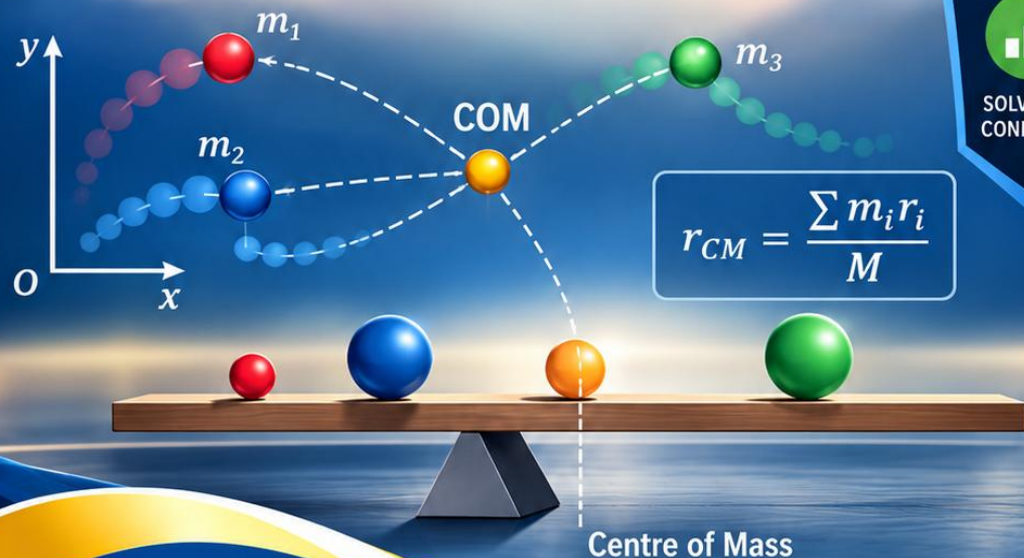


SYSTEM OF PARTICLES & CENTRE OF MASS

NEET PHYSICS ESSENTIALS

CONCEPT SUMMARY

KEY CONCEPTS | FORMULAS | RECOGNITION CUES
MISCONCEPTIONS | EXAM TRAPS | QUICK CHECKS



$$r_{CM} = \frac{\sum m_i r_i}{M}$$

UNDERSTAND
THE PHYSICSRECOGNIZE
THE PATTERNSOLVE WITH
CONFIDENCE

SAME PHYSICS.
A HIGHER SCORE.

CONCEPT SUMMARY

1. Chapter Introduction

Many Physics problems involve more than one object: interacting bodies, recoil, explosions, collisions, a man on a plank, or bodies connected by a spring. The System of Particles and Centre of Mass approach gives a simpler way to describe what the complete system is doing.

Key question: “What is my system?” Once the system is chosen, its boundary tells us which interactions are internal and which are external. Momentum, impulse and Centre of Mass then become connected descriptions of the same physical system.

2. Chapter in One View

Central Idea: Internal interactions can change the arrangement and relative motion of the parts. External influence changes the collective motion of the complete system.

Choose the system and define its boundary.

Classify interactions as internal or external.

Use total momentum to describe collective motion.

Use external impulse to decide whether momentum changes.

Look at mass distribution to locate the Centre of Mass.

Use external force to understand COM motion.

Use the COM frame when common translational motion hides relative motion.

3. MUST-KNOW CONCEPTS

System of Particles A chosen group of particles or bodies studied together.

Internal Force Interaction between members of the chosen system.

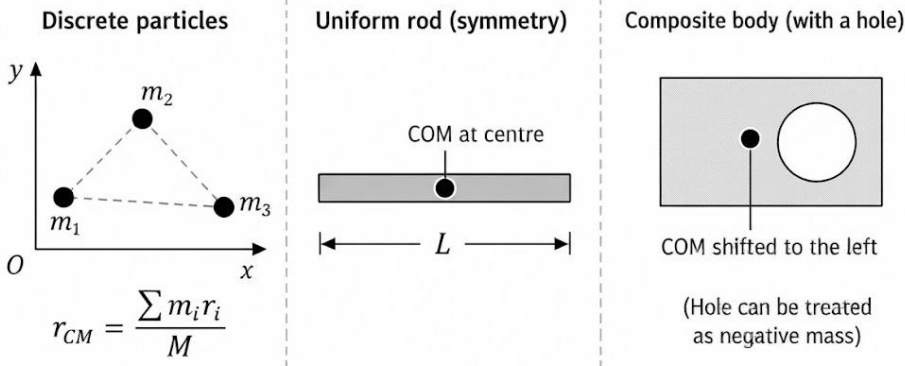
External Force Interaction between the system and something outside it.

Total Momentum $P = \sum m_i v_i = MV_{CM}$ Represents the combined momentum of all particles in the system.

External Impulse External impulse changes total momentum.

Momentum Conservation If net external impulse is zero/negligible over the chosen interval $\rightarrow$ total momentum remains constant.

Centre of Mass (CM) Mass-weighted position of the complete system.



COM methods: Discrete masses, symmetry, continuous distribution, composite bodies and bodies with holes.

COM motion: External force controls COM acceleration for a complete fixed-mass system in an inertial frame.

COM frame: A frame moving with the Centre of Mass; it removes common translational motion and highlights relative motion.

4. Formula + Meaning

Momentum Relations

- **Total Momentum**

$$P = \sum m_i v_i = M V_{CM}$$

Meaning: Total momentum of the system. *Use:* When collective momentum or COM velocity is asked. *Condition:* M is the total mass of the chosen system. *Exam Trap:* Do not confuse one particle's velocity with V_{CM} .

Force and COM Acceleration

- External Force Relation

$$F_{\text{ext}} = \frac{dP}{dt} = MA_{\text{CM}}$$

Meaning: Net external force determines COM acceleration. *Use:* For a complete fixed-mass system. *Condition:* Inertial reference frame. *Exam Trap:* Choose the correct system before applying it.

Impulse and Momentum Change

- Impulse Relation

$$J_{\text{ext}} = \Delta P$$

Meaning: External impulse produces change in total momentum. *Use:* For finite interval and external impulse/force. *Condition:* Use net external impulse on the chosen system. *Exam Trap:* Momentum is conserved only when net external impulse ≈ 0 .

Centre of Mass Position

- Discrete System

$$r_{\text{CM}} = \frac{\sum m_i r_i}{M}$$

Meaning: Mass-weighted position of a discrete system. *Use:* When masses and positions are known. *Condition:* $M = \sum m_i$. *Exam Trap:* COM is not a literal point where all mass is concentrated.

- Continuous Distribution

$$r_{\text{CM}} = \frac{1}{M} \int r \, dm$$

Meaning: Mass-weighted position for a continuous distribution.

Use: When continuous mass description is required. *Condition:*

dm must represent actual distribution. *Exam Trap:* First understand density/mass distribution before constructing dm .

5. Formula Selection Guide

Situation	Think This Model	Use This
Several interacting bodies	Choose the system	Define system boundary
Total momentum asked	Collective motion	$P = \sum m_i v_i$
Total mass + COM velocity	System momentum	$P = MV_{\text{CM}}$
External force on complete system	COM dynamics	$F_{\text{ext}} = MA_{\text{CM}}$
Finite interval + external force	Momentum change	$J_{\text{ext}} = \Delta P$
Zero/negligible external impulse	Momentum conservation	$P_f = P_i$

Situation	Think This Model	Use This
Known masses and positions	Discrete COM	$r_{CM} = \frac{\sum m_i r_i}{M}$
Symmetric mass distribution	COM by symmetry	Locate directly
Continuous distribution	Distributed mass	$r_{CM} = \frac{1}{M} \int r \, dm$
Composite body	Component COMs	Mass-weighted combination
Body with a hole	Missing mass	Negative-mass method
Parts move but external force is zero	Collective vs internal motion	Check COM motion
Two-body common translation	COM frame	Remove V_{CM}

6. When to Use / When Not to Use

Momentum Conservation

Use when: Net external impulse is zero or negligible over the selected interval.

Do not use blindly when: A significant external impulse acts.

COM Motion Relation

Use when: A complete fixed-mass system is considered in an inertial frame.

Do not use blindly when: The system boundary or frame conditions are not satisfied.

Discrete COM Formula

Use when: Individual masses and positions are identifiable.

Do not use blindly when: A continuous-density treatment is required.

Symmetry

Use when: The mass distribution has the required symmetry.

Do not use blindly when: Geometry or density breaks that symmetry.

7. Common Misconceptions

Wrong idea: "If the parts move, the COM must move." →

Correct Physics: Parts can move relative to each other while the COM remains fixed or moves uniformly. →

Why it matters: Check external force on the complete system.

Wrong idea: "Momentum is always conserved." →

Correct Physics: It is conserved over an interval only when net external impulse is zero or negligible. →

Why it matters: Check external impulse first.

Wrong idea: “Internal forces change total momentum.” →

Correct Physics: For the complete system, internal action-reaction contributions cancel. →

Why it matters: Define the system boundary first.

Wrong idea: “The COM is where all mass is physically concentrated.” →

Correct Physics: It is a mass-weighted position used to represent the system. →

Why it matters: Do not confuse representation with physical concentration.

Wrong idea: “COM problems always require integration.” →

Correct Physics: Symmetry, discrete and composite methods may be simpler. →

Why it matters: Look at mass distribution before calculating.

8. Exam Traps

Choosing the formula before choosing the system.

Using momentum conservation without checking external impulse.

Confusing individual particle velocity with COM velocity.

Ignoring symmetry and doing unnecessary calculation.

Treating a hole as ordinary positive mass.

Starting a continuous-body problem with integration before identifying dm .

Forgetting the conditions of $F_{ext} = MA_{CM}$

Following every object separately when a complete-system description is simpler.

9. See This → Think This

Several interacting bodies → Choose the system first.

Total momentum asked → Think collective motion.

No external impulse → Check momentum conservation.

Known masses and positions → Think mass-weighted COM.

Equal masses → Ordinary average of positions.

Symmetric body → Check COM from symmetry.

Complicated body made of simple pieces → Composite-body method.

Body with a cut-out → Missing mass / negative mass.

Parts move but no net external force → Separate internal motion from COM motion.

Two bodies with common translational motion → Consider the COM frame.

Explosion, recoil or collision → Identify the system and check external impulse first.

10. Key Diagrams / Physical Situations

System Boundary

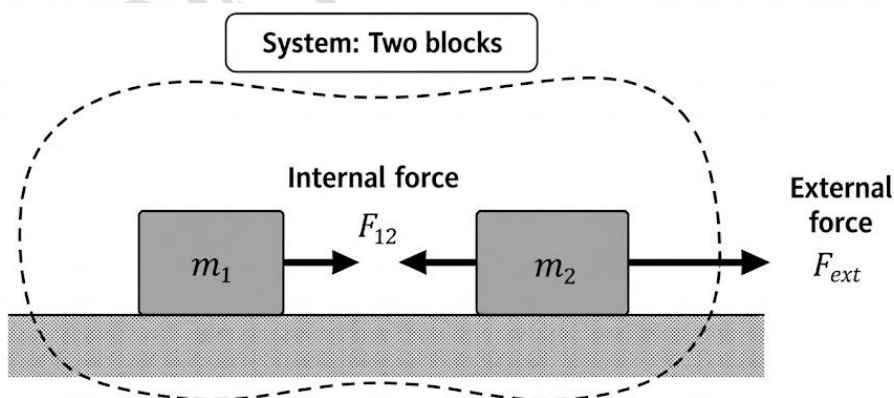
Notice: The same interaction can be internal or external depending on the chosen system.

Exam Use: Prevents incorrect force and momentum equations.

Mass Distribution and COM

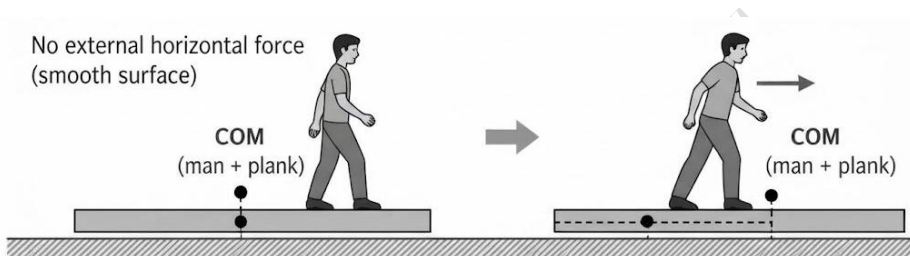
Notice: The COM shifts toward the region containing more mass.

Exam Use: Recognize symmetry, unequal-mass and composite-body problems.



Man + Plank / Internal Motion

Notice: Bodies can move relative to each other while the system COM remains unchanged when there is no external horizontal force.



Notice:

- No external horizontal force $\rightarrow$ COM of man + plank remains at rest in horizontal direction.
- Man moves right, plank moves left so that COM stays fixed.

Exam Use:

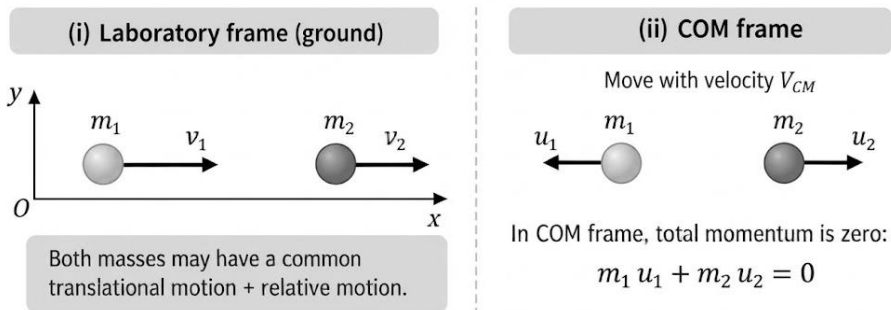
- Use momentum conservation or COM concept for man–plank problems.
- Individual bodies move, but COM can remain at rest (if no external force).

Exam Use: Separate individual motion from collective COM motion.

COM Frame

Notice: The COM is at rest in the COM frame.

Exam Use: Remove common translational motion and simplify relative motion.



11. Quick Checks

Q: What should you choose before classifying a force? → The system and its boundary.

Q: What changes total momentum? → Net external impulse.

Q: When is momentum conserved? → When net external impulse is zero or negligible.

Q: Equal masses at two positions: which shortcut? → Average of the positions.

Q: Symmetric uniform body: what first? → Check COM from symmetry.

Q: Body with a hole: which method? → Negative-mass method.

Q: Can parts move while COM stays fixed? → Yes, under appropriate zero-external-force conditions.

Q: What does the COM frame remove? → Common translational motion.

12. MINI EXAM REASONING

Clue → Physics Situation → Model → Relation → Check

- **Clue:** A system is isolated horizontally.

Physics situation: No external horizontal impulse/force.

Model: Complete system.

Relation: Momentum conserved / COM has no horizontal acceleration.

Check: Confirm the system boundary.

- **Clue:** A complicated body contains a hole.

Physics situation: Non-uniform shape with a known missing region.

Model: Composite / negative-mass method.

Relation: Mass-weighted COM.

Check: Give the missing mass a negative sign.

- **Clue:** Two bodies separate after an explosion.

Physics situation: Internal redistribution.

Model: Complete system.

Relation: $P_f = P_i$ if external impulse is negligible.

Check: Treat momentum as a vector.

- **Clue:** A two-body problem has large common translational velocity.

Physics situation: Collective + relative motion.

Model: COM frame.

Relation: $v'_i = v_i - V_{\text{CM}}$. **Check:** Relative velocity is unchanged.

13. ONE-MINUTE RECALL

- **System** → Define the boundary.
- **Internal force** → Interaction within the chosen system.
- **External force** → Interaction across the boundary.
- **Momentum relation** →

$$P = \sum m_i v_i = M V_{\text{CM}}$$

- **Impulse relation** →

$$J_{\text{ext}} = \Delta P$$

- **Momentum conservation** → Zero/negligible external impulse → $P_f = P_i$.
- **Centre of Mass (COM)** → Mass-weighted position.
- **Symmetry** → Possible direct COM shortcut.
- **Composite body** → Combine component COMs.

- **Body with a hole** → Subtract missing mass (negative-mass method).
- **Force relation** →

$$F_{\text{ext}} = MA_{\text{CM}}$$

Complete fixed-mass system, inertial frame.

- **COM frame** → Removes common translational motion:

$$v'_i = v_i - V_{\text{CM}}$$

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