times that of steel)

(a) 90°C (b) 50°C (c) 10°C (d) 67°C

55. A metal rod of length 20cm and diameter 2 cm is covered with a non conducting substance. One of its ends is maintained at 100°C while the other end is in ice at 0°C . It is found that 25 g of ice melts in 5 min. Calculate the coefficient of thermal conductivity of the metal. Latent heat of ice = 80 cal gram^{-1}

(a) $2.56 \text{ Js}^{-1}\text{m}^{-1}^\circ\text{C}^{-1}$ (b) $1.32 \text{ Js}^{-1}\text{m}^{-1}^\circ\text{C}^{-1}$
 (c) $3.12 \text{ Js}^{-1}\text{m}^{-1}^\circ\text{C}^{-1}$ (d) $1.78 \text{ Js}^{-1}\text{m}^{-1}^\circ\text{C}^{-1}$

56. A cylinder A of a material of thermal conductivity K_1 is surrounded by a cylindrical shell of inner radius equal to the cylinder. The shell is made of a material of thermal conductivity K_2 . The two ends of the combined system

- are maintained at two different temperature. If the effective thermal conductivity of the system is $\frac{4K_1 + 5K_2}{9}$, find the ratio of outer radius of the shell to the radius of the cylinder.
 (a) 2.0 (b) $\frac{5}{2}$ (c) $\frac{5}{3}$ (d) $\frac{3}{2}$
57. The temperature difference across two cylindrical rods A and B of same material and same mass are 40°C and 60°C respectively. In steady state, if the rates of flow of heat through the rods A and B are in the ratio 3 : 8, the ratio of the lengths of the rods A and B is
 (a) 1 : 3 (b) 5 : 3 (c) 4 : 3 (d) 2 : 3
58. The length of a metal bar is 20 cm and the area of cross section is $4 \times 10^{-4} \text{ m}^2$. If one end of the rod is kept in ice at 0°C and the other end is kept in steam at 100°C , the mass of ice melted in one minute is 5 g. The thermal conductivity of the metal in $\text{Wm}^{-1}\text{K}^{-1}$ is
 (Latent heat of fusion = 80 cal/gm)
 (a) 140 (b) 120 (c) 100 (d) 160
59. In a room where the temperature is 30°C , a body cools from 61°C to 59°C in 4 minutes. The time (in minutes) taken by the body to cool from 51°C to 49°C will be
 (a) 8 (b) 5 (c) 6 (d) 4
60. In a surrounding medium of temperature 10°C , a body takes 7 min for a fall of temperature from 60°C to 40°C . In what time the temperature of the body will fall from 40°C to 28°C ?
 (a) 7 min (b) 11 min (c) 14 min (d) 21 min

Exercise 3 :

PREVIOUS YEARS MCQs

- If the values of the temperature of a body in Fahrenheit and Celcius scales are in the ratio of 13 : 5, then the temperature of the body is [2025]
 (a) 80°F (b) 104°C (c) 40°C (d) 40°F
- A rectangular slab consists of two cubes of copper and brass of equal sides having thermal conductivities in the ratio 4 : 1. If the free face of brass is at 0°C and that of copper is at 100°C , then the temperature of their interface is [2024]
 (a) 80°C (b) 20°C (c) 60°C (d) 40°C
- If some heat is given to a metal of mass 100 g, its temperature rises by 20°C . If the same heat is given to 20 g of water, the change in its temperature (in $^\circ\text{C}$) is (The ratio of specific heat capacities of metal and water is 1 : 10) [2023]
 (a) 5 (b) 10 (c) 12 (d) 15
- The temperature of water of mass 100 g is raised from 24°C to 90°C by adding steam to it. The mass of the steam added is [2022]
 (Latent heat of steam = 540 cal g^{-1} and specific heat capacity of water = $1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$)
 (a) 10 g (b) 12 g (c) 8 g (d) 16 g
- If a body cools from a temperature of 62°C to 50°C in 10 minutes and to 42°C in the next 10 minutes, then the temperature of the surroundings is [2021]
 (a) 12°C (b) 26°C (c) 36°C (d) 21°C
- A metal metre scale that is accurate up to 0.5 mm is made at a temperature of 25°C . The range of temperatures within which it can be used is (Coefficient of linear expansion of the metal = $10^{-5} / ^\circ\text{C}$) [2020]
 (a) $+25^\circ\text{C}$ to $+75^\circ\text{C}$ (b) $+25^\circ\text{C}$ to $+50^\circ\text{C}$
 (c) -25°C to $+75^\circ\text{C}$ (d) 0°C to $+50^\circ\text{C}$
- The temperature of a body shown by a faulty Celsius thermometer is 49°C and by a correct Fahrenheit thermometer is 122°F . The correction to be applied to the faulty thermometer is [2019]
 (a) -12°C (b) $+1^\circ\text{C}$ (c) $+12^\circ\text{C}$ (d) -1°C
- The temperature at which the reading on Fahrenheit scale becomes 90% more than the reading on Celsius scale is [2018]
 (a) 280°F (b) 580°F (c) 608°F (d) 320°F
- To increase the length of a metal rod by 0.4%, the temperature of the rod is to be increased by (Coefficient of linear expansion of the metal = $20 \times 10^{-6} / ^\circ\text{C}$) [2017]
 (a) 373 K (b) 473 K (c) 200 K (d) 100 K
- A body cools from a temperature of 60°C to 50°C in 10 minutes and 50°C to 40°C in 15 minutes. The time taken in minutes for the body to cool from 40°C to 30°C is [2016]
 (a) 30 (b) 20 (c) 25 (d) 40
- Water falls from a height of 200 m into a pool. Calculate the rise in temperature of the water assuming no heat dissipation from the water in the pool. [2015]
 (Take $g = 10 \text{ m/s}^2$, specific heat of water = 4200 J/(kg K))
 (a) 0.23 K (b) 0.36 K (c) 0.14 K (d) 0.48 K
- A small quantity of water of mass 'm' at temperature $\theta^\circ\text{C}$ is mixed with a large mass 'M' of ice which is at its melting point. If 's' is specific heat capacity of water and 'L' is the Latent heat of fusion of ice, then the mass of ice melted is [2014]
 (a) $\frac{ML}{ms\theta}$ (b) $\frac{ms\theta}{ML}$ (c) $\frac{Ms\theta}{L}$ (d) $\frac{ms\theta}{L}$
- Steam at 100°C is passed into 114 g of water at 30°C . The mass of water present in the mixture when the temperature of the water becomes 70°C is (Latent heat of steam = 540 cal g^{-1} ; specific heat capacity of water = $1 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$) [2013]
 (a) 122 g (b) 132 g (c) 142 g (d) 152 g

14. Water of mass 5 kg in a closed vessel is at a temperature of 20°C . If the temperature of the water when heated for a time of 10 minutes becomes 30°C , then the increase in the internal energy of the water is [2011]
(Specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$)
(a) 100 kJ (b) 420 kJ (c) 510 kJ (d) 210 kJ
15. A bimetallic strip is made of aluminium and steel ($\alpha_{\text{Al}} > \alpha_{\text{steel}}$). On heating, the strip will [2010]
(a) remain straight
(b) get twisted
(c) will bend with aluminium on concave side
(d) will bend with steel on concave side
16. A metallic bar of Young's modulus, $0.5 \times 10^{11} \text{ Nm}^{-2}$ and coefficient of linear thermal expansion $10^{-5} \text{ }^{\circ}\text{C}^{-1}$, length 1 m and area of cross-section 10^{-3} m^2 is heated from 0°C to 100°C without expansion or bending. The compressive force developed in it is : [2009]
(a) $5 \times 10^3 \text{ N}$ (b) $50 \times 10^3 \text{ N}$
(c) $100 \times 10^3 \text{ N}$ (d) $2 \times 10^3 \text{ N}$
17. On celcius scale the temperature of body increases by 40°C . The increase in temperature on Fahrenheit scale is: [2009]
(a) 70°F (b) 68°F (c) 72°F (d) 75°F
18. On a temperature scale 'X'. The boiling point of water is 65°X and the freezing point is -15°X . Assume that the X scale is linear. The equivalent temperature corresponding to -95°X on the Farenheit scale would be: [2008]
(a) -63°F (b) -112°F (c) -48°F (d) -148°F
19. The pressure (P) and temperature (T) relationship of an ideal gas obeys the equation $PT^2 = \text{constant}$. The volume expansion coefficient of the gas will be: [2007]
(a) $3T^2$ (b) $\frac{3}{T^2}$ (c) $\frac{3}{T^3}$ (d) $\frac{3}{T}$
20. A rod, of length L at room temperature and uniform area of cross section A, is made of a metal having coefficient of linear expansion $\alpha/^{\circ}\text{C}$. It is observed that an external compressive force F, is applied on each of its ends, prevents any change in the length of the rod, when its temperature rises by $\Delta T \text{ K}$. Young's modulus, Y, for this metal is: [2006]
(a) $\frac{F}{A \alpha \Delta T}$ (b) $\frac{F}{A \alpha (\Delta T - 273)}$
(c) $\frac{F}{2A \alpha \Delta T}$ (d) $\frac{2F}{A \alpha \Delta T}$

ANSWER KEYS

Exercise 1 : WARM-UP Topic-wise MCQs

1	(a)	11	(a)	21	(a)	31	(d)	41	(c)	51	(c)	61	(b)	71	(b)	81	(b)	91	(d)
2	(a)	12	(b)	22	(c)	32	(c)	42	(c)	52	(c)	62	(d)	72	(a)	82	(a)	92	(c)
3	(a)	13	(c)	23	(a)	33	(a)	43	(b)	53	(a)	63	(a)	73	(c)	83	(a)	93	(c)
4	(c)	14	(a)	24	(c)	34	(d)	44	(b)	54	(a)	64	(b)	74	(d)	84	(a)	94	(b)
5	(b)	15	(b)	25	(c)	35	(c)	45	(a)	55	(c)	65	(c)	75	(a)	85	(b)	95	(b)
6	(c)	16	(b)	26	(c)	36	(d)	46	(a)	56	(d)	66	(a)	76	(a)	86	(d)	96	(c)
7	(d)	17	(c)	27	(c)	37	(b)	47	(c)	57	(a)	67	(a)	77	(c)	87	(b)	97	(b)
8	(c)	18	(b)	28	(a)	38	(c)	48	(a)	58	(c)	68	(d)	78	(c)	88	(a)	98	(b)
9	(c)	19	(b)	29	(a)	39	(b)	49	(c)	59	(b)	69	(a)	79	(c)	89	(b)	99	(b)
10	(c)	20	(a)	30	(b)	40	(a)	50	(a)	60	(d)	70	(a)	80	(d)	90	(a)	100	(a)

Exercise 2 : ACCELERATOR Topic-wise MCQs

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

Exercise 3 : PREVIOUS YEARS MCQs

1	(c)	3	(b)	5	(b)	7	(b)	9	(c)	11	(d)	13	(a)	15	(d)	17	(c)	19	(d)
2	(a)	4	(b)	6	(c)	8	(c)	10	(a)	12	(d)	14	(d)	16	(b)	18	(d)	20	(a)