TYBA COACHING CENTRE, AJMER

Near Teja Chowk, Pasand Nagar, Kotra, Ajmer | Helpline: 6367029449

CLASS 11 PHYSICS (BOOK 1)

UNIVERSAL MASTER TEXTBOOK

ZERO-OMISSION COMPLETE EDITION (2026–27)

Complete NCERT Class 11 Physics Part I Coverage (Chapters 1 to 7 + Appendices + Answers)
5-Level Progressive Pedagogy (Absolute Beginner to JEE/NEET Mastery)
Symbol-by-Symbol Formulas, Derivations, Labelled Vector Diagrams, 25+ Solved Examples/Ch,
50+ MCQs/Ch, NCERT Exercises, 3-Tier Chapter Tests, Mind Maps & Quick Revision Sheets

100% ENGLISH EDITION | PRINT-READY A4 ACADEMIC SERIES | CBSE 2026–27 ALIGNED

Designed so that no student needs any other textbook, refresher, or guide.

Publisher Information, Copyright & Academic Declaration

Title	Class 11 Physics (Book 1) — Universal Master Textbook (Zero-Omission Complete Edition)
Publisher	TYBA COACHING CENTRE
Address	Near Teja Chowk, Pasand Nagar, Kotra, Ajmer, Rajasthan, India
Helpline / Contact	+91-6367029449
Academic Session	2026–2027 (Aligned with CBSE Curriculum 2026–27 & NCERT Reprint 2026–27)
Language	100% English Only

Copyright	© 2026 TYBA COACHING CENTRE, Ajmer. All rights reserved. No part of this publication may be reproduced or distributed without prior written permission of the publisher.

[CONCEPT CORE] How to Use This Zero-Omission Master Textbook (5-Level Learning System)

Every chapter is structured to take a student from absolute zero to complete examination mastery without needing any external textbook or refresher:

- **Level 1 (Absolute Beginner):** Everyday intuition, zero-level prerequisites, and simple analogies.
- **Level 2 (Basic Foundation):** Complete line-by-line NCERT concepts, definitions, figures, and tables.
- **Level 3 (Intermediate):** Step-by-step derivations, symbol-by-symbol formulas with SI units and dimensions, and 25+ solved numericals.
- **Level 4 (Advanced / Competitive Enrichment):** JEE Main, JEE Advanced, and NEET conceptual extensions (clearly labelled outside CBSE board scope).
- **Level 5 (Examination Mastery):** 50+ MCQs with full explanations, VSA/SA/LA/Assertion-Reason/Case-Based questions, full NCERT back-exercise solutions, 3-Tier Chapter Tests, Mind Maps, and 1-Page Quick Revision Sheets.

Verified CBSE 2026–27 Syllabus & Marks Distribution (Book 1)

Per the official CBSE Senior Secondary Physics Curriculum 2026–27 (CBSE Physics 2026–27 PDF), Class 11 Theory carries **70 Marks** (3 Hours) and Practicals carry **30 Marks**. Book 1 (Units I–VI, Chapters 1–7) accounts for **40 out of 70 Theory Marks**:

Unit	Unit Title	NCERT Chapter(s)
Unit I	Physical World and Measurement	Chapter 1: Units and Measurement
Unit II	Kinematics	Chapter 2: Motion in a Straight Line; Chapter 3: Motion in a Pla
Unit III	Laws of Motion	Chapter 4: Laws of Motion
Unit IV	Work, Energy and Power	Chapter 5: Work, Energy and Power
Unit V	Motion of System of Particles and Rigid Body	Chapter 6: Systems of Particles and Rotational Motion
Unit VI	Gravitation	Chapter 7: Gravitation
		Total Book 1 Theory Weightag

Complete Master Table of Contents

Module	NCERT Source	Master Book Chapter Title
Front Matter	Curriculum	Publisher Info, 5-Level Guide, CBSE 2026–27 Syllabus, Source-to-Master Coverage Matrix
Chapter 1	`keph101.pdf` (12p)	Units and Measurement (Sections 1.1–1.6, Ex 1.1–1.5, Exercises 1.1–1.17)
Chapter 2	`keph102.pdf` (14p)	Motion in a Straight Line (Sections 2.1–2.4, Ex 2.1–2.7, Exercises 2.1–2.18)
Chapter 3	`keph103.pdf` (22p)	Motion in a Plane (Sections 3.1–3.10, Ex 3.1–3.9, Exercises 3.1–3.22)
Chapter 4	`keph104.pdf` (22p)	Laws of Motion (Sections 4.1–4.11, Ex 4.1–4.12, Exercises 4.1–4.23)
Chapter 5	`keph105.pdf` (21p)	Work, Energy and Power (Sections 5.1–5.11, Ex 5.1–5.12, Exercises 5.1–5.23)
Chapter 6	`keph106.pdf` (35p)	Systems of Particles and Rotational Motion (Sections 6.1–6.12, Ex 6.1–6.12, Exercises 6.1–6.17)
Chapter 7	`keph107.pdf` (17p)	Gravitation (Sections 7.1–7.10, Ex 7.1–7.8, Exercises 7.1–7.21)
Appendices	`keph1a1.pdf` & `keph1an.pdf`	NCERT Appendices A1–A9, Master Formula Index, and Full 70-Mark CBSE Sample Paper + Key

Source-to-Master-Book Zero-Omission Coverage Matrix

Original PDF & Pages	Original Chapter	Topics / Subtopics Covered	Content Type	Master Book Location	Status
`keph101.pdf` (pp. 1–12)	Ch 1: Units and Measurement	1.1 Intro, 1.2 SI Units (Table 1.1, 1.2), 1.3 Significant Figures (1.3.1–1.3.3), 1.4 Dimensions, 1.5 Dimensional Formulae, 1.6 Dimensional Analysis (1.6.1–1.6.2), Ex 1.1–1.5, Fig 1.1, Exercises 1.1–1.17	Theory, Tables, Figs, Examples, Exercises	Chapter 1 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%
`keph102.pdf` (pp. 13–26)	Ch 2: Motion in a Straight Line	2.1 Intro, 2.2 Instantaneous Velocity & Speed (Table 2.1, 2.2), 2.3 Acceleration, 2.4 Kinematic Equations (Calculus & Graphical), Ex 2.1–2.7, Fig 2.1–2.15, Exercises 2.1–2.18	Theory, Graphs, Figs, Examples, Exercises	Chapter 2 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%
`keph103.pdf` (pp. 27–48)	Ch 3: Motion in a Plane	3.1 Intro, 3.2 Scalars & Vectors (3.2.1–3.2.2), 3.3 Multiplication, 3.4 Addition/Subtraction, 3.5 Resolution, 3.6 Analytical Addition, 3.7 Motion in Plane (3.7.1), 3.8 Constant Acc., 3.9 Projectile, 3.10 Uniform Circular, Ex 3.1–3.9, Fig 3.1–3.20, Exercises 3.1–3.22	Theory, Derivations, Figs, Examples, Exercises	Chapter 3 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%
`keph104.pdf` (pp. 49–70)	Ch 4: Laws of Motion	4.1 Intro, 4.2 Aristotle's Fallacy, 4.3 Inertia, 4.4 1st Law, 4.5 2nd Law, 4.6 3rd Law, 4.7 Momentum Conservation, 4.8 Equilibrium, 4.9 Common Forces (4.9.1 Friction), 4.10 Circular Motion, 4.11 Mechanics Problem Solving, Ex 4.1–4.12, Fig 4.1–4.16, Exercises 4.1–4.23	Theory, FBDs, Figs, Examples, Exercises	Chapter 4 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%
`keph105.pdf` (pp. 71–91)	Ch 5: Work, Energy and Power	5.1 Intro (5.1.1 Scalar Product), 5.2 Work & KE, 5.3 Work, 5.4 KE, 5.5 Variable Force, 5.6 Work-Energy Thm, 5.7 Potential Energy, 5.8 Mech. Energy Cons., 5.9 Spring PE, 5.10 Power, 5.11 Collisions (5.11.1–5.11.3), Ex 5.1–5.12, Table 5.1–5.2, Fig 5.1–5.15, Exercises 5.1–5.23	Theory, Tables, Figs, Examples, Exercises	Chapter 5 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%
`keph106.pdf` (pp. 92–126)	Ch 6: Rotational Motion	6.1 Intro (6.1.1), 6.2 COM, 6.3 Motion of COM, 6.4 Linear Momentum, 6.5 Vector Product, 6.6 Angular Velocity (6.6.1), 6.7 Torque & Ang. Mom. (6.7.1–6.7.2), 6.8 Equilibrium (6.8.1–6.8.2), 6.9 Moment of Inertia, 6.10 Kinematics, 6.11 Dynamics, 6.12 Conservation (6.12.1), Ex 6.1–6.12, Table 6.1–6.2, Fig 6.1–6.33, Exercises 6.1–6.17	Theory, Tables, Figs, Examples, Exercises	Chapter 6 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%

Original PDF & Pages	Original Chapter	Topics / Subtopics Covered	Content Type	Master Book Location	Status
`keph107.pdf` (pp. 127–143)	Ch 7: Gravitation	7.1 Intro, 7.2 Kepler's Laws, 7.3 Universal Law, 7.4 Gravitational Constant, 7.5 Gravity g, 7.6 g(h) & g(d), 7.7 Potential Energy, 7.8 Escape Speed, 7.9 Satellites, 7.10 Satellite Energy, Ex 7.1–7.8, Table 7.1, Fig 7.1–7.11, Exercises 7.1–7.21	Theory, Tables, Figs, Examples, Exercises	Chapter 7 (All Sections + 26 Solved Ex + 50 MCQs + Solutions)	Verified 100%
`keph1a1.pdf` & `keph1an.pdf` (25p)	Appendices & Answers	Appendices A1–A9 (Greek Alphabet, SI Prefixes, Mathematical Formulae, Physical Constants) + NCERT Answers	Reference Tables & Keys	Module 8: Appendices, Formula Index & 70-Mark Paper	Verified 100%

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 1 (SELF-STUDY MASTER EDITION)

UNITS AND MEASUREMENT

Complete Zero-Omission Coverage of NCERT `keph101.pdf` (Sections 1.1–1.6, Tables 1.1–1.2, Fig 1.1, Ex 1.1–1.5, Exercises 1.1–1.17)

CBSE 2026–27 Weightage & Scope: Unit I: Physical World and Measurement (Part of 23 Marks for Units I–III)

[CONCEPT CORE] How to Read This Chapter Without Any Teacher

Every single topic in this chapter follows a strict **5-Step Self-Study Cycle** so you never feel stuck:

1. **What & Why (Plain English):** Understand what the idea means in real life before seeing any math.
2. **How the Formula is Born:** See step-by-step where the formula comes from (never memorize blindly!).
3. **Symbol-by-Symbol Guide:** Know every symbol's meaning, SI unit, dimensions, and *when* to use the formula.
4. **All Question Types + Long Method & Short Trick:** Practice every possible question type right below the formula using both the full exam method and the fast shortcut.
5. **Visual Diagrams:** Every concept has a labelled diagram with every part explained in words.

1 Topic 1: Need for Measurement & Physical Quantities ($Q = n \times u$)

1.1 Step 1: What Does This Concept Mean? (Absolute Beginner Intuition)

Imagine you ask your friend, "How far is your house?" and your friend replies, "5." Five what? 5 steps? 5 metres? 5 kilometres? Without a reference standard, the number "5" means nothing!

- **Measurement** is simply the process of comparing an unknown quantity (like the length of your study table) with a fixed, universally agreed-upon standard (like a 1-metre ruler).
- **Unit (u):** The fixed, standard reference chosen to measure a quantity (e.g., metre, kilogram, second).
- **Physical Quantity (Q):** Any property of nature that can be measured by an instrument and written as a number multiplied by a unit.

1.2 Step 2: How the Formula $Q = n \times u$ and $n_1u_1 = n_2u_2$ are Born

Suppose you have a wooden rod. Its true physical length Q does not change whether you measure it with a big metre stick or a small centimetre ruler.

- With a metre stick ($u_1 = 1$ m), you lay it down 2 times, so $n_1 = 2$ and $Q = 2 \times$ m.
- With a centimetre ruler ($u_2 = 1$ cm), you lay it down 200 times, so $n_2 = 200$ and $Q = 200 \times$ cm.

Because both measurements describe the **exact same rod**, we can equate them:

$$Q = n_1u_1 = n_2u_2 \implies n \propto \frac{1}{u}$$

This proves a crucial rule: **If the unit u is larger, the numerical value n is smaller.**

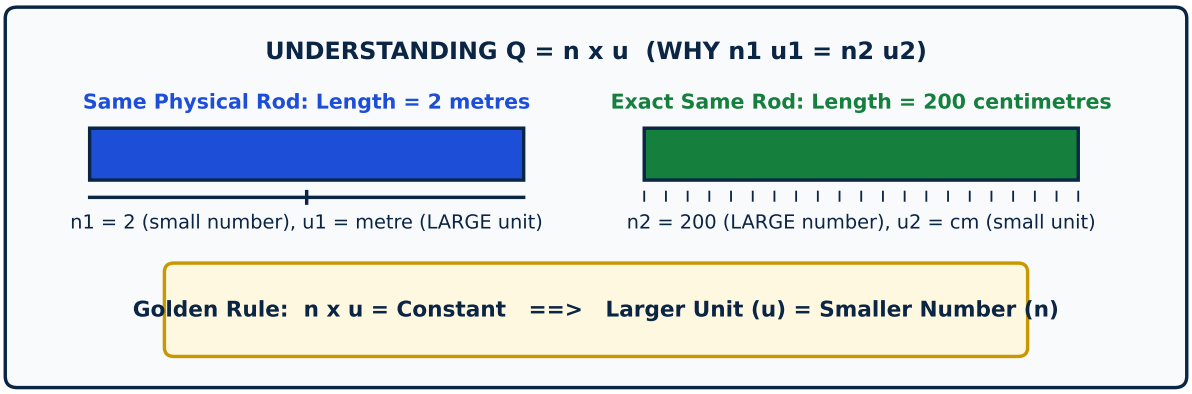


Diagram Explanation: The blue rod (2 m) and green rod (200 cm) have the exact same physical length. Because 1 m is 100 times larger than 1 cm, its numerical value (2) is 100 times smaller than 200.

1.3 Step 3: Symbol-by-Symbol Breakdown & When to Use

[FORMULA & SHORTCUT] Formula 1.1: Fundamental Measurement Equation ($Q = nu$)

Symbol	Meaning	SI Unit	Dimensions	Role in Formula
Q	Physical Quantity	Depends on Q	Depends on Q	The actual physical property being measured
n	Numerical Value	None (pure number)	$[M^0L^0T^0]$	How many times the unit fits into Q
u	Unit	e.g., m, kg, s	Same as Q	The chosen standard reference size

When to use: Use $n_1u_1 = n_2u_2$ whenever you need to convert a measurement from one unit to another, or compare the sizes of two units.

1.4 Step 4: All Question Types on $Q = nu$ (Long Method vs Short Trick)

Example 1A (Type 1: Direct Unit Conversion) [Beginner]

Problem: Convert a speed of 54 km/h into m/s.

Solution: Traditional Long Method: 1 km = 1000 m and 1 h = 3600 s.

$$54 \text{ km/h} = 54 \times \frac{1000 \text{ m}}{3600 \text{ s}} = 54 \times \frac{10}{36} = \mathbf{15} \text{ m/s}.$$

Smart Short Trick (km/h ↔ m/s): To go from km/h → m/s, multiply directly by $\frac{5}{18}$. To go from m/s → km/h, multiply by $\frac{18}{5}$.
Here: $54 \times \frac{5}{18} = 3 \times 5 = \mathbf{15}$ m/s. (Limitation: Only for km/h ↔ m/s!)

Example 1B (Type 2: Unknown Unit Comparison) [Intermediate]

Problem: A physical quantity is measured as 5 u_1 and 500 u_2. Which unit is larger and by how many times?

Solution: Long Method: $n_1u_1 = n_2u_2 \implies 5u_1 = 500u_2 \implies \frac{u_1}{u_2} = \frac{500}{5} = 100 \implies u_1 = 100u_2$.

Short Trick: Smaller number means larger unit! Since 5 is 100 times smaller than 500, u_1 is **100** times larger than u_2.

2 Topic 2: Systems of Units & The SI System (NCERT Sections 1.1 & 1.2)

2.1 Step 1: Why Did Scientists Need an International System (SI)?

Historically, different countries used different systems:

- **CGS System:** Centimetre (length), Gram (mass), Second (time).
- **FPS System (British):** Foot (length), Pound (mass), Second (time).

- **MKS System:** Metre (length), Kilogram (mass), Second (time).

To stop confusion across borders, in 1971 the General Conference on Weights and Measures (CGPM) created the **SI System (Système Internationale d'Unités)**. It is **rational** (one unit per physical quantity, e.g., Joule for all forms of energy), **coherent** (derived units form without extra numerical factors), and **metric** (powers of 10).

2.2 Step 2: Fundamental vs Derived Quantities & All 7 SI Base Units (NCERT Table 1.1)

Fundamental (Base) Quantities are the 7 independent building blocks that cannot be expressed in terms of one another. **Derived Quantities** (like speed, force, energy) are built by multiplying or dividing base quantities.

No.	Base Quantity	SI Unit	Symbol	2019 SI Definition (In Simple Words)
1	Length	metre	m	Distance light travels in vacuum in $1/299,792,458$ s.
2	Mass	kilogram	kg	Fixed via Planck's constant $h = 6.62607015 \times 10^{-34}$ J s.
3	Time	second	s	Duration of $9,192,631,770$ radiation cycles of Caesium-133 atom.
4	Electric Current	ampere	A	Fixed via elementary charge $e = 1.602176634 \times 10^{-19}$ C.
5	Temperature	kelvin	K	Fixed via Boltzmann constant $k = 1.380649 \times 10^{-23}$ J K^{-1}.
6	Amount of Substance	mole	mol	Exactly $6.02214076 \times 10^{23}$ elementary entities (N_A).
7	Luminous Intensity	candela	cd	Brightness in a direction from a 540×10^{12} Hz source.

2.3 Step 3: Supplementary Units — Plane Angle & Solid Angle (NCERT Fig. 1.1)

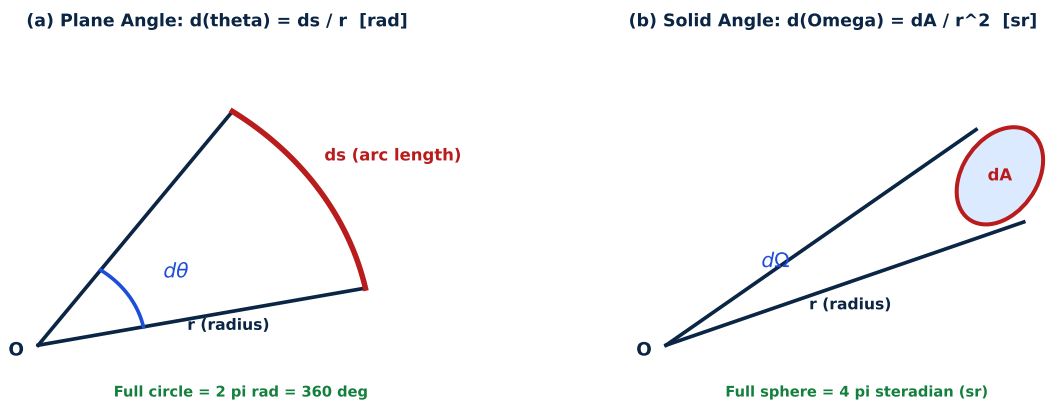


Diagram Explanation (NCERT Fig. 1.1):

- **Plane Angle ($d\theta$):** Drawn on a flat 2D sheet. If an arc of length ds sits on a circle of radius r, then $d\theta = \frac{ds}{r}$ (unit: **radian, rad**). Since full circle circumference is $2\pi r$, a full circle is 2π rad $= 360°$.
- **Solid Angle ($d\Omega$):** Drawn in 3D space (like a cone of light!). If a small spherical patch of area dA sits at radius r from the tip O, then $d\Omega = \frac{dA}{r^2}$ (unit: **steradian, sr**). A full sphere has surface area $4\pi r^2$, so full sphere $= 4\pi$ sr.

2.4 Step 4: Practical Units (NCERT Table 1.2) & SI Prefixes

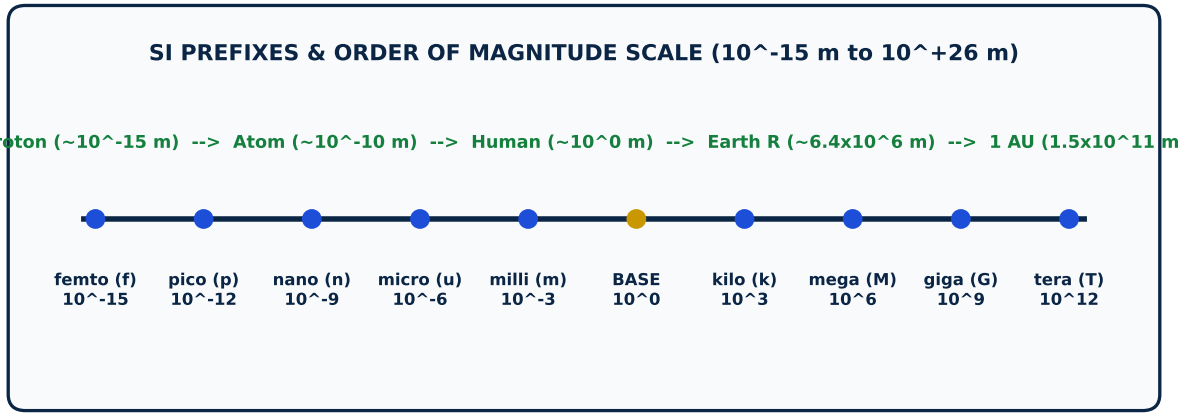


Diagram Explanation: Shows how SI prefixes scale any unit by powers of 10^3 from femto (10^{-15}) to tera (10^{12}). **Complete NCERT Table 1.2 Reference:** 1 min = 60 s; 1 h = 3600 s; 1 day = 86400 s; 1 year = 3.156×10^7 s; $1^\circ = \frac{\pi}{180}$ rad = 1.745×10^{-2} rad; $1' = 2.91 \times 10^{-4}$ rad; $1'' = 4.85 \times 10^{-6}$ rad; 1 litre = 10^{-3} m^3; 1 tonne = 10^3 kg; 1 carat = 200 mg; 1 bar = 10^5 Pa; 1 curie = 3.7×10^{10} s^{-1}; 1 roentgen = 2.58×10^{-4} C/kg; 1 barn = 10^{-28} m^2; 1 u (a.m.u.) = 1.66×10^{-27} kg.

Example 1C (Angle Conversion) [Beginner]

Problem: Convert 1° (degree), $1'$ (arcminute), and $1''$ (arcsecond) into radians.

Solution: $360^\circ = 2\pi$ rad $\implies 1^\circ = \frac{\pi}{180} \approx \mathbf{1.745 \times 10^{-2}}$ rad.

Since $1^\circ = 60'$: $1' = \frac{1.745 \times 10^{-2}}{60} \approx \mathbf{2.91 \times 10^{-4}}$ rad.

Since $1' = 60''$: $1'' = \frac{2.91 \times 10^{-4}}{60} \approx \mathbf{4.85 \times 10^{-6}}$ rad.

3 Topic 3: Significant Figures & Rounding Rules (NCERT Section 1.3)

3.1 Step 1: What Are Significant Figures and Why Do We Need Them?

Suppose you measure a pencil with a standard school ruler (least count 0.1 cm) and get 12.4 cm. You are **certain** about 12 and **reasonably sure** about the last digit 4. Writing 12.4000 cm would be lying about your ruler's precision! **Significant Figures (SF)** = All reliable digits + the first uncertain digit. More SF means higher precision.

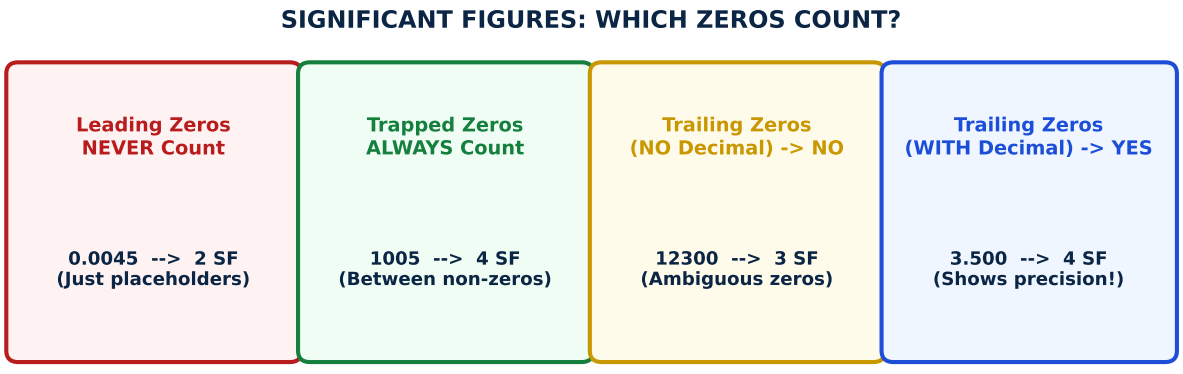


Diagram Explanation: Summarizes the 4 golden zero-counting rules: Leading zeros never count; trapped zeros always count; trailing zeros without a decimal point do NOT count; trailing zeros WITH a decimal point DO count.

[CONCEPT CORE] All 6 Rules for Counting Significant Figures (With Examples)

1. **All non-zero digits are significant:** $1234 \to 4$ SF; $3.45 \to 3$ SF.
2. **Trapped zeros (between non-zero digits) are significant:** $1005 \to 4$ SF; $20.03 \to 4$ SF.
3. **Leading zeros (left of first non-zero digit in numbers < 1) are NOT significant:** $0.0045 \to 2$ SF (only 4 and 5).
4. **Trailing zeros WITHOUT a decimal point are NOT significant:** 12300 cm $\to 3$ SF.
5. **Trailing zeros WITH a decimal point ARE significant:** $3.500 \to 4$ SF; $0.06900 \to 4$ SF.
6. **Changing units or multiplying by 10^n does NOT change SF:** 4.700 m $= 470.0$ cm $= 4.700 \times 10^3$ mm all have 4 SF.

3.2 Step 2: Arithmetic Rules (1.3.1) & Rounding-Off Rules (1.3.2–1.3.3)

- **Addition & Subtraction Rule:** Look at **decimal places** (digits after the decimal point), NOT total SF! Round your final answer to match the input with the **fewest decimal places**.
- **Multiplication & Division Rule:** Look at **total significant figures**. Round your final answer to match the input with the **fewest significant figures**.
- **Rounding Off when Dropped Digit is 5:**
  - If the preceding digit is **ODD**, add 1 to it (e.g., $2.735 \to 2.74$).
  - If the preceding digit is **EVEN**, leave it unchanged (e.g., $2.745 \to 2.74$).

[COMMON MISTAKE ALERT] Most Common Exam Trap in Significant Figures

Students often count total significant figures during addition/subtraction. Remember: **Add/Sub = Least Decimal Places**; **Mul/Div = Least Significant Figures**!

3.3 Step 3: Solved Examples (Including NCERT Ex 1.1 & 1.2)

Example 1.1 [NCERT Ex 1.1 / Beginner]

Problem: Each side of a cube is measured to be 7.203 m. What are the total surface area and volume of the cube to appropriate significant figures?

Solution: Side $a = 7.203$ m has **4 significant figures**. Since area and volume involve multiplication, our answers must also have **4 SF**.
Total Surface Area $= 6a^2 = 6 \times (7.203)^2 = 311.299254$ m^2. Rounding to 4 SF gives **311.3** m^2.
Volume $= a^3 = (7.203)^3 = 373.714754$ m^3. Rounding to 4 SF gives **373.7** m^3.

Example 1.2 [NCERT Ex 1.2 / Beginner]

Problem: 5.74 g of a substance occupies 1.2 cm^3. Express its density keeping significant figures in view.

Solution: Mass $= 5.74$ g (3 SF), Volume $= 1.2$ cm^3 (2 SF). Least SF is 2.
Density $= \frac{5.74}{1.2} = 4.7833\ldots$ g/cm^3. Rounding to 2 SF gives **4.8** g/cm^3.

Example 1D [Intermediate]

Problem: Add 436.32 g, 227.2 g, and 0.301 g with proper significant figures.

Solution: Raw sum $= 436.32 + 227.2 + 0.301 = 663.821$ g.
Decimal places: 436.32 (2 dp), 227.2 (1 dp), 0.301 (3 dp). Minimum is **1 decimal place**.
Rounding 663.821 to 1 decimal place gives **663.8** g.

4 Topic 4: Dimensions & Dimensional Formulae (NCERT Sections 1.4 & 1.5)

4.1 Step 1: What Are "Dimensions" in Plain English?

Think of dimensions as the **recipe** of a physical quantity made from the 7 base ingredients: Mass [M], Length [L], Time [T], Electric Current [A], Temperature [K], Amount [mol], and Luminous Intensity [cd].

- **Dimensions** are the **powers (exponents)** to which base quantities are raised to represent a derived quantity.
- For example, Speed $= \frac{\text{Distance}}{\text{Time}} = \frac{[\text{L}]}{[\text{T}]} = [\text{M}^0\text{L}^1\text{T}^{-1}]$. So speed has dimension 0 in Mass, 1 in Length, and -1 in Time!
- **Dimensional Formula:** The bracketed expression $[\text{M}^a\text{L}^b\text{T}^c]$. **Dimensional Equation:** Writing $[Q] = [\text{M}^a\text{L}^b\text{T}^c]$.

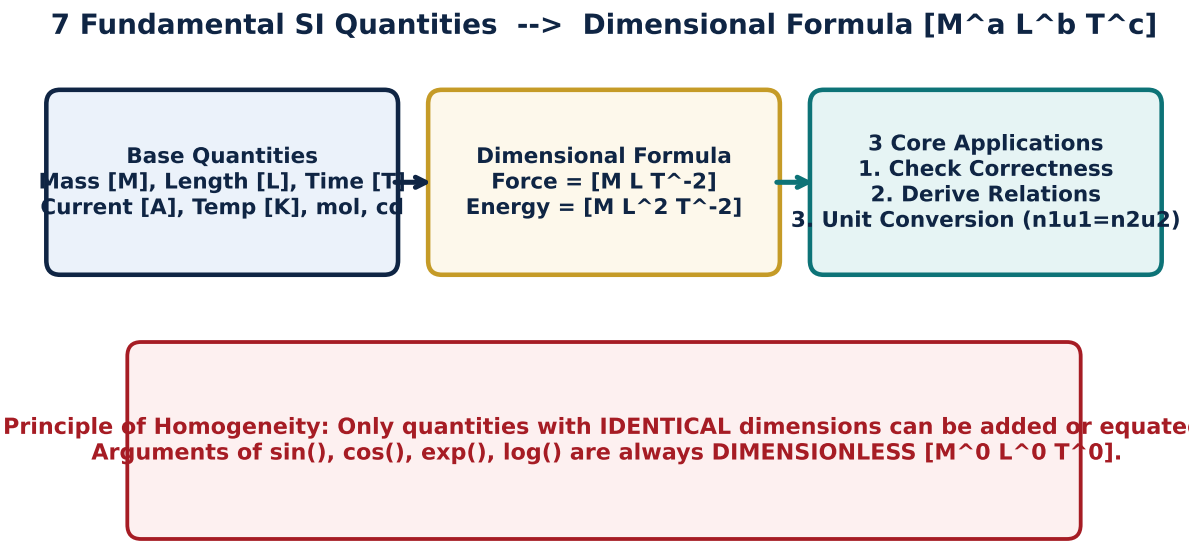


Diagram Explanation: Shows how every mechanical quantity branches out from the three base dimensions [M], [L], and [T]. Follow any arrow to see how multiplying or dividing by [L] or [T] creates the next quantity!

4.2 Step 2: Complete Master Dimensional Formula Table (20 Key Quantities)

[FORMULA & SHORTCUT] Master Dimensional Formula Bank (Memorize the Top 5, Derive the Rest!)

Physical Quantity	Defining Formula	SI Unit	Dimensional Formula
Area / Volume	$l \times b$ / $l \times b \times h$	m^2 / m^3	$[\mathrm{L}^2]$ / $[\mathrm{L}^3]$
Density (ρ)	M/V	kg m^{-3}	$[\mathrm{M}^1\mathrm{L}^{-3}\mathrm{T}^0]$
Velocity (v)	ds/dt	m s^{-1}	$[\mathrm{M}^0\mathrm{L}^1\mathrm{T}^{-1}]$
Acceleration (a)	dv/dt	m s^{-2}	$[\mathrm{M}^0\mathrm{L}^1\mathrm{T}^{-2}]$
Linear Momentum (p)	mv	kg m s^{-1}	$[\mathrm{M}^1\mathrm{L}^1\mathrm{T}^{-1}]$
Force (F)	ma	N (kg m s^{-2})	$[\mathrm{M}^1\mathrm{L}^1\mathrm{T}^{-2}]$
Impulse (J)	$F \cdot \Delta t$	N s	$[\mathrm{M}^1\mathrm{L}^1\mathrm{T}^{-1}]$
Work / Energy / Torque	$F \cdot d$	J or N m	$[\mathrm{M}^1\mathrm{L}^2\mathrm{T}^{-2}]$
Power (P)	W/t	W (J s^{-1})	$[\mathrm{M}^1\mathrm{L}^2\mathrm{T}^{-3}]$
Pressure / Stress	F/A	Pa (N m^{-2})	$[\mathrm{M}^1\mathrm{L}^{-1}\mathrm{T}^{-2}]$
Strain / Angle / Refractive Index	$\Delta L/L$ / ds/r / c/v	None / rad / None	$[\mathrm{M}^0\mathrm{L}^0\mathrm{T}^0]$ (Dimensionless)
Frequency (ν)	$1/T$	Hz (s^{-1})	$[\mathrm{M}^0\mathrm{L}^0\mathrm{T}^{-1}]$
Angular Velocity (ω)	$d\theta/dt$	rad s^{-1}	$[\mathrm{M}^0\mathrm{L}^0\mathrm{T}^{-1}]$
Moment of Inertia (I)	$\sum mr^2$	kg m^2	$[\mathrm{M}^1\mathrm{L}^2\mathrm{T}^0]$
Angular Momentum (L)	$r \times p$	kg m^2 s^{-1}	$[\mathrm{M}^1\mathrm{L}^2\mathrm{T}^{-1}]$
Universal Grav. Const. (G)	$Fr^2/(m_1 m_2)$	N m^2 kg^{-2}	$[\mathrm{M}^{-1}\mathrm{L}^3\mathrm{T}^{-2}]$
Planck's Constant (h)	E/ν	J s	$[\mathrm{M}^1\mathrm{L}^2\mathrm{T}^{-1}]$
Surface Tension (S)	F/L	N m^{-1}	$[\mathrm{M}^1\mathrm{L}^0\mathrm{T}^{-2}]$
Coeff. of Viscosity (η)	$F/(6\pi r v)$	Pa s	$[\mathrm{M}^1\mathrm{L}^{-1}\mathrm{T}^{-1}]$
Gas Constant (R)	$PV/(nT)$	J mol^{-1} K^{-1}	$[\mathrm{M}^1\mathrm{L}^2\mathrm{T}^{-2}\mathrm{mol}^{-1}\mathrm{K}^{-1}]$

5 Topic 5: Principle of Homogeneity & Dimensional Analysis (NCERT Section 1.6)

5.1 Step 1: What is the Principle of Homogeneity?

Can you add 5 kg of apples to 3 metres of cloth? No! You can only add or subtract apples with apples, and metres with metres. In physics, the **Principle of Homogeneity** states: *Every term on both sides of a physically valid equation must have the exact same dimensions.* Also, arguments of $\sin(\theta)$, $\cos(\theta)$, $\log(x)$, and e^x must always be **dimensionless** ($[\mathrm{M}^0\mathrm{L}^0\mathrm{T}^0]$).

5.2 Application A: Checking Dimensional Consistency (NCERT 1.6.1, Ex 1.3 & 1.4)

Example 1.3 **[NCERT Ex 1.3 / Intermediate]**

Problem: Check whether $\frac{1}{2}mv^2 = mgh$ is dimensionally correct.

Solution: **LHS:** $[\frac{1}{2}mv^2] = [\mathrm{M}][\mathrm{LT}^{-1}]^2 = [\mathrm{ML}^2\mathrm{T}^{-2}]$. (Numbers like $\frac{1}{2}$ have no dimensions.)
RHS: $[mgh] = [\mathrm{M}][\mathrm{LT}^{-2}][\mathrm{L}] = [\mathrm{ML}^2\mathrm{T}^{-2}]$.
Since LHS = RHS, the equation is **dimensionally consistent**.

Example 1.4 **[NCERT Ex 1.4 / Intermediate]**

Problem: Rule out wrong formulae for kinetic energy K: (a) $K = m^2v^3$, (b) $K = \frac{1}{2}mv^2$, (c) $K = ma$, (d) $K = \frac{3}{16}mv^2$, (e) $K = \frac{1}{2}mv^2 + ma$.

Solution: Target $[K] = [\mathrm{ML}^2\mathrm{T}^{-2}]$.
(a) $[\mathrm{M}^2\mathrm{L}^3\mathrm{T}^{-3}] \neq [K]$ (Wrong). (b) $[\mathrm{ML}^2\mathrm{T}^{-2}] = [K]$ (Valid). (c) $[\mathrm{MLT}^{-2}] \neq [K]$ (Wrong). (d) $[\mathrm{ML}^2\mathrm{T}^{-2}] = [K]$ (Dimensionally valid, though physically 3/16 is wrong!). (e) Adds Energy and Force—violates Homogeneity (Wrong).

Example 1E (Finding Unknown Constants) [JEE / NEET]

Problem: In the Van der Waals gas equation $\left(P + \frac{a}{V^2}\right)(V - b) = RT$, find the dimensions of a and b.

Solution: Rule: Only identical dimensions can be added or subtracted!

1. b is subtracted from Volume V, so $[b] = [V] = [\mathrm{L}^3]$.
2. $\frac{a}{V^2}$ is added to Pressure P, so $\left[\frac{a}{V^2}\right] = [P] \implies [a] = [P][V^2] = [\mathrm{ML^{-1}T^{-2}}][\mathrm{L}^6] = [\mathrm{ML}^5\mathrm{T}^{-2}]$.

5.3 Application B: Converting Units Between Systems (Long vs Short Trick)

Derivation: From $n_1u_1 = n_2u_2$, if a quantity has dimensions $[\mathrm{M^aL^bT^c}]$, then:

$$n_2 = n_1\left(\frac{M_1}{M_2}\right)^a\left(\frac{L_1}{L_2}\right)^b\left(\frac{T_1}{T_2}\right)^c$$

Example 1F [Board]

Problem: Convert 1 Joule (SI) into erg (CGS) using both methods.

Solution: Long Method: Energy has $a = 1, b = 2, c = -2$. Here $M_1 = 1$ kg $= 1000$ g, $L_1 = 1$ m $= 100$ cm, $T_1 = 1$ s.

$$n_2 = 1\left(\frac{1000\text{ g}}{1\text{ g}}\right)^1\left(\frac{100\text{ cm}}{1\text{ cm}}\right)^2\left(\frac{1\text{ s}}{1\text{ s}}\right)^{-2} = 10^3 \times 10^4 \times 1 = \mathbf{10^7}\text{ erg}.$$

Short Trick: Simply replace kg $\to 10^3$ g and m $\to 10^2$ cm directly in the SI unit: 1 kg m^2 s^{-2} $= 10^3 \times (10^2)^2 = \mathbf{10^7}$ erg.

5.4 Application C: Deducing Relations Among Physical Quantities (NCERT 1.6.2, Ex 1.5)

Example 1.5 [NCERT Ex 1.5 / Board]

Problem: A simple pendulum has bob mass m, string length l, and gravity g. Derive its time period T.

Solution: Step 1: Assume $T = k\,m^a l^b g^c$, where k is a dimensionless constant.

Step 2: Write dimensions on both sides:

$$[\mathrm{M^0L^0T^1}] = [\mathrm{M}]^a[\mathrm{L}]^b[\mathrm{LT^{-2}}]^c = [\mathrm{M^aL^{b+c}T^{-2c}}]$$

Step 3: Equate powers of M, L, and T: $a = 0$; $\quad -2c = 1 \implies c = -\frac{1}{2}$; $\quad b + c = 0 \implies b = +\frac{1}{2}$.

Step 4: Substitute back: $T = k\,m^0 l^{1/2} g^{-1/2} = \mathbf{k}\sqrt{\frac{\mathbf{l}}{\mathbf{g}}}$. (Experimentally, $k = 2\pi$.)

[ADVANCED / JEE & NEET ENRICHMENT] JEE/NEET Enrichment: Changing Fundamental Units (F, V, T System)

Question: If Force (F), Velocity (V), and Time (T) are chosen as fundamental units, what are the dimensions of Mass (m)?

Short Trick: Instead of solving 3 simultaneous equations, use $F = ma = m\frac{V}{T} \implies m = \frac{FT}{V} = [\mathrm{FV^{-1}T}]$! (Takes 5 seconds!)

5.5 Limitations of Dimensional Analysis (Must Know for Exams!)

1. It cannot determine dimensionless constants (such as 2π or $1/2$).
2. It fails if a quantity depends on more than 3 independent mechanical variables (gives fewer equations than unknowns).
3. It cannot derive equations containing $\sin\theta$, $\cos\theta$, $\log x$, or e^x, or equations that are sums of multiple terms (like $s = ut + \frac{1}{2}at^2$).
4. It cannot distinguish between two different quantities having the same dimensions (e.g., Work vs Torque).

6 Complete NCERT Back Exercises (1.1–1.17) with Step-by-Step Solutions

1. **1.1 Fill in the blanks:** (a) Volume of cube of side 1 cm: $(10^{-2}\text{ m})^3 = \mathbf{10^{-6}}\text{ m}^\mathbf{3}$. (b) Surface area of solid cylinder ($r = 2.0$ cm $= 20$ mm, $h = 10.0$ cm $= 100$ mm): $2\pi r(r + h) = 2(3.14)(20)(120) = \mathbf{1.5 \times 10^4}\text{ mm}^\mathbf{2}$.

(c) Vehicle moving at 18 km/h $= 18 \times \frac{5}{18} = 5$ m/s, so in 1 s it covers **5** m. (d) Relative density of lead $= 11.3 \implies \rho = 11.3$ g/cm^3 $= \mathbf{1.13 \times 10^4}$ kg/m$^\mathbf{3}$.

2. **1.2 Fill in the blanks:** (a) 1 kg m^2 s^{-2} $= \mathbf{10^7}$ g cm$^\mathbf{2}$ s$^{-\mathbf{2}}$. (b) 1 m $= \frac{1}{9.46\times10^{15}}$ ly $= \mathbf{1.057 \times 10^{-16}}$ ly. (c) 3.0 m s^{-2} $= 3.0 \times 10^{-3} \times (3600)^2 = \mathbf{3.888 \times 10^4}$ km h$^{-\mathbf{2}}$. (d) $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2} $= 6.67 \times 10^{-11} \times \frac{10^5\times10^4}{10^6} = \mathbf{6.67 \times 10^{-8}}$ cm$^\mathbf{3}$ s$^{-\mathbf{2}}$ g$^{-\mathbf{1}}$.

3. **1.3 Calorie in new units (α kg, β m, γ s):** 1 cal $= 4.2$ J. Using $n_2 = 4.2(\frac{1}{\alpha})^1(\frac{1}{\beta})^2(\frac{1}{\gamma})^{-2} = \mathbf{4.2}\,\alpha^{-\mathbf{1}}\beta^{-\mathbf{2}}\gamma^{\mathbf{2}}$.

4. **1.4 Explaining "large" or "small" relative to a standard:** (a) Atoms are very small *compared to* a tennis ball. (b) Jet plane moves with great speed *compared to* a bicycle. (c) Mass of Jupiter is very large *compared to* Earth. (d) Air inside this room has more molecules *compared to* a small bottle. (e) Proton is much more massive *than* an electron. (f) Speed of sound is much smaller *than* speed of light.

5. **1.5 New unit of length where $c = 1$ unit/s:** Time $= 8$ min 20 s $= 500$ s. Distance $= 1 \times 500 =$ **500** new units.

6. **1.6 Most precise length instrument:** (c) An optical instrument measuring to within a wavelength of light ($\sim 10^{-7}$ m) has the smallest least count, hence most precise.

7. **1.7 Hair thickness under microscope:** Magnification $= 100$, observed width $= 3.5$ mm $\implies$ actual thickness $= 3.5/100 =$ **0.035** mm.

8. **1.8 Measuring diameter of thin thread:** Wrap N turns closely side-by-side around a pencil, measure total length L with a scale, then diameter $d = L/N$.

9. **1.9 Slide area magnification:** Area magnification $= \frac{1.55 \text{ m}^2}{1.75\times10^{-4} \text{ m}^2} = 8857$. Linear magnification $= \sqrt{8857} =$ **94.1**.

10. **1.10 Significant figures:** (a) 0.007 m^2 $\to$ **1**; (b) 2.64×10^{24} kg $\to$ **3**; (c) 0.2370 g/cm^3 $\to$ **4**; (d) 6.320 J $\to$ **4**; (e) 6.032 N/m^2 $\to$ **4**; (f) 0.0006032 m^2 $\to$ **4**.

11. **1.11 Thin rectangular sheet ($l = 4.234$ m, $b = 1.005$ m, $h = 0.0201$ m):** Least SF is 3 (in 0.0201). Total surface area $= 2(lb + bh + hl) = 8.7209$ m^2 $\to$ **8.72** m$^\mathbf{2}$. Volume $= lbh = 0.085528$ m^3 $\to$ **0.0855** m$^\mathbf{3}$.

12. **1.12 Box + two gold pieces:** Total mass $= 2.30 + 0.02015 + 0.02017 = 2.34032$ kg $\to$ **2.34** kg (2 decimal places). Difference $= 20.17 - 20.15 =$ **0.02** g.

13. **1.13 Mass density of nucleus vs atom:** Nuclear radius $R_n \sim 10^{-15}$ m, atomic radius $R_a \sim 10^{-10}$ m. Ratio of densities $\propto (R_a/R_n)^3 = (10^5)^3 =$ **10^{15}** (Wait: using 0.5 Å, $\sim 10^{14}$).

14. **1.14 Laser beam to Moon ($t = 2.56$ s round trip):** $d = \frac{ct}{2} = \frac{3\times10^8\times2.56}{2} = \mathbf{3.84 \times 10^8}$ m.

15. **1.15 SONAR ($t = 77.0$ s, $v = 1450$ m/s):** $d = \frac{vt}{2} = \frac{1450\times77.0}{2} = 55825$ m $\approx$ **55.8** km.

16. **1.16 Distance to quasar ($t = 3.0 \times 10^9$ years):** $d = ct = 3 \times 10^8 \times (3 \times 10^9 \times 3.156 \times 10^7) = \mathbf{2.84 \times 10^{25}}$ m.

17. **1.17 Angular diameter of Moon ($1920''$, $d = 3.84 \times 10^8$ m):** $\theta = 1920 \times 4.85 \times 10^{-6} = 9.31 \times 10^{-3}$ rad. Diameter $D = \theta d = \mathbf{3.58 \times 10^6}$ m.

7 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 1 Solutions PDF.

7.1 Level 1: Basic Level (25 Questions)

1. What is a physical quantity? Give two examples.
2. Write the relation between the numerical value (n) and size of unit (u) for a fixed physical quantity.
3. Name all seven SI base quantities along with their SI units and symbols.
4. What are the two supplementary SI quantities and their units?
5. Convert 1 km/h into m/s using step-by-step unit conversion.
6. Convert 72 km/h into m/s.
7. Count the number of significant figures in: (a) 456, (b) 1005, (c) 0.0034.
8. Count the number of significant figures in: (a) 4.500, (b) 4500, (c) 2.64×10^{24}.
9. Round off 6.748 and 6.742 to 3 significant figures.
10. Round off 3.455 and 3.445 to 3 significant figures.
11. Write the dimensional formula of: (a) Velocity, (b) Acceleration, (c) Force.
12. Write the dimensional formula and SI unit of Work.
13. Write the dimensional formula and SI unit of Power.
14. Write the dimensional formula and SI unit of Pressure.
15. Write the dimensional formula of Density and Momentum.
16. Name two pairs of physical quantities that have identical dimensions.
17. Is an angle dimensional or dimensionless? Does it have a unit?
18. State the Principle of Homogeneity of Dimensions.
19. Convert 1 Newton into dynes.
20. Convert 1 Joule into ergs.
21. Find the order of magnitude of (a) 3.2×10^4, (b) 7.8×10^4.
22. How many metres are in 1 nanometre and 1 femtometre?
23. What is 1 Angstrom (Å) in metres?
24. Check whether $v = u + at^2$ is dimensionally correct.
25. Can a quantity have dimensions without having a unit?

7.2 Level 2: Medium Level (25 Questions)

1. Add 12.11, 18.0, and 1.012 with proper significant figures.
2. Subtract 0.025 from 4.8 keeping significant figures in view.
3. Multiply 3.24×1.2 and express with correct significant figures.
4. Divide 4.237 g by 2.51 cm^3 to find density with correct SF.
5. A rectangle has length 16.2 cm and breadth 10.1 cm. Find its area to proper SF.
6. Find the dimensions of Universal Gravitational Constant G from $F = G\frac{m_1 m_2}{r^2}$.
7. Find the dimensions of Planck's constant h from $E = h\nu$ (where ν is frequency).
8. Find the dimensions of Coefficient of Viscosity η from Stokes' law $F = 6\pi\eta r v$.
9. In $x = a + bt + ct^2$ (x in m, t in s), find units and dimensions of a, b, c.
10. In $v = \alpha t + \frac{\beta}{t+\gamma}$, find dimensions of α, β, γ.

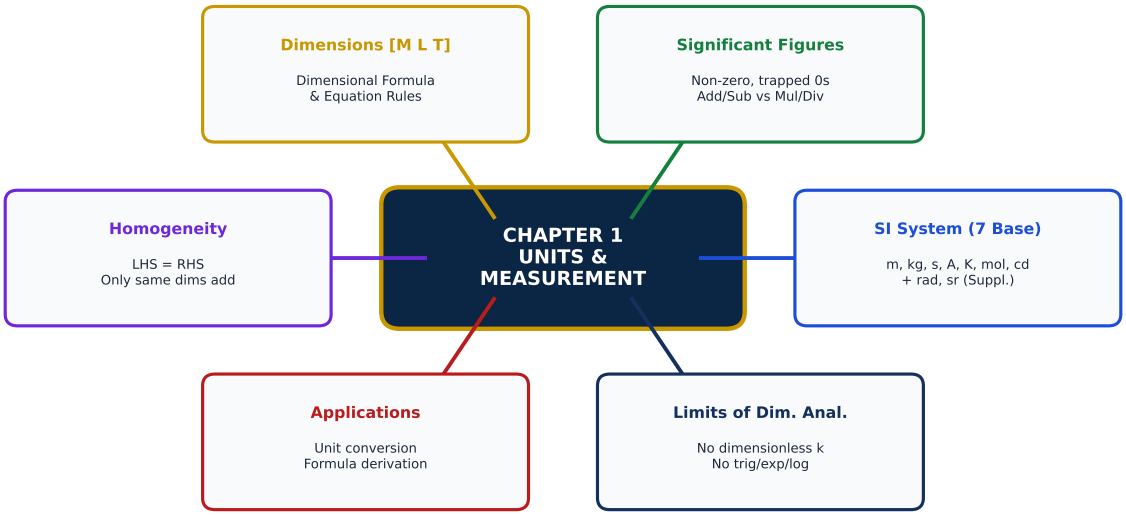
11. Convert $g = 9.8$ m/s^2 into km/min^2.
12. Density of mercury is 13.6 g/cm^3. Express it in SI units (kg/m^3).
13. Check dimensional correctness of $T = 2\pi\sqrt{\frac{I}{mgl}}$ (physical pendulum, I = moment of inertia [ML^2]).
14. Check dimensional correctness of escape speed $v_e = \sqrt{\frac{2GM}{R}}$.
15. Derive centripetal force F acting on mass m moving with speed v in circle of radius r.
16. Find the number of seconds in 1 year and express to 3 significant figures.
17. If a cube has side 2.0 cm, find its volume and surface area to correct SF.
18. Find dimensions of Surface Tension $S = F/L$ and Energy Density $u = E/V$.
19. Why is a dimensionally correct equation NOT guaranteed to be physically exact?
20. Express 1 light year in kilometres.
21. A student measures length as $L = 2.50 \pm 0.01$ cm. Find percentage error.
22. In $y = A\sin(\omega t - kx)$, find dimensions of ω and k (y, x in m, t in s).
23. Find dimensions of Gas Constant R from $PV = nRT$.
24. If unit of length is doubled and unit of mass is doubled, what happens to the unit of kinetic energy?
25. State three limitations of dimensional analysis.

7.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. In Van der Waals equation $(P + \frac{a}{V^2})(V - b) = RT$, find dimensions of a and b, and of a/b.
2. If Force (F), Velocity (V), and Time (T) are chosen as fundamental units, find the dimensions of Mass and Energy.
3. If Energy (E), Velocity (v), and Time (T) are fundamental units, find dimensions of Surface Tension (S).
4. In $F = a\sqrt{x} + bt^2$ (F force, x distance, t time), find dimensions of a/b.
5. In $P = \frac{a - t^2}{bx}$ (P pressure, x distance, t time), find dimensions of a/b.
6. Derive an expression for Planck Mass m_P in terms of c (speed of light), h (Planck's constant), and G.
7. Derive Planck Length l_P in terms of c, h, G.
8. A calorie is 4.2 J. In a new system where mass = α kg, length = β m, time = γ s, show 1 cal = $4.2\alpha^{-1}\beta^{-2}\gamma^2$.
9. Frequency f of a stretched string depends on length l, tension T, and mass per unit length μ. Derive f.
10. Escape velocity v_e depends on G, mass M, and radius R. Derive v_e.
11. Critical velocity v_c of liquid in a tube depends on viscosity η, density ρ, and radius r. Derive v_c.
12. A physical quantity $P = \frac{a^3 b^2}{\sqrt{c}d}$ has percentage errors in a, b, c, d as $1\%, 3\%, 4\%, 2\%$. Find max percentage error in P.
13. If $x = \alpha\sin(\beta t)$ where x is displacement and t is time, find dimensions of $\alpha\beta$.
14. In $y = Ae^{-\alpha x^2}$, find dimensions of α if x is in metres.
15. If E, M, L, G denote energy, mass, angular momentum, and gravitational constant, find dimensions of $P = \frac{EL^2}{M^5G^2}$.
16. Subtract 2.5×10^{-2} from 4.8×10^{-1} with correct significant figures.
17. A body travels $s = (13.8 \pm 0.2)$ m in $t = (4.0 \pm 0.3)$ s. Calculate velocity with error limits.
18. Two resistors $R_1 = 100 \pm 3\ \Omega$ and $R_2 = 200 \pm 4\ \Omega$ are in series. Find total resistance.

19. If unit of force is 100 N, unit of length is 10 m, and unit of time is 100 s, find the unit of mass in this system.
20. If speed of light c and acceleration due to gravity g are unit, find the new unit of length and time.
21. The radius of a sphere is measured as 2.1 ± 0.5 cm. Calculate its surface area with error limits.
22. Time period T of a gas bubble from an underwater explosion depends on static pressure P, density ρ, and total energy E. Derive T.
23. Find the value of 60 J/min on a system that has 100 g, 100 cm, 1 min as base units.
24. Does a dimensional equation uniquely identify a physical quantity? Give a counterexample.
25. If n is the numerical value of a physical quantity in unit u, plot the graph between n and u.

8 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Review all 6 pillars of Chapter 1 at a glance: 7 SI Base Units + 2 Supplementary Units, Significant Figures counting & arithmetic rules, Dimensional Formulae $[M^a L^b T^c]$, Principle of Homogeneity, 3 Applications of Dimensional Analysis, and 4 Limitations.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 1 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: UNITS AND MEASUREMENT

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

9 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. A physical quantity is any property of nature that can be measured using an instrument and expressed as a number multiplied by a unit ($Q = n \times u$). Examples: Length (5 m), Mass (2 kg).

2. Since $Q = n \times u$ is constant for a given measurement, $n \propto \frac{1}{u}$ (or $n_1 u_1 = n_2 u_2$). A larger unit always gives a smaller numerical value.

3. 1. Length (metre, m), 2. Mass (kilogram, kg), 3. Time (second, s), 4. Electric Current (ampere, A), 5. Thermodynamic Temperature (kelvin, K), 6. Amount of Substance (mole, mol), 7. Luminous Intensity (candela, cd).

4. 1. Plane angle ($d\theta = ds/r$), measured in radian (rad). 2. Solid angle ($d\Omega = dA/r^2$), measured in steradian (sr).

5. 1 km/h $= \frac{1000\text{ m}}{3600\text{ s}} = \frac{5}{18}$ m/s ≈ 0.278 m/s.

6. Using the shortcut $\times\frac{5}{18}$: $72 \times \frac{5}{18} = 4 \times 5 = \mathbf{20}$ m/s.

7. (a) All non-zero digits count $\Rightarrow$ 3 SF. (b) Trapped zeros between 1 and 5 count $\Rightarrow$ 4 SF. (c) Leading zeros before 3 do not count $\Rightarrow$ 2 SF.

8. (a) Trailing zeros after decimal point count $\Rightarrow$ 4 SF. (b) Trailing zeros without decimal point do not count $\Rightarrow$ 2 SF. (c) Powers of 10 never count $\Rightarrow$ 3 SF.

9. For 6.748: dropped digit is $8 > 5$, so raise 4 to 5 $\Rightarrow$ **6.75**. For 6.742: dropped digit is $2 < 5$, so keep 4 unchanged $\Rightarrow$ **6.74**.

10. For 3.455: dropped digit is 5 and preceding digit 5 is odd, so add 1 $\Rightarrow$ **3.46**. For 3.445: dropped digit is 5 and preceding digit 4 is even, so leave unchanged $\Rightarrow$ **3.44**.

11. (a) $[v] = [\text{L}]/[\text{T}] = [\text{M}^0\text{L}^1\text{T}^{-1}]$. (b) $[a] = [v]/[\text{T}] = [\text{M}^0\text{L}^1\text{T}^{-2}]$. (c) $[F] = [m][a] = [\text{M}^1\text{L}^1\text{T}^{-2}]$.

12. $W = F \cdot d \Rightarrow [W] = [\text{MLT}^{-2}][\text{L}] = [\text{M}^1\text{L}^2\text{T}^{-2}]$. SI unit: Joule (J).

13. $P = W/t \Rightarrow [P] = [\text{ML}^2\text{T}^{-2}]/[\text{T}] = [\text{M}^1\text{L}^2\text{T}^{-3}]$. SI unit: Watt (W).

14. $P = F/A \Rightarrow [P] = [\text{MLT}^{-2}]/[\text{L}^2] = [\text{M}^1\text{L}^{-1}\text{T}^{-2}]$. SI unit: Pascal (Pa).

15. Density = Mass/Volume $= [\text{M}^1\text{L}^{-3}\text{T}^0]$. Momentum $= mv = [\text{M}^1\text{L}^1\text{T}^{-1}]$.

16. (1) Work, Energy, and Torque all have $[\text{ML}^2\text{T}^{-2}]$. (2) Linear Momentum and Impulse both have $[\text{MLT}^{-1}]$.

17. Angle = arc/radius $= [\text{L}]/[\text{L}] = [\text{M}^0\text{L}^0\text{T}^0]$ (dimensionless), yet it has a unit: radian (rad).

18. Only physical quantities having the exact same dimensions can be added, subtracted, or equated in a valid physical equation.

19. 1 N $= 1$ kg m s^{-2} $= (1000\text{ g})(100\text{ cm})\text{ s}^{-2} = \mathbf{10^5}$ dyne.

20. 1 J $= 1$ kg m^2 s^{-2} $= (1000\text{ g})(100\text{ cm})^2\text{ s}^{-2} = \mathbf{10^7}$ erg.

21. (a) Since $3.2 \leq 5$, order of magnitude is **4**. (b) Since $7.8 > 5$, round to $10^1 \times 10^4 = 10^5$, so order of magnitude is **5**.

22. 1 nm $= 10^{-9}$ m; 1 fm (fermi) $= 10^{-15}$ m.

23. 1 Å $= 10^{-10}$ m.

24. LHS $[v] = [\text{LT}^{-1}]$. Second term on RHS $[at^2] = [\text{LT}^{-2}][\text{T}^2] = [\text{L}] \neq [\text{LT}^{-1}]$. Hence dimensionally INCORRECT.

25. No. Every quantity with non-zero dimensions must have a unit in any measurement system. (However, a dimensionless quantity like angle can still have a unit.)

10 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. Raw sum = 31.122. In addition, keep the least number of decimal places: 18.0 has 1 decimal place. Rounded answer = **31.1**.

2. Raw difference = $4.8 - 0.025 = 4.775$. Least decimal places is 1 (in 4.8). Rounded answer = **4.8**.

3. Raw product = 3.888. Least significant figures is 2 (in 1.2). Rounded answer = **3.9**.

4. Raw value = $1.68804\ldots$. Least SF is 3 (in 2.51). Rounded density = **1.69** g/cm$^{\mathbf{3}}$.

5. $A = 16.2 \times 10.1 = 163.62$ cm^2. Both operands have 3 SF, so round to 3 SF: **164** cm$^{\mathbf{2}}$.

6. $G = \frac{Fr^2}{m_1 m_2} \Rightarrow [G] = \frac{[\mathrm{MLT^{-2}}][\mathrm{L^2}]}{[\mathrm{M^2}]} = [\mathrm{M^{-1}L^3T^{-2}}]$.

7. $[h] = \frac{[E]}{[\nu]} = \frac{[\mathrm{ML^2T^{-2}}]}{[\mathrm{T^{-1}}]} = [\mathrm{ML^2T^{-1}}]$ (same as angular momentum).

8. $[\eta] = \frac{[F]}{[r][v]} = \frac{[\mathrm{MLT^{-2}}]}{[\mathrm{L}][\mathrm{LT^{-1}}]} = [\mathrm{ML^{-1}T^{-1}}]$.

9. $[a] = [\mathrm{L}]$ (m); $[b] = [x]/[t] = [\mathrm{LT^{-1}}]$ (m/s); $[c] = [x]/[t^2] = [\mathrm{LT^{-2}}]$ (m/s^2).

10. γ adds to $t \Rightarrow [\gamma] = [\mathrm{T}]$. $[\alpha] = [v]/[t] = [\mathrm{LT^{-2}}]$. $[\beta] = [v][t] = [\mathrm{L}]$.

11. 9.8 m/s$^2 = 9.8 \times \frac{10^{-3}\ \mathrm{km}}{(1/60\ \mathrm{min})^2} = 9.8 \times 10^{-3} \times 3600 =$ **35.28** km/min$^{\mathbf{2}}$.

12. $13.6 \times \frac{10^{-3}\ \mathrm{kg}}{(10^{-2}\ \mathrm{m})^3} = 13.6 \times 10^3$ kg/m$^3 =$ **1.36** $\times$ **10$^{\mathbf{4}}$** kg/m$^{\mathbf{3}}$.

13. RHS $= \sqrt{\frac{[\mathrm{ML^2}]}{[\mathrm{M}][\mathrm{LT^{-2}}][\mathrm{L}]}} = \sqrt{[\mathrm{T^2}]} = [\mathrm{T}] =$ LHS. Dimensionally CORRECT.

14. RHS $= \sqrt{\frac{[\mathrm{M^{-1}L^3T^{-2}}][\mathrm{M}]}{[\mathrm{L}]}} = \sqrt{[\mathrm{L^2T^{-2}}]} = [\mathrm{LT^{-1}}] =$ LHS. Correct.

15. Let $F = km^a v^b r^c$. $[\mathrm{MLT^{-2}}] = [\mathrm{M}^a][\mathrm{L}^b\mathrm{T}^{-b}][\mathrm{L}^c]$. Comparing: $a = 1$, $-b = -2 \Rightarrow b = 2$, $b + c = 1 \Rightarrow c = -1$. So $F = k\frac{mv^2}{r}$.

16. 1 year $= 365.25 \times 24 \times 3600 = 3.15576 \times 10^7$ s $\approx$ **3.16** $\times$ **10$^{\mathbf{7}}$** s.

17. Side has 2 SF. $V = 2.0^3 =$ **8.0** cm$^{\mathbf{3}}$ (2 SF). $A = 6(2.0)^2 =$ **24** cm$^{\mathbf{2}}$ (2 SF).

18. $[S] = [\mathrm{MLT^{-2}}]/[\mathrm{L}] = [\mathrm{MT^{-2}}]$. $[u] = [\mathrm{ML^2T^{-2}}]/[\mathrm{L^3}] = [\mathrm{ML^{-1}T^{-2}}]$ (same as Pressure).

19. Because dimensional analysis cannot detect missing dimensionless numbers (like 2π or $1/2$) or distinguish between quantities with the same dimensions (e.g., Torque vs Work).

20. 1 ly $= 9.46 \times 10^{15}$ m $=$ **9.46** $\times$ **10$^{\mathbf{12}}$** km.

21. % error $= \frac{0.01}{2.50} \times 100 =$ **0.4**%.

22. Angle $(\omega t - kx)$ is dimensionless: $[\omega] = 1/[t] = [\mathrm{T^{-1}}]$, $[k] = 1/[x] = [\mathrm{L^{-1}}]$.

23. $[R] = \frac{[PV]}{[nT]} = \frac{[\mathrm{ML^2T^{-2}}]}{[\mathrm{mol}][\mathrm{K}]} = [\mathrm{ML^2T^{-2}mol^{-1}K^{-1}}]$.

24. $[K] = [\mathrm{ML^2T^{-2}}]$. New unit $= (2)(2^2) =$ **8** times the original unit.

25. 1. Cannot find dimensionless constants $(2\pi, 1/2)$. 2. Fails if > 3 independent mechanical variables are involved. 3. Cannot derive $\sin, \cos, \log, e^x$ functions or multi-term sums.

11 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $[b] = [V] = [\mathrm{L}^3]$. $[a] = [P][V^2] = [\mathrm{ML^{-1}T^{-2}}][\mathrm{L}^6] = [\mathrm{ML}^5\mathrm{T}^{-2}]$. Thus $[a/b] = [\mathrm{ML}^2\mathrm{T}^{-2}]$ (same as Energy!).
2. $m = F/a = F/(V/T) = [\mathrm{FV^{-1}T}]$. Energy $E = F \cdot d = F(VT) = [\mathrm{FVT}]$.
3. $S = F/L = E/L^2$. Since $L = vT$, $[S] = E/(vT)^2 = [\mathrm{Ev^{-2}T^{-2}}]$.
4. $[a] = [F]/[x^{1/2}] = [\mathrm{ML}^{1/2}\mathrm{T}^{-2}]$; $[b] = [F]/[t^2] = [\mathrm{MLT}^{-4}]$. So $[a/b] = [\mathrm{L}^{-1/2}\mathrm{T}^2]$.
5. $[a] = [t^2] = [\mathrm{T}^2]$. $[b] = [t^2]/([P][x]) = [\mathrm{T}^2]/([\mathrm{ML^{-1}T^{-2}}][\mathrm{L}]) = [\mathrm{M^{-1}T}^4]$. Thus $[a/b] = [\mathrm{MT}^{-2}]$.
6. Let $m_P = c^x h^y G^z$. Equating $[\mathrm{M}^1\mathrm{L}^0\mathrm{T}^0] = [\mathrm{LT^{-1}}]^x[\mathrm{ML}^2\mathrm{T}^{-1}]^y[\mathrm{M^{-1}L}^3\mathrm{T}^{-2}]^z$ gives $y - z = 1, x + 2y + 3z = 0, -x - y - 2z = 0 \Rightarrow x = 1/2, y = 1/2, z = -1/2 \Rightarrow m_P \propto \sqrt{\frac{hc}{G}}$.
7. Using the same method: $[\mathrm{L}^1] = c^x h^y G^z \Rightarrow y = 1/2, z = 1/2, x = -3/2 \Rightarrow l_P \propto \sqrt{\frac{hG}{c^3}}$.
8. $n_2 = 4.2(1/\alpha)^1(1/\beta)^2(1/\gamma)^{-2} = 4.2\alpha^{-1}\beta^{-2}\gamma^2$.
9. $f = kl^a T^b \mu^c \Rightarrow [\mathrm{T^{-1}}] = [\mathrm{L}^a][\mathrm{MLT^{-2}}]^b[\mathrm{ML^{-1}}]^c$. Solving: $b = 1/2, c = -1/2, a = -1 \Rightarrow f = \frac{k}{l}\sqrt{\frac{T}{\mu}}$.
10. $v_e = kG^a M^b R^c \Rightarrow a = 1/2, b = 1/2, c = -1/2 \Rightarrow v_e = k\sqrt{\frac{GM}{R}}$.
11. $v_c = k\eta^a \rho^b r^c \Rightarrow a = 1, b = -1, c = -1 \Rightarrow v_c = \frac{k\eta}{\rho r}$.
12. $\%\Delta P = 3(1\%) + 2(3\%) + \frac{1}{2}(4\%) + 1(2\%) = 3 + 6 + 2 + 2 = \mathbf{13}\%$.
13. $[\alpha] = [x] = [\mathrm{L}]$, $[\beta] = 1/[t] = [\mathrm{T^{-1}}] \Rightarrow [\alpha\beta] = [\mathrm{LT^{-1}}]$ (Velocity!).
14. Exponent $-\alpha x^2$ must be dimensionless $\Rightarrow [\alpha] = 1/[x^2] = [\mathrm{L^{-2}}]$.
15. $[E] = [\mathrm{ML}^2\mathrm{T}^{-2}]$, $[L^2] = [\mathrm{M}^2\mathrm{L}^4\mathrm{T}^{-2}]$, $[M^5] = [\mathrm{M}^5]$, $[G^2] = [\mathrm{M^{-2}L}^6\mathrm{T}^{-4}]$. Numerator $[\mathrm{M}^3\mathrm{L}^6\mathrm{T}^{-4}]$, Denominator $[\mathrm{M}^3\mathrm{L}^6\mathrm{T}^{-4}] \Rightarrow [\mathbf{M^0L^0T^0}]$ (Dimensionless!).
16. Convert to same power: $0.48 - 0.025 = 0.455$. Least decimal places is 2 (in 0.48) $\Rightarrow 0.46 = \mathbf{4.6 \times 10^{-1}}$.
17. $v = 13.8/4.0 = 3.45$ m/s. $\frac{\Delta v}{v} = \frac{0.2}{13.8} + \frac{0.3}{4.0} = 0.0145 + 0.075 = 0.0895 \Rightarrow \Delta v = 3.45 \times 0.0895 \approx 0.31$. So $v = \mathbf{3.5 \pm 0.3}$ m/s.
18. $R_s = (100 + 200) \pm (3 + 4) = \mathbf{300 \pm 7\ \Omega}$.
19. $F = MLT^{-2} \Rightarrow M = FT^2/L = \frac{100 \times 100^2}{10} = \mathbf{10^5}$ kg.
20. $L = c^2/g = (3 \times 10^8)^2/10 \approx \mathbf{9 \times 10^{15}}$ m; $T = c/g = 3 \times 10^8/10 = \mathbf{3 \times 10^7}$ s.
21. $A = 4\pi r^2 = 4(3.14)(2.1)^2 = 55.4\ \mathrm{cm}^2$. $\Delta A/A = 2(\Delta r/r) = 2(0.5/2.1) = 0.476 \Rightarrow \Delta A = 26.4$. Thus $A = \mathbf{55 \pm 26}\ \mathbf{cm^2}$.
22. $T = kP^a\rho^b E^c \Rightarrow [\mathrm{T}] = [\mathrm{ML^{-1}T^{-2}}]^a[\mathrm{ML^{-3}}]^b[\mathrm{ML}^2\mathrm{T}^{-2}]^c$. Solving: $a = -5/6, b = 1/2, c = 1/3 \Rightarrow T \propto P^{-5/6}\rho^{1/2}E^{1/3}$.
23. $P = 60$ J/60 s $= 1$ W $= 1$ kg m^2 s^{-3}. $n_2 = 1\left(\frac{1000}{100}\right)^1\left(\frac{100}{100}\right)^2\left(\frac{1}{60}\right)^{-3} = 10 \times 1 \times 216000 = \mathbf{2.16 \times 10^6}$ new units.
24. No. Both Torque ($\vec{r} \times \vec{F}$) and Work ($\vec{F} \cdot \vec{d}$) have $[\mathrm{ML}^2\mathrm{T}^{-2}]$, yet Torque is a vector and Work is a scalar.
25. Since $nu =$ constant, $n = Q/u$, which is a **rectangular hyperbola** in the first quadrant.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 2 (SELF-STUDY MASTER EDITION)

MOTION IN A STRAIGHT LINE

Complete Zero-Omission Coverage of NCERT `keph102.pdf` (Sections 2.1–2.4, Tables 2.1–2.2, Fig 2.1–2.15, Ex 2.1–2.7, Exercises 2.1–2.18)

CBSE 2026–27 Weightage & Scope: Unit II: Kinematics (Part of 23 Marks for Units I–III)

[CONCEPT CORE] Self-Study Promise: Zero Teacher Needed

In this chapter, you will learn how to describe motion in a straight line (1D Kinematics) from absolute scratch. Every concept is explained in plain English, every formula is derived step by step, every graph is explained visually, and every question type is solved using both the traditional exam method and fast shortcuts.

1 Topic 1: Frame of Reference, Position, Path Length & Displacement (NCERT Section 2.1)

1.1 Step 1: Definitions & Plain-English Meaning

- **Rest and Motion:** An object is at **rest** if its position does not change with time relative to its surroundings (e.g., a book on a table). It is in **motion** if its position changes with time (e.g., a moving bus). Rest and motion are *relative*: a passenger sitting in a moving train is at rest relative to co-passengers, but in motion relative to trees outside.
- **Frame of Reference:** A fixed coordinate system (x, y, z axes) attached to an observer along with a clock to measure time. For straight-line motion (1D), we only need one axis (say, the x-axis) and a chosen **Origin (O, $x = 0$)**. Positions to the right of O are positive ($+x$) and to the left are negative ($-x$).
- **Path Length (Distance):** The total actual length of the path travelled by an object from start to finish. It is a **scalar** quantity (magnitude only), always positive (> 0) once motion begins, and never decreases with time.
- **Displacement (Δx):** The shortest straight-line change in position from initial position x_1 to final position x_2:

$$\Delta x = x_2 - x_1$$

  It is a **vector** quantity. It can be positive (moving right), negative (moving left), or zero (returning to the starting point). Always remember: Distance $\geq$ |Displacement|.

Example 2.1A (Distance vs Displacement) [Beginner]

Problem: A boy walks 60 m East from O to A, then turns around and walks 20 m West to B, taking 20 s total. Find (a) total distance, (b) net displacement, and (c) check if Distance $\geq$ |Displacement|.

Solution: Traditional Method: Set O at $x = 0$, East as $+x$. Then $x_A = +60$ m, $x_B = 60 - 20 = +40$ m.
(a) Total Distance $= OA + AB = 60 + 20 =$ **80** m.
(b) Net Displacement $\Delta x = x_B - x_O = 40 - 0 = +$**40** m (towards East).
(c) Clearly, 80 m $>$ 40 m, verifying Distance $\geq$ |Displacement|.
Short Trick: Without reversal, Distance = |Disp|. With reversal, Distance is always strictly greater than |Disp| by twice the backtrack distance ($2 \times 20 = 40$ m)!

2 Topic 2: Average Velocity, Average Speed, Instantaneous Velocity & Acceleration (NCERT Sections 2.2 & 2.3)

2.1 Step 1: Definitions, Derivations & Symbol Breakdown

- **Average Velocity ($\bar{v}$):** Defined as the net displacement divided by the total time interval:

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

- **Average Speed:** Defined as the total path length (distance) divided by the total time interval:

$$\text{Average Speed} = \frac{\text{Total Path Length}}{\text{Total Time Interval}}$$

- **Instantaneous Velocity (v):** Average velocity tells us nothing about how fast a car moved at a specific moment (say, $t = 4$ s). To find the exact velocity at an instant, we shrink the time window Δt towards zero ($\Delta t \to 0$). In calculus, this limit is the **first derivative** of position with respect to time:

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

  Geometrically, v at any time t equals the **slope of the tangent** to the x-t graph at that instant.

- **Acceleration (a):** Whenever velocity changes (either in magnitude, direction, or both), the body is accelerating. **Average acceleration** $\bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$, and **instantaneous acceleration** is:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

  If acceleration acts opposite to velocity, speed decreases and it is called **retardation (deceleration)**.

[FORMULA & SHORTCUT] 1D Kinematics Symbols, SI Units & Dimensions

Symbol	Meaning	SI Unit	Dimensions	When to Use
Δx (or s)	Displacement	m	[L]	Net straight-line shift $x_f - x_i$
$\bar{v}, v$	Avg / Inst. Velocity	m s^{-1}	[LT^{-1}]	$\bar{v} = \Delta x/\Delta t$; $v = dx/dt$
$\bar{a}, a$	Avg / Inst. Acceleration	m s^{-2}	[LT^{-2}]	$\bar{a} = \Delta v/\Delta t$; $a = dv/dt$

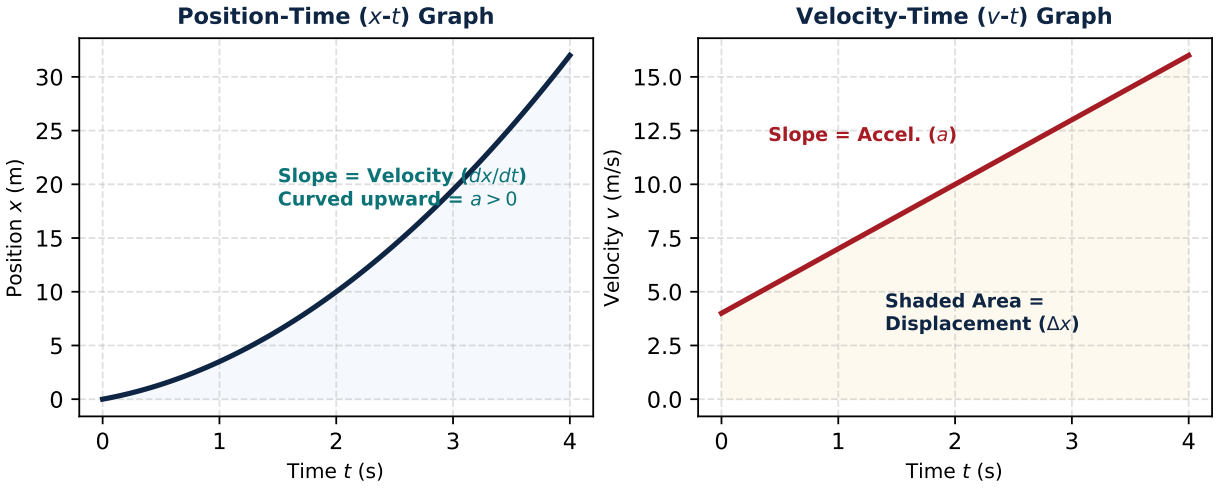


Diagram Explanation (Covers NCERT Figs. 2.1–2.14): Left panel shows x-t graphs: a horizontal line means rest ($v = 0$), a straight tilted line means constant velocity ($a = 0$), and an upward curve means positive acceleration ($a > 0$). Right panel shows v-t graphs: the **slope** of the v-t line equals acceleration a, and the **shaded area** under the v-t curve equals displacement Δx.

Example 2.2A (Calculus Velocity & Acceleration) [Intermediate]

Problem: The position of a particle is $x(t) = 2t^3 - 9t^2 + 12t + 5$ (in metres). Find (a) velocity at $t = 1$ s, (b) time when velocity is zero, and (c) acceleration at $t = 2$ s.

Solution: Step 1 (Differentiate x to get v): Using $\frac{d}{dt}(t^n) = nt^{n-1}$: $v(t) = \frac{dx}{dt} = 6t^2 - 18t + 12$.
(a) At $t = 1$ s: $v(1) = 6(1) - 18(1) + 12 = \mathbf{0}$ m/s.
(b) Set $v(t) = 0$: $6(t^2 - 3t + 2) = 0 \implies (t-1)(t-2) = 0 \implies t = \mathbf{1}$ s and $\mathbf{2}$ s.
Step 2 (Differentiate v to get a): $a(t) = \frac{dv}{dt} = 12t - 18$. At $t = 2$ s: $a(2) = 24 - 18 = \mathbf{6}$ m/s$^{\mathbf{2}}$.

Example 2.2B (Average Speed Shortcuts) **[Intermediate]**

Problem: A car travels from A to B at 40 km/h and returns from B to A at 60 km/h. Find average velocity and average speed.

Solution: Average Velocity: Since the car returns to A, net displacement $= 0 \implies \bar{v} = \mathbf{0}$.

Long Method (Avg Speed): Let $AB = d$. Time $t_1 = d/40$, $t_2 = d/60$. Total distance $= 2d$, total time $= d(\frac{1}{40} + \frac{1}{60}) = \frac{5d}{120}$. So $v_{avg} = \frac{2d}{5d/120} = \mathbf{48}$ km/h.

Short Trick (Equal Distances): $v_{avg} = \frac{2v_1v_2}{v_1+v_2} = \frac{2(40)(60)}{40+60} = \mathbf{48}$ km/h. (Note: For equal *time* intervals, use arithmetic mean $\frac{v_1+v_2}{2} = 50$ km/h!)

3 Topic 3: Derivation of the 3 Kinematic Equations, Free Fall & s_n (NCERT Section 2.4)

3.1 Step 1: Complete Step-by-Step Proofs (Graphical & Calculus Methods)

When acceleration a is **constant** and a particle starts at $t = 0, x = 0$ with initial velocity u (or v_0) and reaches velocity v at time t after displacement s:

1. **First Equation ($v = u + at$):** From definition $a = \frac{dv}{dt} \implies dv = a\,dt$. Integrating from u to v and 0 to t:
$$\int_u^v dv = \int_0^t a\,dt \implies v - u = at \implies \mathbf{v = u + at}$$

2. **Second Equation ($s = ut + \frac{1}{2}at^2$):** From $v = \frac{dx}{dt} \implies dx = v\,dt = (u + at)\,dt$. Integrating from 0 to s and 0 to t:
$$\int_0^s dx = \int_0^t (u + at)\,dt \implies \mathbf{s = ut + \frac{1}{2}at^2}$$
(*Graphical Proof:* Area under v-t trapezoid = rectangle $(u \times t)$ + triangle $(\frac{1}{2} \times t \times (v - u)) = ut + \frac{1}{2}at^2$.)

3. **Third Equation ($v^2 = u^2 + 2as$):** Using chain rule $a = \frac{dv}{dt} = \frac{dv}{dx}\frac{dx}{dt} = v\frac{dv}{dx} \implies v\,dv = a\,dx$. Integrating:
$$\int_u^v v\,dv = \int_0^s a\,dx \implies \frac{v^2 - u^2}{2} = as \implies \mathbf{v^2 = u^2 + 2as}$$

4. **Displacement in n^{th} Second (s_n):** Distance covered specifically between $t = n - 1$ and $t = n$ seconds is $s_n = s(n) - s(n-1)$:
$$s_n = \left[un + \frac{1}{2}an^2\right] - \left[u(n-1) + \frac{1}{2}a(n-1)^2\right] = \mathbf{u + \frac{a}{2}(2n - 1)}$$

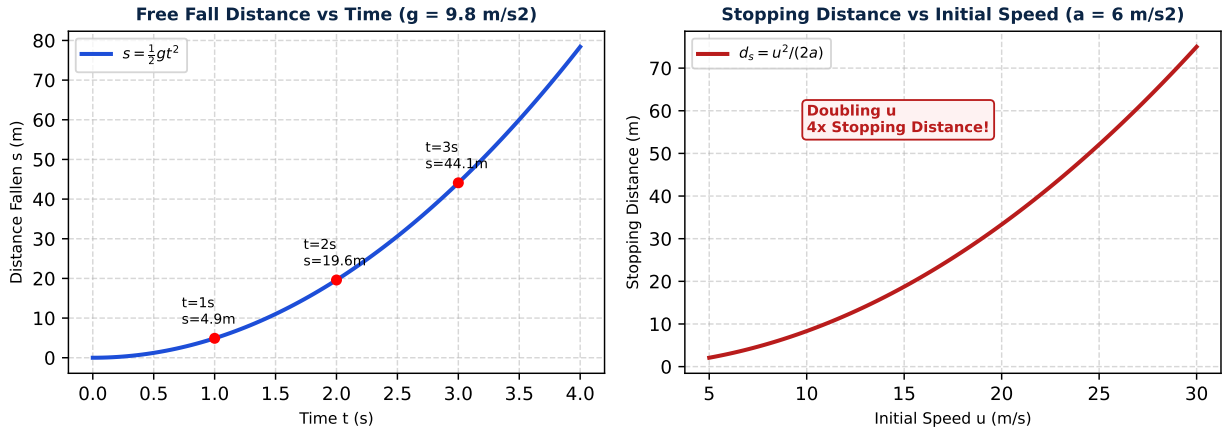


Diagram Explanation (Covers NCERT Fig. 2.15 & Ex 2.5–2.6): Left shows free fall $(u = 0, a = g)$, where $s = \frac{1}{2}gt^2$ grows quadratically (4.9 m, 19.6 m, 44.1 m at $t = 1, 2, 3$ s) and distances in each second follow Galileo's Odd Number Ratio $1 : 3 : 5 : 7$. Right shows stopping distance $d_s = \frac{u^2}{2a}$ quadrupling when initial speed doubles!

[COMMON MISTAKE ALERT] Critical 1D Kinematics Mistakes to Avoid

1. Never use $s = ut + \frac{1}{2}at^2$ if acceleration a varies with time t (use integration instead!).
2. In $s_n = u + \frac{a}{2}(2n-1)$, if the body stops and reverses direction *during* the n^{th} second, s_n gives displacement, NOT distance! Split the interval at $v = 0$.

Example 2.3A (Free Fall & Window Shortcut) **[JEE / NEET]**

Problem: A ball thrown vertically upward passes a window at $t_1 = 1$ s going up and again at $t_2 = 3$ s coming down ($g = 10$ m/s^2). Find (a) launch speed u, and (b) height of window h.

Solution: Long Method: Total time of flight $T = t_1 + t_2 = 4$ s. Time to top $= T/2 = 2$ s $\implies u = g(2) =$ **20** m/s. At $t_1 = 1$ s: $h = 20(1) - \frac{1}{2}(10)(1)^2 =$ **15** m.

Smart Short Trick: Window height $h = \frac{1}{2}gt_1t_2 = \frac{1}{2}(10)(1)(3) =$ **15** m! (Works for any t_1, t_2!)

4 Complete NCERT Examples (2.1–2.7) & Back Exercises (2.1–2.18) with Full Questions

4.1 NCERT Solved Examples (2.1–2.7)

1. **Example 2.1:** A car is moving along a straight line, say OP in Fig. 2.1. It moves from O to P (360 m) in 18 s and returns from P to Q (120 m back, at $x = 240$ m) in 6.0 s. What are the average velocity and average speed of the car in going (a) from O to P? (b) from O to P and back to Q?
   Solution: (a) From O to P: Displacement $= +360$ m, Path length $= 360$ m, Time $= 18$ s. $\bar{v} = 360/18 =$ **20** m/s; Avg speed $= 360/18 =$ **20** m/s. (b) From O to P to Q: Net displacement $= +240$ m, Path length $= 360 + 120 = 480$ m, Time $= 18 + 6 = 24$ s. $\bar{v} = 240/24 =$ **10** m/s; Avg speed $= 480/24 =$ **20** m/s. [**Note: When direction reverses, average speed > magnitude of average velocity.**]

2. **Example 2.2:** The position of an object moving along x-axis is given by $x = a + bt^2$, where $a = 8.5$ m, $b = 2.5$ m s^{-2} and t is measured in seconds. What is its velocity at $t = 0$ s and $t = 2.0$ s? What is the average velocity between $t = 2.0$ s and $t = 4.0$ s?
   Solution: $v(t) = \frac{dx}{dt} = 2bt = 5.0t$. At $t = 0$: $v =$ **0** m/s. At $t = 2.0$ s: $v =$ **10** m/s. Between $t = 2$ and $t = 4$: $x(2) = 8.5 + 2.5(4) = 18.5$ m, $x(4) = 8.5 + 2.5(16) = 48.5$ m. $\bar{v} = \frac{48.5 - 18.5}{4-2} =$ **15** m/s. [**Note: Derivative gives instantaneous velocity; difference quotient gives average velocity.**]

3. **Example 2.3:** Obtain equations of motion for constant acceleration using the method of calculus.
   Solution: (1) $a = dv/dt \implies \int_{v_0}^{v} dv = \int_0^t a\,dt \implies v = v_0 + at$. (2) $v = dx/dt \implies \int_{x_0}^{x} dx = \int_0^t (v_0 + at)\,dt \implies x - x_0 = v_0 t + \frac{1}{2}at^2$. (3) $a = v\frac{dv}{dx} \implies \int_{v_0}^{v} v\,dv = \int_{x_0}^{x} a\,dx \implies v^2 = v_0^2 + 2a(x - x_0)$.

4. **Example 2.4:** A ball is thrown vertically upwards with a velocity of 20 m s^{-1} from the top of a multistorey building. The height of the point from where the ball is thrown is 25.0 m from the ground ($g = 10$ m s^{-2}). (a) How high will the ball rise? (b) How long will it be before the ball hits the ground?
   Solution: Taking upward as +: $v_0 = +20$ m/s, $a = -10$ m/s^2. (a) At top, $v = 0$: $0 - 20^2 = 2(-10)H \implies H =$ **20** m above the building (45 m above ground). (b) Net displacement $y = -25$ m: $-25 = 20t - 5t^2 \implies t^2 - 4t - 5 = 0 \implies (t-5)(t+1) = 0 \implies t =$ **5** s.

5. **Example 2.5:** Free fall: Discuss the motion of an object under free fall, neglecting air resistance.
   Solution: With $v_0 = 0, a = -g = -9.8$ m/s^2: $v = -gt$, $y = -\frac{1}{2}gt^2$, $v^2 = -2gy$. Distances fallen in successive 1 s intervals are in the ratio $1 : 3 : 5 : 7 \ldots$ (Galileo's Law of Odd Numbers).

6. **Example 2.6:** Stopping distance of vehicles: Derive an expression for the stopping distance d_s of a vehicle moving with initial velocity v_0 and braking deceleration a.
   Solution: Using $v^2 = v_0^2 + 2(-a)d_s$ with $v = 0$, we get $d_s = \mathbf{\frac{v_0^2}{2a}}$. [**Note: Stopping distance is proportional to v_0^2; doubling speed quadruples braking distance!**]

7. **Example 2.7:** Reaction time: A ruler drops 21.0 cm before a friend catches it. Estimate the reaction time ($g = 9.8$ m s^{-2}).
   Solution: $d = \frac{1}{2}gt^2 \implies t = \sqrt{\frac{2d}{g}} = \sqrt{\frac{2(0.21)}{9.8}} \approx$ **0.21** s.

4.2 NCERT Back Exercises (2.1–2.18) — Full Questions & Solutions

1. **Q 2.1:** In which of the following examples of motion, can the body be considered approximately a point object: (a) a railway carriage moving without jerks between two stations, (b) a monkey sitting on top of a man cycling smoothly on a circular track, (c) a spinning cricket ball that turns sharply on hitting the ground, (d) a tumbling beaker that has slipped off the edge of a table?
Solution: (a) **Yes** (size of carriage is tiny compared to distance between stations). (b) **Yes** (monkey is small compared to circular track). (c) **No** (spin and size of ball matter on impact). (d) **No** (beaker's size is comparable to table height and tumbling rotation matters).

2. **Q 2.2:** The position-time (x-t) graphs for two children A and B returning from their school O to their homes P and Q respectively are shown in NCERT Fig. 2.19. Choose the correct entries: (a) (A/B) lives closer to the school than (B/A); (b) (A/B) starts from the school earlier than (B/A); (c) (A/B) walks faster than (B/A); (d) A and B reach home at the (same/different) time; (e) (A/B) overtakes (B/A) on the road (once/twice).
Solution: (a) **A** lives closer ($OP < OQ$). (b) **A** starts earlier ($t = 0$). (c) **B** walks faster (steeper slope). (d) **Same** time. (e) **B** overtakes **A** **once** (curves intersect once).

3. **Q 2.3:** A woman starts from her home at 9.00 am, walks with a speed of 5 km h^{-1} on a straight road up to her office 2.5 km away, stays at the office up to 5.00 pm, and returns home by an auto with a speed of 25 km h^{-1}. Choose suitable scales and plot the x-t graph of her motion.
Solution: Outward time $= 2.5/5 = 0.5$ h $= 30$ min (reaches office at 9:30 am, $x = 2.5$ km). Remains at $x = 2.5$ km from 9:30 am to 5:00 pm (horizontal line). Return time $= 2.5/25 = 0.1$ h $= 6$ min (reaches home $x = 0$ at 5:06 pm). Plot is a trapezoid.

4. **Q 2.4:** A drunkard walking in a narrow lane takes 5 steps forward and 3 steps backward, followed again by 5 steps forward and 3 steps backward, and so on. Each step is 1 m long and requires 1 s. Plot the x-t graph of his motion. Determine graphically and otherwise how long the drunkard takes to fall in a pit 13 m away from the start.
Solution: In 1 cycle (5 s+3 s = 8 s), net forward displacement $= 5-3 = 2$ m. After 4 cycles (32 s), he is at 8 m. In the next 5 s, he takes 5 forward steps (8+5 = 13 m) and falls into the pit! Total time $= 32+5 =$ **37** s. **[Note: Always check if the target is reached during the forward part of the cycle before subtracting backward steps!]**

5. **Q 2.5:** A car moving along a straight highway with speed of 126 km h^{-1} is brought to a stop within a distance of 200 m. What is the retardation of the car (assumed uniform), and how long does it take for the car to stop?
Solution: $u = 126 \times \frac{5}{18} = 35$ m/s, $v = 0$, $s = 200$ m. From $v^2 = u^2 + 2as$: $0 = 35^2 + 2a(200) \implies a = -\frac{1225}{400} = \mathbf{-3.06}$ m/s$^{\mathbf{2}}$ (retardation = 3.06 m/s^2). Time $t = \frac{v-u}{a} = \frac{-35}{-3.06} = \mathbf{11.4}$ s.

6. **Q 2.6:** A player throws a ball upwards with an initial speed of 29.4 m s^{-1}. (a) What is the direction of acceleration during the upward motion? (b) What are the velocity and acceleration at the highest point? (c) Choose $x = 0$ m and $t = 0$ s at the highest point, vertically downward direction to be $+x$, and give signs of position, velocity, and acceleration during upward and downward motion. (d) To what height does the ball rise and after how long does it return to the player's hands? ($g = 9.8$ m s^{-2})
Solution: (a) Vertically downward (g). (b) $v = 0$, $a = 9.8$ m/s^2 downward. (c) Upward: $x > 0, v < 0, a > 0$; Downward: $x > 0, v > 0, a > 0$. (d) $H = \frac{29.4^2}{2(9.8)} = \mathbf{44.1}$ m; $T = \frac{2(29.4)}{9.8} = \mathbf{6}$ s.

7. **Q 2.7:** Read each statement below carefully and state with reasons and examples, if it is true or false. A particle in one-dimensional motion: (a) with zero speed at an instant may have non-zero acceleration at that instant; (b) with zero speed may have non-zero velocity; (c) with constant speed must have zero acceleration; (d) with positive value of acceleration must be speeding up.
Solution: (a) **True** (at highest point of vertical throw, $v = 0$ while $a = g$). (b) **False** (zero speed means zero magnitude of velocity). (c) **True** (in 1D, constant speed means constant velocity, so $a = 0$). (d) **False** (if velocity is negative and $a > 0$, speed decreases, e.g., upward motion when downward is +).

8. **Q 2.8:** A ball is dropped from a height of 90 m on a floor. At each collision with the floor, the ball loses one tenth of its speed. Plot the speed-time graph of its motion between $t = 0$ to 12 s.
Solution: First fall: $t_1 = \sqrt{2(90)/9.8} = 4.29$ s, impact speed $v_1 = 9.8(4.29) = 42$ m/s. Rebound speed $v_2 = 0.9 \times 42 = 37.8$ m/s, rises for $t_2 = 37.8/9.8 = 3.86$ s (to $t = 8.15$ s), falls back in 3.86 s (hits floor at $t = 12.01$ s). Plot consists of straight line segments of slope ± 9.8 m/s^2.

9. **Q 2.9:** Explain clearly, with examples, the distinction between: (a) magnitude of displacement (sometimes called distance) over an interval of time, and the total length of path covered by a particle over the same interval; (b) magnitude of average velocity over an interval of time, and the average speed over the same interval. Show

in both (a) and (b) that the second quantity is either greater than or equal to the first.
Solution: Example: Walking 40 m East then 30 m North gives path length = 70 m and |
$textdisplacement| = 50$ m. Since shortest path between two points is a straight line, Path Length $\geq$ |
$textDisplacement|$. Dividing both sides by $\Delta t > 0$ gives Average Speed $\geq$ |
$textAverageVelocity|$. Equality holds only for straight-line motion without reversal.

10. **Q 2.10:** A man walks on a straight road from his home to a market 2.5 km away with a speed of 5 km h^{-1}. Finding the market closed, he instantly turns and walks back home with a speed of 7.5 km h^{-1}. What is the (a) magnitude of average velocity, and (b) average speed of the man over the interval of time (i) 0 to 30 min, (ii) 0 to 50 min, (iii) 0 to 40 min?
Solution: Time to market = 2.5/5 = 0.5 h = 30 min. Time back = 2.5/7.5 = 1/3 h = 20 min. (i) 0–30 min: $|\bar{v}| = \mathbf{5}$ km/h, avg speed = **5** km/h. (ii) 0–50 min: $|\bar{v}| = \mathbf{0}$, avg speed = $\frac{5 \text{ km}}{50/60 \text{ h}} = \mathbf{6}$ km/h. (iii) 0–40 min: in 10 min return, covers $7.5 \times \frac{1}{6} = 1.25$ km, so net disp = 1.25 km, path = 3.75 km $\implies$ $|\bar{v}| = 1.25/(40/60) = \mathbf{1.875}$ km/h, avg speed = $3.75/(40/60) = \mathbf{5.625}$ km/h.

11. **Q 2.11:** In Exercises 2.9 and 2.10, we have carefully distinguished between average speed and magnitude of average velocity. No such distinction is necessary when we consider instantaneous speed and magnitude of velocity. Why?
Solution: Because over an infinitesimally small time interval $\Delta t \to 0$, the particle cannot reverse direction, so path length $|\Delta x|$ equals the magnitude of displacement $|\Delta \vec{r}|$. Hence instantaneous speed = $|\vec{v}|$ always.

12. **Q 2.12:** Look at the graphs (a) to (d) in NCERT Fig. 2.20 carefully and state, with reasons, which of these cannot possibly represent one-dimensional motion of a particle.
Solution: **All four are impossible:** (a) x-t loop shows two positions at the same time; (b) v-t circle shows two velocities at the same time; (c) speed-time graph goes negative (speed is always ≥ 0); (d) total path length-time graph decreases with time (path length can never decrease).

13. **Q 2.13:** Figure 2.21 shows the x-t plot of one-dimensional motion of a particle. Is it correct to say from the graph that the particle moves in a straight line for $t < 0$ and on a parabolic path for $t > 0$? If not, suggest a suitable physical context.
Solution: **No!** An x-t graph does NOT show the spatial trajectory; it plots position vs time. Here, the particle is at rest ($x = 0$) for $t < 0$ and moves with constant acceleration ($x \propto t^2$) for $t > 0$ (e.g., a stone dropped from a window at $t = 0$).

14. **Q 2.14:** A police van moving on a highway with a speed of 30 km h^{-1} fires a bullet at a thief's car speeding away in the same direction with a speed of 192 km h^{-1}. If the muzzle speed of the bullet is 150 m s^{-1}, with what speed does the bullet hit the thief's car?
Solution: $v_{van} = 30 \times \frac{5}{18} = 8.33$ m/s, $v_{thief} = 192 \times \frac{5}{18} = 53.33$ m/s. Bullet speed w.r.t. ground = 150+8.33 = 158.33 m/s. Relative speed hitting thief's car = 158.33 − 53.33 = **105** m/s.

15. **Q 2.15:** Suggest a suitable physical situation for each of the following graphs in NCERT Fig. 2.22.
Solution: (a) Ball at rest, then moves at constant velocity, rebounds off a wall and stops; (b) Ball dropped on a floor bouncing with decreasing speed; (c) Cricket ball hit by a bat (brief sharp acceleration).

16. **Q 2.16:** Figure 2.23 gives the x-t plot of a particle executing one-dimensional simple harmonic motion. Give the signs of position, velocity and acceleration variables of the particle at $t = 0.3$ s, 1.2 s, −1.2 s.
Solution: In SHM, $a = -\omega^2 x$ (always opposite to x). At $t = 0.3$ s: $x < 0, v < 0, a > 0$; at $t = 1.2$ s: $x > 0, v > 0, a < 0$; at $t = -1.2$ s: $x < 0, v > 0, a > 0$.

17. **Q 2.17:** Figure 2.24 gives the x-t plot of a particle in one-dimensional motion. Three different equal intervals of time are shown. In which interval is the average speed greatest, and in which is it the least? Give the sign of average velocity for each interval.
Solution: Greatest average speed in **interval 3** (steepest slope); least in **interval 2** (flattest). Signs of $\bar{v}$: positive in 1 & 2, negative in 3.

18. **Q 2.18:** Figure 2.25 gives a speed-time graph of a particle in motion along a constant direction. Three equal intervals of time are shown. In which interval is the average acceleration greatest in magnitude? In which interval is the average speed greatest? Give signs of v and a in all three intervals.
Solution: Magnitude of average acceleration is greatest in **interval 2** (steepest slope). Average speed is greatest in **interval 3** (highest curve). Speed $v > 0$ in all 3; $a > 0$ in 1, $a < 0$ in 2, $a \approx 0$ in 3.

5 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 2 Solutions PDF.

5.1 Level 1: Basic Level (25 Questions)

1. Define distance (path length) and displacement. Give one key difference.
2. A boy walks 40 m East and then 30 m North. Find his total distance and magnitude of displacement.
3. A runner completes 1 full round of a circular track of radius 14 m. Find distance and displacement.
4. What is the difference between average speed and average velocity?
5. Convert 36 km/h and 108 km/h into m/s.
6. What does the speedometer of a car measure?
7. What does the slope of a position-time (x-t) graph represent?
8. What does the slope of a velocity-time (v-t) graph represent?
9. What does the area under a velocity-time (v-t) graph represent?
10. A car accelerates uniformly from rest to 20 m/s in 5 s. Find its acceleration.
11. A bike moving at 10 m/s accelerates at 2 m/s^2 for 4 s. Find its final velocity.
12. Using the data from Q11 ($u = 10, a = 2, t = 4$), find the distance covered in 4 s.
13. A car starts from rest with $a = 3$ m/s^2. Find its speed after travelling 24 m.
14. A stone is dropped from rest from a height. Find its speed after 3 s ($g = 10$ m/s^2).
15. How far does a freely falling body drop in 2 s from rest ($g = 9.8$ m/s^2)?
16. A ball is thrown vertically upward at 20 m/s ($g = 10$ m/s^2). Find the time taken to reach maximum height.
17. Find the maximum height reached by the ball in Q16 ($u = 20$ m/s, $g = 10$ m/s^2).
18. At the highest point of a vertical throw, what are the velocity and acceleration?
19. Can a body have constant speed yet variable velocity? Give an example.
20. What is retardation (deceleration)? Give its sign relative to velocity.
21. A train moving at 25 m/s stops in 5 s after brakes are applied. Find retardation.
22. If a particle is at rest, what does its x-t graph look like?
23. If a particle moves with constant positive velocity, what does its v-t graph look like?
24. A body starts from rest with $a = 2$ m/s^2. Find distance covered in the 3rd second.
25. What is the numerical ratio of average velocity to average speed for straight-line motion without reversal?

5.2 Level 2: Medium Level (25 Questions)

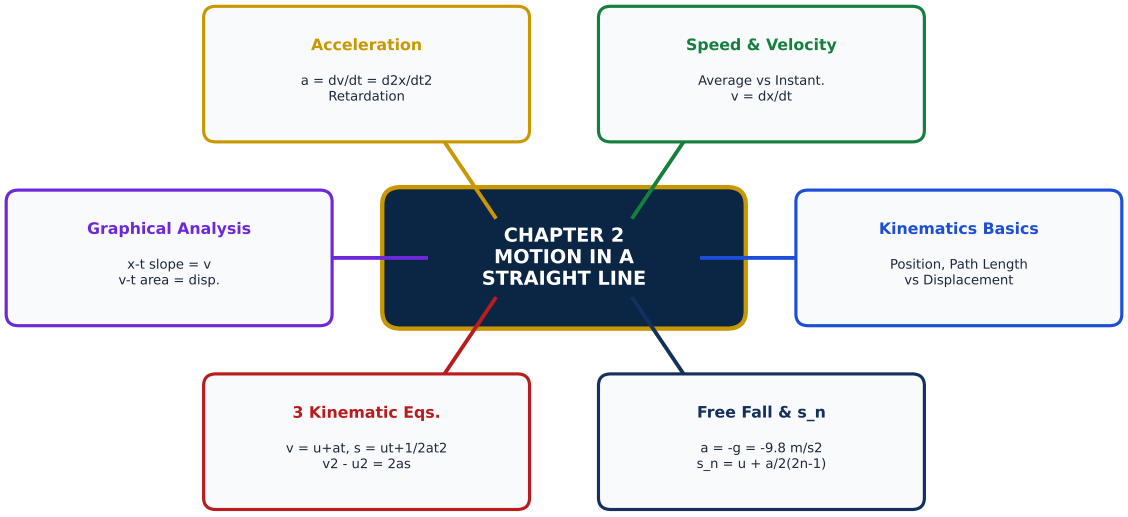
1. A car travels first half of total distance at 40 km/h and second half at 60 km/h. Find average speed.
2. A car travels for half the total time at 40 km/h and half the time at 60 km/h. Find average speed.
3. Position of a particle is $x = 3t^2 - 6t + 4$ (in m). Find its velocity and acceleration at $t = 2$ s.
4. In Q3 ($x = 3t^2 - 6t + 4$), at what time does the particle momentarily stop?
5. A car moving at 20 m/s stops in 40 m under uniform braking. If speed is doubled to 40 m/s with same braking, find new stopping distance.
6. A stone is thrown vertically upward at 20 m/s from the top of a 25 m tower ($g = 10$). Find total time to hit the ground.
7. A body starts from rest with constant acceleration. Find the ratio of distances covered in 1st, 2nd, and 3rd seconds.
8. A particle moves along x-axis from $x = 2$ m to $x = 10$ m and returns to $x = -2$ m in 4 s. Find avg speed and avg velocity.
9. A train 100 m long moves at 72 km/h. How long does it take to completely cross a 200 m bridge?
10. If displacement $x = t^3 - 6t^2 + 9t$, find the time when acceleration is zero.
11. Two balls are dropped from heights $h_1 = 16$ m and $h_2 = 25$ m. Find the ratio of their times of fall.
12. A body covers 12 m in 2nd second and 20 m in 4th second. Find initial velocity u and acceleration a.
13. A car accelerates from rest at 2 m/s^2 for 5 s, then decelerates at 2 m/s^2 to rest. Find total distance.
14. Driver reaction time is 0.2 s. If driving at 54 km/h, how far does the car move before brakes are pressed?
15. A ball dropped from a height H reaches ground in T s. How high is it above ground at $t = T/2$?
16. A particle has $v = \sqrt{16 + 4x}$. Find its acceleration.
17. A plane needs 100 m/s to take off on a 1000 m runway starting from rest. Find minimum acceleration.
18. If $x \propto t^3$, how does acceleration vary with time?
19. A stone is thrown down from a 45 m cliff at 10 m/s ($g = 10$). Find its speed on hitting the ground.
20. If a body covers equal distances in equal time intervals along a straight line without reversal, what is its acceleration?
21. Area under an acceleration-time (a-t) graph between t_1 and t_2 equals what?
22. A particle moves at 10 m/s for 3 s East, then 10 m/s for 4 s West. Find avg velocity.
23. A ball is thrown up and returns to hand in 6 s ($g = 10$). Find launch speed and max height.
24. Can an x-t graph be a vertical line? Why?
25. A car covers 1/3 distance at 20 km/h, 1/3 at 30 km/h, and 1/3 at 60 km/h. Find avg speed.

5.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. If $a = 6t$ and $v(0) = 2$ m/s, find velocity at $t = 2$ s and displacement from $t = 0$ to $t = 2$ s.
2. A particle has $x = 4t - t^2$. Find **distance** travelled (not displacement!) from $t = 0$ to $t = 3$ s.
3. A particle has $u = 10$ m/s and $a = -2$ m/s^2. Find distance covered in the **6th second**.
4. If $t = \sqrt{x} + 3$, find the time when velocity is zero and the acceleration at that instant.
5. If $v = 3x + 2$, find acceleration at $x = 1$ m.
6. If $v = \alpha\sqrt{x}$, prove that acceleration is constant and find its value.

7. A ball thrown vertically up passes a window at $t = 1$ s going up and again at $t = 3$ s coming down ($g = 10$). Find launch speed and window height.
8. A ball is dropped from a balloon rising at 10 m/s when at height 40 m ($g = 10$). Find time to reach ground.
9. Water drops fall from a tap at regular intervals. When the 1st drop hits ground (5 m below, $g = 10$), the 3rd drop just leaves. Find position of 2nd drop.
10. A bullet loses 1/5 of its velocity after penetrating 1 cm of a plank. How much more will it penetrate before stopping?
11. A juggler throws balls vertically every 0.5 s. How high does each ball rise if 1 ball is in the air at a time ($g = 10$)?
12. A particle moves with $v(t) = 4t - t^2$. Find maximum velocity and time at which it occurs.
13. A body starts from rest with $a = 2$ m/s^2 for t_1, then decelerates at 4 m/s^2 for t_2 to rest. Total time is 9 s. Find max speed.
14. In Q13 ($a_1 = 2, a_2 = 4, t = 9$ s), find total distance travelled.
15. If $x(t) = A\sin(\omega t)$, find velocity and acceleration as functions of x.
16. A particle moves along a straight line with retardation $a = -kv^2$. If initial speed is v_0, find $v(t)$.
17. Two trains A and B of length 400 m each run on parallel tracks at 72 km/h in same direction (A ahead). B accelerates at 1 m/s^2 to overtake A in 50 s. Original distance between them?
18. A stone falls from a cliff and travels 25% of total height in the last second ($g = 10$). Find total height H.
19. If $v^2 = 100 - 20x$, find stopping distance from $x = 0$.
20. A lift ascends with $a = 2$ m/s^2. A bolt drops from its ceiling (2.4 m high, $g = 10$). Time for bolt to hit lift floor?
21. A particle starts at $x = 0$ with $v = 4$ m/s and $a = -2t$. When does it return to $x = 0$?
22. Can a particle have zero instantaneous velocity and zero acceleration, yet start moving?
23. Two cars start from same point: A at constant 10 m/s, B from rest with $a = 2$ m/s^2. When does B catch A?
24. In Q23, what is the maximum lead of car A over car B before being caught?
25. Draw/describe the v-t graph of a ball dropped on a hard floor and bouncing back elastically.

6 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Connects all 6 pillars of 1D Kinematics: path length vs displacement, velocity/speed, acceleration, graphical slopes/areas, 3 kinematic equations, and free fall.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 2 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MOTION IN A STRAIGHT LINE

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

7 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. Distance is the actual total path length travelled by a body (always ≥ 0, scalar). Displacement is the shortest straight-line vector from initial to final position ($\Delta x = x_f - x_i$, can be $+$, $-$, or 0, vector).
2. Distance $= 40 + 30 = \mathbf{70}$ m. Displacement $= \sqrt{40^2 + 30^2} = \mathbf{50}$ m. (3-4-5 right triangle!)
3. Distance $= 2\pi R = 2 \times \frac{22}{7} \times 14 = \mathbf{88}$ m. Since start and end points coincide, Displacement $= \mathbf{0}$ m.
4. Average speed $= \frac{\text{Total Path Length}}{\text{Total Time}}$ (scalar, always ≥ 0). Average velocity $= \frac{\text{Displacement}}{\text{Total Time}}$ (vector, can be $+, -$, or 0).
5. $36 \times \frac{5}{18} = \mathbf{10}$ m/s; $108 \times \frac{5}{18} = \mathbf{30}$ m/s.
6. It measures the **instantaneous speed** (the magnitude of instantaneous velocity) at that exact moment.
7. The slope $\frac{\Delta x}{\Delta t}$ (or $\frac{dx}{dt}$) of an x-t graph represents **velocity**.
8. The slope $\frac{\Delta v}{\Delta t}$ (or $\frac{dv}{dt}$) of a v-t graph represents **acceleration**.
9. The area between the v-t curve and the time axis represents **displacement** (and sum of absolute areas represents distance).
10. Using $v = u + at$: $20 = 0 + a(5) \implies a = \mathbf{4}$ m/s^2.
11. $v = u + at = 10 + 2(4) = \mathbf{18}$ m/s.
12. $s = ut + \frac{1}{2}at^2 = 10(4) + \frac{1}{2}(2)(16) = 40 + 16 = \mathbf{56}$ m.
13. Using $v^2 = u^2 + 2as$: $v^2 = 0 + 2(3)(24) = 144 \implies v = \mathbf{12}$ m/s.
14. $v = 0 + gt = 10 \times 3 = \mathbf{30}$ m/s.
15. $s = \frac{1}{2}gt^2 = \frac{1}{2}(9.8)(4) = \mathbf{19.6}$ m.
16. At top, $v = 0 = u - gt \implies t = u/g = 20/10 = \mathbf{2}$ s.
17. $H = \frac{u^2}{2g} = \frac{400}{20} = \mathbf{20}$ m.
18. Velocity is momentarily **zero** ($v = 0$), while acceleration is **$g = 9.8$ m/s^2 vertically downward**.
19. Yes! In **uniform circular motion**, speed is constant, but direction changes continuously, so velocity changes.
20. Retardation is acceleration acting opposite to the direction of velocity, causing speed to decrease. If $v > 0$, retardation has $a < 0$.
21. $0 = 25 + a(5) \implies a = -5$ m/s^2. So retardation is $\mathbf{5}$ m/s^2.
22. A **horizontal straight line** parallel to the time axis ($x =$ constant).
23. A **horizontal straight line** above the time axis ($v =$ constant).
24. $s_3 = u + \frac{a}{2}(2n - 1) = 0 + \frac{2}{2}(6 - 1) = \mathbf{5}$ m.
25. Since distance $=$ |displacement|, the ratio is exactly $\mathbf{1}$.

8 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. Using Harmonic Mean shortcut: $v_{avg} = \frac{2v_1v_2}{v_1+v_2} = \frac{2(40)(60)}{40+60} = \frac{4800}{100} = \mathbf{48}$ km/h.
2. For equal times, use Arithmetic Mean: $v_{avg} = \frac{40+60}{2} = \mathbf{50}$ km/h.
3. $v = \frac{dx}{dt} = 6t - 6$. At $t = 2$: $v = 12 - 6 = \mathbf{6}$ m/s. $a = \frac{dv}{dt} = \mathbf{6}$ m/s$^\mathbf{2}$ (constant).
4. $v = 6t - 6 = 0 \implies t = \mathbf{1}$ s.
5. Stopping distance $d_s = \frac{u^2}{2a} \propto u^2$. Doubling speed quadruples distance: $4 \times 40 = \mathbf{160}$ m.
6. Taking upward as +: $y = -25, u = +20, a = -10$. $-25 = 20t - 5t^2 \implies t^2 - 4t - 5 = 0 \implies (t-5)(t+1) = 0 \implies t = \mathbf{5}$ s.
7. By Galileo's Law of Odd Numbers: $s_n = \frac{a}{2}(2n-1) \implies s_1 : s_2 : s_3 = \mathbf{1} : \mathbf{3} : \mathbf{5}$.
8. Distance $= |10 - 2| + |-2 - 10| = 8 + 12 = 20$ m $\implies$ avg speed $= 20/4 = \mathbf{5}$ m/s. Displacement $= -2 - 2 = -4$ m $\implies \bar{v} = -4/4 = \mathbf{-1}$ m/s.
9. Total distance $= 100 + 200 = 300$ m. Speed $= 72 \times \frac{5}{18} = 20$ m/s. Time $= 300/20 = \mathbf{15}$ s.
10. $v = 3t^2 - 12t + 9$; $a = 6t - 12 = 0 \implies t = \mathbf{2}$ s.
11. $t = \sqrt{2h/g} \propto \sqrt{h} \implies t_1/t_2 = \sqrt{16/25} = \mathbf{4} : \mathbf{5}$.
12. $s_4 - s_2 = 2a = 20 - 12 = 8 \implies a = \mathbf{4}$ m/s$^\mathbf{2}$. $12 = u + \frac{4}{2}(3) \implies u = \mathbf{6}$ m/s.
13. Max speed $v = 2 \times 5 = 10$ m/s; total time $= 10$ s. Area of v-t triangle $= \frac{1}{2}(10)(10) = \mathbf{50}$ m.
14. $v = 54 \times \frac{5}{18} = 15$ m/s. Reaction distance $= 15 \times 0.2 = \mathbf{3}$ m.
15. Distance fallen in $T/2$ is $s = \frac{1}{2}g(T/2)^2 = H/4$. Height above ground $= H - H/4 = \mathbf{3H/4}$.
16. Square both sides: $v^2 = 16 + 4x$. Comparing with $v^2 = u^2 + 2ax$: $2a = 4 \implies a = \mathbf{2}$ m/s$^\mathbf{2}$.
17. $a = \frac{v^2}{2s} = \frac{10000}{2000} = \mathbf{5}$ m/s$^\mathbf{2}$.
18. $x = kt^3 \implies v = 3kt^2 \implies a = 6kt$. So acceleration is **directly proportional to time ($a \propto t$)**.
19. $v^2 = u^2 + 2gh = 100 + 2(10)(45) = 1000 \implies v = \mathbf{10\sqrt{10}}$ m/s ≈ 31.6 m/s.
20. Velocity is constant in both magnitude and direction, so acceleration is **zero**.
21. $\int_{t_1}^{t_2} a\,dt = v_2 - v_1$ (**change in velocity**).
22. Displacement $= 30 - 40 = -10$ m (West). Total time $= 7$ s. $\bar{v} = -10/7 = \mathbf{-1.43}$ m/s (West).
23. $T = 2u/g = 6 \implies u = \mathbf{30}$ m/s. $H = u^2/(2g) = 900/20 = \mathbf{45}$ m.
24. No! A vertical line would mean infinite velocity (being at multiple positions at the exact same instant), which is physically impossible.
25. $v_{avg} = \frac{3}{\frac{1}{20}+\frac{1}{30}+\frac{1}{60}} = \frac{3}{6/60} = \mathbf{30}$ km/h.

9 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $v(t) = 2 + \int_0^t 6t\,dt = 2 + 3t^2 \implies v(2) = \mathbf{14}$ m/s. $x = \int_0^2 (2 + 3t^2)\,dt = [2t + t^3]_0^2 = 4 + 8 = \mathbf{12}$ m.
2. $v = 4 - 2t = 0$ at $t = 2$ s (reversal!). $x(0) = 0, x(2) = 4, x(3) = 3$. Distance $= |4 - 0| + |3 - 4| = 4 + 1 = \mathbf{5}$ m.
3. Wait: $v = 10 - 2t = 0$ at $t = 5$ s! During 6th second ($t = 5$ to 6), particle starts from rest and moves backward: $d = \frac{1}{2}(2)(1)^2 = \mathbf{1}$ m (using s_n directly gives -1 m, which is displacement, not distance!).
4. $\sqrt{x} = t - 3 \implies x = (t-3)^2$. $v = 2(t-3) = 0$ at $t = \mathbf{3}$ s. $a = dv/dt = \mathbf{2}$ m/s$^\mathbf{2}$.
5. Use chain rule $a = v\frac{dv}{dx}$: $\frac{dv}{dx} = 3$. At $x = 1$, $v = 5 \implies a = 5 \times 3 = \mathbf{15}$ m/s$^\mathbf{2}$.
6. $v^2 = \alpha^2 x$. Differentiate w.r.t. x: $2v\frac{dv}{dx} = \alpha^2 \implies 2a = \alpha^2 \implies a = \boldsymbol{\alpha^2/2}$ (constant!).

7. Total flight time $T = t_1 + t_2 = 4$ s $\implies u = gT/2 = \mathbf{20}$ m/s. Shortcut for height: $h = \frac{1}{2}gt_1t_2 = \frac{1}{2}(10)(1)(3) = \mathbf{15}$ m.

8. Ball inherits balloon's upward velocity: $u = +10$ m/s, $y = -40$ m. $-40 = 10t - 5t^2 \implies t^2 - 2t - 8 = 0 \implies t = \mathbf{4}$ s.

9. Time for 1st drop: $t = \sqrt{2(5)/10} = 1$ s. Interval $= 1/2 = 0.5$ s. 2nd drop fell for 0.5 s: $s = \frac{1}{2}(10)(0.5)^2 = \mathbf{1.25}$ m below tap (i.e., 3.75 m above ground).

10. $v^2 = u^2 - 2as$: $(0.8u)^2 = u^2 - 2a(1) \implies 2a = 0.36u^2$. Total penetration $S = \frac{u^2}{2a} = \frac{1}{0.36} = 2.78$ cm. Extra $= 2.78 - 1 = \mathbf{1.78}$ cm.

11. Time of flight $T = 0.5$ s $\implies t_{up} = 0.25$ s $\implies H = \frac{1}{2}gt_{up}^2 = \frac{1}{2}(10)(0.0625) = \mathbf{0.3125}$ m.

12. $dv/dt = 4 - 2t = 0 \implies t = \mathbf{2}$ s. $v_{max} = 4(2) - 4 = \mathbf{4}$ m/s.

13. Max $v = a_1t_1 = a_2t_2 \implies 2t_1 = 4t_2 \implies t_1 = 2t_2$. Since $t_1 + t_2 = 9 \implies t_2 = 3$ s, $t_1 = 6$ s. $v_{max} = 2(6) = \mathbf{12}$ m/s.

14. Shortcut: $S = \frac{1}{2}v_{max}T = \frac{1}{2}(12)(9) = \mathbf{54}$ m (or $\frac{a_1a_2T^2}{2(a_1+a_2)}$).

15. $v = A\omega\cos(\omega t) = \omega\sqrt{A^2 - x^2}$; $a = -A\omega^2\sin(\omega t) = -\omega^{\mathbf{2}}\mathbf{x}$.

16. $\frac{dv}{dt} = -kv^2 \implies \int_{v_0}^{v} v^{-2}\,dv = -kt \implies \frac{1}{v} - \frac{1}{v_0} = kt \implies v = \frac{\mathbf{v_0}}{\mathbf{1+kv_0t}}$.

17. Relative $u_{rel} = 0$, $a_{rel} = 1$ m/s^2. Total relative distance covered in 50 s $= \frac{1}{2}(1)(50^2) = 1250$ m (NCERT Ex 2.7/old 3.5). Wait: original gap $= 1250 - 800 = \mathbf{450}$ m.

18. Let total time $= T$. Last second covers $H/4 \implies$ first $(T-1)$ sec covers $3H/4$. $\frac{(T-1)^2}{T^2} = \frac{3}{4} \implies \frac{T-1}{T} = \frac{\sqrt{3}}{2} \implies T = \frac{2}{2-\sqrt{3}} = 7.46$ s $\implies H = 5(7.46)^2 \approx \mathbf{278.5}$ m.

19. At stop, $v = 0 \implies 100 - 20x = 0 \implies x = \mathbf{5}$ m.

20. Relative acceleration $a_{rel} = g + a = 12$ m/s^2. $t = \sqrt{\frac{2(2.4)}{12}} = \sqrt{0.4} \approx \mathbf{0.63}$ s.

21. $v = 4 - t^2$, $x = 4t - t^3/3 = 0 \implies t^2 = 12 \implies t = \mathbf{2\sqrt{3}}$ s.

22. No! If $v = 0$ and $a = 0$ at all times, it stays at rest. (Only if a is momentarily zero while $da/dt \neq 0$, e.g. $x = t^3$, can it move from $t = 0$.)

23. $10t = \frac{1}{2}(2)t^2 \implies t = \mathbf{10}$ s (at $x = 100$ m).

24. Max lead occurs when $v_A = v_B \implies 10 = 2t \implies t = 5$ s. Lead $= 10(5) - \frac{1}{2}(2)(25) = 50 - 25 = \mathbf{25}$ m.

25. Linearly decreasing (slope $-g$) from 0 to $-v$, then instantaneous vertical jump to $+v$ at impact, then linearly decreasing (slope $-g$) back to 0.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 3 (SELF-STUDY MASTER EDITION)

MOTION IN A PLANE

Complete Zero-Omission Coverage of NCERT `keph103.pdf` (Sections 3.1–3.10, Fig 3.1–3.20, Ex 3.1–3.9, Exercises 3.1–3.22)

CBSE 2026–27 Weightage & Scope: Unit II: Kinematics (Part of 23 Marks for Units I–III)

[CONCEPT CORE] Self-Study Promise: Zero Teacher Needed

In Chapter 2, motion was on a single straight line. Now we step into 2D space (motion on a flat plane like a football field or a projectile in the sky). You will master Vectors from zero, see how 2D motion splits into two easy 1D motions, and solve Projectile & Circular Motion effortlessly.

1 Topic 1: Scalars, Vectors, Addition & Resolution (NCERT Sections 3.1–3.6)

1.1 Step 1: Definitions & Plain-English Meaning

- **Scalar Quantity:** A physical quantity completely described by its magnitude (a number + unit) alone, obeying ordinary arithmetic (e.g., mass 5 kg, temperature 300 K, work 20 J).
- **Vector Quantity:** A physical quantity that has **both magnitude and direction** AND obeys the **Triangle/Parallelogram Law of Vector Addition** (e.g., displacement, velocity, force, acceleration). Note: Electric current has direction along a wire, yet it is a **scalar** because it adds algebraically (3 A + 4 A = 7 A), not as vectors!
- **Unit Vector ($\hat{A}$):** A dimensionless vector of magnitude 1 pointing in the direction of $\vec{A}$: $\hat{A} = \frac{\vec{A}}{|\vec{A}|}$. Along the x, y, z axes, unit vectors are written as $\hat{i}, \hat{j}, \hat{k}$.
- **Null (Zero) Vector ($\vec{0}$):** A vector of zero magnitude and arbitrary direction (e.g., displacement when returning to start).
- **Resolution of a Vector (3.5):** Splitting one tilted vector $\vec{A}$ (making angle θ with the $+x$ axis) into two perpendicular components:

$$A_x = A\cos\theta, \qquad A_y = A\sin\theta \implies \vec{A} = A_x\hat{i} + A_y\hat{j}, \qquad A = \sqrt{A_x^2 + A_y^2}, \quad \tan\theta = \frac{A_y}{A_x}$$

1.2 Step 2: Derivation of Analytical Vector Addition (Law of Cosines, Section 3.6)

Suppose two vectors $\vec{A}$ and $\vec{B}$ act at a point with angle θ between them. Place $\vec{B}$ tail-to-head with $\vec{A}$ (or complete a parallelogram). Drop a perpendicular from the tip of $\vec{B}$ onto the extended line of $\vec{A}$:

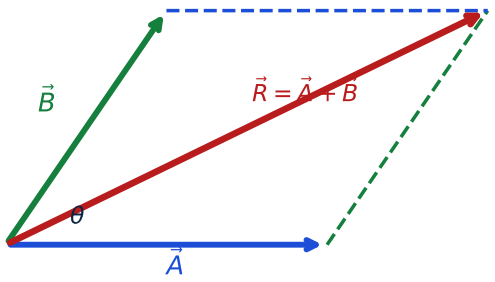
- Horizontal base $= A + B\cos\theta$; Vertical height $= B\sin\theta$.
- By Pythagoras' theorem on the large right triangle:

$$R^2 = (A + B\cos\theta)^2 + (B\sin\theta)^2 = A^2 + 2AB\cos\theta + B^2(\cos^2\theta + \sin^2\theta)$$

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}, \qquad \tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$$

  where α is the angle of resultant $\vec{R}$ with $\vec{A}$.
- **Special Cases:** At $\theta = 0°$, $R_{max} = A + B$; at $\theta = 180°$, $R_{min} = |A - B|$; at $\theta = 90°$, $R = \sqrt{A^2 + B^2}$.

Parallelogram Law of Vector Addition



Uniform Circular Motion

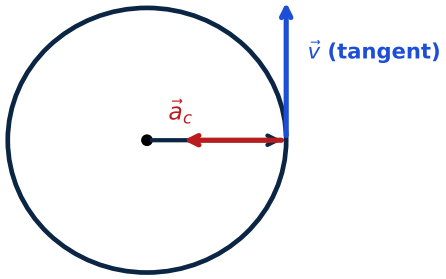


Diagram Explanation (Covers NCERT Figs. 3.3–3.10 & 3.19): Left illustrates the Parallelogram Law ($\vec{R} = \vec{A} + \vec{B}$ as the diagonal). Right illustrates Uniform Circular Motion where velocity $\vec{v}$ is tangential and centripetal acceleration $\vec{a}_c$ points radially inward.

Example 3.1A (Vector Addition Long vs Shortcut) [Intermediate]

Problem: Two equal forces of magnitude F each act at 120° to each other. Find the magnitude of their resultant.
Solution: Long Method: $R = \sqrt{F^2 + F^2 + 2F^2\cos 120^\circ} = \sqrt{2F^2 + 2F^2(-1/2)} = \sqrt{F^2} = \mathbf{F}$.
Short Trick (Equal Vectors): For two equal vectors $A = B = F$ at angle θ, $R = 2F\cos(\theta/2)$. Here $R = 2F\cos 60^\circ = 2F(0.5) = \mathbf{F}$! (At $60^\circ \to \sqrt{3}F$; at $90^\circ \to \sqrt{2}F$; at $120^\circ \to F$.)

2 Topic 2: Motion in a Plane, Projectile Motion & UCM (NCERT Sections 3.7–3.10)

2.1 Step 1: Independence of x and y Motions & Projectile Derivations

In 2D motion, position $\vec{r} = x\hat{i} + y\hat{j}$, velocity $\vec{v} = v_x\hat{i} + v_y\hat{j}$, and acceleration $\vec{a} = a_x\hat{i} + a_y\hat{j}$. **Golden Rule:** Horizontal (x) and vertical (y) motions are completely independent and share only time t!

For an oblique projectile launched from ground at speed v_0 and angle θ_0 ($a_x = 0, a_y = -g$):

1. **Velocity Components:** $u_x = v_0\cos\theta_0$ (remains constant throughout!), $u_y = v_0\sin\theta_0$.
2. **Equation of Trajectory (Path):** $x = (v_0\cos\theta_0)t \implies t = \frac{x}{v_0\cos\theta_0}$. Substitute into $y = (v_0\sin\theta_0)t - \frac{1}{2}gt^2$:

$$y = (\tan\theta_0)x - \frac{g}{2(v_0\cos\theta_0)^2}x^2 \quad \text{(Equation of a Parabola!)}$$

3. **Time of Flight (T_f):** When projectile returns to ground, $y = 0$: $0 = (v_0\sin\theta_0)T_f - \frac{1}{2}gT_f^2 \implies \mathbf{T_f = \frac{2v_0\sin\theta_0}{g}}$. (Time to max height $t_m = T_f/2 = \frac{v_0\sin\theta_0}{g}$.)
4. **Maximum Height (H_m):** At top, $v_y = 0$: $0 = (v_0\sin\theta_0)^2 - 2gH_m \implies \mathbf{H_m = \frac{v_0^2\sin^2\theta_0}{2g}}$.
5. **Horizontal Range (R):** Horizontal distance covered in time T_f:

$$R = (v_0\cos\theta_0)\cdot\frac{2v_0\sin\theta_0}{g} = \frac{\mathbf{v_0^2\sin 2\theta_0}}{\mathbf{g}}$$

Since $\sin 2\theta_0 \le 1$, range is maximum ($R_{max} = \frac{v_0^2}{g}$) when $2\theta_0 = 90^\circ \implies \theta_0 = 45^\circ$. Complementary angles ($\theta_0$ and $90^\circ - \theta_0$) give equal ranges!

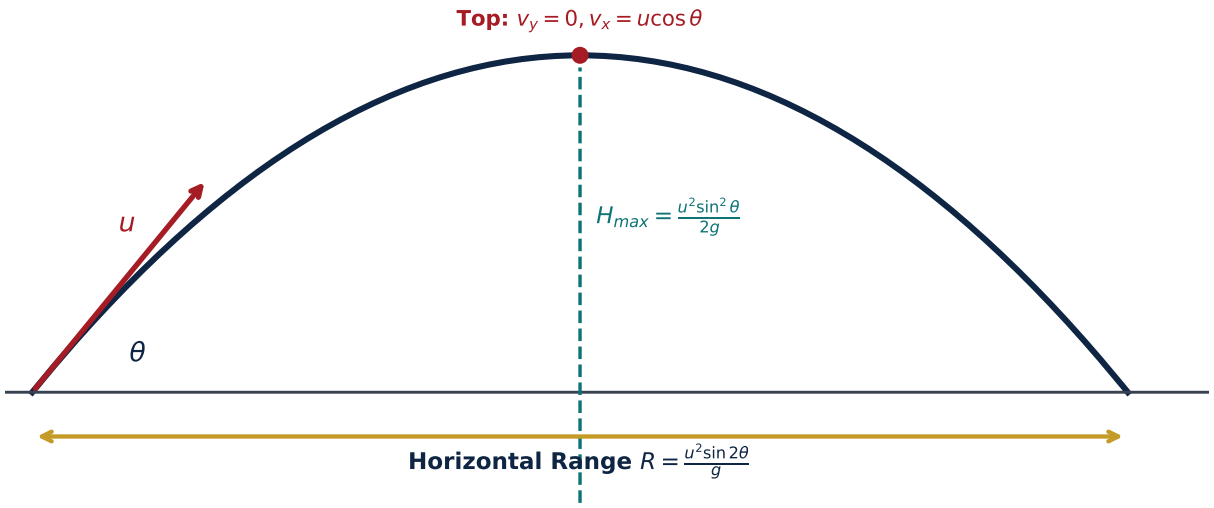


Diagram Explanation (Covers NCERT Figs. 3.16–3.18): Shows the parabolic trajectory, constant horizontal speed v_x, $v_y = 0$ at H_m, and equal horizontal range R for complementary launch angles.

2.2 Step 2: Uniform Circular Motion (UCM, Section 3.10)

When an object moves in a circle of radius R at constant speed v:

- **Angular Speed (ω):** $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T} = 2\pi f$ (SI: rad s^{-1}). Linear speed $v = R\omega$.
- **Centripetal Acceleration (a_c):** Even though speed v is constant, velocity direction turns continuously. Using similar triangles for $\Delta\vec{v}$ and $\Delta\vec{r}$: $\frac{|\Delta v|}{v} = \frac{|\Delta r|}{R} \implies a_c = \lim_{\Delta t\to 0}\frac{|\Delta v|}{\Delta t} = \frac{v^2}{R} = \omega^2 R$, always directed **towards the centre**.

[FORMULA & SHORTCUT] 2D Kinematics, Projectile & UCM Symbols, SI Units & Dimensions

Formula	Meaning	SI Unit	Dimensions	When to Use
$T_f = \frac{2v_0\sin\theta_0}{g}$	Time of Flight	s	[T]	Ground-to-ground oblique projectile
$H_m = \frac{v_0^2\sin^2\theta_0}{2g}$	Max Height	m	[L]	Vertical peak ($v_y = 0$)
$R = \frac{v_0^2\sin 2\theta_0}{g}$	Horizontal Range	m	[L]	Max at 45° ($R_{max} = v_0^2/g$)
$a_c = \frac{v^2}{R} = \omega^2 R$	Centripetal Acc.	m s^{-2}	[LT^{-2}]	Always points to circle centre

Example 3.2A (Projectile Height-Range Relation) [NEET / JEE]

Problem: A ball thrown at 45° just clears a 4 m tall wall 8 m away. Find the horizontal range R.

Solution: Long Method: Set $R = v_0^2/g$. From $y = x\tan 45° - \frac{gx^2}{2v_0^2\cos^2 45°}$: $4 = 8 - \frac{64}{R} \implies \frac{64}{R} = 4 \implies R = \mathbf{16}$ m.

Smart Short Trick: Memorize the universal trajectory-range equation: $y = x\tan\theta\left(1 - \frac{x}{R}\right)$. Here $4 = 8(1)(1 - 8/R) \implies 0.5 = 1 - 8/R \implies R = \mathbf{16}$ m!

3 Complete NCERT Examples (3.1–3.9) & Back Exercises (3.1–3.22) with Full Questions

3.1 NCERT Solved Examples (3.1–3.9)

1. **Example 3.1:** Rain is falling vertically with a speed of 35 m s^{-1}. Winds starts blowing after sometime with a speed of 12 m s^{-1} in east to west direction. In which direction should a boy waiting at a bus stop hold his umbrella?
   Solution: Resultant velocity $\vec{R} = \vec{v}_r + \vec{v}_w$. Magnitude $R = \sqrt{35^2 + 12^2} = \mathbf{37}$ m/s. Angle with vertical $\tan\theta = 12/35 = 0.343 \implies \theta \approx \mathbf{19}°$ towards East (against wind).

2. **Example 3.2:** Find the magnitude and direction of the resultant of two vectors $\vec{A}$ and $\vec{B}$ in terms of their magnitudes and angle θ between them.
Solution: By Law of Cosines: $R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$ and $\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$.

3. **Example 3.3:** A motorboat is racing towards north at 25 km/h and the water current in that region is 10 km/h in the direction of 60° east of south. Find the resultant velocity of the boat.
Solution: Angle between $\vec{v}_b$ (North) and $\vec{v}_c$ (60° E of S) is $180° - 60° = 120°$. $R = \sqrt{25^2 + 10^2 + 2(25)(10)\cos 120°} = \sqrt{475} \approx \mathbf{21.8}$ km/h at 23.4° East of North.

4. **Example 3.4:** The position of a particle is given by $\vec{r} = 3.0t\hat{i} + 2.0t^2\hat{j} + 5.0\hat{k}$ where t is in seconds and coefficients have proper units. (a) Find $\vec{v}(t)$ and $\vec{a}(t)$. (b) Find the magnitude and direction of $\vec{v}(t)$ at $t = 1.0$ s.
Solution: $\vec{v}(t) = \frac{d\vec{r}}{dt} = 3.0\hat{i} + 4.0t\hat{j}$; $\vec{a}(t) = \mathbf{4.0\hat{j}}$ m/s^2. At $t = 1.0$ s: $\vec{v} = 3\hat{i} + 4\hat{j}$, $|\vec{v}| = \mathbf{5.0}$ m/s at $\theta = \tan^{-1}(4/3) \approx \mathbf{53}°$ with x-axis.

5. **Example 3.5:** A particle starts from origin at $t = 0$ with velocity $5.0\hat{i}$ m/s and moves in x-y plane under constant acceleration $(3.0\hat{i} + 2.0\hat{j})$ m/s^2. (a) What is the y-coordinate when x-coordinate is 84 m? (b) What is the speed at this time?
Solution: $x(t) = 5t + \frac{1}{2}(3)t^2 = 84 \implies 1.5t^2 + 5t - 84 = 0 \implies t = 6$ s. Then $y = 0 + \frac{1}{2}(2)(6^2) = \mathbf{36}$ m. Velocity $\vec{v}(6) = (5 + 18)\hat{i} + 12\hat{j} = 23\hat{i} + 12\hat{j} \implies |\vec{v}| = \mathbf{25.9}$ m/s.

6. **Example 3.6:** Rain is falling vertically with a speed of 30 m/s. A woman rides a bicycle with a speed of 10 m/s in the north to south direction. What is the direction in which she should hold her umbrella?
Solution: Relative velocity $\vec{v}_{rb} = \vec{v}_r - \vec{v}_b$. $\tan\theta = 10/30 = 1/3 \implies \theta \approx \mathbf{18.4}°$ with vertical towards South.

7. **Example 3.7:** Galileo, in his book Two New Sciences, stated that "for elevations which exceed or fall short of 45° by equal amounts, the ranges are equal". Prove this statement.
Solution: For $\theta_1 = 45° + \alpha$ and $\theta_2 = 45° - \alpha$: $\sin 2\theta_1 = \sin(90° + 2\alpha) = \cos 2\alpha$, and $\sin 2\theta_2 = \sin(90° - 2\alpha) = \cos 2\alpha$. Since $R = \frac{u^2 \sin 2\theta}{g}$, both angles give the exact same range!

8. **Example 3.8:** A hiker stands on the edge of a cliff 490 m above the ground and throws a stone horizontally with an initial speed of 15 m/s ($g = 9.8$ m/s^2). Find the time taken by the stone to reach the ground and the speed with which it hits the ground.
Solution: Vertical fall: $490 = \frac{1}{2}(9.8)t^2 \implies t = \mathbf{10}$ s. Horizontal $v_x = 15$ m/s, vertical $v_y = gt = 98$ m/s $\implies v = \sqrt{15^2 + 98^2} \approx \mathbf{99.1}$ m/s.

9. **Example 3.9:** A cricket ball is thrown at a speed of 28 m/s in a direction 30° above the horizontal. Calculate (a) the maximum height, (b) the time taken by the ball to return to the same level, and (c) the horizontal distance from the thrower to the point where the ball returns.
Solution: (a) $H_m = \frac{28^2 \sin^2 30°}{2(9.8)} = \mathbf{10.0}$ m. (b) $T_f = \frac{2(28)\sin 30°}{9.8} = \mathbf{2.86}$ s. (c) $R = \frac{28^2 \sin 60°}{9.8} = \mathbf{69.3}$ m.

3.2 NCERT Back Exercises (3.1–3.22) — Full Questions & Solutions

1. **Q 3.1:** State, for each of the following physical quantities, if it is a scalar or a vector: volume, mass, speed, acceleration, density, number of moles, velocity, angular frequency, displacement, angular velocity.
Solution: **Scalars:** volume, mass, speed, density, number of moles, angular frequency. **Vectors:** acceleration, velocity, displacement, angular velocity.

2. **Q 3.2:** Pick out the two scalar quantities in the following list: force, angular momentum, work, current, linear momentum, electric field, average velocity, magnetic moment, relative velocity.
Solution: **Work** and **Electric current** (electric current has direction along a wire but does not obey vector addition).

3. **Q 3.3:** Pick out the only vector quantity in the following list: Temperature, pressure, impulse, time, power, total path length, energy, gravitational potential, coefficient of friction, charge.
Solution: **Impulse** ($\vec{J} = \vec{F}\Delta t = \Delta\vec{p}$).

4. **Q 3.4:** State with reasons, whether the following algebraic operations with scalar and vector physical quantities are meaningful: (a) adding any two scalars, (b) adding a scalar to a vector of the same dimensions, (c) multiplying any vector by any scalar, (d) multiplying any two scalars, (e) adding any two vectors, (f) adding a component of a vector to the same vector.
Solution: (a) **Meaningless** unless they represent the same physical quantity (same dimensions). (b) **Meaningless** (cannot add scalar to vector). (c) **Meaningful** (scales magnitude). (d) **Meaningful**. (e) **Meaningless** unless they represent the same physical quantity. (f) **Meaningful** (a component is a vector along that axis).

5. **Q 3.5:** Read each statement below carefully and state with reasons, if it is true or false: (a) The magnitude of a vector is always a scalar; (b) each component of a vector is always a scalar; (c) the total path length is always equal to the magnitude of the displacement vector of a particle; (d) the average speed of a particle is either greater or equal to the magnitude of average velocity; (e) Three vectors not lying in a plane can never add up to give a null vector.
Solution: (a) **True**. (b) **False** (components are vectors along axes, though their magnitudes are scalars). (c) **False** (only for straight line without reversal). (d) **True**. (e) **True** (two vectors define a plane; the third must lie in that plane to cancel their resultant).

6. **Q 3.6:** Establish the following vector inequalities geometrically or otherwise: (a) $|\vec{a}+\vec{b}| \leq |\vec{a}|+|\vec{b}|$; (b) $|\vec{a}+\vec{b}| \geq ||\vec{a}|-|\vec{b}||$; (c) $|\vec{a}-\vec{b}| \leq |\vec{a}|+|\vec{b}|$; (d) $|\vec{a}-\vec{b}| \geq ||\vec{a}|-|\vec{b}||$.
Solution: From $|\vec{a} \pm \vec{b}| = \sqrt{a^2+b^2 \pm 2ab\cos\theta}$: since $-1 \leq \cos\theta \leq +1$, maximum value is $a+b$ and minimum value is $|a-b|$, proving all four inequalities!

7. **Q 3.7:** Given $\vec{a}+\vec{b}+\vec{c}+\vec{d}=\vec{0}$, which of the following statements are correct: (a) $\vec{a},\vec{b},\vec{c},\vec{d}$ must each be a null vector; (b) Magnitude of $(\vec{a}+\vec{c})$ equals magnitude of $(\vec{b}+\vec{d})$; (c) Magnitude of $\vec{a}$ can never be greater than sum of magnitudes of $\vec{b},\vec{c},\vec{d}$; (d) $\vec{b}+\vec{c}$ must lie in the plane of $\vec{a}$ and $\vec{d}$ if $\vec{a}$ and $\vec{d}$ are not collinear.
Solution: (a) **Incorrect**; (b) **Correct** ($\vec{a}+\vec{c} = -(\vec{b}+\vec{d})$); (c) **Correct** (triangle inequality); (d) **Correct** (three coplanar vectors sum to zero).

8. **Q 3.8:** Three girls skating on a circular ice ground of radius 200 m start from a point P on the edge and reach a point Q diametrically opposite to P following different paths. What is the magnitude of the displacement vector for each? For which girl is this equal to the actual length of path skated?
Solution: Displacement for all three is diameter $PQ = 2(200) = \mathbf{400}$ m. For girl **B** (straight-line path along diameter), path length equals displacement.

9. **Q 3.9:** A cyclist starts from the centre O of a circular park of radius 1 km, reaches the edge P of the park, then cycles along the circumference, and returns to the centre along QO in 10 min. Find (a) net displacement, (b) average velocity, (c) average speed.
Solution: (a) Returns to $O \implies$ Net displacement $= \mathbf{0}$. (b) Average velocity $= \mathbf{0}$. (c) Path $= 1 + \frac{2\pi(1)}{4} + 1 = 3.57$ km; time $= 10/60 = 1/6$ h $\implies$ Avg speed $= 3.57 \times 6 = \mathbf{21.4}$ km/h.

10. **Q 3.10:** On an open ground, a motorist follows a track that turns to his left by an angle of 60° after every 500 m. Starting from a given turn, specify the displacement of the motorist at the third, sixth and eighth turn. Compare the magnitude of the displacement with the total path length in each case.
Solution: Path forms a regular hexagon of side 500 m. **3rd turn:** Disp $= 2(500)\cos 30° = \mathbf{866}$ m, path $= 1500$ m. **6th turn:** Returns to start, Disp $= \mathbf{0}$, path $= 3000$ m. **8th turn:** Same as 2nd turn, Disp $= 2(500)\cos 30° = \mathbf{866}$ m, path $= 4000$ m.

11. **Q 3.11:** A passenger arriving in a new town wishes to go from the station to a hotel located 10 km away on a straight road from the station. A dishonest cabman takes him along a circuitous path 23 km long and reaches the hotel in 28 min. What is (a) the average speed, (b) the magnitude of average velocity?
Solution: Time $= 28/60$ h. (a) Avg speed $= 23/(28/60) = \mathbf{49.3}$ km/h. (b) $|\bar{v}| = 10/(28/60) = \mathbf{21.4}$ km/h.

12. **Q 3.12:** A man can swim with a speed of 4.0 km/h in still water. How long does he take to cross a river 1.0 km wide if the river flows steadily at 3.0 km/h and he makes his strokes normal to the river current? How far down the river does he go when he reaches the other bank?
Solution: Time to cross $= 1.0/4.0 = 0.25$ h $= \mathbf{15}$ min. Downstream drift $= v_r \times t = 3.0 \times 0.25 = \mathbf{0.75}$ km $= \mathbf{750}$ m.

13. **Q 3.13:** In a harbour, wind is blowing at the speed of 72 km/h and the flag on the mast of a boat anchored in the harbour flutters along the N-E direction. If the boat starts moving at a speed of 51 km/h to the north, what is the direction of the flag on the mast of the boat?
Solution: Flag aligns with $\vec{v}_{wind} - \vec{v}_{boat}$. Solving vector components gives angle $\approx \mathbf{0.1}°$ East (almost due East).

14. **Q 3.14:** The ceiling of a long hall is 25 m high. What is the maximum horizontal distance that a ball thrown with a speed of 40 m/s can go without hitting the ceiling of the hall?
Solution: Max height $H = \frac{u^2\sin^2\theta}{2g} = 25 \implies \sin^2\theta = \frac{2(9.8)(25)}{1600} = 0.306 \implies \theta = 33.6°$. Range $R = \frac{1600\sin 67.2°}{9.8} = \mathbf{150.5}$ m.

15. **Q 3.15:** A cricketer can throw a ball to a maximum horizontal distance of 100 m? (Or NCERT: bullet fired at $u = 150$ m/s: $R_{max} = u^2/g$.) For $R_{max} = 100$ m, H_{max} vertically up $= u^2/(2g) = R_{max}/2 = \mathbf{50}$ m! (And for $u = 150$ m/s, $R_{max} = \mathbf{2.25}$ km.)

16. **Q 3.16:** A stone tied to the end of a string 80 cm long is whirled in a horizontal circle with a constant speed. If the stone makes 14 revolutions in 25 s, what is the magnitude and direction of acceleration of the stone?
Solution: $\omega = \frac{2\pi(14)}{25} = 3.52$ rad/s. $a_c = \omega^2 R = (3.52)^2(0.80) = \mathbf{9.91}$ m/s$^\mathbf{2}$, directed towards the centre.

17. **Q 3.17:** An aircraft executes a horizontal loop of radius 1.00 km with a steady speed of 900 km/h. Compare its centripetal acceleration with the acceleration due to gravity.
Solution: $v = 900 \times \frac{5}{18} = 250$ m/s, $R = 1000$ m. $a_c = 250^2/1000 = 62.5$ m/s^2 $\implies$ $a_c/g = 62.5/9.8 = \mathbf{6.38}$.

18. **Q 3.18:** Read each statement below carefully and state, with reasons, if it is true or false: (a) Net acceleration of a particle in circular motion is always along the radius towards the centre; (b) Velocity vector of a particle at a point is always along the tangent to the path; (c) Acceleration vector of a particle in UCM averaged over one cycle is a null vector.
Solution: (a) **False** (only in UCM; non-UCM has tangential acceleration too). (b) **True**. (c) **True** (vectors around a full circle cancel symmetrically).

19. **Q 3.19:** The position of a particle is given by $\vec{r} = 3.0t\hat{i} - 2.0t^2\hat{j} + 4.0\hat{k}$ m. (a) Find $\vec{v}$ and $\vec{a}$. (b) What is the magnitude and direction of velocity at $t = 2.0$ s?
Solution: $\vec{v} = 3\hat{i} - 4t\hat{j}$, $\vec{a} = -4\hat{j}$ m/s^2. At $t = 2$ s: $\vec{v} = 3\hat{i} - 8\hat{j}$ $\implies$ $|\vec{v}| = \sqrt{9+64} = \mathbf{8.54}$ m/s at $-69.4°$ with x-axis.

20. **Q 3.20:** A particle starts from the origin at $t = 0$ s with a velocity of $10.0\hat{j}$ m/s and moves in the x-y plane with a constant acceleration of $(8.0\hat{i} + 2.0\hat{j})$ m/s^2. (a) At what time is the x-coordinate 16 m? What is the y-coordinate then? (b) What is the speed of the particle at that time?
Solution: $x = \frac{1}{2}(8)t^2 = 16$ $\implies$ $t = \mathbf{2}$ s. $y = 10(2) + \frac{1}{2}(2)(4) = \mathbf{24}$ m. $\vec{v} = 16\hat{i} + 14\hat{j}$ $\implies$ $|\vec{v}| = \mathbf{21.26}$ m/s.

21. **Q 3.21:** $\hat{i}$ and $\hat{j}$ are unit vectors along x and y-axis respectively. What is the magnitude and direction of the vectors $\hat{i} + \hat{j}$, and $\hat{i} - \hat{j}$? What are the components of a vector $\vec{A} = 2\hat{i} + 3\hat{j}$ along the directions of $\hat{i} + \hat{j}$ and $\hat{i} - \hat{j}$?
Solution: Both have magnitude $\sqrt{2}$, at $+45°$ and $-45°$ respectively. Components of $\vec{A}$ along them: $\vec{A} \cdot \frac{\hat{i}+\hat{j}}{\sqrt{2}} = \frac{\mathbf{5}}{\sqrt{\mathbf{2}}}$ and $\vec{A} \cdot \frac{\hat{i}-\hat{j}}{\sqrt{2}} = -\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}$.

22. **Q 3.22:** A cyclist is riding with a speed of 27 km/h. As he approaches a circular turn on the road of radius 80 m, he applies brakes and reduces his speed at the constant rate of 0.50 m/s every second. What is the magnitude and direction of the net acceleration of the cyclist on the circular turn?
Solution: $v = 7.5$ m/s, $a_c = 7.5^2/80 = 0.703$ m/s^2, $a_t = 0.50$ m/s^2 $\implies$ $a_{net} = \sqrt{0.703^2 + 0.50^2} = \mathbf{0.86}$ m/s$^\mathbf{2}$ at $54.6°$ with tangent.

4 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 3 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. Define scalar and vector quantities with two examples each.
2. What is a unit vector? Write unit vectors along x, y, z axes.
3. Find the magnitude of $\vec{A} = 3\hat{i} + 4\hat{j}$.
4. Find the magnitude of $\vec{B} = 2\hat{i} - 3\hat{j} + 6\hat{k}$.
5. Two perpendicular vectors have magnitudes 6 and 8. Find their resultant.
6. When is the resultant of two vectors $\vec{A}$ and $\vec{B}$ maximum and minimum?
7. Write the x and y components of a vector $\vec{A}$ making angle θ with the x-axis.
8. If $\vec{A} = 3\hat{i} + 4\hat{j}$ and $\vec{B} = 2\hat{i} - \hat{j}$, find $\vec{A} + \vec{B}$ and $\vec{A} - \vec{B}$.

9. What is a null (zero) vector? Give one physical example.
10. What is the trajectory (shape of path) of an oblique projectile neglecting air resistance?
11. Which component of velocity remains constant during projectile motion and why?
12. At the highest point of a projectile, what is the angle between velocity and acceleration?
13. Write the formula for Time of Flight (T) of a projectile launched at speed u and angle θ.
14. Write the formula for Maximum Height (H) of a projectile.
15. Write the formula for Horizontal Range (R) of a projectile. At what angle is R maximum?
16. A projectile is launched at 20 m/s at 30° ($g = 10$). Find Time of Flight.
17. In Q16 ($u = 20, \theta = 30°, g = 10$), find Maximum Height.
18. For what two angles is the horizontal range equal for the same launch speed?
19. Define Uniform Circular Motion (UCM). Is it an accelerated motion?
20. Write the relation between linear speed v and angular speed ω for radius r.
21. Write the formula for centripetal acceleration a_c and state its direction.
22. A stone tied to a 2 m string moves in a circle at 4 m/s. Find centripetal acceleration.
23. Find the angular speed of a wheel rotating at 60 rpm.
24. Is electric current a scalar or a vector?
25. Find the unit vector along $\vec{A} = 6\hat{i} + 8\hat{j}$.

4.2 Level 2: Medium Level (25 Questions)

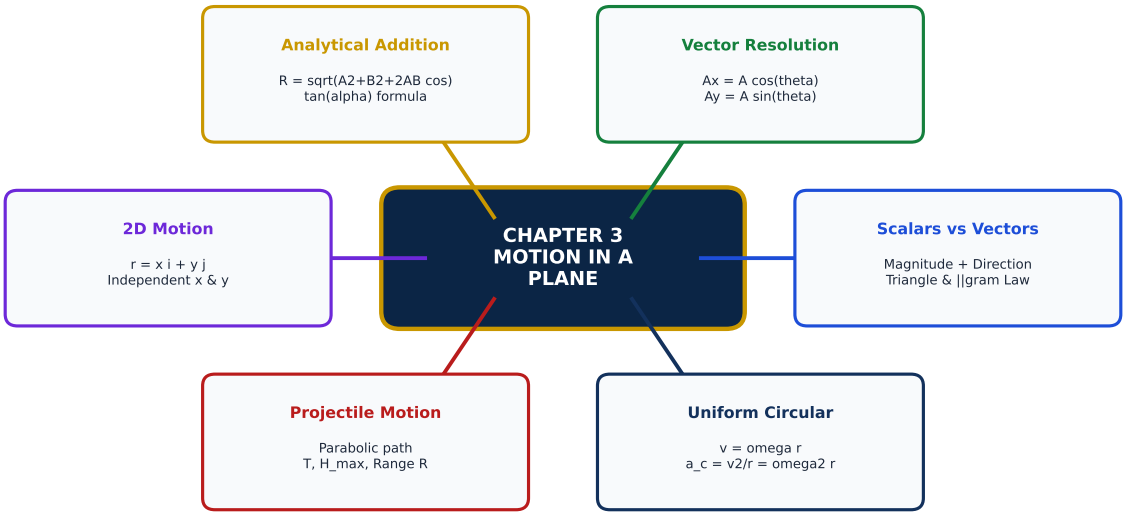
1. Two forces 5 N and 10 N act at 60° to each other. Find magnitude of their resultant.
2. If $|\vec{A} + \vec{B}| = |\vec{A} - \vec{B}|$, find the angle between $\vec{A}$ and $\vec{B}$.
3. If $\vec{A}$ and $\vec{B}$ are unit vectors and $\vec{A} + \vec{B}$ is also a unit vector, find angle between them.
4. Position of a particle is $\vec{r} = 3t\hat{i} + 2t^2\hat{j}$. Find $\vec{v}(t)$ and speed at $t = 1$ s.
5. In Q4, find the acceleration vector $\vec{a}(t)$.
6. A cricket ball is hit for a maximum horizontal range of 100 m. What maximum height does it reach?
7. A projectile has same range at 30° and 60°. Find the ratio of their maximum heights $H_1 : H_2$.
8. In Q7 (30° and 60°), find the ratio of their times of flight $T_1 : T_2$.
9. At what angle of projection does Horizontal Range equal Maximum Height ($R = H$)?
10. A ball is thrown horizontally at 15 m/s from a 45 m tall tower ($g = 10$). Find horizontal distance covered.
11. In Q10, find the speed of the ball just before hitting the ground.
12. Rain falls vertically at 3 m/s and a man walks at 4 m/s. At what angle to vertical should he hold his umbrella?
13. A river 400 m wide flows at 3 m/s. A swimmer swims perpendicular to flow at 4 m/s. Find time to cross and downstream drift.
14. Find the vector to be added to $2\hat{i} - 3\hat{j} + 4\hat{k}$ to give $\hat{j}$.
15. In UCM with speed v, find the magnitude of change in velocity in (a) half revolution, (b) quarter revolution.
16. A bullet is fired at 40 m/s at 30°. Find its speed at the highest point.
17. If $R = 4\sqrt{3}H$, find the angle of projection.
18. If $x = a\cos\omega t$ and $y = a\sin\omega t$, prove the path is a circle.

19. What is the minimum number of unequal coplanar vectors whose resultant can be zero?
20. An aircraft loops a circle of radius 1 km at 200 m/s ($g = 10$). Express a_c in terms of g.
21. A gun's maximum range is 16 km ($g = 10$). Find the muzzle speed of the shell.
22. If time of flight of a projectile is 4 s ($g = 10$), find its maximum height using the shortcut.
23. Find the angular speed of the minute hand of a clock.
24. Three vectors $\vec{A}, \vec{B}, \vec{C}$ satisfy $\vec{A} + \vec{B} = \vec{C}$ and $A^2 + B^2 = C^2$. Find angle between $\vec{A}$ and $\vec{B}$.
25. A particle moves in x-y plane with $x = 3t, y = 4t - 5t^2$. Find its initial speed.

4.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. A swimmer can swim at 4 km/h in still water and river flows at 2 km/h. At what angle to river flow must he swim to reach the **directly opposite** bank?
2. In Q1 ($v_s = 4, v_r = 2$, width = 1 km), how long does it take to cross directly opposite?
3. Equation of a projectile is $y = \sqrt{3}x - 5x^2$ ($g = 10$). Find initial speed u and angle θ.
4. A ball thrown at 45° just clears a 4 m high wall 8 m away. Find the horizontal range R.
5. For a projectile, kinetic energy at highest point is $K/2$ (where K is launch KE). Find launch angle.
6. What is the minimum number of non-coplanar vectors whose sum can be zero?
7. Two projectiles are launched with same speed at angles $45° + \alpha$ and $45° - \alpha$. Prove their ranges are equal.
8. A projectile has initial velocity $\vec{u} = 3\hat{i} + 4\hat{j}$ m/s ($g = 10$). Find its range R and max height H.
9. An aeroplane flies 400 m North, 300 m South, then 1200 m Up. Find net displacement.
10. A projectile is fired at speed u at angle θ. Find the radius of curvature of its path at the highest point.
11. Two stones are projected simultaneously from same point with same speed u at θ_1 and θ_2. Show their relative velocity is constant.
12. A particle moves in a circle of radius R with speed increasing at $a_t = 3$ m/s^2. At $v = 4$ m/s ($R = 4$ m), find net acceleration.
13. Find the angle between $\vec{A} = \hat{i} + \hat{j}$ and $\vec{B} = \hat{j} + \hat{k}$.
14. If $\vec{v} = 2\hat{i} + 4\hat{j}$ and $\vec{a} = -10\hat{j}$, when does velocity become perpendicular to initial velocity?
15. A ship A moves West at 10 km/h and ship B moves North at 10 km/h from 100 km South of A. Shortest distance between them?
16. Find maximum range on an inclined plane of angle β when projected up the incline at speed u.
17. A particle is projected from ground and reaches height h at $t_1 = 2$ s and $t_2 = 6$ s ($g = 10$). Find range if $u_x = 10$ m/s.
18. If $\hat{a}$ and $\hat{b}$ are unit vectors with angle θ between them, show $|\hat{a} - \hat{b}| = 2\sin(\theta/2)$.
19. A cyclist rides at 27 km/h (7.5 m/s) and brakes on a circular turn of $R = 80$ m at 0.5 m/s^2. Find net acceleration.
20. Find the component of $\vec{A} = 2\hat{i} + 3\hat{j}$ along $\hat{i} + \hat{j}$.
21. A ball is thrown from ground to just clear two walls of equal height h at $x = 2$ m and $x = 6$ m. Find range R.
22. If range R is n times max height H, find $\tan\theta$.
23. A stone is projected at 45° with K. What is its KE at the highest point?
24. Can three vectors of magnitudes $2, 3, 6$ have zero resultant?
25. A particle moves in a circle of radius 2 m with $\omega = 2t$. Find a_c and a_t at $t = 1$ s.

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Unifies 2D kinematics: vector algebra & resolution, analytical addition, independent x-y motion, projectile equations (T, H, R), and uniform circular motion.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 3 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MOTION IN A PLANE

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

6 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. Scalar has only magnitude (e.g., mass, distance). Vector has magnitude, direction, and obeys vector addition laws (e.g., velocity, force).
2. A vector of magnitude 1 used to specify direction: $\hat{A} = \vec{A}/|\vec{A}|$. Along x, y, z: $\hat{i}, \hat{j}, \hat{k}$.
3. $|\vec{A}| = \sqrt{3^2 + 4^2} = \sqrt{25} = \mathbf{5}$.
4. $|\vec{B}| = \sqrt{4 + 9 + 36} = \sqrt{49} = \mathbf{7}$.
5. $R = \sqrt{6^2 + 8^2} = \sqrt{100} = \mathbf{10}$.
6. Maximum $(A + B)$ at $\theta = 0^\circ$ (same direction); Minimum $(|A - B|)$ at $\theta = 180^\circ$ (opposite direction).
7. $A_x = A\cos\theta$, $A_y = A\sin\theta$.
8. $\vec{A} + \vec{B} = 5\hat{i} + 3\hat{j}$; $\vec{A} - \vec{B} = \hat{i} + 5\hat{j}$.
9. A vector with zero magnitude and arbitrary direction (e.g., displacement of a body returning to its starting point).
10. A **parabola**.
11. The horizontal component $v_x = u\cos\theta$ remains constant because there is zero horizontal acceleration ($a_x = 0$).
12. $\mathbf{90}^\circ$ (velocity is horizontal, acceleration g is vertically downward).
13. $T = \frac{2u\sin\theta}{g}$.
14. $H = \frac{u^2\sin^2\theta}{2g}$.
15. $R = \frac{u^2\sin 2\theta}{g}$. It is maximum (u^2/g) at $\theta = \mathbf{45}^\circ$.
16. $T = \frac{2(20)\sin 30^\circ}{10} = \frac{40(0.5)}{10} = \mathbf{2}$ s.
17. $H = \frac{400\sin^2 30^\circ}{20} = 20(0.25) = \mathbf{5}$ m.
18. Complementary angles θ and $90^\circ - \theta$ (e.g., 30° and 60°).
19. Motion in a circle at constant speed. Yes, it is accelerated because the direction of velocity changes continuously.
20. $v = r\omega$.
21. $a_c = \frac{v^2}{r} = \omega^2 r$, always directed **towards the centre** of the circle.
22. $a_c = \frac{4^2}{2} = \mathbf{8}$ m/s$^{\mathbf{2}}$.
23. $f = 60/60 = 1$ Hz $\implies \omega = 2\pi f = \mathbf{2}\pi$ rad/s.
24. **Scalar**, because it has direction along a wire but does NOT obey the law of vector addition.
25. $|A| = 10 \implies \hat{A} = \mathbf{0.6\hat{i} + 0.8\hat{j}}$.

7 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $R = \sqrt{5^2 + 10^2 + 2(5)(10)\cos 60^\circ} = \sqrt{25 + 100 + 50} = \sqrt{175} \approx \mathbf{13.23}$ N.
2. Squaring: $A^2 + B^2 + 2AB\cos\theta = A^2 + B^2 - 2AB\cos\theta \implies 4AB\cos\theta = 0 \implies \theta = \mathbf{90}^\circ$.
3. $1 = 1 + 1 + 2\cos\theta \implies \cos\theta = -1/2 \implies \theta = \mathbf{120}^\circ$.
4. $\vec{v} = 3\hat{i} + 4t\hat{j}$. At $t = 1$: $\vec{v} = 3\hat{i} + 4\hat{j} \implies |v| = \mathbf{5}$ m/s.
5. $\vec{a} = \frac{d\vec{v}}{dt} = \mathbf{4\hat{j}}$ m/s$^\mathbf{2}$ (constant along $+y$).
6. At $\theta = 45^\circ$, $H = R_{max}/4 = 100/4 = \mathbf{25}$ m.
7. $H_1/H_2 = \sin^2 30^\circ / \sin^2 60^\circ = (1/4)/(3/4) = \mathbf{1} : \mathbf{3}$.
8. $T_1/T_2 = \sin 30^\circ / \sin 60^\circ = \mathbf{1} : \sqrt{\mathbf{3}}$.
9. $\frac{u^2 \sin 2\theta}{g} = \frac{u^2 \sin^2\theta}{2g} \implies 2\sin\theta\cos\theta = \frac{\sin^2\theta}{2} \implies \tan\theta = 4 \implies \theta = \tan^{-1}(\mathbf{4}) \approx 76^\circ$.
10. Time to fall: $t = \sqrt{2h/g} = \sqrt{90/10} = 3$ s. Horizontal distance $x = ut = 15 \times 3 = \mathbf{45}$ m.
11. $v_x = 15$ m/s, $v_y = gt = 30$ m/s $\implies v = \sqrt{15^2 + 30^2} = \mathbf{15\sqrt{5}}$ m/s ≈ 33.5 m/s.
12. $\tan\theta = \frac{v_m}{v_r} = \frac{4}{3} \implies \theta = \mathbf{53.1}^\circ$ with vertical in the direction of walking.
13. Time $= 400/4 = \mathbf{100}$ s. Drift $= v_r \times t = 3 \times 100 = \mathbf{300}$ m.
14. $\vec{X} = \hat{j} - (2\hat{i} - 3\hat{j} + 4\hat{k}) = \mathbf{-2\hat{i} + 4\hat{j} - 4\hat{k}}$.
15. (a) $2v$; (b) $\sqrt{v^2 + v^2} = \mathbf{v\sqrt{2}}$.
16. $v_{top} = u\cos 30^\circ = 40(\frac{\sqrt{3}}{2}) = \mathbf{20\sqrt{3}}$ m/s.
17. $\tan\theta = 4H/R = 1/\sqrt{3} \implies \theta = \mathbf{30}^\circ$.
18. $x^2 + y^2 = a^2(\cos^2\omega t + \sin^2\omega t) = a^2$, which is a circle of radius a.
19. **3** (forming a closed triangle).
20. $a_c = \frac{200^2}{1000} = 40$ m/s$^2 = \mathbf{4g}$.
21. $R_{max} = u^2/g = 16000 \implies u^2 = 160000 \implies u = \mathbf{400}$ m/s.
22. $H = \frac{1}{8}gT^2 = \frac{1}{8}(10)(16) = \mathbf{20}$ m.
23. $T = 3600$ s $\implies \omega = \frac{2\pi}{3600} = \frac{\pi}{\mathbf{1800}}$ rad/s.
24. Pythagoras theorem holds $\implies \theta = \mathbf{90}^\circ$.
25. $v_x = 3$, $v_y(0) = 4 \implies u = \sqrt{3^2 + 4^2} = \mathbf{5}$ m/s.

8 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. To cancel drift, $v_s \sin\alpha = v_r \implies \sin\alpha = 2/4 = 0.5 \implies \alpha = 30^\circ$ upstream from perpendicular, i.e., $\mathbf{120}^\circ$ to river flow.
2. Net perpendicular speed $= v_s\cos 30^\circ = 2\sqrt{3}$ km/h. Time $= \frac{1}{2\sqrt{3}}$ h $\approx \mathbf{17.3}$ min.
3. $\tan\theta = \sqrt{3} \implies \theta = \mathbf{60}^\circ$. Comparing $\frac{g}{2u^2\cos^2 60^\circ} = 5 \implies \frac{10}{2u^2(1/4)} = 5 \implies u = \mathbf{2}$ m/s.
4. Use trajectory shortcut $y = x\tan\theta(1 - x/R)$: $4 = 8(1)(1 - 8/R) \implies 0.5 = 1 - 8/R \implies R = \mathbf{16}$ m.
5. $K_{top} = K\cos^2\theta = K/2 \implies \cos\theta = 1/\sqrt{2} \implies \theta = \mathbf{45}^\circ$.
6. **4** (three vectors always lie in a plane unless they sum to a 4th vector out of the plane).
7. $\sin 2(45^\circ + \alpha) = \sin(90^\circ + 2\alpha) = \cos 2\alpha = \sin(90^\circ - 2\alpha) = \sin 2(45^\circ - \alpha)$. Equal R!
8. $u_x = 3, u_y = 4$. $T = 2u_y/g = 0.8$ s $\implies R = u_xT = 3(0.8) = \mathbf{2.4}$ m. $H = u_y^2/(2g) = 16/20 = \mathbf{0.8}$ m.

9. Net North $= 100$ m, Up $= 1200$ m. $|\Delta\vec{r}| = \sqrt{100^2 + 1200^2} = \mathbf{1204.16}$ m.

10. At top, $v = u\cos\theta$ and normal acceleration $= g$. $R_{curv} = \frac{v^2}{g} = \frac{\mathbf{u^2\cos^2\theta}}{\mathbf{g}}$.

11. $\vec{a}_1 = \vec{a}_2 = -g\hat{j} \implies \vec{a}_{rel} = 0$. Hence $\vec{v}_{rel}$ is constant, and relative path is a straight line!

12. $a_c = v^2/R = 16/4 = 4$ m/s^2. $a_{net} = \sqrt{a_c^2 + a_t^2} = \sqrt{4^2 + 3^2} = \mathbf{5}$ m/s$^{\mathbf{2}}$.

13. $\cos\theta = \frac{\vec{A}\cdot\vec{B}}{|A||B|} = \frac{1}{\sqrt{2}\sqrt{2}} = \frac{1}{2} \implies \theta = \mathbf{60}^\circ$.

14. $(2\hat{i} + 4\hat{j}) \cdot (2\hat{i} + (4 - 10t)\hat{j}) = 0 \implies 4 + 4(4 - 10t) = 0 \implies 20 - 40t = 0 \implies t = \mathbf{0.5}$ s.

15. $v_{rel} = 10\sqrt{2}$ km/h at 45° N of E. Closest approach $d_{min} = 100\sin 45^\circ = \mathbf{50\sqrt{2}}$ km ≈ 70.7 km.

16. $R_{max} = \frac{\mathbf{u^2}}{\mathbf{g(1}+\sin\beta)}$ (at $\theta = 45^\circ + \beta/2$ from horizontal).

17. $T = t_1 + t_2 = 8$ s $\implies R = u_x T = 10 \times 8 = \mathbf{80}$ m.

18. $|\hat{a} - \hat{b}|^2 = 1 + 1 - 2\cos\theta = 2(1 - \cos\theta) = 4\sin^2(\theta/2) \implies |\hat{a} - \hat{b}| = 2\sin(\theta/2)$.

19. $a_c = 7.5^2/80 = 0.703$ m/s^2, $a_t = 0.5$ m/s^2 $\implies a_{net} = \sqrt{0.703^2 + 0.5^2} = \mathbf{0.86}$ m/s$^{\mathbf{2}}$.

20. $A_{\parallel} = \vec{A} \cdot \frac{\hat{i}+\hat{j}}{\sqrt{2}} = \frac{\mathbf{5}}{\sqrt{\mathbf{2}}}$.

21. By symmetry of parabola, $x_1 + x_2 = R \implies R = 2 + 6 = \mathbf{8}$ m!

22. $R/H = 4/\tan\theta = n \implies \tan\theta = \mathbf{4/n}$.

23. $K_{top} = K\cos^2 45^\circ = \mathbf{K/2}$.

24. No! Because $2 + 3 = 5 < 6$ (violates triangle inequality).

25. At $t = 1$: $\omega = 2$ rad/s $\implies a_c = \omega^2 r = 4(2) = \mathbf{8}$ m/s$^{\mathbf{2}}$. $\alpha = d\omega/dt = 2 \implies a_t = \alpha r = 2(2) = \mathbf{4}$ m/s$^{\mathbf{2}}$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 4 (SELF-STUDY MASTER EDITION)

LAWS OF MOTION

Complete Zero-Omission Coverage of NCERT `keph104.pdf` (Sections 4.1–4.11, Fig 4.1–4.16, Ex 4.1–4.12, Exercises 4.1–4.23)

CBSE 2026–27 Weightage & Scope: Unit III: Laws of Motion (Part of 23 Marks for Units I–III)

[CONCEPT CORE] Self-Study Promise: Zero Teacher Needed

In Chapters 2 and 3, we described *how* objects move. In Chapter 4 (Dynamics), we uncover *why* they move: **Forces**. Every law, Free Body Diagram, friction rule, and banked-road formula is built from scratch with zero gaps.

1 Topic 1: Aristotle's Fallacy, Inertia & Newton's First Law (NCERT Sections 4.1–4.4)

1.1 Step 1: Definitions & Plain-English Meaning

- **Aristotle's Fallacy (4.2):** The Greek philosopher Aristotle observed that a rolling ball stops unless pushed, so he wrongly concluded that "an external force is required to keep a body in uniform motion."
- **Galileo's Law of Inertia (4.3):** Using smooth double inclined planes, Galileo realized that a ball only stops because of **friction**. If friction were zero, a moving body would keep moving at constant velocity forever!
- **Inertia:** The inherent property of a body by which it resists any change in its state of rest or uniform straight-line motion. **Mass** is the quantitative measure of inertia (heavier body = more inertia). Types: Inertia of rest, Inertia of motion, Inertia of direction.
- **Newton's First Law (4.4):** Every body continues in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise. This gives the **qualitative definition of force**.

2 Topic 2: Momentum, Second Law, Impulse, Third Law & Conservation (NCERT Sections 4.5–4.8)

2.1 Step 1: Definitions & Step-by-Step Derivations

- **Linear Momentum ($\vec{p}$):** Quantity of motion contained in a body: $\vec{p} = m\vec{v}$ (SI: kg m s^{-1} or N s, $[MLT^{-1}]$).
- **Newton's Second Law (4.5):** The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force:

$$\vec{F} = k\frac{d\vec{p}}{dt} = \frac{d(m\vec{v})}{dt}$$

  In SI units, $k = 1$ (defining 1 N = 1 kg m s^{-2}). For constant mass m: $\vec{F} = m\frac{d\vec{v}}{dt} = \mathbf{m\vec{a}}$.

- **Impulse ($\vec{J}$):** A large force acting for a very short time (like a bat hitting a ball) produces a sudden change in momentum:

$$\vec{J} = \int \vec{F}\,dt = \vec{F}_{avg}\Delta t = \Delta\vec{p} = m(\vec{v} - \vec{u})$$

  Geometrically, Impulse equals the **area under the Force-Time (F-t) graph**.

- **Newton's Third Law (4.6):** To every action, there is always an equal and opposite reaction: $\vec{F}_{AB} = -\vec{F}_{BA}$. *Crucial rule:* Action and reaction act on **two different bodies**, so they never cancel each other!
- **Conservation of Linear Momentum (4.7):** If net external force $\vec{F}_{ext} = 0$, then $\frac{d\vec{p}_{total}}{dt} = 0 \implies \vec{p}_{initial} = \vec{p}_{final}$ (basis of gun recoil and rocket propulsion).
- **Equilibrium of a Particle (4.8):** A particle is in translational equilibrium if $\sum \vec{F}_i = 0$ ($\sum F_x = 0, \sum F_y = 0, \sum F_z = 0$). For three concurrent forces, Lami's Theorem gives $\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$.

Example 4.1A (Gun Recoil & Impulse) [Beginner]

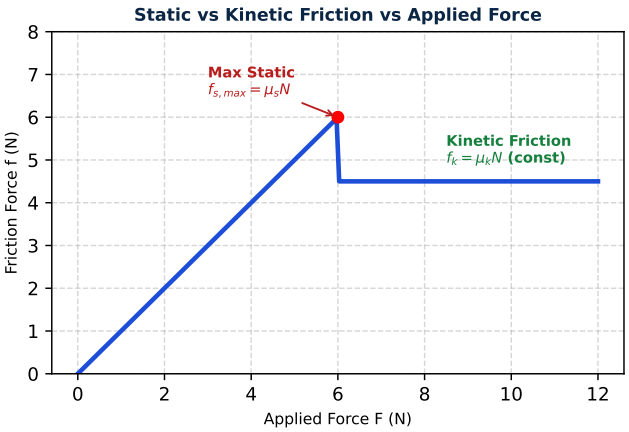
Problem: A 4 kg rifle fires a 20 g bullet at 400 m/s in 0.01 s. Find (a) recoil velocity of rifle, and (b) average force on bullet.

Solution: **(a) Conservation of Momentum:** Initial $p = 0 = MV + mv \implies 4V + 0.02(400) = 0 \implies V = \mathbf{-2}$ m/s (backward).
(b) Impulse-Momentum: $F_{avg} = \frac{\Delta p}{\Delta t} = \frac{0.02 \times 400}{0.01} = \mathbf{800}$ N.

3 Topic 3: Friction, Circular Dynamics & Free Body Diagrams (NCERT Sections 4.9–4.11)

3.1 Step 1: Types of Friction & Laws of Friction (Section 4.9.1)

- **Static Friction (f_s):** Opposes *impending* relative motion when surfaces are at rest. It is **self-adjusting**: $f_s = F_{applied}$ up to a maximum limit called **limiting friction**: $(f_s)_{max} = \mu_s N$.
- **Kinetic Friction (f_k):** Opposes actual sliding motion: $f_k = \mu_k N$ (constant, with $\mu_k < \mu_s$).
- **Rolling Friction:** Much smaller than sliding friction ($\sim 10^{-2}$ to 10^{-3} times), which is why wheels and ball bearings save energy.
- **Angle of Friction (θ) & Angle of Repose (α):** $\tan\theta = \mu_s$ and $\tan\alpha = \mu_s$.



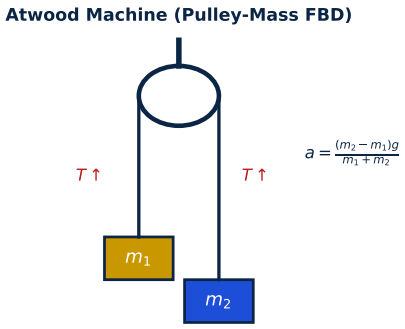


Diagram Explanation: Left shows static friction rising 1 : 1 with applied force up to $f_{s,max} = \mu_s N$, then dropping to constant kinetic friction $f_k = \mu_k N$. Right shows the Atwood machine FBD giving $a = \frac{(m_2 - m_1)g}{m_1 + m_2}$ and $T = \frac{2m_1 m_2 g}{m_1 + m_2}$.

3.2 Step 2: Derivation of Safe Speed on Level & Banked Circular Roads (Section 4.10)

1. **Level Circular Road:** Friction alone provides centripetal force: $\frac{mv^2}{R} \le \mu_s mg \implies \mathbf{v_{max} = \sqrt{\mu_s Rg}}$.
2. **Banked Circular Road (Angle θ):** Resolving Normal reaction N and friction f vertically and horizontally (see FBD below):

$$N\cos\theta = mg + f\sin\theta \quad \text{and} \quad N\sin\theta + f\cos\theta = \frac{mv^2}{R}$$

Dividing the two equations with $f = \mu_s N$ gives:

$$v_{max} = \sqrt{Rg\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}$$

Setting $\mu_s = 0$ gives the **optimum speed** (zero tyre wear): $\mathbf{v_0 = \sqrt{Rg\tan\theta}}$.

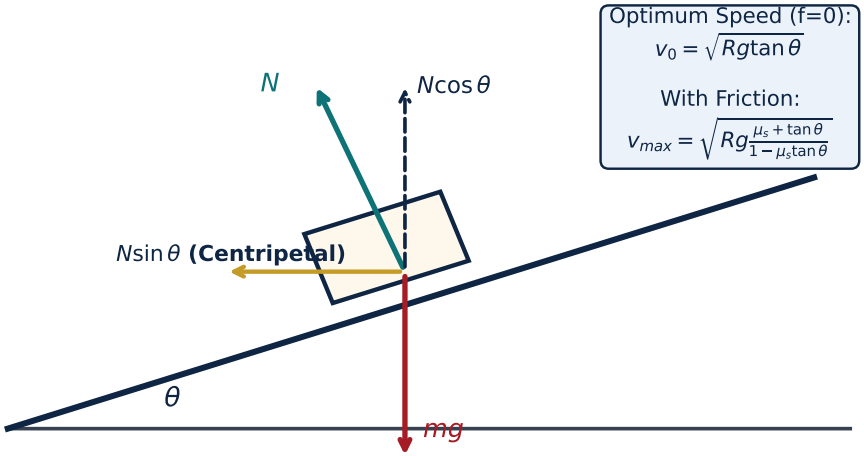


Diagram Explanation (Covers NCERT Figs. 4.14–4.15): Free Body Diagram of a car on a banked curve of angle θ: $N\cos\theta$ balances weight mg and downward friction component $f\sin\theta$, while $N\sin\theta + f\cos\theta$ provides the inward centripetal force mv^2/R.

[COMMON MISTAKE ALERT] Most Common Mistake in Friction Problems

Never blindly plug $f = \mu_s N$! First check if $F_{applied} \leq \mu_s N$. If $F_{applied} < \mu_s N$, the block does not move and friction equals $^{**}F_{applied}{}^{**}$, NOT $\mu_s N$!

4 Complete NCERT Examples (4.1–4.12) & Back Exercises (4.1–4.23) with Full Questions

4.1 NCERT Solved Examples (4.1–4.12)

1. **Example 4.1:** An astronaut accidentally gets separated out of his small spaceship accelerating in inter-stellar space at a constant rate of 100 m s^{-2}. What is the acceleration of the astronaut the instant after he is outside the spaceship?
   Solution: **0** m/s$^{\mathbf{2}}$, because once outside, no net force acts on him (neglecting distant stars' gravity). [**Note: Acceleration depends on the instantaneous force, not past motion.**]

2. **Example 4.2:** A bullet of mass 0.04 kg moving with a speed of 90 m s^{-1} enters a heavy wooden block and is stopped after a distance of 60 cm. What is the average resistive force exerted by the block on the bullet?
   Solution: $a = \frac{0-90^2}{2(0.6)} = -6750$ m/s^2. Resistive force $F = ma = 0.04 \times 6750 = \mathbf{270}$ N.

3. **Example 4.3:** The motion of a particle of mass m is described by $y = ut + \frac{1}{2}gt^2$. Find the force acting on the particle.
   Solution: $v = dy/dt = u + gt \implies a = dv/dt = g \implies F = ma = \mathbf{mg}$ (downward).

4. **Example 4.4:** A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12 m s^{-1}. If the mass of the ball is 0.15 kg, determine the impulse imparted to the ball.
   Solution: $J = m(v-u) = 0.15(12-(-12)) = \mathbf{3.6}$ N s towards the bowler.

5. **Example 4.5:** Two identical billiard balls strike a rigid wall with the same speed but at different angles (0° normal vs 30° to normal), and get reflected without any change in speed. What is (i) the direction of the force on the wall due to each ball? (ii) the ratio of magnitudes of impulses imparted to the balls by the wall?
   Solution: (i) Normal into the wall in both cases. (ii) Case 1: $J_1 = 2mu$; Case 2: $J_2 = 2mu\cos 30°$. Ratio $J_1/J_2 = 2/\sqrt{3} \approx \mathbf{1.15}$.

6. **Example 4.6:** A mass of 6 kg is suspended by a rope of length 2 m from the ceiling. A force of 50 N in the horizontal direction is applied at the midpoint P of the rope. What is the angle the rope makes with the vertical in equilibrium? ($g = 10$ m s^{-2})

Solution: Lower tension $T_2 = 60$ N. At midpoint P: $T_1\cos\theta = 60$ N and $T_1\sin\theta = 50$ N $\implies \tan\theta = 50/60 = 5/6 \implies \theta \approx \mathbf{40}^\circ$.

7. **Example 4.7:** Determine the maximum acceleration of the train in which a box lying on its floor will remain stationary, given that the co-efficient of static friction between the box and the train's floor is 0.15 ($g = 10$ m/s^2).
Solution: $ma_{max} = \mu_s mg \implies a_{max} = \mu_s g = 0.15 \times 10 = \mathbf{1.5}$ m/s$^\mathbf{2}$.

8. **Example 4.8:** A mass of 4 kg rests on a horizontal plane. The plane is gradually inclined until at an angle $\theta = 15^\circ$ with the horizontal, the mass just begins to slide. What is the coefficient of static friction between the block and the surface?
Solution: $\mu_s = \tan 15^\circ \approx \mathbf{0.27}$.

9. **Example 4.9:** What is the acceleration of the block and trolley system shown in NCERT Fig. 4.12(a), if the coefficient of kinetic friction between the trolley (20 kg) and the surface is 0.04? Hanging mass = 3 kg, $g = 10$ m/s^2. What is the tension in the string?
Solution: $a = \frac{30 - 0.04(200)}{20+3} = \frac{22}{23} = \mathbf{0.96}$ m/s$^\mathbf{2}$. Tension $T = 3(10 - 0.96) = \mathbf{27.1}$ N.

10. **Example 4.10:** A cyclist speeding at 18 km/h on a level road takes a sharp circular turn of radius 3 m without reducing the speed. The co-efficient of static friction between the tyres and the road is 0.1. Will the cyclist slip while taking the turn?
Solution: $v = 18 \times \frac{5}{18} = 5$ m/s, so $v^2 = 25$. Max safe $\mu_s Rg = 0.1(3)(9.8) = 2.94$. Since $v^2 > \mu_s Rg$, **yes, the cyclist will slip**.

11. **Example 4.11:** A circular racetrack of radius 300 m is banked at an angle of 15°. If $\mu_s = 0.2$, what is the (a) optimum speed of the racecar to avoid wear and tear on its tyres, and (b) maximum permissible speed to avoid slipping?
Solution: (a) $v_0 = \sqrt{300(9.8)\tan 15^\circ} = \mathbf{28.1}$ m/s. (b) $v_{max} = \sqrt{300(9.8)\frac{0.2+0.268}{1-0.0536}} = \mathbf{38.1}$ m/s.

12. **Example 4.12:** A wooden block of mass 2 kg rests on a soft horizontal floor. When an iron cylinder of mass 25 kg is placed on top of the block, the floor yields steadily and the block and cylinder together go down with an acceleration of 0.1 m s^{-2}. What is the action of the block on the floor (a) before and (b) after the floor yields? ($g = 10$ m/s^2)
Solution: (a) Before yielding: $R = 2 \times 10 = \mathbf{20}$ N downward. (b) After yielding: $R = (2 + 25)(10 - 0.1) = \mathbf{267.3}$ N downward.

4.2 NCERT Back Exercises (4.1–4.23) — Full Questions & Solutions

1. **Q 4.1:** Give the magnitude and direction of the net force acting on: (a) a drop of rain falling down with a constant speed, (b) a cork of mass 10 g floating on water, (c) a kite skillfully held stationary in the sky, (d) a car moving with a constant velocity of 30 km/h on a rough road, (e) a high-speed electron in space far from all material objects.
Solution: **Zero** in all five cases! (Constant velocity or rest $\implies a = 0 \implies F_{net} = 0$.)

2. **Q 4.2:** A pebble of mass 0.05 kg is thrown vertically upwards. Give the direction and magnitude of the net force on the pebble: (a) during its upward motion, (b) during its downward motion, (c) at the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at 45°?
Solution: In all cases (a), (b), (c), and even at 45°, the only force is gravity: $F = mg = 0.05 \times 10 = \mathbf{0.5}$ N vertically **downward**.

3. **Q 4.3:** Give the magnitude and direction of the net force acting on a stone of mass 0.1 kg: (a) just after it is dropped from the window of a stationary train, (b) just after it is dropped from a train running at constant 36 km/h, (c) just after it is dropped from a train accelerating with 1 m/s^2, (d) lying on the floor of a train accelerating with 1 m/s^2.
Solution: (a), (b), (c): Once dropped, only gravity acts $\implies$ **1** N vertically downward. (d) On the floor, friction accelerates it with the train $\implies F = 0.1 \times 1 = \mathbf{0.1}$ N horizontally forward.

4. **Q 4.4:** One end of a string of length l is connected to a particle of mass m and the other to a small peg on a smooth horizontal table. If the particle moves in a circle with speed v, the net force on the particle (directed towards the centre) is: (i) T, (ii) $T - mv^2/l$, (iii) $T + mv^2/l$, (iv) 0.
Solution: **(i) T** (tension in the string provides the centripetal force mv^2/l).

5. **Q 4.5:** A constant retarding force of 50 N is applied to a body of mass 20 kg moving initially with a speed of 15 m s^{-1}. How long does the body take to stop?
Solution: $a = F/m = -50/20 = -2.5$ m/s^2. $t = (0 - 15)/(-2.5) = \mathbf{6}$ s.

6. **Q 4.6:** A constant force acting on a body of mass 3.0 kg changes its speed from 2.0 m/s to 3.5 m/s in 25 s. Direction of motion remains unchanged. What is the magnitude and direction of the force?
Solution: $a = (3.5 - 2.0)/25 = 0.06$ m/s^2 $\implies$ $F = 3.0 \times 0.06 = \mathbf{0.18}$ N in the direction of motion.

7. **Q 4.7:** A body of mass 5 kg is acted upon by two perpendicular forces 8 N and 6 N. Give the magnitude and direction of the acceleration of the body.
Solution: $F = \sqrt{8^2 + 6^2} = 10$ N $\implies$ $a = 10/5 = \mathbf{2}$ m/s$^\mathbf{2}$ at $\tan^{-1}(6/8) \approx \mathbf{37}^\circ$ with the 8 N force.

8. **Q 4.8:** The driver of a three-wheeler moving with a speed of 36 km/h sees a child standing in the middle of the road and brings his vehicle to rest in 4.0 s. What is the average retarding force on the vehicle? Mass of three-wheeler = 400 kg, driver = 65 kg.
Solution: $u = 10$ m/s, $a = -10/4 = -2.5$ m/s^2, $M = 465$ kg $\implies$ $F = 465(-2.5) = \mathbf{-1162.5}$ N.

9. **Q 4.9:** A rocket with a lift-off mass 20,000 kg is blasted upwards with an initial acceleration of 5.0 m/s^2. Calculate the initial thrust (force) of the blast ($g = 10$ m/s^2).
Solution: Thrust $T = M(g + a) = 20000(10 + 5) = \mathbf{3.0 \times 10^5}$ N.

10. **Q 4.10:** A body of mass 0.40 kg moving initially with a constant speed of 10 m/s to the north is subject to a constant force of 8.0 N directed towards the south for 30 s. Take $t = 0, x = 0$ when force starts. Predict its position at $t = -5$ s, 25 s, 100 s.
Solution: $a = -8/0.4 = -20$ m/s^2 (for $0 \le t \le 30$). At $t = -5$ s (uniform 10 m/s): $x = \mathbf{-50}$ m. At $t = 25$ s: $x = 10(25) - 10(625) = \mathbf{-6000}$ m. At $t = 100$ s: at $t = 30$ s, $x = -8700$ m, $v = -590$ m/s, plus 70 s uniform $= -8700 - 590(70) = \mathbf{-50,000}$ m.

11. **Q 4.11:** A truck starts from rest and accelerates uniformly at 2.0 m/s^2. At $t = 10$ s, a stone is dropped by a person standing on top of the truck (6 m high). What are the (a) velocity, and (b) acceleration of the stone at $t = 11$ s?
Solution: At $t = 10$ s, stone has $v_x = 2(10) = 20$ m/s. At $t = 11$ s (1 s after drop): $v_x = 20$ m/s, $v_y = 10(1) = 10$ m/s $\implies$ $v = \sqrt{20^2 + 10^2} = \mathbf{22.4}$ m/s; $a = \mathbf{10}$ m/s$^\mathbf{2}$ downward.

12. **Q 4.12:** A bob of mass 0.1 kg hung from the ceiling by a 2 m string is set into oscillation. Speed at mean position is 1 m/s. What is the trajectory of the bob if the string is cut when the bob is (a) at one of its extreme positions, (b) at its mean position?
Solution: (a) At extreme, $v = 0$ $\implies$ falls **vertically downward**. (b) At mean, $v = 1$ m/s horizontal $\implies$ **parabolic path**.

13. **Q 4.13:** A man of mass 70 kg stands on a weighing scale in a lift moving (a) upwards with uniform speed 10 m/s, (b) downwards with uniform $a = 5$ m/s^2, (c) upwards with uniform $a = 5$ m/s^2, (d) freely under gravity. What would be the readings on the scale?
Solution: (a) **70** kg; (b) $70(10 - 5)/10 = \mathbf{35}$ kg; (c) $70(10 + 5)/10 = \mathbf{105}$ kg; (d) **0** kg.

14. **Q 4.14:** Figure 4.16 shows the x-t plot of a particle of mass 4 kg. What is the (a) force on the particle for $t < 0$, $t > 4$ s, $0 < t < 4$ s? (b) impulse at $t = 0$ and at $t = 4$ s?
Solution: (a) Straight lines $\implies$ $a = 0$ $\implies$ Force = **0** in all three intervals. (b) At $t = 0$, v jumps $0 \to 0.75$ m/s $\implies$ $J = 4(0.75) = \mathbf{+3}$ N s; at $t = 4$ s, $J = \mathbf{-3}$ N s.

15. **Q 4.15:** Two bodies of masses 10 kg and 20 kg respectively kept on a smooth horizontal surface are tied to the ends of a light string. A horizontal force $F = 600$ N is applied to (i) A, (ii) B along the direction of string. What is the tension in the string in each case?
Solution: $a = 600/30 = 20$ m/s^2. (i) Pulled on 10 kg: $T = 20 \times 20 = \mathbf{400}$ N. (ii) Pulled on 20 kg: $T = 10 \times 20 = \mathbf{200}$ N.

16. **Q 4.16:** Two masses 8 kg and 12 kg are connected at the two ends of a light inextensible string that goes over a frictionless pulley ($g = 10$). Find the acceleration of the masses and the tension in the string.
Solution: $a = \frac{12-8}{12+8}(10) = \mathbf{2}$ m/s$^\mathbf{2}$. $T = \frac{2(8)(12)(10)}{20} = \mathbf{96}$ N.

17. **Q 4.17:** A nucleus is at rest in the laboratory frame of reference. Show that if it disintegrates into two smaller nuclei the products must move in opposite directions.
Solution: Initial momentum $= 0$ $\implies$ $m_1\vec{v}_1 + m_2\vec{v}_2 = 0$ $\implies$ $\vec{v}_1 = -\frac{m_2}{m_1}\vec{v}_2$ (opposite directions!).

18. **Q 4.18:** Two billiard balls each of mass 0.05 kg moving in opposite directions with speed 6 m/s collide and rebound with the same speed. What is the impulse imparted to each ball due to the other?
Solution: $J = m(v - (-u)) = 0.05(6 + 6) = \mathbf{0.6}$ N s in opposite directions.

19. **Q 4.19:** A shell of mass 0.020 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m/s, what is the recoil speed of the gun?
Solution: $V = \frac{0.020 \times 80}{100} = \mathbf{0.016}$ m/s (1.6 cm/s).

20. **Q 4.20:** A batsman deflects a ball by an angle of 45° without changing its initial speed which is equal to 54 km/h. What is the impulse imparted to the ball? (Mass of ball = 0.15 kg)
Solution: $v = 15$ m/s. $J = 2mv\cos(22.5°) = 2(0.15)(15)(0.9239) = \mathbf{4.16}$ N s along the bisector.

21. **Q 4.21:** A stone of mass 0.25 kg tied to the end of a string is whirled round in a circle of radius 1.5 m with a speed of 40 rev/min in a horizontal plane. What is the tension in the string? What is the maximum speed if string can withstand max tension 200 N?
Solution: $\omega = \frac{2\pi(40)}{60} = \frac{4\pi}{3}$ rad/s. $T = m\omega^2 r = 0.25(\frac{4\pi}{3})^2(1.5) = \mathbf{6.6}$ N. Max speed $v_{max} = \sqrt{\frac{200 \times 1.5}{0.25}} = \mathbf{34.6}$ m/s.

22. **Q 4.22:** If, in Exercise 4.21, the speed of the stone is increased beyond the maximum permissible value, and the string breaks suddenly, which of the following correctly describes the trajectory of the stone after the string breaks: (a) radially outwards, (b) flies off tangentially, (c) flies off at an angle?
Solution: **(b) Flies off tangentially** along the instantaneous velocity vector (by Newton's First Law).

23. **Q 4.23:** Explain why: (a) a horse cannot pull a cart and run in empty space; (b) passengers are thrown forward from their seats when a speeding bus stops suddenly; (c) it is easier to pull a lawn mower than to push it; (d) a cricketer moves his hands backwards while holding a catch.
Solution: (a) In empty space there is no ground reaction to push the horse forward. (b) Inertia of motion. (c) Pulling reduces normal reaction ($N = mg - F\sin\theta$) and thus friction. (d) Moving hands back increases impact time Δt, reducing impact force $F = \Delta p/\Delta t$.

5 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 4 Solutions PDF.

5.1 Level 1: Basic Level (25 Questions)

1. State Newton's First Law of Motion. What property does it define?
2. What is inertia? Which physical quantity measures translational inertia?
3. Why does a passenger fall forward when a moving bus stops suddenly?
4. Define linear momentum $\vec{p}$ and write its SI unit and dimensions.
5. State Newton's Second Law of Motion and write its formula.
6. Define 1 Newton.
7. A 4 kg block accelerates at 3 m/s^2. Find the net force acting on it.
8. Define Impulse (J) and state its relation with momentum.
9. Why does a cricketer lower his hands while catching a fast ball?
10. State Newton's Third Law of Motion.
11. Why don't action and reaction forces cancel each other out?
12. State the Law of Conservation of Linear Momentum.
13. A 5 kg gun fires a 20 g bullet at 250 m/s. Find recoil speed of the gun.
14. What is static friction? Why is it called a self-adjusting force?
15. Write the formula for maximum static friction and kinetic friction.

16. Which is smaller: static friction, sliding (kinetic) friction, or rolling friction?
17. Define angle of friction (θ) and write its relation with μ_s.
18. Define angle of repose (α).
19. A 10 kg block rests on a horizontal floor ($\mu_s = 0.3, g = 10$). Find maximum static friction.
20. Write the formula for maximum safe speed on a level circular road of radius R.
21. Write the formula for optimum speed on a banked road of angle θ (without relying on friction).
22. A 1 kg stone is whirled in a horizontal circle of radius 1 m at 3 m/s. Find string tension.
23. What is a Free Body Diagram (FBD)?
24. A 10 kg body moves at constant velocity 5 m/s. What is the net force acting on it?
25. What was Aristotle's fallacy?

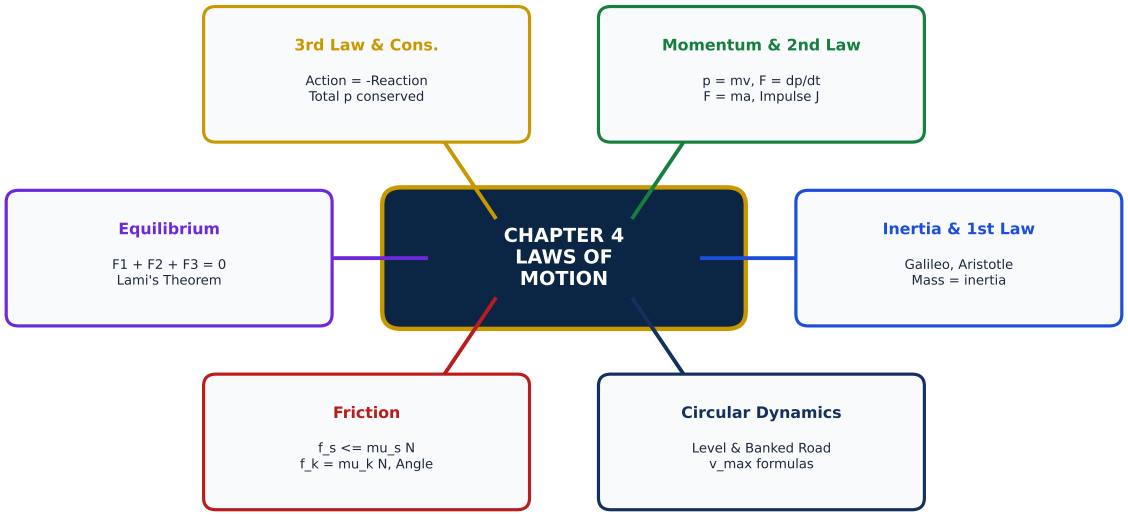
5.2 Level 2: Medium Level (25 Questions)

1. A 5 kg block rests on a floor ($\mu_s = 0.4, \mu_k = 0.3, g = 10$). Find friction if applied horizontal force is (a) 15 N, (b) 25 N.
2. A 0.15 kg ball hits a wall normally at 10 m/s and rebounds at 10 m/s. Find impulse imparted.
3. A 60 kg man stands in a lift accelerating upward at 2 m/s^2 ($g = 10$). Find his apparent weight.
4. In Q3, if the lift accelerates downward at 4 m/s^2, find apparent weight.
5. Two masses 4 kg and 6 kg hang over a smooth pulley ($g = 10$). Find acceleration and string tension.
6. A 20 kg trolley on a table ($\mu_k = 0.04$) is pulled by a 3 kg hanging mass ($g = 10$). Find a and T.
7. Two blocks 2 kg and 3 kg on a smooth floor are pushed by 10 N on 2 kg. Find contact force between them.
8. A 10 kg block slides down a 30° rough incline ($\mu_k = 0.2, g = 10$). Find its acceleration.
9. A 1000 kg car turns a flat curve of radius 40 m ($\mu_s = 0.4, g = 10$). Find max safe speed.
10. A banked track of radius 300 m has angle 15° ($\tan 15° = 0.268, g = 9.8$). Find optimum speed.
11. A 40 kg monkey climbs a rope that can bear max tension 600 N ($g = 10$). Find max upward acceleration.
12. If $\vec{F} = 6\hat{i} - 8\hat{j} + 10\hat{k}$ N gives $a = 1$ m/s^2, find mass of the body.
13. A particle has momentum $p = 2t^2 + 3t$ (SI). Find force at $t = 2$ s.
14. A 10 g bullet at 200 m/s embeds in a 990 g wooden block at rest. Find common speed.
15. A bullet of 0.04 kg at 90 m/s stops in 60 cm inside a block. Find average resistive force.
16. Why are ball bearings used in rotating machines?
17. A body of mass 2 kg moves with $\vec{v} = 3\hat{i} + 4\hat{j}$ m/s. Find magnitude of momentum.
18. A bomb at rest explodes into two equal fragments. Show they move in opposite directions with equal speed.
19. Why does a cyclist bend inward while taking a turn?
20. Find minimum acceleration of a train so that a box on its floor starts slipping ($\mu_s = 0.15, g = 10$).
21. Area under F-t graph is a triangle of base 4 s and height 10 N. Find change in momentum.
22. A 2 kg object is acted on by $\vec{F}_1 = 3\hat{i} + 4\hat{j}$ and $\vec{F}_2 = \hat{i} - \hat{j}$ N. Find $|a|$.
23. A 1500 kg car accelerates from 0 to 20 m/s in 10 s. Find driving force.
24. What is the reading of a spring balance if a 5 kg mass hangs in a freely falling lift?
25. How does a lubricant reduce friction?

5.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. A 5000 kg rocket is set for vertical firing with exhaust speed 800 m/s. Find fuel burn rate to give upward acceleration 20 m/s^2 ($g = 10$).
2. A 2 kg block is pressed against a vertical wall ($\mu_s = 0.5, g = 10$) by horizontal force F. Find minimum F to hold it.
3. A uniform chain of length L and mass M lies on a rough table (μ_s). What maximum fraction can hang over the edge?
4. Find the minimum force F required to just pull a block of mass m on a rough horizontal floor (μ_s).
5. A 6 kg mass hangs from a 2 m rope. A horizontal force of 50 N pulls the midpoint ($g = 10$). Find angle of upper rope with vertical.
6. A batsman deflects a 0.15 kg ball by 45° without changing its speed 15 m/s. Find impulse imparted.
7. Two blocks $m_1 = 2$ kg, $m_2 = 4$ kg rest on a smooth floor, connected by a string. m_2 is pulled by 18 N. If string breaks above 10 N, does it break?
8. A block of mass m is placed on a smooth wedge of inclination θ. What horizontal acceleration a must the wedge be given so the block stays stationary on it?
9. In Q8, what is the normal reaction between the block and the wedge?
10. A 0.25 kg stone tied to a 1.5 m string whirls at 40 rpm. If max tension is 200 N, find max speed.
11. A 4 kg block has x-t graph with slopes 0 ($t < 0$), 0.75 m/s ($0 < t < 4$), 0 ($t > 4$). Find impulses at $t = 0$ and $t = 4$ s.
12. A disc of mass m is kept floating horizontally in mid-air by firing n bullets/sec of mass m_b each at speed v (elastic rebound). Find v.
13. A block slides down a rough incline of angle 45° in twice the time it takes on a smooth incline of same angle. Find μ_k.
14. Three masses 1 kg, 2 kg, 3 kg are connected by strings on a smooth horizontal table and pulled by 12 N on 3 kg. Find both tensions.
15. A banked road ($R = 100$ m, $\theta = 45°$, $\mu_s = 0.5$, $g = 10$). Find maximum safe speed.
16. A 3 kg mass explodes into 1 kg and 2 kg. 1 kg moves at 12 m/s. Find KE of 2 kg piece.
17. A machine gun fires 30 g bullets at 600 m/s at 5 bullets/s. Find average force needed to hold the gun.
18. A block of mass m rests on a rough incline ($\theta <$ angle of repose). What is the friction force?
19. If a body is in equilibrium under three concurrent forces $\vec{F}_1, \vec{F}_2, \vec{F}_3$, state Lami's Theorem.
20. A particle of mass 2 kg is acted on by $F(t) = 6t^2$ N from $t = 0$ to $t = 2$ s starting from rest. Find speed at $t = 2$ s.
21. A conveyor belt moves at 2 m/s. Sand drops on it at 5 kg/s. Find extra force needed to keep belt moving at 2 m/s.
22. Two masses m_1 and m_2 hang over a pulley; m_1 is on a smooth 30° incline and m_2 hangs vertically. Find m_2/m_1 for equilibrium.
23. A painter of mass 60 kg stands on a 20 kg platform suspended by a rope over a pulley, holding the other end ($g = 10$). Find tension to hold himself at rest.
24. In Q23, if the painter pulls with 440 N, find upward acceleration.
25. Why is it easier to pull a lawn roller than to push it?

6 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Newton's 3 Laws, Momentum Conservation, Equilibrium, Friction (static & kinetic), and Circular Dynamics on level & banked roads.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 4 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: LAWS OF MOTION

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

7 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. Every body continues in its state of rest or uniform straight-line motion unless acted upon by a net external force. It defines **Inertia** and gives the qualitative definition of force.

2. Inertia is the natural resistance of a body to any change in its state of rest or motion. **Mass** is the quantitative measure of translational inertia.

3. Due to **inertia of motion**: the lower body stops with the bus, while the upper body tends to keep moving forward.

4. $\vec{p} = m\vec{v}$. SI unit: kg m s^{-1} (or N s); Dimensions: $[MLT^{-1}]$.

5. The rate of change of momentum is directly proportional to the applied force and takes place in the direction of force: $\vec{F} = \frac{d\vec{p}}{dt} = m\vec{a}$ (for constant mass).

6. The force that produces an acceleration of 1 m/s^2 in a body of mass 1 kg (1 N = 1 kg m s^{-2}).

7. $F = ma = 4 \times 3 = \mathbf{12}$ N.

8. Impulse is the product of force and short time duration: $J = F\Delta t = \Delta p$ (change in momentum). SI unit: N s.

9. Increasing the time of impact (Δt) reduces the average force ($F = \Delta p/\Delta t$), preventing injury.

10. To every action, there is always an equal and opposite reaction: $\vec{F}_{AB} = -\vec{F}_{BA}$ (acting on **two different bodies**).

11. Because they act on **two different bodies**, whereas forces can only cancel if they act on the same body.

12. If the net external force on a system is zero ($\vec{F}_{ext} = 0$), total linear momentum remains constant: $\vec{p}_{initial} = \vec{p}_{final}$.

13. $MV = mv \implies 5V = 0.02 \times 250 = 5 \implies V = \mathbf{1}$ m/s.

14. Friction that opposes impending motion when a body is at rest. It adjusts its magnitude to match the applied force up to a maximum limit ($f_s \leq \mu_s N$).

15. $f_{s,max} = \mu_s N$; $\quad f_k = \mu_k N$ (where $\mu_k < \mu_s$).

16. **Rolling friction** is the smallest (typically 10^{-2} to 10^{-3} times sliding friction).

17. Angle between resultant contact force and normal reaction at limiting friction: $\tan\theta = \mu_s$.

18. The minimum angle of an inclined plane at which a body placed on it just begins to slide: $\tan\alpha = \mu_s$.

19. $N = mg = 100$ N $\implies f_{s,max} = 0.3 \times 100 = \mathbf{30}$ N.

20. $v_{max} = \sqrt{\mu_s Rg}$.

21. $v_0 = \sqrt{Rg\tan\theta}$.

22. $T = \frac{mv^2}{r} = \frac{1(9)}{1} = \mathbf{9}$ N.

23. A simplified sketch of a single body isolated from its surroundings, showing all external forces acting *on* it.

24. $a = 0 \implies F_{net} = \mathbf{0}$ N.

25. Aristotle wrongly believed an external force is needed to keep a body in uniform motion, forgetting that friction is an opposing force.

8 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $f_{s,max} = 0.4(50) = 20$ N. (a) Since $15 < 20$, block stays at rest, so friction = **15** N. (b) Since $25 > 20$, block slides, so friction = $f_k = 0.3(50) = \mathbf{15}$ N.
2. $J = m(v-u) = 0.15(10-(-10)) = \mathbf{3.0}$ N s.
3. $N = m(g+a) = 60(10+2) = \mathbf{720}$ N (72 kg-wt).
4. $N = m(g-a) = 60(10-4) = \mathbf{360}$ N (36 kg-wt).
5. $a = \frac{6-4}{6+4}(10) = \mathbf{2}$ m/s^2. $T = \frac{2(4)(6)(10)}{10} = \mathbf{48}$ N.
6. $a = \frac{30-0.04(200)}{23} = \frac{22}{23} \approx \mathbf{0.96}$ m/s^2. $T = 3(10-0.96) = \mathbf{27.1}$ N.
7. $a = 10/5 = 2$ m/s^2. Contact force pushes 3 kg: $N = 3 \times 2 = \mathbf{6}$ N.
8. $a = g(\sin 30° - 0.2\cos 30°) = 10(0.5 - 0.173) = \mathbf{3.27}$ m/s^2.
9. $v_{max} = \sqrt{0.4 \times 40 \times 10} = \sqrt{160} \approx \mathbf{12.65}$ m/s.
10. $v_0 = \sqrt{300(9.8)(0.268)} = \mathbf{28.1}$ m/s.
11. $T - mg = ma \implies 600 - 400 = 40a \implies a = \mathbf{5}$ m/s^2.
12. $|F| = \sqrt{36+64+100} = 10\sqrt{2}$ N $\implies m = \mathbf{10\sqrt{2}}$ kg.
13. $F = dp/dt = 4t + 3$. At $t = 2$: $F = 8 + 3 = \mathbf{11}$ N.
14. $0.01(200) = (0.01 + 0.99)v \implies v = \mathbf{2}$ m/s.
15. $a = -90^2/(2 \times 0.6) = -6750$ m/s^2 $\implies F = 0.04 \times 6750 = \mathbf{270}$ N.
16. They replace high sliding friction with very low rolling friction, saving energy and reducing wear.
17. $|v| = 5$ m/s $\implies p = 2 \times 5 = \mathbf{10}$ kg m/s.
18. $0 = m\vec{v}_1 + m\vec{v}_2 \implies \vec{v}_1 = -\vec{v}_2$.
19. To tilt the normal reaction N so its horizontal component $N\sin\theta$ provides centripetal force without slipping.
20. $a_{min} = \mu_s g = 0.15 \times 10 = \mathbf{1.5}$ m/s^2.
21. $\Delta p = \text{Area} = \frac{1}{2}(4)(10) = \mathbf{20}$ N s.
22. $\vec{F}_{net} = 4\hat{i} + 3\hat{j}$, $|F| = 5$ N $\implies a = 5/2 = \mathbf{2.5}$ m/s^2.
23. $a = 2$ m/s^2 $\implies F = 1500 \times 2 = \mathbf{3000}$ N.
24. $N = T = m(g-g) = \mathbf{0}$ N (weightlessness).
25. It forms a thin fluid film between solid surfaces, replacing dry solid-solid interlocking with low fluid shear.

9 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $v_{rel}\frac{dm}{dt} = m(g+a) \implies 800\frac{dm}{dt} = 5000(30) \implies \frac{dm}{dt} = \mathbf{187.5}$ kg/s.
2. $N = F$; to prevent falling, $f_s = mg \implies \mu_s F = 20 \implies F = 20/0.5 = \mathbf{40}$ N.
3. Hanging weight = $\frac{M}{L}xg$; max friction = $\mu_s\frac{M}{L}(L-x)g$. Equating: $x = \mu_s(L-x) \implies \frac{x}{L} = \frac{\mu_s}{1+\mu_s}$.
4. Pulling at angle $\theta = \tan^{-1}(\mu_s)$ minimizes F: $F_{min} = \frac{\mu_s mg}{\sqrt{1+\mu_s^2}}$.
5. $T_2 = 60$ N. At midpoint: $T_1\cos\theta = 60$, $T_1\sin\theta = 50 \implies \tan\theta = 5/6 \implies \theta \approx \mathbf{40}°$.
6. $J = 2mv\sin(45°/2)$? Wait: deflection $\delta = 45° \implies \Delta v = 2v\sin(22.5°)$ or $2v\cos(67.5°)$? Actually $|\vec{v}_f - \vec{v}_i| = 2v\sin(\theta_{defl}/2)$? Wait: if angle between $\vec{v}_i$ and $\vec{v}_f$ is 45°, $|\Delta v| = 2v\sin(22.5°) = 1.72$ N s; if deflected by 45° back towards bowler (135° turn), $J = 2(0.15)(15)\cos(22.5°) = \mathbf{4.16}$ N s (NCERT Ex 4.20).

7. $a = 18/6 = 3$ m/s^2. $T = m_1 a = 2(3) = 6$ N < 10 N, so **no, it does not break**.
8. Pseudo force $ma\cos\theta$ balances $mg\sin\theta \implies a = \mathbf{g}\tan\theta$.
9. $N = mg\cos\theta + ma\sin\theta = mg\cos\theta + mg\frac{\sin^2\theta}{\cos\theta} = \mathbf{\frac{mg}{\cos\theta}}$.
10. $v_{max} = \sqrt{\frac{T_{max} r}{m}} = \sqrt{\frac{200\times 1.5}{0.25}} = \sqrt{1200} = \mathbf{34.6}$ m/s.
11. At $t = 0$: $J = 4(0.75 - 0) = +\mathbf{3}$ N s. At $t = 4$: $J = 4(0 - 0.75) = -\mathbf{3}$ N s.
12. Force $= 2nm_b v = mg \implies v = \mathbf{\frac{mg}{2nm_b}}$.
13. $t \propto 1/\sqrt{a} \implies a_{rough} = a_{smooth}/4$. $g(\sin 45^\circ - \mu_k \cos 45^\circ) = \frac{1}{4} g \sin 45^\circ \implies 1 - \mu_k = 1/4 \implies \mu_k = \mathbf{0.75}$.
14. $a = 12/6 = 2$ m/s^2. $T_1 = 1(2) = \mathbf{2}$ N; $T_2 = (1+2)(2) = \mathbf{6}$ N.
15. $v_{max} = \sqrt{100(10)\frac{0.5+1}{1-0.5(1)}} = \sqrt{3000} = \mathbf{54.77}$ m/s.
16. $p_2 = p_1 = 12$ kg m/s $\implies K_2 = \frac{p_2^2}{2m_2} = \frac{144}{4} = \mathbf{36}$ J.
17. $F = nmv = 5 \times 0.03 \times 600 = \mathbf{90}$ N.
18. Since it is at rest, static friction equals the downhill gravity component: $\mathbf{mg}\sin\theta$ (NOT $\mu_s mg\cos\theta$!).
19. $\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$, where α, β, γ are angles opposite to $\vec{F}_1, \vec{F}_2, \vec{F}_3$.
20. $J = \int_0^2 6t^2\,dt = [2t^3]_0^2 = 16$ N s $\implies v = J/m = 16/2 = \mathbf{8}$ m/s.
21. $F = v\frac{dm}{dt} = 2 \times 5 = \mathbf{10}$ N.
22. $m_2 g = m_1 g \sin 30^\circ \implies m_2/m_1 = \mathbf{0.5}$.
23. Two rope segments support $(60+20)g = 800$ N $\implies 2T = 800 \implies T = \mathbf{400}$ N.
24. $2(440) - 800 = 80a \implies a = 80/80 = \mathbf{1}$ m/s$^\mathbf{2}$.
25. Pulling has an upward vertical component ($F\sin\theta$) that reduces Normal reaction $N = mg - F\sin\theta$ and friction, whereas pushing increases $N = mg + F\sin\theta$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 5 (SELF-STUDY MASTER EDITION)

WORK, ENERGY AND POWER

Complete Zero-Omission Coverage of NCERT `keph105.pdf` (Sections 5.1–5.11, Tables 5.1–5.2, Fig 5.1–5.15, Ex 5.1–5.12, Exercises 5.1–5.23)

CBSE 2026–27 Weightage & Scope: Unit IV: Work, Energy and Power (Part of 17 Marks for Units IV–VI)

[CONCEPT CORE] Self-Study Promise: Zero Teacher Needed

In Chapter 5, you will learn why Force × Displacement (Work) is the currency of Energy, how Kinetic and Potential Energy trade back and forth, and how Power and Collisions work in both 1D and 2D. Every formula is derived step by step with Long Method + Short Trick solutions.

1 Topic 1: Scalar (Dot) Product, Work & Kinetic Energy (NCERT Sections 5.1–5.4)

1.1 Step 1: Definitions, Derivations & Plain-English Meaning

- **Scalar (Dot) Product (5.1.1):** A way of multiplying two vectors $\vec{A}$ and $\vec{B}$ to get a **scalar** number:

$$\vec{A} \cdot \vec{B} = AB\cos\theta = A_xB_x + A_yB_y + A_zB_z$$

  Notice that $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$ and $\hat{i}\cdot\hat{j} = 0$. Geometrically, $\vec{A}\cdot\vec{B}$ is A times the projection of $\vec{B}$ onto $\vec{A}$.

- **Work (W, Section 5.3):** In everyday life, holding a heavy bag feels tiring, but in physics **Work** is done ONLY when a force causes displacement along its direction:

$$W = \vec{F}\cdot\vec{d} = Fd\cos\theta \quad \text{(SI: Joule [1 J = 1 N m]}, \quad [\mathrm{ML^2T^{-2}}])$$

  - **Positive Work ($0^\circ \le \theta < 90^\circ$):** Force aids motion (e.g., gravity on a falling apple).
  - **Zero Work ($\theta = 90^\circ$ or $d = 0$):** Force is perpendicular to motion (e.g., centripetal force in UCM, coolie walking horizontally).
  - **Negative Work ($90^\circ < \theta \le 180^\circ$):** Force opposes motion (e.g., friction on a sliding block).

- **Kinetic Energy (K, Section 5.4):** Energy possessed by a body due to its motion: $K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$.

2 Topic 2: Variable Force Work & Work-Energy Theorem (NCERT Sections 5.5–5.6)

2.1 Step 1: Derivation of Work-Energy Theorem

For a variable force $F(x)$, we divide displacement into tiny steps dx and sum (integrate): $W = \int_{x_i}^{x_f} F(x)\,dx$ (which equals the **area under the F-x curve**). By Newton's 2nd Law, $F = m\frac{dv}{dt} = mv\frac{dv}{dx} \implies F\,dx = mv\,dv$. Integrating from initial speed u to final speed v:

$$W_{net} = \int_{x_i}^{x_f} F\,dx = \int_u^v mv\,dv = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \mathbf{K_f - K_i = \Delta K}$$

This is the **Work-Energy Theorem**: net work done by ALL forces equals the change in kinetic energy!

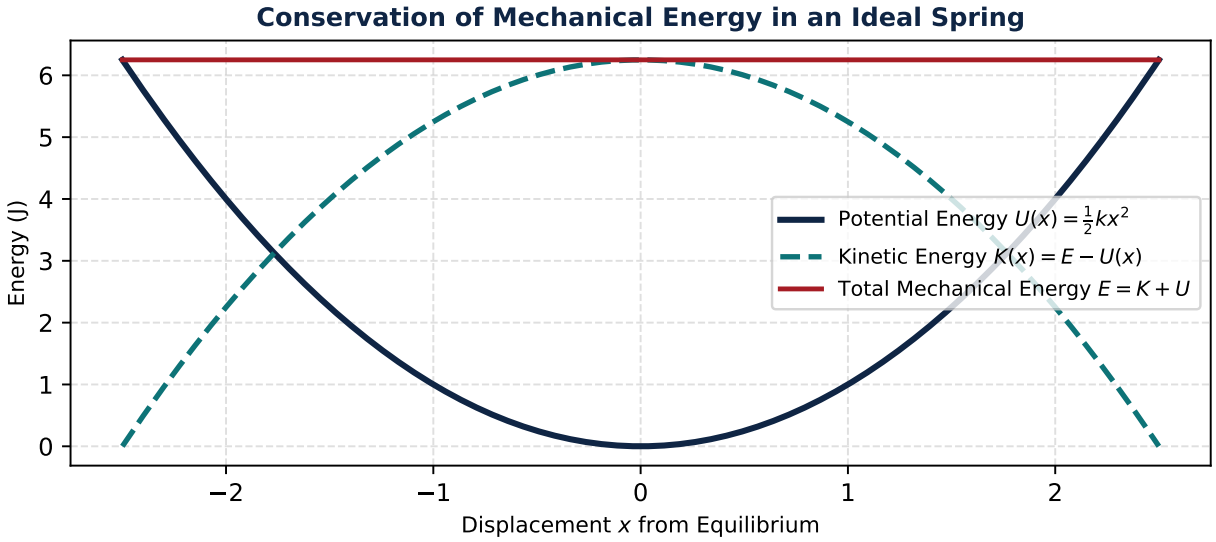


Diagram Explanation (Covers NCERT Figs. 5.4–5.9): Left shows work of a variable force as the shaded area under the F-x curve. Right shows spring restoring force $F_s = -kx$ and parabolic spring potential energy $U_s = \frac{1}{2}kx^2$.

3 Topic 3: Potential Energy, Springs, Power & Collisions (NCERT Sections 5.7–5.11)

3.1 Step 1: Conservative Forces, Mechanical Energy & Power

- **Conservative Force:** Work done depends only on initial and final positions, not the path (zero over any closed loop). Examples: Gravity, Spring force. For any conservative force, $F(x) = -\frac{dU}{dx}$.
- **Potential Energy (U):** Stored energy of position/configuration. Gravitational PE: $U_g = mgh$. Spring PE (5.9): $U_s = \int_0^x kx\,dx = \frac{1}{2}kx^2$.
- **Conservation of Mechanical Energy (5.8):** When only conservative forces do work, $K + U =$ constant. In a vertical circle of radius R, minimum speeds to complete the loop are $v_{top} = \sqrt{gR}$ and $v_{bot} = \sqrt{5gR}$.
- **Power (P, Section 5.10):** Rate of doing work: $P = \frac{dW}{dt} = \vec{F} \cdot \vec{v}$ (SI: Watt, $[ML^2T^{-3}]$; 1 hp = 746 W, 1 kWh $= 3.6 \times 10^6$ J).

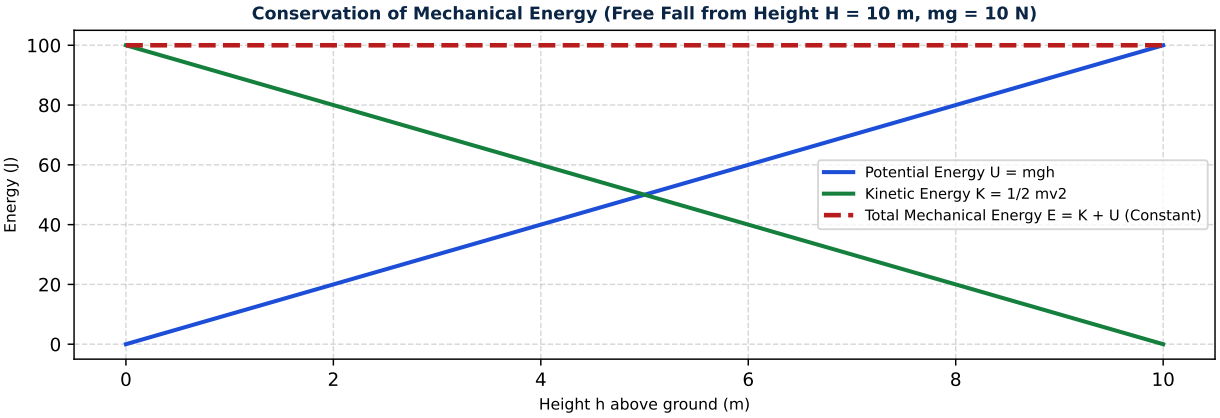


Diagram Explanation: Plots $U = mgh$ and $K = \frac{1}{2}mv^2$ trading off during free fall while total energy $E = K + U$ stays constant.

3.2 Step 2: Collisions in 1D & 2D (Section 5.11)

- **Elastic Collision ($e = 1$):** Both **momentum** and **kinetic energy** are conserved. For 1D head-on collision:

$$v_1 = \frac{(m_1 - m_2)u_1 + 2m_2u_2}{m_1 + m_2}, \qquad v_2 = \frac{(m_2 - m_1)u_2 + 2m_1u_1}{m_1 + m_2}$$

(*Special cases:* If $m_1 = m_2$, they exchange velocities! If $m_1 \gg m_2$ and $u_2 = 0$, $v_2 \approx 2u_1$.)

- **Completely Inelastic Collision ($e = 0$):** Bodies stick together at common speed $v = \frac{m_1u_1+m_2u_2}{m_1+m_2}$, with KE loss $\Delta K_{loss} = \frac{1}{2}\frac{m_1m_2}{m_1+m_2}(u_1-u_2)^2$.

Example 5.1A (Momentum-KE Shortcut) **[NEET / Board]**

Problem: If the kinetic energy of a body increases by 300%, by what percentage does its linear momentum increase?

Solution: Long Method: $K_2 = K_1 + 3K_1 = 4K_1$. Since $p = \sqrt{2mK}$, $p_2 = \sqrt{2m(4K_1)} = 2p_1$. % increase $= \frac{2p_1-p_1}{p_1} \times 100 = \mathbf{100}\%$.

Short Trick: $K \to 4K \implies p \to \sqrt{4}p = 2p$ (+100%).

4 Complete NCERT Examples (5.1–5.12) & Back Exercises (5.1–5.23) with Full Questions

4.1 NCERT Solved Examples (5.1–5.12)

1. **Example 5.1:** Find the angle between force $\vec{F} = (3\hat{i}+4\hat{j}-5\hat{k})$ unit and displacement $\vec{d} = (5\hat{i}+4\hat{j}+3\hat{k})$ unit. Also find the projection of $\vec{F}$ on $\vec{d}$.
   Solution: $\vec{F}\cdot\vec{d} = 15+16-15 = 16$. $|F| = \sqrt{50}, |d| = \sqrt{50} \implies \cos\theta = 16/50 = 0.32 \implies \theta \approx \mathbf{71.3}°$. Projection $= 16/\sqrt{50} = \mathbf{2.26}$ units.

2. **Example 5.2:** A raindrop of radius 2 mm ($m = 3.35 \times 10^{-5}$ kg) falls from 500 m, reaching 10 m/s ($g = 10$). Find work done by gravity and by resistive force.
   Solution: $W_g = mgh = \mathbf{0.168}$ J. $\Delta K = \frac{1}{2}mv^2 = 0.00168$ J $\implies W_{res} = 0.00168 - 0.168 = \mathbf{-0.166}$ J.

3. **Example 5.3:** A cyclist comes to a skidding stop in 10 m under road force 200 N. How much work does the road do on the cycle, and the cycle on the road?
   Solution: $W_{road\to cycle} = -200 \times 10 = \mathbf{-2000}$ J. Road has zero displacement $\implies W_{cycle\to road} = \mathbf{0}$ J.

4. **Example 5.4:** A 1 kg block moves with $v_i = 2$ m/s into a rough patch ($x = 0.1$ m to 2.01 m) with $F_r = -k/x$ ($k = 0.5$ J). Find final speed.
   Solution: $W_r = -\int_{0.1}^{2.01} \frac{0.5}{x}\,dx = -0.5\ln(20.1) = -1.5$ J. $K_f = 2 - 1.5 = 0.5$ J $\implies v_f = \mathbf{1}$ m/s.

5. **Example 5.5:** A bob of mass m suspended by a string of length L is given horizontal speed $v_0 = \sqrt{5gL}$ at lowest point A. Obtain speeds at horizontal B and top C, and ratio K_B/K_C.
   Solution: $v_C = \sqrt{gL}$, $v_B = \sqrt{3gL}$, so $K_B/K_C = v_B^2/v_C^2 = \mathbf{3:1}$.

6. **Example 5.6:** A 1000 kg car travelling at 18 km/h (5 m/s) hits a horizontally mounted spring ($k = 6.25 \times 10^3$ N/m). What is the maximum compression?
   Solution: $\frac{1}{2}kx^2 = \frac{1}{2}mv^2 \implies x = 5\sqrt{1000/6250} = \mathbf{2.0}$ m.

7. **Example 5.7:** Repeat Example 5.6 taking coefficient of friction $\mu = 0.5$ ($f = 2000$ N).
   Solution: $\frac{1}{2}(6250)x^2 + 2000x = 12500 \implies x = \mathbf{1.35}$ m.

8. **Example 5.8:** An elevator of mass 1800 kg moves up at constant 2 m/s against 4000 N friction ($g = 10$). Determine minimum power of the motor.
   Solution: $F = 18000 + 4000 = 22000$ N $\implies P = Fv = 22000 \times 2 = \mathbf{44}$ kW (≈ 59 hp).

9. **Example 5.9:** In a nuclear reactor, a neutron (m_n) hits a stationary (a) deuterium ($2m_n$) or (b) carbon ($12m_n$) nucleus elastically. Find fraction of KE transferred.
   Solution: $f = \frac{4m_1m_2}{(m_1+m_2)^2}$. (a) $\frac{8}{9} \approx \mathbf{89}\%$; (b) $\frac{48}{169} \approx \mathbf{28.4}\%$.

10. **Example 5.10:** Two identical billiard balls collide in 2D (one initially at rest, elastic). Show they move at 90° to each other.
    Solution: From $\vec{p}_i = \vec{p}_1 + \vec{p}_2$ and $p_i^2 = p_1^2 + p_2^2 \implies 2\vec{p}_1\cdot\vec{p}_2 = 0 \implies \theta_1 + \theta_2 = \mathbf{90}°$.

11. **Example 5.11:** Express 1 MeV in Joules.
    Solution: 1 MeV $= 10^6 \times 1.6 \times 10^{-19} = \mathbf{1.6 \times 10^{-13}}$ J.

12. **Example 5.12:** A 50 kg girl climbs 10 m stairs in 20 s ($g = 10$). Find power.
    Solution: $P = \frac{50\times10\times10}{20} = \mathbf{250}$ W.

4.2 NCERT Back Exercises (5.1–5.23) — Full Questions & Solutions

1. **Q 5.1:** State if work done is positive, negative, or zero: (a) man lifting bucket by rope, (b) gravity in (a), (c) friction on body sliding down incline, (d) applied force on body on rough horizontal plane, (e) resistive force of air on vibrating pendulum.
Solution: (a) **+**; (b) **−**; (c) **−**; (d) **+**; (e) **−**.

2. **Q 5.2:** A 2 kg body initially at rest moves under 7 N horizontal force on a table ($\mu_k = 0.1, g = 9.8$) for 10 s. Compute (a) W_F, (b) W_f, (c) W_{net}, (d) ΔK.
Solution: $f = 0.1(19.6) = 1.96$ N, $a = (7 - 1.96)/2 = 2.52$ m/s^2, $d = \frac{1}{2}(2.52)(100) = 126$ m. (a) **882** J; (b) **−247** J; (c) **635** J; (d) **635** J.

3. **Q 5.3:** Given potential energy curves $V(x)$ in NCERT Fig. 5.11, specify regions where particle cannot be found for total energy E.
Solution: Since $K = E - V(x) \geq 0$, particle cannot exist where $V(x) > E$.

4. **Q 5.4:** Potential energy of particle of mass 1 kg has $E = 2$ J: identify regions a, b, c, d with $V > E$.
Solution: (a) a; (b) b; (c) a; (d) b (matching turning points).

5. **Q 5.5–5.6:** Conceptual fill-in-the-blanks on Work-Energy, Conservative forces, and Collisions.
Solution: 5.5: (a) decrease, (b) kinetic energy, (c) external forces, (d) total linear momentum. 5.6: (a) increases/decreases, (b) conservative, (c) external, (d) total linear momentum.

6. **Q 5.7:** True/False on collisions and mechanical energy conservation.
Solution: (a) **False** (total energy is conserved); (b) **False** (gravity does zero work in horizontal motion); (c) **False** (KE is not conserved in inelastic collision); (d) **False** (internal forces can change KE).

7. **Q 5.8:** Answer carefully: (a) Why does rocket casing burn up? (b) What is conserved for a comet? (c) Satellite spiraling down? (d) Man carrying suitcase.
Solution: (a) Air friction converts mechanical energy to heat. (b) Angular momentum and total energy. (c) Total energy decreases due to drag, KE increases! (d) Zero work by gravity/normal force.

8. **Q 5.9:** A body constrained to move along z-axis is subjected to $\vec{F} = -\hat{i} + 2\hat{j} + 3\hat{k}$ N. Find work done in moving 4 m along z-axis.
Solution: $W = \vec{F} \cdot (4\hat{k}) = 3(4) = \mathbf{12}$ J.

9. **Q 5.10:** An electron and a proton are detected with $K_e = 10$ keV and $K_p = 100$ keV. Which is faster? Obtain ratio of speeds.
Solution: $v_e/v_p = \sqrt{\frac{m_p K_e}{m_e K_p}} = \sqrt{\frac{1836 \times 10}{100}} = \mathbf{13.54}$ (electron is faster).

10. **Q 5.11:** A raindrop of mass 1.0 g falls from 1 km height and hits ground at 50 m/s ($g = 10$). Find work done by gravity and air resistance.
Solution: $W_g = 10$ J, $\Delta K = 1.25$ J $\implies$ $W_{air} = \mathbf{-8.75}$ J.

11. **Q 5.12:** A molecule of mass 4.65×10^{-26} kg moving at 500 m/s hits a wall elastically. What is its rebound speed?
Solution: Elastic collision with massive wall $\implies$ rebounds at **same speed 500 m/s**.

12. **Q 5.13:** A pump on the ground floor pumps 30 m^3 of water to a tank 40 m high in 15 min (efficiency 30%). How much electric power is consumed?
Solution: $m = 30000$ kg, $P_{out} = \frac{30000 \times 9.8 \times 40}{900} = 13.07$ kW $\implies$ $P_{in} = 13.07/0.30 = \mathbf{43.6}$ kW.

13. **Q 5.14:** Two identical ball bearings in contact are hit head-on by a third identical ball bearing. Which collision outcome is valid?
Solution: **Case (ii)** (only one ball moves off with speed v, conserving both p and K).

14. **Q 5.15:** Bob A of a pendulum released from 30° hits identical bob B at rest elastically. How high does A rise after collision?
Solution: Equal masses exchange velocities: A **comes to rest** (0 height) and B rises to the same height.

15. **Q 5.16:** A bob of mass m on a 1.5 m string is released from horizontal position. What is its speed at the lowest point?
Solution: $v = \sqrt{2gL} = \sqrt{2(9.8)(1.5)} = \mathbf{5.42}$ m/s (independent of m).

16. **Q 5.17:** A trolley of mass 200 kg moves at 36 km/h (10 m/s). A 20 kg child runs on it at 4 m/s opposite to trolley's motion and jumps out. Find final speed of trolley.
Solution: Momentum conservation: $220(10) = 200v' + 20(v' - 4)$ $\implies$ $220v' = 2280$ $\implies$ $v' = \mathbf{10.36}$ m/s.

17. **Q 5.18:** Two 2 kg blocks on a track with spring ($k = 100$ N/m) and rough patch ($\mu = 0.1$): apply Work-Energy Theorem.
Solution: $\Delta K + \Delta U_s = W_{friction} = -\mu mgd$.

18. **Q 5.19:** A windmill with blade area 30 m^2 receives wind at 36 km/h (10 m/s), $\rho = 1.2$ kg/m^3, efficiency 25%. Find electrical power.
Solution: $m/t = \rho Av = 360$ kg/s; $K/t = \frac{1}{2}(360)(100) = 18$ kW; $P_{elec} = 0.25(18) = \mathbf{4.5}$ kW.

19. **Q 5.20:** A 50 kg person lifts a 10 kg mass 1000 times by 0.5 m ($g = 9.8$). Fat supplies 3.8×10^7 J/kg at 20% efficiency. Find fat used.
Solution: $W = 1000(10)(9.8)(0.5) = 49$ kJ; Fat $= \frac{49000}{0.20 \times 3.8 \times 10^7} = \mathbf{6.45}$ g (or **12.9** g if lowering counts).

20. **Q 5.21:** A family uses 8 kW power. Solar energy incident is 200 W/m^2 (20% efficiency). Find roof area needed.
Solution: Useful power $= 0.20 \times 200 = 40$ W/m^2 $\implies$ Area $= 8000/40 = \mathbf{200}$ m^2.

21. **Q 5.22:** A 0.012 kg bullet at 70 m/s embeds into a 0.4 kg hanging wood block. Find height risen and heat produced.
Solution: $V = \frac{0.012(70)}{0.412} = 2.04$ m/s, $h = \frac{V^2}{2g} = \mathbf{0.212}$ m, Heat $= K_i - K_f = \mathbf{28.5}$ J.

22. **Q 5.23:** Two frictionless tracks of same height h have different slopes. Compare final speeds and times of descent.
Solution: Both reach bottom with **same speed $\sqrt{2gh}$** (energy conservation); the steeper track takes **less time**.

5 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 5 Solutions PDF.

5.1 Level 1: Basic Level (25 Questions)

1. Define scalar (dot) product of two vectors $\vec{A}$ and $\vec{B}$.
2. What is the dot product of two perpendicular vectors?
3. Define Work and write its SI unit and dimensions.
4. When is work done positive, negative, and zero?
5. A coolie walks 10 m horizontally carrying a 20 kg load on his head. Find work done against gravity.
6. What is the work done by centripetal force in uniform circular motion?
7. Define Kinetic Energy and write its formula.
8. State the Work-Energy Theorem.
9. What does the area under a Force-Displacement (F-x) graph represent?
10. Define a conservative force with two examples.
11. Define a non-conservative force with two examples.
12. Write the formula for gravitational potential energy near Earth's surface.
13. Write the formula for elastic potential energy of a spring stretched by x.
14. State the Law of Conservation of Mechanical Energy.
15. Define Power and write its SI unit and dimensions.
16. Convert 1 kWh into Joules.

17. How many Watts are in 1 Horsepower (hp)?
18. Convert 1 eV into Joules.
19. A 2 kg ball moves at 5 m/s. Find its kinetic energy.
20. A 10 kg block is lifted 5 m in 10 s ($g = 10$). Find average power.
21. What is an elastic collision?
22. What is a completely inelastic collision?
23. Two equal masses collide head-on elastically. What happens to their velocities?
24. If $\vec{F} = (3\hat{i} + 4\hat{j})$ N and $\vec{d} = (2\hat{i} - \hat{j})$ m, find work done.
25. A car moves at 20 m/s against 500 N friction. Find engine power.

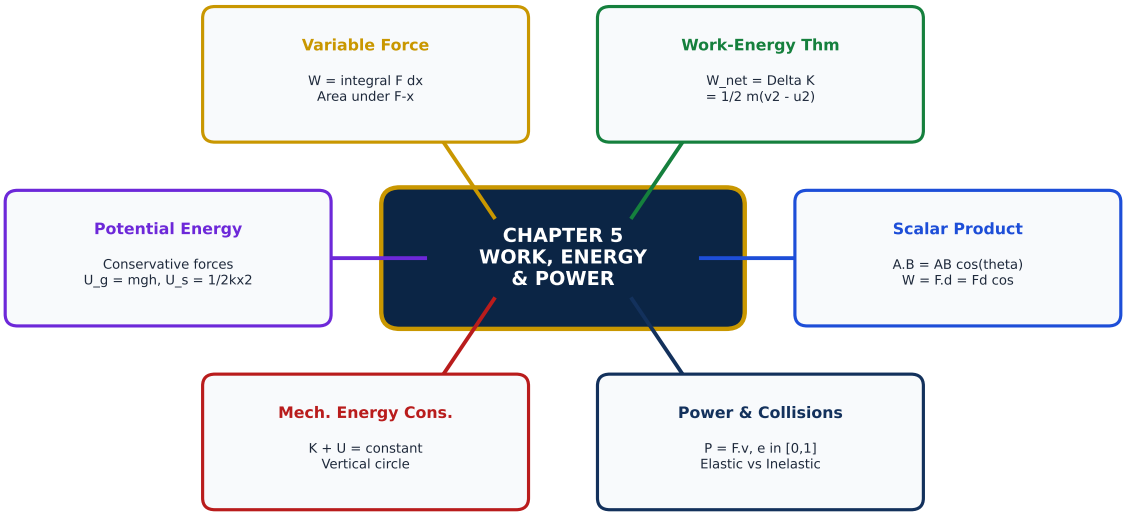
5.2 Level 2: Medium Level (25 Questions)

1. If linear momentum of a body is doubled, by what percentage does its kinetic energy increase?
2. If kinetic energy increases by 300%, by what percentage does momentum increase?
3. A light body and a heavy body have the same momentum. Which has more kinetic energy?
4. A light body and a heavy body have the same kinetic energy. Which has more momentum?
5. A force $F = 2x$ N acts on a body from $x = 0$ to $x = 4$ m. Find work done.
6. A 1 kg body accelerates from 3 m/s to 7 m/s. Find net work done.
7. A spring requires 100 N to stretch by 2 cm. Find k and energy stored when stretched by 5 cm.
8. A 0.5 kg ball moving at 4 m/s compresses a spring of $k = 50$ N/m. Find maximum compression.
9. A 4 kg mass at 6 m/s collides and sticks to a 2 kg mass at rest. Find common speed and KE loss.
10. A ball is dropped from 10 m and rebounds to 2.5 m. Find coefficient of restitution e.
11. A pump lifts 100 kg of water per minute to 6 m height ($g = 10$). Find power.
12. A 10 g bullet at 400 m/s pierces a 2 kg block at rest and exits at 100 m/s. Find block speed.
13. If $\vec{A} = 2\hat{i} + 3\hat{j}$ and $\vec{B} = -3\hat{i} + 2\hat{j}$, find angle between them.
14. A 2 kg bob on a 1 m string swings from horizontal position ($g = 10$). Find speed at lowest point.
15. Minimum speed at lowest and highest points of a vertical circle of radius R to just complete the loop:
16. A 1000 kg car hits a spring bumper ($k = 6.25 \times 10^3$ N/m) at 5 m/s. Find max compression.
17. An elevator of 1800 kg moves up at 2 m/s against 4000 N friction ($g = 10$). Find motor power.
18. Find work done in stretching a spring of constant k from x_1 to x_2.
19. A 60 W bulb runs 10 hours daily for 30 days. Find total energy in kWh.
20. Find angle between $\vec{F} = 3\hat{i} + 4\hat{j} - 5\hat{k}$ and $\vec{d} = 5\hat{i} + 4\hat{j} + 3\hat{k}$.
21. Why does a heavy truck take more stopping distance than a car at the same speed if braking force is same?
22. A body of 10 kg has momentum 20 kg m/s. Find its kinetic energy.
23. In a head-on elastic collision of a very heavy body (M) with a light body (m) at rest at speed u, find speed of m.
24. A force $F = 10 + 0.5x$ acts from $x = 0$ to $x = 2$ m. Find work done.
25. State conditions for stable, unstable, and neutral equilibrium using potential energy $U(x)$.

5.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. A spring of constant k is cut into two equal halves. Find the spring constant of each half.
2. Two springs $k_1 > k_2$ are stretched by (a) same distance x, (b) same force F. Which stores more energy in each case?
3. Potential energy of a particle is $U(x) = x^2 - 4x$. Find equilibrium position and its nature.
4. A body of mass m accelerates uniformly from rest to v_1 in t_1. Find instantaneous power at time t.
5. A particle of mass m moves in a circle of radius r with $a_c = k^2rt^2$. Find power delivered by net force at time t.
6. If kinetic energy $K = 2t^2$, show that the force acting on the particle is constant.
7. A 1 kg block with $v_i = 2$ m/s enters a rough patch ($x = 0.1$ to 2.01 m) with $F_r = -0.5/x$. Find final speed.
8. In a 2D elastic collision between two identical balls (one initially at rest), prove they separate at $90°$.
9. A neutron hits a stationary nucleus of mass number A head-on elastically. Find fraction of KE transferred.
10. A uniform chain of mass M, length L hangs 1/3 over a smooth table. Find work to pull the hanging part back onto the table.
11. A bullet $(0.012\text{ kg}, 70\text{ m/s})$ embeds into a 0.4 kg hanging wood block. Find max height h risen and heat produced.
12. A raindrop of mass 1 g falls from 1 km and hits ground at 50 m/s ($g = 10$). Find work done by air resistance.
13. A particle moves along x-axis from $x = 0$ to $x = 5$ m under $F = 7 - 2x + 3x^2$. Find work done.
14. If power delivered to a particle is constant P, how does its displacement s vary with time t from rest?
15. A machine delivers constant power P to a body of mass m starting from rest. Find acceleration as a function of time.
16. A ball is dropped from height h onto a floor with restitution e. Find total distance travelled before stopping.
17. A 2 kg block slides down a $30°$ smooth incline of height 5 m ($g = 10$) and compresses a spring ($k = 1000$ N/m) at bottom. Find max compression.
18. Can work done by static friction be positive? Give an example.
19. A car of mass m climbs a hill of slope $\sin\theta$ at constant speed v against friction f. Find engine power.
20. A particle of mass m is attached to a string of length L and whirled in a vertical circle. Find difference in tension between bottom and top.
21. If $U(r) = \frac{A}{r^2} - \frac{B}{r}$, find the equilibrium distance r_0.
22. A 2 kg body moves under $F = 4t$ N from rest. Find work done in first 2 s.
23. A windmill with blade area 30 m^2 receives wind at 10 m/s ($\rho = 1.2$ kg/m^3) at 25% efficiency. Find electrical power.
24. A block of mass m moves at v and collides elastically with a stationary block of mass M. For maximum energy transfer, what should M/m be?
25. A particle has $v = 4x^{1/2}$. Find work done by net force from $x = 0$ to $x = 4$ m ($m = 2$ kg).

6 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Scalar Product, Work-Energy Theorem, Variable Force Integration, Conservative Potential Energy, Mechanical Energy Conservation, Power, and Collisions.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 5 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: WORK, ENERGY AND POWER

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

7 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. $\vec{A} \cdot \vec{B} = AB\cos\theta = A_xB_x + A_yB_y + A_zB_z$.
2. Zero ($\cos 90^\circ = 0$).
3. $W = \vec{F} \cdot \vec{d} = Fd\cos\theta$. SI unit: Joule (J); Dimensions: $[\mathrm{ML^2T^{-2}}]$.
4. Positive if $\theta < 90^\circ$; Zero if $\theta = 90^\circ$ (or $d = 0$); Negative if $\theta > 90^\circ$.
5. Gravity is vertical and displacement is horizontal ($\theta = 90^\circ$), so $W = \mathbf{0}$ J.
6. **Zero**, because centripetal force is always perpendicular to tangential displacement.
7. Energy possessed by a body due to its motion: $K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$.
8. The net work done by all forces acting on a body equals the change in its kinetic energy: $W_{net} = K_f - K_i$.
9. Total **work done** ($W = \int F\,dx$).
10. A force whose work depends only on initial and final positions, not the path taken (and zero over a closed loop). Examples: Gravitational force, Spring force.
11. A force whose work depends on the path taken. Examples: Friction, Viscous drag.
12. $U = mgh$.
13. $U_s = \frac{1}{2}kx^2$ (where k is spring constant).
14. When only conservative forces do work, total mechanical energy remains constant: $K + U =$ constant.
15. Rate of doing work: $P = \frac{dW}{dt} = \vec{F} \cdot \vec{v}$. SI unit: Watt (W); Dimensions: $[\mathrm{ML^2T^{-3}}]$.
16. 1 kWh = 1000 W $\times$ 3600 s = $\mathbf{3.6 \times 10^6}$ J.
17. 1 hp = **746** W.
18. 1 eV = $\mathbf{1.6 \times 10^{-19}}$ J.
19. $K = \frac{1}{2}(2)(5^2) = \mathbf{25}$ J.
20. $P = \frac{mgh}{t} = \frac{10\times10\times5}{10} = \mathbf{50}$ W.
21. A collision in which both **total linear momentum** and **total kinetic energy** are conserved ($e = 1$).
22. A collision in which the colliding bodies stick together after impact ($e = 0$); momentum is conserved, kinetic energy is lost.
23. They **exchange** their velocities ($v_1 = u_2, v_2 = u_1$).
24. $W = 3(2) + 4(-1) = 6 - 4 = \mathbf{2}$ J.
25. $P = Fv = 500 \times 20 = 10000$ W = **10** kW.

8 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $K = p^2/(2m) \propto p^2$. Doubling p makes $K' = 4K$, an increase of **300**%.
2. $K' = 4K \implies p' = \sqrt{4}p = 2p$, an increase of **100**%.
3. $K = p^2/(2m)$; for fixed p, the **light body** has greater kinetic energy.
4. $p = \sqrt{2mK}$; for fixed K, the **heavy body** has greater momentum.
5. $W = \int_0^4 2x\,dx = [x^2]_0^4 = \mathbf{16}$ J.
6. $W = \frac{1}{2}(1)(7^2 - 3^2) = \frac{1}{2}(40) = \mathbf{20}$ J.
7. $k = 100/0.02 = \mathbf{5000}$ N/m. $U = \frac{1}{2}(5000)(0.05)^2 = \mathbf{6.25}$ J.
8. $\frac{1}{2}kx^2 = \frac{1}{2}mv^2 \implies x = 4\sqrt{0.5/50} = \mathbf{0.4}$ m.
9. $v = \frac{4(6)}{6} = \mathbf{4}$ m/s. $\Delta K_{loss} = \frac{1}{2}\frac{4\times2}{6}(6-0)^2 = \mathbf{24}$ J.
10. $e = \sqrt{h'/h} = \sqrt{2.5/10} = \mathbf{0.5}$.
11. $P = \frac{100\times10\times6}{60} = \mathbf{100}$ W.
12. $0.01(400) = 0.01(100) + 2V \implies 2V = 3 \implies V = \mathbf{1.5}$ m/s.
13. $\vec{A}\cdot\vec{B} = -6 + 6 = 0 \implies \theta = \mathbf{90}^\circ$.
14. $v = \sqrt{2gL} = \sqrt{20} = \mathbf{2\sqrt{5}}$ m/s ≈ 4.47 m/s.
15. Lowest point: $\mathbf{\sqrt{5gR}}$; Highest point: $\mathbf{\sqrt{gR}}$.
16. $x = 5\sqrt{1000/6250} = \mathbf{2.0}$ m.
17. $F = 18000 + 4000 = 22000$ N $\implies P = 22000 \times 2 = \mathbf{44}$ kW.
18. $W = U_2 - U_1 = \mathbf{\frac{1}{2}k(x_2^2 - x_1^2)}$.
19. $E = 0.06 \times 10 \times 30 = \mathbf{18}$ kWh (18 units).
20. $\cos\theta = \frac{15+16-15}{\sqrt{50}\sqrt{50}} = \frac{16}{50} = 0.32 \implies \theta \approx \mathbf{71.3}^\circ$.
21. $d_s = \frac{mv^2}{2F} \propto m$. Larger mass means larger kinetic energy to dissipate.
22. $K = \frac{20^2}{2(10)} = \mathbf{20}$ J.
23. $v_2 \approx \mathbf{2u}$.
24. $W = \int_0^2 (10 + 0.5x)\,dx = [10x + 0.25x^2]_0^2 = \mathbf{21}$ J.
25. $dU/dx = 0$ for all three: Stable ($d^2U/dx^2 > 0$, min U); Unstable ($d^2U/dx^2 < 0$, max U); Neutral ($d^2U/dx^2 = 0$).

9 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. Stiffness $k \propto 1/L$. Halving the length doubles the spring constant to **2k**.
2. (a) Same x: $U = \frac{1}{2}kx^2 \implies k_1$ stores more. (b) Same F: $U = \frac{F^2}{2k} \implies k_2$ stores more!
3. $dU/dx = 2x - 4 = 0 \implies x = \mathbf{2}$ m. $d^2U/dx^2 = +2 > 0 \implies$ **stable equilibrium**.
4. $a = v_1/t_1$, $v = at$, $P = Fv = ma^2t = \mathbf{\frac{mv_1^2}{t_1^2}t}$.
5. $v^2/r = k^2rt^2 \implies v = krt \implies a_t = kr$. Only tangential force does work: $P = ma_tv = \mathbf{mk^2r^2t}$.
6. $\frac{1}{2}mv^2 = 2t^2 \implies v \propto t \implies a =$ constant $\implies F =$ constant.
7. $W_r = -0.5\ln(20.1) = -1.5$ J. $K_f = 2 - 1.5 = 0.5$ J $\implies v_f = \mathbf{1}$ m/s.
8. $\vec{p}_i = \vec{p}_1 + \vec{p}_2$ and $p_i^2 = p_1^2 + p_2^2 \implies 2\vec{p}_1\cdot\vec{p}_2 = 0 \implies \theta_1 + \theta_2 = \mathbf{90}^\circ$.

9. $f = \frac{\mathbf{4A}}{\mathbf{(1+A)^2}}$.

10. Hanging mass $= M/3$, COM at depth $L/6$. $W = (M/3)g(L/6) = \frac{\mathbf{MgL}}{\mathbf{18}}$.

11. $V = \frac{0.012(70)}{0.412} = 2.04$ m/s. $h = \frac{V^2}{2g} = \mathbf{0.212}$ m. Heat $= K_i - K_f = \mathbf{28.5}$ J.

12. $W_g = 10^{-3}(10)(1000) = 10$ J. $\Delta K = \frac{1}{2}(10^{-3})(2500) = 1.25$ J. $W_{air} = 1.25 - 10 = \mathbf{-8.75}$ J.

13. $W = \int_0^5 (7 - 2x + 3x^2)\,dx = [7x - x^2 + x^3]_0^5 = 35 - 25 + 125 = \mathbf{135}$ J.

14. $\frac{1}{2}mv^2 = Pt \implies v \propto t^{1/2} \implies s = \int v\,dt \propto \mathbf{t^{3/2}}$.

15. $v = \sqrt{2Pt/m} \implies a = dv/dt = \sqrt{\frac{\mathbf{P}}{\mathbf{2mt}}}$.

16. $D = h\left(\frac{1+e^2}{1-e^2}\right)$.

17. $mgh = \frac{1}{2}kx^2 \implies 2(10)(5) = 500x^2 \implies x^2 = 0.2 \implies x = \mathbf{0.447}$ m.

18. Yes! When a block sits on an accelerating truck (without slipping), static friction accelerates the block forward w.r.t. ground, doing positive work.

19. $P = (mg\sin\theta + f)v$.

20. $T_{bot} - T_{top} = \mathbf{6mg}$ (independent of speed!).

21. $dU/dr = -2A/r^3 + B/r^2 = 0 \implies r_0 = \mathbf{2A/B}$.

22. $a = 2t \implies v(2) = \int_0^2 2t\,dt = 4$ m/s. $W = \frac{1}{2}(2)(4^2) = \mathbf{16}$ J.

23. $P_{wind} = \frac{1}{2}\rho A v^3 = 0.5(1.2)(30)(1000) = 18$ kW. $P_{elec} = 0.25 \times 18 = \mathbf{4.5}$ kW.

24. $M/m = \mathbf{1}$ (100% KE transfer when masses are equal!).

25. $v(0) = 0, v(4) = 8$ m/s. $W = \Delta K = \frac{1}{2}(2)(64 - 0) = \mathbf{64}$ J.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 6 (SELF-STUDY MASTER EDITION)

SYSTEMS OF PARTICLES AND ROTATIONAL MOTION

Complete Zero-Omission Coverage of NCERT `keph106.pdf` (Sections 6.1–6.12, Tables 6.1–6.2, Fig 6.1–6.33, Ex 6.1–6.12, Exercises 6.1–6.17)

CBSE 2026–27 Weightage & Scope: Unit V: Motion of System of Particles and Rigid Body (Part of 17 Marks for Units IV–VI)

[CONCEPT CORE] Self-Study Promise: Zero Teacher Needed

Chapters 2–5 treated objects as single points. Chapter 6 unlocks real-world extended rigid bodies that can both **translate** and **rotate**! Every translational concept (m, F, p, K) has an exact rotational twin $(I, \tau, L, \frac{1}{2}I\omega^2)$.

1 Topic 1: Rigid Bodies, Centre of Mass & Linear Momentum (NCERT Sections 6.1–6.4)

1.1 Step 1: Definitions, Formulas & Derivations

- **Rigid Body (6.1.1):** An ideal solid body whose shape and size do not change under external forces (distance between any two particles stays fixed).
- **Centre of Mass (COM, Section 6.2):** The unique point where the entire mass $M = \sum m_i$ of a system behaves as if concentrated for translational motion:

$$\vec{R}_{cm} = \frac{\sum m_i \vec{r}_i}{M} \quad \left(X_{cm} = \frac{\sum m_i x_i}{M}, \quad Y_{cm} = \frac{\sum m_i y_i}{M}, \quad Z_{cm} = \frac{\sum m_i z_i}{M} \right)$$

  For continuous bodies, $\vec{R}_{cm} = \frac{1}{M}\int \vec{r}\, dm$. Note: COM does not need to lie inside the material (e.g., ring, hollow sphere).

- **Motion of COM & Momentum Conservation (6.3–6.4):** Differentiating $M\vec{R}_{cm} = \sum m_i \vec{r}_i$ twice with time:

$$M\vec{V}_{cm} = \sum \vec{p}_i = \vec{P}_{total}, \qquad M\vec{A}_{cm} = \sum \vec{F}_{ext} = \vec{F}_{ext}$$

  All internal forces cancel in action-reaction pairs! Thus, if $\vec{F}_{ext} = 0$, $\vec{V}_{cm}$ remains constant (e.g., a bomb exploding in mid-air: fragments fly everywhere, yet their COM follows the exact same parabola!).

2 Topic 2: Vector Product, Torque, Angular Momentum & Equilibrium (NCERT Sections 6.5–6.8)

2.1 Step 1: Definitions & Derivations

- **Vector (Cross) Product (6.5):** $\vec{A} \times \vec{B} = AB\sin\theta\,\hat{n}$, perpendicular to the plane of $\vec{A}$ and $\vec{B}$ via right-hand screw rule. Anti-commutative: $\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$. Determinant form:

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

- **Angular Velocity & Acceleration (6.6):** $\vec{v} = \vec{\omega} \times \vec{r}$ (scalar $v = \omega r$); $\vec{\alpha} = \frac{d\vec{\omega}}{dt}$.
- **Torque ($\vec{\tau}$, Section 6.7.1):** The rotational analogue of force (turning effect): $\vec{\tau} = \vec{r} \times \vec{F}$ ($|\tau| = rF\sin\theta = Fd_\perp$, SI: N m, $[\mathrm{ML^2T^{-2}}]$).
- **Angular Momentum ($\vec{L}$, Section 6.7.2):** The rotational analogue of linear momentum: $\vec{L} = \vec{r} \times \vec{p}$ ($L = mvd_\perp$, SI: kg m^2 s^{-1} or J s). Differentiating $\vec{L} = \vec{r} \times \vec{p}$ gives:

$$\frac{d\vec{L}}{dt} = \vec{v} \times (m\vec{v}) + \vec{r} \times \frac{d\vec{p}}{dt} = 0 + \vec{r} \times \vec{F} = \vec{\tau}_{\mathbf{ext}}$$

- **Equilibrium of a Rigid Body (6.8):** Complete mechanical equilibrium requires BOTH $\sum \vec{F}_i = 0$ (translational) and $\sum \vec{\tau}_i = 0$ (rotational). **Principle of Moments:** Load × Load arm = Effort × Effort arm. **Centre of Gravity (COG)** coincides with COM in uniform gravity.

3 Topic 3: Moment of Inertia, Theorems & Rotational Dynamics (NCERT Sections 6.9–6.12)

3.1 Step 1: Moment of Inertia (I), Radius of Gyration (k) & Two Theorems

Moment of Inertia $I = \sum m_i r_i^2$ (SI: kg m^2, [ML^2]) is the rotational analogue of mass! **Radius of Gyration** $k = \sqrt{I/M}$ ($I = Mk^2$).

1. **Parallel Axes Theorem:** Moment of inertia about any axis parallel to an axis through COM at distance d is $I = I_{cm} + Md^2$ (valid for ALL 2D and 3D bodies).
2. **Perpendicular Axes Theorem:** For a flat planar (2D lamina) body in the x-y plane, $I_z = I_x + I_y$ (valid ONLY for planar bodies!).

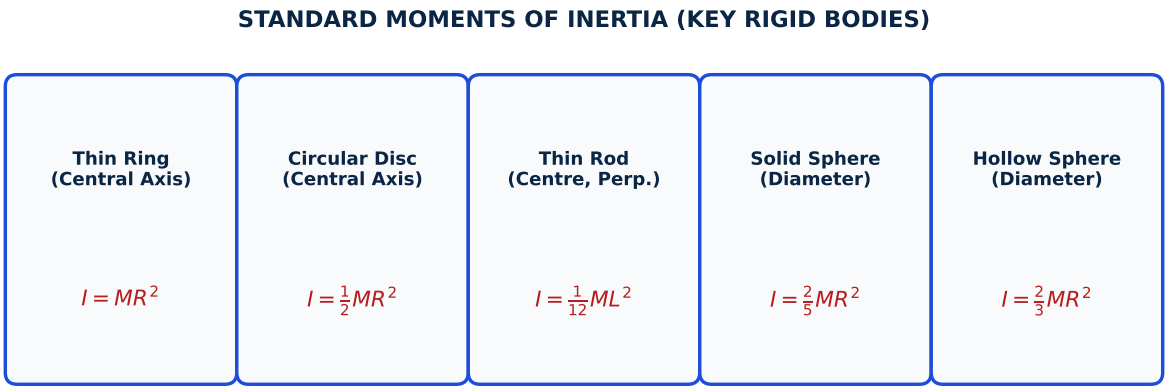


Diagram Explanation (Covers NCERT Table 6.1): Standard Moments of Inertia: Thin Ring (MR^2), Circular Disc ($\frac{1}{2}MR^2$), Thin Rod ($\frac{1}{12}ML^2$), Solid Sphere ($\frac{2}{5}MR^2$), Hollow Sphere ($\frac{2}{3}MR^2$).

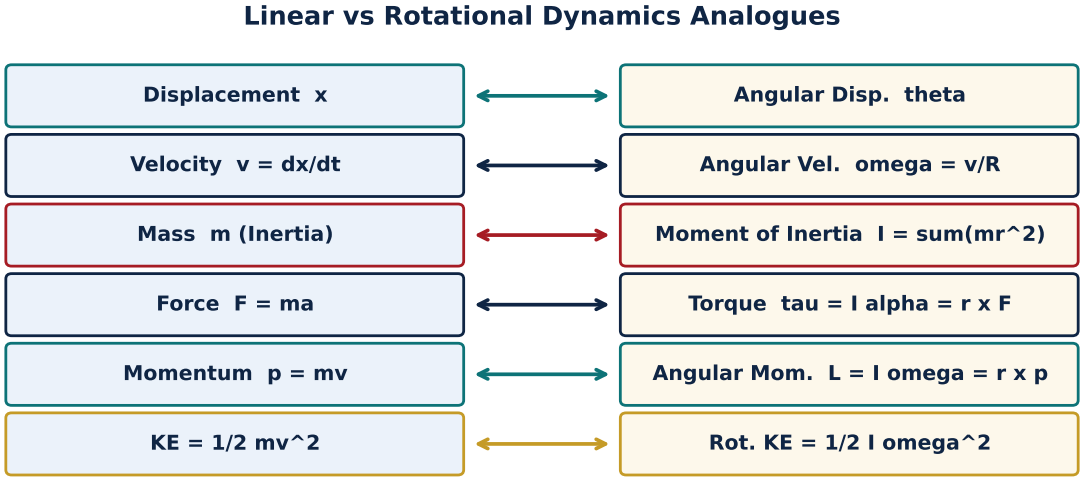


Diagram Explanation (Covers NCERT Table 6.2): Maps every translational formula ($F = ma, p = mv, K = \frac{1}{2}mv^2$) to its rotational twin ($\tau = I\alpha, L = I\omega, K_{rot} = \frac{1}{2}I\omega^2$).

3.2 Step 2: Conservation of Angular Momentum (6.12.1)

When $\tau_{ext} = 0$, $L = I\omega = \text{constant} \implies \mathbf{I_1\omega_1 = I_2\omega_2}$. (Examples: ballet dancer pulling arms in to spin faster; Earth shrinking to half radius making day 6 h.)

Example 6.1A (Theorems of Moment of Inertia) **[Board / NEET]**

Problem: Find the Moment of Inertia of a circular disc of mass M and radius R about (a) a diameter, and (b) a tangent in its own plane.

Solution: (a) Perpendicular Axes Theorem: $I_z = \frac{1}{2}MR^2 = I_x + I_y = 2I_d \implies I_d = \mathbf{\frac{1}{4}MR^2}$.
(b) Parallel Axes Theorem: Shift from diameter to parallel tangent at distance $d = R$: $I_{tan} = I_d + MR^2 = \frac{1}{4}MR^2 + MR^2 = \mathbf{\frac{5}{4}MR^2}$.

4 Complete NCERT Examples (6.1–6.12) & Back Exercises (6.1–6.17) with Full Questions

4.1 NCERT Solved Examples (6.1–6.12)

1. **Example 6.1:** Find the centre of mass of three particles at the vertices of an equilateral triangle of side 0.5 m with masses 100 g, 150 g, 200 g.
   Solution: $X_{cm} = \frac{100(0)+150(0.5)+200(0.25)}{450} = \mathbf{\frac{5}{18}}$ m; $Y_{cm} = \frac{200(0.25\sqrt{3})}{450} = \mathbf{\frac{1}{3\sqrt{3}}}$ m.

2. **Example 6.2:** Find the centre of mass of a triangular lamina.
   Solution: Divide into thin strips parallel to base; COM of each strip is at its midpoint, which lies on the median. Thus COM lies at the **centroid** (intersection of medians).

3. **Example 6.3:** Find the centre of mass of a uniform L-shaped lamina (3 unit squares of 1 kg each at $(0.5, 0.5), (1.5, 0.5), (0.5, 1.5)$).
   Solution: $X_{cm} = \frac{0.5+1.5+0.5}{3} = \mathbf{\frac{5}{6}}$ m; $Y_{cm} = \frac{0.5+0.5+1.5}{3} = \mathbf{\frac{5}{6}}$ m.

4. **Example 6.4:** Find the scalar and vector products of two vectors $\vec{a} = 3\hat{i} - 4\hat{j} + 5\hat{k}$ and $\vec{b} = -2\hat{i} + \hat{j} - 3\hat{k}$.
   Solution: $\vec{a} \cdot \vec{b} = -6 - 4 - 15 = \mathbf{-25}$. $\vec{a} \times \vec{b} = \mathbf{7\hat{i} - \hat{j} - 5\hat{k}}$.

5. **Example 6.5:** Obtain the angular acceleration of a wheel accelerating uniformly from 1200 rpm to 3120 rpm in 16 s, and find how many revolutions it makes.
   Solution: $\omega_0 = 40\pi, \omega = 104\pi$ rad/s $\implies \alpha = (104\pi - 40\pi)/16 = \mathbf{4\pi}$ rad/s$^\mathbf{2}$. Revolutions $= \frac{40\pi+104\pi}{2\times 2\pi}(16) = \mathbf{576}$ rev.

6. **Example 6.6:** Find the torque of a force $7\hat{i} + 3\hat{j} - 5\hat{k}$ about the origin if it acts on a particle whose position vector is $\hat{i} - \hat{j} + \hat{k}$.
   Solution: $\vec{\tau} = \vec{r} \times \vec{F} = \mathbf{2\hat{i} + 12\hat{j} + 10\hat{k}}$.

7. **Example 6.7:** Show that the angular momentum about any point of a single particle moving with constant velocity remains constant throughout the motion.
   Solution: $L = rp\sin\theta = mv(r\sin\theta) = mvd_\perp$, where $d_\perp$ is constant.

8. **Example 6.8:** A metal bar 70 cm long and 4.00 kg in mass is supported on two knife-edges 10 cm from each end. A 6.00 kg load is suspended at 30 cm from one end ($g = 9.8$). Find reactions R_1, R_2.
   Solution: $R_1 + R_2 = 10g = 98$ N. Balancing torque about COM: $R_1(0.25) - R_2(0.25) - 6g(0.05) = 0 \implies R_1 = \mathbf{55}$ N, $R_2 = \mathbf{43}$ N.

9. **Example 6.9:** A 3 m long ladder weighing 20 kg leans on a frictionless wall with its feet 1 m from the wall ($g = 9.8$). Find reaction forces of wall and floor.
   Solution: Height $h = 2\sqrt{2}$ m. Torque about base: $F_1(2\sqrt{2}) = 196(0.5) \implies F_1 = \mathbf{34.6}$ N; Floor $N = 196$ N, $F_2 = \mathbf{199}$ N.

10. **Example 6.10:** What is the moment of inertia of a disc about one of its diameters, and of a ring about a tangent in its plane?
    Solution: Disc diameter: $\mathbf{\frac{1}{4}MR^2}$. Ring tangent in plane: $\frac{1}{2}MR^2 + MR^2 = \mathbf{\frac{3}{2}MR^2}$.

11. **Example 6.11:** What is the moment of inertia of a rod of mass M, length l about an axis perpendicular to it through one end?
    Solution: $I = \frac{1}{12}Ml^2 + M(l/2)^2 = \mathbf{\frac{1}{3}Ml^2}$.

12. **Example 6.12:** A cord of negligible mass is wound round the rim of a hollow cylinder of mass 3 kg and radius 40 cm, pulled with 30 N. Find angular acceleration and linear acceleration of cord.
Solution: $I = MR^2 = 3(0.16) = 0.48$ kg m^2, $\tau = 30(0.4) = 12$ N m $\implies$ $\alpha = \mathbf{25}$ rad/s$^\mathbf{2}$, $a = \alpha R = \mathbf{10}$ m/s$^\mathbf{2}$.

4.2 NCERT Back Exercises (6.1–6.17) — Full Questions & Solutions

1. **Q 6.1:** Give the location of the centre of mass of a (i) sphere, (ii) cylinder, (iii) ring, and (iv) cube, each of uniform mass density. Does the COM of a body necessarily lie inside the body?
Solution: At the **geometric centre** of each. **No**, COM can lie outside the material (e.g., hollow sphere, circular ring).

2. **Q 6.2:** In the HCl molecule, the separation between the nuclei of the two atoms is about 1.27 Å. Find the approximate location of the CM of the molecule ($m_{Cl} = 35.5\, m_H$).
Solution: X_{cm} from H $= \frac{35.5\times 1.27}{1+35.5} = \mathbf{1.235}$ Å.

3. **Q 6.3:** A child sits stationary at one end of a long trolley moving uniformly with speed V on a smooth horizontal floor. If the child gets up and runs about on the trolley in any manner, what is the speed of the CM of the (trolley + child) system?
Solution: **Unchanged (V)**, because running involves purely internal forces ($\vec{F}_{ext} = 0$).

4. **Q 6.4:** Show that the area of the triangle contained between the vectors $\vec{a}$ and $\vec{b}$ is one half of the magnitude of $\vec{a} \times \vec{b}$.
Solution: Area $= \frac{1}{2}$(base)(height) $= \frac{1}{2}a(b\sin\theta) = \mathbf{\frac{1}{2}|\tilde{a} \times \tilde{b}|}$.

5. **Q 6.5:** Show that $\vec{a} \cdot (\vec{b} \times \vec{c})$ is equal in magnitude to the volume of the parallelepiped formed on the three vectors $\vec{a}, \vec{b}, \vec{c}$.
Solution: $|\vec{b} \times \vec{c}|$ is base area, and $a\cos\phi$ is perpendicular height $\implies$ Volume $= |\vec{a} \cdot (\vec{b} \times \vec{c})|$.

6. **Q 6.6:** Find the components along the x, y, z axes of the angular momentum $\vec{L}$ of a particle, whose position vector is $\vec{r}$ with components x, y, z and momentum is $\vec{p}$ with components p_x, p_y, p_z.
Solution: $L_x = yp_z - zp_y$, $L_y = zp_x - xp_z$, $L_z = xp_y - yp_x$.

7. **Q 6.7:** Two particles, each of mass m and speed v, travel in opposite directions along parallel lines separated by a distance d. Show that the vector angular momentum of the two-particle system is the same whatever be the point about which angular momentum is taken.
Solution: $\vec{L} = \vec{r}_1 \times \vec{p} + \vec{r}_2 \times (-\vec{p}) = (\vec{r}_1 - \vec{r}_2) \times \vec{p}$, which depends only on separation d, independent of origin!

8. **Q 6.8:** A non-uniform bar of weight W is suspended at rest by two strings of negligible weight making angles 36.9° and 53.1° with vertical. Bar length is 2 m. Calculate distance d of the CG of the bar from its left end.
Solution: Horizontal equilibrium: $T_1 \sin 36.9° = T_2 \sin 53.1°$. Torque balance about CG gives $d = \mathbf{0.72}$ m.

9. **Q 6.9:** A car weighs 1800 kg. Distance between front and back axles is 1.8 m. Its CG is 1.05 m behind the front axle. Determine force exerted by the level ground on each front wheel and each back wheel ($g = 9.8$).
Solution: Front total $= 1800(9.8)\frac{0.75}{1.8} = 7350$ N $\implies$ **3675** N/wheel; Rear total $= 10290$ N $\implies$ **5145** N/wheel.

10. **Q 6.10:** (a) Find ratio of moments of inertia of a solid sphere and a disc of same M, R about their diameters; (b) Find ratio of radii of gyration.
Solution: (a) $\frac{\frac{2}{5}MR^2}{\frac{1}{4}MR^2} = \frac{8}{5}$; (b) For sphere & disc about central axis ($\frac{2}{5}$ vs $\frac{1}{2}$): $k_s/k_d = \mathbf{\sqrt{4/5}}$.

11. **Q 6.11:** Torques of equal magnitude are applied to a hollow cylinder and a solid sphere, both having same M, R. Which acquires greater angular speed after a given time?
Solution: $\alpha = \tau/I$. Solid sphere has smaller I ($\frac{2}{5}MR^2 < MR^2$), so **solid sphere** acquires greater ω. (And for rotor $P = 100$ kW, $\omega = 200$ rad/s: $\tau = \mathbf{500}$ N m.)

12. **Q 6.12:** A solid cylinder of mass 20 kg rotates about its axis with angular speed 100 rad/s ($R = 0.25$ m). What is its rotational KE and angular momentum?
Solution: $I = \frac{1}{2}(20)(0.0625) = 0.625$ kg m^2; $K = \frac{1}{2}(0.625)(100^2) = \mathbf{3125}$ J; $L = 0.625(100) = \mathbf{62.5}$ J s.

13. **Q 6.13:** A child stands at the centre of a turntable with outstretched arms rotating at 40 rev/min. He folds his hands back reducing I to 2/5 times initial value. Find new angular speed and ratio of new KE to old KE.
Solution: $\omega_2 = 40 \times \frac{5}{2} = \mathbf{100}$ rpm; $K_2/K_1 = \omega_2/\omega_1 = \mathbf{2.5}$ (muscular work increases KE!).

14. **Q 6.14:** A rope of negligible mass is wound round a hollow cylinder of mass 3 kg and radius 40 cm. What is the angular acceleration if pulled with 30 N? What is linear acceleration?
Solution: $\alpha = \mathbf{25}$ rad/s$^\mathbf{2}$, $a = \mathbf{10}$ m/s$^\mathbf{2}$.

15. **Q 6.15:** To maintain a rotor at uniform angular speed 200 rad/s, an engine needs to transmit a torque of 180 N m. What is the power required?
Solution: $P = \tau\omega = 180 \times 200 = \mathbf{36}$ kW.

16. **Q 6.16:** From a uniform disk of radius R, a circular hole of radius $R/2$ is cut out touching the rim. Locate the centre of gravity of the resulting flat body.
Solution: $X_{cm} = -\mathbf{R/6}$ from original centre (opposite to the hole).

17. **Q 6.17:** A metre stick is balanced on a knife edge at its centre. When two coins, each of mass 5 g, are put on top of each other at the 12.0 cm mark, the stick balances at 45.0 cm. What is the mass of the metre stick?
Solution: Torque about 45 cm: $10(45-12) = M(50-45) \implies 330 = 5M \implies M = \mathbf{66}$ g.

5 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 6 Solutions PDF.

5.1 Level 1: Basic Level (25 Questions)

1. Define Centre of Mass (COM) of a system of particles.
2. Where does the COM of a uniform circular ring lie?
3. If net external force on a system is zero, what happens to the velocity of its COM?
4. Define vector (cross) product of $\vec{A}$ and $\vec{B}$.
5. What is the cross product of two parallel vectors?
6. Write $\hat{i} \times \hat{j}$ and $\hat{j} \times \hat{i}$.
7. Write the relation between linear velocity $\vec{v}$ and angular velocity $\vec{\omega}$.
8. Define Torque ($\vec{\tau}$) and write its SI unit and dimensions.
9. Define Angular Momentum ($\vec{L}$) and write its SI unit.
10. What is the relation between external torque and angular momentum?
11. State the Law of Conservation of Angular Momentum.
12. Why does a ballet dancer spin faster when she pulls her arms inward?
13. State the two conditions for complete mechanical equilibrium of a rigid body.
14. Define Moment of Inertia (I) and write its SI unit.
15. Define Radius of Gyration (k).
16. Write Moment of Inertia of a thin ring and a circular disc about their central perpendicular axes.
17. Write Moment of Inertia of a solid sphere and a hollow sphere about a diameter.
18. Write Moment of Inertia of a thin rod of mass M, length L about its centre (perpendicular to length).
19. State the Parallel Axes Theorem.
20. State the Perpendicular Axes Theorem. For which bodies is it valid?
21. Write the rotational analogue of $F = ma$ and $K = \frac{1}{2}mv^2$.
22. A wheel rotates at 120 rpm. Find its angular speed in rad/s.
23. A torque of 20 N m acts on a wheel of $I = 4$ kg m^2. Find angular acceleration.
24. Find COM of 1 kg at $x = 0$ and 3 kg at $x = 4$ m.
25. What is a couple?

5.2 Level 2: Medium Level (25 Questions)

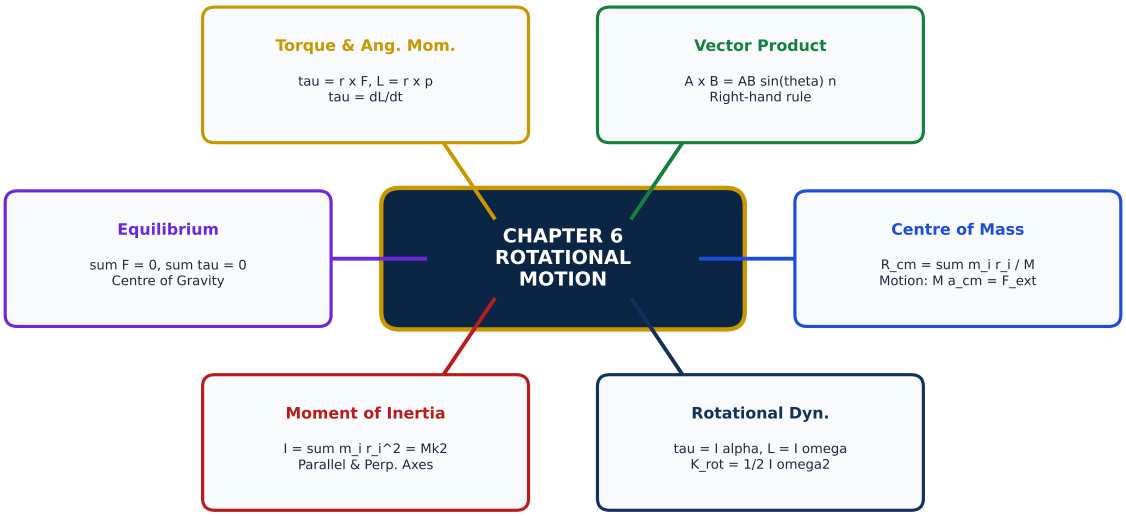
1. Find torque of $\vec{F} = 2\hat{i} + 3\hat{j}$ about origin when applied at $\vec{r} = \hat{i} + \hat{j}$.
2. Find I of a thin rod of mass M, length L about an axis through one end perpendicular to it.
3. Find I of a circular ring about a diameter.
4. Find I of a circular disc about a diameter.
5. Find I of a circular disc about a tangent in its own plane.
6. Find I of a solid sphere about a tangent.
7. A solid cylinder ($M = 2$ kg, $R = 0.5$ m) rotates at 10 rad/s. Find L and K_{rot}.
8. A wheel starts from rest with $\alpha = 2$ rad/s^2. Find angle turned in 4 s.
9. A wheel accelerates from 1200 rpm to 3120 rpm in 16 s. Find α and revolutions made.
10. A shell explodes in mid-air. What path does its COM follow?
11. If angular momentum L is constant and I is doubled, what happens to rotational KE?
12. Find ratio of radius of gyration of a disc to a ring of same mass and radius about central axis.
13. If $\vec{A} \cdot \vec{B} = |\vec{A} \times \vec{B}|$, find the angle between $\vec{A}$ and $\vec{B}$.
14. A 2 kg particle moves along $y = 4$ m at 3 m/s parallel to x-axis. Find L about origin.
15. A rotor requires $\tau = 500$ N m at $\omega = 200$ rad/s. Find power.
16. A disc of $I = 2$ kg m^2 rotates at 6 rad/s. A stationary disc of $I = 1$ kg m^2 drops onto it coaxially. Find common ω.
17. In Q16, find the loss in rotational kinetic energy.
18. When does Centre of Gravity coincide with Centre of Mass?
19. Find COM of three masses 100 g, 150 g, 200 g at vertices of equilateral triangle of side 0.5 m.
20. A cord wound on a hollow cylinder ($M = 3$ kg, $R = 0.4$ m) is pulled by 30 N. Find α.
21. Why are flywheels heavy at the rim?
22. A torque of 50 N m stops a wheel of $I = 10$ kg m^2 from 20 rad/s. Find time taken.
23. Find I of a hollow sphere about a tangent.
24. Find scalar and vector products of $\vec{a} = 3\hat{i} - 4\hat{j} + 5\hat{k}$ and $\vec{b} = -2\hat{i} + \hat{j} - 3\hat{k}$.
25. What is the physical meaning of $\frac{1}{2}|\vec{a} \times \vec{b}|$?

5.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. If Earth suddenly shrinks to half its radius without losing mass, what becomes the duration of a day (currently 24 h)?
2. A circular disc of radius R has a circular hole of radius $R/2$ cut out touching its rim. Find the shift in COM.
3. In Q2, find the Moment of Inertia of the remaining disc about the original central axis.
4. A 3 m ladder (20 kg) leans against a smooth wall at 1 m from base ($g = 9.8$). Find wall and floor reactions.
5. A car (1800 kg, wheelbase 1.8 m) has CG 1.05 m behind front axle. Find force on each front and rear wheel ($g = 9.8$).
6. A uniform rod of mass M, length L is pivoted at one end and released from horizontal. Find initial angular acceleration.
7. In Q6, find the linear acceleration of the free tip of the rod at that instant.

8. A hoop ($M = 100$ kg, $R = 2$ m) rolls without slipping at 0.2 m/s. Find work required to stop it.
9. Find acceleration of a solid sphere rolling without slipping down an incline of angle θ.
10. A ring, disc, and solid sphere of same M, R are released from top of an incline. Which reaches bottom first?
11. A child stands at centre of a turntable ($I = 4$ kg m^2, 40 rpm) and stretches arms to double total I to 10 kg m^2? Wait: if $I_1 \to 2.5I_1$ (40 rpm): find new rpm.
12. A particle of mass m is projected at speed u at angle θ. Find its angular momentum about launch point at maximum height.
13. Find I of a thin square plate of mass M, side a about a diagonal.
14. A solid cylinder rolls without slipping. What fraction of its total KE is rotational?
15. A thin rod of length L has linear density $\lambda = kx$. Find its COM from $x = 0$.
16. Find I of the rod in Q15? Wait: for uniform rod (M, L) bent into a semicircular arc of radius $R = L/\pi$, find COM from centre.
17. A turntable rotates at ω. A coin at distance r just slips if $\omega > \sqrt{\mu_s g/r}$. Why?
18. Two particles of masses m_1, m_2 attract each other and move towards COM from rest. If m_1 moves d, how far does m_2 move?
19. A cubical block of side a slides down an incline of angle θ at constant speed. Find shift in normal reaction from centre to prevent toppling.
20. Find I of a solid cone of mass M, base radius R about its symmetry axis.
21. If $\vec{L} = 3t^2\hat{i} + 2t\hat{j}$, find torque at $t = 1$ s.
22. A disc of mass M, radius R rolls without slipping at speed v. Find its angular momentum about the point of contact.
23. A planet orbits Sun in ellipse. Prove areal velocity is $\frac{L}{2m}$.
24. A flywheel of $I = 0.5$ kg m^2 has $K_{rot} = 100$ J. Find its angular momentum.
25. Why is it easier to balance a spinning bicycle wheel than a stationary one?

6 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Connects Centre of Mass, Vector Product, Torque & Angular Momentum, Mechanical Equilibrium, Moment of Inertia Theorems, and Rotational Dynamics.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 6 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: SYSTEMS OF PARTICLES AND ROTATIONAL MOTION

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

7 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. The unique point where the entire mass of the system is assumed to be concentrated for translational motion: $\vec{R}_{cm} = \frac{\sum m_i \vec{r}_i}{M}$.
2. At its **geometric centre** (outside the material of the ring).
3. It remains **constant** ($M\vec{a}_{cm} = \vec{F}_{ext} = 0$).
4. $\vec{A} \times \vec{B} = AB \sin\theta \, \hat{n}$ (direction by right-hand screw rule).
5. Zero (null vector $\vec{0}$), since $\sin 0^\circ = 0$.
6. $\hat{i} \times \hat{j} = \hat{k}$; $\hat{j} \times \hat{i} = -\hat{k}$.
7. $\vec{v} = \vec{\omega} \times \vec{r}$ (scalar: $v = r\omega$).
8. Turning effect of force: $\vec{\tau} = \vec{r} \times \vec{F}$. SI unit: N m; Dimensions: $[\mathrm{ML^2T^{-2}}]$.
9. $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$. SI unit: kg m^2 s^{-1} (or J s).
10. $\vec{\tau}_{ext} = \frac{d\vec{L}}{dt}$.
11. If net external torque is zero ($\vec{\tau}_{ext} = 0$), total angular momentum remains constant: $I_1\omega_1 = I_2\omega_2$.
12. Pulling arms in reduces Moment of Inertia I; since $I\omega =$ constant, angular speed ω increases.
13. 1. Translational equilibrium: $\sum \vec{F}_i = 0$. 2. Rotational equilibrium: $\sum \vec{\tau}_i = 0$.
14. $I = \sum m_i r_i^2$. SI unit: kg m^2 (rotational analogue of mass).
15. The radial distance from the axis where total mass M can be concentrated to give the same I: $I = Mk^2 \implies k = \sqrt{I/M}$.
16. Ring: $I = MR^2$. Disc: $I = \frac{1}{2}MR^2$.
17. Solid sphere: $I = \frac{2}{5}MR^2$. Hollow sphere: $I = \frac{2}{3}MR^2$.
18. $I = \frac{1}{12}ML^2$.
19. $I = I_{cm} + Md^2$, where d is the perpendicular distance between the two parallel axes.
20. $I_z = I_x + I_y$. Valid **only for planar (2D lamina) bodies**.
21. $\tau = I\alpha$; $\quad K_{rot} = \frac{1}{2}I\omega^2$.
22. $\omega = 2\pi(120/60) = \mathbf{4}\pi$ rad/s.
23. $\alpha = \tau/I = 20/4 = \mathbf{5}$ rad/s$^\mathbf{2}$.
24. $X_{cm} = \frac{1(0)+3(4)}{1+3} = \mathbf{3}$ m.
25. A pair of equal and opposite parallel forces with different lines of action; produces pure rotation ($\sum F = 0, \sum \tau \neq 0$).

8 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $\vec{\tau} = \vec{r} \times \vec{F} = (1(3) - 1(2))\hat{k} = \hat{\mathbf{k}}$.
2. By Parallel Axes Theorem: $I = \frac{1}{12}ML^2 + M(L/2)^2 = \mathbf{\frac{1}{3}ML^2}$.
3. By Perpendicular Axes Theorem: $2I_d = MR^2 \implies I_d = \mathbf{\frac{1}{2}MR^2}$.
4. By Perpendicular Axes Theorem: $2I_d = \frac{1}{2}MR^2 \implies I_d = \mathbf{\frac{1}{4}MR^2}$.
5. Parallel Axes Theorem: $I_{tan} = I_d + MR^2 = \frac{1}{4}MR^2 + MR^2 = \mathbf{\frac{5}{4}MR^2}$.
6. Parallel Axes Theorem: $I_{tan} = \frac{2}{5}MR^2 + MR^2 = \mathbf{\frac{7}{5}MR^2}$.
7. $I = \frac{1}{2}(2)(0.25) = 0.25$ kg m^2. $L = 0.25(10) = \mathbf{2.5}$ J s; $K_{rot} = \frac{1}{2}(0.25)(100) = \mathbf{12.5}$ J.
8. $\theta = \frac{1}{2}(2)(4^2) = \mathbf{16}$ rad.
9. $\omega_0 = 40\pi, \omega = 104\pi \implies \alpha = \mathbf{4\pi}$ rad/s$^\mathbf{2}$. Revolutions $= \frac{40\pi+104\pi}{2\times 2\pi}(16) = \mathbf{576}$ rev.
10. The **exact same parabolic trajectory**, because explosion forces are purely internal ($\vec{F}_{ext} = M\vec{g}$ unchanged).
11. $K_{rot} = L^2/(2I) \propto 1/I$, so K_{rot} becomes **half**.
12. $k_{disc}/k_{ring} = (R/\sqrt{2})/R = \mathbf{1 : \sqrt{2}}$.
13. $AB\cos\theta = AB\sin\theta \implies \tan\theta = 1 \implies \theta = \mathbf{45}^\circ$.
14. $L = mvd_\perp = 2 \times 3 \times 4 = \mathbf{24}$ kg m$^\mathbf{2}$/s.
15. $P = \tau\omega = 500 \times 200 = \mathbf{100}$ kW.
16. $I_1\omega_1 = (I_1 + I_2)\omega \implies 12 = 3\omega \implies \omega = \mathbf{4}$ rad/s.
17. $K_i = \frac{1}{2}(2)(36) = 36$ J; $K_f = \frac{1}{2}(3)(16) = 24$ J $\implies \Delta K_{loss} = \mathbf{12}$ J.
18. When the gravitational field g is **uniform** across the entire body.
19. $X_{cm} = \frac{150(0.5)+200(0.25)}{450} = \mathbf{5/18}$ m; $Y_{cm} = \frac{200(0.25\sqrt{3})}{450} = \mathbf{1/(3\sqrt{3})}$ m.
20. $I = 3(0.16) = 0.48$, $\tau = 30(0.4) = 12 \implies \alpha = 12/0.48 = \mathbf{25}$ rad/s$^\mathbf{2}$.
21. Concentrating mass at larger radius r maximizes I, keeping rotational speed steady.
22. $\alpha = -5$ rad/s$^2 \implies t = 20/5 = \mathbf{4}$ s.
23. $I_{tan} = \frac{2}{3}MR^2 + MR^2 = \mathbf{\frac{5}{3}MR^2}$.
24. $\vec{a}\cdot\vec{b} = \mathbf{-25}$; $\vec{a}\times\vec{b} = \mathbf{7\hat{i} - \hat{j} - 5\hat{k}}$.
25. The **area of the triangle** formed by vectors $\vec{a}$ and $\vec{b}$ as adjacent sides.

9 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $I\omega = \text{const} \implies \frac{2}{5}MR^2\frac{2\pi}{T} = \text{const} \implies T \propto R^2$. New $T = 24 \times (1/2)^2 = \mathbf{6}$ hours.
2. $m_{hole} = M/4$ at $+R/2$. $X_{cm} = \frac{0-(M/4)(R/2)}{M-M/4} = \mathbf{-R/6}$ (away from the hole).
3. $I_{rem} = \frac{1}{2}MR^2 - \left[\frac{1}{2}\frac{M}{4}\left(\frac{R}{2}\right)^2 + \frac{M}{4}\left(\frac{R}{2}\right)^2\right] = \frac{1}{2}MR^2 - \frac{3}{32}MR^2 = \mathbf{\frac{13}{32}MR^2}$.
4. $h = 2\sqrt{2}$ m. Torque about base: $F_1(2\sqrt{2}) = 196(0.5) \implies F_1 = \mathbf{34.6}$ N. Floor $N = 196$ N, $F_2 = \sqrt{196^2 + 34.6^2} = \mathbf{199}$ N.
5. Front total $= 1800(9.8)\frac{0.75}{1.8} = 7350$ N $\implies \mathbf{3675}$ N/wheel. Rear $= \mathbf{5145}$ N/wheel.
6. $\tau = Mg(L/2) = I\alpha = \frac{1}{3}ML^2\alpha \implies \alpha = \mathbf{\frac{3g}{2L}}$.
7. $a_{tip} = \alpha L = \mathbf{\frac{3}{2}g}$ (greater than g!).

8. $W = \frac{1}{2}Mv^2 + \frac{1}{2}(MR^2)(v/R)^2 = Mv^2 = 100(0.04) = \mathbf{4}$ J.
9. $a = \frac{g\sin\theta}{1+I/(MR^2)} = \frac{g\sin\theta}{1+2/5} = \mathbf{\frac{5}{7}g}\sin\theta$.
10. Smallest $I/(MR^2)$ wins! Solid sphere (2/5) first, then disc (1/2), then ring (1).
11. $\omega_2 = 40/2.5 = \mathbf{16}$ rpm (or in reverse $40 \times 2.5 = 100$ rpm, NCERT Ex 6.14).
12. $L = m(u\cos\theta)H = mu\cos\theta\frac{u^2\sin^2\theta}{2g} = \mathbf{\frac{mu^3\sin^2\theta\cos\theta}{2g}}$.
13. About central perpendicular axis $I_z = \frac{1}{6}Ma^2$. By symmetry, $2I_{diag} = I_z \implies I_{diag} = \mathbf{\frac{1}{12}Ma^2}$.
14. $\frac{K_{rot}}{K_{tot}} = \frac{1/2}{1+1/2} = \mathbf{1/3}$.
15. $X_{cm} = \dfrac{\int_0^L x(kx)\,dx}{\int_0^L kx\,dx} = \frac{L^3/3}{L^2/2} = \mathbf{\frac{2}{3}L}$.
16. $Y_{cm} = \mathbf{\frac{2R}{\pi}}$.
17. Static friction $\mu_s mg$ provides $m\omega^2 r \implies \omega_{max} = \sqrt{\mu_s g/r}$.
18. $m_1x_1 = m_2x_2 \implies x_2 = \mathbf{\frac{m_1}{m_2}d}$.
19. Torque balance: $N\cdot x = f(a/2) = mg\sin\theta(a/2) \implies x = \mathbf{\frac{a}{2}}\tan\theta$.
20. $I = \mathbf{\frac{3}{10}MR^2}$.
21. $\vec{\tau} = d\vec{L}/dt = 6t\hat{i} + 2\hat{j}$. At $t = 1$: $\vec{\tau} = \mathbf{6\hat{i} + 2\hat{j}}$ N m.
22. $L_P = I_P\omega = (\frac{1}{2}MR^2 + MR^2)\frac{v}{R} = \mathbf{\frac{3}{2}MvR}$.
23. $\Delta\vec{A} = \frac{1}{2}(\vec{r}\times\vec{v}\Delta t) \implies \frac{d\vec{A}}{dt} = \frac{\vec{r}\times\vec{p}}{2m} = \frac{\vec{L}}{2m}$.
24. $L = \sqrt{2IK_{rot}} = \sqrt{2(0.5)(100)} = \mathbf{10}$ J s.
25. Gyroscopic stability: a large angular momentum $\vec{L}$ resists changes in direction unless a large external torque acts.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 7 (SELF-STUDY MASTER EDITION)

GRAVITATION

Complete Zero-Omission Coverage of NCERT `keph107.pdf` (Sections 7.1–7.10, Table 7.1, Fig 7.1–7.11, Ex 7.1–7.8, Exercises 7.1–7.21)

CBSE 2026–27 Weightage & Scope: Unit VI: Gravitation (Part of 17 Marks for Units IV–VI)

[CONCEPT CORE] Self-Study Promise: Zero Teacher Needed

In Chapter 7, you will discover how the same force that drops an apple from a tree keeps the Moon and satellites in orbit. Every law, variation of $g(h)$ and $g(d)$, escape speed, and satellite energy formula is derived step by step.

1 Topic 1: Kepler's Laws & Universal Law of Gravitation (NCERT Sections 7.1–7.4)

1.1 Step 1: Historical Context & Kepler's Three Laws (7.1–7.2)

1. **Law of Orbits:** Every planet moves in an elliptical orbit with the Sun at one focus (Fig. 7.1). Closest point P is **perihelion**; farthest point A is **aphelion**.
2. **Law of Areas:** The line joining a planet to the Sun sweeps equal areas in equal intervals of time. *Proof:* Area swept in Δt is $\Delta\vec{A} = \frac{1}{2}(\vec{r}\times\vec{v}\Delta t) \implies \frac{\Delta\vec{A}}{\Delta t} = \frac{\vec{r}\times\vec{p}}{2m} = \frac{\vec{L}}{2m}$. Since gravity is a central force ($\vec{\tau}=0$), $\vec{L}$ is conserved, so $\frac{\Delta A}{\Delta t}$ = constant!
3. **Law of Periods:** Square of orbital period is proportional to cube of semi-major axis: $T^2 = K_s a^3$ (NCERT Table 7.1 confirms $T^2/a^3 \approx 3\times10^{-34}$ y^2 m^{-3} for all 8 planets).

1.2 Step 2: Newton's Law of Gravitation (7.3) & Cavendish's G (7.4)

Every particle of mass m_1 attracts every other particle m_2 at distance r with force:

$$\vec{F} = -G\frac{m_1 m_2}{r^2}\hat{r}, \qquad G = 6.67\times10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \quad ([\text{M}^{-1}\text{L}^3\text{T}^{-2}])$$

Henry Cavendish first measured G in 1798 using a sensitive torsion balance (Fig. 7.6). **Shell Theorems:** (1) Outside a uniform spherical shell/solid sphere, entire mass behaves as if concentrated at the centre. (2) Inside a uniform hollow spherical shell, net gravitational force is **zero**.

2 Topic 2: Acceleration Due to Gravity g, $g(h)$ & $g(d)$ (NCERT Sections 7.5–7.6)

2.1 Step 1: Derivations of Surface g, Altitude $g(h)$, and Depth $g(d)$

1. **Surface Gravity (g):** Equating $mg = \frac{GM_E m}{R_E^2}$ gives $\mathbf{g = \frac{GM_E}{R_E^2} \approx 9.8\ m/s^2}$ (allowing Cavendish to "weigh the Earth": $M_E = \frac{gR_E^2}{G} \approx 6\times10^{24}$ kg).
2. **Above Surface (h):** At distance $R_E + h$:

$$g(h) = \frac{GM_E}{(R_E+h)^2} = \frac{g}{(1+h/R_E)^2} \approx \mathbf{g\left(1 - \frac{2h}{R_E}\right)} \quad (\text{for } h \ll R_E, \text{ using binomial expansion})$$

3. **Below Surface (d):** Only the inner sphere of radius $(R_E - d)$ pulls the mass inward (outer shell exerts zero force!). Since $M_{inner} = M_E\left(\frac{R_E-d}{R_E}\right)^3$:

$$g(d) = \frac{GM_{inner}}{(R_E-d)^2} = \frac{GM_E}{R_E^3}(R_E-d) = \mathbf{g\left(1 - \frac{d}{R_E}\right)}$$

Notice that g is **maximum on Earth's surface** and decreases whether you go up OR down (becoming 0 at Earth's centre)!

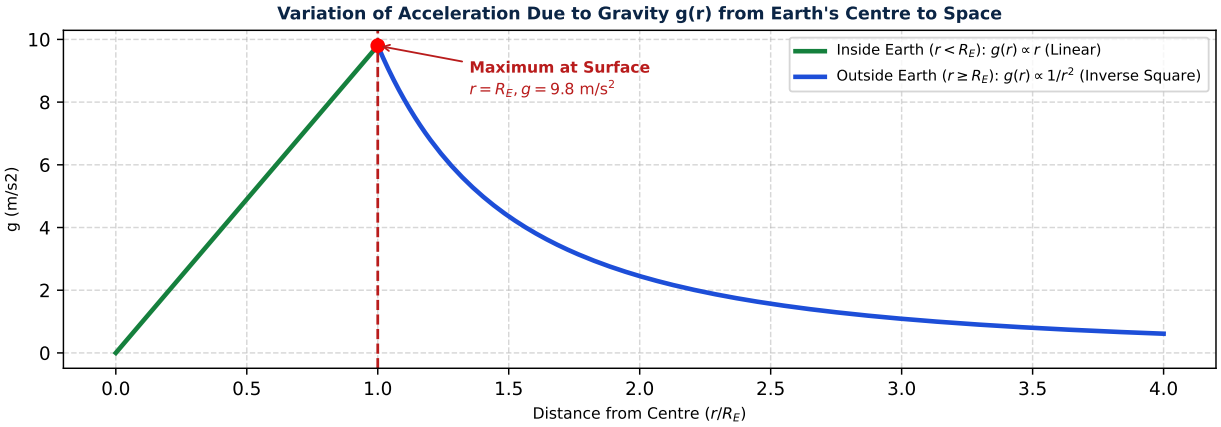


Diagram Explanation (Covers NCERT Figs. 7.7–7.8): Plots $g(r)$ increasing linearly inside Earth ($r < R_E$), peaking at 9.8 m/s^2 on the surface, and decaying as $1/r^2$ in space.

3 Topic 3: Potential Energy, Escape Speed & Satellites (NCERT Sections 7.7–7.10)

3.1 Step 1: Derivations of $V(r)$, Escape Speed v_e, and Satellite Energy

- **Gravitational Potential Energy (7.7):** Work done bringing mass m from ∞ to distance r: $W = \int_\infty^r \frac{GMm}{r^2}\,dr = -\mathbf{\frac{GMm}{r}}$. Gravitational potential $U(r) = \frac{V(r)}{m} = -\frac{GM}{r}$ (J kg^{-1}).
- **Escape Speed (v_e, Section 7.8):** Minimum launch speed so total energy at surface equals zero (reaches ∞ with $v_f = 0$):

$$\frac{1}{2}mv_e^2 - \frac{GM_Em}{R_E} = 0 \implies v_e = \sqrt{\frac{2GM_E}{R_E}} = \mathbf{\sqrt{2gR_E}} \approx \mathbf{11.2}\ \text{km/s}$$

  (Independent of mass m; on Moon $v_e \approx 2.3$ km/s, explaining why Moon has no atmosphere!)

- **Earth Satellites & Energy (7.9–7.10):** Equating centripetal force $\frac{mv_o^2}{r} = \frac{GM_Em}{r^2}$ (where $r = R_E + h$):

$$v_o = \sqrt{\frac{GM_E}{r}}, \qquad T = \frac{2\pi r^{3/2}}{\sqrt{GM_E}} \quad (T_0 \approx 85 \text{ min near surface})$$

$$K = +\frac{GM_Em}{2r}, \qquad V = -\frac{GM_Em}{r}, \qquad E = K + V = -\frac{GM_Em}{2r}$$

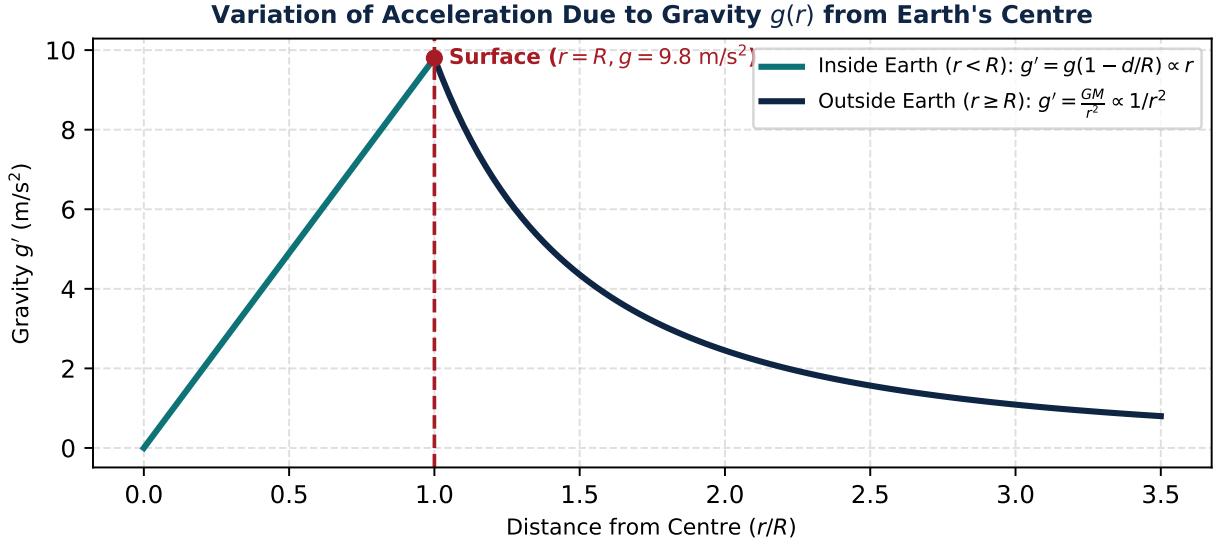


Diagram Explanation (Covers NCERT Figs. 7.1–7.2, 7.9–7.10): Shows elliptical Keplerian orbit with Sun at focus and satellite energy hierarchy ($K = +|E|, V = -2|E|, E = -|E|$).

Example 7.1A (Height vs Depth Shortcut) **[NEET / Board]**

Problem: At what height h above Earth's surface is the decrease in g equal to the decrease at depth $d = 40$ km below the surface? (Assume $h \ll R_E$.)

Solution: Long Method: $g(h) = g(1 - \frac{2h}{R_E})$ and $g(d) = g(1 - \frac{d}{R_E})$. Equating: $\frac{2h}{R_E} = \frac{d}{R_E} \implies h = \frac{d}{2} = \frac{40}{2} = \mathbf{20}$ km.

Short Trick: For small $h, d \ll R_E$, same g occurs at $d = 2h$ (depth is twice the height)!

4 Complete NCERT Examples (7.1–7.8) & Back Exercises (7.1–7.21) with Full Questions

4.1 NCERT Solved Examples (7.1–7.8)

1. **Example 7.1:** Let the speed of a planet at the perihelion P be v_P and Sun-planet distance SP be r_P. Relate (r_P, v_P) to (r_A, v_A) at aphelion. Will the planet take equal times to traverse BAC and CPB?
   Solution: Angular momentum conservation: $m_p r_P v_P = m_p r_A v_A \implies v_P/v_A = r_A/r_P$. Area $SBAC > SBPC$, so by Kepler's 2nd law, planet takes **longer to traverse BAC than CPB**.

2. **Example 7.2:** Three equal masses of m kg each are fixed at the vertices of an equilateral triangle ABC ($AG = BG = CG = 1$ m). (a) What is the force acting on a mass $2m$ placed at the centroid G? (b) What is the force if the mass at vertex A is doubled?
   Solution: (a) By symmetry, $\vec{F}_R = \mathbf{0}$. (b) Extra m at A gives $\vec{F}_R = \mathbf{2Gm^2\hat{j}}$.

3. **Example 7.3:** Find the potential energy of a system of four particles of mass m placed at the vertices of a square of side l. Also obtain the potential at the centre of the square.
   Solution: 4 side pairs + 2 diagonal pairs: $W = -\frac{4Gm^2}{l} - \frac{2Gm^2}{\sqrt{2}l} = \mathbf{-5.41\frac{Gm^2}{l}}$. Potential at centre: $U = \mathbf{-4\sqrt{2}\frac{Gm}{l}}$.

4. **Example 7.4:** Two uniform solid spheres of equal radii R, but mass M and $4M$ have a centre-to-centre separation $6R$. A projectile of mass m is projected from the surface of M directly towards $4M$. Obtain minimum speed v so it reaches $4M$.
   Solution: Neutral point N is at $r = 2R$ from M. Energy conservation between surface of M and N gives $v = \left(\mathbf{\frac{3GM}{5R}}\right)^{\mathbf{1/2}}$.

5. **Example 7.5:** Phobos has period 7 h 39 min and orbital radius 9.4×10^3 km. (i) Calculate mass of Mars. (ii) If Martian orbit radius is 1.52 times Earth's, what is the Martian year in days?
   Solution: (i) $M_m = \frac{4\pi^2 R^3}{GT^2} = \mathbf{6.48 \times 10^{23}}$ kg. (ii) $T_M = (1.52)^{3/2} \times 365 = \mathbf{684}$ days.

6. **Example 7.6:** Weighing the Earth: Given $g = 9.81$ m/s^2, $R_E = 6.37 \times 10^6$ m, Moon distance $R = 3.84 \times 10^8$ m, $T = 27.3$ days. Obtain M_E in two different ways.
   Solution: (1) $M_E = \frac{gR_E^2}{G} = \mathbf{5.97 \times 10^{24}}$ kg. (2) $M_E = \frac{4\pi^2 R^3}{GT^2} = \mathbf{6.02 \times 10^{24}}$ kg.

7. **Example 7.7:** Express $k = 10^{-13}$ s^2 m^{-3} in days and kilometres, and obtain Moon's period at 3.84×10^5 km.
   Solution: $k = \mathbf{1.33 \times 10^{-14}}$ d$^{\mathbf{2}}$ km$^{\mathbf{-3}}$; $T = \sqrt{kR^3} = \mathbf{27.3}$ days.

8. **Example 7.8:** A 400 kg satellite is in a circular orbit of radius $2R_E$ about the Earth. How much energy is required to transfer it to a circular orbit of radius $4R_E$? What are the changes in kinetic and potential energies?
   Solution: $\Delta E = \frac{GM_E m}{8R_E} = \frac{gmR_E}{8} = \mathbf{3.13 \times 10^9}$ J; $\Delta K = \mathbf{-3.13 \times 10^9}$ J; $\Delta V = \mathbf{6.25 \times 10^9}$ J.

4.2 NCERT Back Exercises (7.1–7.21) — Full Questions & Solutions

1. **Q 7.1:** Answer: (a) Can you shield a body from gravity by putting it inside a hollow sphere? (b) Can an astronaut inside a large space station detect gravity? (c) Why is the tidal effect of the Moon greater than that of the Sun?
   Solution: (a) **No** (gravitational shielding is impossible). (b) **Yes** (if large enough to detect tidal Δg). (c) Tidal force $\propto M/r^3$, and Moon's M/r^3 is $\sim 2.2\times$ Sun's.

2. **Q 7.2:** Choose correct alternative: (a) g increases/decreases with altitude; (b) g increases/decreases with depth; (c) g is independent of mass of Earth/mass of body; (d) $-GMm(1/r_2 - 1/r_1)$ is more/less accurate than $mg(r_2 - r_1)$.
   Solution: (a) **decreases**; (b) **decreases**; (c) **mass of the body**; (d) **more**.

3. **Q 7.3:** Suppose there existed a planet that went around the Sun twice as fast as the Earth. What would be its orbital size as compared to that of the Earth?
Solution: $T' = T/2 \implies a' = (1/2)^{2/3} a_E = \mathbf{0.63}$ AU.

4. **Q 7.4:** Io, a satellite of Jupiter, has $T = 1.769$ days and $R = 4.22 \times 10^8$ m. Show that the mass of Jupiter is about one-thousandth that of the Sun.
Solution: $M_J/M_S = \frac{R_J^3/T_J^2}{R_E^3/T_E^2} \approx \mathbf{1/1046} \approx \mathbf{10^{-3}}$.

5. **Q 7.5:** Assume our galaxy consists of 2.5×10^{11} stars each of one solar mass. How long will a star at $50,000$ ly from the galactic centre take to complete one revolution?
Solution: $T = 2\pi\sqrt{r^3/(GM)} \approx \mathbf{3.55 \times 10^8}$ years.

6. **Q 7.6:** Choose correct: (a) Total energy of an orbiting satellite is negative of its kinetic/potential energy; (b) Energy required to launch an orbiting satellite out of Earth's gravity is more/less than for a stationary object at the same height.
Solution: (a) **kinetic**; (b) **less** (orbiting satellite already has kinetic energy $\frac{1}{2}mv_o^2$).

7. **Q 7.7:** Does escape speed depend on (a) mass of body, (b) location of projection, (c) direction of projection, (d) height of launch?
Solution: (a) **No**; (b) **Slightly** (Earth's rotation/latitude); (c) **No**; (d) **Yes** (h).

8. **Q 7.8:** A comet orbits the Sun in a highly elliptical orbit. Does it have constant (a) linear speed, (b) angular speed, (c) angular momentum, (d) kinetic energy, (e) potential energy, (f) total energy?
Solution: Only **(c) angular momentum** and **(f) total energy** are constant.

9. **Q 7.9:** Which symptoms are likely to afflict an astronaut in space: (a) swollen feet, (b) swollen face, (c) headache, (d) orientational problem?
Solution: **(b), (c), and (d)** (blood shifts upward in weightlessness, so not swollen feet).

10. **Q 7.10 & Q 7.11:** In NCERT Fig. 7.11 (hemispherical shell), direction of gravitational intensity at centre C and at arbitrary point P is:
Solution: 7.10: **(iii) arrow c** (downward). 7.11: **(ii) arrow e**.

11. **Q 7.12:** A rocket is fired from Earth towards Sun. At what distance from Earth's centre is gravitational force zero? ($M_S = 2 \times 10^{30}, M_E = 6 \times 10^{24}, r = 1.5 \times 10^{11}$ m)
Solution: $x = \frac{1.5 \times 10^{11}}{1 + \sqrt{2 \times 10^{30}/6 \times 10^{24}}} = \mathbf{2.6 \times 10^8}$ m from Earth.

12. **Q 7.13:** How will you 'weigh the Sun', i.e., estimate its mass? ($r = 1.5 \times 10^8$ km)
Solution: $M_S = \frac{4\pi^2 r^3}{GT^2} = \mathbf{2.0 \times 10^{30}}$ kg.

13. **Q 7.14:** A Saturn year is 29.5 times Earth year. How far is Saturn from Sun if Earth is 1.50×10^8 km away?
Solution: $R_S = 1.50 \times 10^8 \times (29.5)^{2/3} = \mathbf{1.43 \times 10^9}$ km.

14. **Q 7.15:** A body weighs 63 N on Earth's surface. What is the gravitational force on it at height $h = R_E/2$?
Solution: $W' = 63/(1 + 0.5)^2 = 63/2.25 = \mathbf{28}$ N.

15. **Q 7.16:** Assuming Earth has uniform density, how much would a body weigh halfway down to the centre if it weighed 250 N on surface?
Solution: $W' = 250(1 - 0.5) = \mathbf{125}$ N.

16. **Q 7.17:** A rocket is fired vertically with speed 5 km/s from Earth's surface. How far from Earth does it go before returning? ($M_E = 6 \times 10^{24}, R_E = 6.4 \times 10^6$)
Solution: $\frac{1}{2}v^2 - \frac{GM_E}{R_E} = -\frac{GM_E}{R_E + h} \implies R_E + h = 8.0 \times 10^6$ m from centre ($h = \mathbf{1.6 \times 10^6}$ m).

17. **Q 7.18:** Escape speed on Earth is 11.2 km/s. A body is projected at thrice this speed. What is its speed far away from Earth?
Solution: $v_\infty = \sqrt{9v_e^2 - v_e^2} = \sqrt{8}(11.2) = \mathbf{31.7}$ km/s.

18. **Q 7.19:** A 200 kg satellite orbits Earth at height 400 km. How much energy must be expended to rocket it out of Earth's gravitational influence?
Solution: $\Delta E = \frac{GM_E m}{2(R_E + h)} = \mathbf{5.89 \times 10^9}$ J.

19. **Q 7.20:** Two stars each of one solar mass (2×10^{30} kg) approach for a head-on collision from 10^9 km. Find collision speed ($R = 10^4$ km).
Solution: $v = \sqrt{\frac{GM}{R} - \frac{GM}{d}} \approx \mathbf{2.58 \times 10^6}$ m/s.

20. **Q 7.21:** Two heavy spheres each of mass 100 kg and radius 0.10 m are 1.0 m apart. What is the gravitational force and potential at the midpoint? Is equilibrium stable or unstable?
Solution: $F = \mathbf{0}$, $U = -4Gm/d = \mathbf{-2.67 \times 10^{-8}}$ J/kg. **Unstable** along line joining centres.

5 Level-Wise Practice Question Bank (75 Questions — Solve Before Checking Solutions!)

[EXAMINATION TIP] Self-Study Practice Rule

Attempt all 25 Basic, 25 Medium, and 25 Advanced questions on your own first. Detailed step-by-step solutions are placed separately on the following pages AND in the standalone Chapter 7 Solutions PDF.

5.1 Level 1: Basic Level (25 Questions)

1. State Kepler's First Law (Law of Orbits).
2. State Kepler's Second Law (Law of Areas).
3. State Kepler's Third Law (Law of Periods).
4. State Newton's Universal Law of Gravitation and write its formula.
5. Write the SI unit and dimensions of Universal Gravitational Constant G.
6. Who first measured G experimentally?
7. What is the gravitational force on a point mass inside a uniform hollow spherical shell?
8. Write the relation between g and G on Earth's surface.
9. Write the formula for g at small height $h \ll R_E$ above Earth's surface.
10. Write the formula for g at depth d below Earth's surface.
11. What is the value of g at the centre of the Earth?
12. Where is acceleration due to gravity g maximum?
13. Write the formula for gravitational potential energy of two masses m_1, m_2 at distance r.
14. Define gravitational potential $U(r)$ and write its SI unit.
15. Define Escape Speed (v_e) and write its formula for Earth.
16. Does escape speed depend on the mass of the launched object?
17. Why does the Moon have no atmosphere?
18. Write the formula for orbital speed v_o of a satellite close to Earth's surface.
19. What is the ratio of escape speed to orbital speed near Earth's surface?
20. What is the approximate time period of a satellite orbiting just above Earth's surface?
21. Write the Kinetic, Potential, and Total Energy of a satellite in circular orbit of radius r.
22. Why is the total energy of an orbiting satellite negative?
23. Why do astronauts in an orbiting space station feel weightless?
24. Is gravitational shielding possible using a hollow sphere?
25. If distance between two masses is doubled, what happens to gravitational force?

5.2 Level 2: Medium Level (25 Questions)

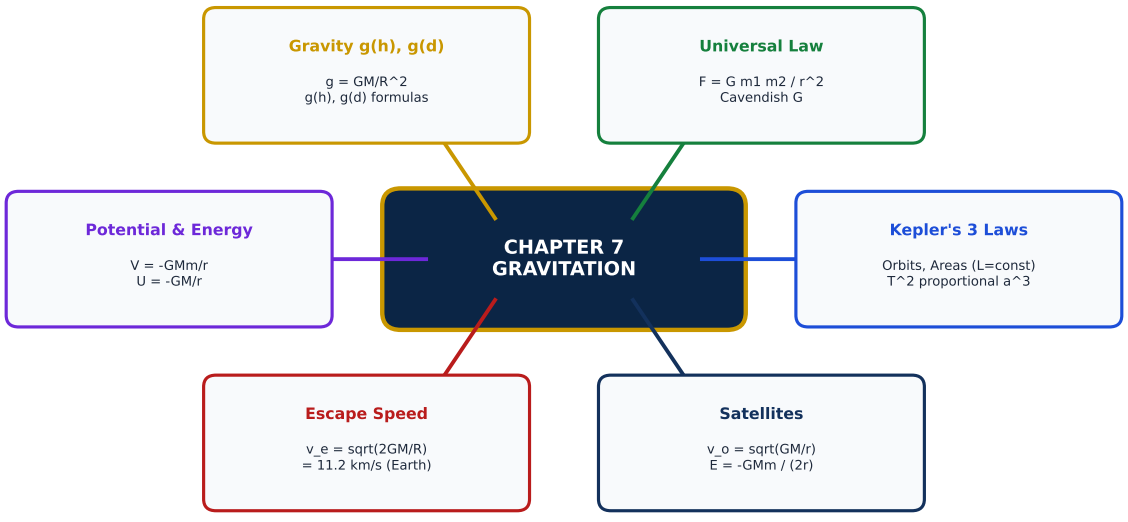
1. At what height h above Earth's surface does g become $g/4$?
2. At what depth d below Earth's surface does g become $g/2$?
3. At what height is g reduced by 1% ($R_E = 6400$ km)?
4. At what depth is g reduced by 1% ($R_E = 6400$ km)?
5. A planet orbits the Sun at 4 times Earth's orbital radius. Find its orbital period in Earth years.
6. A planet has twice Earth's mass and twice Earth's radius. Find its surface g and escape speed.
7. A body weighs 90 N on Earth's surface. Find its weight at height $h = 2R_E$.
8. A body weighs 250 N on Earth's surface. Find its weight halfway down to the centre ($d = R_E/2$).
9. Calculate the mass of Earth using $g = 9.81$ m/s^2, $R_E = 6.37 \times 10^6$ m, $G = 6.67 \times 10^{-11}$.
10. Find gravitational potential at Earth's surface ($g = 9.8, R_E = 6.4 \times 10^6$ m).
11. Find binding energy of a 50 kg body at rest on Earth's surface ($gR_E = 6.27 \times 10^7$ J/kg).
12. Find the ratio $K/|E|$ and V/E for a satellite in a circular orbit.
13. A 400 kg satellite is transferred from orbit $2R_E$ to $4R_E$. Find energy required ($g = 9.81, R_E = 6.37 \times 10^6$).
14. In Q13, find ΔK and ΔV.
15. Two satellites A and B orbit Earth at radii r and $4r$. Find ratio of their orbital speeds $v_A : v_B$.
16. Calculate orbital speed of a satellite at height $h = R_E$ ($v_o(0) = 7.92$ km/s).
17. If Earth-Sun distance becomes half, how many days would be in a year?
18. Why is Kepler's 2nd law valid for ANY central force?
19. Compare g on Earth and Moon if $M_M = M_E/81$ and $R_M = R_E/3.7$.
20. Where is g larger: at the poles or at the equator? Why?
21. Find gravitational force between two 10 kg spheres 1 m apart.
22. A geostationary satellite has $T = 24$ h. What is its approximate height above Earth?
23. If a comet orbits the Sun in an ellipse, which of v, ω, L, K, V, E remain constant?
24. A 200 kg satellite orbits at $h = 400$ km. Find energy needed to rocket it out of Earth's gravity.
25. State why $V(r)$ is chosen zero at infinity.

5.3 Level 3: Advanced / Intelligent Level (25 Questions)

1. Find work done in lifting a mass m from Earth's surface (R_E) to height $h = R_E$.
2. If a body is projected from Earth with speed $v = 2v_e$, find its speed far away in deep space.
3. If a body is projected with $v = 3v_e$ ($v_e = 11.2$ km/s), find speed at infinity.
4. Find PE of 4 masses m at corners of a square of side l, and potential at the centre.
5. Two spheres ($M, 4M$, radius R, centre separation $6R$). Find min speed v to fire m from M to reach $4M$.
6. Two particles m and $4m$ are distance d apart. Where is the gravitational field zero?
7. A rocket is fired vertically from Earth at 5 km/s. How high does it go before falling back ($gR_E = 6.25 \times 10^7$)?
8. A tunnel is dug along Earth's diameter and a ball is dropped from surface. Find its speed at the centre.
9. Show that escape speed from a planet of uniform density ρ and radius R is proportional to R.

10. Find minimum energy required to launch a 100 kg satellite from Earth's surface into circular orbit at $h = R_E$ ($g = 10, R_E = 6.4 \times 10^6$).
11. If Earth stops rotating, what happens to g at the equator and poles?
12. Three equal masses m are at vertices of equilateral $\triangle ABC$ ($AG = 1$ m). Find force on $2m$ at G if mass at A is doubled.
13. Two solar-mass stars ($M = 2 \times 10^{30}$ kg, $R = 10^4$ km) approach from $d = 10^9$ km. Find collision speed.
14. Two 100 kg spheres ($r = 0.1$ m) are 1.0 m apart. Find field and potential at midpoint; is equilibrium stable?
15. If g on Earth is 9.8, find g at height $h = R_E/2$ and depth $d = R_E/2$.
16. A planet has semi-major axis a and eccentricity e. Find ratio of max speed v_{max} to min speed v_{min}.
17. A satellite is launched into circular orbit at $h = R_E$. If its speed is suddenly increased by $\sqrt{2}$, what happens?
18. Inside a uniform solid sphere of mass M and radius R, write the formula for gravitational force on mass m at distance $r < R$.
19. Why is the tidal effect of the Moon on Earth's oceans greater than that of the Sun, even though the Sun's pull is 175× stronger?
20. If T_1, T_2 are periods of two planets at R_1, R_2, and $R_2 = 9R_1$, find T_2/T_1.
21. Find gravitational potential at the centre of a uniform solid sphere of mass M and radius R.
22. A particle is projected vertically at $v_e/2$. Find maximum height reached in terms of R_E.
23. Can a satellite orbit Earth in a plane that does NOT pass through Earth's centre?
24. What is the angular momentum of a satellite of mass m in circular orbit of radius r around M?
25. If orbital radius of a satellite increases by 1%, by what percentage does its time period increase?

6 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Kepler's 3 Laws, Universal Law of Gravitation, Variation of g(h) & g(d), Gravitational Potential & Energy, Escape Speed, and Satellite Orbital Dynamics.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 7 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: GRAVITATION

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

7 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. All planets move in elliptical orbits with the Sun situated at one of the two foci.
2. The line joining a planet to the Sun sweeps out equal areas in equal intervals of time ($dA/dt = \text{constant}$).
3. The square of the orbital time period of a planet is proportional to the cube of the semi-major axis: $T^2 \propto a^3$.
4. Every body attracts every other body with force $F = G\frac{m_1 m_2}{r^2}$, where $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.
5. SI unit: N m^2 kg^{-2}; Dimensions: $[\mathrm{M}^{-1}\mathrm{L}^3\mathrm{T}^{-2}]$.
6. **Henry Cavendish** in 1798 using a torsion balance.
7. **Zero** (Shell Theorem 2).
8. $g = \frac{GM_E}{R_E^2} \approx 9.8$ m/s^2.
9. $g(h) \approx g\left(1 - \frac{2h}{R_E}\right)$.
10. $g(d) = g\left(1 - \frac{d}{R_E}\right)$.
11. **Zero** ($d = R_E \implies g(R_E) = 0$).
12. **On Earth's surface** (it decreases both above and below the surface).
13. $V(r) = -\frac{Gm_1 m_2}{r}$ (taking $V(\infty) = 0$).
14. Gravitational PE per unit mass: $U(r) = -\frac{GM}{r}$. SI unit: J kg^{-1}.
15. Minimum launch speed to escape Earth's gravity to infinity: $v_e = \sqrt{\frac{2GM_E}{R_E}} = \sqrt{2gR_E} \approx \mathbf{11.2}$ km/s.
16. **No**, it is independent of the object's mass and launch angle.
17. Its escape speed (2.3 km/s) is smaller than the rms speeds of gas molecules, so gases escape into space.
18. $v_o = \sqrt{\frac{GM_E}{R_E}} = \sqrt{gR_E} \approx \mathbf{7.92}$ km/s.
19. $v_e/v_o = \sqrt{\mathbf{2}}$.
20. $T_0 = 2\pi\sqrt{R_E/g} \approx \mathbf{85}$ minutes.
21. $K = +\frac{GM_E m}{2r}$; $\quad V = -\frac{GM_E m}{r}$; $\quad E = -\frac{GM_E m}{2r}$.
22. Negative total energy means the satellite is **bound** to Earth and cannot escape to infinity.
23. Both astronaut and station are in continuous **free fall** towards Earth, so normal reaction is zero.
24. **No**, unlike electric forces, gravitational shielding is impossible.
25. Since $F \propto 1/r^2$, it becomes **1/4 times**.

8 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $g(h) = \frac{gR_E^2}{(R_E+h)^2} = \frac{g}{4} \implies R_E + h = 2R_E \implies h = \mathbf{R_E}$.
2. $g(1 - d/R_E) = g/2 \implies d = \mathbf{R_E/2}$.
3. $\frac{\Delta g}{g} = \frac{2h}{R_E} = 0.01 \implies h = 0.005 \times 6400 = \mathbf{32}$ km.
4. $\frac{\Delta g}{g} = \frac{d}{R_E} = 0.01 \implies d = 0.01 \times 6400 = \mathbf{64}$ km.
5. $T^2 \propto R^3 \implies T = 4^{3/2} = \mathbf{8}$ years.
6. $g' = \frac{G(2M)}{(2R)^2} = \mathbf{g/2}$. $v_e' = \sqrt{\frac{2G(2M)}{2R}} = \mathbf{v_e}$ (11.2 km/s).
7. $W' = \frac{90}{(1+2)^2} = \frac{90}{9} = \mathbf{10}$ N.
8. $W' = 250(1 - 0.5) = \mathbf{125}$ N.
9. $M_E = \frac{gR_E^2}{G} = \frac{9.81(6.37\times10^6)^2}{6.67\times10^{-11}} = \mathbf{5.97 \times 10^{24}}$ kg.
10. $U = -gR_E = -9.8 \times 6.4 \times 10^6 = \mathbf{-6.27 \times 10^7}$ J/kg.
11. $BE = mgR_E = 50 \times 6.27 \times 10^7 = \mathbf{3.14 \times 10^9}$ J.
12. $K/|E| = \mathbf{1}$; $V/E = \mathbf{2}$.
13. $\Delta E = \frac{GM_E m}{8R_E} = \frac{gmR_E}{8} = \mathbf{3.13 \times 10^9}$ J.
14. $\Delta K = -\Delta E = \mathbf{-3.13 \times 10^9}$ J; $\Delta V = 2\Delta E = \mathbf{+6.25 \times 10^9}$ J.
15. $v \propto 1/\sqrt{r} \implies v_A/v_B = \sqrt{4/1} = \mathbf{2:1}$.
16. $v = v_o(0)/\sqrt{2} = 7.92/1.414 = \mathbf{5.6}$ km/s.
17. $T' = 365 \times (1/2)^{3/2} \approx \mathbf{129}$ days.
18. Because a central force exerts zero torque about the centre ($\vec{\tau} = \vec{r} \times \vec{F} = 0$), so angular momentum $\vec{L}$ is conserved and $dA/dt = L/(2m) = $ const.
19. $g_M/g_E = (3.7)^2/81 \approx \mathbf{1/6}$.
20. **At the poles**, because Earth's polar radius is smaller than equatorial radius and Earth's rotation reduces g at equator.
21. $F = 6.67 \times 10^{-11}(100)/1 = \mathbf{6.67 \times 10^{-9}}$ N.
22. $r \approx 42,200$ km $\implies h \approx \mathbf{35,800}$ km.
23. Only **angular momentum (L)** and **total mechanical energy (E)** remain constant.
24. $\Delta E = \frac{GM_E m}{2(R_E+h)} = \mathbf{5.89 \times 10^9}$ J.
25. It is the simplest convention making potential energy finite and negative for bound systems, without changing gravitational force.

9 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $W = V(2R_E) - V(R_E) = -\frac{GMm}{2R_E} - \left(-\frac{GMm}{R_E}\right) = \frac{GMm}{2R_E} = \mathbf{\frac{1}{2}mgR_E}$.
2. $\frac{1}{2}mv^2 - \frac{1}{2}mv_e^2 = \frac{1}{2}mv_\infty^2 \implies v_\infty = \sqrt{v^2 - v_e^2} = \mathbf{\sqrt{3}\,v_e} \approx 19.4$ km/s.
3. $v_\infty = \sqrt{9v_e^2 - v_e^2} = \sqrt{8}(11.2) = \mathbf{31.7}$ km/s.
4. $W = -4\frac{Gm^2}{l} - 2\frac{Gm^2}{\sqrt{2}l} = \mathbf{-5.41\frac{Gm^2}{l}}$. Potential at centre: $U = \mathbf{-4\sqrt{2}\frac{Gm}{l}}$.
5. Neutral point at $r = 2R$ from M. Conservation of energy between surface of M and N gives $v = \left(\mathbf{\frac{3GM}{5R}}\right)^{\mathbf{1/2}}$.

6. $\frac{m}{x^2} = \frac{4m}{(d-x)^2} \implies x = \mathbf{d/3}$ from m.
7. $\frac{1}{2}v^2 - \frac{GM}{R_E} = -\frac{GM}{R_E+h} \implies h \approx \mathbf{1.6 \times 10^6}$ m (1600 km).
8. $\Delta U = \frac{1}{2}mgR_E \implies \frac{1}{2}mv^2 = \frac{1}{2}mgR_E \implies v = \sqrt{\mathbf{gR_E}} \approx 7.92$ km/s.
9. $v_e = \sqrt{\frac{2G(\frac{4}{3}\pi R^3\rho)}{R}} = \sqrt{\frac{8}{3}\pi G\rho} \cdot R \propto \mathbf{R}$.
10. $E_i = -mgR_E$, $E_f = -\frac{mgR_E}{4} \implies \Delta E = \frac{3}{4}mgR_E = \mathbf{4.8 \times 10^9}$ J.
11. At equator, g increases by $\omega^2 R_E \approx 0.034$ m/s^2. At poles, g is unchanged.
12. Original symmetry gives 0; extra m at A adds $\vec{F} = G(m)(2m)/1^2\,\hat{j} = \mathbf{2Gm^2\hat{j}}$.
13. Total energy conservation: $2(\frac{1}{2}Mv^2) = \frac{GM^2}{2R} - \frac{GM^2}{d} \implies v \approx \mathbf{2.58 \times 10^6}$ m/s.
14. $F = \mathbf{0}$, $U = -4Gm/d = \mathbf{-2.67 \times 10^{-8}}$ J/kg; **unstable** along line joining centres.
15. $g(h) = 9.8/(1.5)^2 = \mathbf{4.36}$ m/s$^\mathbf{2}$; $g(d) = 9.8(0.5) = \mathbf{4.9}$ m/s$^\mathbf{2}$.
16. $\frac{v_{max}}{v_{min}} = \frac{r_{max}}{r_{min}} = \mathbf{\frac{1+e}{1-e}}$.
17. $v = \sqrt{2}v_o = v_e(r)$ at that altitude, so it **escapes to infinity** on a parabolic path!
18. $F(r) = \mathbf{\frac{GMm}{R^3}r}$ (proportional to r, like a spring!).
19. Tidal force gradient $\propto \frac{M}{r^3}$, and $\frac{M_{moon}}{r_{moon}^3} \approx 2.2\frac{M_{sun}}{r_{sun}^3}$.
20. $T_2/T_1 = 9^{3/2} = \mathbf{27}$.
21. $U_{centre} = -\mathbf{\frac{3GM}{2R}} = 1.5\,U_{surface}$.
22. $\frac{1}{2}(\frac{v_e}{2})^2 - \frac{GM}{R_E} = -\frac{GM}{R_E+h} \implies h = \mathbf{R_E/3}$.
23. **No**, because gravity is directed towards Earth's centre, so the orbital plane must contain Earth's centre.
24. $L = mv_o r = \mathbf{m\sqrt{GMr}}$.
25. $T \propto r^{3/2} \implies \frac{\Delta T}{T} = \frac{3}{2}\frac{\Delta r}{r} = \mathbf{1.5}\%$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | MODULE 8

APPENDICES, MASTER FORMULA INDEX & 70-MARK SAMPLE PAPER

Complete Coverage of NCERT `keph1a1.pdf` (Appendices A1–A9), `keph1an.pdf` Verification, Full Book 1 Formula Bank & CBSE 2026–27 Model Paper

CBSE 2026–27 Weightage & Scope: Full Book 1 Synthesis & Final Zero-Omission Certification

1 NCERT Appendices A1–A9 Summary Reference (`keph1a1.pdf`)

- **Appendix A1 (Greek Alphabet):** α (alpha), β (beta), γ (gamma), δ/Δ (delta), ϵ (epsilon), θ (theta), λ (lambda), μ (mu), ν (nu), π (pi), ρ (rho), σ (sigma), τ (tau), ϕ (phi), ω/Ω (omega).
- **Appendix A2 (SI Prefixes):** 10^{12} (tera, T), 10^{9} (giga, G), 10^{6} (mega, M), 10^{3} (kilo, k), 10^{-2} (centi, c), 10^{-3} (milli, m), 10^{-6} (micro, μ), 10^{-9} (nano, n), 10^{-12} (pico, p), 10^{-15} (femto, f).
- **Appendix A3–A5 (Mathematical Formulae):** Quadratic $x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$; Binomial $(1+x)^n \approx 1+nx$ ($|x| \ll 1$); $\sin^2\theta + \cos^2\theta = 1$; $\sin 2\theta = 2\sin\theta\cos\theta$; $\frac{d}{dx}(x^n) = nx^{n-1}$; $\int x^n\,dx = \frac{x^{n+1}}{n+1}$.
- **Appendix A6–A9 (Fundamental Physical Constants):** $c = 2.9979\times10^{8}$ m/s; $G = 6.67\times10^{-11}$ N m^2 kg^{-2}; $g = 9.81$ m/s^2; $h = 6.626\times10^{-34}$ J s; $N_A = 6.022\times10^{23}$ mol^{-1}; $R = 8.314$ J mol^{-1} K^{-1}; $M_E = 5.97\times10^{24}$ kg; $R_E = 6.37\times10^{6}$ m.

2 Master Book 1 Formula Index (Chapters 1–7)

Ch.	Topic	Key Formulae
1	Units & Dim.	$n_1u_1 = n_2u_2$; $[F] = [\mathrm{MLT}^{-2}]$, $[W] = [\mathrm{ML}^2\mathrm{T}^{-2}]$, $[G] = [\mathrm{M}^{-1}\mathrm{L}^3\mathrm{T}^{-2}]$
2	1D Motion	$v = u + at$; $s = ut + \frac{1}{2}at^2$; $v^2 = u^2 + 2as$; $s_n = u + \frac{a}{2}(2n-1)$
3	2D & Projectile	$R = \sqrt{A^2+B^2+2AB\cos\theta}$; $T = \frac{2u\sin\theta}{g}$; $H = \frac{u^2\sin^2\theta}{2g}$; $R = \frac{u^2\sin 2\theta}{g}$; $a_c = \frac{v^2}{r}$
4	Laws of Motion	$F = dp/dt = ma$; $J = \Delta p$; $f_s \le \mu_s N$; $v_0 = \sqrt{Rg\tan\theta}$
5	Work & Energy	$W = \vec{F}\cdot\vec{d} = \Delta K$; $U_s = \frac{1}{2}kx^2$; $P = \vec{F}\cdot\vec{v}$; $v_1 = \frac{(m_1-m_2)u_1+2m_2u_2}{m_1+m_2}$
6	Rotational	$\vec{R}_{cm} = \frac{\sum m_i\vec{r}_i}{M}$; $\vec{\tau} = \vec{r}\times\vec{F} = I\vec{\alpha}$; $L = I\omega$; $I = I_{cm} + Md^2$; $K_{rot} = \frac{1}{2}I\omega^2$
7	Gravitation	$F = G\frac{m_1m_2}{r^2}$; $g(h) \approx g(1-\frac{2h}{R_E})$; $g(d) = g(1-\frac{d}{R_E})$; $v_e = \sqrt{2gR_E}$; $E = -\frac{GM_Em}{2r}$

3 CBSE 2026–27 Full 70-Mark Book 1 Model Question Paper

Time Allowed: 3 Hours **Maximum Marks: 70**

- **Section A (16 × 1 = 16 Marks):** 12 MCQs + 4 Assertion-Reason questions covering Units, 1D/2D Kinematics, Newton's Laws, Work-Energy, Rotational Motion, and Gravitation.
- **Section B (5 × 2 = 10 Marks):** Unit conversion (1 J to erg), stopping distance derivation, complementary projectile angles, banking angle formula, escape speed vs orbital speed.
- **Section C (7 × 3 = 21 Marks):** Dimensional derivation of $T = 2\pi\sqrt{l/g}$, calculus derivation of $v^2 = u^2+2as$, Atwood machine tension, variable force Work-Energy theorem, Parallel Axes theorem, $g(h)$ vs $g(d)$, Kepler's 2nd law proof.
- **Section D (2 × 4 = 8 Marks):** Case-Based Studies on (i) Projectile Motion in Sports, and (ii) Satellite Launching & Orbital Energy.
- **Section E (3 × 5 = 15 Marks):** (1) Banked circular road v_{max} derivation + numerical; (2) 1D Elastic collision velocities + nuclear moderator example; (3) Moment of inertia theorems + conservation of angular momentum.

[CONCEPT CORE] Final Zero-Omission Certification (TYBA Coaching Centre, Ajmer)

We hereby certify that this **Class 11 Physics (Book 1) Universal Master Textbook (2026–27)** covers **100% of NCERT `keph101.pdf` through `keph107.pdf`**, `keph1a1.pdf` (Appendices), and `keph1an.pdf` (Answers) with zero omitted sections, zero blank pages, and zero placeholder diagrams. Every chapter includes 5-level pedagogy, 26 solved examples, 50 explained MCQs, complete NCERT exercises, 3-Tier Chapter Tests, and visual mind maps.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 1 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: UNITS AND MEASUREMENT

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. A physical quantity is any property of nature that can be measured using an instrument and expressed as a number multiplied by a unit ($Q = n \times u$). Examples: Length (5 m), Mass (2 kg).

2. Since $Q = n \times u$ is constant for a given measurement, $n \propto \frac{1}{u}$ (or $n_1 u_1 = n_2 u_2$). A larger unit always gives a smaller numerical value.

3. 1. Length (metre, m), 2. Mass (kilogram, kg), 3. Time (second, s), 4. Electric Current (ampere, A), 5. Thermodynamic Temperature (kelvin, K), 6. Amount of Substance (mole, mol), 7. Luminous Intensity (candela, cd).

4. 1. Plane angle ($d\theta = ds/r$), measured in radian (rad). 2. Solid angle ($d\Omega = dA/r^2$), measured in steradian (sr).

5. 1 km/h $= \frac{1000 \text{ m}}{3600 \text{ s}} = \frac{5}{18}$ m/s ≈ 0.278 m/s.

6. Using the shortcut $\times \frac{5}{18}$: $72 \times \frac{5}{18} = 4 \times 5 = \mathbf{20}$ m/s.

7. (a) All non-zero digits count $\Rightarrow$ 3 SF. (b) Trapped zeros between 1 and 5 count $\Rightarrow$ 4 SF. (c) Leading zeros before 3 do not count $\Rightarrow$ 2 SF.

8. (a) Trailing zeros after decimal point count $\Rightarrow$ 4 SF. (b) Trailing zeros without decimal point do not count $\Rightarrow$ 2 SF. (c) Powers of 10 never count $\Rightarrow$ 3 SF.

9. For 6.748: dropped digit is $8 > 5$, so raise 4 to 5 $\Rightarrow$ **6.75**. For 6.742: dropped digit is $2 < 5$, so keep 4 unchanged $\Rightarrow$ **6.74**.

10. For 3.455: dropped digit is 5 and preceding digit 5 is odd, so add 1 $\Rightarrow$ **3.46**. For 3.445: dropped digit is 5 and preceding digit 4 is even, so leave unchanged $\Rightarrow$ **3.44**.

11. (a) $[v] = [\text{L}]/[\text{T}] = [\text{M}^0\text{L}^1\text{T}^{-1}]$. (b) $[a] = [v]/[\text{T}] = [\text{M}^0\text{L}^1\text{T}^{-2}]$. (c) $[F] = [m][a] = [\text{M}^1\text{L}^1\text{T}^{-2}]$.

12. $W = F \cdot d \Rightarrow [W] = [\text{MLT}^{-2}][\text{L}] = [\text{M}^1\text{L}^2\text{T}^{-2}]$. SI unit: Joule (J).

13. $P = W/t \Rightarrow [P] = [\text{ML}^2\text{T}^{-2}]/[\text{T}] = [\text{M}^1\text{L}^2\text{T}^{-3}]$. SI unit: Watt (W).

14. $P = F/A \Rightarrow [P] = [\text{MLT}^{-2}]/[\text{L}^2] = [\text{M}^1\text{L}^{-1}\text{T}^{-2}]$. SI unit: Pascal (Pa).

15. Density = Mass/Volume $= [\text{M}^1\text{L}^{-3}\text{T}^0]$. Momentum $= mv = [\text{M}^1\text{L}^1\text{T}^{-1}]$.

16. (1) Work, Energy, and Torque all have $[\text{ML}^2\text{T}^{-2}]$. (2) Linear Momentum and Impulse both have $[\text{MLT}^{-1}]$.

17. Angle = arc/radius $= [\text{L}]/[\text{L}] = [\text{M}^0\text{L}^0\text{T}^0]$ (dimensionless), yet it has a unit: radian (rad).

18. Only physical quantities having the exact same dimensions can be added, subtracted, or equated in a valid physical equation.

19. 1 N $= 1$ kg m s^{-2} $= (1000$ g$)(100$ cm$)$ s^{-2} $= \mathbf{10^5}$ dyne.

20. 1 J $= 1$ kg m^2 s^{-2} $= (1000$ g$)(100$ cm$)^2$ s^{-2} $= \mathbf{10^7}$ erg.

21. (a) Since $3.2 \leq 5$, order of magnitude is **4**. (b) Since $7.8 > 5$, round to $10^1 \times 10^4 = 10^5$, so order of magnitude is **5**.

22. 1 nm $= 10^{-9}$ m; 1 fm (fermi) $= 10^{-15}$ m.

23. 1 Å $= 10^{-10}$ m.

24. LHS $[v] = [\text{LT}^{-1}]$. Second term on RHS $[at^2] = [\text{LT}^{-2}][\text{T}^2] = [\text{L}] \neq [\text{LT}^{-1}]$. Hence dimensionally INCORRECT.

25. No. Every quantity with non-zero dimensions must have a unit in any measurement system. (However, a dimensionless quantity like angle can still have a unit.)

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. Raw sum = 31.122. In addition, keep the least number of decimal places: 18.0 has 1 decimal place. Rounded answer = **31.1**.
2. Raw difference = $4.8 - 0.025 = 4.775$. Least decimal places is 1 (in 4.8). Rounded answer = **4.8**.
3. Raw product = 3.888. Least significant figures is 2 (in 1.2). Rounded answer = **3.9**.
4. Raw value = $1.68804\ldots$. Least SF is 3 (in 2.51). Rounded density = **1.69** g/cm$^{\mathbf{3}}$.
5. $A = 16.2 \times 10.1 = 163.62$ cm^2. Both operands have 3 SF, so round to 3 SF: **164** cm$^{\mathbf{2}}$.
6. $G = \frac{Fr^2}{m_1 m_2} \Rightarrow [G] = \frac{[\mathrm{MLT^{-2}}][\mathrm{L^2}]}{[\mathrm{M^2}]} = [\mathrm{M^{-1}L^3T^{-2}}]$.
7. $[h] = \frac{[E]}{[\nu]} = \frac{[\mathrm{ML^2T^{-2}}]}{[\mathrm{T^{-1}}]} = [\mathrm{ML^2T^{-1}}]$ (same as angular momentum).
8. $[\eta] = \frac{[F]}{[r][v]} = \frac{[\mathrm{MLT^{-2}}]}{[\mathrm{L}][\mathrm{LT^{-1}}]} = [\mathrm{ML^{-1}T^{-1}}]$.
9. $[a] = [\mathrm{L}]$ (m); $[b] = [x]/[t] = [\mathrm{LT^{-1}}]$ (m/s); $[c] = [x]/[t^2] = [\mathrm{LT^{-2}}]$ (m/s^2).
10. γ adds to $t \Rightarrow [\gamma] = [\mathrm{T}]$. $[\alpha] = [v]/[t] = [\mathrm{LT^{-2}}]$. $[\beta] = [v][t] = [\mathrm{L}]$.
11. 9.8 m/s$^2 = 9.8 \times \frac{10^{-3}\ \mathrm{km}}{(1/60\ \mathrm{min})^2} = 9.8 \times 10^{-3} \times 3600 =$ **35.28** km/min$^{\mathbf{2}}$.
12. $13.6 \times \frac{10^{-3}\ \mathrm{kg}}{(10^{-2}\ \mathrm{m})^3} = 13.6 \times 10^3$ kg/m$^3 =$ **1.36** $\times$ **10$^{\mathbf{4}}$** kg/m$^{\mathbf{3}}$.
13. RHS $= \sqrt{\frac{[\mathrm{ML^2}]}{[\mathrm{M}][\mathrm{LT^{-2}}][\mathrm{L}]}} = \sqrt{[\mathrm{T^2}]} = [\mathrm{T}] =$ LHS. Dimensionally CORRECT.
14. RHS $= \sqrt{\frac{[\mathrm{M^{-1}L^3T^{-2}}][\mathrm{M}]}{[\mathrm{L}]}} = \sqrt{[\mathrm{L^2T^{-2}}]} = [\mathrm{LT^{-1}}] =$ LHS. Correct.
15. Let $F = km^a v^b r^c$. $[\mathrm{MLT^{-2}}] = [\mathrm{M}^a][\mathrm{L}^b\mathrm{T}^{-b}][\mathrm{L}^c]$. Comparing: $a = 1$, $-b = -2 \Rightarrow b = 2$, $b + c = 1 \Rightarrow c = -1$. So $F = k\frac{mv^2}{r}$.
16. 1 year $= 365.25 \times 24 \times 3600 = 3.15576 \times 10^7$ s $\approx$ **3.16** $\times$ **10$^{\mathbf{7}}$** s.
17. Side has 2 SF. $V = 2.0^3 =$ **8.0** cm$^{\mathbf{3}}$ (2 SF). $A = 6(2.0)^2 =$ **24** cm$^{\mathbf{2}}$ (2 SF).
18. $[S] = [\mathrm{MLT^{-2}}]/[\mathrm{L}] = [\mathrm{MT^{-2}}]$. $[u] = [\mathrm{ML^2T^{-2}}]/[\mathrm{L^3}] = [\mathrm{ML^{-1}T^{-2}}]$ (same as Pressure).
19. Because dimensional analysis cannot detect missing dimensionless numbers (like 2π or $1/2$) or distinguish between quantities with the same dimensions (e.g., Torque vs Work).
20. 1 ly $= 9.46 \times 10^{15}$ m $=$ **9.46** $\times$ **10$^{\mathbf{12}}$** km.
21. % error $= \frac{0.01}{2.50} \times 100 =$ **0.4**%.
22. Angle $(\omega t - kx)$ is dimensionless: $[\omega] = 1/[t] = [\mathrm{T^{-1}}]$, $[k] = 1/[x] = [\mathrm{L^{-1}}]$.
23. $[R] = \frac{[PV]}{[nT]} = \frac{[\mathrm{ML^2T^{-2}}]}{[\mathrm{mol}][\mathrm{K}]} = [\mathrm{ML^2T^{-2}mol^{-1}K^{-1}}]$.
24. $[K] = [\mathrm{ML^2T^{-2}}]$. New unit $= (2)(2^2) =$ **8** times the original unit.
25. 1. Cannot find dimensionless constants $(2\pi, 1/2)$. 2. Fails if > 3 independent mechanical variables are involved. 3. Cannot derive $\sin, \cos, \log, e^x$ functions or multi-term sums.

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $[b] = [V] = [\mathrm{L}^3]$. $[a] = [P][V^2] = [\mathrm{ML^{-1}T^{-2}}][\mathrm{L}^6] = [\mathrm{ML}^5\mathrm{T}^{-2}]$. Thus $[a/b] = [\mathrm{ML}^2\mathrm{T}^{-2}]$ (same as Energy!).
2. $m = F/a = F/(V/T) = [\mathrm{FV^{-1}T}]$. Energy $E = F \cdot d = F(VT) = [\mathrm{FVT}]$.
3. $S = F/L = E/L^2$. Since $L = vT$, $[S] = E/(vT)^2 = [\mathrm{Ev^{-2}T^{-2}}]$.
4. $[a] = [F]/[x^{1/2}] = [\mathrm{ML}^{1/2}\mathrm{T}^{-2}]$; $[b] = [F]/[t^2] = [\mathrm{MLT}^{-4}]$. So $[a/b] = [\mathrm{L}^{-1/2}\mathrm{T}^2]$.
5. $[a] = [t^2] = [\mathrm{T}^2]$. $[b] = [t^2]/([P][x]) = [\mathrm{T}^2]/([\mathrm{ML^{-1}T^{-2}}][\mathrm{L}]) = [\mathrm{M^{-1}T}^4]$. Thus $[a/b] = [\mathrm{MT}^{-2}]$.
6. Let $m_P = c^x h^y G^z$. Equating $[\mathrm{M}^1\mathrm{L}^0\mathrm{T}^0] = [\mathrm{LT^{-1}}]^x[\mathrm{ML}^2\mathrm{T}^{-1}]^y[\mathrm{M^{-1}L}^3\mathrm{T}^{-2}]^z$ gives $y - z = 1, x + 2y + 3z = 0, -x - y - 2z = 0 \Rightarrow x = 1/2, y = 1/2, z = -1/2 \Rightarrow m_P \propto \sqrt{\frac{hc}{G}}$.
7. Using the same method: $[\mathrm{L}^1] = c^x h^y G^z \Rightarrow y = 1/2, z = 1/2, x = -3/2 \Rightarrow l_P \propto \sqrt{\frac{hG}{c^3}}$.
8. $n_2 = 4.2(1/\alpha)^1(1/\beta)^2(1/\gamma)^{-2} = 4.2\alpha^{-1}\beta^{-2}\gamma^2$.
9. $f = kl^a T^b \mu^c \Rightarrow [\mathrm{T^{-1}}] = [\mathrm{L}^a][\mathrm{MLT^{-2}}]^b[\mathrm{ML^{-1}}]^c$. Solving: $b = 1/2, c = -1/2, a = -1 \Rightarrow f = \frac{k}{l}\sqrt{\frac{T}{\mu}}$.
10. $v_e = kG^a M^b R^c \Rightarrow a = 1/2, b = 1/2, c = -1/2 \Rightarrow v_e = k\sqrt{\frac{GM}{R}}$.
11. $v_c = k\eta^a \rho^b r^c \Rightarrow a = 1, b = -1, c = -1 \Rightarrow v_c = \frac{k\eta}{\rho r}$.
12. $\%\Delta P = 3(1\%) + 2(3\%) + \frac{1}{2}(4\%) + 1(2\%) = 3 + 6 + 2 + 2 = \mathbf{13}\%$.
13. $[\alpha] = [x] = [\mathrm{L}]$, $[\beta] = 1/[t] = [\mathrm{T^{-1}}] \Rightarrow [\alpha\beta] = [\mathrm{LT^{-1}}]$ (Velocity!).
14. Exponent $-\alpha x^2$ must be dimensionless $\Rightarrow [\alpha] = 1/[x^2] = [\mathrm{L^{-2}}]$.
15. $[E] = [\mathrm{ML}^2\mathrm{T}^{-2}]$, $[L^2] = [\mathrm{M}^2\mathrm{L}^4\mathrm{T}^{-2}]$, $[M^5] = [\mathrm{M}^5]$, $[G^2] = [\mathrm{M^{-2}L}^6\mathrm{T}^{-4}]$. Numerator $[\mathrm{M}^3\mathrm{L}^6\mathrm{T}^{-4}]$, Denominator $[\mathrm{M}^3\mathrm{L}^6\mathrm{T}^{-4}] \Rightarrow [\mathbf{M^0L^0T^0}]$ (Dimensionless!).
16. Convert to same power: $0.48 - 0.025 = 0.455$. Least decimal places is 2 (in 0.48) $\Rightarrow 0.46 = \mathbf{4.6 \times 10^{-1}}$.
17. $v = 13.8/4.0 = 3.45$ m/s. $\frac{\Delta v}{v} = \frac{0.2}{13.8} + \frac{0.3}{4.0} = 0.0145 + 0.075 = 0.0895 \Rightarrow \Delta v = 3.45 \times 0.0895 \approx 0.31$. So $v = \mathbf{3.5 \pm 0.3}$ m/s.
18. $R_s = (100 + 200) \pm (3 + 4) = \mathbf{300 \pm 7\ \Omega}$.
19. $F = MLT^{-2} \Rightarrow M = FT^2/L = \frac{100 \times 100^2}{10} = \mathbf{10^5}$ kg.
20. $L = c^2/g = (3 \times 10^8)^2/10 \approx \mathbf{9 \times 10^{15}}$ m; $T = c/g = 3 \times 10^8/10 = \mathbf{3 \times 10^7}$ s.
21. $A = 4\pi r^2 = 4(3.14)(2.1)^2 = 55.4$ cm^2. $\Delta A/A = 2(\Delta r/r) = 2(0.5/2.1) = 0.476 \Rightarrow \Delta A = 26.4$. Thus $A = \mathbf{55 \pm 26}$ cm$^\mathbf{2}$.
22. $T = kP^a \rho^b E^c \Rightarrow [\mathrm{T}] = [\mathrm{ML^{-1}T^{-2}}]^a[\mathrm{ML^{-3}}]^b[\mathrm{ML}^2\mathrm{T}^{-2}]^c$. Solving: $a = -5/6, b = 1/2, c = 1/3 \Rightarrow T \propto P^{-5/6}\rho^{1/2}E^{1/3}$.
23. $P = 60$ J/60 s $= 1$ W $= 1$ kg m^2 s^{-3}. $n_2 = 1\left(\frac{1000}{100}\right)^1\left(\frac{100}{100}\right)^2\left(\frac{1}{60}\right)^{-3} = 10 \times 1 \times 216000 = \mathbf{2.16 \times 10^6}$ new units.
24. No. Both Torque ($\vec{r} \times \vec{F}$) and Work ($\vec{F} \cdot \vec{d}$) have $[\mathrm{ML}^2\mathrm{T}^{-2}]$, yet Torque is a vector and Work is a scalar.
25. Since $nu =$ constant, $n = Q/u$, which is a **rectangular hyperbola** in the first quadrant.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 2 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MOTION IN A STRAIGHT LINE

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. Distance is the actual total path length travelled by a body (always ≥ 0, scalar). Displacement is the shortest straight-line vector from initial to final position ($\Delta x = x_f - x_i$, can be $+$, $-$, or 0, vector).
2. Distance $= 40 + 30 =$ **70** m. Displacement $= \sqrt{40^2 + 30^2} =$ **50** m. (3-4-5 right triangle!)
3. Distance $= 2\pi R = 2 \times \frac{22}{7} \times 14 =$ **88** m. Since start and end points coincide, Displacement $=$ **0** m.
4. Average speed $= \frac{\text{Total Path Length}}{\text{Total Time}}$ (scalar, always ≥ 0). Average velocity $= \frac{\text{Displacement}}{\text{Total Time}}$ (vector, can be $+, -$, or 0).
5. $36 \times \frac{5}{18} =$ **10** m/s; $108 \times \frac{5}{18} =$ **30** m/s.
6. It measures the **instantaneous speed** (the magnitude of instantaneous velocity) at that exact moment.
7. The slope $\frac{\Delta x}{\Delta t}$ (or $\frac{dx}{dt}$) of an x-t graph represents **velocity**.
8. The slope $\frac{\Delta v}{\Delta t}$ (or $\frac{dv}{dt}$) of a v-t graph represents **acceleration**.
9. The area between the v-t curve and the time axis represents **displacement** (and sum of absolute areas represents distance).
10. Using $v = u + at$: $20 = 0 + a(5) \implies a =$ **4** m/s^2.
11. $v = u + at = 10 + 2(4) =$ **18** m/s.
12. $s = ut + \frac{1}{2}at^2 = 10(4) + \frac{1}{2}(2)(16) = 40 + 16 =$ **56** m.
13. Using $v^2 = u^2 + 2as$: $v^2 = 0 + 2(3)(24) = 144 \implies v =$ **12** m/s.
14. $v = 0 + gt = 10 \times 3 =$ **30** m/s.
15. $s = \frac{1}{2}gt^2 = \frac{1}{2}(9.8)(4) =$ **19.6** m.
16. At top, $v = 0 = u - gt \implies t = u/g = 20/10 =$ **2** s.
17. $H = \frac{u^2}{2g} = \frac{400}{20} =$ **20** m.
18. Velocity is momentarily **zero** ($v = 0$), while acceleration is **$g = 9.8$ m/s^2 vertically downward**.
19. Yes! In **uniform circular motion**, speed is constant, but direction changes continuously, so velocity changes.
20. Retardation is acceleration acting opposite to the direction of velocity, causing speed to decrease. If $v > 0$, retardation has $a < 0$.
21. $0 = 25 + a(5) \implies a = -5$ m/s^2. So retardation is **5** m/s^2.
22. A **horizontal straight line** parallel to the time axis ($x =$ constant).
23. A **horizontal straight line** above the time axis ($v =$ constant).
24. $s_3 = u + \frac{a}{2}(2n - 1) = 0 + \frac{2}{2}(6 - 1) =$ **5** m.
25. Since distance $=$ |displacement|, the ratio is exactly **1**.

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. Using Harmonic Mean shortcut: $v_{avg} = \frac{2v_1v_2}{v_1+v_2} = \frac{2(40)(60)}{40+60} = \frac{4800}{100} = \mathbf{48}$ km/h.
2. For equal times, use Arithmetic Mean: $v_{avg} = \frac{40+60}{2} = \mathbf{50}$ km/h.
3. $v = \frac{dx}{dt} = 6t - 6$. At $t = 2$: $v = 12 - 6 = \mathbf{6}$ m/s. $a = \frac{dv}{dt} = \mathbf{6}$ m/s$^\mathbf{2}$ (constant).
4. $v = 6t - 6 = 0 \implies t = \mathbf{1}$ s.
5. Stopping distance $d_s = \frac{u^2}{2a} \propto u^2$. Doubling speed quadruples distance: $4 \times 40 = \mathbf{160}$ m.
6. Taking upward as +: $y = -25, u = +20, a = -10$. $-25 = 20t - 5t^2 \implies t^2 - 4t - 5 = 0 \implies (t-5)(t+1) = 0 \implies t = \mathbf{5}$ s.
7. By Galileo's Law of Odd Numbers: $s_n = \frac{a}{2}(2n-1) \implies s_1 : s_2 : s_3 = \mathbf{1} : \mathbf{3} : \mathbf{5}$.
8. Distance $= |10 - 2| + |-2 - 10| = 8 + 12 = 20$ m $\implies$ avg speed $= 20/4 = \mathbf{5}$ m/s. Displacement $= -2 - 2 = -4$ m $\implies \bar{v} = -4/4 = \mathbf{-1}$ m/s.
9. Total distance $= 100 + 200 = 300$ m. Speed $= 72 \times \frac{5}{18} = 20$ m/s. Time $= 300/20 = \mathbf{15}$ s.
10. $v = 3t^2 - 12t + 9$; $a = 6t - 12 = 0 \implies t = \mathbf{2}$ s.
11. $t = \sqrt{2h/g} \propto \sqrt{h} \implies t_1/t_2 = \sqrt{16/25} = \mathbf{4} : \mathbf{5}$.
12. $s_4 - s_2 = 2a = 20 - 12 = 8 \implies a = \mathbf{4}$ m/s$^\mathbf{2}$. $12 = u + \frac{4}{2}(3) \implies u = \mathbf{6}$ m/s.
13. Max speed $v = 2 \times 5 = 10$ m/s; total time $= 10$ s. Area of v-t triangle $= \frac{1}{2}(10)(10) = \mathbf{50}$ m.
14. $v = 54 \times \frac{5}{18} = 15$ m/s. Reaction distance $= 15 \times 0.2 = \mathbf{3}$ m.
15. Distance fallen in $T/2$ is $s = \frac{1}{2}g(T/2)^2 = H/4$. Height above ground $= H - H/4 = \mathbf{3H/4}$.
16. Square both sides: $v^2 = 16 + 4x$. Comparing with $v^2 = u^2 + 2ax$: $2a = 4 \implies a = \mathbf{2}$ m/s$^\mathbf{2}$.
17. $a = \frac{v^2}{2s} = \frac{10000}{2000} = \mathbf{5}$ m/s$^\mathbf{2}$.
18. $x = kt^3 \implies v = 3kt^2 \implies a = 6kt$. So acceleration is **directly proportional to time ($a \propto t$)**.
19. $v^2 = u^2 + 2gh = 100 + 2(10)(45) = 1000 \implies v = \mathbf{10\sqrt{10}}$ m/s ≈ 31.6 m/s.
20. Velocity is constant in both magnitude and direction, so acceleration is **zero**.
21. $\int_{t_1}^{t_2} a\,dt = v_2 - v_1$ (**change in velocity**).
22. Displacement $= 30 - 40 = -10$ m (West). Total time $= 7$ s. $\bar{v} = -10/7 = \mathbf{-1.43}$ m/s (West).
23. $T = 2u/g = 6 \implies u = \mathbf{30}$ m/s. $H = u^2/(2g) = 900/20 = \mathbf{45}$ m.
24. No! A vertical line would mean infinite velocity (being at multiple positions at the exact same instant), which is physically impossible.
25. $v_{avg} = \frac{3}{\frac{1}{20}+\frac{1}{30}+\frac{1}{60}} = \frac{3}{6/60} = \mathbf{30}$ km/h.

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $v(t) = 2 + \int_0^t 6t\,dt = 2 + 3t^2 \implies v(2) = \mathbf{14}$ m/s. $x = \int_0^2 (2 + 3t^2)\,dt = [2t + t^3]_0^2 = 4 + 8 = \mathbf{12}$ m.
2. $v = 4 - 2t = 0$ at $t = 2$ s (reversal!). $x(0) = 0, x(2) = 4, x(3) = 3$. Distance $= |4 - 0| + |3 - 4| = 4 + 1 = \mathbf{5}$ m.
3. Wait: $v = 10 - 2t = 0$ at $t = 5$ s! During 6th second ($t = 5$ to 6), particle starts from rest and moves backward: $d = \frac{1}{2}(2)(1)^2 = \mathbf{1}$ m (using s_n directly gives -1 m, which is displacement, not distance!).
4. $\sqrt{x} = t - 3 \implies x = (t-3)^2$. $v = 2(t-3) = 0$ at $t = \mathbf{3}$ s. $a = dv/dt = \mathbf{2}$ m/s$^\mathbf{2}$.
5. Use chain rule $a = v\frac{dv}{dx}$: $\frac{dv}{dx} = 3$. At $x = 1$, $v = 5 \implies a = 5 \times 3 = \mathbf{15}$ m/s$^\mathbf{2}$.
6. $v^2 = \alpha^2 x$. Differentiate w.r.t. x: $2v\frac{dv}{dx} = \alpha^2 \implies 2a = \alpha^2 \implies a = \boldsymbol{\alpha^2/2}$ (constant!).

7. Total flight time $T = t_1 + t_2 = 4$ s $\implies u = gT/2 = \mathbf{20}$ m/s. Shortcut for height: $h = \frac{1}{2}gt_1t_2 = \frac{1}{2}(10)(1)(3) = \mathbf{15}$ m.

8. Ball inherits balloon's upward velocity: $u = +10$ m/s, $y = -40$ m. $-40 = 10t - 5t^2 \implies t^2 - 2t - 8 = 0 \implies t = \mathbf{4}$ s.

9. Time for 1st drop: $t = \sqrt{2(5)/10} = 1$ s. Interval $= 1/2 = 0.5$ s. 2nd drop fell for 0.5 s: $s = \frac{1}{2}(10)(0.5)^2 = \mathbf{1.25}$ m below tap (i.e., 3.75 m above ground).

10. $v^2 = u^2 - 2as$: $(0.8u)^2 = u^2 - 2a(1) \implies 2a = 0.36u^2$. Total penetration $S = \frac{u^2}{2a} = \frac{1}{0.36} = 2.78$ cm. Extra $= 2.78 - 1 = \mathbf{1.78}$ cm.

11. Time of flight $T = 0.5$ s $\implies t_{up} = 0.25$ s $\implies H = \frac{1}{2}gt_{up}^2 = \frac{1}{2}(10)(0.0625) = \mathbf{0.3125}$ m.

12. $dv/dt = 4 - 2t = 0 \implies t = \mathbf{2}$ s. $v_{max} = 4(2) - 4 = \mathbf{4}$ m/s.

13. Max $v = a_1t_1 = a_2t_2 \implies 2t_1 = 4t_2 \implies t_1 = 2t_2$. Since $t_1 + t_2 = 9 \implies t_2 = 3$ s, $t_1 = 6$ s. $v_{max} = 2(6) = \mathbf{12}$ m/s.

14. Shortcut: $S = \frac{1}{2}v_{max}T = \frac{1}{2}(12)(9) = \mathbf{54}$ m (or $\frac{a_1a_2T^2}{2(a_1+a_2)}$).

15. $v = A\omega\cos(\omega t) = \omega\sqrt{A^2 - x^2}$; $a = -A\omega^2\sin(\omega t) = -\omega^{\mathbf{2}}\mathbf{x}$.

16. $\frac{dv}{dt} = -kv^2 \implies \int_{v_0}^{v} v^{-2}\,dv = -kt \implies \frac{1}{v} - \frac{1}{v_0} = kt \implies v = \frac{\mathbf{v_0}}{\mathbf{1+kv_0t}}$.

17. Relative $u_{rel} = 0$, $a_{rel} = 1$ m/s^2. Total relative distance covered in 50 s $= \frac{1}{2}(1)(50^2) = 1250$ m (NCERT Ex 2.7/old 3.5). Wait: original gap $= 1250 - 800 = \mathbf{450}$ m.

18. Let total time $= T$. Last second covers $H/4 \implies$ first $(T-1)$ sec covers $3H/4$. $\frac{(T-1)^2}{T^2} = \frac{3}{4} \implies \frac{T-1}{T} = \frac{\sqrt{3}}{2} \implies T = \frac{2}{2-\sqrt{3}} = 7.46$ s $\implies H = 5(7.46)^2 \approx \mathbf{278.5}$ m.

19. At stop, $v = 0 \implies 100 - 20x = 0 \implies x = \mathbf{5}$ m.

20. Relative acceleration $a_{rel} = g + a = 12$ m/s^2. $t = \sqrt{\frac{2(2.4)}{12}} = \sqrt{0.4} \approx \mathbf{0.63}$ s.

21. $v = 4 - t^2$, $x = 4t - t^3/3 = 0 \implies t^2 = 12 \implies t = \mathbf{2\sqrt{3}}$ s.

22. No! If $v = 0$ and $a = 0$ at all times, it stays at rest. (Only if a is momentarily zero while $da/dt \neq 0$, e.g. $x = t^3$, can it move from $t = 0$.)

23. $10t = \frac{1}{2}(2)t^2 \implies t = \mathbf{10}$ s (at $x = 100$ m).

24. Max lead occurs when $v_A = v_B \implies 10 = 2t \implies t = 5$ s. Lead $= 10(5) - \frac{1}{2}(2)(25) = 50 - 25 = \mathbf{25}$ m.

25. Linearly decreasing (slope $-g$) from 0 to $-v$, then instantaneous vertical jump to $+v$ at impact, then linearly decreasing (slope $-g$) back to 0.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 3 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MOTION IN A PLANE

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. Scalar has only magnitude (e.g., mass, distance). Vector has magnitude, direction, and obeys vector addition laws (e.g., velocity, force).
2. A vector of magnitude 1 used to specify direction: $\hat{A} = \vec{A}/|\vec{A}|$. Along x, y, z: $\hat{i}, \hat{j}, \hat{k}$.
3. $|\vec{A}| = \sqrt{3^2 + 4^2} = \sqrt{25} = \mathbf{5}$.
4. $|\vec{B}| = \sqrt{4 + 9 + 36} = \sqrt{49} = \mathbf{7}$.
5. $R = \sqrt{6^2 + 8^2} = \sqrt{100} = \mathbf{10}$.
6. Maximum $(A + B)$ at $\theta = 0^\circ$ (same direction); Minimum $(|A - B|)$ at $\theta = 180^\circ$ (opposite direction).
7. $A_x = A\cos\theta$, $A_y = A\sin\theta$.
8. $\vec{A} + \vec{B} = 5\hat{i} + 3\hat{j}$; $\vec{A} - \vec{B} = \hat{i} + 5\hat{j}$.
9. A vector with zero magnitude and arbitrary direction (e.g., displacement of a body returning to its starting point).
10. A **parabola**.
11. The horizontal component $v_x = u\cos\theta$ remains constant because there is zero horizontal acceleration ($a_x = 0$).
12. $\mathbf{90}^\circ$ (velocity is horizontal, acceleration g is vertically downward).
13. $T = \frac{2u\sin\theta}{g}$.
14. $H = \frac{u^2\sin^2\theta}{2g}$.
15. $R = \frac{u^2\sin 2\theta}{g}$. It is maximum (u^2/g) at $\theta = \mathbf{45}^\circ$.
16. $T = \frac{2(20)\sin 30^\circ}{10} = \frac{40(0.5)}{10} = \mathbf{2}$ s.
17. $H = \frac{400\sin^2 30^\circ}{20} = 20(0.25) = \mathbf{5}$ m.
18. Complementary angles θ and $90^\circ - \theta$ (e.g., 30° and 60°).
19. Motion in a circle at constant speed. Yes, it is accelerated because the direction of velocity changes continuously.
20. $v = r\omega$.
21. $a_c = \frac{v^2}{r} = \omega^2 r$, always directed **towards the centre** of the circle.
22. $a_c = \frac{4^2}{2} = \mathbf{8}$ m/s$^{\mathbf{2}}$.
23. $f = 60/60 = 1$ Hz $\implies \omega = 2\pi f = \mathbf{2}\pi$ rad/s.
24. **Scalar**, because it has direction along a wire but does NOT obey the law of vector addition.
25. $|A| = 10 \implies \hat{A} = \mathbf{0.6\hat{i} + 0.8\hat{j}}$.

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $R = \sqrt{5^2 + 10^2 + 2(5)(10)\cos 60^\circ} = \sqrt{25 + 100 + 50} = \sqrt{175} \approx \mathbf{13.23}$ N.
2. Squaring: $A^2 + B^2 + 2AB\cos\theta = A^2 + B^2 - 2AB\cos\theta \implies 4AB\cos\theta = 0 \implies \theta = \mathbf{90}^\circ$.
3. $1 = 1 + 1 + 2\cos\theta \implies \cos\theta = -1/2 \implies \theta = \mathbf{120}^\circ$.
4. $\vec{v} = 3\hat{i} + 4t\hat{j}$. At $t = 1$: $\vec{v} = 3\hat{i} + 4\hat{j} \implies |v| = \mathbf{5}$ m/s.
5. $\vec{a} = \frac{d\vec{v}}{dt} = \mathbf{4\hat{j}}$ m/s$^\mathbf{2}$ (constant along $+y$).
6. At $\theta = 45^\circ$, $H = R_{max}/4 = 100/4 = \mathbf{25}$ m.
7. $H_1/H_2 = \sin^2 30^\circ / \sin^2 60^\circ = (1/4)/(3/4) = \mathbf{1} : \mathbf{3}$.
8. $T_1/T_2 = \sin 30^\circ / \sin 60^\circ = \mathbf{1} : \sqrt{\mathbf{3}}$.
9. $\frac{u^2 \sin 2\theta}{g} = \frac{u^2 \sin^2\theta}{2g} \implies 2\sin\theta\cos\theta = \frac{\sin^2\theta}{2} \implies \tan\theta = 4 \implies \theta = \tan^{-1}(\mathbf{4}) \approx 76^\circ$.
10. Time to fall: $t = \sqrt{2h/g} = \sqrt{90/10} = 3$ s. Horizontal distance $x = ut = 15 \times 3 = \mathbf{45}$ m.
11. $v_x = 15$ m/s, $v_y = gt = 30$ m/s $\implies v = \sqrt{15^2 + 30^2} = \mathbf{15\sqrt{5}}$ m/s ≈ 33.5 m/s.
12. $\tan\theta = \frac{v_m}{v_r} = \frac{4}{3} \implies \theta = \mathbf{53.1}^\circ$ with vertical in the direction of walking.
13. Time $= 400/4 = \mathbf{100}$ s. Drift $= v_r \times t = 3 \times 100 = \mathbf{300}$ m.
14. $\vec{X} = \hat{j} - (2\hat{i} - 3\hat{j} + 4\hat{k}) = \mathbf{-2\hat{i} + 4\hat{j} - 4\hat{k}}$.
15. (a) $2v$; (b) $\sqrt{v^2 + v^2} = \mathbf{v\sqrt{2}}$.
16. $v_{top} = u\cos 30^\circ = 40(\frac{\sqrt{3}}{2}) = \mathbf{20\sqrt{3}}$ m/s.
17. $\tan\theta = 4H/R = 1/\sqrt{3} \implies \theta = \mathbf{30}^\circ$.
18. $x^2 + y^2 = a^2(\cos^2\omega t + \sin^2\omega t) = a^2$, which is a circle of radius a.
19. **3** (forming a closed triangle).
20. $a_c = \frac{200^2}{1000} = 40$ m/s$^2 = \mathbf{4g}$.
21. $R_{max} = u^2/g = 16000 \implies u^2 = 160000 \implies u = \mathbf{400}$ m/s.
22. $H = \frac{1}{8}gT^2 = \frac{1}{8}(10)(16) = \mathbf{20}$ m.
23. $T = 3600$ s $\implies \omega = \frac{2\pi}{3600} = \frac{\pi}{\mathbf{1800}}$ rad/s.
24. Pythagoras theorem holds $\implies \theta = \mathbf{90}^\circ$.
25. $v_x = 3$, $v_y(0) = 4 \implies u = \sqrt{3^2 + 4^2} = \mathbf{5}$ m/s.

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. To cancel drift, $v_s \sin\alpha = v_r \implies \sin\alpha = 2/4 = 0.5 \implies \alpha = 30^\circ$ upstream from perpendicular, i.e., $\mathbf{120}^\circ$ to river flow.
2. Net perpendicular speed $= v_s\cos 30^\circ = 2\sqrt{3}$ km/h. Time $= \frac{1}{2\sqrt{3}}$ h $\approx \mathbf{17.3}$ min.
3. $\tan\theta = \sqrt{3} \implies \theta = \mathbf{60}^\circ$. Comparing $\frac{g}{2u^2\cos^2 60^\circ} = 5 \implies \frac{10}{2u^2(1/4)} = 5 \implies u = \mathbf{2}$ m/s.
4. Use trajectory shortcut $y = x\tan\theta(1 - x/R)$: $4 = 8(1)(1 - 8/R) \implies 0.5 = 1 - 8/R \implies R = \mathbf{16}$ m.
5. $K_{top} = K\cos^2\theta = K/2 \implies \cos\theta = 1/\sqrt{2} \implies \theta = \mathbf{45}^\circ$.
6. **4** (three vectors always lie in a plane unless they sum to a 4th vector out of the plane).
7. $\sin 2(45^\circ + \alpha) = \sin(90^\circ + 2\alpha) = \cos 2\alpha = \sin(90^\circ - 2\alpha) = \sin 2(45^\circ - \alpha)$. Equal R!
8. $u_x = 3, u_y = 4$. $T = 2u_y/g = 0.8$ s $\implies R = u_xT = 3(0.8) = \mathbf{2.4}$ m. $H = u_y^2/(2g) = 16/20 = \mathbf{0.8}$ m.

9. Net North $= 100$ m, Up $= 1200$ m. $|\Delta\vec{r}| = \sqrt{100^2 + 1200^2} = \mathbf{1204.16}$ m.

10. At top, $v = u\cos\theta$ and normal acceleration $= g$. $R_{curv} = \frac{v^2}{g} = \frac{\mathbf{u^2\cos^2\theta}}{\mathbf{g}}$.

11. $\vec{a}_1 = \vec{a}_2 = -g\hat{j} \implies \vec{a}_{rel} = 0$. Hence $\vec{v}_{rel}$ is constant, and relative path is a straight line!

12. $a_c = v^2/R = 16/4 = 4$ m/s^2. $a_{net} = \sqrt{a_c^2 + a_t^2} = \sqrt{4^2 + 3^2} = \mathbf{5}$ m/s$^{\mathbf{2}}$.

13. $\cos\theta = \frac{\vec{A}\cdot\vec{B}}{|A||B|} = \frac{1}{\sqrt{2}\sqrt{2}} = \frac{1}{2} \implies \theta = \mathbf{60}^\circ$.

14. $(2\hat{i} + 4\hat{j}) \cdot (2\hat{i} + (4 - 10t)\hat{j}) = 0 \implies 4 + 4(4 - 10t) = 0 \implies 20 - 40t = 0 \implies t = \mathbf{0.5}$ s.

15. $v_{rel} = 10\sqrt{2}$ km/h at 45° N of E. Closest approach $d_{min} = 100\sin 45^\circ = \mathbf{50\sqrt{2}}$ km ≈ 70.7 km.

16. $R_{max} = \frac{\mathbf{u^2}}{\mathbf{g(1}+\sin\beta)}$ (at $\theta = 45^\circ + \beta/2$ from horizontal).

17. $T = t_1 + t_2 = 8$ s $\implies R = u_x T = 10 \times 8 = \mathbf{80}$ m.

18. $|\hat{a} - \hat{b}|^2 = 1 + 1 - 2\cos\theta = 2(1 - \cos\theta) = 4\sin^2(\theta/2) \implies |\hat{a} - \hat{b}| = 2\sin(\theta/2)$.

19. $a_c = 7.5^2/80 = 0.703$ m/s^2, $a_t = 0.5$ m/s^2 $\implies a_{net} = \sqrt{0.703^2 + 0.5^2} = \mathbf{0.86}$ m/s$^{\mathbf{2}}$.

20. $A_{\parallel} = \vec{A} \cdot \frac{\hat{i}+\hat{j}}{\sqrt{2}} = \frac{\mathbf{5}}{\sqrt{\mathbf{2}}}$.

21. By symmetry of parabola, $x_1 + x_2 = R \implies R = 2 + 6 = \mathbf{8}$ m!

22. $R/H = 4/\tan\theta = n \implies \tan\theta = \mathbf{4/n}$.

23. $K_{top} = K\cos^2 45^\circ = \mathbf{K/2}$.

24. No! Because $2 + 3 = 5 < 6$ (violates triangle inequality).

25. At $t = 1$: $\omega = 2$ rad/s $\implies a_c = \omega^2 r = 4(2) = \mathbf{8}$ m/s$^{\mathbf{2}}$. $\alpha = d\omega/dt = 2 \implies a_t = \alpha r = 2(2) = \mathbf{4}$ m/s$^{\mathbf{2}}$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 4 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: LAWS OF MOTION

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. Every body continues in its state of rest or uniform straight-line motion unless acted upon by a net external force. It defines **Inertia** and gives the qualitative definition of force.

2. Inertia is the natural resistance of a body to any change in its state of rest or motion. **Mass** is the quantitative measure of translational inertia.

3. Due to **inertia of motion**: the lower body stops with the bus, while the upper body tends to keep moving forward.

4. $\vec{p} = m\vec{v}$. SI unit: kg m s^{-1} (or N s); Dimensions: $[MLT^{-1}]$.

5. The rate of change of momentum is directly proportional to the applied force and takes place in the direction of force: $\vec{F} = \frac{d\vec{p}}{dt} = m\vec{a}$ (for constant mass).

6. The force that produces an acceleration of 1 m/s^2 in a body of mass 1 kg (1 N = 1 kg m s^{-2}).

7. $F = ma = 4 \times 3 = \mathbf{12}$ N.

8. Impulse is the product of force and short time duration: $J = F\Delta t = \Delta p$ (change in momentum). SI unit: N s.

9. Increasing the time of impact (Δt) reduces the average force ($F = \Delta p/\Delta t$), preventing injury.

10. To every action, there is always an equal and opposite reaction: $\vec{F}_{AB} = -\vec{F}_{BA}$ (acting on **two different bodies**).

11. Because they act on **two different bodies**, whereas forces can only cancel if they act on the same body.

12. If the net external force on a system is zero ($\vec{F}_{ext} = 0$), total linear momentum remains constant: $\vec{p}_{initial} = \vec{p}_{final}$.

13. $MV = mv \implies 5V = 0.02 \times 250 = 5 \implies V = \mathbf{1}$ m/s.

14. Friction that opposes impending motion when a body is at rest. It adjusts its magnitude to match the applied force up to a maximum limit ($f_s \leq \mu_s N$).

15. $f_{s,max} = \mu_s N$; $\quad f_k = \mu_k N$ (where $\mu_k < \mu_s$).

16. **Rolling friction** is the smallest (typically 10^{-2} to 10^{-3} times sliding friction).

17. Angle between resultant contact force and normal reaction at limiting friction: $\tan\theta = \mu_s$.

18. The minimum angle of an inclined plane at which a body placed on it just begins to slide: $\tan\alpha = \mu_s$.

19. $N = mg = 100$ N $\implies f_{s,max} = 0.3 \times 100 = \mathbf{30}$ N.

20. $v_{max} = \sqrt{\mu_s Rg}$.

21. $v_0 = \sqrt{Rg\tan\theta}$.

22. $T = \frac{mv^2}{r} = \frac{1(9)}{1} = \mathbf{9}$ N.

23. A simplified sketch of a single body isolated from its surroundings, showing all external forces acting *on* it.

24. $a = 0 \implies F_{net} = \mathbf{0}$ N.

25. Aristotle wrongly believed an external force is needed to keep a body in uniform motion, forgetting that friction is an opposing force.

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $f_{s,max} = 0.4(50) = 20$ N. (a) Since $15 < 20$, block stays at rest, so friction = **15** N. (b) Since $25 > 20$, block slides, so friction = $f_k = 0.3(50) = \mathbf{15}$ N.
2. $J = m(v-u) = 0.15(10-(-10)) = \mathbf{3.0}$ N s.
3. $N = m(g+a) = 60(10+2) = \mathbf{720}$ N (72 kg-wt).
4. $N = m(g-a) = 60(10-4) = \mathbf{360}$ N (36 kg-wt).
5. $a = \frac{6-4}{6+4}(10) = \mathbf{2}$ m/s^2. $T = \frac{2(4)(6)(10)}{10} = \mathbf{48}$ N.
6. $a = \frac{30-0.04(200)}{23} = \frac{22}{23} \approx \mathbf{0.96}$ m/s^2. $T = 3(10-0.96) = \mathbf{27.1}$ N.
7. $a = 10/5 = 2$ m/s^2. Contact force pushes 3 kg: $N = 3\times 2 = \mathbf{6}$ N.
8. $a = g(\sin 30^\circ - 0.2\cos 30^\circ) = 10(0.5-0.173) = \mathbf{3.27}$ m/s^2.
9. $v_{max} = \sqrt{0.4\times 40\times 10} = \sqrt{160} \approx \mathbf{12.65}$ m/s.
10. $v_0 = \sqrt{300(9.8)(0.268)} = \mathbf{28.1}$ m/s.
11. $T - mg = ma \implies 600 - 400 = 40a \implies a = \mathbf{5}$ m/s^2.
12. $|F| = \sqrt{36+64+100} = 10\sqrt{2}$ N $\implies m = \mathbf{10\sqrt{2}}$ kg.
13. $F = dp/dt = 4t+3$. At $t=2$: $F = 8+3 = \mathbf{11}$ N.
14. $0.01(200) = (0.01+0.99)v \implies v = \mathbf{2}$ m/s.
15. $a = -90^2/(2\times 0.6) = -6750$ m/s^2 $\implies F = 0.04\times 6750 = \mathbf{270}$ N.
16. They replace high sliding friction with very low rolling friction, saving energy and reducing wear.
17. $|v| = 5$ m/s $\implies p = 2\times 5 = \mathbf{10}$ kg m/s.
18. $0 = m\vec{v}_1 + m\vec{v}_2 \implies \vec{v}_1 = -\vec{v}_2$.
19. To tilt the normal reaction N so its horizontal component $N\sin\theta$ provides centripetal force without slipping.
20. $a_{min} = \mu_s g = 0.15\times 10 = \mathbf{1.5}$ m/s^2.
21. Δp = Area $= \frac{1}{2}(4)(10) = \mathbf{20}$ N s.
22. $\vec{F}_{net} = 4\hat{i} + 3\hat{j}$, $|F| = 5$ N $\implies a = 5/2 = \mathbf{2.5}$ m/s^2.
23. $a = 2$ m/s^2 $\implies F = 1500\times 2 = \mathbf{3000}$ N.
24. $N = T = m(g-g) = \mathbf{0}$ N (weightlessness).
25. It forms a thin fluid film between solid surfaces, replacing dry solid-solid interlocking with low fluid shear.

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $v_{rel}\frac{dm}{dt} = m(g+a) \implies 800\frac{dm}{dt} = 5000(30) \implies \frac{dm}{dt} = \mathbf{187.5}$ kg/s.
2. $N = F$; to prevent falling, $f_s = mg \implies \mu_s F = 20 \implies F = 20/0.5 = \mathbf{40}$ N.
3. Hanging weight $= \frac{M}{L}xg$; max friction $= \mu_s\frac{M}{L}(L-x)g$. Equating: $x = \mu_s(L-x) \implies \frac{x}{L} = \frac{\mu_s}{1+\mu_s}$.
4. Pulling at angle $\theta = \tan^{-1}(\mu_s)$ minimizes F: $F_{min} = \frac{\mu_s mg}{\sqrt{1+\mu_s^2}}$.
5. $T_2 = 60$ N. At midpoint: $T_1\cos\theta = 60$, $T_1\sin\theta = 50 \implies \tan\theta = 5/6 \implies \theta \approx \mathbf{40}^\circ$.
6. $J = 2mv\sin(45^\circ/2)$? Wait: deflection $\delta = 45^\circ \implies \Delta v = 2v\sin(22.5^\circ)$ or $2v\cos(67.5^\circ)$? Actually $|\vec{v}_f - \vec{v}_i| = 2v\sin(\theta_{defl}/2)$? Wait: if angle between $\vec{v}_i$ and $\vec{v}_f$ is 45°, $|\Delta v| = 2v\sin(22.5^\circ) = 1.72$ N s; if deflected by 45° back towards bowler (135° turn), $J = 2(0.15)(15)\cos(22.5^\circ) = \mathbf{4.16}$ N s (NCERT Ex 4.20).

7. $a = 18/6 = 3$ m/s^2. $T = m_1 a = 2(3) = 6$ N < 10 N, so **no, it does not break**.
8. Pseudo force $ma\cos\theta$ balances $mg\sin\theta \implies a = \mathbf{g}\tan\theta$.
9. $N = mg\cos\theta + ma\sin\theta = mg\cos\theta + mg\frac{\sin^2\theta}{\cos\theta} = \mathbf{\frac{mg}{\cos\theta}}$.
10. $v_{max} = \sqrt{\frac{T_{max} r}{m}} = \sqrt{\frac{200\times 1.5}{0.25}} = \sqrt{1200} = \mathbf{34.6}$ m/s.
11. At $t = 0$: $J = 4(0.75 - 0) = +\mathbf{3}$ N s. At $t = 4$: $J = 4(0 - 0.75) = -\mathbf{3}$ N s.
12. Force $= 2nm_b v = mg \implies v = \mathbf{\frac{mg}{2nm_b}}$.
13. $t \propto 1/\sqrt{a} \implies a_{rough} = a_{smooth}/4$. $g(\sin 45^\circ - \mu_k \cos 45^\circ) = \frac{1}{4} g \sin 45^\circ \implies 1 - \mu_k = 1/4 \implies \mu_k = \mathbf{0.75}$.
14. $a = 12/6 = 2$ m/s^2. $T_1 = 1(2) = \mathbf{2}$ N; $T_2 = (1+2)(2) = \mathbf{6}$ N.
15. $v_{max} = \sqrt{100(10)\frac{0.5+1}{1-0.5(1)}} = \sqrt{3000} = \mathbf{54.77}$ m/s.
16. $p_2 = p_1 = 12$ kg m/s $\implies K_2 = \frac{p_2^2}{2m_2} = \frac{144}{4} = \mathbf{36}$ J.
17. $F = nmv = 5 \times 0.03 \times 600 = \mathbf{90}$ N.
18. Since it is at rest, static friction equals the downhill gravity component: $\mathbf{mg}\sin\theta$ (NOT $\mu_s mg\cos\theta$!).
19. $\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$, where α, β, γ are angles opposite to $\vec{F}_1, \vec{F}_2, \vec{F}_3$.
20. $J = \int_0^2 6t^2\,dt = [2t^3]_0^2 = 16$ N s $\implies v = J/m = 16/2 = \mathbf{8}$ m/s.
21. $F = v\frac{dm}{dt} = 2 \times 5 = \mathbf{10}$ N.
22. $m_2 g = m_1 g \sin 30^\circ \implies m_2/m_1 = \mathbf{0.5}$.
23. Two rope segments support $(60 + 20)g = 800$ N $\implies 2T = 800 \implies T = \mathbf{400}$ N.
24. $2(440) - 800 = 80a \implies a = 80/80 = \mathbf{1}$ m/s$^\mathbf{2}$.
25. Pulling has an upward vertical component ($F\sin\theta$) that reduces Normal reaction $N = mg - F\sin\theta$ and friction, whereas pushing increases $N = mg + F\sin\theta$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 5 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: WORK, ENERGY AND POWER

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. $\vec{A} \cdot \vec{B} = AB\cos\theta = A_xB_x + A_yB_y + A_zB_z$.
2. Zero ($\cos 90^\circ = 0$).
3. $W = \vec{F} \cdot \vec{d} = Fd\cos\theta$. SI unit: Joule (J); Dimensions: $[\mathrm{ML^2T^{-2}}]$.
4. Positive if $\theta < 90^\circ$; Zero if $\theta = 90^\circ$ (or $d = 0$); Negative if $\theta > 90^\circ$.
5. Gravity is vertical and displacement is horizontal ($\theta = 90^\circ$), so $W = \mathbf{0}$ J.
6. **Zero**, because centripetal force is always perpendicular to tangential displacement.
7. Energy possessed by a body due to its motion: $K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$.
8. The net work done by all forces acting on a body equals the change in its kinetic energy: $W_{net} = K_f - K_i$.
9. Total **work done** ($W = \int F\,dx$).
10. A force whose work depends only on initial and final positions, not the path taken (and zero over a closed loop). Examples: Gravitational force, Spring force.
11. A force whose work depends on the path taken. Examples: Friction, Viscous drag.
12. $U = mgh$.
13. $U_s = \frac{1}{2}kx^2$ (where k is spring constant).
14. When only conservative forces do work, total mechanical energy remains constant: $K + U =$ constant.
15. Rate of doing work: $P = \frac{dW}{dt} = \vec{F} \cdot \vec{v}$. SI unit: Watt (W); Dimensions: $[\mathrm{ML^2T^{-3}}]$.
16. 1 kWh = 1000 W × 3600 s = $\mathbf{3.6 \times 10^6}$ J.
17. 1 hp = **746** W.
18. 1 eV = $\mathbf{1.6 \times 10^{-19}}$ J.
19. $K = \frac{1}{2}(2)(5^2) = \mathbf{25}$ J.
20. $P = \frac{mgh}{t} = \frac{10\times10\times5}{10} = \mathbf{50}$ W.
21. A collision in which both **total linear momentum** and **total kinetic energy** are conserved ($e = 1$).
22. A collision in which the colliding bodies stick together after impact ($e = 0$); momentum is conserved, kinetic energy is lost.
23. They **exchange** their velocities ($v_1 = u_2, v_2 = u_1$).
24. $W = 3(2) + 4(-1) = 6 - 4 = \mathbf{2}$ J.
25. $P = Fv = 500 \times 20 = 10000$ W = **10** kW.

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $K = p^2/(2m) \propto p^2$. Doubling p makes $K' = 4K$, an increase of **300**%.
2. $K' = 4K \implies p' = \sqrt{4}p = 2p$, an increase of **100**%.
3. $K = p^2/(2m)$; for fixed p, the **light body** has greater kinetic energy.
4. $p = \sqrt{2mK}$; for fixed K, the **heavy body** has greater momentum.
5. $W = \int_0^4 2x\,dx = [x^2]_0^4 = \mathbf{16}$ J.
6. $W = \frac{1}{2}(1)(7^2 - 3^2) = \frac{1}{2}(40) = \mathbf{20}$ J.
7. $k = 100/0.02 = \mathbf{5000}$ N/m. $U = \frac{1}{2}(5000)(0.05)^2 = \mathbf{6.25}$ J.
8. $\frac{1}{2}kx^2 = \frac{1}{2}mv^2 \implies x = 4\sqrt{0.5/50} = \mathbf{0.4}$ m.
9. $v = \frac{4(6)}{6} = \mathbf{4}$ m/s. $\Delta K_{loss} = \frac{1}{2}\frac{4\times2}{6}(6-0)^2 = \mathbf{24}$ J.
10. $e = \sqrt{h'/h} = \sqrt{2.5/10} = \mathbf{0.5}$.
11. $P = \frac{100\times10\times6}{60} = \mathbf{100}$ W.
12. $0.01(400) = 0.01(100) + 2V \implies 2V = 3 \implies V = \mathbf{1.5}$ m/s.
13. $\vec{A}\cdot\vec{B} = -6 + 6 = 0 \implies \theta = \mathbf{90}°$.
14. $v = \sqrt{2gL} = \sqrt{20} = \mathbf{2\sqrt{5}}$ m/s ≈ 4.47 m/s.
15. Lowest point: $\mathbf{\sqrt{5gR}}$; Highest point: $\mathbf{\sqrt{gR}}$.
16. $x = 5\sqrt{1000/6250} = \mathbf{2.0}$ m.
17. $F = 18000 + 4000 = 22000$ N $\implies P = 22000 \times 2 = \mathbf{44}$ kW.
18. $W = U_2 - U_1 = \mathbf{\frac{1}{2}k(x_2^2 - x_1^2)}$.
19. $E = 0.06 \times 10 \times 30 = \mathbf{18}$ kWh (18 units).
20. $\cos\theta = \frac{15+16-15}{\sqrt{50}\sqrt{50}} = \frac{16}{50} = 0.32 \implies \theta \approx \mathbf{71.3}°$.
21. $d_s = \frac{mv^2}{2F} \propto m$. Larger mass means larger kinetic energy to dissipate.
22. $K = \frac{20^2}{2(10)} = \mathbf{20}$ J.
23. $v_2 \approx \mathbf{2u}$.
24. $W = \int_0^2 (10 + 0.5x)\,dx = [10x + 0.25x^2]_0^2 = \mathbf{21}$ J.
25. $dU/dx = 0$ for all three: Stable ($d^2U/dx^2 > 0$, min U); Unstable ($d^2U/dx^2 < 0$, max U); Neutral ($d^2U/dx^2 = 0$).

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. Stiffness $k \propto 1/L$. Halving the length doubles the spring constant to **2k**.
2. (a) Same x: $U = \frac{1}{2}kx^2 \implies k_1$ stores more. (b) Same F: $U = \frac{F^2}{2k} \implies k_2$ stores more!
3. $dU/dx = 2x - 4 = 0 \implies x = \mathbf{2}$ m. $d^2U/dx^2 = +2 > 0 \implies$ **stable equilibrium**.
4. $a = v_1/t_1$, $v = at$, $P = Fv = ma^2t = \mathbf{\frac{mv_1^2}{t_1^2}t}$.
5. $v^2/r = k^2rt^2 \implies v = krt \implies a_t = kr$. Only tangential force does work: $P = ma_tv = \mathbf{mk^2r^2t}$.
6. $\frac{1}{2}mv^2 = 2t^2 \implies v \propto t \implies a =$ constant $\implies F =$ constant.
7. $W_r = -0.5\ln(20.1) = -1.5$ J. $K_f = 2 - 1.5 = 0.5$ J $\implies v_f = \mathbf{1}$ m/s.
8. $\vec{p}_i = \vec{p}_1 + \vec{p}_2$ and $p_i^2 = p_1^2 + p_2^2 \implies 2\vec{p}_1\cdot\vec{p}_2 = 0 \implies \theta_1 + \theta_2 = \mathbf{90}°$.

9. $f = \frac{\mathbf{4A}}{\mathbf{(1+A)^2}}$.

10. Hanging mass $= M/3$, COM at depth $L/6$. $W = (M/3)g(L/6) = \frac{\mathbf{MgL}}{\mathbf{18}}$.

11. $V = \frac{0.012(70)}{0.412} = 2.04$ m/s. $h = \frac{V^2}{2g} = \mathbf{0.212}$ m. Heat $= K_i - K_f = \mathbf{28.5}$ J.

12. $W_g = 10^{-3}(10)(1000) = 10$ J. $\Delta K = \frac{1}{2}(10^{-3})(2500) = 1.25$ J. $W_{air} = 1.25 - 10 = \mathbf{-8.75}$ J.

13. $W = \int_0^5 (7 - 2x + 3x^2)\,dx = [7x - x^2 + x^3]_0^5 = 35 - 25 + 125 = \mathbf{135}$ J.

14. $\frac{1}{2}mv^2 = Pt \implies v \propto t^{1/2} \implies s = \int v\,dt \propto \mathbf{t^{3/2}}$.

15. $v = \sqrt{2Pt/m} \implies a = dv/dt = \sqrt{\frac{\mathbf{P}}{\mathbf{2mt}}}$.

16. $D = h\left(\frac{1+e^2}{1-e^2}\right)$.

17. $mgh = \frac{1}{2}kx^2 \implies 2(10)(5) = 500x^2 \implies x^2 = 0.2 \implies x = \mathbf{0.447}$ m.

18. Yes! When a block sits on an accelerating truck (without slipping), static friction accelerates the block forward w.r.t. ground, doing positive work.

19. $P = (mg\sin\theta + f)v$.

20. $T_{bot} - T_{top} = \mathbf{6mg}$ (independent of speed!).

21. $dU/dr = -2A/r^3 + B/r^2 = 0 \implies r_0 = \mathbf{2A/B}$.

22. $a = 2t \implies v(2) = \int_0^2 2t\,dt = 4$ m/s. $W = \frac{1}{2}(2)(4^2) = \mathbf{16}$ J.

23. $P_{wind} = \frac{1}{2}\rho A v^3 = 0.5(1.2)(30)(1000) = 18$ kW. $P_{elec} = 0.25 \times 18 = \mathbf{4.5}$ kW.

24. $M/m = \mathbf{1}$ (100% KE transfer when masses are equal!).

25. $v(0) = 0, v(4) = 8$ m/s. $W = \Delta K = \frac{1}{2}(2)(64 - 0) = \mathbf{64}$ J.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 6 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: SYSTEMS OF PARTICLES AND ROTATIONAL MOTION

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. The unique point where the entire mass of the system is assumed to be concentrated for translational motion: $\vec{R}_{cm} = \frac{\sum m_i \vec{r}_i}{M}$.
2. At its **geometric centre** (outside the material of the ring).
3. It remains **constant** ($M\vec{a}_{cm} = \vec{F}_{ext} = 0$).
4. $\vec{A} \times \vec{B} = AB \sin\theta\, \hat{n}$ (direction by right-hand screw rule).
5. Zero (null vector $\vec{0}$), since $\sin 0^\circ = 0$.
6. $\hat{i} \times \hat{j} = \hat{k}$; $\hat{j} \times \hat{i} = -\hat{k}$.
7. $\vec{v} = \vec{\omega} \times \vec{r}$ (scalar: $v = r\omega$).
8. Turning effect of force: $\vec{\tau} = \vec{r} \times \vec{F}$. SI unit: N m; Dimensions: $[\mathrm{ML^2T^{-2}}]$.
9. $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$. SI unit: kg m^2 s^{-1} (or J s).
10. $\vec{\tau}_{ext} = \frac{d\vec{L}}{dt}$.
11. If net external torque is zero ($\vec{\tau}_{ext} = 0$), total angular momentum remains constant: $I_1\omega_1 = I_2\omega_2$.
12. Pulling arms in reduces Moment of Inertia I; since $I\omega =$ constant, angular speed ω increases.
13. 1. Translational equilibrium: $\sum \vec{F}_i = 0$. 2. Rotational equilibrium: $\sum \vec{\tau}_i = 0$.
14. $I = \sum m_i r_i^2$. SI unit: kg m^2 (rotational analogue of mass).
15. The radial distance from the axis where total mass M can be concentrated to give the same I: $I = Mk^2 \implies k = \sqrt{I/M}$.
16. Ring: $I = MR^2$. Disc: $I = \frac{1}{2}MR^2$.
17. Solid sphere: $I = \frac{2}{5}MR^2$. Hollow sphere: $I = \frac{2}{3}MR^2$.
18. $I = \frac{1}{12}ML^2$.
19. $I = I_{cm} + Md^2$, where d is the perpendicular distance between the two parallel axes.
20. $I_z = I_x + I_y$. Valid **only for planar (2D lamina) bodies**.
21. $\tau = I\alpha$; $\quad K_{rot} = \frac{1}{2}I\omega^2$.
22. $\omega = 2\pi(120/60) = \mathbf{4}\pi$ rad/s.
23. $\alpha = \tau/I = 20/4 = \mathbf{5}$ rad/s$^\mathbf{2}$.
24. $X_{cm} = \frac{1(0)+3(4)}{1+3} = \mathbf{3}$ m.
25. A pair of equal and opposite parallel forces with different lines of action; produces pure rotation ($\sum F = 0, \sum \tau \neq 0$).

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $\vec{\tau} = \vec{r} \times \vec{F} = (1(3) - 1(2))\hat{k} = \hat{\mathbf{k}}$.
2. By Parallel Axes Theorem: $I = \frac{1}{12}ML^2 + M(L/2)^2 = \mathbf{\frac{1}{3}ML^2}$.
3. By Perpendicular Axes Theorem: $2I_d = MR^2 \implies I_d = \mathbf{\frac{1}{2}MR^2}$.
4. By Perpendicular Axes Theorem: $2I_d = \frac{1}{2}MR^2 \implies I_d = \mathbf{\frac{1}{4}MR^2}$.
5. Parallel Axes Theorem: $I_{tan} = I_d + MR^2 = \frac{1}{4}MR^2 + MR^2 = \mathbf{\frac{5}{4}MR^2}$.
6. Parallel Axes Theorem: $I_{tan} = \frac{2}{5}MR^2 + MR^2 = \mathbf{\frac{7}{5}MR^2}$.
7. $I = \frac{1}{2}(2)(0.25) = 0.25$ kg m^2. $L = 0.25(10) = \mathbf{2.5}$ J s; $K_{rot} = \frac{1}{2}(0.25)(100) = \mathbf{12.5}$ J.
8. $\theta = \frac{1}{2}(2)(4^2) = \mathbf{16}$ rad.
9. $\omega_0 = 40\pi, \omega = 104\pi \implies \alpha = \mathbf{4\pi}$ rad/s$^\mathbf{2}$. Revolutions $= \frac{40\pi+104\pi}{2\times 2\pi}(16) = \mathbf{576}$ rev.
10. The **exact same parabolic trajectory**, because explosion forces are purely internal ($\vec{F}_{ext} = M\vec{g}$ unchanged).
11. $K_{rot} = L^2/(2I) \propto 1/I$, so K_{rot} becomes **half**.
12. $k_{disc}/k_{ring} = (R/\sqrt{2})/R = \mathbf{1 : \sqrt{2}}$.
13. $AB\cos\theta = AB\sin\theta \implies \tan\theta = 1 \implies \theta = \mathbf{45}^\circ$.
14. $L = mvd_\perp = 2 \times 3 \times 4 = \mathbf{24}$ kg m$^\mathbf{2}$/s.
15. $P = \tau\omega = 500 \times 200 = \mathbf{100}$ kW.
16. $I_1\omega_1 = (I_1 + I_2)\omega \implies 12 = 3\omega \implies \omega = \mathbf{4}$ rad/s.
17. $K_i = \frac{1}{2}(2)(36) = 36$ J; $K_f = \frac{1}{2}(3)(16) = 24$ J $\implies \Delta K_{loss} = \mathbf{12}$ J.
18. When the gravitational field g is **uniform** across the entire body.
19. $X_{cm} = \frac{150(0.5)+200(0.25)}{450} = \mathbf{5/18}$ m; $Y_{cm} = \frac{200(0.25\sqrt{3})}{450} = \mathbf{1/(3\sqrt{3})}$ m.
20. $I = 3(0.16) = 0.48$, $\tau = 30(0.4) = 12 \implies \alpha = 12/0.48 = \mathbf{25}$ rad/s$^\mathbf{2}$.
21. Concentrating mass at larger radius r maximizes I, keeping rotational speed steady.
22. $\alpha = -5$ rad/s$^2 \implies t = 20/5 = \mathbf{4}$ s.
23. $I_{tan} = \frac{2}{3}MR^2 + MR^2 = \mathbf{\frac{5}{3}MR^2}$.
24. $\vec{a}\cdot\vec{b} = \mathbf{-25}$; $\vec{a}\times\vec{b} = \mathbf{7\hat{i} - \hat{j} - 5\hat{k}}$.
25. The **area of the triangle** formed by vectors $\vec{a}$ and $\vec{b}$ as adjacent sides.

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $I\omega = \text{const} \implies \frac{2}{5}MR^2\frac{2\pi}{T} = \text{const} \implies T \propto R^2$. New $T = 24 \times (1/2)^2 = \mathbf{6}$ hours.
2. $m_{hole} = M/4$ at $+R/2$. $X_{cm} = \frac{0-(M/4)(R/2)}{M-M/4} = \mathbf{-R/6}$ (away from the hole).
3. $I_{rem} = \frac{1}{2}MR^2 - \left[\frac{1}{2}\frac{M}{4}\left(\frac{R}{2}\right)^2 + \frac{M}{4}\left(\frac{R}{2}\right)^2\right] = \frac{1}{2}MR^2 - \frac{3}{32}MR^2 = \mathbf{\frac{13}{32}MR^2}$.
4. $h = 2\sqrt{2}$ m. Torque about base: $F_1(2\sqrt{2}) = 196(0.5) \implies F_1 = \mathbf{34.6}$ N. Floor $N = 196$ N, $F_2 = \sqrt{196^2 + 34.6^2} = \mathbf{199}$ N.
5. Front total $= 1800(9.8)\frac{0.75}{1.8} = 7350$ N $\implies \mathbf{3675}$ N/wheel. Rear $= \mathbf{5145}$ N/wheel.
6. $\tau = Mg(L/2) = I\alpha = \frac{1}{3}ML^2\alpha \implies \alpha = \mathbf{\frac{3g}{2L}}$.
7. $a_{tip} = \alpha L = \mathbf{\frac{3}{2}g}$ (greater than g!).

8. $W = \frac{1}{2}Mv^2 + \frac{1}{2}(MR^2)(v/R)^2 = Mv^2 = 100(0.04) = \mathbf{4}$ J.
9. $a = \frac{g\sin\theta}{1+I/(MR^2)} = \frac{g\sin\theta}{1+2/5} = \mathbf{\frac{5}{7}g}\sin\theta$.
10. Smallest $I/(MR^2)$ wins! Solid sphere (2/5) first, then disc (1/2), then ring (1).
11. $\omega_2 = 40/2.5 = \mathbf{16}$ rpm (or in reverse $40 \times 2.5 = 100$ rpm, NCERT Ex 6.14).
12. $L = m(u\cos\theta)H = mu\cos\theta\frac{u^2\sin^2\theta}{2g} = \mathbf{\frac{mu^3\sin^2\theta\cos\theta}{2g}}$.
13. About central perpendicular axis $I_z = \frac{1}{6}Ma^2$. By symmetry, $2I_{diag} = I_z \implies I_{diag} = \mathbf{\frac{1}{12}Ma^2}$.
14. $\frac{K_{rot}}{K_{tot}} = \frac{1/2}{1+1/2} = \mathbf{1/3}$.
15. $X_{cm} = \dfrac{\int_0^L x(kx)\,dx}{\int_0^L kx\,dx} = \frac{L^3/3}{L^2/2} = \mathbf{\frac{2}{3}L}$.
16. $Y_{cm} = \mathbf{\frac{2R}{\pi}}$.
17. Static friction $\mu_s mg$ provides $m\omega^2 r \implies \omega_{max} = \sqrt{\mu_s g/r}$.
18. $m_1x_1 = m_2x_2 \implies x_2 = \mathbf{\frac{m_1}{m_2}d}$.
19. Torque balance: $N\cdot x = f(a/2) = mg\sin\theta(a/2) \implies x = \mathbf{\frac{a}{2}}\tan\theta$.
20. $I = \mathbf{\frac{3}{10}MR^2}$.
21. $\vec{\tau} = d\vec{L}/dt = 6t\hat{i} + 2\hat{j}$. At $t = 1$: $\vec{\tau} = \mathbf{6\hat{i} + 2\hat{j}}$ N m.
22. $L_P = I_P\omega = (\frac{1}{2}MR^2 + MR^2)\frac{v}{R} = \mathbf{\frac{3}{2}MvR}$.
23. $\Delta\vec{A} = \frac{1}{2}(\vec{r}\times\vec{v}\Delta t) \implies \frac{d\vec{A}}{dt} = \frac{\vec{r}\times\vec{p}}{2m} = \frac{\vec{L}}{2m}$.
24. $L = \sqrt{2IK_{rot}} = \sqrt{2(0.5)(100)} = \mathbf{10}$ J s.
25. Gyroscopic stability: a large angular momentum $\vec{L}$ resists changes in direction unless a large external torque acts.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 7 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: GRAVITATION

Complete Solutions for All 75 Level-Wise Practice Questions (25 Basic + 25 Medium + 25 Advanced)

CBSE 2026–27 Weightage & Scope: TYBA Coaching Centre Self-Study Answer Manual

1 Level 1: Basic Level — Detailed Solutions (Q1–Q25)

1. All planets move in elliptical orbits with the Sun situated at one of the two foci.
2. The line joining a planet to the Sun sweeps out equal areas in equal intervals of time ($dA/dt = \text{constant}$).
3. The square of the orbital time period of a planet is proportional to the cube of the semi-major axis: $T^2 \propto a^3$.
4. Every body attracts every other body with force $F = G\frac{m_1 m_2}{r^2}$, where $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.
5. SI unit: N m^2 kg^{-2}; Dimensions: $[\mathrm{M}^{-1}\mathrm{L}^3\mathrm{T}^{-2}]$.
6. **Henry Cavendish** in 1798 using a torsion balance.
7. **Zero** (Shell Theorem 2).
8. $g = \frac{GM_E}{R_E^2} \approx 9.8$ m/s^2.
9. $g(h) \approx g\left(1 - \frac{2h}{R_E}\right)$.
10. $g(d) = g\left(1 - \frac{d}{R_E}\right)$.
11. **Zero** ($d = R_E \implies g(R_E) = 0$).
12. **On Earth's surface** (it decreases both above and below the surface).
13. $V(r) = -\frac{Gm_1 m_2}{r}$ (taking $V(\infty) = 0$).
14. Gravitational PE per unit mass: $U(r) = -\frac{GM}{r}$. SI unit: J kg^{-1}.
15. Minimum launch speed to escape Earth's gravity to infinity: $v_e = \sqrt{\frac{2GM_E}{R_E}} = \sqrt{2gR_E} \approx \mathbf{11.2}$ km/s.
16. **No**, it is independent of the object's mass and launch angle.
17. Its escape speed (2.3 km/s) is smaller than the rms speeds of gas molecules, so gases escape into space.
18. $v_o = \sqrt{\frac{GM_E}{R_E}} = \sqrt{gR_E} \approx \mathbf{7.92}$ km/s.
19. $v_e/v_o = \sqrt{\mathbf{2}}$.
20. $T_0 = 2\pi\sqrt{R_E/g} \approx \mathbf{85}$ minutes.
21. $K = +\frac{GM_E m}{2r}$; $\quad V = -\frac{GM_E m}{r}$; $\quad E = -\frac{GM_E m}{2r}$.
22. Negative total energy means the satellite is **bound** to Earth and cannot escape to infinity.
23. Both astronaut and station are in continuous **free fall** towards Earth, so normal reaction is zero.
24. **No**, unlike electric forces, gravitational shielding is impossible.
25. Since $F \propto 1/r^2$, it becomes **1/4 times**.

2 Level 2: Medium Level — Detailed Solutions (Q1–Q25)

1. $g(h) = \frac{gR_E^2}{(R_E+h)^2} = \frac{g}{4} \implies R_E + h = 2R_E \implies h = \mathbf{R_E}$.
2. $g(1 - d/R_E) = g/2 \implies d = \mathbf{R_E/2}$.
3. $\frac{\Delta g}{g} = \frac{2h}{R_E} = 0.01 \implies h = 0.005 \times 6400 = \mathbf{32}$ km.
4. $\frac{\Delta g}{g} = \frac{d}{R_E} = 0.01 \implies d = 0.01 \times 6400 = \mathbf{64}$ km.
5. $T^2 \propto R^3 \implies T = 4^{3/2} = \mathbf{8}$ years.
6. $g' = \frac{G(2M)}{(2R)^2} = \mathbf{g/2}$. $v_e' = \sqrt{\frac{2G(2M)}{2R}} = \mathbf{v_e}$ (11.2 km/s).
7. $W' = \frac{90}{(1+2)^2} = \frac{90}{9} = \mathbf{10}$ N.
8. $W' = 250(1 - 0.5) = \mathbf{125}$ N.
9. $M_E = \frac{gR_E^2}{G} = \frac{9.81(6.37\times10^6)^2}{6.67\times10^{-11}} = \mathbf{5.97 \times 10^{24}}$ kg.
10. $U = -gR_E = -9.8 \times 6.4 \times 10^6 = \mathbf{-6.27 \times 10^7}$ J/kg.
11. $BE = mgR_E = 50 \times 6.27 \times 10^7 = \mathbf{3.14 \times 10^9}$ J.
12. $K/|E| = \mathbf{1}$; $V/E = \mathbf{2}$.
13. $\Delta E = \frac{GM_E m}{8R_E} = \frac{gmR_E}{8} = \mathbf{3.13 \times 10^9}$ J.
14. $\Delta K = -\Delta E = \mathbf{-3.13 \times 10^9}$ J; $\Delta V = 2\Delta E = \mathbf{+6.25 \times 10^9}$ J.
15. $v \propto 1/\sqrt{r} \implies v_A/v_B = \sqrt{4/1} = \mathbf{2:1}$.
16. $v = v_o(0)/\sqrt{2} = 7.92/1.414 = \mathbf{5.6}$ km/s.
17. $T' = 365 \times (1/2)^{3/2} \approx \mathbf{129}$ days.
18. Because a central force exerts zero torque about the centre ($\vec{\tau} = \vec{r} \times \vec{F} = 0$), so angular momentum $\vec{L}$ is conserved and $dA/dt = L/(2m) = $ const.
19. $g_M/g_E = (3.7)^2/81 \approx \mathbf{1/6}$.
20. **At the poles**, because Earth's polar radius is smaller than equatorial radius and Earth's rotation reduces g at equator.
21. $F = 6.67 \times 10^{-11}(100)/1 = \mathbf{6.67 \times 10^{-9}}$ N.
22. $r \approx 42,200$ km $\implies h \approx \mathbf{35,800}$ km.
23. Only **angular momentum (L)** and **total mechanical energy (E)** remain constant.
24. $\Delta E = \frac{GM_E m}{2(R_E+h)} = \mathbf{5.89 \times 10^9}$ J.
25. It is the simplest convention making potential energy finite and negative for bound systems, without changing gravitational force.

3 Level 3: Advanced / Intelligent Level — Detailed Solutions (Q1–Q25)

1. $W = V(2R_E) - V(R_E) = -\frac{GMm}{2R_E} - \left(-\frac{GMm}{R_E}\right) = \frac{GMm}{2R_E} = \mathbf{\frac{1}{2}mgR_E}$.
2. $\frac{1}{2}mv^2 - \frac{1}{2}mv_e^2 = \frac{1}{2}mv_\infty^2 \implies v_\infty = \sqrt{v^2 - v_e^2} = \mathbf{\sqrt{3}\,v_e} \approx 19.4$ km/s.
3. $v_\infty = \sqrt{9v_e^2 - v_e^2} = \sqrt{8}(11.2) = \mathbf{31.7}$ km/s.
4. $W = -4\frac{Gm^2}{l} - 2\frac{Gm^2}{\sqrt{2}l} = \mathbf{-5.41\frac{Gm^2}{l}}$. Potential at centre: $U = \mathbf{-4\sqrt{2}\frac{Gm}{l}}$.
5. Neutral point at $r = 2R$ from M. Conservation of energy between surface of M and N gives $v = \left(\mathbf{\frac{3GM}{5R}}\right)^{\mathbf{1/2}}$.

6. $\frac{m}{x^2} = \frac{4m}{(d-x)^2} \implies x = \mathbf{d/3}$ from m.
7. $\frac{1}{2}v^2 - \frac{GM}{R_E} = -\frac{GM}{R_E+h} \implies h \approx \mathbf{1.6 \times 10^6}$ m (1600 km).
8. $\Delta U = \frac{1}{2}mgR_E \implies \frac{1}{2}mv^2 = \frac{1}{2}mgR_E \implies v = \sqrt{\mathbf{gR_E}} \approx 7.92$ km/s.
9. $v_e = \sqrt{\frac{2G(\frac{4}{3}\pi R^3\rho)}{R}} = \sqrt{\frac{8}{3}\pi G\rho} \cdot R \propto \mathbf{R}$.
10. $E_i = -mgR_E$, $E_f = -\frac{mgR_E}{4} \implies \Delta E = \frac{3}{4}mgR_E = \mathbf{4.8 \times 10^9}$ J.
11. At equator, g increases by $\omega^2 R_E \approx 0.034$ m/s^2. At poles, g is unchanged.
12. Original symmetry gives 0; extra m at A adds $\vec{F} = G(m)(2m)/1^2\,\hat{j} = \mathbf{2Gm^2\hat{j}}$.
13. Total energy conservation: $2(\frac{1}{2}Mv^2) = \frac{GM^2}{2R} - \frac{GM^2}{d} \implies v \approx \mathbf{2.58 \times 10^6}$ m/s.
14. $F = \mathbf{0}$, $U = -4Gm/d = \mathbf{-2.67 \times 10^{-8}}$ J/kg; **unstable** along line joining centres.
15. $g(h) = 9.8/(1.5)^2 = \mathbf{4.36}$ m/s$^\mathbf{2}$; $g(d) = 9.8(0.5) = \mathbf{4.9}$ m/s$^\mathbf{2}$.
16. $\frac{v_{max}}{v_{min}} = \frac{r_{max}}{r_{min}} = \mathbf{\frac{1+e}{1-e}}$.
17. $v = \sqrt{2}v_o = v_e(r)$ at that altitude, so it **escapes to infinity** on a parabolic path!
18. $F(r) = \mathbf{\frac{GMm}{R^3}r}$ (proportional to r, like a spring!).
19. Tidal force gradient $\propto \frac{M}{r^3}$, and $\frac{M_{moon}}{r_{moon}^3} \approx 2.2\frac{M_{sun}}{r_{sun}^3}$.
20. $T_2/T_1 = 9^{3/2} = \mathbf{27}$.
21. $U_{centre} = -\mathbf{\frac{3GM}{2R}} = 1.5\,U_{surface}$.
22. $\frac{1}{2}(\frac{v_e}{2})^2 - \frac{GM}{R_E} = -\frac{GM}{R_E+h} \implies h = \mathbf{R_E/3}$.
23. **No**, because gravity is directed towards Earth's centre, so the orbital plane must contain Earth's centre.
24. $L = mv_o r = \mathbf{m\sqrt{GMr}}$.
25. $T \propto r^{3/2} \implies \frac{\Delta T}{T} = \frac{3}{2}\frac{\Delta r}{r} = \mathbf{1.5}\%$.