CHAPTER 3

Motion in a Plane

CBSE · Physics · Class 11

WHAT THIS CHAPTER DOES

Boards prep that builds confidence, not anxiety.

TODAY'S MISSION

Today's mission

WHY THIS MATTERS

Why this chapter matters

TOPIC

A

Part A — Scalars, vectors, unit vectors

TOPIC

Scalars vs vectors vs unit vectors

POINT 1	POINT 2	POINT 3	POINT 4

TOPIC

Quick recap — scalar or vector?

TOPIC

B

Part B — Vector addition and resolution

THEOREM · LOAD-BEARING RESULT

Triangle and parallelogram laws of vector addition

> "Triangle law: To add A and B, place the tail of B at the head of A. The resultant R goes from the tail of A to the head of B. Parallelogram law: Place A and B with a common tail, complete the parallelogram. The diagonal from the common tail equals R. Magnitude: R = sqrt(A^2 + B^2 + 2AB cos theta), where theta is the angle between A and B. Direction (angle alpha that R makes with A): tan alpha = B sin ... et

STATEMENT

Triangle law: To add A and B, place the tail of B at the head of A. The resultant R goes from the tail of A to the head of B. Parallelogram law: Place A and B with a common tail, complete the parallelogram.

WHY THIS MATTERS

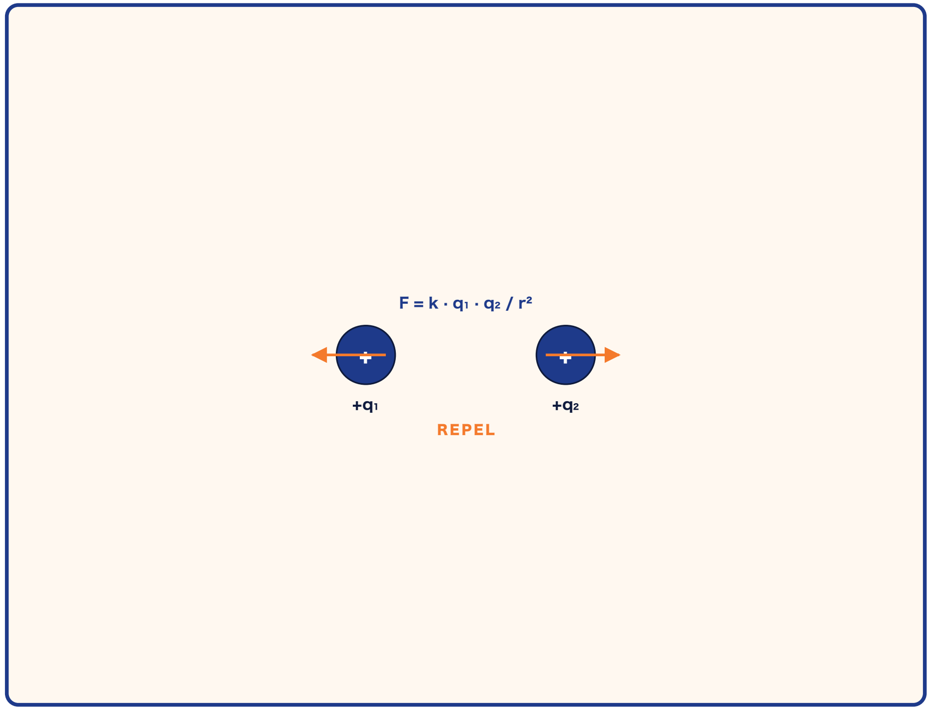
- Vectors cannot be added by simple arithmetic because direction matters
- The geometric laws encode the angle between vectors
- Both laws give the same result — the parallelogram is just the triangle traced twice.

WATCH OUT FOR

NOTE When theta = 0 (parallel), R = A + B (max). When theta = 180 (anti-parallel), R = |A - B| (min). When theta = 90, R = sqrt(A^2 + B^2). Memorise these three limiting cases for quick MCQ checks.

WORKED EXAMPLE

Example 1: Adding two vectors at an angle



TOPIC

Resultant of two vectors — limiting cases

WORKED EXAMPLE

Example 2: Resolving a vector into components

TOPIC

C

Part C — Projectile motion

THEOREM · LOAD-BEARING RESULT

Projectile motion — the four master formulas

> " A body projected from ground level with speed u at angle theta to the horizontal (in the absence of air resistance) follows a parabolic path. Resolving the initial velocity into u_x = u cos theta (horizontal) and u_y = u sin theta (vertical): (1) Time of flight T = 2u sin theta / g. (2) Maximum height H = $u^2 \sin^2$ theta / (2g). (3) Horizontal range R = u^2 sin(2 theta) / g. (4) Range is maximum at theta = 45 ... x

STATEMENT

A body projected from ground level with speed u at angle theta to the horizontal (in the absence of air resistance) follows a parabolic path. Resolving the initial velocity into u_x = u cos

WHY THIS MATTERS

- Horizontal and vertical motions are independent
- Horizontally there is no acceleration (constant velocity u cos theta)
- Vertically the body undergoes free fall with initial velocity u sin theta and acceleration -g

WATCH OUT FOR

NOTE These formulas apply ONLY to ground-to-ground projection (same launch and landing height). For projection from a cliff or platform of height H, derive from scratch using independent x and y motions — DO NOT plug into the formulas above blindly.

WORKED EXAMPLE

Example 3: Projectile from ground at angle theta

TRY IT · SOLVE BEFORE YOU PEEK

Quick test — projectile reasoning

Work it out before you flip the answer.

SOLUTION

WORKED EXAMPLE

Example 4: Horizontal projectile from a height

TOPIC

D

Part D — Uniform circular motion

TOPIC

Uniform circular motion — key quantities

POINT 1

POINT 2

POINT 3

POINT 4

WORKED EXAMPLE

Example 5: Centripetal acceleration of a stone on a string

PYQ PATTERNS

PYQ patterns — last 5 years

MARKS DISTRIBUTION

Where the marks live (per board paper)

TOPPER TEMPLATE · MARK-BY-MARK

Topper template — Projectile from ground (5 marks)

1. RESOLVE U INTO U_X, U_Y + LIST KNOWNS
   1 m
2. APPLY T = 2 U SIN THETA / G AND H = U^2 SIN^2 THETA / (2G)
   2 m
3. APPLY R = U^2 SIN(2 THETA) / G + STATE ALL WITH UNITS + VERIFY
   2 m

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Horizontal and vertical motions of a projectile depend on each other.

✓ **CORRECT** They are INDEPENDENT. Horizontal motion has zero acceleration (constant velocity u cos theta). Vertical motion has a = -g and is identical to a 1D vertical throw with initial velocity u sin theta. Treat them as two separate 1D problems sharing only time t.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** At the highest point of a projectile, the velocity is zero.

✓ **CORRECT** Only the VERTICAL component v_y is zero at the peak. The HORIZONTAL component v_x = u cos theta is unchanged throughout the flight. So total velocity at the peak = u cos theta (horizontal), not zero.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Maximum range of a projectile is at theta = 45 degrees regardless of launch height.

✓ **CORRECT** Maximum range is at 45 degrees ONLY when projectile lands at the same height it was launched (ground-to-ground). For projection from a cliff or platform, the optimum angle is LESS than 45 degrees.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Centripetal acceleration changes the speed of the body.

✓ **CORRECT** In UNIFORM circular motion, speed is constant. Centripetal acceleration only changes the DIRECTION of velocity, not its magnitude. The acceleration vector is always perpendicular to the velocity vector — that is why speed stays constant.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Adding vectors means adding magnitudes: $|A + B| = |A| + |B|$.

✓ **CORRECT** Only true when A and B are PARALLEL and same direction. In general $|A + B| = \sqrt{A^2 + B^2 + 2AB\cos\theta}$ where theta is the angle between them. For perpendicular vectors, $|A + B| = \sqrt{A^2 + B^2}$ (Pythagoras).

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Unit vectors i-hat, j-hat, k-hat have units of metre.

✓ **CORRECT** Unit vectors are DIMENSIONLESS. They only indicate direction along x, y, z axes. The vector quantity (with units) is the scalar component: e.g. (5 m) i-hat means 5 metres along +x.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Dot product gives a vector and cross product gives a scalar.

✓ **CORRECT** Reversed. A . B (dot product) = AB cos theta is a SCALAR. A x B (cross product) = AB sin theta n-hat is a VECTOR perpendicular to both A and B (right-hand rule).

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Time of flight T of a projectile depends on its mass.

✓ **CORRECT** T = 2u sin(theta)/g — depends only on initial vertical velocity component and g. Mass cancels out (gravity gives same acceleration to all bodies, ignoring air resistance). Same for range R and max height H.

TOPPER TEMPLATE · MARK-BY-MARK

Projectile launched from ground at angle theta with initial speed u — find range, max height.

1	**RESOLVE U INTO COMPONENTS + LIST U_X, U_Y, A_X, A_Y** 1 m	Taking horizontal +x and vertical +y upward. Given u = 20 m/s, theta = 30 degrees, g = 10 m/s^2. u_x = u cos theta = 20 cos 30 = 17.32 m/s. u_y = u sin theta = 20 sin 30 = 10 m/s. a_x = 0, a_y = -g = -10 m/s^2.
2	**APPLY T = 2U SIN THETA / G AND H = U^2 SIN^2 THETA / (2G)** 2 m	Time of flight T = 2(20)(sin 30)/10 = 2(20)(0.5)/10 = 2 s. Max height H = (20)^2 (sin 30)^2 / (2*10) = 400 * 0.25 / 20 = 5 m.
3	**APPLY R = U^2 SIN(2 THETA) / G + STATE RESULTS WITH UNITS** 2 m	Range R = (20)^2 sin(60) / 10 = 400 * 0.866 / 10 = 34.64 m. Answer: T = 2 s, H = 5 m, R = 34.64 m.

TOPPER TEMPLATE · MARK-BY-MARK

Find resultant of two vectors A and B inclined at angle theta — magnitude and direction.

1 DRAW THE PARALLELOGRAM / TRIANGLE + LABEL A, B, THETA 1 m

Vectors A = 5 N and B = 12 N at angle theta = 60 degrees. Place them tail-to-tail; complete the parallelogram. The diagonal is R.

2 APPLY R = SQRT(A^2 + B^2 + 2AB COS THETA) 1 m

R = sqrt(25 + 144 + 2(5)(12)(0.5)) = sqrt(25 + 144 + 60) = sqrt(229) = 15.13 N.

3 FIND DIRECTION ANGLE ALPHA FROM A USING TAN ALPHA = B SIN THETA / (A + B COS THETA) 1 m

tan alpha = (12 * sin 60) / (5 + 12 cos 60) = (12 * 0.866) / (5 + 6) = 10.39 / 11 = 0.9447 => alpha = 43.4 degrees. Answer: R = 15.13 N at 43.4 degrees from A.

TOPPER TEMPLATE · MARK-BY-MARK

Horizontal projectile from height H with horizontal speed u — find time of flight and

1. **DECOUPLE INTO VERTICAL AND HORIZONTAL MOTIONS + LIST KNOWNS** (1 m)

   Take downward +ve. Vertical: u_y = 0, a_y = g = 10 m/s^2, s_y = H = 80 m. Horizontal: u_x = u = 20 m/s, a_x = 0.

2. **FIND TIME OF FLIGHT FROM VERTICAL MOTION** (1 m)

   H = (1/2) g t^2 => 80 = (1/2)(10) t^2 => t^2 = 16 => t = 4 s.

3. **FIND HORIZONTAL RANGE AND STATE WITH UNITS** (1 m)

   Range R = u_x * t = 20 * 4 = 80 m. Answer: t = 4 s, R = 80 m.

PYQ PATTERNS

Top PYQ patterns to drill

#1	Projectile from ground level at angle theta	find range R, max height H, time of flight T using R = u^2 sin(2 theta)/g, H = u^2 sin^2(theta)/(2g), T = 2u sin(theta)/g. (5 marks) — 95%
#2	Vector addition by triangle/parallelogram law	find resultant magnitude and direction of two vectors at angle theta. (3 marks) — 80%
#3	Resolve a single vector into rectangular components along x and y axes. (2 marks)	78%
#4	Uniform circular motion	find centripetal acceleration a_c = v^2/r or a_c =

RECAP · MEMORISE THESE

Summary — what to remember

1 Vectors have magnitude AND direction; scalars only magnitude. Unit vectors (i-hat, j-hat, k-hat) are dimensionless.

2 Vector addition: R = sqrt(A^2 + B^2 + 2AB cos theta). State both magnitude AND direction.

3 Resolution: A_x = A cos theta, A_y = A sin theta (theta from +x axis).

4 Projectile: T = 2u sin theta / g, H = u^2 sin^2 theta / (2g), R = u^2 sin(2 theta) / g.

5 Horizontal projectile from height: t = sqrt(2H/g), R = u t.

6 Uniform circular motion: a_c = v^2/r = omega^2 r, directed toward centre. Speed

WHAT'S NEXT

Next class

→

Practice now

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Boards prep that builds confidence, not anxiety.