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CUET · PHYSICS · CLASS XI · CODE 322

Motion in a Plane

CUET unit: Motion in a Plane

By **UniDrill** · NCERT-grounded study material

📌 Snapshot

- Extends 1-D kinematics of Chapter 2 to two dimensions by introducing the language of **vectors** — magnitude, direction, addition/subtraction, resolution and unit vectors (NCERT §3.2–§3.6, pp. 27–34).
- Establishes that any plane motion with constant acceleration can be treated as **two independent 1-D motions** along perpendicular axes (NCERT §3.8, pp. 37–38).
- Develops **projectile motion** as the canonical example — parabolic trajectory, time of flight, maximum height, horizontal range, optimum angle 45° (NCERT §3.9, pp. 38–40).
- Develops **uniform circular motion** and the idea of **centripetal acceleration** $a_c = v^2/R = \omega^2 R$ directed always toward the centre (NCERT §3.10, pp. 40–42).
- Distinguishes carefully between **scalar and vector** quantities, the triangle and parallelogram laws of addition, and the **analytical-component** method using unit vectors $\hat{i}$, $\hat{j}$, $\hat{k}$.
- CUET regularly tests definitions (scalar vs vector), the analytical-component method of vector addition, and direct plug-and-chug numericals from projectile/UCM formulae.

📖 Detailed Notes

2.1 Core concepts

Physical quantities split into two classes. A **scalar** has only magnitude with the proper unit (distance, mass, temperature, time, density, work, energy) — its value is specified by a single number. A **vector** has both magnitude **and** direction and obeys the triangle/parallelogram law of addition (displacement, velocity, acceleration, force, momentum, electric field) (NCERT §3.2, pp. 27–28). The **position vector** OP = r locates a particle from a chosen origin O; the **displacement vector** PP′ joins the initial to the final position and is path-independent — its magnitude is always less than or equal to the actual path length traversed (NCERT §3.2.1, p. 28, Fig. 3.1). Two vectors are **equal** if and only if they have the same magnitude **and** the same direction; vectors of equal length but different directions are unequal (NCERT §3.2.2, p. 28).

Scalar multiplication scales a vector A by a real number λ: a positive λ keeps the direction unchanged and multiplies the magnitude by λ; a negative λ reverses the direction; multiplying by zero gives the null/zero vector 0, which has zero magnitude and unspecified direction (NCERT §3.3, p. 29). **Graphical vector addition** uses either the head-to-tail (triangle) method (NCERT Fig. 3.4, p. 29) or the equivalent parallelogram method (NCERT Fig. 3.6, p. 31). Vector addition is commutative (A + B = B + A) and associative ((A + B) + C = A + (B + C)) (NCERT §3.4, pp. 29–31). The null vector 0 satisfies A + 0 = A, $\lambda \cdot 0 = 0$, and 0·A = 0; it arises naturally when an object returns to its starting point so that the net displacement is zero (NCERT §3.4, p. 30). **Subtraction** is defined as A – B = A + (–B) (NCERT §3.4, p. 30).

A vector A in a plane can be **resolved** into components along any two non-collinear directions a, b: $A = \lambda a + \mu b$. In rectangular Cartesian axes $A = A_x \hat{i} + A_y \hat{j}$, where $A_x = A \cos \theta$ and $A_y = A \sin \theta$ (NCERT §3.5, pp. 31–32). The **unit vectors** $\hat{i}, \hat{j}, \hat{k}$ are vectors of magnitude 1, dimensionless and unit-less, mutually perpendicular along the x-, y-, z-axes; their sole role is to specify direction (NCERT §3.5, p. 32). The magnitude is recovered as $A = \sqrt{A_x^2 + A_y^2}$, and the direction by $\tan \theta = A_y/A_x$. **Analytical addition** is then straightforward: if R = A + B, then $R_x = A_x + B_x$, $R_y = A_y + B_y$. For two vectors A, B with angle θ between them, the **law of cosines** gives $R = \sqrt{A^2 + B^2 + 2AB \cos \theta}$, and the direction by the **law of sines** $R/\sin \beta = A/\sin \gamma = B/\sin \alpha$ (NCERT §3.6, pp. 33–34).

For **motion in a plane**, the position vector $r = x \hat{i} + y \hat{j}$ depends on time. The **average velocity** is $\bar{v} = \Delta r/\Delta t$; the **instantaneous velocity** $v = dr/dt = v_x \hat{i} + v_y \hat{j}$ is always tangential to the path (NCERT §3.7, pp. 35–36, Fig. 3.13). The **average acceleration** is $\bar{a} = \Delta v/\Delta t$; the **instantaneous acceleration** $a = dv/dt = a_x \hat{i} + a_y \hat{j}$. A key qualitative difference from 1-D motion: in a plane, v and a can have any angle between 0° and 180° (NCERT §3.7, pp. 36–37). For **constant acceleration in a plane**, the vector kinematic equations are $v = v_0 + at$ and $r = r_0 + v_0 t + \frac{1}{2} at^2$; the motions along x- and y-axes are **independent simultaneous 1-D motions** — a deep simplification that NCERT proves component-wise (NCERT §3.8, pp. 37–38).

The canonical application is **projectile motion**. A projectile fired with initial speed v_0 at angle θ_0 to the horizontal experiences $a_x = 0$ (no horizontal force in the absence of air resistance) and $a_y = -g$. The component equations are: $x = (v_0 \cos \theta_0) t$, $y = (v_0 \sin \theta_0) t - \frac{1}{2} g t^2$, $v_x = v_0 \cos \theta_0$ (constant), $v_y = v_0 \sin \theta_0 - g t$ (NCERT §3.9, pp. 38–39, Fig. 3.16). Eliminating t between the first two yields the **equation of trajectory** $y = (\tan \theta_0) x - g x^2/(2 v_0^2 \cos^2 \theta_0)$, a parabola (NCERT §3.9, p. 39, Fig. 3.17). The time to reach maximum height is $t_m = v_0 \sin \theta_0 /g$; the **total time of flight** is $T_f = 2 v_0 \sin \theta_0 /g$; the **maximum height** is $h_m = (v_0 \sin \theta_0)^2/(2g)$; the **horizontal range** is $R = v_0^2 \sin 2\theta_0 /g$ (NCERT §3.9, pp. 39–40). The range is maximum when $\theta_0 = 45°$ ($\sin 2\theta_0 = 1$), with $R_m = v_0^2/g$. For elevations exceeding or falling short of 45° by equal amounts, the range is the same — because $\sin(90° + 2\alpha) = \sin(90° - 2\alpha) = \cos 2\alpha$ (NCERT §3.9, Example 3.6, p. 40).

Uniform circular motion (UCM). The speed v is constant but the direction changes continuously, so the particle is accelerated — even though its speed is unchanging. The acceleration always points toward the centre of the circle and is called **centripetal**

acceleration, with magnitude $a_c = v^2/R$ (NCERT §3.10, pp. 40–42). The **angular speed** $\omega = \Delta\theta/\Delta t$ connects to the linear speed by $v = \omega R$, and hence $a_c = \omega^2 R$. The **time period** is $T = 2\pi R/v$, the frequency $\nu = 1/T$; the connections $\omega = 2\pi/T = 2\pi\nu$, $v = 2\pi R\nu$, $a_c = 4\pi^2\nu^2 R$ follow at once (NCERT §3.10, p. 42). NCERT emphasises that although the magnitude of a_c is constant, its direction changes continuously (always toward the centre), so a_c is not a constant vector — a frequent assertion–reason topic.

2.2 Definitions to memorise

Term	Definition	Page
Scalar	Quantity having only magnitude, specified by a single number with a unit	27
Vector	Quantity having both magnitude and direction, obeying triangle/parallelogram law of addition	28
Position vector r	Straight line from origin to instantaneous position of the particle	28
Displacement vector	Straight line joining initial and final positions; path-independent	28
Equal vectors	Two vectors with the same magnitude AND same direction	28
Null (zero) vector	Vector of zero magnitude; direction unspecified	30
Unit vector	Vector of unit magnitude that fixes direction only; dimensionless	32
Resolution of a vector	Expressing a vector as a sum of two (or three) component vectors along chosen axes	31–32
Component (Ax)	Scalar projection of A along an axis; e.g. $A_x = A \cos\theta$	32
Triangle law	Head-to-tail graphical addition rule for vectors	29
Parallelogram law	Equivalent graphical rule placing vectors tail-to-tail	31
Average velocity	$\bar{v} = \Delta r/\Delta t$; directed along Δr	35
Instantaneous velocity	$v = dr/dt$; tangential to the path	35–36
Average acceleration	$\bar{a} = \Delta v/\Delta t$	36
Instantaneous acceleration	$a = dv/dt$	36
Projectile	An object in flight after being thrown/projected; subject only to gravity (no air resistance)	38
Trajectory (projectile)	$y = (\tan\theta_0)\, x - g x^2/(2 v_0^2 \cos^2\theta_0)$; a parabola	39
Time of flight (Tf)	Total time for which the projectile is in flight: $T_f = 2 v_0 \sin\theta_0 / g$	39
Horizontal range (R)	Horizontal distance to return to launch level: $R = v_0^2 \sin 2\theta_0 / g$	39–40

Term	Definition	Page
Maximum height (hm)	Highest vertical point reached: $h_m = (v_0 \sin \theta_0)^2/(2g)$	39
Uniform circular motion	Motion along a circular path at constant speed	40
Centripetal acceleration	Acceleration of a body in UCM, directed toward the centre; magnitude $v^2/R = \omega^2 R$	42
Angular speed (ω)	Time rate of change of angular displacement; $\omega = \Delta\theta/\Delta t$	42
Time period (T)	Time for one complete revolution; $T = 2\pi R/v = 2\pi/\omega$	42
Frequency (ν)	Number of revolutions per second; $\nu = 1/T$	42

2.3 Diagrams / processes to remember

Fig. 3.1 (p. 28) establishes that the displacement vector PQ between two points is the same regardless of whether the particle travels via path PABCQ, PDQ or PBEFQ — displacement is path-independent, distance is not. **Fig. 3.4 (p. 29)** illustrates the head-to-tail (triangle) law of vector addition and the associative property visually: (A + B) + C = A + (B + C). **Fig. 3.6 (p. 31)** demonstrates the equivalence of the parallelogram method (bring tails to a common origin, draw diagonal) with the triangle method. **Fig. 3.9 (pp. 32–33)** shows the unit vectors $\hat{i}$, $\hat{j}$, $\hat{k}$ as the directional skeleton of Cartesian coordinates and the resolution $A = A_x \hat{i} + A_y \hat{j}$. **Fig. 3.13 (p. 35)** explains why instantaneous velocity is tangential: as $\Delta t \to 0$ the chord Δr aligns with the tangent to the path. **Fig. 3.16 (p. 39)** plots the projectile trajectory with components — horizontal velocity stays constant, vertical velocity changes uniformly. **Fig. 3.17 (p. 39)** displays the resulting parabolic path. **Fig. 3.18 (p. 41)** is the centripetal-acceleration derivation: the vector Δv is perpendicular to Δr, and in the limit $\Delta t \to 0$ it points toward the centre of the circle.

Two **procedural backbones** carry most problems: (i) the **component method for vector problems** — choose axes, resolve each vector into perpendicular components, add components scalar-wise to get R_x and R_y, recover $R = \sqrt{(R_x^2 + R_y^2)}$ and $\theta = \arctan(R_y/R_x)$; and (ii) the **projectile recipe** — write x(t) and y(t) separately, eliminate t for trajectory or solve for the required quantity (time of flight from y = 0 at landing, range from x at landing, max height from $v_y = 0$). For UCM the recipe is similarly mechanical: identify R and v (or ω, T, ν), apply $a_c = v^2/R = \omega^2 R = 4\pi^2 \nu^2 R$, remember that a_c always points to the centre and that v is always tangential — they are mutually perpendicular at every instant. CUET routinely tests students on whether they can convert between the various forms (v, ω, T, ν, a_c) of UCM parameters with a single substitution.

2.4 Common confusions / NTA trap points

- Treating **displacement and path length as the same** — they coincide only when the object moves in one direction without reversing (NCERT Points to Ponder 1, p. 46).
- Forgetting that a **component Ax of a vector is itself a scalar number**, while Ax î is a vector (NCERT §3.5, p. 32).
- Using the formula $v = v_0 + at$ for **uniform circular motion** — the kinematic equations of uniform acceleration do **not** apply because in UCM the direction of a changes (NCERT Points to Ponder 4, p. 46).
- Confusing the angle of projection that gives **maximum height (90°)** with the angle that gives **maximum range (45°)**: R is maximum at $\theta_0 = 45°$, hm is maximum at $\theta_0 = 90°$ (NCERT §3.9, pp. 39–40).
- Treating **centripetal acceleration as a constant vector** — its magnitude is constant but its direction continually changes, so it is NOT a constant vector (NCERT §3.10, p. 42; Example 3.9, p. 42).
- Forgetting that in projectile motion the **horizontal velocity is unchanged** throughout the flight ($v_x = v_0 \cos \theta_0$) while only vy changes (NCERT §3.9, p. 39).
- The formula $R = v_0^2 \sin 2\theta_0 /g$ is valid **only** when launch and landing are at the same height; using it for a projectile launched from a height is a classic error.
- For UCM, **velocity (tangent) and centripetal acceleration (radius) are perpendicular** at every instant — so the work done by the centripetal force is zero, hence kinetic energy is constant.
- Two equal-and-opposite vectors give a **null vector**, not "no vector at all" — the null vector is a legitimate mathematical object with zero magnitude and unspecified direction (NCERT §3.4, p. 30).
- **The maximum range $R_m = v_0^2/g$** (at $\theta_0 = 45°$) is twice the maximum height attainable at that angle — students sometimes wrongly equate the two.
- The **scalar (dot) product** is not introduced in this chapter — its first appearance is in Chapter 5 (Work, Energy, Power). Don't import it here without justification.
- **Angular speed ω is in rad s^{-1}**, not rev s^{-1}; to convert revolutions to radians multiply by 2π. CUET sometimes hands you "5 revolutions per second" and expects $\omega = 10\pi$ rad s^{-1}.

2.5 Key formulas

Symbol	Formula	Meaning	NCERT page
A (components)	A = Ax î + Ay ĵ	Resolution along axes	32
	A		$A = \sqrt{(A_x^2 + A_y^2)}$

Symbol	Formula	Meaning	NCERT page
θ	$\tan\theta = Ay/Ax$	Direction from components	32
R (cos law)	$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$	Magnitude of sum (law of cosines)	34
sin law	$R/\sin\beta = A/\sin\gamma = B/\sin\alpha$	Direction of resultant	34
v	v = dr/dt	Instantaneous velocity in a plane	35
a	a = dv/dt	Instantaneous acceleration in a plane	36
v(t)	$v = v_0 + at$	Vector form (constant a)	37
r(t)	$r = r_0 + v_0 t + \frac{1}{2}at^2$	Vector form (constant a)	37
x(t) projectile	$x = (v_0 \cos\theta_0)\, t$	Horizontal motion	39
y(t) projectile	$y = (v_0 \sin\theta_0)\, t - \frac{1}{2} g t^2$	Vertical motion	39
Trajectory	$y = (\tan\theta_0)x - g x^2/(2v_0^2 \cos^2\theta_0)$	Parabolic path	39
Tf	$Tf = 2 v_0 \sin\theta_0 /g$	Time of flight	39
hm	$hm = (v_0 \sin\theta_0)^2/(2g)$	Maximum height	39
R	$R = v_0^2 \sin 2\theta_0 /g$	Horizontal range	39
Rm	$Rm = v_0^2/g$	Maximum range (at $\theta_0 = 45°$)	40
a_c	$a\_c = v^2/R = \omega^2 R$	Centripetal acceleration	42
v (UCM)	$v = \omega R = 2\pi R\nu$	Linear speed in UCM	42
T	$T = 2\pi R/v = 2\pi/\omega$	Time period in UCM	42
a_c (freq)	$a\_c = 4\pi^2\nu^2 R$	Centripetal acceleration from ν	42

🎯 Practice MCQs

📊 PYQ Alignment

> This chapter is one of the highest-yielding topics in CUET Physics, with roughly 8–10 questions across recent papers (2023–2025). Typical questions focus on (i) direct identification of scalars vs vectors, (ii) plug-and-chug numericals on projectile range, maximum height, time of flight, and the optimum angle of 45°, and (iii) UCM formulae (a_c

$= v^2/R = \omega^2 R$, $v = \omega R$, $a_c = 4\pi^2\nu^2 R$), often as assertion–reason items contrasting the constancy of speed with the changing direction of velocity/acceleration. For year-wise solved PYQs see /pyq/physics.

CUET 2023–25 — Actual PYQs from this chapter

No PYQs from this chapter appeared in CUET 2023, 2024 or 2025.