📘 Chapter 2 — Kinematics (NEET 2025)

🚀 1. Introduction – The Language of Motion

Everywhere around you, something is moving: cars on the road, planets around the Sun, blood inside your veins, even the electrons in the wires of your phone charger.
Kinematics is the branch of physics that describes *how* things move—without asking *why* they move.

So, we're not yet worrying about forces or energy. We're simply learning to describe and measure motion:

- How far?
- How fast?
- In what direction?
- How the motion changes with time?

Mastering kinematics is like learning the **grammar of motion**—it gives you the vocabulary and equations that later help you understand forces, work, and energy.

🧭 2. Types of Motion

1. **Translatory motion** – The entire body moves in the same direction.
   → Example: a car moving on a straight road.
2. **Rotational motion** – The body spins about an axis.
   → Example: the spinning of a ceiling fan.
3. **Oscillatory motion** – Back-and-forth movement about a mean position.
   → Example: pendulum, guitar string.

For now, we'll deal mainly with *translatory motion*, especially **motion along a straight line (1-D)** and **motion in a plane (2-D)**.

📏 3. Basic Quantities of Motion

Quantity	Symbol	Definition	SI Unit
Distance	s	Length of actual path	meter (m)
Displacement	→s	Straight-line change of position	meter (m)
Speed	v	Rate of change of distance	m/s

Quantity	Symbol	Definition	SI Unit
Velocity	$\vec{v}$	Rate of change of displacement	m/s
Acceleration	$\vec{a}$	Rate of change of velocity	m/s^2

👉 Distance vs Displacement

Distance only tells *how much ground* you covered, while displacement tells *where you ended up relative to start*.

If you jog 3 km east then 4 km north:

- Distance = 7 km
- Displacement = $\sqrt{(3^2 + 4^2)}$ = 5 km northeast

Hence, **displacement ≤ distance** always.

⏱️ 4. Speed and Velocity

4.1 Average and Instantaneous

Average speed=Total distanceTotal time\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}}Average speed=Total timeTotal distance
Average velocity=Net displacementTotal time\text{Average velocity} = \frac{\text{Net displacement}}{\text{Total time}}Average velocity=Total timeNet displacement

Instantaneous velocity is the velocity at a particular moment → slope of the position–time graph at that point.

📊 5. Graphical Interpretation

Graphs make motion visible.

5.1 Position–Time (x–t) Graph

- Slope = velocity
- Straight line → uniform velocity
- Curved line → non-uniform velocity

5.2 Velocity–Time (v–t) Graph

- Slope = acceleration
- Area under graph = displacement

5.3 Acceleration–Time (a–t) Graph

- Area under curve = change in velocity

Understanding these graphs gives you an intuitive feel of motion—exactly what NEET loves to test.

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6. Equations of Uniformly Accelerated Motion

For motion with constant acceleration (a):

v=u+atv = u + atv=u+at s=ut+12at2s = ut + \tfrac{1}{2}at^{2}s=ut+21at2 v2=u2+2asv^{2} = u^{2} + 2asv2=u2+2as s=(u+v)2ts = \tfrac{(u+v)}{2}ts=2(u+v)t

where
u = initial velocity, v = final velocity, s = displacement, t = time.

These hold only when acceleration is constant.

Example:
A car starts from rest (u = 0), accelerates at 2 m/s^2 for 5 s.
→ v = 0 + 2×5 = 10 m/s
→ s = 0 + ½×2×25 = 25 m

Hence the car moves 25 m and reaches 10 m/s.

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7. Motion Under Gravity

Near Earth's surface, all bodies fall with the same **acceleration due to gravity (g)** ≈ 9.8 m/s^2 downward.

Equations of motion become:

v=u+gt,s=ut+12gt2,v2=u2+2gsv = u + gt,\quad s = ut + \tfrac{1}{2}gt^{2},\quad v^{2} = u^{2} + 2gsv=u+gt,s=ut+21gt2,v2=u2+2gs

When thrown upward, take upward as positive and g = −9.8 m/s^2.

Example:
A ball thrown upward at 20 m/s:
At highest point v = 0
→ 0 = 20 − 9.8 t → t ≈ 2.04 s
Height = $u^2/(2g) = 20^2/(19.6)$ ≈ 20.4 m.

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8. Relative Velocity in One Dimension

Motion is always *relative*—we measure velocity with respect to some reference.

If object A moves at velocity v_a and object B at v_b (in same line), vAB=vA−vBv_{AB} = v_{A} - v_{B}vAB=vA−vB

is velocity of A relative to B.

Example: Two cars move east at 60 km/h and 40 km/h.
Relative velocity = 20 km/h east.
If opposite directions → 100 km/h.

This simple idea becomes vital in river-boat and air-plane problems later.

🧭 9. Vector Nature of Motion

In one dimension, direction is shown by sign (+/−).
In two or three dimensions, we use **vectors**.

A vector has both **magnitude** and **direction**, represented as $\vec{\mathbf{A}}$.
Operations on vectors follow geometry rules:

Operation	Expression	Meaning
Addition	$\vec{R} = \vec{A} + \vec{B}$	Combine effects
Subtraction	$\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$	Opposite direction
Dot product	$\vec{A}\cdot\vec{B} = AB\cos\theta$	Scalar → projection
Cross product	$\vec{A}\times\vec{B} = AB\sin\theta\,\hat{n}$	Vector → perpendicular

For **2-D motion**, resolve every vector into x- and y-components:

Ax=Acosθ,Ay=AsinθA_x = A\cos\theta,\quad A_y = A\sin\thetaAx=Acosθ,Ay=Asinθ

Then apply 1-D equations separately to x and y.

🏀 10. Projectile Motion (2-D Motion)

Projectile motion is the classic NEET favorite: a particle thrown obliquely near Earth moves along a curved path called a **parabola**.

Let the projectile be thrown with velocity u at an angle θ above the horizontal.

Horizontal component = $u_x = u\cos\theta$
Vertical component = $u_y = u\sin\theta$

Equations of motion:

x=ucosθ t,y=usinθ t−12gt2x = u\cos\theta \, t,\quad y = u\sin\theta \, t - \tfrac{1}{2}gt^{2}x=ucosθt,y=usinθt−21gt2

Eliminate t to get trajectory:

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

— a parabola.

Key Results

- **Time of flight:** $T = \frac{2u\sin\theta}{g}$
- **Maximum height:** $H = \frac{u^{2}\sin^{2}\theta}{2g}$
- **Range:** $R = \frac{u^{2}\sin2\theta}{g}$
- For same u, R is maximum at $\theta = 45°$.

Example:
$u = 20$ m/s, $\theta = 45°$
→ $T = (2\times20\times0.707)/9.8 \approx 2.89$ s
→ $R = 20^2 \sin 90°/9.8 \approx 40.8$ m.

🎯 11. Motion in a Circle

When an object moves in a circle of radius r at speed v, it changes direction continuously, meaning it has **centripetal acceleration** toward the center.

$$a_c = \frac{v^{2}}{r}$$

and **centripetal force** needed:

$$F_c = m\frac{v^{2}}{r}$$

This keeps planets in orbit, cars turning safely, and electrons circling nuclei (conceptually).

Example:
A 1000 kg car turns a curve of radius 50 m at 10 m/s.
Required $F = (1000\times10^2)/50 = 2\times10^4$ N toward center.

🧩 12. Relative Velocity in Two Dimensions

When two motions occur in perpendicular directions (like a boat crossing a river), combine them as vector components.

If river flows east with velocity v_r and boat velocity relative to water is v_b north,
Resultant velocity relative to ground:

$$v = \sqrt{v_b^{2} + v_r^{2}}$$

Direction: $\tan\theta = v_r/v_b$.

If you want the boat to go straight north, aim *against* the current by angle θ so $\tan\theta = v_r/v\_b$.

These are typical NEET conceptual numericals.

📚 13. Relative Motion Between Two Projectiles

If two projectiles are fired simultaneously, their relative motion is itself a projectile.
Time of flight remains same, relative velocity determines path difference.
This concept builds intuition for "collision in air" and "meeting point" problems.

⚙️ 14. Derivation Recap and Dimensional Check

Formula	Dimensional Check
$s = ut + \frac{1}{2}at^2$	$[L] = [L T^{-1} T] + [L T^{-2} T^2]$ ✓
$v^2 = u^2 + 2as$	$[L^2 T^{-2}]$ both sides ✓
$R = u^2 \sin 2\theta / g$ $[L]$ both sides ✓	

Always check dimensions → a good NEET trick to catch wrong options quickly.

💡 15. Common Conceptual Questions

1. *Can velocity be zero when acceleration isn't?*
   ✓ Yes—at highest point of projectile, velocity = 0 vertically but acceleration = g.
2. *Can acceleration be zero when velocity isn't?*
   ✓ Yes—uniform motion (constant velocity).
3. *Why does a coin fall slower in air than in vacuum?*
   ✓ Air resistance → additional upward acceleration reduces net g.
4. *When are average speed and average velocity equal?*
   ✓ When motion is in a straight line in one direction.

🧠 16. Application of Kinematics in Real Life

- **Automotive design:** acceleration, braking distance, turning radius.
- **Sports:** trajectory of cricket ball, long-jump, basketball shot.
- **Aerospace:** rocket launch angles and escape velocity.

- **Medical:** blood-flow measurement (Doppler effect uses velocity).
- **Meteorology:** predicting projectile debris or rainfall patterns.

Everywhere something moves, kinematics silently governs it.

📃 17. Summary – Key Takeaways

1. **Kinematics** describes motion without forces.
2. **Scalar quantities** have only magnitude; **vectors** have magnitude + direction.
3. **Displacement ≤ distance.**
4. **Velocity–time graphs** give displacement; **slope = acceleration.**
5. **Equations of motion** apply only for constant acceleration.
6. **Projectile motion** → parabolic; maximum range at 45°.
7. **Circular motion** → centripetal force = mv^2/r.
8. **Relative velocity** helps solve river-boat, rain-man, and airplane problems.
9. Always check **units & dimensions** for validity.
10. Kinematics builds foundation for all mechanics — master it to breeze through the next chapters.