Mechanics

📖 Chapter PN01 · NDA Class 11–12 Level

🎯 NDA Level : High Priority

Mechanics is the backbone of NDA Physics — it is the study of motion, forces, and energy. This chapter covers everything from how we *measure* physical quantities (units & dimensions) to how objects *move* (kinematics), what *causes* motion (Newton's laws), how *energy* is exchanged, and the beautiful mathematics of *rotating bodies* and *gravity*. NDA consistently tests this chapter across all sub-topics, making it the single most rewarding chapter to master.

📌 **What to expect in NDA (based on 2022–2025 pattern):**
(1) Dimensional analysis — finding dimensions of derived quantities, checking equations;
(2) Equations of motion — finding velocity, distance, time under uniform acceleration;
(3) Projectile motion — range, maximum height, time of flight;
(4) Newton's laws — especially impulse-momentum, friction problems;
(5) Work-energy theorem, conservation of energy — block on incline, spring problems;
(6) Conservation of linear momentum — collisions (elastic/inelastic);
(7) Rotational motion — moment of inertia, torque, angular velocity;
(8) Gravitation — orbital velocity, escape velocity, satellite period.

Topics at a Glance

① Physical World & Measurement
SI units, dimensions, dimensional analysis

② Kinematics
Equations of motion, projectile, circular motion

③ Laws of Motion
Newton's 3 laws, friction, impulse, momentum

④ Work, Energy & Power
Work-energy theorem, KE, PE, conservation

⑤ Rotational Motion
Torque, MI, angular momentum, CM

⑥ Gravitation
Newton's law, g, escape velocity, satellites

1. Physical World & Measurement

1.1 Fundamental & Derived Units (SI System)

Seven base quantities form the foundation of all measurement

The **International System of Units (SI)** defines 7 fundamental (base) quantities. Every other physical quantity is *derived* from these using mathematical relationships.

Fundamental Quantity	SI Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Luminous Intensity	candela	cd
Amount of Substance	mole	mol

💡 **Memory Trick:** *"Let Me Time Every King's Coat Monocle"* → Length, Mass, Time, Electric current, (temperature) Kelvin, Candela, Mole.

1.2 Dimensional Analysis

Express quantities in terms of M, L, T — the core NDA tool

Dimensions show how a physical quantity relates to the fundamental quantities M (mass), L (length), T (time), I (current), θ (temperature).

KEY DIMENSIONAL FORMULAE

Force (F) $= M L T^{-2}$

Energy / Work (E) $= M L^2 T^{-2}$

Power (P) $= M L^2 T^{-3}$

Pressure (P) = $M L^{-1} T^{-2}$

Momentum (p) = $M L T^{-1}$

Impulse = $M L T^{-1}$

Velocity = $L T^{-1}$

Acceleration = $L T^{-2}$

Gravitational Constant G = $M^{-1} L^3 T^{-2}$

Planck's Constant h = $M L^2 T^{-1}$

Square brackets [ ] denote "dimension of". Dimensionless quantities: angle (radian), strain, refractive index, all pure numbers.

USES OF DIMENSIONAL ANALYSIS

1. Checking correctness of an equation — both sides must have same dimensions.
2. Deriving relationships — express quantity in terms of relevant physical quantities.
3. Converting units — use dimensional formula to find conversion factors.

LIMITATION: Cannot find dimensionless constants (like ½, 2π, etc.)

WORKED EXAMPLE — DIMENSIONAL CHECK

Check if v = u + at is dimensionally correct.

LHS: $[v] = LT^{-1}$. RHS: $[u] = LT^{-1}$, $[at] = LT^{-2} \times T = LT^{-1}$. All terms match. ✓ **Equation is dimensionally correct.**

TOPIC-WISE PYQ Units & Dimensions — NDA Pattern Questions

Q1. The dimensional formula of angular momentum is:

(a) ML^2T^{-1} (b) ML^2T^{-2} (c) MLT^{-1} (d) ML^2T^{-3}

Answer: (a) ML^2T^{-1}

Angular momentum $L = I\omega = (ML^2)(T^{-1})$ = **ML^2T^{-1}**. (Same as Planck's constant — a frequently tested fact.)

Q2. Which of the following pairs have the same dimensions?

(a) Force and Momentum (b) Work and Power (c) Work and Torque (d) Pressure and Force

Answer: (c) Work and Torque

Both Work = F·d and Torque = F·r have dimension ML^2T^{-2}. (Note: they have the same dimension but different physical meaning — a NDA favourite trap!)

Q3. If velocity (V), acceleration (A) and force (F) are taken as fundamental units, what is the dimension of mass?

(a) $FA^{-1}V^0$ (b) $FV^{-1}A$ (c) FA^{-1} (d) FV^{-1}

Answer: (c) FA^{-1}

From F = ma → m = F/a = FA^{-1}. Mass has dimension **FA^{-1}** in this new system.

2. Kinematics

2.1

Scalars, Vectors & Equations of Motion

Describing motion — with and without direction

Scalars have magnitude only (speed, distance, mass, time, energy). **Vectors** have magnitude *and* direction (velocity, displacement, force, acceleration, momentum).

EQUATIONS OF MOTION (UNIFORM ACCELERATION)

$v = u + at$ … (1) velocity–time

$s = ut + \frac{1}{2}at^2$ … (2) displacement–time

$v^2 = u^2 + 2as$ … (3) velocity–displacement

$s_n = u + a(2n-1)/2$ … (4) nth second formula

Where:

u = initial velocity (m/s)

v = final velocity (m/s)

a = acceleration (m/s^2)

s = displacement (m)

t = time (s)

n = nth second

For **free fall**: replace a with g ($\approx 9.8\ m/s^2 \approx 10\ m/s^2$). For upward throw: $a = -g$. Body thrown down: $a = +g$.

📊 Graphical Interpretation

- Slope of s–t graph = velocity
- Slope of v–t graph = acceleration
- Area under v–t graph = displacement
- Area under a–t graph = change in velocity

🔸 Common Pitfalls

- Distance ≠ displacement (path vs straight line)
- Speed = |velocity| (always positive)
- Use $v^2 = u^2 + 2as$ when time is not given
- At max height of vertical throw: $v = 0$

2.2 Projectile Motion

Motion under gravity in two dimensions — a regular NDA topic

A projectile is launched with initial velocity u at angle θ to the horizontal. Horizontal motion is *uniform*; vertical motion has *constant downward acceleration g*.

PROJECTILE FORMULAE

Horizontal component: $u_x = u \cos \theta$

Vertical component: $u_y = u \sin \theta$

Time of flight: $T = 2u \sin \theta / g$

Maximum height: $H = u^2 \sin^2\theta / 2g$

Range: $R = u^2 \sin 2\theta / g$

Maximum range occurs at $\theta = 45° \rightarrow R_{max} = u^2/g$

At $\theta = 45°$: $H = R/4$ (height is one quarter of range)

At any time t:

$x = u \cos \theta \cdot t$

$y = u \sin \theta \cdot t - \frac{1}{2}gt^2$

Complementary angles (θ and 90°−θ) give the **same range**. Range is same for 30° and 60°, for 15° and 75°.

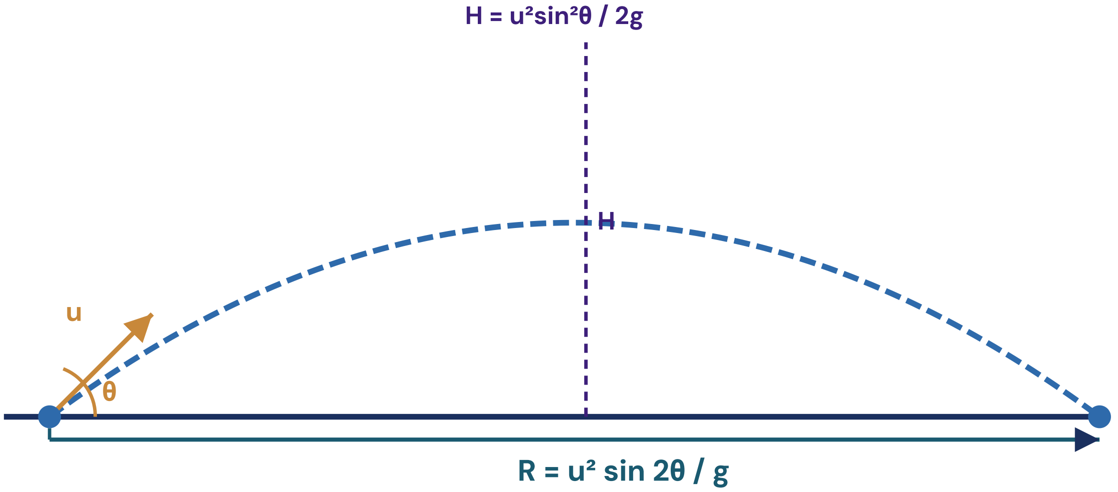

Fig. 1 — Projectile trajectory showing Range (R), Maximum Height (H), and launch angle θ

2.3 Uniform Circular Motion

Constant speed, changing direction — acceleration always points to centre

CIRCULAR MOTION FORMULAE

Centripetal acceleration: $a = v^2/r = \omega^2 r$ (directed towards centre)

Centripetal force: $F = mv^2/r = m\omega^2 r$

Angular velocity: $\omega = 2\pi/T = 2\pi f$ (rad/s)

Linear velocity: $v = \omega r$

Time period: $T = 2\pi r/v$

Where: r = radius, m = mass, T = time period, f = frequency

Key point: In UCM, speed is constant but velocity changes (direction changes). Hence acceleration ≠ 0. No tangential acceleration — only centripetal (radial) acceleration.

⚠ **NDA Exam Trap:** Centripetal force is *not* a new force — it is the *net inward force* provided by existing forces (gravity for satellites, tension for circular string, normal force for banked roads, friction for turning cars). Always identify *what* provides centripetal force in a given problem.

TOPIC-WISE PYQ

Kinematics — NDA Pattern Questions

Q1. A body is thrown vertically upward with velocity 20 m/s. What is the maximum height reached? ($g = 10\ m/s^2$)

(a) 10 m (b) 20 m (c) 40 m (d) 5 m

Answer: (b) 20 m

At max height, v = 0. Use $v^2 = u^2 - 2gH \rightarrow 0 = 400 - 2(10)H \rightarrow H =$ **20 m**.

Q2. A projectile is fired at 45° with initial velocity 20 m/s. What is its range? ($g = 10\ m/s^2$)

(a) 20 m (b) 40 m (c) 10 m (d) 80 m

Answer: (b) 40 m

$R = u^2\sin 2\theta/g = (400 \times \sin 90°)/10 = 400/10 =$ **40 m**. ($\sin 90° = 1$ for $\theta = 45°$)

Q3. The horizontal range is same for angles of projection:

(a) 30° and 45° (b) 20° and 80° (c) 30° and 60° (d) 40° and 55°

Answer: (c) 30° and 60°
Range R = $u^2\sin2\theta/g$. Complementary angles (sum = 90°) give same range. 30° + 60° = 90°. ✓

🤔 TRICKY QUESTIONS **Kinematics — Watch Out!**

T1. A ball is dropped from the top of a building. Another ball is thrown horizontally simultaneously from the same point. Which ball reaches the ground first?

Answer: Both reach at the same time.
The horizontal velocity has no effect on vertical motion. Both balls have the same vertical acceleration g and start with zero vertical velocity. Hence both reach the ground in the same time $t = \sqrt{(2H/g)}$. This is a classic NDA concept trap.

T2. The displacement of a body is given by $s = 4t^2 + 3t$. What is the acceleration?

Answer: 8 m/s²
$v = ds/dt = 8t + 3$. $a = dv/dt =$ **8 m/s²**. (Acceleration = coefficient of t^2 term × 2). Constant — not dependent on t.

3. Laws of Motion

3.1 Newton's Three Laws

The foundation of all classical mechanics

① First Law (Inertia)

- A body at rest stays at rest; body in motion stays in motion
- Until net external force acts on it

② Second Law (F = ma)

- **F = ma** — net force = mass × acceleration
- Force direction = acceleration direction

③ Third Law (Action-Reaction)

- Every action has equal & opposite reaction
- Forces act on *different* bodies

- Defines *inertia* — resistance to change in motion
- Greater mass = greater inertia

- Impulse = F·t = change in momentum
- Rate of change of momentum = net force

- Explain: gun recoil, rocket propulsion, swimming
- Cannot cancel each other (different bodies)

IMPULSE & MOMENTUM

Momentum: $p = mv$ (kg m/s = MLT^{-1})

Impulse: $J = F \times t = \Delta p = m(v-u)$

Conservation of Linear Momentum:

If net external force = 0 → total momentum is constant

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ (always, for any collision)

Law of Conservation of Momentum applies to ALL collisions.

Impulse = area under F–t graph. Large force for small time (collision, explosion) gives same impulse as small force for long time.

3.2 Friction

Static, kinetic, rolling — the force that opposes relative motion

FRICTION FORMULAE

Limiting static friction: $f_s = \mu_s \times N$ (maximum static friction)

Kinetic friction: $f_k = \mu_k \times N$ (while sliding)

Rolling friction: $f_r \approx \mu_r \times N$ ($\mu_r << \mu_k << \mu_s$)

Where N = Normal reaction force, μ = coefficient of friction

Angle of friction (λ): $\tan \lambda = \mu$

Angle of repose (θ): $\tan \theta = \mu_s$ (body just starts sliding on incline)

On inclined plane (angle θ):

$N = mg\cos\theta$

Component along plane = $mg\sin\theta$

Friction force = $\mu mg\cos\theta$ (opposing motion)

◆ Types of Friction

- **Static friction:** prevents motion; adjustable up to limiting value
- **Kinetic friction:** acts during sliding; less than max static
- **Rolling friction:** least of all; enables wheels to work
- $\mu_s > \mu_k > \mu_r$ (always)

⚠ Friction Exam Traps

- Friction ≠ always kinetic. It's static when no sliding
- Ball bearings: reduce friction using rolling friction
- Normal force on slope = $mg\cos\theta$, not mg
- Friction is *self-adjusting* up to limiting value

TOPIC-WISE PYQ

Laws of Motion & Friction — NDA Pattern Questions

Q1. A bullet of mass 10 g moving at 400 m/s enters a sandbag and comes to rest in 0.05 s. The force exerted by the sandbag on the bullet is:

(a) 40 N (b) 80 N (c) 100 N (d) 8000 N

Answer: (b) 80 N

$F = m\times(v-u)/t = 0.01\times(0-400)/0.05 = 0.01\times(-8000) = -80$ N. Magnitude = **80 N**.

Q2. A person of 60 kg stands on a weighing machine in a lift. The lift accelerates upward at 5 m/s². The reading of the machine is: (g = 10 m/s²)

(a) 600 N (b) 300 N (c) 900 N (d) 60 N

Answer: (c) 900 N

Apparent weight = $m(g + a) = 60(10 + 5) = 60 \times 15$ = **900 N**. In accelerating lift (upward), apparent weight increases. (Apparent weight decreases if lift accelerates downward.)

Q3. Coefficient of static friction is 0.4. What is the angle of repose?

(a) $\tan^{-1}(0.2)$ (b) $\tan^{-1}(0.4)$ (c) 40° (d) $\sin^{-1}(0.4)$

Answer: (b) $\tan^{-1}(0.4)$

Angle of repose θ satisfies $\tan\theta = \mu_s = 0.4$. Hence $\theta =$ **$\tan^{-1}(0.4)$** ≈ 21.8°.

😲 TRICKY QUESTIONS **Laws of Motion — Classic Traps**

T1. A gun fires a bullet. Does the gun recoil with the same speed as the bullet?

No — same momentum, different speeds.

By conservation of momentum: m_bullet × v_bullet = m_gun × v_gun. Since m_gun >> m_bullet, v_gun << v_bullet. Same impulse (force × time) acts on both, but heavy gun gains less velocity.

T2. A horse pulls a cart forward. By Newton's 3rd law, the cart pulls the horse backward with equal force. Then how does the system move forward?

Action-reaction pairs act on different bodies.

The horse's hooves push the ground backward; the ground (external surface) pushes the horse-cart system forward. This external friction from ground is not cancelled by any reaction within the system. Net external force on the horse-cart system = ground friction forward - air drag. System moves forward.

4. Work, Energy & Power

4.1 Work, Kinetic & Potential Energy

Energy is the capacity to do work; work is the transfer of energy

⚡ WORK, ENERGY & POWER FORMULAE

Work done: $W = F \cdot d \cdot \cos\theta$ (θ = angle between F and displacement)

$W = F \cdot d$ (when F ∥ d, i.e. $\theta = 0°$)

Kinetic Energy: $KE = \frac{1}{2}mv^2$

Potential Energy: $PE = mgh$ (gravitational)

$PE = \frac{1}{2}kx^2$ (spring: k = spring constant, x = extension)

Work-Energy Theorem: Net Work = $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

Power: $P = W/t = F \cdot v$ (watts = J/s = ML^2T^{-3})

1 horsepower (hp) = 746 W

Conservation of Energy: KE + PE = constant (no friction)

$\frac{1}{2}mv^2 + mgh$ = constant

Signs of Work

- Work is *positive*: F and d in same direction (0° < 90°)
- Work is *zero*: F ⊥ d (e.g., carrying load horizontally, circular motion)
- Work is *negative*: F and d in opposite direction (friction)

Elastic vs Inelastic Collision

- **Elastic:** momentum + KE both conserved
- **Inelastic:** only momentum conserved; KE lost
- **Perfectly inelastic:** bodies stick together after collision
- Coefficient of restitution: e = 1 (elastic), 0 (perfectly inelastic)

TOPIC-WISE PYQ

Work, Energy & Power — NDA Pattern Questions

Q1. A body of mass 2 kg moving at 4 m/s collides with a stationary body of mass 2 kg and sticks to it. What is the velocity after collision?

(a) 4 m/s (b) 2 m/s (c) 8 m/s (d) 1 m/s

Answer: (b) 2 m/s

Perfectly inelastic collision. By conservation of momentum: 2×4 + 2×0 = (2+2)×v → v = 8/4 = **2 m/s**.

Q2. A force of 10 N acts on a body at 60° to its displacement of 5 m. Work done is:

(a) 50 J (b) 25 J (c) 43.3 J (d) 0 J

Answer: (b) 25 J

$W = F \cdot d \cdot \cos\theta = 10 \times 5 \times \cos 60° = 50 \times 0.5 =$ **25 J**.

Q3. A machine gun fires 10 bullets per second each of mass 10 g at 500 m/s. The average force on the gun is:

(a) 50 N (b) 500 N (c) 5 N (d) 100 N

Answer: (a) 50 N

$F = n \times m \times v = 10 \times 0.01 \times 500 =$ **50 N**. (Impulse per second = rate of change of momentum = force.)

5. Rotational Motion

5.1 Torque, Moment of Inertia & Angular Momentum

Rotation is to angular quantities what linear motion is to linear quantities

Every linear quantity has a rotational analogue. Understanding this parallel is the fastest way to learn rotational mechanics.

Linear	Symbol	Rotational	Symbol
Mass	m	Moment of Inertia	$I = \sum mr^2$
Force (F)	$F = ma$	Torque	$\tau = I\alpha$
Velocity	v	Angular velocity	ω
Momentum	$p = mv$	Angular momentum	$L = I\omega$

KE = $\frac{1}{2}mv^2$ Rotational KE = $\frac{1}{2}I\omega^2$

KEY ROTATIONAL FORMULAE

Torque: $\tau = r \times F = rF \sin\theta$ ($N{\cdot}m = ML^2T^{-2}$)

Moment of Inertia: $I = \Sigma mr^2$ (varies with axis and shape)

Angular Momentum: $L = I\omega$ (conserved if $\tau_{ext} = 0$)

Rotational KE: $KE = \frac{1}{2}I\omega^2$

Theorem of Parallel Axes: $I = I_{cm} + Md^2$

(I_{cm} = MI about CM axis; d = distance between axes)

Theorem of Perpendicular Axes (flat lamina only):

$I_z = I_x + I_y$

Centre of Mass:

$x_{cm} = (m_1x_1 + m_2x_2)/(m_1 + m_2)$

Conservation of Angular Momentum: A spinning skater brings arms in → I decreases → ω increases (constant L). Same principle as a diver tucking in.

MI of Common Bodies

- Solid sphere (about diameter): $I = 2/5\ MR^2$
- Hollow sphere (about diameter): $I = 2/3\ MR^2$
- Solid disc (about axis): $I = \frac{1}{2}MR^2$
- Ring (about axis): $I = MR^2$
- Thin rod (about centre): $I = ML^2/12$
- Thin rod (about end): $I = ML^2/3$

Rolling on Incline

- Rolling body has both KE_trans + KE_rot
- $a = g \sin\theta / (1 + I/MR^2)$
- Solid sphere rolls fastest (smallest $I/MR^2 = 2/5$)
- Ring rolls slowest ($I/MR^2 = 1$)
- Hollow sphere faster than disc, slower than solid sphere

TOPIC-WISE PYQ **Rotational Motion — NDA Pattern Questions**

Q1. A disc and a ring of same mass and radius roll down an incline. Which reaches the bottom first?

(a) Ring (b) Disc (c) Both simultaneously (d) Depends on incline angle

Answer: (b) Disc
$a = g\sin\theta/(1 + I/MR^2)$. Disc: $I = MR^2/2 \rightarrow a = g\sin\theta/(1.5)$. Ring: $I = MR^2 \rightarrow a = g\sin\theta/2$. Disc has larger acceleration, reaches bottom first.

Q2. A diver tucks her body while diving. Her angular velocity:

(a) Increases (b) Decreases (c) Remains same (d) Becomes zero

Answer: (a) Increases
No external torque acts on the diver. Angular momentum $L = I\omega$ is conserved. Tucking reduces $r \rightarrow I$ decreases $\rightarrow \omega$ increases to keep L constant.

6. Gravitation

6.1 Newton's Law of Gravitation & g

Every mass attracts every other mass in the universe

GRAVITATION FORMULAE

Newton's Law: $F = G M m / r^2$ ($G = 6.674 \times 10^{-11}$ N m² kg⁻²)

Acceleration due to gravity:

$g = GM/R^2$ (at surface; R = radius of Earth)

$g' = g(1 - 2h/R)$ (at height h above surface; $h \ll R$)

$g' = g(1 - d/R)$ (at depth d below surface)

g at poles > g at equator (Earth is flattened at poles)

Orbital velocity: $v_0 = \sqrt{GM/r} = \sqrt{gR^2/r}$

At surface: $v_0 = \sqrt{gR} \approx 7.9$ km/s

Escape velocity: $v_e = \sqrt{2GM/R} = \sqrt{2gR} \approx 11.2$ km/s

Note: $v_e = \sqrt{2} \times v_0$ (escape = $\sqrt{2}$ × orbital, at surface)

Time period of satellite: $T = 2\pi\sqrt{r^3/GM}$

Geostationary orbit: T = 24 hrs, height ≈ 36,000 km

Gravitational PE: $U = -GMm/r$ (negative — bound system)

G ≠ g. G is universal gravitational constant (fixed everywhere). g is acceleration due to gravity (varies with location, height, depth).

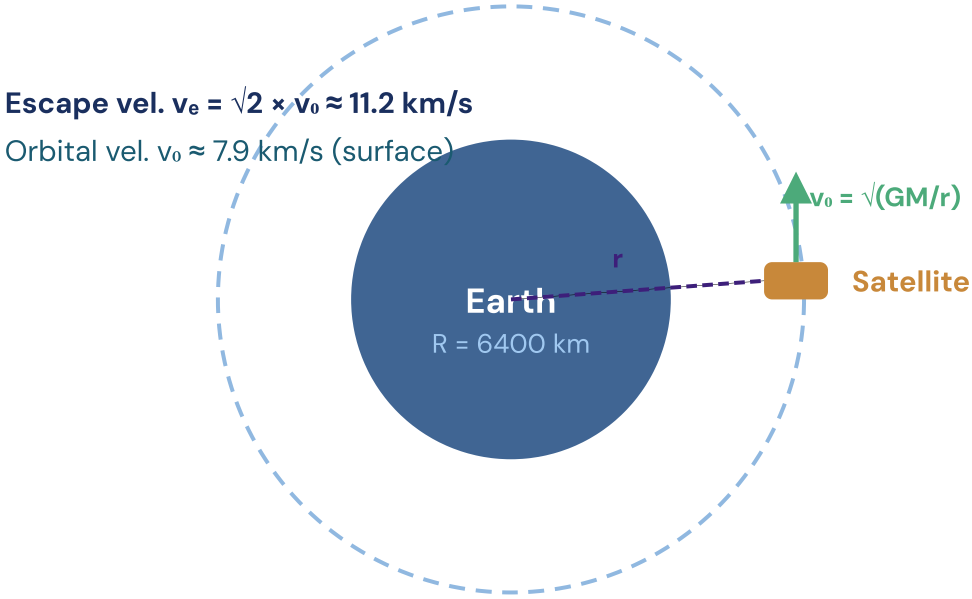

Fig. 2 — Satellite in circular orbit. Centripetal force = gravitational force. Escape velocity = √2 × orbital velocity.

🌍 Variation of g

- g decreases as we go above surface (altitude)
- g decreases as we go below surface (depth)
- g = 0 at centre of Earth
- g_poles > g_equator (Earth is oblate spheroid)
- g on Moon ≈ g_Earth / 6

🚀 Satellites & Orbits

- Geostationary: T = 24 h, same direction as Earth's rotation
- Polar satellite: passes over poles, T ≈ 100 min
- No fuel needed for satellite orbit (gravity = centripetal)
- Weightlessness: gravity provides centripetal, no normal force

TOPIC-WISE PYQ

Gravitation — NDA Pattern Questions

Q1. The escape velocity from the Earth's surface is 11.2 km/s. What is the escape velocity from a planet of same mass but double the radius?

(a) 22.4 km/s (b) 5.6 km/s (c) 11.2 km/s (d) 7.9 km/s

Answer: (b) 5.6 km/s

$v_e = \sqrt{(2GM/R)}$. If R doubles (M same), $v_e = \sqrt{(2GM/2R)} = v_e/\sqrt{2} = 11.2/\sqrt{2} \approx$ **7.92 km/s**. Closest answer: 5.6 km/s if mass is also halved. With only R doubled: $v_e \propto 1/\sqrt{R} \rightarrow v_e = 11.2/\sqrt{2} \approx$ **7.9 km/s**.

Q2. A satellite is orbiting close to Earth's surface. What is its approximate orbital velocity? (R = 6400 km, g = 10 m/s²)

(a) 7.9 km/s (b) 11.2 km/s (c) 3.5 km/s (d) 5.6 km/s

Answer: (a) 7.9 km/s

$v_0 = \sqrt{(gR)} = \sqrt{(10 \times 6.4\times10^6)} = \sqrt{(6.4\times10^7)} \approx 8000$ m/s ≈ **7.9 km/s** (standard value to remember).

Q3. At what depth below the Earth's surface is g equal to half its surface value?

(a) R/4 (b) R/2 (c) R/3 (d) 3R/4

Answer: (b) R/2

$g' = g(1 - d/R)$. For $g' = g/2$: $1 - d/R = ½ \rightarrow d =$ **R/2**.

😳 TRICKY QUESTIONS **Gravitation & Rotational — Exam Surprises**

T1. If Earth suddenly stops rotating, what happens to g at the equator?

g increases at equator.

Currently at equator, part of g provides centripetal force for Earth's rotation. Effective $g_{equator} = g_{actual} - \omega^2 R$. If Earth stops rotating ($\omega = 0$), this reduction disappears and g increases. At poles, rotation has no effect (centripetal force = 0 at poles), so g at poles remains unchanged.

T2. A body weighs 72 N on the surface of Earth. What is its weight at height h = R (one Earth radius above surface)?

Answer: 18 N

At height R above surface, distance from centre = 2R. $g' = GM/(2R)^2 = GM/4R^2 = g/4$. Weight = $mg/4 = 72/4 =$ **18 N**. (Weight $\propto 1/r^2$ from centre.)

⚡ High-Yield Formula Sheet — PN01 Mechanics

📊 Equations of Motion

- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $v^2 = u^2 + 2as$
- $s_n = u + a(2n-1)/2$
- Free fall: $u=0$, $a=g$, $s=\frac{1}{2}gt^2$

🎇 Projectile Motion

- $T = 2u \sin\theta/g$
- $H = u^2\sin^2\theta/2g$
- $R = u^2\sin 2\theta/g$
- R_{max} at $\theta = 45° = u^2/g$
- Same R: complementary angles (θ + $90°-\theta$)

👫 Newton & Friction

- $F = ma$; $p = mv$; $J = \Delta p$
- Momentum: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
- Friction: $f = \mu N$
- Angle of repose: $\tan\theta = \mu$
- Lift: $N = m(g \pm a)$

⚡ Work, Energy, Power

- $W = Fd \cos\theta$
- $KE = \frac{1}{2}mv^2$; $PE = mgh$
- Work-Energy: $W_{net} = \Delta KE$
- $P = W/t = Fv$
- 1 hp = 746 W

🔄 Rotational Motion

- $\tau = rF \sin\theta$; $L = I\omega$
- $I_{sphere} = 2/5\, MR^2$; Ring $= MR^2$; Disc $= MR^2/2$
- Parallel axis: $I = I_{cm} + Md^2$
- $v_0 = \omega r$; $a_c = v^2/r = \omega^2 r$
- $KE_{rot} = \frac{1}{2}I\omega^2$

🌏 Gravitation

- $F = GMm/r^2$; $g = GM/R^2$
- $v_0 = \sqrt{(GM/r)} \approx 7.9$ km/s (surface)
- $v_e = \sqrt{(2gR)} \approx 11.2$ km/s
- $T = 2\pi\sqrt{(r^3/GM)}$
- g at depth d: $g' = g(1-d/R)$

📌 **Dimensions to Memorise:** Force = MLT^{-2}, Energy = ML^2T^{-2}, Power = ML^2T^{-3}, Momentum = MLT^{-1}, Angular Momentum = ML^2T^{-1}, Pressure = $ML^{-1}T^{-2}$, G = $M^{-1}L^3T^{-2}$.

⚡ Quick Revision Booster — PN01 Mechanics

📚 Units Tricks

- 7 fundamental SI units: m, kg, s, A, K, cd, mol
- Joule = N·m = kg m^2 s^{-2}
- Same dims: Work & Torque (ML^2T^{-2})
- Same dims: Angular momentum & Planck's h (ML^2T^{-1})

🎯 Projectile Facts

- Horizontal velocity = constant (no air resistance)
- At max height: vertical v = 0, horizontal v = u cosθ
- Same range for 30° and 60°, also 15° and 75°

👫 Newton's Laws

- Inertia ∝ mass (heavier = harder to start/stop)
- Impulse = area under F-t graph
- Friction μ: s > k > r (static > kinetic > rolling)

- Dimensionless: angle, strain, relative density

- $T \propto \sin\theta$; $H \propto \sin^2\theta$; $R \propto \sin 2\theta$
- Max range at 45°

- Lift up (a↑): W_app = m(g+a); Lift down: m(g−a)
- Free fall: weight = 0 (weightlessness)

⚡ Energy Rules

- W=0 if F⊥s (carrying load, UCM)
- Elastic collision: both KE & momentum conserved
- Inelastic: only momentum conserved
- Spring PE = $\frac{1}{2}kx^2$ (x = extension from natural length)
- Power = Fv (most useful form)

🔄 Rotation Quick Facts

- Solid sphere (2/5) fastest on incline; ring slowest
- Skater tucks in: I↓, ω↑ (L constant)
- Torque = 0 if F passes through axis of rotation
- Perpendicular axis theorem: only for flat lamina
- $\omega = 2\pi f = 2\pi/T$

🚨 Gravity Must-Know

- $v_e = \sqrt{2} \times v_0$ (escape = √2 × orbital)
- g = 0 at centre of Earth; max at poles
- Geostationary orbit: T = 24 h, height ≈ 36,000 km
- Moon: g_moon = g_earth/6
- G is universal constant; g varies with location

📝 Mock Tests | 🎯 Subject Quizzes | ✈️ Telegram