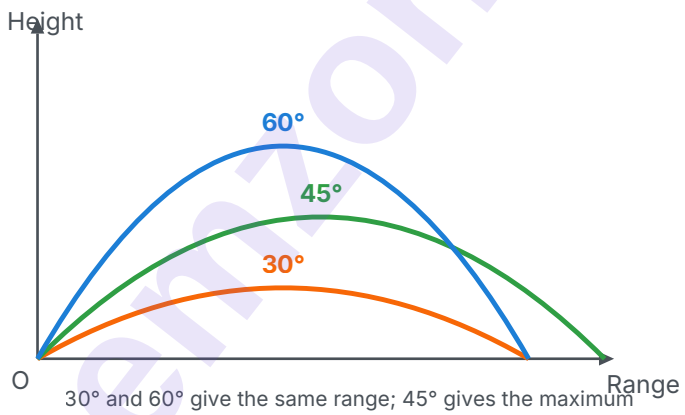
PHYSICS · CLASS 11 · NEW SYLLABUS

UNIT 2

Force and Motion

Complete Study Booklet



30° and 60° give the same range; 45° gives the maximum

Long Questions | Short Questions | MCQs | Solved Exercise

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Numericals, Constructed & Comprehensive

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PART A

Long Questions

Q1 Differentiate between scalars and vectors. Give examples.

Scalars	Vectors
Physical quantities described by **magnitude only**, with no direction.	Physical quantities having **both magnitude and direction**.
Mass — amount of matter, e.g. 2 kg	**Displacement** — change in position, e.g. 10 m towards west
Distance — total path length, e.g. 50 m	**Velocity** — speed in a given direction, e.g. 50 km h^{-1} west
Speed — rate of covering distance, e.g. 40 km h^{-1}	**Acceleration** — rate of change of velocity, e.g. 10 m s^{-2} upward
Time — e.g. 20 s	**Force** — push or pull, e.g. 20 N to the right
Energy — capacity to do work, e.g. 25 J	Momentum, impulse, torque, weight
Temperature — measure of average K.E. of particles, e.g. 20 °C	

Q2 How is a vector represented? Explain.

In print, vectors are written in **bold face** ($\mathbf{A}$, $\mathbf{d}$, $\mathbf{r}$, $\mathbf{v}$) or with an arrow over the symbol. The magnitude of vector $\mathbf{d}$ is written in light face as d.

Graphically, a vector is a directed line segment with an arrowhead at one end. The length of the line, drawn to a chosen scale, gives the magnitude, and the arrowhead gives the direction.

Q3 Define rectangular components of a vector. How are they determined? Find their expressions.

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Components of a vector which are at **right angles** to each other are called its rectangular components.

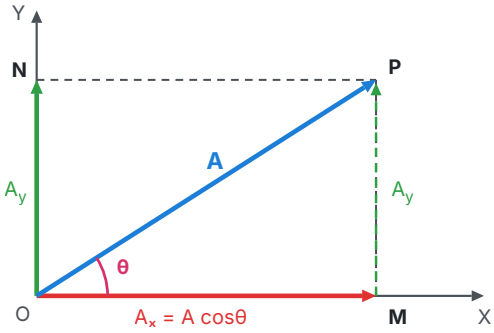
Let vector **A** = OP make angle θ with the x-axis. Drop perpendiculars from P onto the x-axis (at M) and the y-axis (at N). Then OM = A_x along x and ON = MP = A_y along y.

By the head-to-tail rule **A** is the resultant of A_x and A_y, so these are its rectangular components. In right triangle OMP:

$$\cos\theta = \frac{OM}{OP} = \frac{A_x}{A} \Rightarrow \mathbf{A_x = A\cos\theta} \quad ...(1)$$

$$\sin\theta = \frac{MP}{OP} = \frac{A_y}{A} \Rightarrow \mathbf{A_y = A\sin\theta} \quad ...(2)$$

Knowing A and θ, both components can be found.



Rectangular components of A

Q4 How will you find the magnitude and direction of a vector with the help of its rectangular components?

Magnitude: In right triangle OMP, by Pythagoras' theorem:

$$OP^2 = OM^2 + MP^2 \Rightarrow A^2 = A_x^2 + A_y^2$$

$$\mathbf{A = \sqrt{(A_x^2 + A_y^2)}}$$

Direction:

$$\tan\theta = \frac{MP}{OM} = \frac{A_y}{A_x}$$

$$\boldsymbol{\theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)}$$

So if both rectangular components are known, the magnitude and direction of the vector can be found (see figure in Q3).

Q5 What is meant by scalar product? Give examples and describe the important characteristics of the scalar (dot) product.

When two vectors are multiplied and the product is a **scalar**, it is called the scalar product. It is also called the **dot product** because a dot is placed between the vectors.

$$\mathbf{A\cdot B = AB\cos\theta}$$

where A and B are the magnitudes and θ is the angle between the vectors.

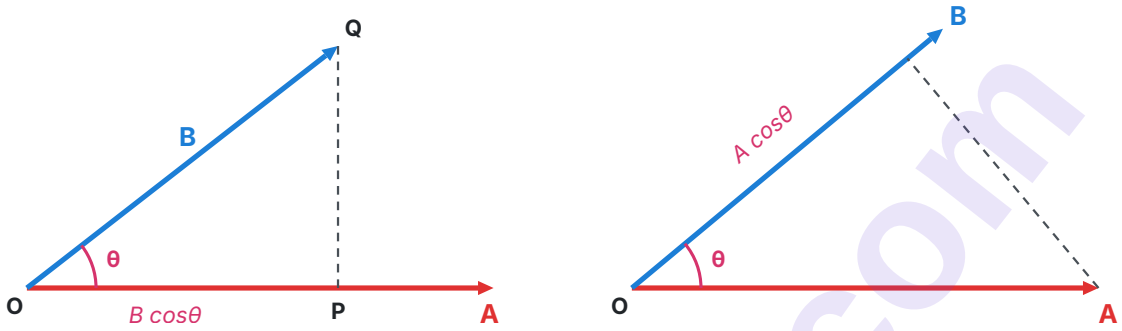
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Explanation

Drop a perpendicular from the head of **B** onto **A**: the length OP = B cos θ is the projection of **B** on **A**. Hence:

$$\mathbf{A}\cdot\mathbf{B} = A\,(B\cos\theta) = AB\cos\theta \quad \ldots(1)$$

Similarly, the projection of **A** on **B** is A cos θ, so $\mathbf{B}\cdot\mathbf{A} = B\,(A\cos\theta) = BA\cos\theta$ …(2). Comparing (1) and (2): $\mathbf{A}\cdot\mathbf{B} = \mathbf{B}\cdot\mathbf{A}$.



(a) projection of B on A

(b) projection of A on B

Projection of one vector on another

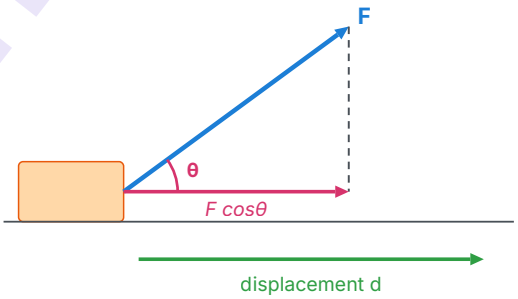
Examples

1. Work: a force **F** moves a body through displacement **d** at angle θ. Only F cos θ acts along the motion:

$$W = (F\cos\theta)\,d = Fd\cos\theta = \mathbf{F}\cdot\mathbf{d}$$

2. Power:

$$P = F\,v\cos\theta = \mathbf{F}\cdot\mathbf{v}$$



Work as a dot product

Characteristics

1. **Commutative:** $\mathbf{A}\cdot\mathbf{B} = AB\cos\theta = BA\cos\theta = \mathbf{B}\cdot\mathbf{A}$. Order does not matter.
2. **Perpendicular vectors:** θ = 90°, cos 90° = 0 ⇒ $\mathbf{A}\cdot\mathbf{B} = 0$ (minimum value).
3. **Parallel vectors:** θ = 0°, cos 0° = 1 ⇒ $\mathbf{A}\cdot\mathbf{B} = AB$ (maximum value).
   Anti-parallel: θ = 180° ⇒ $\mathbf{A}\cdot\mathbf{B} = -AB$.
4. **Self dot product:** $\mathbf{A}\cdot\mathbf{A} = AA\cos 0° = A^2$.
5. **In terms of components:** with $\mathbf{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$ and $\mathbf{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$:

   $$\mathbf{A}\cdot\mathbf{B} = A_xB_x + A_yB_y + A_zB_z$$

6. **Angle between two vectors:**

   $$\cos\theta = \frac{\mathbf{A}\cdot\mathbf{B}}{AB} = \frac{A_xB_x + A_yB_y + A_zB_z}{AB}$$

   $$\boldsymbol{\theta = \cos^{-1}\left(\frac{\mathbf{A}\cdot\mathbf{B}}{AB}\right)}$$

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Q6 Define and explain vector product. Describe its important characteristics.

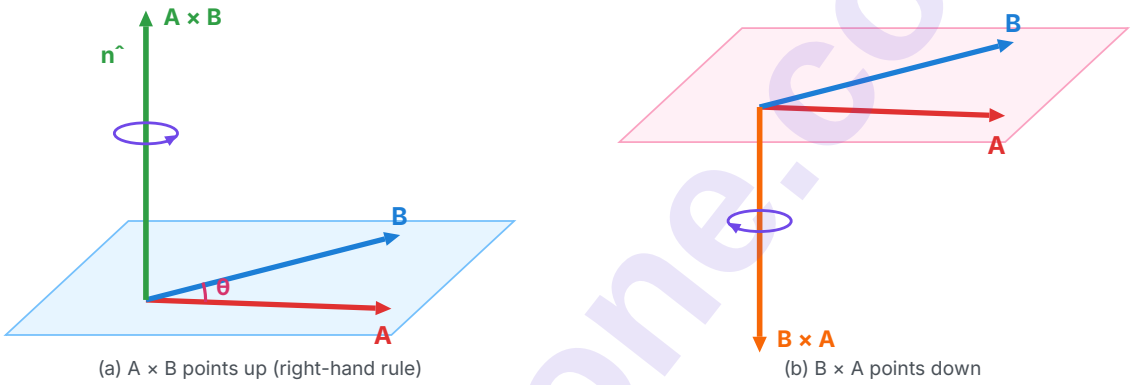
> When two vectors are multiplied and the product is a **vector**, it is called the vector product or **cross product** (a "×" is placed between the vectors).

Magnitude: $|\mathbf{A} \times \mathbf{B}| = AB \sin\theta$, where θ is the angle between $\mathbf{A}$ and $\mathbf{B}$.

Right-Hand Rule (direction)

Rotate $\mathbf{A}$ towards $\mathbf{B}$ through the smaller angle. Curl the fingers of the right hand in the direction of rotation; the extended thumb points along $\mathbf{A} \times \mathbf{B}$. The product is **perpendicular to the plane** containing $\mathbf{A}$ and $\mathbf{B}$. If $\hat{n}$ is a unit vector in that direction:

$$\mathbf{A} \times \mathbf{B} = AB \sin\theta\, \hat{n}$$



Direction of the vector product

Examples

1. Torque — the turning effect of a force:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F} = rF \sin\theta\, \hat{n}$$

2. Angular momentum — cross product of position vector and linear momentum:

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = rp \sin\theta\, \hat{n}$$

Characteristics

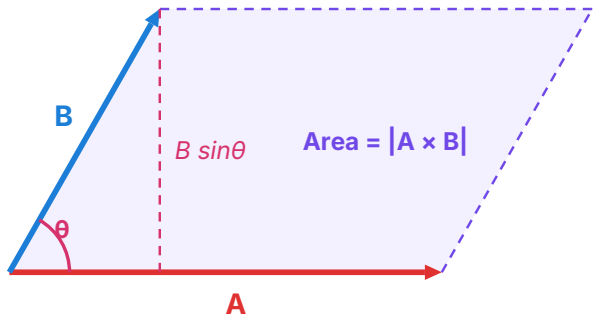
1. **Not commutative:** $\mathbf{A} \times \mathbf{B} = AB \sin\theta\, \hat{n}$ (upward), but $\mathbf{B} \times \mathbf{A} = -AB \sin\theta\, \hat{n}$ (downward).

   $$\mathbf{A} \times \mathbf{B} = -(\mathbf{B} \times \mathbf{A}) \quad \text{though } |\mathbf{A} \times \mathbf{B}| = |\mathbf{B} \times \mathbf{A}|$$

2. **Perpendicular vectors:** $\theta = 90°$, $\sin 90° = 1 \Rightarrow \mathbf{A} \times \mathbf{B} = AB\, \hat{n}$ (maximum magnitude).
3. **Parallel / anti-parallel vectors:** $\sin 0° = \sin 180° = 0 \Rightarrow \mathbf{A} \times \mathbf{B} = \mathbf{0}$ (null vector).
4. **Self cross product:** $\mathbf{A} \times \mathbf{A} = AA \sin 0°\, \hat{n} = \mathbf{0}$.
5. **Area of parallelogram:** if $\mathbf{A}$ and $\mathbf{B}$ are adjacent sides, height = $B \sin\theta$, so

   $$\text{Area} = \text{base} \times \text{height} = A\,(B \sin\theta) = |\mathbf{A} \times \mathbf{B}|$$

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Magnitude of A × B equals the area of the parallelogram

Q7 **How can the equations of motion be used to describe the motion of an object? Also describe their limitations.**

The equations of motion describe motion in terms of three kinematic variables: **velocity (v), position (S) and time (t)**. Pairing them three ways gives:

Pair	Equation	Name
velocity – time	$v_f = v_i + at$	1st equation
position – time	$S = v_i t + \frac{1}{2}at^2$	2nd equation
velocity – position	$2aS = v_f^2 - v_i^2$	3rd equation

Limitation: they apply only to objects moving in a **straight line with constant (uniform) acceleration**.

Q8 **Derive the first equation of motion by algebraic and graphical methods.**

Algebraic method

A body with uniform acceleration has velocity v_i that changes to v_f in time t:

$$a = \frac{v_f - v_i}{t} \Rightarrow at = v_f - v_i$$

$$\mathbf{v_f = v_i + at}$$

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Graphical method

On the velocity–time graph, velocity changes from v_i at A to v_f at B in time t. Draw BD ⊥ time axis and AC ∥ time axis.

OA = v_i, BD = v_f, AC = OD = t

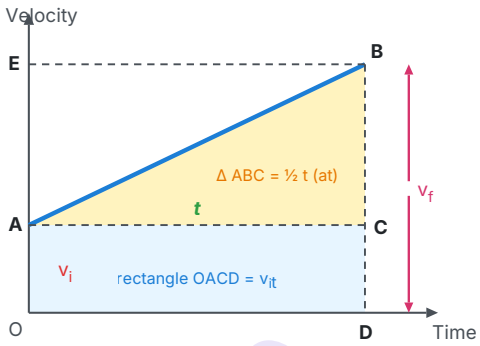
$$BD = BC + CD = BC + OA \Rightarrow v_f = BC + v_i \ldots(1)$$

The slope of AB is the acceleration:

$$a = \frac{BC}{AC} = \frac{BC}{t} \Rightarrow BC = at$$

Putting in (1):

$$\mathbf{v_f = v_i + at}$$



Velocity–time graph

Q9 Derive the second equation of motion by algebraic and graphical methods.

Algebraic method

For non-uniform velocity, displacement = average velocity × time:

$$S = \left(\frac{v_i + v_f}{2}\right) t$$

Put $v_f = v_i + at$:

$$S = \left(\frac{v_i + v_i + at}{2}\right) t = \left(\frac{2v_i + at}{2}\right) t = \left(v_i + \frac{at}{2}\right) t$$

$$\mathbf{S = v_it + \tfrac{1}{2}at^2}$$

Graphical method

Displacement equals the **area under the velocity-time graph** OABD (graph in Q8):

S = area of rectangle OACD + area of triangle ABC

$$S = (OA \times OD) + \tfrac{1}{2}\,(AC \times BC) = v_it + \tfrac{1}{2}\,(t \times BC) \ldots(1)$$

Since slope of AB = a = BC / t, so BC = at. Putting in (1):

$$\mathbf{S = v_it + \tfrac{1}{2}\,t\,(at) = v_it + \tfrac{1}{2}at^2}$$

Q10 Derive the third equation of motion by algebraic and graphical methods.

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Algebraic method

$$S = \left(\frac{v_i + v_f}{2}\right) t \ldots(1) \quad \text{and from the 1st equation} \quad t = \frac{v_f - v_i}{a}$$

$$S = \left(\frac{v_f + v_i}{2}\right)\left(\frac{v_f - v_i}{a}\right) = \frac{v_f^2 - v_i^2}{2a}$$

$$\mathbf{2aS = v_f^2 - v_i^2}$$

Graphical method

Distance = area of trapezium OABD under the velocity–time graph (Q8):

$$S = \tfrac{1}{2} \text{ (sum of parallel sides)} \times \text{height} = \tfrac{1}{2} (OA + BD) \times OD = \tfrac{1}{2} (v_i + v_f)\, t$$

Put $t = (v_f - v_i)/a$:

$$S = \tfrac{1}{2} (v_f + v_i)\left(\frac{v_f - v_i}{a}\right) = \frac{v_f^2 - v_i^2}{2a}$$

$$\mathbf{2aS = v_f^2 - v_i^2}$$

Q11 What is acceleration due to gravity? What is its value? Discuss its sign, write the equations of motion under gravity, and state Galileo's view about falling bodies.

Without air resistance, all objects in free fall near the Earth's surface move towards the Earth with a **uniform acceleration**, called the acceleration due to gravity, **g**. Its average value near the surface is **9.8 m s^{-2}**, directed downward.

Replacing a by g, the equations of motion become:

$$\text{(i) } v_f = v_i + gt \quad \text{(ii) } h = v_i t + \tfrac{1}{2} g t^2 \quad \text{(iii) } 2gh = v_f^2 - v_i^2$$

Sign of g: taken **positive** for a falling body (initial velocity zero / downward) and **negative** for a body thrown vertically upward.

Galileo's view: in vacuum all bodies fall freely with the same acceleration g. Bodies dropped from the same height strike the ground with the same velocity, whatever their mass.

Q12 What is projectile motion? Give examples. Derive expressions for (i) acceleration (ii) distance covered (iii) velocity at any time (iv) time of flight (v) range (vi) maximum height.

> The two-dimensional motion of a body along a curved path under the action of **gravity alone** is called projectile motion. The path is the **trajectory**; the body is the **projectile**.

Examples: a kicked football, a missile fired from a launcher, a bomb dropped from a bomber, a jumping animal.

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Projectile motion covers horizontal and vertical distances at the same time. Two cases: **(1) linear (horizontal) projectile** — thrown horizontally from a height; **(2) oblique projectile** — launched from the ground at angle θ.

(i) Acceleration

Horizontal: no force acts along x (air friction neglected), $F_x = 0$:

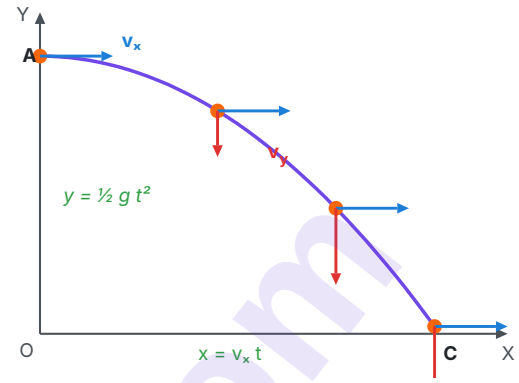
$$a_x = \frac{F_x}{m} = 0$$

so the horizontal velocity stays constant.

Vertical: only the weight w = mg acts:

$$a_y = \frac{w}{m} = \frac{mg}{m} = g$$

Vertical motion is just free fall.



Ball thrown horizontally: v_x constant, v_y grows

(ii) Distance covered (body thrown horizontally)

Vertical: $v_{iy} = 0$, $a_y = g$:

$$y = v_{iy}t + ½a_yt^2 \Rightarrow \mathbf{y = ½gt^2}$$

Horizontal: $a_x = 0$:

$$x = v_{ix}t + ½(0)t^2 \Rightarrow \mathbf{x = v_{ix}t}$$

(iii) Velocity at any instant

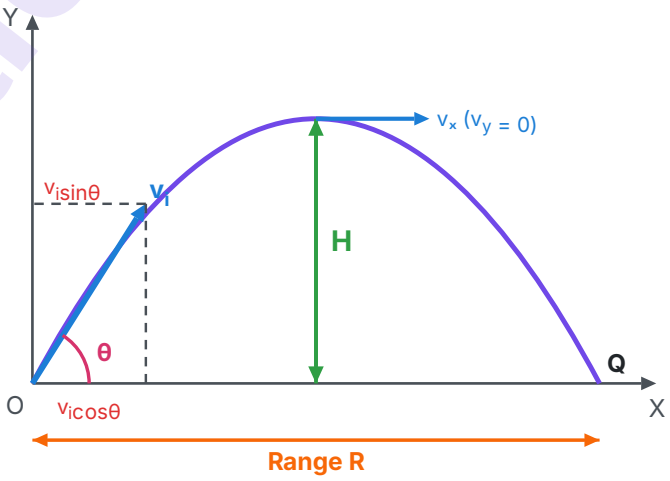
Launched with v_i at angle θ: $v_{ix} = v_i \cos\theta$, $v_{iy} = v_i \sin\theta$.

Horizontal: $v_{fx} = v_{ix} + a_xt = \mathbf{v_i \cos\theta}$ (constant)

Vertical: $v_{fy} = v_{iy} + a_yt = \mathbf{v_i \sin\theta - gt}$ (changes)

$$\mathbf{v = \sqrt{(v_x^2 + v_y^2)} \qquad \varphi = \tan^{-1}(v_y / v_x)}$$

The velocity is maximum just before hitting the ground; its direction φ changes as v_y changes.



Oblique projectile: components, height H and range R

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(iv) Time of flight

Total time to complete the journey. Using the 2nd equation vertically with $y = 0$, $a_y = -g$:

$$0 = v_i \sin\theta \cdot t - \tfrac{1}{2}gt^2 \;\Rightarrow\; \tfrac{1}{2}gt^2 = v_i \sin\theta \cdot t$$

$$\mathbf{T = \frac{2v_i \sin\theta}{g}}$$

(v) Range

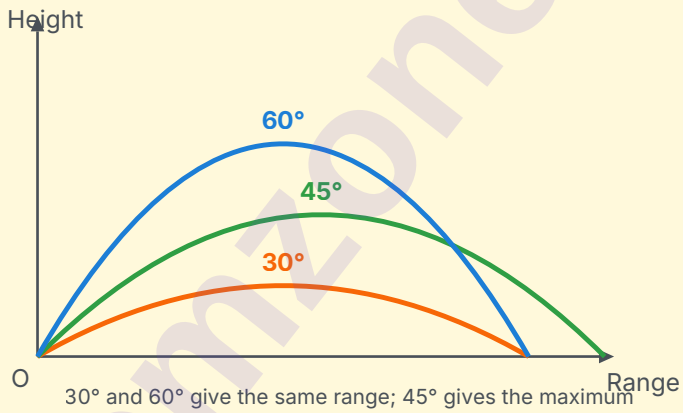
Horizontal distance covered during the whole flight:

$$R = v_{ix} \times T = (v_i \cos\theta)\left(\frac{2v_i \sin\theta}{g}\right) = \frac{v_i^2\,(2 \sin\theta \cos\theta)}{g}$$

$$\mathbf{R = \frac{v_i^2}{g} \sin 2\theta}$$

Maximum range: when $\sin 2\theta = 1 \Rightarrow 2\theta = 90° \Rightarrow \boldsymbol{\theta = 45°}$, giving $R_{max} = v_i^2/g$.
Minimum range: at $\theta = 90°$, $R = (v_i^2/g) \sin 180° = 0$.

Do You Know?



30° and 60° give the same range; 45° gives the maximum

Below 45°, both height and range are less. Above 45° the height is greater but the range again decreases.

(vi) Maximum height

At the top $v_{fy} = 0$. With $a_y = -g$, $v_{iy} = v_i \sin\theta$, using $2a_y h = v_{fy}^2 - v_{iy}^2$:

$$2(-g)h = 0 - (v_i \sin\theta)^2$$

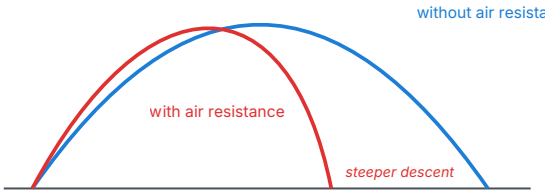
$$\mathbf{H = \frac{v_i^2 \sin^2\theta}{2g}}$$

Q13 **Discuss the effect of air resistance on the range of a projectile.**

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Air resistance slows the projectile's forward motion, reducing v_i. Since R depends on v_i^2, the **range decreases**.

Air resistance is not constant during flight: as the object slows, the resistance also decreases. The object slows down more slowly and speeds up more slowly as it falls. The trajectory is therefore **not a perfect parabola** — it is skewed, with a steeper descent than ascent.



Q14 Define linear momentum. How are force and momentum related? State Newton's second law in terms of momentum.

Momentum is the quantity of motion possessed by a body, equal to the product of mass and velocity: $\mathbf{p = mv}$.

It is a vector in the direction of velocity. SI unit: **kg m s^{-1}** or **N s**; dimensions **[MLT^{-1}]**.

Newton's second law in terms of momentum

A force F acts on mass m for time t, changing its velocity from v_i to v_f:

$$a = \frac{v_f - v_i}{t} \quad \text{and} \quad a = \frac{F}{m} \Rightarrow \frac{F}{m} = \frac{v_f - v_i}{t}$$

$$F = \frac{mv_f - mv_i}{t} = \frac{p_f - p_i}{t}$$

$$\mathbf{F = \frac{\Delta p}{t}}$$

The time rate of change of linear momentum equals the applied force.

Q15 Define impulse and show that it is equal to the change in momentum.

Impulse is the product of a force and the (very short) time interval for which it acts: $\mathbf{I = F \times \Delta t}$, where F is the average force.

Impulse is a vector in the direction of the force. SI unit: **N s** or kg m s^{-1}; dimensions **[MLT^{-1}]**.

Relation with momentum

$$F = \frac{\Delta p}{\Delta t} \Rightarrow F \times \Delta t = \Delta p$$

$$\mathbf{Impulse = I = \Delta p = p_f - p_i = mv_f - mv_i}$$

So impulse always equals the change in linear momentum.

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Q16 State and prove the law of conservation of linear momentum.

> The total linear momentum of an **isolated system** of interacting bodies remains constant.

Isolated system: a system on which no external force acts, e.g. gas molecules enclosed in a closed vessel.

Proof



Two bodies m_1, m_2 move with v_1, v_2 and after collision with v'_1, v'_2. During impact they exert forces F (on m_2) and F′ (on m_1). By Newton's 3rd law:

$$F = -F' \Rightarrow F + F' = 0 \quad ...(1)$$

By the 2nd law in terms of momentum:

$$F\,t = m_2v'_2 - m_2v_2 \quad ...(2) \qquad F'\,t = m_1v'_1 - m_1v_1 \quad ...(3)$$

Adding (2) and (3), and using (1):

$$(F + F')\,t = (m_2v'_2 - m_2v_2) + (m_1v'_1 - m_1v_1) = 0$$

$$\mathbf{m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2}$$

Total momentum before collision = total momentum after collision. Hence proved.

Q17 Define collision. What are its types? Define them.

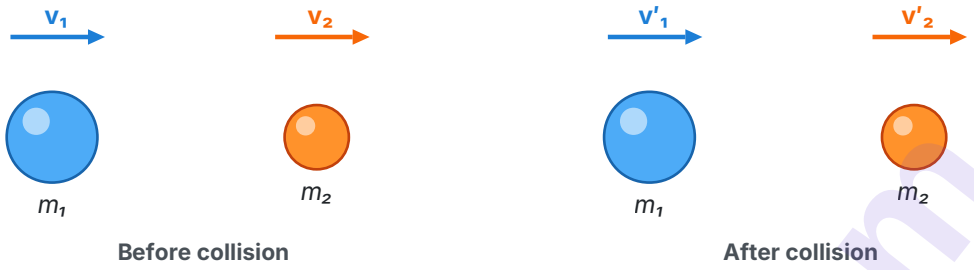
> When two bodies come so close that some interaction takes place between them, the interaction is called a **collision**.

Elastic collision	Inelastic collision
Both total **K.E.** and total **linear momentum** are conserved. Collisions are nearly elastic under certain conditions.	Linear momentum is conserved but **K.E. is not**. Part of the K.E. is lost as heat, sound and friction.
Examples: collisions of gas molecules; a hard ball bouncing on a hard floor (negligible K.E. loss).	**Examples:** car crashes; two clay balls colliding and sticking together.

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Q18 **Discuss elastic collision in one dimension. Prove that speed of approach equals speed of separation. Calculate the velocities after collision and discuss special cases.**

A collision is one-dimensional if the bodies move along the line joining their centres before and after the collision (non-rotating).



Conservation of momentum

$$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2 \Rightarrow m_1(v_1 - v'_1) = m_2(v'_2 - v_2) \ldots(1)$$

Conservation of K.E.

$$\tfrac{1}{2}m_1v_1^2 + \tfrac{1}{2}m_2v_2^2 = \tfrac{1}{2}m_1v'^2_1 + \tfrac{1}{2}m_2v'^2_2$$

$$m_1(v_1^2 - v'^2_1) = m_2(v'^2_2 - v_2^2) \ldots(2)$$

Dividing (2) by (1):

$$v_1 + v'_1 = v'_2 + v_2 \ldots(3) \Rightarrow \mathbf{(v_1 - v_2) = -(v'_1 - v'_2)} \ldots(4)$$

$(v_1 - v_2)$ is the relative speed of **approach**; $(v'_2 - v'_1)$ is the relative speed of **separation**. So **speed of approach = speed of separation**.

Velocities after collision

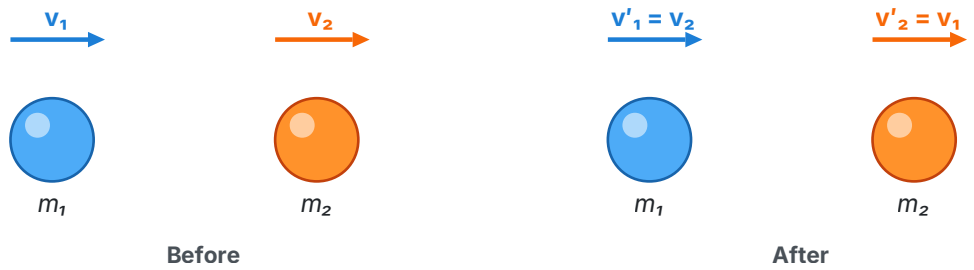
From (3), $v'_2 = v_1 + v'_1 - v_2$. Substituting in (1) and simplifying:

$$\mathbf{v'_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_1 + \left(\frac{2m_2}{m_1 + m_2}\right) v_2 \ldots(5)}$$

$$\mathbf{v'_2 = \left(\frac{2m_1}{m_1 + m_2}\right) v_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right) v_2 \ldots(6)}$$

Special cases

Case I — equal masses ($m_1 = m_2 = m$): (5) and (6) give $\mathbf{v'_1 = v_2}$ and $\mathbf{v'_2 = v_1}$. The bodies exchange velocities.



Case II — equal masses, target at rest ($v_2 = 0$): $v'_1 = 0$, $v'_2 = v_1$. The first body stops; the second moves off with its velocity.

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Case III — light body hits a massive body at rest ($m_1 \ll m_2$, $v_2 = 0$): neglecting m_1:

$$v'_1 = \frac{-m_2}{m_2} v_1 = \mathbf{-v_1} \qquad v'_2 = 0$$

The heavy body stays at rest; the light body rebounds with its own speed.



Case IV — massive body hits a light body at rest ($m_1 \gg m_2$, $v_2 = 0$): neglecting m_2:

$$v'_1 = v_1 \qquad v'_2 = \frac{2m_1}{m_1} v_1 = \mathbf{2v_1}$$

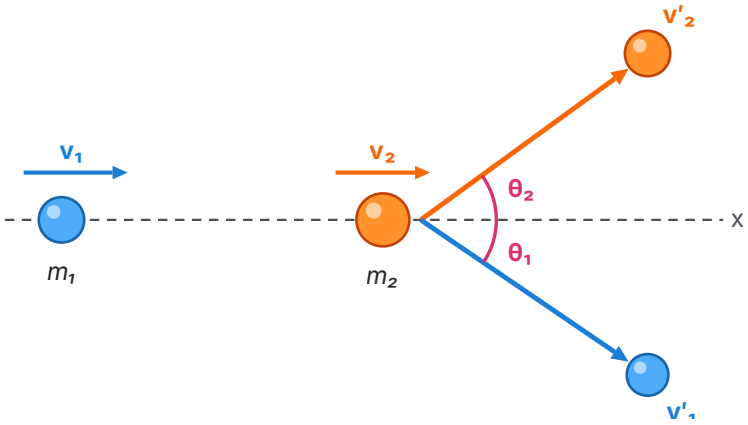
The heavy body continues with the same velocity; the light body moves off at twice that velocity.



Q19 Discuss elastic collision in two dimensions.

Two balls m_1, m_2 moving along a straight line with v_1, v_2 collide elastically and move off with v'_1, v'_2 at angles θ_1 and θ_2 with the x-axis. Both momentum and K.E. are conserved; momentum (a vector) is conserved along each axis.

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Elastic collision in two dimensions

x-axis: $m_1v_1 + m_2v_2 = m_1v'_1 \cos\theta_1 + m_2v'_2 \cos\theta_2$ ...(1)

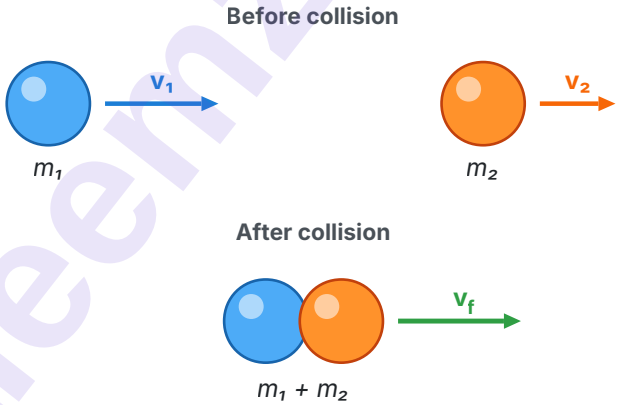
y-axis: $0 = m_1v'_1 \sin\theta_1 - m_2v'_2 \sin\theta_2$ ...(2)

K.E.: $\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v'^2_1 + \frac{1}{2}m_2v'^2_2$ ...(3)

Equations (1)–(3) are used to solve problems on elastic collisions in two dimensions.

Q20 Explain inelastic collision in one dimension.

Bodies m_1 and m_2 move along the same line with $v_1 > v_2$. m_1 is the projectile and m_2 the target. After a perfectly inelastic collision they stick together, combined mass $(m_1 + m_2)$, moving with common velocity v_f.



Perfectly inelastic collision in one dimension

Momentum is conserved:

$$m_1v_1 + m_2v_2 = (m_1 + m_2)\,v_f$$

$$\mathbf{v_f = \frac{m_1}{m_1 + m_2}\,v_1 + \frac{m_2}{m_1 + m_2}\,v_2 \ldots(1)}$$

Special case — target at rest ($v_2 = 0$):

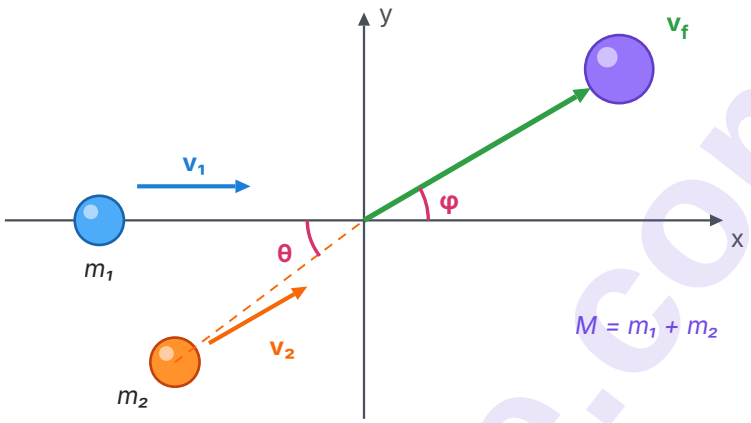
$$v_f = \frac{m_1}{m_1 + m_2}\,v_1$$

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The velocity of m_1 is reduced by the mass ratio $m_1/(m_1 + m_2)$.

Q21 Discuss inelastic collision in two dimensions.

Macroscopic collisions are generally inelastic. In a **perfectly inelastic** collision the objects stick together. Ball m_1 moves along the x-axis with v_1; ball m_2 moves with v_2 at angle θ with the x-axis. They collide at the origin and stick, combined mass $M = m_1 + m_2$, moving with v_f at angle φ.



Perfectly inelastic collision in two dimensions

x-direction: $m_1v_1 + m_2v_2 \cos\theta = M\, v_f \cos\varphi$ ...(1)

y-direction: $0 + m_2v_2 \sin\theta = M\, v_f \sin\varphi$ ...(2)

Equations (1) and (2) give the final velocity v_f and direction φ.

Kinetic energy

K.E. is a scalar, so velocities need not be resolved.

$(K.E.)_i = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$ ...(3) $\quad (K.E.)_f = \frac{1}{2}Mv_f^2$ ...(4)

Loss in K.E. = Δ(K.E.) = $(K.E.)_i - (K.E.)_f$

The lost K.E. changes into heat, sound or deformation.

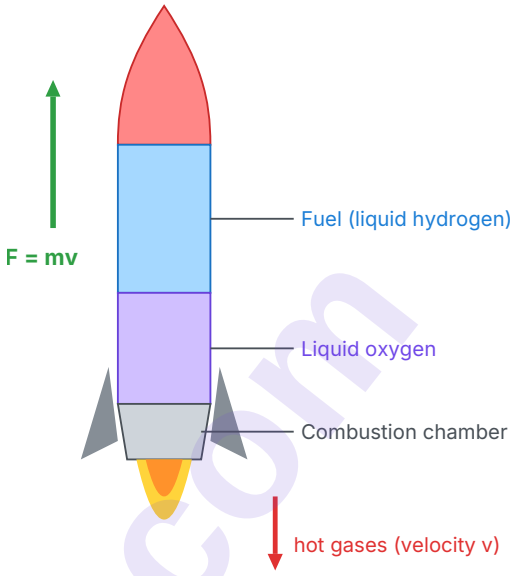
Q22 Discuss some examples of inelastic collision.

1. **Karate chop:** when a karate chop breaks a pile of bricks, the hand does not bounce back. Energy is absorbed by the bricks as heat, sound and the work of breaking them. If the chop is not perfectly vertical, momentum transfer has horizontal and vertical components.
2. **Car crash:** colliding vehicles crumple and deform, absorbing the impact energy. Most K.E. is lost as heat, sound and damage, and the cars do not bounce back.
3. **Ball and bat:** the ball deforms and compresses on impact, and some K.E. becomes heat and sound. The bat also absorbs some energy, so not all initial K.E. is conserved.

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Q23 **What is rocket propulsion? Find an expression for the acceleration of a rocket.**

Rocket motion is based on the **law of conservation of linear momentum**. The rocket and its fuel form an isolated system. Burning fuel produces hot gases expelled at high velocity from the tail. The rocket gains equal momentum in the opposite (upward) direction and keeps speeding up while the engines operate.



Rocket propulsion

Acceleration of the rocket

Let m = mass of gas ejected per second with velocity v (downward, so momentum = −mv). Initial momentum of the fuel = 0:

$$\Delta p = p_f - p_i = -mv - 0 = -mv$$

Rate of change of momentum = force on the gases: F = −mv. By Newton's 3rd law, an equal force acts upward on the rocket:

$$F = mv \quad ...(1)$$

$$\mathbf{a = \frac{F}{M} = \frac{mv}{M} \Rightarrow a = \left(\frac{m}{M}\right) v \quad ...(2)}$$

Since M decreases as fuel is consumed, the acceleration of the rocket **increases**.

It should be noted that

1. A typical rocket consumes fuel at about 10 000 kg s^{-1}.
2. Hot gases leave at about 4000 m s^{-1}.
3. More than 80% of the rocket's mass at launch is fuel.
4. To overcome this, several rockets are linked together — a **multistage rocket**.

Formula Sheet

#	Formula	Description
1	$A_x = A \cos\theta$	x-component of a vector
2	$A_y = A \sin\theta$	y-component of a vector
3	$A = \sqrt{(A_x^2 + A_y^2)}$	Magnitude of a vector
4	$\theta = \tan^{-1}(A_y/A_x)$	Direction of a vector
5	$\mathbf{A}\cdot\mathbf{B} = AB\cos\theta$	Scalar product
6	$\mathbf{A}\cdot\mathbf{B} = 0$	Perpendicular vectors
7	$\mathbf{A}\cdot\mathbf{B} = AB$	Parallel vectors

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8	$\mathbf{A}\cdot\mathbf{B} = -AB$	Anti-parallel vectors
9	$\mathbf{A}\cdot\mathbf{A} = A^2$	Self dot product
10	$\mathbf{A}\cdot\mathbf{B} = A_xB_x + A_yB_y + A_zB_z$	Dot product from components
11	$\theta = \cos^{-1}(\mathbf{A}\cdot\mathbf{B} / AB)$	Angle between two vectors
12	$A\cos\theta = \mathbf{A}\cdot\mathbf{B}/B$	Projection of A on B
13	$B\cos\theta = \mathbf{A}\cdot\mathbf{B}/A$	Projection of B on A
14	$\mathbf{A}\times\mathbf{B} = AB\sin\theta\,\hat{n}$	Vector product
15	$\mathbf{A}\times\mathbf{B} = AB\,\hat{n}$	Perpendicular vectors
16	$\mathbf{A}\times\mathbf{B} = 0$	Parallel / anti-parallel vectors
17	$\mathbf{A}\times\mathbf{A} = 0$	Self cross product
18	$\mathbf{A}\times\mathbf{B} = (A_yB_z - A_zB_y)\hat{i} + (A_zB_x - A_xB_z)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$	Cross product from components
19	$\text{Area} = \lvert\mathbf{A}\times\mathbf{B}\rvert = AB\sin\theta$	Area of parallelogram
20	$\boldsymbol{\tau} = \mathbf{r}\times\mathbf{F} = rF\sin\theta\,\hat{n}$	Torque
21	$\mathbf{F} = m\mathbf{a}$	Newton’s 2nd law
22	$\mathbf{p} = m\mathbf{v}$	Linear momentum
23	$F = (mv_f - mv_i)/t$	2nd law in terms of momentum
24	$I = F\,t = mv_f - mv_i$	Impulse
25	$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$	Conservation of momentum
26	$x = v_{ix}\,t$	Horizontal distance (thrown horizontally)
27	$y = \frac{1}{2}\,g\,t^2$	Vertical distance (thrown horizontally)
28	$v_{fx} = v_i\cos\theta$	x-velocity of projectile
29	$v_{fy} = v_i\sin\theta - gt$	y-velocity of projectile
30	$v = \sqrt{(v_{fx}^2 + v_{fy}^2)}$	Instantaneous velocity
31	$H = v_i^2\sin^2\theta / 2g$	Maximum height
32	$T = 2v_i\sin\theta / g$	Time of flight
33	$R = v_i^2\sin 2\theta / g$	Range
34	$R_{max} = v_i^2 / g$	Maximum range ($\theta = 45°$)
35	$v'_1 = [(m_1-m_2)v_1 + 2m_2v_2] / (m_1+m_2)$	Elastic collision (1-D)
36	$v'_2 = [2m_1v_1 + (m_2-m_1)v_2] / (m_1+m_2)$	Elastic collision (1-D)
37	$a = (m / M)\,v$	Acceleration of rocket

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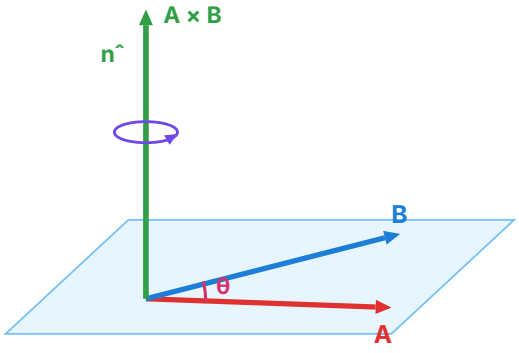
PART B

Short Questions

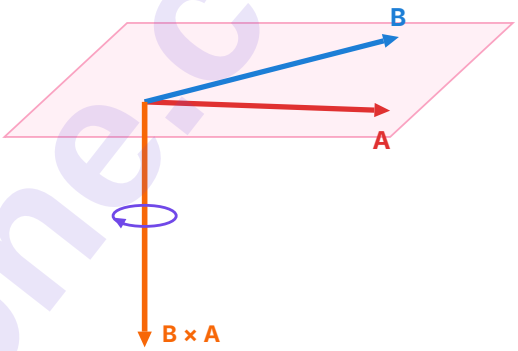
Exercise Short Questions

2.1 State the right-hand rule for two vectors with respect to vector product.

Rotate **A** into **B** through the smaller angle. Curl the fingers of the right hand in the direction of rotation; the erect thumb gives the direction of **A** × **B**, which is perpendicular to the plane containing **A** and **B**.



(a) A × B points up (right-hand rule)



(b) B × A points down

2.2 Define impulse and show how it is related to momentum.

Impulse is the product of force and the time for which it acts: I = F × t. From the 2nd law, F = Δp/Δt, so FΔt = $mv_f - mv_i$.

$$\mathbf{I = mv_f - mv_i = \Delta p}$$

Impulse equals the change in linear momentum.

2.3 Differentiate between elastic and inelastic collision.

Elastic	Inelastic
Total K.E. and total momentum both conserved.	Momentum conserved; K.E. not conserved (lost as heat, sound, friction).
e.g. gas molecules; hard ball on hard floor.	e.g. car crash; clay balls sticking together.

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2.4 Show that rate of change of momentum equals the applied force. State Newton's 2nd law in terms of momentum.

Mass m moving with v_i is acted on by F for time t, reaching v_f:

$$\mathbf{F = ma = \frac{m(v_f - v_i)}{t} = \frac{mv_f - mv_i}{t} = \frac{\Delta p}{t}}$$

Second law: the time rate of change of momentum equals the applied force.

2.5 State the law of conservation of linear momentum. Also state the condition under which it holds.

The total linear momentum of an **isolated system** always remains constant.
Condition: no external force. Real systems are not perfectly isolated (friction acts), but frictional forces are usually very small compared with the interacting forces, so the law is still useful in practice.

2.6 Show that the range of a projectile is maximum at 45°.

$$R = \frac{v_i^2 \sin 2\theta}{g}$$

R is maximum when $\sin 2\theta = 1 \Rightarrow 2\theta = \sin^{-1}(1) = 90° \Rightarrow \mathbf{\theta = 45°}$.

2.7 Find the time taken by a projectile to reach maximum height.

At the top $v_{fy} = 0$; $v_{iy} = v_i \sin\theta$; $a = -g$. Using $v_f = v_i + at$:

$$0 = v_i \sin\theta - gt$$

$$\mathbf{t = \frac{v_i \sin\theta}{g}}$$

(half the total time of flight).

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2.8 **The maximum horizontal range of a projectile is 800 m. Find the height attained at θ = 60°.**

Given: R_{max} = 800 m • θ = 60° • H = ?

$$R_{max} = v_i^2/g \Rightarrow v_i^2 = 9.8 \times 800 = 7840 \text{ m}^2 \text{ s}^{-2}$$

$$H = \frac{v_i^2 \sin^2\theta}{2g} = \frac{7840 \times (0.866)^2}{19.6}$$

H = 300 m

SLO-Based Additional Short Questions + Past Papers (Punjab Boards)

Q1 **The scalar product of a non-zero vector A with an unknown vector B is zero. What can you conclude about B?**

Since $\mathbf{A}\cdot\mathbf{B}$ = AB cos θ = 0 and A ≠ 0, either (i) **B** is a **null vector**, or (ii) **B** is **perpendicular** to **A** (θ = 90°, cos 90° = 0).

Q2 **Can the scalar product of two vectors be negative? Give an example.**

Yes. $\mathbf{A}\cdot\mathbf{B}$ = AB cos θ, and cos θ is negative for 90° < θ ≤ 180°. Example: work done against friction, W = Fd cos 180° = −Fd.

Q3 **Under what condition is the dot product of two vectors zero?**

When the vectors are **perpendicular** (θ = 90°): $\mathbf{A}\cdot\mathbf{B}$ = AB cos 90° = 0. It is also zero if either vector is a null vector.

Q4 **Define scalar product with examples.**

The product of two vectors that gives a scalar: $\mathbf{A}\cdot\mathbf{B}$ = AB cos θ. Examples: work W = $\mathbf{F}\cdot\mathbf{d}$; power P = $\mathbf{F}\cdot\mathbf{v}$.

Q5 **Can the dot product of two vectors equal the product of their magnitudes?**

Yes, when the vectors are **parallel** (θ = 0°): $\mathbf{A}\cdot\mathbf{B}$ = AB cos 0° = AB.

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Q6 **Show that the SI unit of linear momentum is kg m s^{-1} or N s.**

p = mv ⇒ unit = kg × m s^{-1} = kg m s^{-1}. Also kg m s^{-1} = (kg m s^{-2}) × s = **N s**, since 1 N = 1 kg m s^{-2}.

Q7 **Give the general form of Newton's second law.**

Rate of change of momentum equals the applied force: F = Δp/Δt. This form is more general than F = ma because it also covers cases where mass changes (e.g. rockets).

Q8 **How is momentum conserved when a bat hits a ball? Explain briefly.**

The collision is inelastic, but momentum is still conserved: the momentum gained by the ball equals the momentum lost by the bat (and the batsman's arms), so total momentum after equals total momentum before.

Q9 **Define vector product with examples.**

The product of two vectors that gives a vector: $\mathbf{A} \times \mathbf{B}$ = AB sin θ n̂. Examples: torque $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$; angular momentum $\mathbf{L} = \mathbf{r} \times \mathbf{p}$.

Q10 **Under what conditions are the equations of motion useful?**

(i) Only for straight-line motion with uniform acceleration. (ii) Vectors are handled like scalars. (iii) The direction of initial velocity is taken as positive; quantities opposite to it are negative.

Q11 **What is acceleration due to gravity? Write its value.**

Without air resistance, all freely falling objects near the Earth move towards it with uniform acceleration g ≈ **9.8 m s^{-2}**, directed downward.

Q12 **The horizontal range of a projectile is four times its height. Find the angle of projection.**

$$R = 4H \Rightarrow \frac{v_i^2 \sin 2\theta}{g} = 4 \times \frac{v_i^2 \sin^2\theta}{2g}$$

$$2 \sin\theta \cos\theta = 2 \sin^2\theta \Rightarrow \tan\theta = 1$$

$\theta = 45°$

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Q13 Which force is responsible for projectile motion?

The force of **gravity** (the weight of the projectile).

Q14 What is horizontal range? Write its formula.

The horizontal distance covered by a projectile during its flight: $R = \frac{v_i^2}{g} \sin 2\theta$, where v_i is the initial velocity and θ the angle of projection.

Q15 Show that range R and height h are related as R/h = 4 cot θ.

$$\frac{R}{h} = \frac{v_i^2 \sin 2\theta / g}{v_i^2 \sin^2\theta / 2g} = \frac{2 \sin 2\theta}{\sin^2\theta} = \frac{4 \sin\theta \cos\theta}{\sin^2\theta}$$

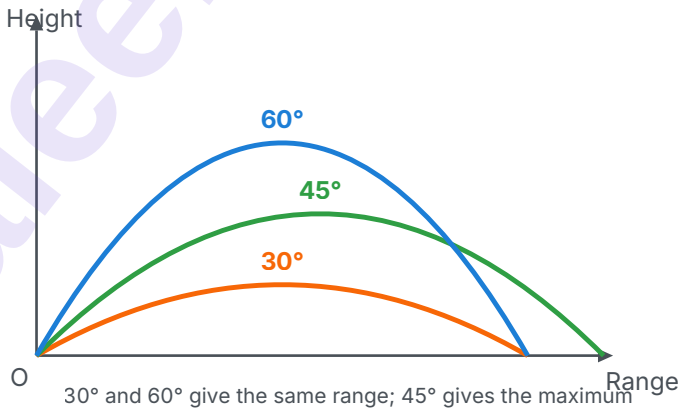
$$\mathbf{\frac{R}{h} = 4 \cot \theta}$$

Q16 Is the range of a projectile the same for 30° and 60°? If yes, prove it.

Yes.

$$R_1 = \frac{v_i^2}{g} \sin 60° = \frac{0.866\, v_i^2}{g} \qquad R_2 = \frac{v_i^2}{g} \sin 120° = \frac{0.866\, v_i^2}{g}$$

$$\mathbf{R_1 = R_2}$$



30° and 60° give the same range; 45° gives the maximum

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Q17 **Show that $R/R_{max} = \sin 2\theta$.**

$$R = \frac{v_i^2}{g} \sin 2\theta \text{ and } R_{max} = \frac{v_i^2}{g} \Rightarrow R = R_{max} \sin 2\theta$$

$$\boxed{\frac{R}{R_{max}} = \sin 2\theta}$$

Q18 **What is the principle of rocket propulsion?**

Conservation of linear momentum: the mass of fuel burnt per second times the velocity of the ejected gases equals the force on the rocket, which pushes it forward in space.

Q19 **Calculate the acceleration of a rocket.**

Let m = mass of gas ejected per second at velocity v. Thrust F = mv. For rocket mass M: Ma = mv

$$\boxed{a = \frac{mv}{M}}$$

Q20 **What is an isolated system? Give an example.**

A system on which no external agency exerts a force, e.g. gas molecules enclosed in a vessel at constant temperature.

Q21 **Does a moving object have impulse?**

Impulse comes from a force acting for some time. An object moving with **variable velocity** has impulse (its momentum changes). With **uniform velocity**, no net force acts, so impulse is zero.

Q22 **Show that torque and work have the same dimensions.**

Torque $\tau = rF \Rightarrow N\ m = kg\ m\ s^{-2} \times m = kg\ m^2\ s^{-2} \Rightarrow [ML^2T^{-2}]$
Work $W = Fd \Rightarrow N\ m = kg\ m^2\ s^{-2} \Rightarrow [ML^2T^{-2}]$

Both have dimensions $[ML^2T^{-2}]$

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PART C

Multiple Choice Questions

Exercise MCQs

1 **The angle at which the dot product equals the cross product (in magnitude) is:**

(a) 65° **(b)** 45°
(c) 76° **(d)** 30°

2 **The projectile gains its maximum height at an angle of:**

(a) 0° **(b)** 45°
(c) 60° **(d)** 90°

3 **The scalar product of two vectors is maximum if they are:**

(a) perpendicular **(b)** parallel
(c) at 30° **(d)** at 45°

4 **The range of a projectile is the same for two angles which are mutually:**

(a) perpendicular **(b)** supplementary
(c) complementary **(d)** 270°

5 **The acceleration at the top of the trajectory of a projectile is:**

(a) maximum **(b)** minimum
(c) zero **(d)** g

6 **SI unit of impulse is:**

(a) kg m s^{-2} **(b)** N m
(c) N s **(d)** N m^2

7 **The rate of change of momentum is:**

(a) force **(b)** impulse
(c) acceleration **(d)** power

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8 **As a rocket moves upward during its journey, its acceleration goes on:**

(a) increasing
(b) decreasing
(c) remaining same
(d) it moves with uniform velocity

9 **Elastic collision involves:**

(a) loss of energy
(b) gain of energy
(c) no gain, no loss of energy
(d) no relation between energy and elastic collision

Answer Key — Exercise MCQs

1	b	2	d	3	b	4	c	5	d	6	c
7	a	8	a	9	c						

Hints

Q1: AB cos θ = AB sin θ ⇒ tan θ = 1 ⇒ 45°. Q4: θ and (90° − θ) give the same sin 2θ. Q5: only gravity acts, so a = g even at the top. Q8: rocket mass decreases, so a = mv/M increases.

SLO-Based Additional MCQs + Past Papers (Punjab Boards)

1 **A scalar is a physical quantity completely specified by:**

(a) number
(b) direction only
(c) number with proper unit
(d) number with direction

2 **Which of the following is a scalar quantity?**

(a) torque
(b) force
(c) energy
(d) acceleration

3 **Name the quantity which is a vector:**

(a) density
(b) power
(c) charge
(d) impulse

4 **F_x of a 30 N force making 60° with the x-axis is:**

(a) 7 N
(b) 15 N
(c) 5 N
(d) 10 N

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5 **A 10 N force makes 30° with the x-axis. Its y-component is:**

(a) 8.66 N
(b) 0 N
(c) 0.776 N
(d) 5 N

6 **Maximum number of rectangular components of a vector in 2-D is:**

(a) one
(b) two
(c) three
(d) infinite

7 **The scalar product of A and B is zero when they are:**

(a) perpendicular to each other
(b) equal vectors
(c) in the same direction
(d) in opposite directions

8 **If $\mathbf{A}$ and $\mathbf{B}$ are parallel, then:**

(a) $\mathbf{A}\cdot\mathbf{B} = AB$
(b) $\mathbf{A}\cdot\mathbf{B} = 1$
(c) $\mathbf{A}\cdot\mathbf{B} = \infty$
(d) $\mathbf{A}\cdot\mathbf{B} = -1$

9 **For a vector $\mathbf{A}$, which is correct?**

(a) $\mathbf{A}\cdot\mathbf{A} = 0$
(b) $\mathbf{A} \times \mathbf{A} = A^2$
(c) $\mathbf{A} \times \mathbf{A} = 1$
(d) $\mathbf{A}\cdot\mathbf{A} = A^2$

10 **The vector product of A and B making angle θ is:**

(a) AB sin θ
(b) AB sin θ $\hat{n}$
(c) AB cos θ
(d) (A sin θ / B) $\hat{n}$

11 **If A·B = 0 when A and B are parallel or anti-parallel, then either A or B is:**

(a) equal
(b) perpendicular
(c) a null vector
(d) not zero

12 **Projection of $\mathbf{B}$ on $\mathbf{A}$ is:**

(a) A cos θ
(b) B cos θ
(c) A sin θ
(d) B sin θ

13 **The scalar product of two vectors is maximum if they are:**

(a) perpendicular
(b) anti-parallel
(c) parallel
(d) all of these

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14 **If $\mathbf{A} \times \mathbf{B}$ points along the positive z-axis, $\mathbf{A}$ and $\mathbf{B}$ lie in the:**

(a) yz-plane
(b) xz-plane
(c) xy-plane
(d) x0-plane

15 **The force on charge q moving with velocity v in magnetic field B is:**

(a) F = q(v·B)
(b) F = q(v × B)
(c) F = (v × B)/q
(d) F = v × B

16 **The cross product of a vector A with itself is:**

(a) 1
(b) A
(c) 2A
(d) null vector

17 **If A × B = 0, then:**

(a) A and B are perpendicular
(b) A and B are parallel
(c) A and B are position vectors
(d) A and B are unit vectors

18 **Which of the following is true?**

(a) $\mathbf{A} \times \mathbf{B} = \mathbf{B} \times \mathbf{A}$
(b) $\mathbf{A} \cdot \mathbf{B} \neq \mathbf{B} \cdot \mathbf{A}$
(c) $\mathbf{A} \times \mathbf{B} \neq \mathbf{B} \times \mathbf{A}$
(d) $\mathbf{A} \cdot \mathbf{B} = -(\mathbf{B} \cdot \mathbf{A})$

19 **If the magnitudes of cross product and dot product are equal, the angle between the vectors is:**

(a) 0°
(b) 90°
(c) 180°
(d) 45°

20 **Both dot and cross products of A and B are zero when:**

(a) A ⊥ B
(b) A and B are anti-parallel
(c) A and B are perpendicular
(d) either one of them is a null vector

21 **The resultant of a 6 N force at right angles to an 8 N force is:**

(a) 2 N
(b) 14 N
(c) 8 N
(d) 10 N

22 **If $\mathbf{A} = 2\hat{i} + \hat{j} + 2\hat{k}$, then $|\mathbf{A}|$ is:**

(a) zero
(b) 3
(c) 5
(d) 9

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23 **The resultant of 3 N and 4 N forces acting parallel is:**

(a) 7 N
(b) 1 N
(c) 6 N
(d) 4 N

24 **A body thrown at an angle with the horizontal, moving freely under gravity, is called a:**

(a) satellite
(b) rocket
(c) space ship
(d) projectile

25 **The trajectory of a projectile is a:**

(a) straight line
(b) parabola
(c) hyperbola
(d) circle

26 **During projectile motion the horizontal component of velocity:**

(a) changes with time
(b) becomes zero
(c) does not change
(d) increases with time

27 **At the highest point of the trajectory the vertical component of velocity is:**

(a) small
(b) maximum
(c) $v_i \cos \theta$
(d) zero

28 **Motion of a projectile is:**

(a) one dimensional
(b) three dimensional
(c) two dimensional
(d) none of these

29 **The horizontal range of a projectile is:**

(a) $2v_i \sin \theta / g$
(b) $2v_i^2 \sin 2\theta / g$
(c) $2v_i^2 \sin \theta \cos \theta / g$
(d) both b and c

30 **For maximum horizontal range, the angle of projection is:**

(a) 90°
(b) 0°
(c) 45°
(d) 30°

31 **The maximum height attained by a projectile is:**

(a) $v_i^2 \sin^2\theta / 2g$
(b) $R_{max} \sin^2\theta / 2$
(c) $2v_i \sin \theta / g$
(d) both a and b

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32 **The velocity of a projectile is maximum:**

(a) at half the height
(b) at the highest point
(c) just before striking the ground and at the point of projection
(d) at one-fourth of maximum height

33 **The horizontal acceleration during projectile motion is:**

(a) 45 m s^{-2}
(b) 0
(c) 9.8 m s^{-2}
(d) maximum

34 **Horizontal component of velocity for v_i = 500 m s^{-1} at 60° is:**

(a) zero
(b) 500 m s^{-1}
(c) 250 m s^{-1}
(d) 1000 m s^{-1}

35 **The vertical component of velocity at any time t is:**

(a) $v_i \cos\theta$
(b) $v_i \sin\theta$
(c) $v_i \sin\theta - gt$
(d) $v_i \cos\theta - gt$

36 **Horizontal range depends upon:**

(a) angle of projection
(b) initial velocity
(c) both initial velocity and angle of projection
(d) final velocity

37 **The range of a projectile is directly proportional to:**

(a) $\sin^2\theta$
(b) $\sin 2\theta$
(c) $\sin\theta$
(d) $2\sin\theta$

38 **The horizontal range at 30° is the same as at:**

(a) 40°
(b) 45°
(c) 90°
(d) 60°

39 **Correct relation between H and T of a projectile:**

(a) $H = gT^2/8$
(b) $H = 8T^2/g$
(c) $H = 8g/T^2$
(d) $H = 8g/gT^2$

40 **The angle of projection for which height and range are equal:**

(a) 45°
(b) 58°
(c) 66°
(d) 76°

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41 **The SI unit of momentum is:**

(a) kg m s^{-2} **(b)** kg m s^{-1}
(c) kg m^2 s **(d)** kg^2 m s^{-1}

42 **A cricket ball hit straight up takes 3 s to reach the highest point. Its initial velocity is:**

(a) 10 m s^{-1} **(b)** 15 m s^{-1}
(c) 29.4 m s^{-1} **(d)** 12.2 m s^{-1}

43 **Distance covered in time t starting from rest is:**

(a) at^2 **(b)** $2at^2$
(c) $\frac{1}{2}at^2$ **(d)** $\frac{1}{2}a^2t$

44 **Dimensions of impulse are similar to those of:**

(a) work **(b)** torque
(c) force **(d)** momentum

45 **SI unit of impulse is:**

(a) kg m s^{-1} **(b)** N m
(c) N s^{-2} **(d)** N m m^2

46 **Before launch, the mass of fuel of a rocket is about:**

(a) 60% of rocket mass **(b)** 50% of rocket mass
(c) 40% of rocket mass **(d)** 80% of rocket mass

47 **A typical rocket ejects burnt gases at a speed of:**

(a) 400 m s^{-1} **(b)** 4000 m s^{-1}
(c) 800 m s^{-1} **(d)** 10 000 m s^{-1}

48 **Motion of a rocket is in accordance with the law of conservation of:**

(a) linear momentum **(b)** energy
(c) mass **(d)** angular momentum

49 **A rocket consuming fuel at 10 000 kg/s ejects burnt gases at over:**

(a) 4000 m/s **(b)** 400 m/s
(c) 4000 cm/s **(d)** 400 cm/s

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50 **A collision in which both K.E. and momentum are conserved is:**

(a) elastic
(b) inelastic
(c) both elastic and inelastic
(d) neither elastic nor inelastic

51 **Neutrons are slowed down most effectively if the stationary targets are:**

(a) β-rays
(b) photons
(c) protons
(d) electrons

52 **If $|a + b| = |a - b|$ when a = b, the angle between a and b is:**

(a) 0°
(b) 30°
(c) 60°
(d) 90°

53 **The dimensions of torque are:**

(a) $[MLT^{-2}]$
(b) $[ML^2T^{-2}]$
(c) $[ML^2T^2]$
(d) $[MLT^{-1}]$

Answer Key — Additional MCQs

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

Hints

Q4: 30 cos 60° = 15 N. Q5: 10 sin 30° = 5 N. Q22: $\sqrt{(4 + 1 + 4)} = 3$. Q31: $R_{max}\ \sin^2\theta/2 = v_i^2\sin^2\theta/2g$, so both a and b. Q39: $v_i \sin\theta = gT/2 \Rightarrow H = gT^2/8$. Q40: $R = H \Rightarrow \tan\theta = 4 \Rightarrow 76°$. Q42: $v_i = gt = 29.4\ m\ s^{-1}$. Q52: $|a + b| = |a - b| \Rightarrow a \cdot b = 0 \Rightarrow 90°$.

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PART D

Solved Exercise

Exercise Numericals

2.1 **The magnitudes of the cross and scalar products of two vectors are $4\sqrt{3}$ and 4 respectively. Find the angle between them.**

Given: $|A \times B| = 4\sqrt{3}$ • $A \cdot B = 4$ • $\theta = ?$

$AB \sin\theta = 4\sqrt{3}$ ...(1) $AB \cos\theta = 4$ ...(2)

Dividing (1) by (2): $\tan\theta = \frac{4\sqrt{3}}{4} = \sqrt{3}$

$\theta = \tan^{-1}(\sqrt{3}) = 60°$

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2.2 **A helicopter is ascending vertically at 19.6 m s^{-1}. When it is 156.8 m above the ground, a stone is dropped. How long does the stone take to reach the ground?**

Given: $v_i = 19.6$ m s^{-1} (up) • $h = 156.8$ m • $g = 9.8$ m s^{-2}

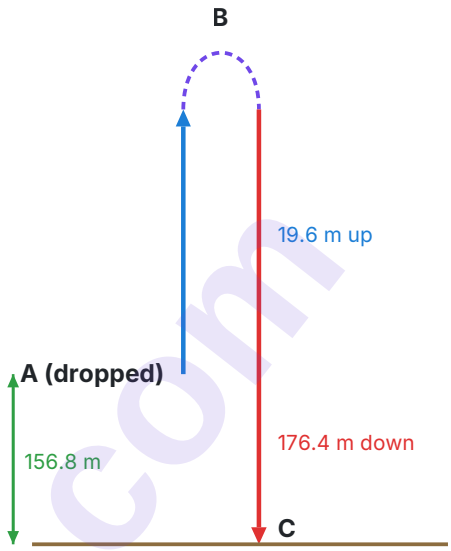
A → B (going up, stone keeps the helicopter's upward velocity):

$$0 = 19.6 - 9.8\, t_1 \Rightarrow t_1 = 2 \text{ s}$$

$$h_1 = 19.6(2) - \tfrac{1}{2}(9.8)(2)^2 = 19.6 \text{ m}$$

B → C (falling from rest): total height = 156.8 + 19.6 = 176.4 m

$$176.4 = \tfrac{1}{2}(9.8)\, t_2^2 \Rightarrow t_2^2 = \frac{176.4}{4.9} = 36 \Rightarrow t_2 = 6 \text{ s}$$



Total time $t = 2 + 6 = 8$ s

Alternative method (upward positive, $s = -156.8$ m, $a = -9.8$ m s^{-2}):

$$-156.8 = 19.6\, t - 4.9\, t^2 \Rightarrow t^2 - 4t - 32 = 0 \Rightarrow (t - 8)(t + 4) = 0$$

$t = 8$ s (t cannot be negative)

2.3 **If $|\mathbf{A} + \mathbf{B}| = |\mathbf{A} - \mathbf{B}|$, prove that A and B are perpendicular.**

$$|\mathbf{A} + \mathbf{B}|^2 = |\mathbf{A} - \mathbf{B}|^2$$

$$A^2 + B^2 + 2\mathbf{A}\cdot\mathbf{B} = A^2 + B^2 - 2\mathbf{A}\cdot\mathbf{B}$$

$$4\mathbf{A}\cdot\mathbf{B} = 0 \Rightarrow AB\cos\theta = 0 \Rightarrow \cos\theta = 0$$

$\theta = 90°$, so $\mathbf{A} \perp \mathbf{B}$

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2.4 **A body of mass M at rest explodes into 3 pieces. Two pieces of mass M/4 each fly off perpendicular to each other with velocities 3 m s^{-1} and 4 m s^{-1}. Find the velocity of the third piece.**

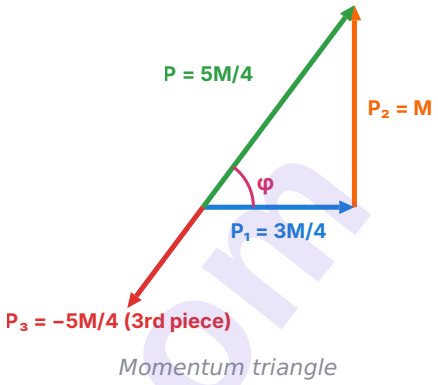
Mass of 3rd piece = M − (M/4 + M/4) = **M/2**

$p_1 = (M/4)(3) = 3M/4$ along x $p_2 = (M/4)(4) = M$ along y

$$P = \sqrt{((3M/4)^2 + M^2)} = \sqrt{\left(\frac{9M^2 + 16M^2}{16}\right)} = \frac{5M}{4}$$

Initial momentum is zero, so the 3rd piece must have equal and opposite momentum:

$$\frac{M}{2} v_3 = -\frac{5M}{4} \Rightarrow v_3 = -\frac{5}{2}$$



Momentum triangle

v_3 = 2.5 m s^{-1}, opposite to the resultant of P_1 and P_2

Direction: the resultant makes $\tan^{-1}(4/3) \approx 53°$ with the x-axis, so the third piece moves at 53° below the negative x-axis.

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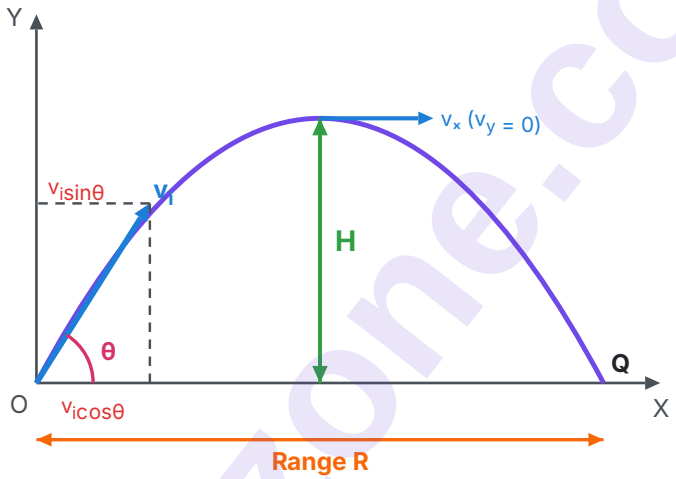
2.5 **A cricket ball is hit upward at 45° with velocity 20 m s^{-1}. Find (a) time of flight (b) maximum height (c) how far away it hits the ground.**

Given: $\theta = 45°$ • $v_i = 20\ m\ s^{-1}$

(a) $T = \frac{2v_i \sin\theta}{g} = \frac{2 \times 20 \times 0.707}{9.8} = \mathbf{2.9\ s}$

(b) $H = \frac{v_i^2 \sin^2\theta}{2g} = \frac{400 \times (0.707)^2}{19.6} = \mathbf{10.2\ m}$

(c) $R = \frac{v_i^2 \sin 2\theta}{g} = \frac{400 \times \sin 90°}{9.8} = \mathbf{40.8\ m \approx 41\ m}$



2.6 **A 20 g ball hits the wall of a squash court with a constant force of 50 N. If the time of impact is 0.50 s, find the impulse.**

Given: m = 20 g = 0.020 kg • F = 50 N • Δt = 0.50 s

$I = F \times \Delta t = 50 \times 0.50$

I = 25 N s

2.7 **A ball is kicked with an average force of 240 N; the impact lasts 0.25 s. Calculate (a) the change in momentum (b) its direction.**

Given: F = 240 N • Δt = 0.25 s

(a) Δp = F × Δt = 240 × 0.25 = 60 N s

(b) The change in momentum is in the **same direction as the applied force**.

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2.8 **An aeroplane moving horizontally at 200 m s^{-1} at a height of 8 km drops a bomb on a target. Find the horizontal distance from the target at which the bomb should be released.**

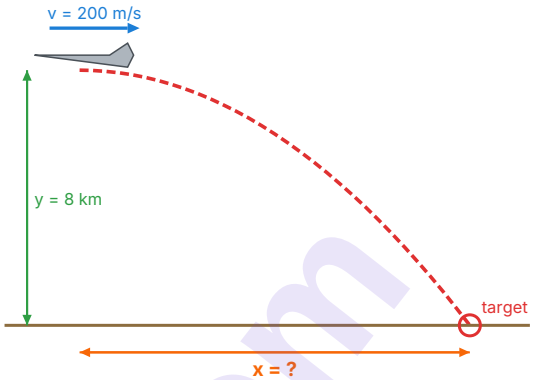
Given: $v_x = 200$ m s^{-1} • $v_{iy} = 0$ • $y = 8$ km = 8000 m

Time to fall 8000 m (vertical motion from rest):

$$8000 = \tfrac{1}{2}(9.8)t^2 \Rightarrow t = \sqrt{\left(\frac{8000}{4.9}\right)} = 40.4 \text{ s}$$

Horizontal velocity stays constant:

$$x = v_x\, t = 200 \times 40.4$$



Bomb released from a moving aeroplane

$x = 8080$ m ≈ 8.08 km

2.9 **Why does the range remain the same when the angle of projection changes from θ to θ′ = 90° − θ? Show that R/R′ = 1 for complementary angles.**

$$R = \frac{v_i^2 \sin 2\theta}{g} \quad \ldots(1)$$

$$R' = \frac{v_i^2 \sin 2(90° - \theta)}{g} = \frac{v_i^2 \sin(180° - 2\theta)}{g} = \frac{v_i^2 \sin 2\theta}{g} \quad \ldots(2)$$

since $\sin(180° - 2\theta) = \sin 2\theta$. So $R = R'$, and dividing (1) by (2):

$$\frac{R}{R'} = 1$$

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2.10 **A 1.0 kg trolley moving at 1.0 m s^{-1} collides with a similar trolley at rest. (i) The 1st stops and the 2nd moves at 1.0 m s^{-1} — show the collision is elastic. (ii) They stick together and move at 0.5 m s^{-1} — show it is inelastic.**

Given: $m_1 = m_2 = 1$ kg • $v_1 = 1$ m s^{-1} • $v_2 = 0$

K.E. before = $\frac{1}{2}(1)(1)^2 + \frac{1}{2}(1)(0)^2 = 0.5$ J



(i) $v'_1 = 0$, $v'_2 = 1$ m s^{-1}:

K.E. after = $\frac{1}{2}(1)(0)^2 + \frac{1}{2}(1)(1)^2 = 0.5$ J

K.E. is conserved ⇒ elastic collision

(ii) combined mass 2 kg, $v' = 0.5$ m s^{-1}:

K.E. after = $\frac{1}{2}(2)(0.5)^2 = 0.25$ J

0.25 J ≠ 0.5 J ⇒ inelastic collision

2.11 **A railway wagon of mass 4×10^4 kg moving at 3 m s^{-1} collides with another wagon of mass 2×10^4 kg at rest. They stick together. Find their combined velocity.**

Given: $m_1 = 4 \times 10^4$ kg • $v_1 = 3$ m s^{-1} • $m_2 = 2 \times 10^4$ kg • $v_2 = 0$

$m_1v_1 + m_2v_2 = (m_1 + m_2)v_f$

$(4 \times 10^4)(3) + 0 = (6 \times 10^4)\, v_f \Rightarrow 12 \times 10^4 = 6 \times 10^4\, v_f$

$v_f = 2$ m s^{-1}

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2.12 **A 575 kg car moving at 15.0 m s^{-1} smashes into the rear of a 1575 kg car moving at 5 m s^{-1} in the same direction. (i) What is the final velocity if they lock together? (ii) How much K.E. is lost?**

Given: $m_1 = 575$ kg • $v_1 = 15$ m s^{-1} • $m_2 = 1575$ kg • $v_2 = 5$ m s^{-1}

(i) Conservation of momentum:

$$575(15) + 1575(5) = (575 + 1575)\,v' \Rightarrow 8625 + 7875 = 2150\,v'$$

$$\mathbf{v' = \frac{16500}{2150} = 7.67\ m\ s^{-1}}$$

(ii)

$$\text{K.E.}_i = \tfrac{1}{2}(575)(15)^2 + \tfrac{1}{2}(1575)(5)^2 = 64\,687.5 + 19\,687.5 = 84\,375\ \text{J}$$

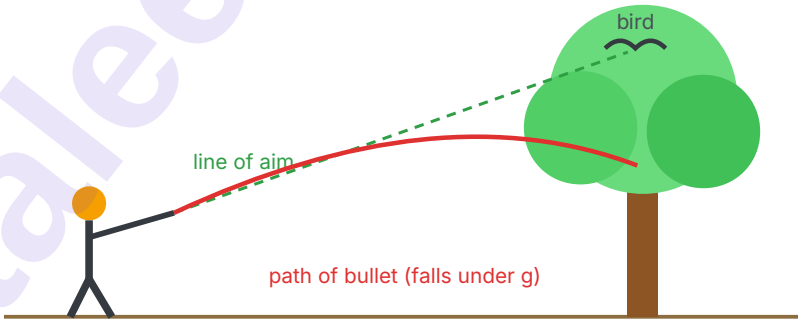
$$\text{K.E.}_f = \tfrac{1}{2}(2150)(7.674)^2 \approx 63\,314\ \text{J}$$

Loss in K.E. = 84 375 − 63 314 ≈ 2.1×10^4 J

Constructed Response Questions

2.1 **Why does a hunter aiming exactly at a bird in a tree miss the target?**

Because of **gravity**. The bullet does not travel in a straight line; it follows a curved (projectile) path, falling under g. Aimed straight at the bird, it passes beneath it. To hit the bird the hunter should aim slightly above it.



Bullet falls below the line of aim

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2.2 Why does a person falling on a heap of sand get hurt less than one falling on a concrete floor?

Sand compresses and **increases the time of impact** Δt. Since F = Δp/Δt, for the same change in momentum the force on the body is smaller. Concrete stops the body suddenly: Δt is very short, so the force is large and causes more injury.

2.3 State the conditions under which birds fly in air.

Birds fly using aerodynamics and Newton's laws:

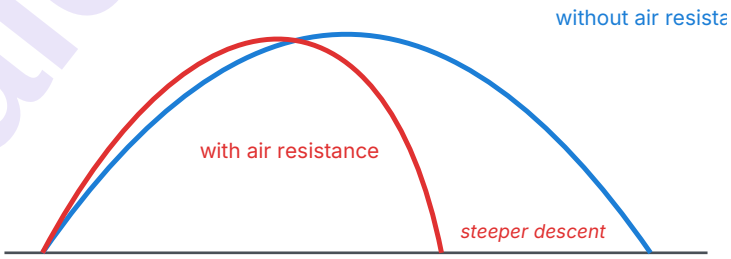
- **Lift:** the aerofoil shape of the wing makes air flow faster over the top than the bottom, creating low pressure above. Lift must be greater than the bird's weight.
- **Thrust:** produced by flapping wings; it must be greater than the drag opposing motion.
- Pushing air downward and backward with the wings pushes the bird upward and forward (Newton's 3rd law).

2.4 Describe circumstances in which, for a vehicle, (i) v is zero but a is not (ii) a is zero but v is not (iii) v and a are perpendicular.

(i) At the instant a braking vehicle comes to rest (or when it just starts from rest).
(ii) When the vehicle moves with **constant velocity** on a straight road.
(iii) When it moves along a **circular path** at constant speed — velocity is tangential and acceleration points to the centre.

2.5 Describe briefly the effects of air resistance on the range of a projectile.

Air resistance reduces the forward velocity v_i, so the range $R = v_i^2 \sin 2\theta/g$ **decreases**. As the object slows, the resistance decreases too, so the path is not a perfect parabola: it is skewed, with a steeper descent than ascent.



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Comprehensive Questions

2.1 **Define and explain scalar product. Write down its important characteristics.**

See **Long Question Q5**.

2.2 **Define and explain the vector product of two vectors. Discuss its important characteristics.**

See **Long Question Q6**.

2.3 **Derive the three equations of motion by graphical method.**

See **Long Question Q8 – Q10**.

2.4 **What is projectile motion? Explain.**

See **Long Question Q12**.

2.5 **Derive expressions for (i) time of flight (ii) height attained (iii) range of a projectile.**

See **Long Question Q12**.

2.6 **Explain elastic collision in one dimension. Show that relative velocities before and after collision are the same.**

See **Long Question Q18**.

2.7 **Explain elastic collision in two dimensions.**

See **Long Question Q19**.

2.8 **Explain an inelastic collision in one and two dimensions.**

See **Long Question Q20 and Q21**.

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