

CUET · PHYSICS · CLASS XI · CODE 322

Motion in a Straight Line

CUET unit: Motion in a Straight Line

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Snapshot

- Establishes **kinematics of rectilinear motion** — how to describe motion (position, velocity, acceleration) without asking what causes it (NCERT §2.1, p. 13).
- Builds the limiting-process definitions of **instantaneous velocity** and **instantaneous acceleration** as derivatives of position and velocity with respect to time (NCERT §2.2–§2.3, pp. 14–16).
- Derives the **three kinematic equations** for uniformly accelerated motion ($v = v_0 + at$; $x = v_0t + \frac{1}{2}at^2$; $v^2 = v_0^2 + 2ax$) both graphically and through calculus (NCERT §2.4, pp. 17–18).
- Applies these equations to staple CUET-style problems — **free fall, Galileo's law of odd numbers, stopping distance** of vehicles, and **reaction time** (NCERT §2.4 examples 2.3–2.7, pp. 18–21).
- Treats position–time and velocity–time **graph analysis** with care: slopes give velocity/acceleration, areas under v - t give displacement.
- CUET tests this chapter heavily because every fact is formula-driven and lends itself to clean single-answer MCQs.

Detailed Notes

2.1 Core concepts

The focus here is **rectilinear motion** — motion of objects along a straight line — and within that, mostly motion with constant acceleration (NCERT §2.1, p. 13). The objects are treated as **point objects**, an approximation valid when the size of the object is much smaller than the distance it moves. **Kinematics** itself is defined as the study of ways to describe motion without going into its causes; the **causes** (forces) come in the next chapter on laws of motion (NCERT §2.1, p. 13).

The first analytical concept is **instantaneous velocity**. The velocity v at an instant t is defined as the limit of the average velocity as the time interval Δt approaches zero: $v = \lim_{\Delta t \rightarrow 0} \Delta x / \Delta t = dx/dt$, i.e., the differential coefficient of position with respect to time (NCERT §2.2, p. 14, Eq. 2.1a–b). Graphically, the instantaneous velocity is the **slope of the tangent** to the position–time curve at that instant; this is illustrated through Fig. 2.1 (p. 14), where successive chords P_1P_2 over shrinking Δt converge to a tangent at $t = 4$ s, and the numerical values in Table 2.1 (Δt from 2.0 s down to 0.010 s) converge

to 3.84 m s^{-1} — an explicit demonstration of the limit definition (NCERT §2.2, p. 14). For **uniform motion**, the velocity is the same as the average velocity at all instants (NCERT §2.2, p. 15). **Instantaneous speed** (or just **speed**) is the magnitude of instantaneous velocity; velocities of $+24.0 \text{ m s}^{-1}$ and -24.0 m s^{-1} both have speed 24.0 m s^{-1} (NCERT §2.2, p. 15). An important asymmetry: although **average speed** over a finite interval is greater than or equal to the magnitude of average velocity, **instantaneous speed equals the magnitude of instantaneous velocity** at every instant (NCERT §2.2, p. 15).

The same limit-building exercise yields **acceleration**. **Average acceleration** a over an interval is the change of velocity divided by the time interval: $a = (v_2 - v_1)/(t_2 - t_1) = \Delta v / \Delta t$, with SI unit m s^{-2} (NCERT §2.3, p. 15, Eq. 2.2). On a v - t plot, average acceleration is the slope of the straight line connecting (v_1, t_1) and (v_2, t_2) . **Instantaneous acceleration** $a = \lim(\Delta t \rightarrow 0) \Delta v / \Delta t = dv/dt$ is the slope of the tangent to the v - t curve at that instant (NCERT §2.3, p. 16, Eq. 2.3). Because velocity is a vector with magnitude and direction, acceleration can arise from a change in **speed, in direction, or in both**; it can be positive, negative, or zero (NCERT §2.3, p. 16). On a position-time graph the curve bends **upward** for positive acceleration, **downward** for negative acceleration, and is a **straight line** for zero acceleration (NCERT §2.3, p. 16, Fig. 2.2). NCERT also states the geometric identity that will reappear throughout mechanics: the **area under the v - t curve between t_1 and t_2 equals the displacement** of the object over that interval (NCERT §2.3, p. 16; Summary §5, p. 22).

The core result is the trio of **kinematic equations** for uniformly accelerated motion: **$v = v_0 + at$** (Eq. 2.4), **$x = v_0t + \frac{1}{2}at^2$** (Eq. 2.6), and **$v^2 = v_0^2 + 2ax$** (Eq. 2.8). These connect five quantities — initial velocity v_0 , final velocity v , acceleration a , time t and displacement x — so that any three determine the other two (NCERT §2.4, pp. 17–18, Eqs. 2.9a). If the starting position at $t = 0$ is x_0 rather than zero, x is simply replaced by $(x - x_0)$ (NCERT §2.4, p. 18, Eqs. 2.9b–c). The equations follow from the average-velocity identity $\bar{v} = (v + v_0)/2$ (valid only for constant acceleration) and can also be derived by **calculus** by integrating $a = dv/dt$ and $v = dx/dt$. The calculus method has the advantage that it generalises to non-uniform acceleration via $a = v(dv/dx)$ (NCERT §2.4, Example 2.2, p. 18). NCERT also derives the same equations **graphically** from the area under a v - t plot: for uniform velocity u , the rectangular area is uT (Fig. 2.4); for uniformly accelerated motion, the trapezium area $= \frac{1}{2}(v + v_0)t + v_0t = v_0t + \frac{1}{2}at^2$ (Fig. 2.5), which is exactly Eq. 2.6 (NCERT §2.4, p. 17).

Three classical applications cement the equations. **Free fall** near the Earth's surface (air resistance neglected) is a special case of motion with uniform acceleration; the magnitude of $g \approx 9.8 \text{ m s}^{-2}$ is directed downward (NCERT §2.4, Example 2.4, p. 19). **Galileo's law of odd numbers** states that the distances traversed by a body falling from rest during equal successive time intervals are in the ratio $1 : 3 : 5 : 7 : 9 : 11 \dots$; the cumulative distances follow $1 : 4 : 9 : 16 : 25 \dots$ (NCERT §2.4, Example 2.5, p. 20, Table 2.2). The **stopping distance** of a vehicle under uniform deceleration is $d_{\square} = -v_0^2/(2a)$ — proportional to the square of the initial velocity, so doubling speed

quadruples stopping distance, a result of great relevance to road safety (NCERT §2.4, Example 2.6, pp. 20–21). **Reaction time** is the time a person takes to observe, think and act in response to a situation; it can be measured very simply by the **ruler-drop experiment**, in which a freely-falling ruler caught between thumb and forefinger gives t_r from $d = \frac{1}{2}g \cdot t_r^2$ (NCERT §2.4, Example 2.7, p. 21).

NCERT closes with a careful Summary and a "Points to Ponder" list emphasising that quantities in kinematic equations are **algebraic** (can be \pm) and depend on the chosen positive direction of the axis; that the equations are valid only for constant acceleration whereas the **definitions** of v and a are always exact; that the sign of acceleration does not by itself say whether speed is increasing or decreasing (that depends on the relative direction of a and v); and that a particle can be momentarily at rest while still accelerating — e.g., at the highest point of a vertical throw $v = 0$ but $a = -g$ (NCERT Points to Ponder, p. 23). These subtleties are favourite CUET trap territory.

2.2 Definitions to memorise

Term	Definition	Page
Rectilinear motion	Motion of an object along a straight line	13
Kinematics	Study of ways to describe motion without going into its causes	13
Point object	Approximation valid when the size of the object is much smaller than the distance it moves	13
Position	Location of an object on a chosen coordinate axis at an instant of time	13
Path length / distance	Total length of the actual path traversed; scalar, always non-negative	13
Displacement	Change in position $\Delta x = x_2 - x_1$; vector along the line	13
Average velocity (\bar{v})	Displacement divided by time interval, $\Delta x / \Delta t$	14
Average speed	Total path length divided by total time	14
Instantaneous velocity (v)	Limit of average velocity as $\Delta t \rightarrow 0$; $v = dx/dt$	14
Instantaneous speed	Magnitude of instantaneous velocity	15
Uniform motion	Motion in which velocity is the same at all instants	15
Average acceleration (\bar{a})	Change of velocity divided by the time interval; $\bar{a} = \Delta v / \Delta t$	15
Instantaneous acceleration (a)	Limit of average acceleration as $\Delta t \rightarrow 0$; $a = dv/dt$	16
Uniform acceleration	Motion with constant a in magnitude and direction	17
Kinematic equations	Three equations (2.4, 2.6, 2.8) valid for uniform acceleration	17

Term	Definition	Page
Free fall	Motion of an object under gravity with air resistance neglected (uniform acceleration g)	19
Acceleration due to gravity (g)	$\approx 9.8 \text{ m s}^{-2}$ near Earth's surface, directed downward	19
Galileo's law of odd numbers	Distances in successive equal intervals of free fall stand in ratio $1 : 3 : 5 : 7 \dots$	20
Stopping distance (d_{stop})	Distance a vehicle travels after brakes are applied, before stopping; $d_{\text{stop}} = -v_0^2/(2a)$	20
Reaction time	Time a person takes to observe, think and act in response to a situation	21
Tangent (on x - t curve)	Line whose slope gives instantaneous velocity at that point	14
Chord (on x - t curve)	Line whose slope gives average velocity over the interval	14
Area under v - t curve	Equals displacement over the same interval	16
Slope of v - t curve	Equals (instantaneous) acceleration	16

2.3 Diagrams / processes to remember

Eight high-yield figures are worth knowing. **Fig. 2.1 (p. 14)** plots the position-time curve $x = 0.08 t^3$ and shows how successive chords P_1P_2 over shrinking Δt converge to the tangent at $t = 4 \text{ s}$; this is the **visual** of the limit definition of velocity. **Table 2.1 (p. 14)** tabulates the corresponding numerical values of $\Delta x/\Delta t$ for Δt ranging from 2.0 s down to 0.010 s centred at $t = 4 \text{ s}$; the sequence converges to 3.84 m s^{-1} — students should be ready for an MCQ that asks them to "identify the instantaneous velocity from the table." **Fig. 2.2 (p. 16)** sketches three position-time curves: one curving **upward** (positive acceleration), one **downward** (negative acceleration), and one **straight line** (zero acceleration). **Fig. 2.3 (p. 16)** shows four characteristic velocity-time graphs of constant acceleration, including the diagnostic case (d) in which an object reverses direction at $t = t_1$ under negative acceleration. **Fig. 2.4 (p. 17)** demonstrates that for uniform velocity u , the rectangular area uT under the v - t graph equals the displacement uT — the area-equals-displacement theorem in its simplest form. **Fig. 2.5 (p. 17)** generalises this to uniform acceleration, where the trapezium area $= v_0t + \frac{1}{2}at^2$, thereby visually deriving Eq. 2.6.

Fig. 2.7 (pp. 19–20) carries the free-fall triple: (a) a vs t is a horizontal line at $-g$, (b) v vs t is a straight line of slope $-g$, (c) y vs t is a downward parabola. CUET often tests students on identifying which of three plots correctly shows free fall — this triple is the answer key. **Fig. 2.8 (p. 21)** sketches the ruler-drop experiment for reaction time: a ruler held between thumb and forefinger is released, and the distance fallen d before being caught gives the reaction time via $t_r = \sqrt{(2d/g)}$. **Table 2.2 (p. 20)** tabulates distances during successive equal intervals in free fall to verify Galileo's odd-number

ratio $1 : 3 : 5 : 7 : 9 : 11 \dots$; the **cumulative** distances follow $1 : 4 : 9 : 16 : 25$, a square-number ratio that is a classic distractor.

The two **process skills** to internalise are (i) **graph reading**: slope of $x-t$ at a point = instantaneous velocity; slope of $v-t$ at a point = instantaneous acceleration; area under $v-t$ = displacement; area under $a-t$ = change in velocity; and (ii) **kinematic-equation selection**: identify which of v_0 , v , a , t , x are known and which is unknown, then pick the kinematic equation that excludes the un-asked variable.

2.4 Common confusions / NTA trap points

- The **sign of acceleration does not** tell you whether speed is increasing or decreasing; that depends on whether a is along or opposite to v (NCERT Points to Ponder 2 & 3, p. 23).
- A particle can be **momentarily at rest with non-zero acceleration** — e.g., a ball at the highest point of its upward throw has $v = 0$ but $a = -g$ (NCERT Points to Ponder 4, p. 23).
- **Average speed \geq |average velocity|** over a finite interval, **but** instantaneous speed = |instantaneous velocity| at every instant (NCERT §2.2, p. 15; Exercise 2.11, p. 25).
- The kinematic equations (2.9) are valid **only** for motion with constant magnitude and direction of acceleration; definitions of v and a (Eqs. 2.1 and 2.3) are always exact (NCERT Points to Ponder 6, p. 23).
- Quantities in kinematic equations are **algebraic** (can be \pm); always assign signs based on the chosen positive direction of the axis before substituting (NCERT Points to Ponder 1 & 5, p. 23).
- The **ratio $1 : 3 : 5 : 7 \dots$** is for **distances in successive equal intervals** of free fall; the ratio $1 : 4 : 9 : 16 \dots$ is for **cumulative** distances at the end of each interval. Mixing the two is a textbook NTA distractor (NCERT Example 2.5, p. 20).
- **Doubling speed quadruples stopping distance**, not double — because $d \propto v_0^2$ (NCERT Example 2.6, p. 21).
- The slope of a chord on the $x-t$ graph gives **average** velocity, not instantaneous; instantaneous needs the **tangent** (NCERT Fig. 2.1, p. 14).
- Path length is **always \geq |displacement|**, with equality only for unidirectional motion; an object that returns to its starting point has zero displacement but non-zero path length.
- **Free fall** in NCERT means motion under gravity **with air resistance neglected** — students should not import drag corrections without being asked.
- For a body thrown vertically up, the time of ascent equals the time of descent **only** if the launch and landing heights are the same; with a building/cliff offset, this no longer holds (NCERT Example 2.3, pp. 18–19).

- The area-under- $v-t$ = displacement rule treats **signed area** — area below the t -axis is negative displacement, which matters whenever the $v-t$ curve crosses the axis (NCERT §2.3, p. 16, Fig. 2.3d).

2.5 Key formulas

Symbol	Formula	Meaning	NCERT page
\bar{v}	$\bar{v} = \Delta x / \Delta t$	Average velocity	14
v	$v = dx/dt$	Instantaneous velocity	14
\bar{a}	$\bar{a} = \Delta v / \Delta t$	Average acceleration	15
a	$a = dv/dt$	Instantaneous acceleration	16
v	$v = v_0 + at$	Kinematic Eq. (2.4)	17
\bar{v}	$\bar{v} = (v + v_0)/2$	Mean velocity for constant a	17
x	$x = v_0t + \frac{1}{2}at^2$	Kinematic Eq. (2.6)	17
v^2	$v^2 = v_0^2 + 2ax$	Kinematic Eq. (2.8)	18
$x - x_0$	$x - x_0 = v_0t + \frac{1}{2}at^2$	Eq. (2.9b) with starting position x_0	18
a	$a = v(dv/dx)$	Calculus form for variable a	18
Displacement	$\int v dt = \text{area under } v-t \text{ curve}$	Area-displacement theorem	16, 22
Δv	$\int a dt = \text{area under } a-t \text{ curve}$	Change-of-velocity from $a-t$	16
y	$y = \frac{1}{2}gt^2$	Free fall from rest, downward	19
v (free fall)	$v = gt$	Speed in free fall from rest	19
Galileo's ratio	1 : 3 : 5 : 7 : 9 ...	Distances in successive equal intervals (free fall)	20
Cumulative ratio	1 : 4 : 9 : 16 : 25 ...	Cumulative distances in free fall	20
d_{\square}	$d_{\square} = -v_0^2/(2a)$	Stopping distance under uniform deceleration	20
t_r	$t_r = \sqrt{(2d/g)}$	Reaction time from ruler drop	21
Max height (up-throw)	$h_{\text{max}} = v_0^2/(2g)$	Maximum height for vertical projection	19
Time of flight (up-throw)	$T = 2v_0/g$	Total time when launch = landing height	19

Practice MCQs

PYQ Alignment

This chapter is among the most consistently tested in the CUET Physics paper: every CUET (UG) 2023–25 cycle has carried questions on the kinematic equations, area under v - t curves, free fall and instantaneous vs average quantities. Expect direct-substitution numericals (stopping distance, time of flight, displacement under uniform acceleration), one or two graph-reading items (slope of x - t = velocity; area under v - t = displacement), and a conceptual statement-based question on the sign of acceleration vs change in speed. 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.

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