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CLASS 11 PHYSICS (BOOK 2)

UNIVERSAL MASTER TEXTBOOK

SELF-STUDY ZERO-OMISSION EDITION (2026–27)

Complete NCERT Class 11 Physics Part II Coverage (Chapters 8 to 14 + Sample Paper)
Zero-Teacher-Needed Plain-English Explanations | Step-by-Step Derivations
Symbol-by-Symbol Formula Banks | Long & Short Methods | Vector Diagrams
Full NCERT Examples & Exercises + 525 Level-Wise Questions & Complete Solutions Manual

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

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[CONCEPT CORE] How to Use This Book 2 Self-Study Master Textbook

Every chapter (Chapters 8 to 14) is written so you can master it independently without a teacher:

- **Plain-English Intuition + Full Derivations:** Every formula is derived from scratch with symbol-by-symbol units and dimensions.
- **Long Method + Short Trick:** Every question type is solved immediately using both the full CBSE board method and fast competitive shortcuts.
- **Complete NCERT Coverage:** Every NCERT example and back exercise is stated with its full question, step-by-step solution, and key notes.
- **75 Level-Wise Questions per Chapter (525 Total):** 25 Basic + 25 Medium + 25 Advanced questions, with complete step-by-step solutions in Part II.

Verified CBSE 2026–27 Syllabus & Marks Distribution (Book 2)

Per the official CBSE Physics Curriculum 2026–27 (CBSE Physics 2026–27 PDF), Book 2 (Units VII–X, Chapters 8–14) carries **30 out of 70 Theory Marks**:

Unit	Unit Title	NCERT Chapter(s)	CBSE 2026–27 Marks
Unit VII	Properties of Bulk Matter	Ch 8 (Solids), Ch 9 (Fluids), Ch 10 (Thermal)	Combined Units VII–IX: 20 Marks
Unit VIII	Thermodynamics	Ch 11: Thermodynamics	Combined Units VII–IX: 20 Marks
Unit IX	Kinetic Theory of Gases	Ch 12: Kinetic Theory	Combined Units VII–IX: 20 Marks
Unit X	Oscillations and Waves	Ch 13 (Oscillations), Ch 14 (Waves)	10 Marks
		Total Book 2 Theory Weightage:	**30 / 70 Marks**

Complete Book 2 Table of Contents & Coverage Matrix

Chapter	NCERT Source	Master Book Coverage
Ch 8	`keph201.pdf`	Mechanical Properties of Solids (Stress-Strain, Hooke's Law, Y, G, B, Elastic Energy + 75 Qs)
Ch 9	`keph202.pdf`	Mechanical Properties of Fluids (Pascal, Bernoulli, Viscosity, Surface Tension, Capillarity + 75 Qs)
Ch 10	`keph203.pdf`	Thermal Properties of Matter (Temp Scales, Expansion, Calorimetry, Conduction, Cooling + 75 Qs)
Ch 11	`keph204.pdf`	Thermodynamics (Zeroth, First, Second Laws, Mayer's $C_p - C_v = R$, Processes + 75 Qs)
Ch 12	`keph205.pdf`	Kinetic Theory (Ideal Gas, $P = \frac{1}{3}\rho v_{rms}^2$, Equipartition, C_v, C_p, γ, Mean Free Path + 75 Qs)
Ch 13	`keph206.pdf`	Oscillations (SHM Kinematics, Energy, Springs, Simple Pendulum + 75 Qs)
Ch 14	`keph207.pdf`	Waves (Transverse/Longitudinal, Speed, Superposition, Standing Waves, Beats + 75 Qs)
Part II	Solutions Manual	Complete Step-by-Step Solutions for All 525 Level-Wise Questions (Ch 8–14)

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 8 (SELF-STUDY MASTER EDITION)

MECHANICAL PROPERTIES OF SOLIDS

Complete Zero-Omission Coverage of NCERT `keph201.pdf` (Sections 8.1–8.6, Hooke's Law, Stress-Strain Curve, Moduli Y, G, B, Exercises 8.1–8.16)

CBSE 2026–27 Weightage & Scope: Unit VII: Properties of Bulk Matter (Part of 20 Marks for Units VII–IX)

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

Why does a steel bridge hold thousands of tons without snapping, while glass shatters? In Chapter 8, you will learn how solids respond to stretching, shearing, and squeezing forces—explained in simple English with full derivations, symbol tables, and solved NCERT examples & exercises.

1 Topic 1: Elastic Behaviour, Stress, Strain & Hooke's Law (NCERT Sections 8.1–8.4)

1.1 Step 1: Definitions & Plain-English Meaning

- **Deforming Force:** An external force that changes the size or shape of a body.
- **Elasticity:** The property of a body by virtue of which it tends to regain its original size and shape after the deforming force is removed (e.g., steel, quartz). **Plasticity:** Inability to regain original shape (e.g., putty, clay).
- **Stress (σ):** When you pull or squeeze a solid, internal molecular forces pull back to resist the change. Stress is the internal restoring force per unit cross-sectional area:

$$\text{Stress } (\sigma) = \frac{F}{A} \quad (\text{SI Unit: N m}^{-2} \text{ or Pascal, Pa}, \quad [\text{ML}^{-1}\text{T}^{-2}])$$

  Three types: **Longitudinal Stress** (tensile or compressive), **Shearing (Tangential) Stress**, and **Hydraulic (Volumetric) Stress**.
- **Strain (ε):** The fractional change in dimension produced by stress: Strain $= \frac{\text{Change in dimension}}{\text{Original dimension}}$ (no unit, dimensionless $[\text{M}^0\text{L}^0\text{T}^0]$). Three types: Longitudinal strain ($\Delta L/L$), Shearing strain ($\theta = \Delta x/L$), Volumetric strain ($\Delta V/V$).
- **Hooke's Law (8.3):** Within the proportional limit, stress is directly proportional to strain: Stress $= E \times$Strain, where E is the **Modulus of Elasticity**.

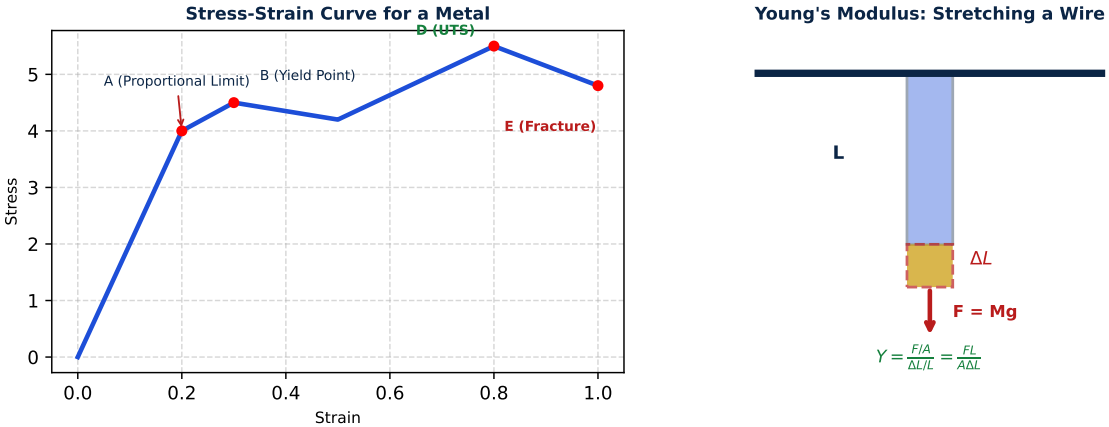


Diagram Explanation (Covers NCERT Fig. 8.2): Left shows the Stress-Strain curve for a metal: $O \to A$ (linear Hooke's law region), B (Yield point / Elastic limit), D (Ultimate Tensile Strength), and E (Fracture point). Materials with large $D \to E$ plastic region are **ductile** (copper); those that snap near B are **brittle** (glass). Right shows Young's modulus setup for a stretched wire.

2 Topic 2: Three Elastic Moduli, Elastic Energy & Applications (NCERT Sections 8.5–8.6)

2.1 Step 1: Definitions, Formulas & Energy Density Derivation

1. **Young's Modulus (Y):** Ratio of longitudinal stress to longitudinal strain: $Y = \frac{F/A}{\Delta L/L} = \mathbf{\frac{FL}{A\Delta L}}$ (only for solids).

2. **Shear Modulus / Modulus of Rigidity (G):** Ratio of shearing stress to shearing strain: $G = \frac{F/A}{\theta} = \mathbf{\frac{FL}{A\Delta x}}$ ($G = 0$ for fluids!).

3. **Bulk Modulus (B):** Ratio of hydraulic stress to volumetric strain: $B = -\mathbf{\frac{\Delta P}{\Delta V/V}}$. Reciprocal $K = 1/B$ is **Compressibility**.

4. **Poisson's Ratio (σ):** Ratio of lateral strain to longitudinal strain: $\sigma = -\frac{\Delta d/d}{\Delta L/L}$ (dimensionless).

5. **Elastic Potential Energy Density (u):** When a wire is stretched from 0 to ΔL, average force is $F/2$, so work done $W = \frac{1}{2}F\Delta L$. Dividing by volume $V = AL$:

$$u = \frac{W}{AL} = \frac{1}{2}\left(\frac{F}{A}\right)\left(\frac{\Delta L}{L}\right) = \mathbf{\frac{1}{2}} \times \text{Stress} \times \text{Strain} = \mathbf{\frac{1}{2}Y\varepsilon^2} = \mathbf{\frac{\sigma^2}{2Y}}$$

Example 8.1A (Why Steel is More Elastic Than Rubber) **[Beginner]**

Problem: Which is more elastic: steel or rubber? Prove mathematically.

Solution: Proof: Elasticity means *resistance to deformation* (Y = Stress/Strain). For equal length L, area A, and load F, rubber stretches far more than steel ($\Delta L_{rubber} \gg \Delta L_{steel}$). Therefore $Y_{steel} \gg Y_{rubber}$, so **steel is much more elastic than rubber**!

3 Complete NCERT Examples (8.1–8.5) & Back Exercises (8.1–8.16) with Full Questions

3.1 NCERT Solved Examples (8.1–8.5)

1. **Example 8.1:** A structural steel rod has radius 10 mm and length 1.0 m. A 100 kN force stretches it along its length ($Y = 2.0 \times 10^{11}$ N/m^2). Calculate (a) stress, (b) elongation, and (c) strain.
Solution: $A = \pi(0.01)^2 = 3.14 \times 10^{-4}$ m^2. (a) $\sigma = \mathbf{3.18 \times 10^8}$ Pa; (b) $\Delta L = \mathbf{1.59}$ mm; (c) $\varepsilon = \mathbf{1.59 \times 10^{-3}}$.

2. **Example 8.2:** A copper wire of length 2.2 m and a steel wire of length 1.6 m, both of diameter 3.0 mm, are connected end to end. When stretched by a load, the net elongation is 0.70 mm. Obtain the load applied.
Solution: Same stress σ: $\sigma(\frac{2.2}{1.1\times10^{11}} + \frac{1.6}{2\times10^{11}}) = 0.7 \times 10^{-3} \implies \sigma = 2.5 \times 10^7$ Pa $\implies F = \mathbf{177}$ N.

3. **Example 8.3:** In a human pyramid, calculate compressional strain on each thighbone ($A = 7.7$ cm$^2, Y = 9.4 \times 10^9$ Pa) supporting 200 kg on two legs.
Solution: Force/leg = 1000 N, $\sigma = 1.3 \times 10^6$ Pa $\implies \varepsilon = \mathbf{1.38 \times 10^{-4}}$.

4. **Example 8.4:** A square lead slab of side 50 cm and thickness 10 cm is subject to shearing force 9.0×10^4 N ($G = 5.6 \times 10^9$ Pa). How much will the upper edge be displaced?
Solution: $\Delta x = \frac{9\times10^4\times0.50}{0.05\times5.6\times10^9} = \mathbf{0.16}$ mm.

5. **Example 8.5:** The average depth of Indian Ocean is 3000 m. Calculate fractional compression $\Delta V/V$ of water at the bottom ($B = 2.2 \times 10^9$ Pa, $g = 10$).
Solution: $P = \rho gh = 3 \times 10^7$ Pa $\implies \Delta V/V = \frac{3\times10^7}{2.2\times10^9} = \mathbf{1.36}\%$.

3.2 NCERT Back Exercises (8.1–8.16) — Full Questions & Solutions

1. **Q 8.1:** A steel wire of length 4.7 m and cross-section 3.0×10^{-5} m^2 stretches by the same amount as a copper wire of length 3.5 m and cross-section 4.0×10^{-5} m^2 under a given load. What is the ratio Y_{steel}/Y_{copper}?
Solution: $Y_s/Y_c = \frac{L_sA_c}{L_cA_s} = \frac{4.7\times4.0}{3.5\times3.0} = \mathbf{1.79}$.

2. **Q 8.2:** From NCERT Fig. 8.7 (stress-strain curve), find Young's modulus and approximate yield strength.
Solution: $Y = \frac{150\times10^6}{0.002} = \mathbf{7.5 \times 10^{10}}$ Pa; Yield strength
$approx \mathbf{3 \times 10^8}$ Pa.

3. **Q 8.3:** Stress-strain graphs for materials A and B: (a) Which has greater Y? (b) Which is stronger?
   Solution: (a) **A** (steeper slope); (b) **A** (higher fracture stress).

4. **Q 8.4:** Read carefully and state True/False: (a) Young's modulus of rubber is greater than steel; (b) Stretching of a coil is determined by its shear modulus.
   Solution: (a) **False** ($Y_{steel} \gg Y_{rubber}$); (b) **True** (coils twist under shear).

5. **Q 8.5:** Two wires of diameter 0.25 cm (steel 1.5 m + brass 1.0 m) loaded with 4 kg and 6 kg. Compute elongations.
   Solution: $\Delta L_{steel} = \mathbf{1.5 \times 10^{-4}}$ m; $\Delta L_{brass} = \mathbf{1.3 \times 10^{-4}}$ m.

6. **Q 8.6:** Edge of an aluminium cube is 10 cm long. One face is fixed, 100 kg mass attached to opposite face ($G = 25$ GPa). Find vertical deflection.
   Solution: $\Delta x = \frac{1000 \times 0.1}{0.01 \times 25 \times 10^9} = \mathbf{4 \times 10^{-7}}$ m.

7. **Q 8.7:** Four identical hollow cylindrical columns of mild steel support a $50,000$ kg structure ($r_1 = 30$ cm, $r_2 = 60$ cm). Calculate compressional strain of each column.
   Solution: $A = \pi(0.6^2 - 0.3^2) = 0.848$ m^2. Strain $= \mathbf{7.22 \times 10^{-7}}$.

8. **Q 8.8:** A piece of copper having rectangular cross-section 15.2 mm$\times$19.1 mm is pulled in tension with $44,500$ N ($G = 4.2 \times 10^{10}$). Calculate resulting strain.
   Solution: $\sigma = 1.53 \times 10^8$ Pa $\implies$ strain $= \mathbf{3.65 \times 10^{-3}}$.

9. **Q 8.9:** A steel cable with radius 1.5 cm supports a chairlift. If max stress is 10^8 Pa, what is the maximum load it can support?
   Solution: $F_{max} = \sigma_{max} \pi r^2 = 10^8 \times \pi(0.015)^2 = \mathbf{7.07 \times 10^4}$ N.

10. **Q 8.10:** A rigid bar of mass 15 kg is supported by 3 wires (2 outer copper, 1 middle iron). Find ratio of diameters for equal tension.
    Solution: $d_c/d_i = \sqrt{Y_i/Y_c} = \sqrt{1.9/1.1} = \mathbf{1.31}$.

11. **Q 8.11:** A 14.5 kg mass on a 1.0 m steel wire ($A = 0.065$ cm^2) whirls in a vertical circle at 2 rev/s. Find elongation at lowest point.
    Solution: $T = 2431.7$ N $\implies$ $\Delta L = \mathbf{1.87}$ mm.

12. **Q 8.12:** Compute bulk modulus of water ($V_i = 100$ L, $\Delta P = 100$ atm, $V_f = 99.5$ L).
    Solution: $B = \mathbf{2.026 \times 10^9}$ Pa.

13. **Q 8.13:** What is the density of water at a depth where pressure is 80.0 atm ($B = 2.2 \times 10^9$ Pa)?
    Solution: $\rho = \mathbf{1003.6}$ kg/m$^\mathbf{3}$.

14. **Q 8.14:** Compute fractional change in volume of a glass slab when subjected to a hydraulic pressure of 10 atm ($B = 3.7 \times 10^{10}$ Pa).
    Solution: $\Delta V/V = \frac{10 \times 1.013 \times 10^5}{3.7 \times 10^{10}} = \mathbf{2.74 \times 10^{-5}}$.

15. **Q 8.15:** Determine volume contraction of a solid copper cube, 10 cm on an edge, under 7.0×10^6 Pa ($B = 1.4 \times 10^{11}$).
    Solution: $\Delta V = V \frac{\Delta P}{B} = 10^{-3} \times \frac{7 \times 10^6}{1.4 \times 10^{11}} = \mathbf{5 \times 10^{-8}}$ m$^\mathbf{3}$ $= 0.05$ cm^3.

16. **Q 8.16:** How much should pressure on a litre of water be changed to compress it by 0.10%?
    Solution: $\Delta P = B \times 0.001 = \mathbf{2.2 \times 10^6}$ Pa.

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 8 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. Define elasticity and plasticity with one example each.
2. Define Stress and write its SI unit and dimensions.
3. Define Strain and write its SI unit and dimensions.
4. Name the three types of stress and strain.
5. State Hooke's Law.
6. Define Young's Modulus (Y) and write its formula.
7. Define Shear Modulus (Modulus of Rigidity, G).
8. Define Bulk Modulus (B) and Compressibility (K).
9. Which is more elastic: steel or rubber? Why?
10. What is an elastomer? Give two examples.
11. Define Poisson's ratio (σ). Is it dimensionless?
12. Write the formula for elastic potential energy stored per unit volume (energy density).
13. A wire of area 2 mm^2 is stretched by 200 N. Find longitudinal stress.
14. A 2 m wire elongates by 2 mm. Find longitudinal strain.
15. Using Q13 and Q14, find Young's modulus Y of the wire.
16. What is the Young's modulus of a perfectly rigid body?
17. What is the Bulk modulus of an incompressible fluid?
18. Why do liquids and gases have zero shear modulus ($G = 0$)?
19. What is the proportional limit on a stress-strain curve?
20. What is the yield point (elastic limit)?
21. What is Ultimate Tensile Strength (UTS)?
22. Define brittle and ductile materials.
23. Why are girders/beams made with an I-shaped cross-section?
24. A 1 m wire of $Y = 2 \times 10^{11}$ Pa has strain 0.001. Find energy density.
25. Does Young's modulus depend on the length or thickness of a wire?

4.2 Level 2: Medium Level (25 Questions)

1. A structural steel rod has radius 10 mm and length 1.0 m. A 100 kN force stretches it ($Y = 2 \times 10^{11}$ Pa). Find stress, elongation, and strain.
2. A copper wire ($L = 2.2$ m) and steel wire ($L = 1.6$ m) of same diameter are joined end-to-end and stretched by a load. Total elongation is 0.7 mm. Find load ($r = 1.5$ mm, $Y_c = 1.1 \times 10^{11}, Y_s = 2 \times 10^{11}$).
3. A square lead slab of side 50 cm and thickness 10 cm is sheared by 9×10^4 N on its narrow face ($G = 5.6 \times 10^9$ Pa). Find displacement.
4. Find pressure required to compress water by 0.1% ($B = 2.2 \times 10^9$ Pa).
5. Two wires of same material have lengths in ratio 1 : 2 and radii in ratio 2 : 1. Pulled by same force, find ratio of elongations.
6. A steel wire of cross-sectional area 1 mm^2 is stretched by 1 mm ($L = 1$ m, $Y = 2 \times 10^{11}$). Find work done.
7. Why are bridges declared unsafe after long use?

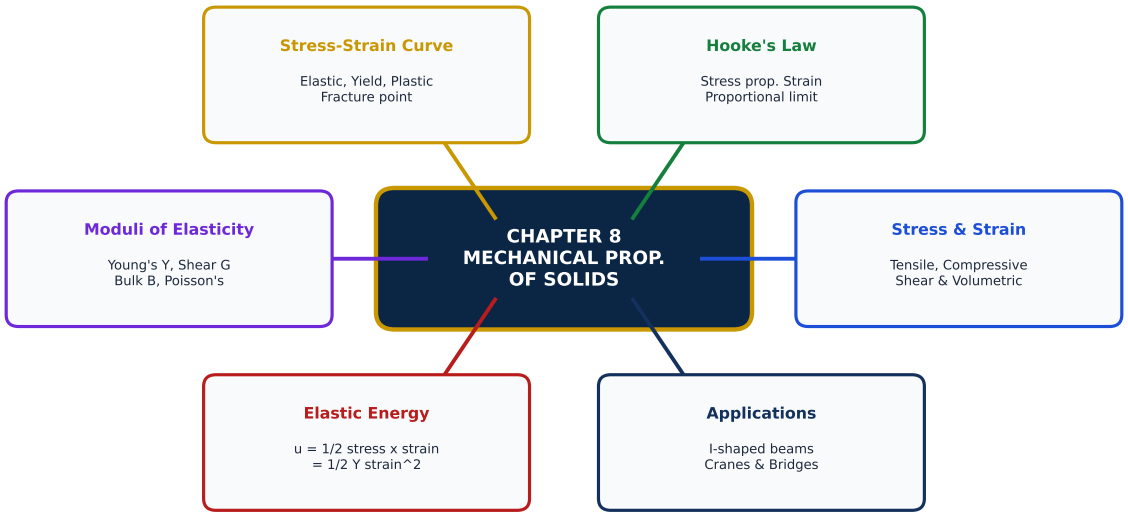
8. Calculate the maximum height of a mountain on Earth if elastic limit of rock is 3×10^8 Pa ($\rho = 3\times10^3$ kg/m^3, $g = 10$).
9. A crane lifts 10^4 kg ($g = 10$) with elastic limit of steel 3×10^8 Pa. Find minimum radius of steel rope.
10. A wire breaks when stretched by 10 kg weight. What load will break a wire of same material with double radius and half length?
11. What is the percentage increase in length of a wire ($Y = 2 \times 10^{11}$ Pa) under stress 2×10^8 Pa?
12. Find depression δ at the centre of a beam of length l, breadth b, depth d loaded with W at centre.
13. Compare Young's modulus of two wires A and B from their Load vs Extension graphs if slope of A is steeper.
14. How does temperature affect Young's modulus of a metal?
15. A 1 m wire of mass M and area A hangs vertically under its own weight. Find elongation.
16. A solid rubber ball of $B = 2 \times 10^8$ Pa is taken 100 m deep in a lake ($\rho = 10^3, g = 10$). Find fractional volume change.
17. If a wire is stretched by x with force F, show work done is $\frac{1}{2}Fx$.
18. Why is hollow shaft stronger than a solid shaft of the same mass and length?
19. A metal cube of side 10 cm is subjected to shearing force 10^4 N and top shifts by 0.05 mm. Find G.
20. What happens to Poisson's ratio for an incompressible material?
21. If a wire of length L is stretched by ΔL, what fraction of work is stored as elastic energy?
22. Two identical springs of steel and copper are equally stretched. On which is more work done?
23. Two identical springs of steel and copper are stretched by equal forces. On which is more work done?
24. Find bulk modulus of an ideal gas in an isothermal process.
25. Find bulk modulus of an ideal gas in an adiabatic process.

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

1. A steel wire of length L, area A, Young's modulus Y, thermal coefficient α is clamped rigidly at both ends and cooled by ΔT. Find thermal stress.
2. In Q1, if $L = 2$ m, $A = 2$ mm^2, $Y = 2 \times 10^{11}$, $\alpha = 1.1 \times 10^{-5}/^\circ$C, $\Delta T = 40^\circ$C, find tension developed.
3. A rigid bar of mass 15 kg is supported symmetrically by three wires (2 m long): two outer copper ($Y_c = 1.1 \times 10^{11}$) and one middle iron ($Y_i = 1.9 \times 10^{11}$). Find ratio of diameters if each has same tension.
4. A 14.5 kg mass fastened to a 1 m steel wire ($A = 0.065$ cm^2) is whirled in a vertical circle at 2 rev/s ($Y = 2 \times 10^{11}, g = 9.8$). Find elongation at lowest point.
5. Compute bulk modulus of water from: $V_i = 100$ L, $\Delta P = 100$ atm (1.013×10^7 Pa), $V_f = 99.5$ L.
6. What is the density of water at a depth where pressure is 80 atm ($B = 2.2 \times 10^9$ Pa, $\rho_0 = 1000$ kg/m^3)?
7. Find the breaking length of a vertical wire of density ρ and breaking stress σ_B hanging under its own weight.
8. A light rod of length 2 m hangs horizontally from two vertical wires A (steel, $A_1 = 1$ mm$^2, Y_1 = 2 \times 10^{11}$) and B (brass, $A_2 = 2$ mm$^2, Y_2 = 1 \times 10^{11}$). Where should a weight W be hung for equal stress?
9. In Q8, where should W be hung for equal strain in both wires?
10. Write the relation between Y, G, B and Poisson's ratio σ.
11. Using Q10, what is the theoretical range of Poisson's ratio σ?
12. A wire elongates by l when loaded with W. If the wire goes over a pulley with W on each side, what is the elongation?
13. A wire of length L is cut into two equal halves. How do its breaking stress and breaking load change?

14. A metallic wire of diameter d, length L, Y is stretched by x. Find the increase in temperature if adiabatic (s = specific heat, ρ = density).
15. Two wires of same length and radius have Y_1 and Y_2. Connected in series, find effective Young's modulus.
16. In Q15, if connected in parallel (same elongation), find effective Young's modulus.
17. A sphere contracts in volume by 0.01% when taken 1 km deep in sea ($\rho = 10^3, g = 9.8$). Find B.
18. A hollow cylinder of inner radius r_1, outer radius r_2 is compressed by F. Find compressive stress.
19. Show that $Y = 2G$ when Poisson's ratio $\sigma = 0$.
20. If a wire of cross-section A is stretched from L to $L + \Delta L$, find change in volume in terms of σ.
21. Why do railway tracks have I-shaped cross-sections?
22. A 4 m wire ($Y = 2 \times 10^{11}, A = 1$ mm^2) is stretched by 2 mm. Find energy stored.
23. A 1 kg mass hangs from a 1 m wire. It is pulled aside by 60° and released. Find stress at bottom ($A = 10^{-6}$ m$^2, g = 10$).
24. What is elastic hysteresis? Why are car tyres made of rubber with low hysteresis?
25. Can a solid have negative Poisson's ratio?

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Stress & Strain, Hooke's Law, Stress-Strain Curve landmarks, Moduli Y, G, B, Elastic Energy Density, and Structural Applications.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 8 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MECHANICAL PROPERTIES OF SOLIDS

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. Elasticity is the property of a body to regain its original size and shape after removing the deforming force (e.g., steel). Plasticity is the inability to regain original shape (e.g., putty, mud).
2. Internal restoring force per unit cross-sectional area: $\sigma = F/A$. SI unit: N m^{-2} (or Pascal, Pa); Dimensions: $[\mathrm{ML}^{-1}\mathrm{T}^{-2}]$.
3. Fractional change in dimension: $\varepsilon = \Delta L/L$. It is a ratio of like quantities, so it has **no unit** and is **dimensionless** ($[\mathrm{M}^0\mathrm{L}^0\mathrm{T}^0]$).
4. 1. Longitudinal (tensile/compressive) stress & strain. 2. Shearing (tangential) stress & strain ($\theta = \Delta x/L$). 3. Hydraulic (volumetric) stress & strain ($\Delta V/V$).
5. Within the proportional limit, stress is directly proportional to strain: Stress $= E \times$ Strain, where E is the modulus of elasticity.
6. Ratio of longitudinal stress to longitudinal strain: $Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$ (SI unit: Pa).
7. Ratio of shearing stress to shearing strain: $G = \frac{F/A}{\theta} = \frac{FL}{A\Delta x}$.
8. Bulk modulus $B = -\frac{\Delta P}{\Delta V/V}$. Compressibility $K = \frac{1}{B}$ (SI unit: Pa^{-1}).
9. **Steel** is more elastic than rubber because for the same stress, steel produces much smaller strain ($Y_{steel} \gg Y_{rubber}$).
10. A material that can be stretched to very large strains without breaking (no well-defined plastic region), e.g., rubber, tissue of aorta.
11. Ratio of lateral strain to longitudinal strain: $\sigma = -\frac{\Delta d/d}{\Delta L/L}$. Yes, it is dimensionless.
12. $u = \frac{1}{2} \times \text{Stress} \times \text{Strain} = \frac{1}{2}Y(\text{Strain})^2 = \frac{(\text{Stress})^2}{2Y}$.
13. $\sigma = \frac{200}{2\times10^{-6}} = \mathbf{10^8}$ $\mathrm{N/m^2}$.
14. $\varepsilon = \frac{2\times10^{-3}}{2} = \mathbf{10^{-3}}$.
15. $Y = \frac{10^8}{10^{-3}} = \mathbf{10^{11}}$ $\mathrm{N/m^2}$.
16. **Infinite** (since strain $\Delta L = 0$ for any finite stress).
17. **Infinite** (since $\Delta V = 0$).
18. Because fluids cannot sustain a static shearing (tangential) force; they flow immediately.
19. The maximum stress up to which Hooke's law (linear proportionality between stress and strain) holds.
20. The point beyond which the material undergoes permanent plastic deformation even after removing the load.
21. The maximum stress a material can withstand before necking and fracture.
22. Ductile materials have a large plastic region between yield point and fracture (e.g., copper). Brittle materials fracture almost immediately after elastic limit (e.g., glass, cast iron).
23. It provides high bending stiffness (large moment of inertia) while saving material and weight at the neutral middle layer.
24. $u = \frac{1}{2}(2\times10^{11})(10^{-3})^2 = \mathbf{10^5}$ $\mathrm{J/m^3}$.
25. **No**, Y is an intrinsic material property (depends only on material and temperature).

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

1. $A = \pi(0.01)^2 = 3.14 \times 10^{-4}$ m^2. Stress $= \frac{10^5}{3.14\times10^{-4}} = \mathbf{3.18 \times 10^8}$ Pa. Strain $= \frac{\sigma}{Y} = \mathbf{1.59 \times 10^{-3}}$. $\Delta L = 1.0 \times 1.59 \times 10^{-3} = \mathbf{1.59}$ mm.

2. Same stress σ: $\Delta L = \sigma(\frac{L_c}{Y_c} + \frac{L_s}{Y_s}) = 0.7 \times 10^{-3} \implies \sigma = 2.5 \times 10^7$ Pa. Load $F = \sigma\pi r^2 \approx \mathbf{177}$ N.

3. Shear area $A = 0.50 \times 0.10 = 0.05$ m^2. $\Delta x = \frac{FL}{AG} = \frac{9\times10^4\times0.50}{0.05\times5.6\times10^9} = \mathbf{0.16}$ mm.

4. $\Delta P = B\frac{\Delta V}{V} = 2.2 \times 10^9 \times 0.001 = \mathbf{2.2 \times 10^6}$ Pa (≈ 22 atm).

5. $\Delta L = \frac{FL}{\pi r^2 Y} \propto \frac{L}{r^2} \implies \frac{\Delta L_1}{\Delta L_2} = \frac{1}{2} \times (\frac{1}{2})^2 = \mathbf{1 : 8}$.

6. $W = \frac{1}{2}\frac{YA}{L}(\Delta L)^2 = \frac{1}{2}\frac{2\times10^{11}\times10^{-6}}{1}(10^{-3})^2 = \mathbf{0.1}$ J.

7. Repeated alternating stress-strain cycles cause **elastic fatigue**, weakening the metal so it may fracture below normal yield stress.

8. $h\rho g \le \sigma_{max} \implies h_{max} = \frac{3\times10^8}{3\times10^3\times10} = \mathbf{10}$ km (matches Mt. Everest ~ 8.85 km!).

9. $\pi r^2 \ge \frac{mg}{\sigma_{max}} = \frac{10^5}{3\times10^8} \implies r \ge \mathbf{1.03}$ cm.

10. Breaking force $F_{max} = \sigma_{max}A \propto r^2$ (independent of length!). Doubling r quadruples breaking load to **40** kg-wt.

11. $\%\Delta L = \frac{\sigma}{Y} \times 100 = \frac{2\times10^8}{2\times10^{11}} \times 100 = \mathbf{0.1}\%$.

12. $\delta = \mathbf{\frac{Wl^3}{4bd^3Y}}$ (making depth d large sharply reduces sagging!).

13. Slope $= F/\Delta L = YA/L$. If dimensions are same, **A has greater Young's modulus**.

14. As temperature increases, interatomic bonds weaken, so Young's modulus **decreases**.

15. Average tension is $Mg/2$ (acts at COM $L/2$). So $\Delta L = \mathbf{\frac{MgL}{2AY}}$.

16. $\Delta P = \rho g h = 10^6$ Pa $\implies \frac{\Delta V}{V} = \frac{10^6}{2\times10^8} = \mathbf{0.005}$ (0.5%).

17. Average force during stretching from 0 to F is $F/2$, so $W = \frac{1}{2}Fx$.

18. Hollow shaft has larger outer radius and thus larger polar moment of inertia, resisting torsion better.

19. $A = 10^{-2}$ m^2, $\theta = 0.05 \times 10^{-3}/0.1 = 5 \times 10^{-4} \implies G = \frac{10^4/10^{-2}}{5\times10^{-4}} = \mathbf{2 \times 10^9}$ Pa.

20. Since volume is constant, $\frac{\Delta V}{V} = (1 - 2\sigma)\frac{\Delta L}{L} = 0 \implies \sigma = \mathbf{0.5}$.

21. 100% (within elastic limit, since restoring force is conservative).

22. $W = \frac{1}{2}kx^2$; since $Y_{steel} > Y_{copper}$, $k_{steel} > k_{copper} \implies$ **more work on steel**.

23. $W = \frac{F^2}{2k}$; smaller k gives larger $W \implies$ **more work on copper**.

24. For $PV = $ const, $P\Delta V + V\Delta P = 0 \implies B_T = -\frac{\Delta P}{\Delta V/V} = \mathbf{P}$.

25. For $PV^\gamma = $ const, $B_S = \gamma\mathbf{P}$.

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

1. Thermal strain $= \alpha\Delta T$, so thermal stress $= \mathbf{Y\alpha\Delta T}$ (independent of L and A!).

2. $F = YA\alpha\Delta T = 2 \times 10^{11}(2 \times 10^{-6})(1.1 \times 10^{-5})(40) = \mathbf{176}$ N.

3. Same tension T and same elongation $\Delta L \implies YA = $ const $\implies d^2Y = $ const $\implies \frac{d_c}{d_i} = \sqrt{\frac{Y_i}{Y_c}} = \sqrt{\frac{1.9}{1.1}} = \mathbf{1.31}$.

4. $T = m\omega^2 r + mg = 14.5(4\pi)^2(1) + 14.5(9.8) = 2431.7$ N. $\Delta L = \frac{TL}{AY} = \mathbf{1.87}$ mm.

5. $B = \frac{1.013\times10^7}{0.5/100} = \mathbf{2.026 \times 10^9}$ Pa.

6. $\frac{\Delta\rho}{\rho_0} = \frac{\Delta P}{B} = \frac{79\times1.013\times10^5}{2.2\times10^9} = 0.00364 \implies \rho = \mathbf{1003.6}$ kg/m$^{\mathbf{3}}$.
7. At top, stress $= \rho g L_{max} = \sigma_B \implies L_{max} = \frac{\sigma_B}{\rho g}$.
8. Equal stress $\sigma = T_1/A_1 = T_2/A_2 \implies T_2 = 2T_1$. Torque about W: $T_1 x = T_2(2-x) \implies x = 2(2-x) \implies x = \mathbf{4/3}$ m from steel wire.
9. Equal strain $\sigma_1/Y_1 = \sigma_2/Y_2 \implies \frac{T_1}{1\times2} = \frac{T_2}{2\times1} \implies T_1 = T_2 \implies x = \mathbf{1}$ m (midpoint!).
10. $Y = 2G(1+\sigma)$ and $Y = 3B(1-2\sigma)$; eliminating σ: $\frac{9}{Y} = \frac{3}{G} + \frac{1}{B}$.
11. Since $G > 0$ and $B > 0$: $-1 < \sigma < 0.5$ (for real solids, $0 \le \sigma \le 0.5$).
12. Tension is still W (not $2W$!), so elongation is still **l**!
13. Both breaking stress (σ_B) and breaking load ($\sigma_B A$) remain **unchanged** (independent of length).
14. Work/vol $= \frac{1}{2}Y(x/L)^2 = \rho s \Delta T \implies \Delta T = \frac{\mathbf{Yx^2}}{\mathbf{2\rho s L^2}}$.
15. $\Delta L = \Delta L_1 + \Delta L_2 \implies \frac{2L}{Y_{eff}} = \frac{L}{Y_1} + \frac{L}{Y_2} \implies Y_{eff} = \frac{\mathbf{2Y_1Y_2}}{\mathbf{Y_1+Y_2}}$.
16. $F = F_1 + F_2 \implies Y_{eff}(2A) = Y_1 A + Y_2 A \implies Y_{eff} = \frac{\mathbf{Y_1+Y_2}}{\mathbf{2}}$.
17. $\Delta P = 10^3(9.8)(1000) = 9.8\times10^6$ Pa $\implies B = \frac{9.8\times10^6}{10^{-4}} = \mathbf{9.8\times10^{10}}$ Pa.
18. $\sigma = \frac{\mathbf{F}}{\pi(\mathbf{r_2^2 - r_1^2})}$.
19. From $Y = 2G(1+\sigma)$, setting $\sigma = 0$ gives $Y = 2G$.
20. $\frac{\Delta V}{V} = (1-2\sigma)\frac{\Delta L}{L} \implies \Delta V = \mathbf{A\Delta L}(\mathbf{1}-\mathbf{2}\sigma)$.
21. To resist bending under heavy train loads with minimum weight of steel.
22. $U = \frac{1}{2}\frac{YA}{L}(\Delta L)^2 = \frac{1}{2}\frac{2\times10^{11}(10^{-6})}{4}(4\times10^{-6}) = \mathbf{0.1}$ J.
23. At bottom, $T = mg(3 - 2\cos60°) = 2mg = 20$ N. Stress $= 20/10^{-6} = \mathbf{2\times10^7}$ Pa.
24. Loop area between loading and unloading curves represents energy lost as heat. Low hysteresis prevents tyres from overheating.
25. Ordinary isotropic solids have $\sigma > 0$, though special engineered auxetic metamaterials can have $\sigma < 0$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 9 (SELF-STUDY MASTER EDITION)

MECHANICAL PROPERTIES OF FLUIDS

Complete Zero-Omission Coverage of NCERT `keph202.pdf` (Sections 9.1–9.6, Pascal, Bernoulli, Stokes, Surface Tension, Capillarity, Exercises 9.1–9.20)

CBSE 2026–27 Weightage & Scope: Unit VII: Properties of Bulk Matter (Part of 20 Marks for Units VII–IX)

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

How does a hydraulic jack lift a 2-ton car with one hand, and why do airplanes fly? Chapter 9 explains Pressure, Pascal's Law, Bernoulli's Theorem, Viscosity, and Surface Tension from scratch with crystal-clear diagrams and full NCERT solutions.

1 Topic 1: Fluid Pressure, Pascal's Law & Archimedes' Principle (NCERT Sections 9.1–9.2)

1.1 Step 1: Definitions & Derivations

- **Fluid:** Any substance that can flow (liquids and gases) because it cannot sustain static shear stress.
- **Pressure (P):** Normal force per unit area: $P = F/A$ (SI: Pascal, Pa = N/m^2, [ML^{-1}T^{-2}]; 1 atm = 1.013×10^5 Pa). Pressure is a **scalar** acting equally in all directions at a point.
- **Variation of Pressure with Depth:** Consider a vertical liquid cylinder of height h and area A in equilibrium: $PA - P_0A = mg = (\rho Ah)g \implies \mathbf{P = P_0 + \rho gh}$. Gauge pressure $= P - P_0 = \rho gh$.
- **Pascal's Law:** Pressure applied to an enclosed incompressible fluid is transmitted undiminished to every part of the fluid. **Hydraulic Lift:** $\frac{F_1}{A_1} = \frac{F_2}{A_2} \implies F_2 = F_1\left(\frac{A_2}{A_1}\right)$ (magnifies force!).

2 Topic 2: Streamline Flow, Continuity & Bernoulli's Theorem (NCERT Sections 9.3–9.4)

2.1 Step 1: Derivations of Continuity & Bernoulli's Equation

- **Equation of Continuity (Mass Conservation):** For steady incompressible flow, mass entering per second equals mass leaving per second: $\rho A_1 v_1 = \rho A_2 v_2 \implies \mathbf{A_1 v_1 = A_2 v_2}$ (narrower pipe = faster flow!).
- **Bernoulli's Theorem (Energy Conservation):** Applying Work-Energy theorem ($W_{net} = \Delta K + \Delta U$) to a fluid element of mass $\Delta m = \rho \Delta V$ moving from (P_1, v_1, h_1) to (P_2, v_2, h_2):

$$(P_1 - P_2)\Delta V = \frac{1}{2}\rho \Delta V(v_2^2 - v_1^2) + \rho \Delta V g(h_2 - h_1) \implies \mathbf{P + \frac{1}{2}\rho v^2 + \rho gh} = \text{constant}$$

- **Torricelli's Law (Speed of Efflux):** For a hole at depth h in an open tank ($P_1 = P_2 = P_0, v_1 \approx 0$), Bernoulli gives $\frac{1}{2}\rho v^2 = \rho gh \implies \mathbf{v = \sqrt{2gh}}$.

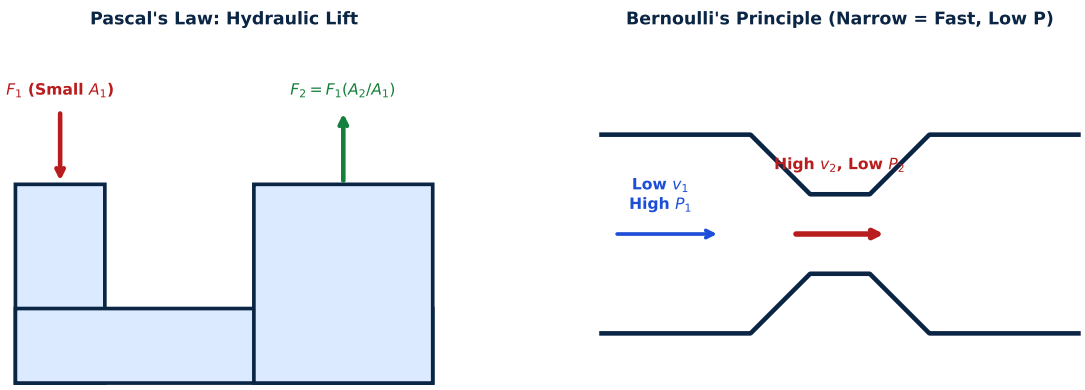


Diagram Explanation: Left shows Pascal's Hydraulic Lift magnifying force by A_2/A_1. Right shows Bernoulli's principle in a narrowing tube: speed increases ($v_2 > v_1$) and pressure drops ($P_2 < P_1$).

3 Topic 3: Viscosity, Stokes' Law, Surface Tension & Capillarity (NCERT Sections 9.5–9.6)

3.1 Step 1: Definitions & Formulas

- **Viscosity (η):** Internal fluid friction opposing relative motion between layers: $F = -\eta A \frac{dv}{dx}$ (SI: Pa s; 1 Pa s = 10 Poise). **Stokes' Law:** Viscous drag on a sphere of radius r at speed v is $F = 6\pi\eta r v$. Equating net gravity-buoyancy to drag gives **Terminal Velocity:** $v_t = \frac{2r^2(\rho-\sigma)g}{9\eta}$.
- **Surface Tension (S):** Force per unit length ($S = F/L$) or surface energy per unit area ($S = \Delta E/\Delta A$, SI: N/m or J/m^2).
- **Excess Pressure:** Inside a liquid drop (1 surface): $\Delta P = \frac{2S}{R}$. Inside a soap bubble (2 surfaces): $\Delta P = \frac{4S}{R}$.
- **Capillary Rise:** Balancing upward surface tension force $2\pi r S\cos\theta$ with weight $\pi r^2 h\rho g$ gives $\mathbf{h = \frac{2S\cos\theta}{r\rho g}}$.

Example 9.1A (Soap Bubble Work & Excess Pressure) [Board / NEET]
Problem: Find work done in blowing a soap bubble of radius 2 cm ($S = 0.03$ N/m), and excess pressure inside it.
Solution: Work Done: Soap bubble has **2 free surfaces** (inner + outer), so $\Delta A = 2(4\pi r^2) = 8\pi(0.02)^2 = 1.005 \times 10^{-2}$ m^2. $W = S\Delta A = 0.03 \times 1.005 \times 10^{-2} = \mathbf{3.02 \times 10^{-4}}$ J.
Excess Pressure: $\Delta P = \frac{4S}{r} = \frac{4(0.03)}{0.02} = \mathbf{6}$ Pa.

4 Complete NCERT Examples (9.1–9.10) & Back Exercises (9.1–9.20) with Full Questions

4.1 NCERT Solved Examples (9.1–9.10)

1. **Example 9.1:** Two thighbones ($A = 10$ cm^2 each) support 40 kg upper body ($g = 10$). Estimate average pressure sustained.
   Solution: $P = \frac{400}{20\times10^{-4}} = \mathbf{2 \times 10^5}$ Pa (
   $approx$2 atm).

2. **Example 9.2:** What is the pressure on a swimmer 10 m below the surface of a lake? ($P_{atm} = 1.01 \times 10^5$ Pa)
   Solution: $P = 1.01 \times 10^5 + 1000(10)(10) = \mathbf{2.01 \times 10^5}$ Pa
   $approx$2 atm.

3. **Example 9.3:** Density of atmosphere at sea level is 1.29 kg/m^3. Assume constant density; how high would the atmosphere extend?
   Solution: $h = \frac{P_0}{\rho g} = \frac{1.01\times10^5}{1.29\times9.8}$
   $approx$**8** km.

4. **Example 9.4:** At depth 1000 m in ocean, what is (a) absolute pressure, (b) gauge pressure, (c) force on a 20 cm × 20 cm submarine window? ($\rho = 1.03 \times 10^3$)
Solution: (a) 1.04×10^7 Pa; (b) 1.03×10^7 Pa; (c) $F = 1.03 \times 10^7 \times 0.04 = \mathbf{4.12 \times 10^5}$ N.

5. **Example 9.5:** Hydraulic lift has piston areas 100 cm^2 and 4×10^{-2} m^2? Wait: $F_2 = 3000 \times 9.8 = 29400$ N, $A_2 = 425$ cm^2. Find max pressure small piston bears.
Solution: $P = \frac{29400}{425 \times 10^{-4}} = \mathbf{6.92 \times 10^5}$ Pa.

6. **Example 9.6:** Blood flow in aorta ($r = 9$ mm, $v = 0.3$ m/s vs 30 capillaries $r = 5 \times 10^{-6}$ m): compare Reynolds / speed.
Solution: By $A_1 v_1 = n A_2 v_2$, capillary speed is ~ 0.5 mm/s.

7. **Example 9.7:** Dynamic lift on aircraft wing ($v_{top} = 70$ m/s, $v_{bot} = 63$ m/s, $A = 2.5$ m^2, $\rho = 1.3$). Find lift.
Solution: $\Delta P = \frac{1}{2}(1.3)(70^2 - 63^2) = 605.15$ Pa $\implies F = \mathbf{1513}$ N.

8. **Example 9.8:** Metal plate (0.10 m^2) connected to 0.010 kg mass over pulley moves at 0.085 m/s over 0.30 mm oil film. Find η.
Solution: $\eta = \frac{F \Delta x}{A v} = \frac{0.098(0.3 \times 10^{-3})}{0.10(0.085)} = \mathbf{3.46 \times 10^{-3}}$ Pa s.

9. **Example 9.9:** Terminal velocity of copper ball ($r = 2$ mm, $\rho = 8.9 \times 10^3$) in oil ($\rho_0 = 1.5 \times 10^3$) is 6.5 cm/s. Find η.
Solution: $\eta = \frac{2r^2(\rho - \rho_0)g}{9 v_t} = \mathbf{0.99}$ Pa s.

10. **Example 9.10:** Lower end of capillary tube ($r = 1$ mm) dipped in water ($S = 0.073$). How much pressure is needed to blow a hemispherical bubble at bottom ($h = 20$ cm)?
Solution: $P_{excess} = \rho g h + \frac{2S}{r} = 1960 + 146 = \mathbf{2106}$ Pa.

4.2 NCERT Back Exercises (9.1–9.20) — Full Questions & Solutions

1. **Q 9.1:** Explain why: (a) Blood pressure in humans is greater at the feet than at the brain; (b) Atmospheric pressure at 6 km height decreases to nearly half; (c) Hydrostatic pressure is a scalar even though pressure is force/area.
Solution: (a) $P = P_0 + \rho g h$ (larger column height at feet). (b) Air density decreases exponentially with height. (c) Pressure acts equally in all directions at a point (no unique direction).

2. **Q 9.2:** Explain why: (a) Angle of contact of mercury with glass is obtuse, while water with glass is acute; (b) Water on clean glass spreads, mercury forms drops; (c) Surface tension is independent of area; (d) Detergent water has small angle of contact; (e) A drop under no external force is spherical.
Solution: (a) Mercury cohesive > adhesive; water adhesive > cohesive. (b) Same reason. (c) It is a molecular surface energy per unit area. (d) Detergent lowers S and θ. (e) Sphere minimizes surface area.

3. **Q 9.3:** Fill in the blanks: (a) Surface tension generally (increases/decreases) with T; (b) Viscosity of gases (increases/decreases) with T, liquids (increases/decreases); (c) Elastic modulus vs fluid shear; (d) Continuity = conservation of _____; (e) Bernoulli = conservation of _____.
Solution: (a) **decreases**; (b) **increases, decreases**; (c) **shear strain**; (d) **mass**; (e) **energy**.

4. **Q 9.4:** Explain why: (a) To keep paper horizontal, blow over it (not under); (b) Closing tap with finger makes fast jet; (c) Needle syringe thumb pressure controls speed more than size; (d) Fluid from vessel exerts backward thrust; (e) Spinning cricket ball curves.
Solution: (a) Blowing over lowers top pressure (Bernoulli). (b) Continuity $Av = $ const. (c) Bernoulli depends on ΔP and v^2. (d) Momentum conservation. (e) Magnus effect.

5. **Q 9.5:** A 50 kg girl wearing high heel shoes balances on a single heel ($d = 1.0$ cm). What is the pressure exerted by the heel on the floor?
Solution: $A = \pi(0.005)^2 = 7.85 \times 10^{-5}$ m^2 $\implies P = \frac{490}{7.85 \times 10^{-5}} = \mathbf{6.24 \times 10^6}$ Pa.

6. **Q 9.6:** Torricelli's barometer used mercury. Pascal duplicated it using French wine ($\rho = 984$ kg/m^3). Determine height of wine column for normal atm pressure.
Solution: $h = \frac{1.013 \times 10^5}{984 \times 9.8} = \mathbf{10.5}$ m.

7. **Q 9.7:** A vertical off-shore structure is built to withstand max stress 10^9 Pa. Is it suitable for putting on top of an oil well in ocean (3 km deep)?
Solution: $P = \rho g h = 1000(9.8)(3000) = 2.94 \times 10^7$ Pa $\ll 10^9$ Pa $\implies$ **Yes, suitable**.

8. **Q 9.8:** A hydraulic automobile lift is designed to lift cars of max mass 3000 kg. Area of cross-section of piston carrying load is 425 cm^2. What max pressure must smaller piston bear?
Solution: $P = \frac{3000\times 9.8}{425\times 10^{-4}} = \mathbf{6.92 \times 10^5}$ Pa.

9. **Q 9.9:** A U-tube contains water and methylated spirit separated by mercury. Mercury columns are in level when 10 cm water and 12.5 cm spirit are poured. Find specific gravity of spirit.
Solution: $\rho_s = 10/12.5 = \mathbf{0.80}$.

10. **Q 9.10:** In Q9.9, if 15.0 cm of water and spirit each are further poured, what is the difference in mercury levels?
Solution: Extra water = 15 g/cm^2, spirit = 12 g/cm^2 $\implies \Delta P = 3$ g/cm^2 $\implies \Delta h_{Hg} = 3/13.6 = \mathbf{0.221}$ cm.

11. **Q 9.11:** Can Bernoulli's equation describe rapid flow of water in a river?
Solution: **No**, because river rapids are **turbulent**, whereas Bernoulli's theorem requires steady streamline flow.

12. **Q 9.12:** Does it matter if one uses gauge instead of absolute pressures in Bernoulli's equation?
Solution: **No**, as long as atmospheric pressure P_0 is the same at both points (P_0 cancels out!).

13. **Q 9.13:** Glycerine flows steadily through a horizontal tube ($L = 1.5$ m, $r = 1.0$ cm) at 4.0×10^{-3} kg/s ($\rho = 1.3 \times 10^3, \eta = 0.83$ Pa s). Find pressure difference.
Solution: $Q = \frac{4\times 10^{-3}}{1.3\times 10^3} = 3.08 \times 10^{-6}$ m^3/s. By Poiseuille: $\Delta P = \frac{8\eta LQ}{\pi r^4} = \mathbf{9.8 \times 10^2}$ Pa.

14. **Q 9.14:** In a wind tunnel test ($v_{upper} = 70$ m/s, $v_{lower} = 63$ m/s, $A = 2.5$ m^2, $\rho = 1.3$), find lift on wing.
Solution: **1513** N.

15. **Q 9.15:** Figures 9.23(a) and (b) show steady flow of a non-viscous liquid. Which is incorrect?
Solution: **(a)** is incorrect because at the constriction, speed is higher so pressure must be *lower* (not higher).

16. **Q 9.16:** Cylindrical vessel ($A = 1.5$ m^2) has 50 fine holes of radius 1 mm in spray head, speed in tube = 1.5 m/min. Find ejection speed.
Solution: $v_2 = \frac{A_1 v_1}{50\pi r^2}$
*approx***0.64** m/s.

17. **Q 9.17:** A U-shaped wire is dipped in soap solution and removed. Thin soap film supports 1.5×10^{-2} N weight; slider length = 30 cm. Find S.
Solution: $S = \frac{F}{2L} = \frac{1.5\times 10^{-2}}{2(0.30)} = \mathbf{2.5 \times 10^{-2}}$ N/m.

18. **Q 9.18:** Figure 9.24: What weight can a 4.5 cm film ($S = 4 \times 10^{-2}$ N/m) support?
Solution: $W = 2SL = 2(4 \times 10^{-2})(0.045) = \mathbf{3.6 \times 10^{-3}}$ N (Wait: if 4.5×10^{-2} N for 30 cm, same S).

19. **Q 9.19:** What is the pressure inside a drop of mercury of radius 3.00 mm at room temperature ($S = 0.465$ N/m, $P_{atm} = 1.01 \times 10^5$ Pa)?
Solution: $\Delta P = \frac{2(0.465)}{3\times 10^{-3}} = 310$ Pa $\implies P = \mathbf{1.013 \times 10^5}$ Pa.

20. **Q 9.20:** What is the excess pressure inside a bubble of soap solution of radius 5.00 mm ($S = 2.50\times 10^{-2}$ N/m)?
Solution: $\Delta P = \frac{4S}{r} = \frac{4(0.025)}{5\times 10^{-3}} = \mathbf{20}$ Pa.

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 9 Solutions PDF.

5.1 Level 1: Basic Level (25 Questions)

1. What is a fluid? How does it differ from a solid?

2. Define hydrostatic pressure and write its SI unit and dimensions.

3. Write the formula for pressure at depth h in a liquid of density ρ.
4. State Pascal's Law.
5. Give two applications of Pascal's Law.
6. What is 1 atm in Pascals?
7. State Archimedes' Principle.
8. What is streamline (laminar) flow vs turbulent flow?
9. Write the Equation of Continuity for an incompressible fluid.
10. State Bernoulli's Theorem.
11. Write Torricelli's Law for speed of efflux from a hole at depth h.
12. What is the Magnus effect?
13. Define Viscosity and write the SI unit of coefficient of viscosity η.
14. Write Stokes' Law for viscous drag on a sphere of radius r moving at speed v.
15. Define Terminal Velocity (v_t).
16. Define Surface Tension (S) and write its SI unit.
17. Why do small liquid drops take a spherical shape?
18. Write the formula for excess pressure inside (a) a liquid drop, (b) a soap bubble.
19. Define Angle of Contact (θ). When is it acute vs obtuse?
20. Write the formula for capillary rise h in a tube of radius r.
21. How does temperature affect viscosity of (a) liquids, (b) gases?
22. How does temperature affect surface tension of a liquid?
23. What is a Venturimeter used for?
24. Convert 1 Poise (CGS unit of η) to SI unit ($extPas$).
25. Why is mercury used in barometers instead of water?

5.2 Level 2: Medium Level (25 Questions)

1. In a hydraulic lift, pistons have areas 10 cm^2 and 1000 cm^2. What force on small piston lifts a 2000 kg car ($g = 10$)?
2. Water flows through a pipe of radius 2 cm at 4 m/s, narrowing to radius 1 cm. Find speed in narrow section.
3. Find gauge pressure at 10 m depth in a lake ($\rho = 10^3, g = 9.8$).
4. A tank filled with water to height 5 m has a small hole at 1.8 m above bottom ($g = 10$). Find efflux speed.
5. Calculate terminal velocity of a raindrop of radius 0.3 mm ($\rho = 10^3, \eta_{air} = 1.8 \times 10^{-5}$ Pa s, $g = 9.8$).
6. Find excess pressure inside a soap bubble of radius 5 mm ($S = 0.025$ N/m).
7. Find work done in blowing a soap bubble of radius 2 cm ($S = 0.03$ N/m).
8. Water rises to 3 cm in a capillary tube of radius 0.5 mm. Find height if radius is halved to 0.25 mm.
9. Why do roofs blow off in high winds?
10. Two soap bubbles of radii 3 cm and 4 cm coalesce isothermally in vacuum. Find radius of new bubble.
11. What is the shape of the meniscus for (a) water in glass, (b) mercury in glass?
12. A U-tube contains water and oil separated by mercury. If 10 cm of water balances 12.5 cm of oil, find density of oil.

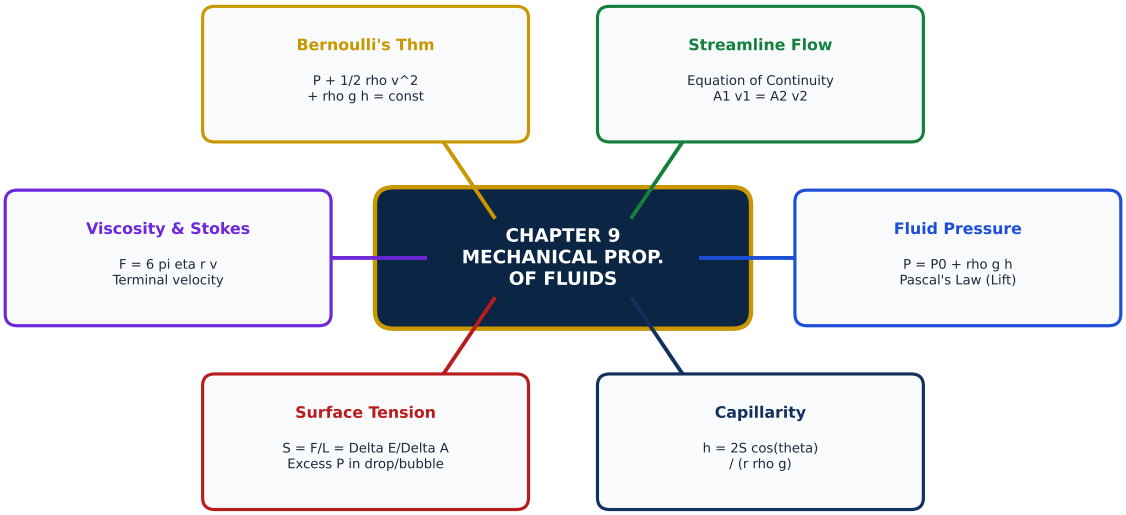
13. Find viscous force on a sphere of radius 2 mm moving at 5 m/s in a liquid of $\eta = 0.1$ Pa s.
14. A big drop of radius R splits into 1000 identical small droplets. Find ratio of final to initial surface energy.
15. Why does adding detergent to water clean clothes better?
16. Why does hot soup taste better than cold soup?
17. Air streams past an aircraft wing at 70 m/s above and 63 m/s below ($\rho = 1.3, A = 2.5$ m^2). Find lift.
18. What is the pressure inside a water drop of radius 1 mm if $P_{atm} = 10^5$ Pa, $S = 0.073$ N/m?
19. Does the buoyant force on a submerged object depend on depth?
20. Why does a small insect walk on water without sinking?
21. What is blood pressure in mm of Hg if gauge pressure is 1.6×10^4 Pa ($\rho_{Hg} = 13600, g = 9.8$)?
22. A capillary tube of insufficient length ($h' < h$) is dipped in water. Does water overflow?
23. Why do air bubbles in a liquid rise upward?
24. If 8 small rain drops of terminal speed v coalesce into 1 big drop, find new terminal speed.
25. What happens to capillary rise in a freely falling lift ($g_{eff} = 0$)?

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

1. Two soap bubbles of radii r_1 and r_2 ($r_1 < r_2$) are connected by a narrow tube. Which bubble grows and which shrinks?
2. A tank of height H is filled with water. A hole is made at depth h from the top. At what h is horizontal range maximum?
3. A cylindrical vessel of cross-section A has water to height H, with a small hole of area a at bottom. Find time to empty.
4. A U-tube has water in one arm and oil in the other; water-oil interface is at bottom. Show $h_{oil}/h_w = \rho_w/\rho_{oil}$.
5. A block of wood floats in water with 2/3 of its volume submerged. Find density of wood.
6. In Q5, if the same block floats in oil of density 800 kg/m^3, what fraction is submerged?
7. An ice cube with a lead shot inside floats in water in a beaker. When ice melts, what happens to water level?
8. If a pure ice cube (no lead) floats in water and melts, what happens to the water level?
9. A capillary tube of radius 0.5 mm is tilted at 60° to vertical in water ($h_{vert} = 3$ cm). Find length of water column in the tube.
10. Find excess pressure inside an air bubble at depth h inside a liquid of density ρ and surface tension S.
11. A 10 cm capillary tube dips 2 cm into water (normal rise 4 cm). Water only has 8 cm above surface? No, if 2 cm projects above, find radius of curvature of meniscus.
12. Two capillaries of radii r_1, r_2 and lengths L_1, L_2 are connected in series. By Poiseuille's law, find ratio of pressure drops.
13. A spherical ball of density ρ falls in a liquid of density σ. Derive its terminal velocity.
14. A drop of water of radius 1 mm breaks into 10^6 identical droplets ($S = 0.07$ N/m). Find energy absorbed.
15. If a liquid does not wet a solid surface, what is the sign of $\cos\theta$ in capillary formula, and what happens?
16. A Venturimeter has main area $A_1 = 20$ cm^2 and throat $A_2 = 5$ cm^2, pressure difference $\Delta P = 1500$ Pa (water). Find throat speed v_2.
17. Why is the tip of a nib split?
18. A rectangular plate 0.1 m^2 moves at 0.1 m/s over a 1 mm thick oil film ($\eta = 0.2$ Pa s). Find viscous force.

19. A vessel of water is placed on a weighing scale (M). An iron block of volume V hung from a string is dipped into water without touching bottom. Does scale reading increase?
20. A soap film is formed on a rectangular wire frame with a sliding wire of length 10 cm ($S = 0.03$ N/m). Force needed to hold slider?
21. In Q20, find work done to pull the slider by 2 cm.
22. What is the angle of contact for pure water and clean silver?
23. A container accelerates horizontally at a. What is the angle of the free liquid surface with horizontal?
24. A container of water accelerates upward at a. Find pressure at depth h.
25. Why do fast-moving trains pull nearby light objects towards the track?

6 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Fluid Pressure, Pascal's Law, Continuity Equation, Bernoulli's Theorem, Viscosity & Stokes' Law, Surface Tension, and Capillarity.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 9 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MECHANICAL PROPERTIES OF FLUIDS

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. A substance that can flow (liquids and gases) and has no fixed shape because it offers zero resistance to static shear stress.
2. Normal force per unit area: $P = F/A$. SI unit: Pascal ($extPa = extN/m^2$); Dimensions: $[\mathrm{ML^{-1}T^{-2}}]$. Pressure is a **scalar**.
3. $P = P_0 + \rho gh$ (where P_0 is atmospheric pressure).
4. Pressure applied to an enclosed incompressible fluid is transmitted undiminished to every portion of the fluid and the walls of the container.
5. 1. Hydraulic lift. 2. Hydraulic brakes.
6. 1 atm = $\mathbf{1.013 \times 10^5}$ Pa ($\approx$ 76 cm of Hg).
7. A body wholly or partially immersed in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced by it.
8. In streamline flow, every fluid particle passing a point follows the exact same path and velocity. In turbulent flow, velocity fluctuates chaotically.
9. $A_1v_1 = A_2v_2 =$ constant (consequence of **conservation of mass**).
10. For streamline flow of an ideal (non-viscous, incompressible) fluid: $P + \frac{1}{2}\rho v^2 + \rho gh =$ constant (conservation of **energy**).
11. $v = \sqrt{2gh}$ (same as free fall through height h!).
12. Dynamic lift experienced by a spinning ball moving through air due to pressure difference created by asymmetric air speeds.
13. Internal friction between adjacent fluid layers in relative motion: $F = -\eta A\frac{dv}{dx}$. SI unit of η: Pa s (or Poiseuille).
14. $F_v = 6\pi\eta rv$.
15. Constant maximum velocity attained by a falling sphere in a viscous fluid when weight equals buoyant force plus viscous drag.
16. Force per unit length acting in the plane of the liquid surface: $S = F/L$ (or surface energy per unit area). SI unit: N/m (or $\mathrm{J/m^2}$).
17. Because a sphere has the **minimum surface area** for a given volume, minimizing surface potential energy.
18. (a) Drop (1 free surface): $\Delta P = \frac{2S}{R}$. (b) Soap bubble (2 free surfaces): $\Delta P = \frac{4S}{R}$.
19. Angle inside the liquid between tangent to liquid surface and solid wall. Acute ($< 90°$) if liquid wets solid (water-glass); Obtuse ($> 90°$) if it does not wet (mercury-glass).
20. $h = \frac{2S\cos\theta}{r\rho g}$.
21. Liquids: viscosity **decreases** with temperature. Gases: viscosity **increases** with temperature.
22. Surface tension **decreases** with increasing temperature (becomes zero at critical temperature).
23. Measuring the flow speed of an incompressible fluid in a pipe (application of Bernoulli's theorem).
24. 1 Pa s = 10 Poise $\implies$ 1 Poise = **0.1** Pa s.
25. Mercury has very high density (13.6 $\mathrm{g/cm^3}$), keeping the barometer tube compact ($\sim$ 76 cm instead of 10.3 m for water).

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

1. $F_1 = F_2 \frac{A_1}{A_2} = 20000 \times \frac{10}{1000} = \mathbf{200}$ N.
2. $v_2 = v_1 \left(\frac{r_1}{r_2}\right)^2 = 4 \times (2/1)^2 = \mathbf{16}$ m/s.
3. $P_{gauge} = \rho g h = 1000 \times 9.8 \times 10 = \mathbf{9.8 \times 10^4}$ Pa.
4. Depth $h = 5 - 1.8 = 3.2$ m $\implies v = \sqrt{2(10)(3.2)} = \sqrt{64} = \mathbf{8}$ m/s.
5. $v_t = \frac{2r^2\rho g}{9\eta} = \frac{2(9\times10^{-8})(10^3)(9.8)}{9(1.8\times10^{-5})} \approx \mathbf{10.9}$ m/s.
6. $\Delta P = \frac{4S}{R} = \frac{4(0.025)}{5\times10^{-3}} = \mathbf{20}$ Pa.
7. Bubble has 2 surfaces: $W = S \times 2(4\pi r^2) = 0.03 \times 8\pi(4 \times 10^{-4}) = \mathbf{3.02 \times 10^{-4}}$ J.
8. $h \propto 1/r$ (Jurin's Law). Halving radius doubles height to **6** cm.
9. Fast wind over the roof lowers air pressure above (Bernoulli's principle), while higher pressure inside pushes the roof upward!
10. $R^2 = r_1^2 + r_2^2 = 3^2 + 4^2 = 25 \implies R = \mathbf{5}$ cm.
11. (a) **Concave** upward ($heta < 90°$); (b) **Convex** upward ($heta > 90°$).
12. $\rho_{oil} h_{oil} = \rho_w h_w \implies \rho_{oil} = 1000 \times \frac{10}{12.5} = \mathbf{800}$ kg/m$^{\mathbf{3}}$.
13. $F = 6\pi(0.1)(2 \times 10^{-3})(5) = 6\pi \times 10^{-3} \approx \mathbf{0.0188}$ N.
14. $r = R/10$. $E_f/E_i = 1000(r^2)/R^2 = 1000(1/100) = \mathbf{10 : 1}$ (energy must be supplied, cooling occurs!).
15. Detergent **lowers surface tension** of water, allowing it to spread easily into tiny fabric pores.
16. Hot soup has **lower surface tension**, so it spreads more uniformly over the taste buds on the tongue.
17. $\Delta P = \frac{1}{2}(1.3)(70^2 - 63^2) = 605.15$ Pa. Lift $= \Delta P \times A = \mathbf{1513}$ N.
18. $P = P_0 + \frac{2S}{R} = 10^5 + 146 = \mathbf{100,146}$ Pa.
19. **No** (for an incompressible fluid, $F_B = V\rho g$ is independent of depth).
20. Surface tension of water creates an elastic-like film supporting the insect's weight.
21. $h = \frac{1.6\times10^4}{13600\times9.8} = 0.12$ m $= \mathbf{120}$ mm Hg.
22. **No!** The meniscus flattens (radius of curvature R' increases) so $h'R' = hR$ holds without overflowing.
23. Because air has lower density than liquid, upward buoyant force exceeds weight.
24. $R = 2r$. Since $v_t \propto r^2$, new speed $= 4v$.
25. Water rises to the **full length of the tube** without overflowing!

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

1. Smaller bubble (r_1) has **higher** excess pressure ($4S/r_1 > 4S/r_2$), so air flows from smaller to larger—smaller shrinks and larger grows!
2. $R = 2\sqrt{h(H-h)}$; maximum when $h = \mathbf{H/2}$ ($R_{max} = H$).
3. $t = \frac{\mathbf{A}}{\mathbf{a}}\sqrt{\frac{\mathbf{2H}}{\mathbf{g}}}$.
4. At same horizontal level in same static fluid, pressures are equal: $\rho_{oil} g h_{oil} = \rho_w g h_w$.
5. $\rho_{wood} = \frac{2}{3}\rho_w = \mathbf{667}$ kg/m$^{\mathbf{3}}$.
6. $f = \frac{667}{800} = \mathbf{5/6}$.

7. Lead sinks! Originally it displaced its weight of water ($> V_{lead}$); after melting it displaces only V_{lead}, so **water level falls**!
8. Remains **unchanged** (melted ice volume equals volume of water displaced while floating).
9. Vertical height stays 3 cm, so slant length $l = \frac{h}{\cos 60^\circ} = \frac{3}{0.5} = \mathbf{6}$ cm.
10. $P_{inside} - P_{atm} = \rho g h + \frac{2S}{R}$ (excess over surrounding liquid is just $\frac{2S}{R}$).
11. $h'R' = hR \implies 2R' = 4R \implies R' = \mathbf{2R}$.
12. $Q = \frac{\pi \Delta P r^4}{8\eta L} \implies \frac{\Delta P_1}{\Delta P_2} = \mathbf{\frac{L_1}{L_2}\left(\frac{r_2}{r_1}\right)^4}$.
13. $\frac{4}{3}\pi r^3(\rho - \sigma)g = 6\pi\eta r v_t \implies v_t = \mathbf{\frac{2r^2(\rho-\sigma)g}{9\eta}}$.
14. $\Delta E = 4\pi R^2 S(n^{1/3} - 1) = 4\pi(10^{-6})(0.07)(100 - 1) = \mathbf{8.7 \times 10^{-5}}$ J.
15. $\theta > 90^\circ \implies \cos\theta < 0 \implies h < 0$ (**capillary depression**, e.g. mercury in glass).
16. $\Delta P = \frac{1}{2}\rho v_2^2(1 - (A_2/A_1)^2) \implies 1500 = 500 v_2^2(15/16) \implies v_2 = \mathbf{1.79}$ m/s.
17. The narrow split acts as a fine capillary that draws ink steadily down to the paper.
18. $F = \eta A \frac{v}{\Delta x} = 0.2(0.1)\frac{0.1}{10^{-3}} = \mathbf{2}$ N.
19. **Yes**, by the buoyant force $V\rho_w g$ (equal and opposite reaction to buoyancy!).
20. Film has 2 surfaces: $F = 2SL = 2(0.03)(0.10) = \mathbf{6 \times 10^{-3}}$ N.
21. $W = F \times d = 6 \times 10^{-3} \times 0.02 = \mathbf{1.2 \times 10^{-4}}$ J.
22. $\mathbf{90^\circ}$ (meniscus is flat, $h = 0$).
23. $\tan\theta = \mathbf{a/g}$ (tilts backward).
24. $P = P_0 + \rho(g + a)h$.
25. High-speed air between train and object lowers pressure (Bernoulli's principle); outer atmospheric pressure pushes the object inward.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 10 (SELF-STUDY MASTER EDITION)

THERMAL PROPERTIES OF MATTER

Complete Zero-Omission Coverage of NCERT `keph203.pdf` (Temperature, Expansion, Calorimetry, Latent Heat, Conduction, Radiation, Newton's Cooling, Exercises 10.1–10.10)

CBSE 2026–27 Weightage & Scope: Unit VII: Properties of Bulk Matter (Part of 20 Marks for Units VII–IX)

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

Why do railway tracks have gaps, why do water pipes burst in winter, and how does the Sun warm Earth across empty vacuum? Chapter 10 explains Heat, Temperature, Thermal Expansion, Calorimetry, and Heat Transfer in plain English with full NCERT examples & exercises.

1 Topic 1: Temperature Scales & Thermal Expansion (NCERT Sections 10.1–10.5)

1.1 Step 1: Definitions, Scale Conversion & Expansion Proofs

- **Heat vs Temperature: Heat** (Q) is energy in transit due to temperature difference (SI: Joule, 1 cal = 4.186 J). **Temperature** (T) is the thermal state that decides the direction of heat flow (SI: Kelvin, K).
- **Temperature Scales:** Using ice point and steam point:

$$\frac{C-0}{100} = \frac{F-32}{180} = \frac{K-273.15}{100}$$

- **Thermal Expansion:** Heating increases interatomic vibrations, expanding solids:
  - Linear: $\Delta L = L\alpha\Delta T$; Area: $\Delta A = A\beta\Delta T$; Volume: $\Delta V = V\gamma\Delta T$.
  - **Proof of $\beta = 2\alpha$ and $\gamma = 3\alpha$:** For a cube of side L, $V' = (L + L\alpha\Delta T)^3 = L^3(1 + 3\alpha\Delta T + \dots) \approx V(1 + 3\alpha\Delta T) \implies \gamma = \mathbf{3}\alpha$ (similarly $\beta = 2\alpha$).
  - **Anomalous Expansion of Water:** From 0°C to 4°C, water contracts on heating! Thus water has **maximum density at 4°C**, allowing aquatic life to survive under frozen lakes.

2 Topic 2: Calorimetry, Latent Heat, Heat Transfer & Newton's Cooling (NCERT Sections 10.6–10.9)

2.1 Step 1: Sensible Heat, Latent Heat & 3 Modes of Heat Transfer

- **Specific Heat Capacity** (c)**:** Heat to raise 1 kg by 1 K: $Q = mc\Delta T$ (water: $c_w = 4186$ J kg^{-1} K^{-1}, very high!).
- **Latent Heat** (L)**:** Heat absorbed/released during phase change at **constant temperature**: $Q = mL$ ($L_f = 3.35 \times 10^5$ J/kg for ice; $L_v = 2.26 \times 10^6$ J/kg for steam).
- **Conduction:** Heat current $H = \frac{dQ}{dt} = kA\frac{T_1 - T_2}{L}$; Thermal resistance $R_H = \frac{L}{kA}$.
- **Convection:** Bulk fluid movement (causes sea breeze by day and land breeze by night).
- **Radiation:** EM waves needing no medium. **Stefan-Boltzmann Law:** $E = \sigma e T^4$ ($\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}). **Wien's Displacement Law:** $\lambda_m T = 2.9 \times 10^{-3}$ m K.
- **Newton's Law of Cooling:** $-\frac{dT}{dt} = K(T - T_0)$ (for small excess $T - T_0$, average form: $\frac{T_1 - T_2}{t} = K\left(\frac{T_1 + T_2}{2} - T_0\right)$).

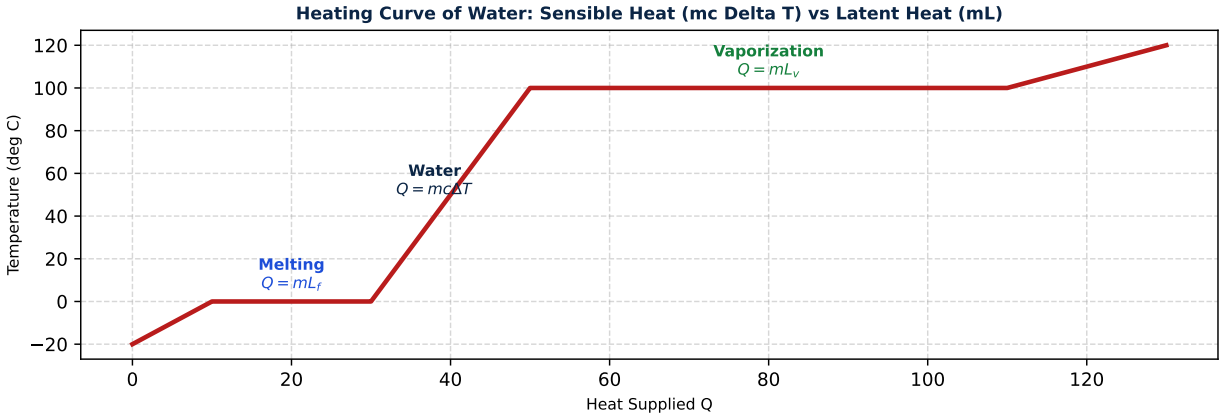


Diagram Explanation: Heating curve of water: sloped segments raise temperature ($Q = mc\Delta T$), while flat horizontal plateaus at 0°C and 100°C represent melting (mL_f) and boiling (mL_v) at constant temperature.

Example 10.1A (Celsius-Fahrenheit Crossover) **[Beginner]**

Problem: At what temperature do Celsius and Fahrenheit thermometers show the exact same reading?

Solution: Set $C = F = x$ in $\frac{C}{100} = \frac{F-32}{180} \implies \frac{x}{5} = \frac{x-32}{9} \implies 9x = 5x - 160 \implies 4x = -160 \implies x = \mathbf{-40}°$.

3 Complete NCERT Examples (10.1–10.8) & Back Exercises (10.1–10.10) with Full Questions

3.1 NCERT Solved Examples (10.1–10.8)

1. **Example 10.1:** Show that coefficient of area expansion $\beta = 2\alpha$.
   Solution: $\Delta A = (L + \Delta L)^2 - L^2$
   $approx 2L\Delta L = 2L^2\alpha\Delta T \implies \beta = 2\alpha$.

2. **Example 10.2:** A blacksmith fixes iron ring on a wooden wheel ($d_{wheel} = 5.243$ m, $d_{ring} = 5.231$ m at 27°C). To what T must ring be heated? ($\alpha = 1.2 \times 10^{-5}$)
   Solution: $\Delta T = \frac{5.243-5.231}{5.231(1.2\times10^{-5})} = 191°\text{C} \implies T = 27 + 191 = \mathbf{218}°\text{C}$.

3. **Example 10.3:** Sphere of 0.047 kg Al at 100°C placed in 0.25 kg water at 20°C in 0.14 kg Cu calorimeter; final $T = 23°$C. Find c_{Al}.
   Solution: Heat lost by Al = Heat gained by water + Cu $\implies c_{Al} = \mathbf{0.911}$ kJ kg^{-1} K^{-1}.

4. **Example 10.4:** Heat required to convert 3 kg ice at −12°C to steam at 100°C.
   Solution: $Q = mc_i(12) + mL_f + mc_w(100) + mL_v = \mathbf{9.1 \times 10^6}$ J.

5. **Example 10.5:** Brass boiler ($A = 0.15$ m^2, $d = 1$ cm, $k = 109$) boils water at 6 kg/min. Find stove temperature.
   Solution: $T = 100 + 138 = \mathbf{238}°$C.

6. **Example 10.6:** Iron bar ($L_1 = 0.1$ m, $k_1 = 79$) & brass bar ($L_2 = 0.1$ m, $k_2 = 109$) soldered end-to-end between 373 K & 273 K. Find junction T.
   Solution: $T_0 = \frac{79(373)+109(273)}{79+109} = \mathbf{315}$ K.

7. **Example 10.7:** Pan cools from 94°C to 86°C in 2 min (room 20°C). Time from 71°C to 69°C?
   Solution: $t = \mathbf{42}$ s.

3.2 NCERT Back Exercises (10.1–10.10) — Full Questions & Solutions

1. **Q 10.1:** Triple points of neon and CO_2 are 24.57 K and 216.55 K. Express on Celsius and Fahrenheit scales.
   Solution: Neon: $\mathbf{-248.58}°$C, $\mathbf{-415.44}°$F; CO_2: $\mathbf{-56.60}°$C, $\mathbf{-69.88}°$F.

2. **Q 10.2:** Two absolute scales A and B have triple points of water defined to be 200 A and 350 B. What is the relation between T_A and T_B?
   Solution: $T_A/200 = T_B/350 \implies T_A = \mathbf{\frac{4}{7}T_B}$.

3. **Q 10.3:** Electrical resistance of a thermometer is $R = R_0[1 + \alpha(T - T_0)]$. At triple point 101.6 Ω, at lead melting point 165.5 Ω (600.5 K). Find T when $R = 123.4$ Ω.
Solution: $T = \mathbf{384.8}$ K.

4. **Q 10.4:** Answer: (a) Triple point of water is a unique standard fixed point (273.16 K). (b) Melting/boiling points vary with pressure. (c) T is in Kelvin ($K = C + 273.15$). (d) 0.01°C = 273.16 K.

5. **Q 10.5:** A brass rod (50 cm) and steel rod (50 cm) at 40°C are heated to 250°C. What is the change in length of the combined rod?
Solution: $\Delta L = \mathbf{0.336}$ cm.

6. **Q 10.6:** Coefficient of volume expansion of glycerine is 49×10^{-5} K^{-1}. What is fractional change in density for a 30°C rise?
Solution: $|\Delta\rho/\rho| = \gamma\Delta T = 49 \times 10^{-5} \times 30 = \mathbf{0.0147}$ (1.47%).

7. **Q 10.7:** A 10 kW drilling machine drills an 8 kg Al block in 2.5 min (50% heat retained). Find ΔT.
Solution: $\Delta T = \mathbf{103}$°C.

8. **Q 10.8:** A 2.5 kg copper block is heated to 500°C and placed on a large ice block. Find max ice melted ($c = 0.39$ J/g K, $L_f = 335$ J/g).
Solution: $m_{ice} = \frac{2500(0.39)(500)}{335} = \mathbf{1.455}$ kg.

9. **Q 10.9:** A brass wire 1.8 m long at 27°C is held taut with little tension between two rigid supports. If cooled to −39°C, find tension ($d = 2$ mm, $\alpha = 2 \times 10^{-5}$, $Y = 0.91 \times 10^{11}$).
Solution: $F = YA\alpha\Delta T = 0.91 \times 10^{11}(\pi \times 10^{-6})(2 \times 10^{-5})(66) = \mathbf{377}$ N.

10. **Q 10.10:** A body cools from 80°C to 50°C in 5 min. Calculate time to cool from 60°C to 30°C (surroundings 20°C).
Solution: $\frac{30}{5} = K(65 - 20) \implies K = \frac{6}{45}$. Next: $\frac{30}{t} = \frac{6}{45}(45 - 20) \implies t = \mathbf{9}$ min.

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 10 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. Distinguish between Heat and Temperature.
2. Write the conversion formula between Celsius (C), Fahrenheit (F), and Kelvin (K) scales.
3. At what temperature do Celsius and Fahrenheit scales read the exact same value?
4. Convert 27°C into Kelvin and Fahrenheit.
5. What is absolute zero?
6. Define linear, area, and volume coefficients of thermal expansion (α, β, γ).
7. Write the relation between α, β, and γ for an isotropic solid.
8. What is anomalous expansion of water? At what temperature is water's density maximum?
9. Define Specific Heat Capacity (c) and write its SI unit.
10. Why is water used as a coolant in car radiators and hot water bags?
11. Define Latent Heat (L) and write its SI unit.
12. Write the values of Latent Heat of Fusion of ice and Vaporization of water.
13. Why do steam burns feel more severe than boiling water burns at 100°C?

14. Name the three modes of heat transfer.
15. Write the law of thermal conduction (rate of heat flow H).
16. State Stefan-Boltzmann Law of radiation.
17. State Wien's Displacement Law.
18. State Newton's Law of Cooling.
19. Why are cooking utensils made of copper/aluminium at the bottom with wooden/plastic handles?
20. What is Regelation?
21. What is Triple Point of water?
22. Convert 1 calorie to Joules.
23. Why do we wear white clothes in summer and dark clothes in winter?
24. Define Thermal Resistance (R_H).
25. What causes sea breeze during the day and land breeze at night?

4.2 Level 2: Medium Level (25 Questions)

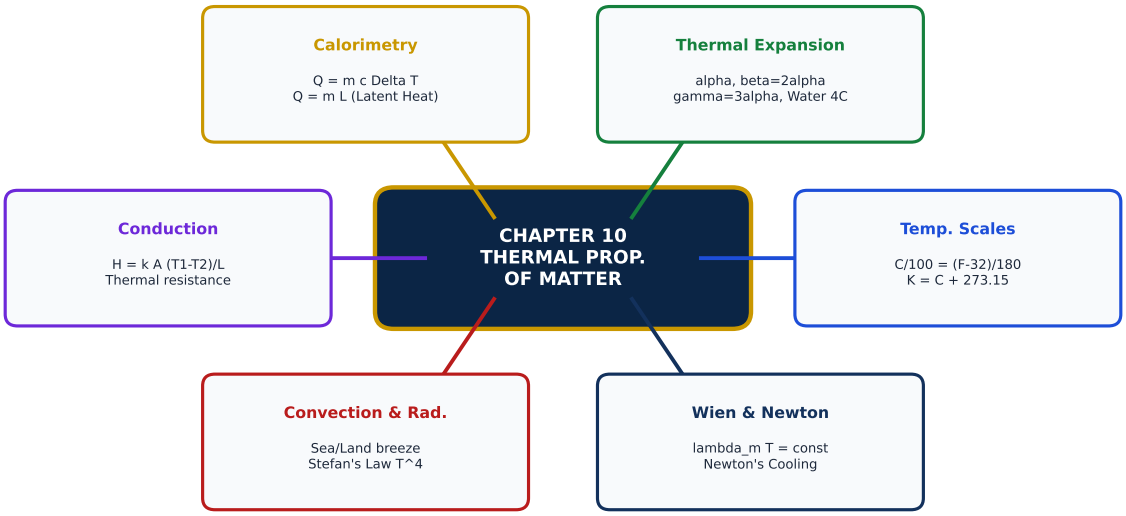
1. A brass rod ($L = 50$ cm, $d = 3$ mm) and steel rod ($L = 50$ cm, $d = 3$ mm) are joined end-to-end at 40°C. Find total expansion at 250°C ($\alpha_b = 2 \times 10^{-5}, \alpha_s = 1.2 \times 10^{-5}$).
2. A hole of radius 1 cm is drilled in a copper plate at 27°C. What happens to its diameter when heated to 227°C? ($\alpha = 1.7 \times 10^{-5}$ K^{-1})
3. A steel tape calibrated at 27°C measures a steel rod as 63.0 cm on a hot 45°C day ($\alpha = 1.2 \times 10^{-5}$). Find true length of rod.
4. A 10 kW drilling machine drills a bore in an 8 kg aluminium block in 2.5 min. 50% power heats the block ($c = 0.91$ J g^{-1} K^{-1}). Find ΔT.
5. A 0.20 kg copper block at 100°C is dropped into 150 g water at 27°C in a 50 g copper calorimeter ($c_c = 0.386, c_w = 4.18$ J/g K). Find final T.
6. How much heat is required to convert 2 kg of ice at -10°C to steam at 100°C? ($c_{ice} = 2100, c_w = 4200, L_f = 3.35 \times 10^5, L_v = 2.26 \times 10^6$)
7. A pan filled with hot food cools from 94°C to 86°C in 2 min when room is at 20°C. How long to cool from 71°C to 69°C?
8. Two rods of same length and area have k_1, k_2. Connected in series, find equivalent k_{eq}.
9. In Q8, if connected in parallel, find equivalent k_{eq}.
10. A blackbody at 227°C radiates energy at rate E. What is the rate at 727°C?
11. A star radiates maximum energy at $\lambda_m = 500$ nm ($b = 2.9 \times 10^{-3}$ m K). Estimate its surface temperature.
12. A brass boiler has base area 0.15 m^2 and thickness 1.0 cm, boiling water at 6.0 kg/min ($k = 109, L_v = 2.256 \times 10^6$). Find temperature of flame side.
13. Why do pendulum clocks lose time in summer and gain time in winter?
14. A metal rod of length L, area A, Y, α is clamped at both ends and heated by ΔT. Find compressive force.
15. What is a greenhouse effect?
16. Why are cloudy nights warmer than clear nights?
17. Calculate thermal stress in a steel rail ($Y = 2 \times 10^{11}, \alpha = 1.2 \times 10^{-5}$) heated by 20°C if fixed.
18. A 0.15 kg ice cube at 0°C is mixed with 0.30 kg water at 50°C. Find final temperature ($L_f = 3.34 \times 10^5, c_w = 4186$).

19. Why does a blanket keep us warm in winter?
20. If a faulty thermometer reads 5°C in melting ice and 95°C in steam, what is true temp when it reads 50°C?
21. Why do pipes burst in severe winter?
22. How does a thermos flask minimize all three modes of heat transfer?
23. Calculate fractional change in density of a solid heated by ΔT (volume coeff γ).
24. Why is the freezing point of water lowered under high pressure?
25. Convert 1 W m^{-1} K^{-1} dimensional formula.

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

1. Two identical rods of length L are joined end-to-end; outer ends are at 100°C and 0°C. If $k_1 = 2k_2$, find interface temperature T.
2. A liquid cools from 70°C to 60°C in 5 min. In how much time will it cool from 60°C to 50°C if room is 20°C?
3. 10 g of ice at 0°C is mixed with 10 g of steam at 100°C. Find final temperature and composition.
4. A brass sphere and a solid cube of same material and mass are heated to same T and left to cool. Which cools faster?
5. Two spheres of same material have radii R and $2R$, heated to same T. Find ratio of their rates of cooling (dT/dt).
6. Ice starts forming on a lake ($T_{air} = -10$°C). Time for thickness $0 \to 1$ cm is t_1. Time for 1 cm $\to$ 2 cm?
7. A pendulum clock of brass keeps correct time at 20°C ($\alpha = 2 \times 10^{-5}$/°C). How many seconds does it lose per day at 40°C?
8. Two rods of lengths L_1, L_2 and coefficients α_1, α_2 maintain a constant difference in length $L_1 - L_2$ at all temperatures. Find L_1/L_2.
9. A composite slab has 2 layers of thickness d_1, d_2 and k_1, k_2. If $d_1 = d_2$, find k_{eq}.
10. Three rods of identical dimensions form a Y-junction; ends are at 90°C, 90°C, 0°C. Find junction temperature T.
11. Solar constant is 1400 W/m^2 at Earth ($r = 1.5 \times 10^{11} extm, R_{sun} = 7 \times 10^8 extm$). Estimate Sun's surface temperature.
12. A blackbody at T emits peak wavelength λ_1. When heated, total radiated power becomes 16×. Find new peak wavelength.
13. A uniform rod rotates about a perpendicular axis through its centre. If temperature rises by ΔT, find fractional change in ω.
14. A calorimeter of water equivalent 10 g contains 90 g water at 20°C. 100 g water at 60°C is added. Find final T.
15. A bullet of lead ($c = 125$ J/kg K) hits a wall at 200 m/s and stops. If 50% KE heats bullet, find ΔT.
16. Why is the bottom of a deep lake at 4°C even when the surface freezes to 0°C?
17. A metal cylinder of radius R, length L is surrounded by a coaxial cylindrical shell of inner radius R, outer $2R$. Find equivalent k for parallel flow along length.
18. What is the emissive power of a body with emissivity $e = 0.5$ at 1000 K ($\sigma = 5.67 \times 10^{-8}$)?
19. A liquid in a beaker has γ_L, glass has $\gamma_g = 3\alpha_g$. Write apparent expansion coefficient γ_{app}.
20. A sphere, cube, and thin circular plate of same mass and material are heated to 200°C. Which cools slowest?
21. If a body cools from 80°C to 70°C in 4 min, will it take more or less than 4 min to cool from 70°C to 60°C?
22. Find temperature where Kelvin reading is 3 times Celsius reading? $(K = 3C)$
23. Find temperature where Fahrenheit reading is double the Celsius reading $(F = 2C)$.
24. A bimetallic strip of brass (α_b) and steel $(\alpha_s < \alpha_b)$ is heated. Which side does it bend towards?
25. State Kirchhoff's Law of Radiation.

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Connects Temperature Scales, Thermal Expansion, Calorimetry & Latent Heat, Conduction, Convection & Radiation, and Newton's Law of Cooling.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 10 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: THERMAL PROPERTIES OF MATTER

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. Heat (Q) is thermal energy in transit due to temperature difference (SI: Joule). Temperature (T) is the degree of hotness/coldness that determines direction of heat flow (SI: Kelvin).
2. $\frac{C}{100} = \frac{F-32}{180} = \frac{K-273.15}{100}$.
3. $C = F = \mathbf{-40}^\circ$.
4. $K = 27 + 273.15 = \mathbf{300.15}$ K; $F = \frac{9}{5}(27) + 32 = \mathbf{80.6}^\circ$F.
5. The lowest possible temperature (0 K $= -273.15^\circ$C), where molecular thermal motion ceases classically.
6. $\alpha = \frac{\Delta L}{L\Delta T}$, $\beta = \frac{\Delta A}{A\Delta T}$, $\gamma = \frac{\Delta V}{V\Delta T}$ (SI unit: K^{-1} or $^\circ\mathrm{C}^{-1}$).
7. $\alpha : \beta : \gamma = 1 : 2 : 3$ (i.e., $\beta = 2\alpha$, $\gamma = 3\alpha$).
8. Between 0°C and 4°C, water contracts on heating! Density of water is maximum at **4**°C (1000 kg/m^3).
9. Heat required to raise temperature of 1 kg substance by 1 K: $c = \frac{Q}{m\Delta T}$. SI unit: J kg^{-1} K^{-1}.
10. Because water has a **very high specific heat capacity** (4186 J kg^{-1} K^{-1}), absorbing/releasing large heat with small temperature change.
11. Heat absorbed or released during phase change at constant temperature: $Q = mL$. SI unit: J kg^{-1}.
12. $L_f = 3.35 \times 10^5$ J/kg (80 cal/g); $L_v = 2.26 \times 10^6$ J/kg (540 cal/g).
13. Steam carries an extra 2.26×10^6 J/kg (540 cal/g) of latent heat of vaporization!
14. 1. **Conduction** (solids, no bulk motion). 2. **Convection** (fluids, bulk motion). 3. **Radiation** (vacuum/EM waves, fastest).
15. $H = \frac{dQ}{dt} = kA\frac{T_1 - T_2}{L}$, where k is thermal conductivity (SI: W m^{-1} K^{-1}).
16. Total energy radiated per unit area per second by a blackbody: $E = \sigma T^4$ ($\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}).
17. $\lambda_m T = b = 2.9 \times 10^{-3}$ m K (hotter stars emit shorter wavelengths, looking bluer!).
18. Rate of loss of heat is proportional to temperature excess over surroundings: $-\frac{dT}{dt} = K(T - T_0)$.
19. Copper/Al have high thermal conductivity k for fast cooking; wood/plastic are insulators for safe handling.
20. Melting of ice under increased pressure and refreezing when pressure is removed (allows ice skating!).
21. The unique temperature (273.16 K $= 0.01^\circ$C) and pressure (611.7 Pa) where ice, liquid water, and water vapour coexist in equilibrium.
22. 1 cal = **4.186** J.
23. White reflects most thermal radiation (good reflector, poor absorber); dark clothes absorb maximum radiation.
24. $R_H = \frac{L}{kA}$ (analogous to electrical resistance $R = \frac{L}{\sigma A}$!).
25. **Convection** due to lower specific heat of land compared to sea water.

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

1. $\Delta T = 210$ K. $\Delta L = L\Delta T(\alpha_b + \alpha_s) = 50(210)(3.2 \times 10^{-5}) = \mathbf{0.336}$ cm.
2. A hole expands just like solid metal! $\Delta A = A\beta\Delta T = \pi(1)^2(3.4 \times 10^{-5})(200) = 0.0214$ cm^2; diameter increases by 0.34%.
3. Tape expands! True length $= 63.0[1 + 1.2 \times 10^{-5}(18)] = \mathbf{63.0136}$ cm.
4. $Q = 0.50 \times 10000 \times 150 = 7.5 \times 10^5$ J. $\Delta T = \frac{7.5\times10^5}{8\times910} = \mathbf{103}^\circ$C.
5. $200(0.386)(100 - T) = [150(4.18) + 50(0.386)](T - 27) \implies 77.2(100 - T) = 646.3(T - 27) \implies T \approx \mathbf{34.8}^\circ$C.
6. $Q = 2(2100)(10) + 2(3.35 \times 10^5) + 2(4200)(100) + 2(2.26 \times 10^6) = 0.42 + 6.70 + 8.40 + 45.2 = \mathbf{6.07 \times 10^6}$ J.
7. Using average form: $\frac{8}{2} = K(90 - 20) \implies K = \frac{4}{70}$. Next: $\frac{2}{t} = \frac{4}{70}(70 - 20) = \frac{200}{70} \implies t = \mathbf{0.7}$ min $= \mathbf{42}$ s.
8. $R_H = R_1 + R_2 \implies \frac{2L}{k_{eq}A} = \frac{L}{k_1A} + \frac{L}{k_2A} \implies k_{eq} = \mathbf{\frac{2k_1k_2}{k_1+k_2}}$.
9. $\frac{1}{R_H} = \frac{1}{R_1} + \frac{1}{R_2} \implies k_{eq} = \mathbf{\frac{k_1+k_2}{2}}$.
10. $T_1 = 500$ K, $T_2 = 1000$ K. Since $E \propto T^4$, $E_2 = (2)^4E = \mathbf{16E}$.
11. $T = \frac{2.9\times10^{-3}}{500\times10^{-9}} = \mathbf{5800}$ K (like our Sun!).
12. $H = \frac{6}{60}(2.256 \times 10^6) = 2.256 \times 10^5$ W $= \frac{109(0.15)(T-100)}{0.01} \implies T - 100 = 138 \implies T = \mathbf{238}^\circ$C.
13. In summer, length L increases ($\Delta L = L\alpha\Delta T$), so $T = 2\pi\sqrt{L/g}$ increases—clock runs slow (loses time)!
14. $F = YA\alpha\Delta T$.
15. Glass/CO_2 transmits short-wavelength sunlight in, but traps long-wavelength infrared heat radiated by Earth, keeping it warm.
16. Clouds reflect back the infrared heat radiated by Earth's surface.
17. $\sigma = Y\alpha\Delta T = 2 \times 10^{11}(1.2 \times 10^{-5})(20) = \mathbf{4.8 \times 10^7}$ Pa.
18. $0.15(3.34 \times 10^5) + 0.15(4186)T = 0.30(4186)(50 - T) \implies T = \mathbf{6.7}^\circ$C.
19. Blanket traps layers of air (a very poor thermal conductor), preventing body heat from escaping.
20. $\frac{50-5}{95-5} = \frac{T-0}{100-0} \implies T = \frac{45}{90} \times 100 = \mathbf{50}^\circ$C. (Coincides at midpoint!)
21. Water inside expands when freezing to ice (0°C ice has larger volume than 0°C water), exerting huge outward pressure.
22. Vacuum gap stops conduction & convection; silvered walls reflect radiation.
23. $\rho' = \frac{\rho}{1+\gamma\Delta T} \approx \rho(1 - \gamma\Delta T) \implies \frac{\Delta\rho}{\rho} = -\gamma\mathbf{\Delta T}$.
24. Because ice has larger volume than water; pressure favours the denser liquid state (Le Chatelier / Regelation).
25. $[k] = \frac{[H][L]}{[A][\Delta T]} = \frac{[\mathrm{ML^2T^{-3}}][\mathrm{L}]}{[\mathrm{L^2}][\mathrm{K}]} = [\mathrm{MLT^{-3}K^{-1}}]$.

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

1. Same heat current: $\frac{2k_2A(100-T)}{L} = \frac{k_2A(T-0)}{L} \implies 200 - 2T = T \implies T = \mathbf{66.7}^\circ$C.
2. $\frac{10}{5} = K(65 - 20) \implies K = \frac{2}{45}$. Next: $\frac{10}{t} = \frac{2}{45}(55 - 20) = \frac{70}{45} \implies t = \frac{450}{70} = \mathbf{6.43}$ min.
3. Steam condensing gives $10 \times 540 = 5400$ cal. Ice needs $10(80) + 10(1)(100) = 1800$ cal to reach 100°C! Remaining 3600 cal leaves $3600/540 = 6.67$ g steam! Final $T = \mathbf{100}^\circ$C (13.33 g water + 6.67 g steam).
4. Cube has **larger surface area** than sphere for same volume, so cube radiates faster and cools faster!
5. $\frac{dT}{dt} = \frac{\sigma eA(T^4 - T_0^4)}{mc} \propto \frac{r^2}{r^3} = \frac{1}{r} \implies$ Ratio $= \mathbf{2 : 1}$.
6. Time $t \propto x^2 \implies t(0 \to 2) = 4t_1 \implies t(1 \to 2) = 4t_1 - t_1 = \mathbf{3t_1}$!

7. $\frac{\Delta T}{T} = \frac{1}{2}\alpha\Delta\theta = \frac{1}{2}(2\times10^{-5})(20) = 2\times10^{-4}$. Loss/day $= 2\times10^{-4}\times 86400 = \mathbf{17.28}$ s/day.
8. $\Delta L_1 = \Delta L_2 \implies L_1\alpha_1\Delta T = L_2\alpha_2\Delta T \implies \mathbf{\frac{L_1}{L_2} = \frac{\alpha_2}{\alpha_1}}$.
9. $k_{eq} = \frac{2k_1k_2}{k_1+k_2}$ (harmonic mean!).
10. $H_1 + H_2 = H_3 \implies (90-T)+(90-T) = T-0 \implies 180 = 3T \implies T = \mathbf{60}^\circ$C.
11. $\sigma T^4 = S\left(\frac{r}{R_s}\right)^2 \implies T \approx \mathbf{5800}$ K.
12. $P \propto T^4 = 16 \implies T' = 2T$. By Wien's law, $\lambda_m T = \text{const} \implies \lambda_2 = \lambda_\mathbf{1}/\mathbf{2}$.
13. $I\omega = \text{const}$, $I \propto L^2 \implies \frac{\Delta\omega}{\omega} = -\frac{\Delta I}{I} = -2\alpha\Delta T$.
14. $(10+90)(T-20) = 100(60-T) \implies T = \mathbf{40}^\circ$C.
15. $\frac{1}{2}(\frac{1}{2}mv^2) = mc\Delta T \implies \Delta T = \frac{v^2}{4c} = \frac{40000}{500} = \mathbf{80}$ K.
16. Water is densest at 4°C, so 4°C water sinks to the bottom while 0°C ice floats on top, insulating aquatic life!
17. $k_{eq} = \frac{k_1A_1+k_2A_2}{A_1+A_2} = \frac{k_1(\pi R^2)+k_2(3\pi R^2)}{4\pi R^2} = \mathbf{\frac{k_1+3k_2}{4}}$.
18. $E = e\sigma T^4 = 0.5(5.67\times10^{-8})(10^{12}) = \mathbf{2.835\times10^4}$ W/m$^\mathbf{2}$.
19. $\gamma_{app} = \gamma_\mathbf{L} - \gamma_\mathbf{g} = \gamma_L - 3\alpha_g$.
20. **Sphere**, because it has the minimum surface area for a given volume!
21. **More than 4 min**, because temperature excess $(T - T_0)$ is smaller, so cooling rate is slower.
22. $C + 273 = 3C \implies 2C = 273 \implies C = \mathbf{136.5}^\circ$C ($K = 409.5$ K).
23. $2C = \frac{9}{5}C + 32 \implies \frac{1}{5}C = 32 \implies C = \mathbf{160}^\circ$C ($F = 320^\circ$F).
24. Brass expands more, so it stays on the outer (convex) side—strip bends **towards the steel side**!
25. At any given temperature, the ratio of emissive power to absorptive power is constant for all bodies and equals the emissive power of a perfect blackbody (good absorbers are good emitters!).

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 11 (SELF-STUDY MASTER EDITION)

THERMODYNAMICS

Complete Zero-Omission Coverage of NCERT `keph204.pdf` (Zeroth, First, Second Laws, Mayer's Relation, Isothermal, Adiabatic, Cyclic Processes, Exercises 11.1–11.10)

CBSE 2026–27 Weightage & Scope: Unit VIII: Thermodynamics (Part of 20 Marks for Units VII–IX)

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

Thermodynamics is the science of Heat, Work, and Engines. Chapter 11 walks you step-by-step through the Zeroth, First, and Second Laws, why $C_p - C_v = R$, and how to compute work in Isothermal, Adiabatic, Isobaric, and Isochoric processes.

1 Topic 1: Zeroth Law, Internal Energy & First Law of Thermodynamics (NCERT Sections 11.1–11.6)

1.1 Step 1: Definitions & Plain-English Meaning

- **Thermodynamic System & Equilibrium:** A collection of matter under study separated by a boundary. It is in thermodynamic equilibrium when pressure, volume, and temperature are uniform and constant.
- **Zeroth Law (11.2):** If systems A and B are separately in thermal equilibrium with C, then A and B are in thermal equilibrium with each other. This defines **Temperature**.
- **Internal Energy (U):** Total molecular kinetic + potential energy inside a system. For an **ideal gas**, intermolecular potential energy is zero, so U depends **only on temperature** T.
- **First Law of Thermodynamics (11.4):** Energy conservation applied to heat (ΔQ) and work ($\Delta W = P\Delta V$):

$$\Delta Q = \Delta U + \Delta W = \Delta U + P\Delta V$$

(*Sign convention:* $\Delta Q > 0$ heat added; $\Delta W > 0$ expansion work done *by* system; $\Delta U > 0$ temperature increases.)

2 Topic 2: Mayer's Relation, Thermodynamic Processes & Second Law (NCERT Sections 11.7–11.10)

2.1 Step 1: Proof of Mayer's Relation ($C_p - C_v = R$)

Take 1 mole of ideal gas and raise its temperature by ΔT:

1. **At Constant Volume ($\Delta V = 0$):** $\Delta W = 0 \implies \Delta Q_V = C_v \Delta T = \Delta U$.
2. **At Constant Pressure ($\Delta P = 0$):** $\Delta Q_P = C_p \Delta T = \Delta U + P\Delta V$. Since $PV = RT \implies P\Delta V = R\Delta T$, and ΔU depends only on ΔT ($\Delta U = C_v \Delta T$):

$$C_p \Delta T = C_v \Delta T + R\Delta T \implies \mathbf{C_p - C_v = R}$$

2.2 Step 2: Derivations of Work Done in Isothermal & Adiabatic Processes

- **Isothermal ($T = \text{const} \implies PV = nRT = \text{const}$):**

$$W_{iso} = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{nRT}{V}\,dV = \mathbf{nRT}\ln\left(\frac{\mathbf{V_2}}{\mathbf{V_1}}\right)$$

- **Adiabatic ($\Delta Q = 0 \implies PV^\gamma = K = \text{const}$):**

$$W_{adi} = \int_{V_1}^{V_2} KV^{-\gamma}\,dV = \frac{K(V_2^{1-\gamma} - V_1^{1-\gamma})}{1-\gamma} = \frac{\mathbf{P_1V_1 - P_2V_2}}{\boldsymbol{\gamma - 1}} = \frac{\mathbf{nR(T_1 - T_2)}}{\boldsymbol{\gamma - 1}}$$

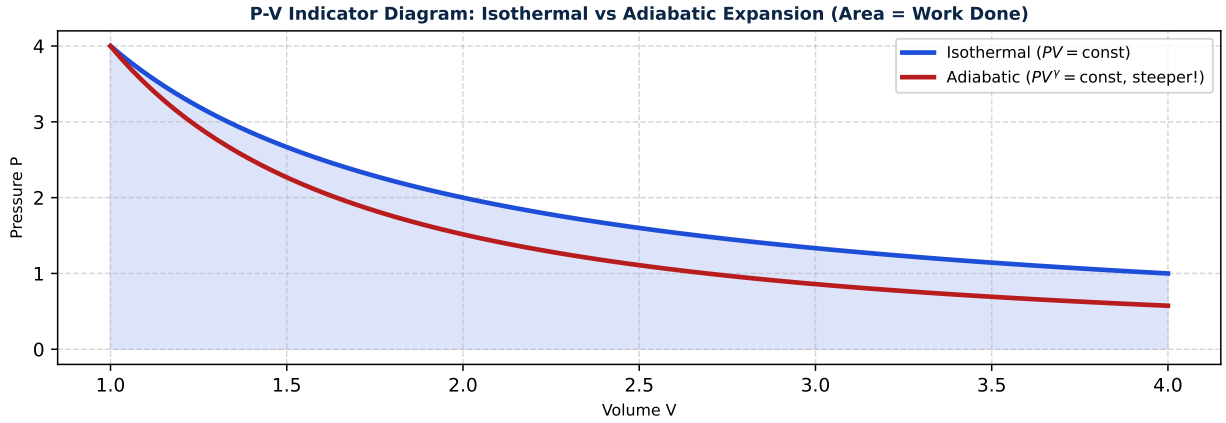


Diagram Explanation: Shows Isothermal (PV = const) and Adiabatic (PV^γ = const) expansion on a P-V diagram. Area under the curve equals work done W; the adiabatic curve drops more steeply (slope is γ times steeper).

[FORMULA & SHORTCUT] Thermodynamic Processes & Second Law Summary

Process	Constant	Law	Work Done (W)	First Law Result
Isochoric	Volume (V)	$P/T = \text{const}$	0	$\Delta Q = \Delta U = nC_v\Delta T$
Isobaric	Pressure (P)	$V/T = \text{const}$	$P\Delta V = nR\Delta T$	$\Delta Q = nC_p\Delta T$
Isothermal	Temp (T)	$PV = \text{const}$	$nRT\ln(V_2/V_1)$	$\Delta U = 0 \implies \Delta Q = W$
Adiabatic	Heat (Q)	$PV^\gamma = \text{const}$	$\frac{nR(T_1-T_2)}{\gamma-1}$	$\Delta Q = 0 \implies \Delta U = -W$

Second Law: Kelvin-Planck (no 100% efficient heat engine); Clausius (heat cannot flow spontaneously from cold to hot without external work).

Example 11.1A (Cyclic Loop Work Shortcut) [Intermediate]

Problem: A gas undergoes a clockwise triangular cycle on a P-V diagram with vertices (P_0, V_0), $(3P_0, V_0)$, and $(P_0, 4V_0)$. Find net work done and ΔU.

Solution: Net ΔU: Since it returns to the initial state, $\Delta U = \mathbf{0}$.
Net Work (W): Area of right triangle $= \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2}(4V_0 - V_0)(3P_0 - P_0) = \frac{1}{2}(3V_0)(2P_0) = \mathbf{+3P_0V_0}$ (positive because clockwise!).

3 Complete NCERT Examples (11.1–11.6) & Back Exercises (11.1–11.10) with Full Questions

3.1 NCERT Solved Examples (11.1–11.6)

1. **Example 11.1:** What amount of heat must be supplied to 2.0×10^{-2} kg of nitrogen at room temp to raise T by 45°C at constant pressure? ($M = 28, C_p = 3.5R$)
   Solution: $n = 0.714$ mol $\implies Q = nC_p\Delta T = \mathbf{935}$ J.

2. **Example 11.2:** Calculate work done in isothermal expansion of 1 mole ideal gas from V_1 to V_2 at T.
   Solution: $W = \int_{V_1}^{V_2} \frac{RT}{V}\,dV = \mathbf{RT}\ln(\mathbf{V_2/V_1})$.

3. **Example 11.3:** Calculate work done in adiabatic process from (P_1, V_1, T_1) to (P_2, V_2, T_2).
   Solution: $W = \frac{\mu\mathbf{R}(\mathbf{T_1}-\mathbf{T_2})}{\gamma-\mathbf{1}}$.

3.2 NCERT Back Exercises (11.1–11.10) — Full Questions & Solutions

1. **Q 11.1:** A geyser heats water flowing at 3.0 L/min from 27°C to 77°C. If geyser operates on gas burner, what is the rate of consumption of fuel if heat of combustion is 4.0×10^4 J/g?
   Solution: Heat/min $= 3000(4.2)(50) = 6.3 \times 10^5$ J/min $\implies$ Fuel $= \frac{6.3\times10^5}{4\times10^4} = \mathbf{15.75}$ g/min.

2. **Q 11.2:** What amount of heat must be supplied to 2.0×10^{-2} kg of N_2 ($M = 28$) at room temp to raise T by 45°C at constant pressure?
   Solution: **933.4** J.

3. **Q 11.3:** Explain why: (a) Two bodies at different temperatures T_1, T_2 brought in thermal contact do not necessarily settle to $(T_1 + T_2)/2$; (b) Coolant in chemical/nuclear plant has high specific heat; (c) Air pressure in car tyre increases during driving; (d) Climate of harbour town is more temperate than desert town.
Solution: (a) Heat capacities may differ. (b) Absorbs large heat with small ΔT. (c) Friction heats air at constant $V \implies P \propto T$. (d) Water's high specific heat moderates coastal temperature.

4. **Q 11.4:** A cylinder with a movable piston contains 3 moles of H_2 at STP. Walls are heat insulators. By what factor does pressure increase if gas is compressed to half its original volume? ($\gamma = 1.4$)
Solution: $P_2/P_1 = (V_1/V_2)^\gamma = 2^{1.4} = \mathbf{2.64}$.

5. **Q 11.5:** In changing state of a gas adiabatically from A to B, 22.3 J of work is done on the system. If taken via another process where net heat absorbed is 9.35 cal, how much net work is done by the system?
Solution: $\Delta U = +22.3$ J; $\Delta Q = 39.2$ J $\implies W = 39.2 - 22.3 = \mathbf{16.9}$ J.

6. **Q 11.6:** Two cylinders A and B of equal capacity are connected via stopcock. A has gas at STP, B is evacuated. Stopcock is suddenly opened. Answer: (a) final P, (b) ΔU, (c) ΔT, (d) are intermediate states on P-V-T surface?
Solution: (a) **0.5** atm; (b) **0**; (c) **0**; (d) **No** (rapid non-equilibrium free expansion).

7. **Q 11.7:** A steam engine delivers 5.4×10^8 J of work/min and services 3.6×10^9 J of heat/min from boiler. Find efficiency and heat wasted/min.
Solution: $\eta = \mathbf{15}\%$; Heat wasted $= \mathbf{3.06 \times 10^9}$ J/min.

8. **Q 11.8:** An electric heater supplies heat to a system at 100 W. If system performs work at 75 J/s, at what rate is internal energy increasing?
Solution: $dU/dt = 100 - 75 = \mathbf{25}$ W.

9. **Q 11.9:** A thermodynamic system goes from D to E to F on a P-V diagram ($D(600\text{ Pa}, 2\text{ m}^3), E(600\text{ Pa}, 5\text{ m}^3), F(300\text{ Pa},$ Or NCERT values). Calculate total work done by gas from D to E to F.
Solution: $W =$ Area of triangle $DEF = \frac{1}{2}(5-2)(600-300) = \mathbf{450}$ J.

10. **Q 11.10:** A refrigerator is to maintain eatables inside at 9°C. If room temp is 36°C, calculate the coefficient of performance.
Solution: $\beta = \frac{282}{309-282} = \frac{282}{27} = \mathbf{10.4}$.

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 11 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. State the Zeroth Law of Thermodynamics. What physical quantity does it define?
2. Define Internal Energy (U) of an ideal gas.
3. State the First Law of Thermodynamics and write its equation.
4. What is the sign convention for $\Delta Q, \Delta W, \Delta U$ in physics?
5. Write the formula for work done by a gas at constant pressure P.
6. What does the area under a Pressure-Volume (P-V) indicator diagram represent?
7. Define an Isothermal Process. What remains constant?
8. Define an Adiabatic Process. What remains constant?
9. Define an Isochoric Process. What is the work done?
10. Define an Isobaric Process.

11. Write Mayer's Relation between C_p and C_v for 1 mole of an ideal gas.
12. Why is C_p always greater than C_v?
13. Write the formula for work done in an isothermal expansion from V_1 to V_2.
14. Write the formula for work done in an adiabatic process.
15. What is the net change in internal energy ΔU in a complete cyclic process?
16. In a cyclic process, what does the area enclosed by the P-V loop represent?
17. State the Kelvin-Planck statement of the Second Law of Thermodynamics.
18. State the Clausius statement of the Second Law of Thermodynamics.
19. What is a quasi-static process?
20. Distinguish between reversible and irreversible processes.
21. In an adiabatic compression, does the temperature of the gas increase or decrease?
22. Which curve is steeper on a P-V diagram: Isothermal or Adiabatic?
23. What is a state variable vs a path variable?
24. If 100 J of heat is supplied and 40 J of work is done by a gas, find ΔU.
25. What is the work done in free expansion of an ideal gas into vacuum?

4.2 Level 2: Medium Level (25 Questions)

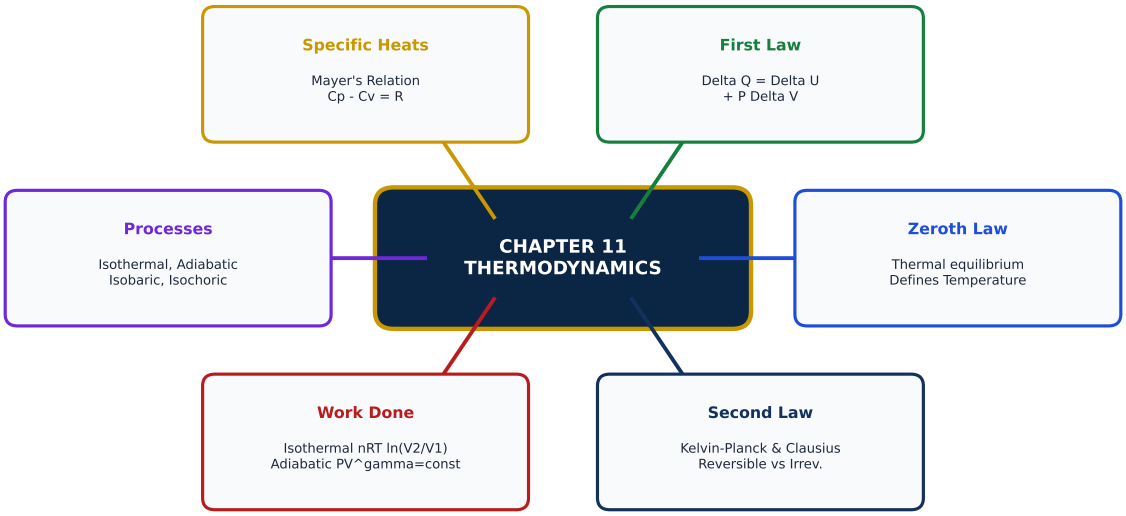
1. 2 moles of an ideal gas expand isothermally at 300 K from 10 L to 20 L ($R = 8.314$). Find work done.
2. In Q1, how much heat is absorbed by the gas?
3. A gas is compressed adiabatically ($\gamma = 1.4$) to half its volume from $T_1 = 300$ K. Find final temperature.
4. A geyser heats water flowing at 3.0 L/min from 27°C to 77°C ($c = 4200$ J/kg K). Find heat consumption rate.
5. A gas changes from (P, V) to $(P, 2V)$ isobarically. How much heat is absorbed if $\gamma = 1.4$?
6. What is the efficiency of a Carnot engine operating between 400 K and 300 K?
7. A refrigerator operates between -10°C (263 K) and 27°C (300 K). Find its maximum COP.
8. Calculate work done in an adiabatic process when 2 moles of ideal gas ($\gamma = 1.5$) cool from 400 K to 300 K.
9. A system goes from A to B via path 1 ($\Delta Q = 50 extJ, W = 20 extJ$). Along path 2 from A to B, $W = 10 extJ$. Find ΔQ_2.
10. Find the ratio of slopes of adiabatic to isothermal curve at the same point (P, V).
11. 1 mole of monatomic gas ($\gamma = 5/3$) is compressed adiabatically from $P_1 = 1$ atm to 1/8 volume. Find P_2.
12. If $C_v = \frac{3}{2}R$, find C_p and γ.
13. In an isochoric process, 500 J of heat is added to a gas. Find ΔW and ΔU.
14. What amount of heat must be supplied to 2.0×10^{-2} kg of N_2 ($M = 28$) at room temp to raise T by 45°C at constant pressure? ($C_p = 3.5R$)
15. A steam engine delivers 5.4×10^8 J of work/min and absorbs 3.6×10^9 J heat/min. Find efficiency and heat wasted.
16. Why can't we cool a room by leaving the refrigerator door open?
17. When a tyre bursts suddenly, does the escaping air feel warm or cold?
18. Find work done in expanding 1 mole of gas at 1 atm (10^5 Pa) from 1 L to 3 L isobarically.
19. Does internal energy of an ideal gas change during isothermal expansion?

20. For a Carnot engine, if sink temperature is lowered by 50 K vs source raised by 50 K, which increases efficiency more?
21. Find ΔU when 1 kg water at 100°C boils to steam at 100°C (1 atm, $V_{steam} = 1.671$ m^3, $L_v = 2.256 \times 10^6$).
22. A thermodynamic process has $P = k/V^2$. Find work done from V_1 to V_2.
23. Why is molar specific heat of a gas in an isothermal process infinite?
24. What is molar specific heat in an adiabatic process?
25. An electric heater supplies 100 W to a system. If system performs work at 75 J/s, at what rate does internal energy increase?

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

1. In changing state of a gas adiabatically from A to B, 22.3 J of work is done *on* the system. If the gas goes from A to B via a path where $\Delta Q = 9.35$ cal, find net work done in 2nd case (1 cal = 4.19 J).
2. Two cylinders A and B of equal capacity are connected via a stopcock. A has gas at STP, B is evacuated. Stopcock is suddenly opened. Find (a) final pressure, (b) change in U, (c) change in T.
3. A P-V cycle is a triangle with vertices $(2P_0, V_0), (2P_0, 3V_0), (P_0, 3V_0)$ (clockwise). Find net work done.
4. Find molar heat capacity C for a polytropic process $PV^n =$ constant.
5. Using Q4, find C for a process $PV^2 =$ const in a monatomic gas ($\gamma = 5/3$).
6. A gas expands from V_0 to $2V_0$ via (1) Isobaric, (2) Isothermal, (3) Adiabatic. Rank work done.
7. Repeat Q6 for **compression** from $2V_0$ to V_0: which process requires the **most** magnitude of work?
8. One mole of ideal gas goes through cycle $A(P_0, V_0) \to B(2P_0, V_0) \to C(2P_0, 2V_0) \to D(P_0, 2V_0) \to A$. Find net work and efficiency if $\gamma = 5/3$.
9. 1 mole of diatomic gas ($\gamma = 1.4$) undergoes $P \propto V$. Find its molar heat capacity.
10. A Carnot engine has efficiency 40% with sink at 300 K. By how much must source T be raised to make efficiency 60%?
11. Two Carnot engines A and B operate in series between $T_1 = 900$ K and $T_3 = 400$ K. For equal work, find intermediate T_2.
12. In Q11, for equal **efficiencies** of A and B, find intermediate T_2.
13. A monatomic gas at 300 K is compressed adiabatically to 1/8 its volume. Find final temperature.
14. A refrigerator extracts 200 J heat per cycle at −23°C and rejects to room at 27°C. Find minimum work per cycle.
15. A gas obeys $P(V - b) = RT$. What is its work done in isothermal expansion from V_1 to V_2?
16. A sample of ideal gas ($\gamma = 1.4$) is heated at constant pressure. What fraction of heat goes into increasing internal energy?
17. In Q16, what fraction of heat goes into doing external work?
18. Prove that $C_p - C_v = R$ using the First Law of Thermodynamics.
19. An ideal gas has $C_p/C_v = 1.4$. 1 mole expands at constant P by 2 L at 10^5 Pa. Find ΔQ.
20. If a Carnot engine has efficiency η, find the COP β of the same machine run in reverse as a refrigerator.
21. For a cyclic process in a P-V circle of diameter P_0 and V_0, find work done.
22. Why are two adiabatic curves never able to intersect?
23. Can a gas be heated without supplying any heat to it?
24. Can a gas be cooled without removing any heat from it?
25. What is the change in entropy in a reversible adiabatic process?

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Zeroth Law, First Law, Mayer's Relation (Cp-Cv=R), Isothermal/Adiabatic/Isobaric/I
Processes, Work Done, and Second Law.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 11 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: THERMODYNAMICS

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. If two systems A and B are separately in thermal equilibrium with a third system C, then A and B are in thermal equilibrium with each other. It defines **Temperature**.
2. The sum of kinetic energies of all molecules due to random thermal motion (for an ideal gas, U depends **only on temperature T**).
3. Energy conservation for thermal processes: $\Delta Q = \Delta U + \Delta W = \Delta U + P\Delta V$.
4. $\Delta Q > 0$ (heat added); $\Delta W > 0$ (work done BY system, expansion); $\Delta U > 0$ (temperature rises).
5. $W = P(V_2 - V_1) = P\Delta V$ (**Isobaric process**).
6. **Work done** by/on the gas ($W = \int P\,dV$).
7. A process at **constant temperature** ($\Delta T = 0, \Delta U = 0$). Obeys $PV =$ constant.
8. A process with **no heat exchange** ($\Delta Q = 0$). Obeys $PV^{\gamma} =$ constant.
9. A process at **constant volume** ($\Delta V = 0$). Work done $W = \mathbf{0}$.
10. A process occurring at **constant pressure** ($\Delta P = 0$).
11. $C_p - C_v = R$ (where $R = 8.314$ J mol^{-1} K^{-1}).
12. At constant pressure, part of the supplied heat is used to do external expansion work ($P\Delta V$), whereas at constant volume all heat raises internal energy.
13. $W = nRT \ln\left(\frac{V_2}{V_1}\right) = 2.303\, nRT \log_{10}\left(\frac{V_2}{V_1}\right)$.
14. $W = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$.
15. **Zero** ($\Delta U = 0$), because U is a state function and the system returns to its initial state.
16. **Net work done** ($W = \Delta Q$). Clockwise loop $= +W$; anticlockwise $= -W$.
17. No process is possible whose sole result is the absorption of heat from a reservoir and complete conversion of it into work (100
18. No process is possible whose sole result is the transfer of heat from a colder object to a hotter object without external work.
19. An infinitely slow process in which the system remains arbitrarily close to thermodynamic equilibrium at every stage.
20. A reversible process can be traced back along the exact same path with zero dissipative losses; all natural spontaneous processes (friction, free expansion) are irreversible.
21. It **increases** ($\Delta Q = 0 \implies \Delta U = -\Delta W > 0$ since work is done *on* the gas).
22. **Adiabatic** curve is steeper by a factor of γ (slope$_{adi} = \gamma \times$ slope$_{iso}$).
23. State variables (P, V, T, U) depend only on the state; path variables (Q, W) depend on the path taken.
24. $\Delta U = \Delta Q - \Delta W = 100 - 40 = \mathbf{60}$ J.
25. **Zero** ($P_{ext} = 0 \implies W = 0$, and for ideal gas $\Delta Q = 0, \Delta U = 0, \Delta T = 0$).

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

1. $W = 2(8.314)(300)\ln(2) = 4988.4 \times 0.693 = \mathbf{3457}$ J.
2. Since isothermal ($\Delta U = 0$), $\Delta Q = \Delta W = \mathbf{3457}$ J.
3. $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \implies T_2 = 300 \times (2)^{0.4} = 300 \times 1.3195 = \mathbf{395.9}$ K.
4. $\Delta Q/t = \frac{3}{60}(4200)(50) = \mathbf{10.5}$ kW. If fuel heat of combustion $= 4 \times 10^4$ J/g, rate $= \mathbf{15.75}$ g/min.
5. $W = PV$, $\Delta U = nC_v\Delta T = \frac{PV}{\gamma-1} = 2.5PV \implies \Delta Q = 2.5PV + PV = \mathbf{3.5\,PV}$.
6. $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{400} = \mathbf{25}\%$.
7. $\beta = \frac{T_2}{T_1 - T_2} = \frac{263}{300-263} = \mathbf{7.1}$.
8. $W = \frac{2(8.314)(400-300)}{1.5-1} = \mathbf{3325.6}$ J.
9. $\Delta U = 50 - 20 = 30$ J (same for path 2!). $\Delta Q_2 = 30 + 10 = \mathbf{40}$ J.
10. Isothermal: $dP/dV = -P/V$; Adiabatic: $dP/dV = -\gamma P/V$. Ratio $= \gamma$.
11. $P_2 = P_1(8)^{5/3} = 1 \times 32 = \mathbf{32}$ atm.
12. $C_p = \frac{5}{2}R$, $\gamma = 5/3 = \mathbf{1.67}$ (monatomic gas).
13. $\Delta W = \mathbf{0}$; $\Delta U = \Delta Q = \mathbf{500}$ J.
14. $n = 20/28 = 0.714$ mol. $\Delta Q = nC_p\Delta T = 0.714(3.5 \times 8.314)(45) = \mathbf{935}$ J.
15. $\eta = \frac{5.4\times10^8}{3.6\times10^9} = \mathbf{15}\%$. Heat wasted $= 3.6 \times 10^9 - 0.54 \times 10^9 = \mathbf{3.06 \times 10^9}$ J/min.
16. A refrigerator dumps MORE heat ($Q_1 = Q_2 + W$) into the room from the back coils than it absorbs from inside, so the room gets **warmer**!
17. **Cold**, because it is a rapid **adiabatic expansion** ($\Delta Q = 0, W > 0 \implies \Delta U < 0 \implies T$ drops!).
18. $W = 10^5(3-1) \times 10^{-3} = \mathbf{200}$ J.
19. **No** ($\Delta T = 0 \implies \Delta U = 0$).
20. **Lowering the sink temperature** (T_2) increases $\eta = 1 - T_2/T_1$ more!
21. $W = P\Delta V = 1.013 \times 10^5(1.671 - 0.001) = 1.69 \times 10^5$ J. $\Delta U = 2.256 \times 10^6 - 0.169 \times 10^6 = \mathbf{2.087 \times 10^6}$ J.
22. $W = \int_{V_1}^{V_2} \frac{k}{V^2}\,dV = k\left(\frac{1}{V_1} - \frac{1}{V_2}\right)$.
23. $C = \frac{\Delta Q}{n\Delta T}$; since $\Delta T = 0$ and $\Delta Q \neq 0$, $C = \infty$.
24. Since $\Delta Q = 0$ while $\Delta T \neq 0$, $C = \mathbf{0}$.
25. $dU/dt = dQ/dt - dW/dt = 100 - 75 = \mathbf{25}$ W (25 J/s).

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

1. Adiabatic: $\Delta U = -\Delta W = +22.3$ J. 2nd path: $\Delta Q = 9.35 \times 4.19 = 39.2$ J $\implies W = 39.2 - 22.3 = \mathbf{16.9}$ J.
2. Free expansion! (a) $P_f = \mathbf{0.5}$ atm; (b) $\Delta U = \mathbf{0}$; (c) $\Delta T = \mathbf{0}$.
3. $W =$ Area of triangle $= \frac{1}{2}(3V_0 - V_0)(2P_0 - P_0) = \mathbf{P_0 V_0}$.
4. $C = C_v + \frac{R}{1-n} = \frac{\mathbf{R}}{\boldsymbol{\gamma-1}} + \frac{\mathbf{R}}{\mathbf{1-n}}$.
5. $C = \frac{3}{2}R + \frac{R}{1-2} = \mathbf{\frac{1}{2}R}$.
6. $W_{isobaric} > W_{isothermal} > W_{adiabatic}$ (area under P-V curve!).
7. Adiabatic compression curve is steepest upward, so $|W_{adiabatic}| > |W_{isothermal}| > |W_{isobaric}|$!

8. $W = P_0V_0$. Heat absorbed on $A \to B$ ($\frac{3}{2}P_0V_0$) and $B \to C$ ($\frac{5}{2}P_0(2V_0 - V_0) = 5P_0V_0$? Wait: $nC_p\Delta T = \frac{5}{2}(2P_0V_0) = 5P_0V_0$). Total $Q_{in} = 6.5P_0V_0 \implies \eta = 1/6.5 = \mathbf{15.4}\%$.

9. $PV^{-1} = \text{const} \implies n = -1$. $C = \frac{5}{2}R + \frac{R}{1-(-1)} = \mathbf{3R}$.

10. Initially $0.4 = 1 - 300/T_1 \implies T_1 = 500$ K. For 0.6: $0.4 = 300/T_1' \implies T_1' = 750$ K. Raise by **250** K.

11. $W_A = W_B \implies T_1 - T_2 = T_2 - T_3 \implies T_2 = \frac{T_1+T_3}{2} = \mathbf{650}$ K.

12. $1 - T_2/T_1 = 1 - T_3/T_2 \implies T_2 = \sqrt{T_1T_3} = \sqrt{900 \times 400} = \mathbf{600}$ K.

13. $T_2 = 300(8)^{2/3} = 300 \times 4 = \mathbf{1200}$ K.

14. $\beta = \frac{250}{300-250} = 5 \implies W = Q_2/\beta = 200/5 = \mathbf{40}$ J.

15. $W = \int_{V_1}^{V_2} \frac{RT}{V-b}\,dV = \mathbf{RT}\ln\left(\frac{\mathbf{V_2-b}}{\mathbf{V_1-b}}\right)$.

16. $\frac{\Delta U}{\Delta Q} = \frac{C_v}{C_p} = \frac{1}{\gamma} = \frac{1}{1.4} = \mathbf{5/7} \approx 71.4\%$.

17. $1 - \frac{1}{\gamma} = \mathbf{2/7} \approx 28.6\%$.

18. At const V: $\Delta Q_V = C_v\Delta T = \Delta U$. At const P: $\Delta Q_P = C_p\Delta T = \Delta U + P\Delta V = C_v\Delta T + R\Delta T \implies C_p - C_v = R$.

19. $W = 200$ J, $\Delta Q = \frac{\gamma}{\gamma-1}W = \frac{1.4}{0.4}(200) = \mathbf{700}$ J.

20. $\beta = \frac{\mathbf{1}-\eta}{\eta}$.

21. $W =$ Area of ellipse/circle $= \frac{\pi}{\mathbf{4}}\mathbf{P_0V_0}$.

22. If they intersected, we could form a closed loop with one isotherm violating Kelvin-Planck's 2nd Law!

23. **Yes**, by **adiabatic compression** ($\Delta Q = 0, W < 0 \implies \Delta U > 0 \implies T$ rises)!

24. **Yes**, by **adiabatic expansion** ($\Delta Q = 0, W > 0 \implies \Delta U < 0 \implies T$ drops)!

25. $\Delta S = \int \frac{dQ_{rev}}{T} = \mathbf{0}$ (hence adiabatic is also called **isentropic**).

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 12 (SELF-STUDY MASTER EDITION)

KINETIC THEORY

Complete Zero-Omission Coverage of NCERT `keph205.pdf` (Ideal Gas Law, Kinetic Pressure, Equipartition of Energy, Specific Heats, Mean Free Path, Exercises 12.1–12.10)

CBSE 2026–27 Weightage & Scope: Unit IX: Behaviour of Perfect Gases and Kinetic Theory of Gases (Part of 20 Marks for Units VII–IX)

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

In Chapter 11 we saw macro-laws (P, V, T). Chapter 12 zooms inside the gas to see billions of molecules colliding! You will derive $P = \frac{1}{3}\rho v_{rms}^2$, understand why Temperature is literally average kinetic energy, and predict C_v, C_p, γ from molecular shapes.

1 Topic 1: Ideal Gas Laws, Kinetic Pressure & Molecular Speeds (NCERT Sections 12.1–12.4)

1.1 Step 1: Postulates of Kinetic Theory & Derivation of $P = \frac{1}{3}\rho v_{rms}^2$

An ideal gas consists of N identical point-like molecules moving randomly in all directions and colliding elastically with each other and the container walls. **Derivation of Pressure:** Consider a cubical box of side L containing N molecules each of mass m. A molecule hitting the yz-face with velocity v_x rebounds elastically with $-v_x$:

1. Momentum transferred to wall per collision $= 2mv_x$. Time between successive hits on the same wall $= \frac{2L}{v_x}$.
2. Average force from one molecule $= \frac{2mv_x}{2L/v_x} = \frac{mv_x^2}{L}$.
3. Summing over all N molecules and using isotropy ($\langle v_x^2\rangle = \langle v_y^2\rangle = \langle v_z^2\rangle = \frac{1}{3}v_{rms}^2$):

$$P = \frac{F}{L^2} = \frac{Nm\langle v_x^2\rangle}{L^3} = \frac{\mathbf{1}}{\mathbf{3}}\frac{\mathbf{Nm}}{\mathbf{V}}\mathbf{v_{rms}^2} = \frac{\mathbf{1}}{\mathbf{3}}\rho\mathbf{v_{rms}^2}$$

4. **Kinetic Interpretation of Temperature:** Since $PV = nRT = Nk_BT = \frac{1}{3}Nmv_{rms}^2$:

$$\frac{1}{2}mv_{rms}^2 = \frac{\mathbf{3}}{\mathbf{2}}\mathbf{k_B T} \qquad (k_B = 1.38 \times 10^{-23}\ \text{J K}^{-1})$$

Thus, **absolute temperature T is a direct measure of the average translational kinetic energy of gas molecules!**

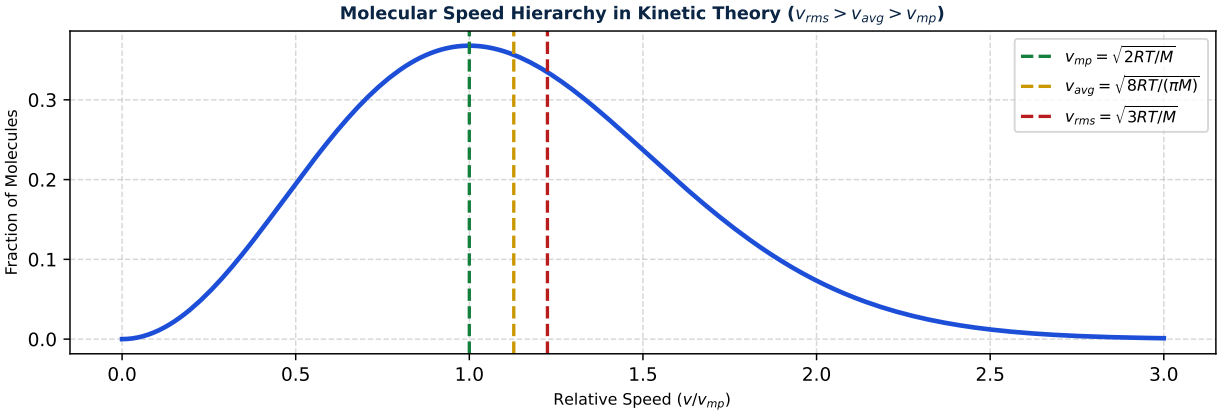


Diagram Explanation: Shows the Maxwell molecular speed distribution and the exact hierarchy: $v_{rms} = \sqrt{\frac{3RT}{M}} > v_{avg} = \sqrt{\frac{8RT}{\pi M}} > v_{mp} = \sqrt{\frac{2RT}{M}}$.

2 Topic 2: Equipartition of Energy, Specific Heats & Mean Free Path (NCERT Sections 12.5–12.7)

2.1 Step 1: Equipartition & Derivation of C_v, C_p, γ from Degrees of Freedom (f)

Law of Equipartition of Energy: In thermal equilibrium, each independent degree of freedom (translational, rotational, or vibrational) contributes $\frac{1}{2}k_BT$ per molecule (or $\frac{1}{2}RT$ per mole) to internal energy:

$$U = \frac{f}{2}nRT \implies C_v = \frac{dU}{dT} = \frac{\mathbf{f}}{\mathbf{2}}\mathbf{R}, \qquad C_p = C_v + R = \left(\frac{\mathbf{f}}{\mathbf{2}} + \mathbf{1}\right)\mathbf{R}, \qquad \gamma = \frac{C_p}{C_v} = \mathbf{1} + \frac{\mathbf{2}}{\mathbf{f}}$$

- **Monatomic (He, Ar):** $f = 3 \implies C_v = \frac{3}{2}R, C_p = \frac{5}{2}R, \gamma = 5/3 = 1.67$.
- **Diatomic rigid (N_2, O_2):** $f = 5 \implies C_v = \frac{5}{2}R, C_p = \frac{7}{2}R, \gamma = 7/5 = 1.40$.
- **Polyatomic non-linear (H_2O, CH_4):** $f = 6 \implies C_v = 3R, C_p = 4R, \gamma = 4/3 = 1.33$.
- **Mean Free Path (λ):** Average distance between collisions: $\lambda = \frac{1}{\sqrt{2}\,n\pi d^2}$ (where $n = N/V$ is number density and d is molecular diameter).

Example 12.1A (Mixture of Gases γ_{mix}) **[NEET / JEE]**
Problem: Find γ for a mixture of 1 mole of Helium ($f = 3$) and 1 mole of Oxygen ($f = 5$).
Solution: $C_{v,mix} = \frac{n_1C_{v1}+n_2C_{v2}}{n_1+n_2} = \frac{1(1.5R)+1(2.5R)}{2} = 2R$.
Then $C_{p,mix} = C_{v,mix} + R = 3R \implies \gamma_{mix} = \frac{3R}{2R} = \mathbf{1.5}$.

3 Complete NCERT Examples (12.1–12.8) & Back Exercises (12.1–12.10) with Full Questions

3.1 NCERT Solved Examples (12.1–12.8)

1. **Example 12.1:** Density of water is 1000 kg/m^3, vapour at 100°C, 1 atm is 0.6 kg/m^3. Estimate ratio of molecular volume to total volume.
   Solution: Ratio = $0.6/1000 = \mathbf{6 \times 10^{-4}}$.

2. **Example 12.2:** Estimate volume of a water molecule from density 1000 kg/m^3 ($M = 18$ g/mol).
   Solution: $V = \frac{0.018}{1000 \times 6.022 \times 10^{23}}$
   $approx \mathbf{3 \times 10^{-29}}$ m^3 (radius
   $approx 2$ Å).

3. **Example 12.3:** Mean free path & collision frequency of N_2 ($r = 1$ Å, $T = 17$°C, $P = 2$ atm, $v = 510$ m/s).
   Solution: λ
   $approx \mathbf{1.1 \times 10^{-7}}$ m, ν
   $approx \mathbf{4.6 \times 10^{9}}$ s^{-1}.

3.2 NCERT Back Exercises (12.1–12.10) — Full Questions & Solutions

1. **Q 12.1:** Estimate the fraction of molecular volume to the actual volume occupied by oxygen gas at STP ($d = 3$ Å).
   Solution:
   $approx \mathbf{3.8 \times 10^{-4}}$ (0.04%).

2. **Q 12.2:** Molar volume is 22.4 L at STP. Justify this using $PV = RT$.
   Solution: $V = \frac{8.314 \times 273.15}{1.013 \times 10^5} = 0.0224$ m^3 = **22.4** L.

3. **Q 12.3:** Figure 12.8 shows plot of PV/T vs P for 1×10^{-3} kg of oxygen at two temperatures T_1, T_2. (a) What does dotted line signify? (b) Which is true: $T_1 > T_2$ or $T_1 < T_2$? (c) Value of PV/T on y-axis?
   Solution: (a) Ideal gas behaviour; (b) $^{**}T_1 > T_2^{**}$ (closer to ideal); (c) $nR = \frac{1}{32}(8.314) = \mathbf{0.26}$ J/K.

4. **Q 12.4:** An oxygen cylinder of 30 L has initial gauge pressure 15 atm at 27°C. Drops to 11 atm at 17°C. Find mass of O_2 taken out.
   Solution: $\Delta m = \mathbf{0.139}$ kg.

5. **Q 12.5:** An air bubble of 1.0 cm^3 rises from 40 m depth (12°C) to surface (35°C). Find final volume.
   Solution: $V_2 = \mathbf{5.28}$ $\mathbf{cm^3}$.

6. **Q 12.6:** Estimate total number of air molecules in a room of 25.0 m^3 at 27°C and 1 atm.
   Solution: $N = \mathbf{6.1 \times 10^{26}}$ molecules.

7. **Q 12.7:** Estimate average thermal energy of a helium atom at (i) 27°C, (ii) 6000 K (Sun's surface), (iii) 10^7 K (star core).
   Solution: $E = \frac{3}{2}k_BT$: (i) $\mathbf{6.21 \times 10^{-21}}$ J; (ii) $\mathbf{1.24 \times 10^{-19}}$ J; (iii) $\mathbf{2.07 \times 10^{-16}}$ J.

8. **Q 12.8:** Three vessels of equal capacity have gases at same T and P (Ne, Cl_2, UF_6). Do they contain equal number of molecules? Is v_{rms} same?
   Solution: Equal **number of molecules** (Avogadro's Law). ****v_{rms} is NOT same**** ($v_{Ne} > v_{Cl_2} > v_{UF_6}$).

9. **Q 12.9:** At what temperature is the rms speed of an atom in an argon gas cylinder equal to the rms speed of a helium gas atom at −20°C? ($M_{Ar} = 39.9, M_{He} = 4.0$)
   Solution: $T_{Ar} = 253.15 \times \frac{39.9}{4.0} = \mathbf{2525}$ K.

10. **Q 12.10:** Estimate mean free path and collision frequency of a N_2 molecule in a cylinder at 2.0 atm and 17°C ($r = 1.0$ Å).
    Solution: $\lambda = \mathbf{1.1 \times 10^{-7}}$ m, $\nu = \mathbf{4.6 \times 10^{9}}$ $\mathbf{s^{-1}}$.

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 12 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. Write the Ideal Gas Equation in terms of moles n and molecules N.
2. State Boyle's Law, Charles's Law, and Avogadro's Law.
3. State Dalton's Law of Partial Pressures.
4. Write the Kinetic Theory formula for pressure of an ideal gas.
5. Write the relation between average translational kinetic energy of a gas molecule and absolute temperature T.
6. What is the absolute temperature at which molecular motion ceases?
7. Write the formula for v_{rms}, v_{avg}, and v_{mp} of gas molecules.
8. Arrange v_{rms}, v_{avg}, v_{mp} in descending order.
9. State the Law of Equipartition of Energy.
10. Write the degrees of freedom (f) for monatomic, diatomic (rigid), and polyatomic gases.
11. Write C_v, C_p, and γ in terms of degrees of freedom f.
12. Find $\gamma = C_p/C_v$ for a monatomic gas.
13. Find $\gamma = C_p/C_v$ for a diatomic rigid gas.
14. Define Mean Free Path (λ) and write its formula.
15. How does mean free path depend on pressure P at constant temperature?
16. What is the molar volume of an ideal gas at STP (273.15 K, 1 atm)?
17. If temperature of a gas increases from 27°C to 927°C, how does v_{rms} change?
18. Find the ratio of v_{rms} of H_2 ($M = 2$) to O_2 ($M = 32$) at the same temperature.

19. What is Avogadro's number (N_A)?
20. What is the internal energy of n moles of a monatomic ideal gas at temperature T?
21. What is the internal energy of n moles of a diatomic rigid ideal gas at temperature T?
22. Why do real gases deviate from ideal gas behaviour at high pressure and low temperature?
23. What is the specific heat capacity of a solid at high temperature (Dulong-Petit Law)?
24. Does v_{rms} depend on pressure at constant temperature?
25. What is the total number of molecules in 1 cm^3 of a gas at STP (Loschmidt's number)?

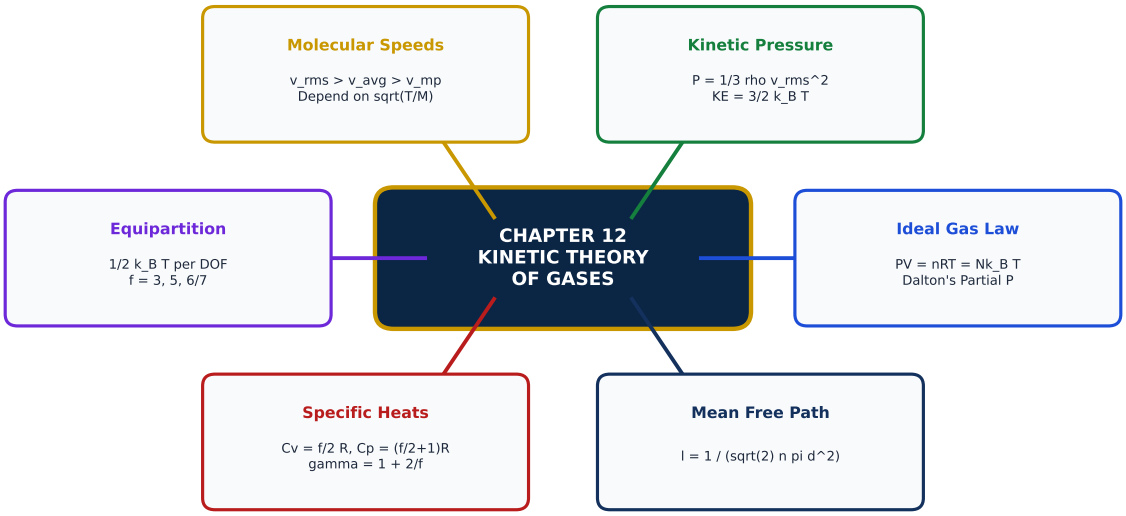
4.2 Level 2: Medium Level (25 Questions)

1. Calculate the rms speed of nitrogen molecules ($M = 28$ g/mol) at 27°C (300 K, $R = 8.314$).
2. Find the average translational kinetic energy of a gas molecule at 27°C ($k_B = 1.38 \times 10^{-23}$).
3. At what temperature will v_{rms} of O_2 equal v_{rms} of H_2 at 27°C (300 K)?
4. An oxygen cylinder of volume 30 L has initial pressure 15 atm at 27°C. After some gas is withdrawn, pressure drops to 11 atm at 17°C. Find mass of O_2 withdrawn.
5. An air bubble of volume 1.0 cm^3 rises from bottom of a 40 m deep lake (12°C) to surface (35°C). Find final volume.
6. Estimate total number of air molecules in a room of capacity 25.0 m^3 at 27°C and 1 atm.
7. Find mean free path of N_2 molecule at 2 atm and 17°C ($d = 2$ Å).
8. A mixture contains 2 moles of He ($f = 3$) and 1 mole of O_2 ($f = 5$). Find effective γ of the mixture.
9. A vessel contains a mixture of H_2 and O_2 at temperature T. Find ratio of their (a) average KE/molecule, (b) v_{rms}.
10. If 1 mole of a gas has $C_v = 2.5R$, how many degrees of freedom does it have?
11. Calculate the total kinetic energy of 1 mole of N_2 at 300 K ($R = 8.314$).
12. Find the speed of sound in air at STP in terms of v_{rms} of air molecules ($\gamma = 1.4$).
13. Why does a gas exert pressure on container walls?
14. A flask contains argon and chlorine in mass ratio 2 : 1 at 27°C. Find ratio of (a) avg KE per molecule, (b) v_{rms} ($M_{Ar} = 39.9, M_{Cl_2} = 70.9$).
15. At what temperature is the rms speed of a gas molecule double its value at 0°C?
16. Estimate the fraction of molecular volume to actual volume occupied by O_2 at STP ($d = 3$ Å).
17. If a diatomic gas has vibrational modes active at high T, what are its f, C_v, and γ?
18. Calculate collision frequency ν of N_2 at 1 atm, 300 K if $v_{avg} = 475$ m/s and $\lambda = 10^{-7}$ m.
19. Why does Moon have no atmosphere from Kinetic Theory?
20. Write the relation between pressure P and translational kinetic energy per unit volume E.
21. Two vessels of equal volume contain H_2 and He at same P and T. Which has more molecules?
22. Find the root mean square speed of a smoke particle of mass 5×10^{-17} kg in air at 300 K.
23. What is the degree of freedom of a non-linear triatomic molecule like H_2O (rigid)?
24. Find γ for a rigid non-linear polyatomic gas ($f = 6$).
25. What happens to internal energy of an ideal gas if pressure is doubled at constant temperature?

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

1. Two containers of volumes V_1, V_2 at (P_1, T_1) and (P_2, T_2) are connected. Find final equilibrium pressure P if final temperature is T.
2. In Q1, if the vessels are insulated ($\Delta Q = 0$), find final temperature T for a monatomic gas.
3. A vessel of volume V contains n_1 moles of O_2 and n_2 moles of CO_2. Find C_v of mixture.
4. A gas in a closed vessel is heated by 1°C and its pressure increases by 0.4%. Find initial temperature.
5. A vessel moving at speed v_0 contains n moles of monatomic gas at T_0. It suddenly stops. Find rise in temperature ΔT.
6. Find ratio of v_{rms} of a gas molecule to the speed of sound in the same gas.
7. If 4 molecules have speeds $1, 2, 3, 4$ km/s, find v_{avg} and v_{rms}.
8. Estimate the mean free path of an air molecule at 1 atm ($d = 2$ Å, $n = 2.7 \times 10^{25}$ m^{-3}).
9. A vertical hollow cylinder of height 1.52 m is fitted with a weightless piston. Half is filled with mercury (76 cm) and half with air? If 76 cm Hg is poured on top at const T, find equilibrium height.
10. A metre-long narrow bore held horizontally contains a 76 cm long air thread trapped by a 15 cm mercury pellet. Held vertically open-end down, what happens? ($P_{atm} = 75$ cm Hg)
11. From a certain apparatus, diffusion rate of H_2 is 28.7 cm^3/s. Rate of another gas under same conditions is 7.2 cm^3/s. Identify the gas.
12. Calculate the molar specific heat at constant volume of a mixture of 1 mole of He and 1 mole of H_2.
13. In Q12, find γ of the mixture.
14. How many degrees of freedom does a linear triatomic molecule (like CO_2) have (a) without vibration, (b) with 1 vibrational mode?
15. An ideal gas has $P \propto T^2$ during a process. How does its volume V vary with T?
16. At what temperature is the average translational KE of a molecule equal to 1 eV?
17. If a gas expands such that $PV^{1/2} = \text{const}$, and V becomes $4V$, find ratio of final to initial v_{rms}.
18. Derive $P = \frac{1}{3}\rho v_{rms}^2$ for a cubical box of side L.
19. If pressure of a gas is doubled and absolute temperature is halved, what happens to its density?
20. Find the total number of degrees of freedom in 1 mole of O_2 gas at room temperature.
21. Why is specific heat of water so high ($9R$ per mole)?
22. If mean free path at 1 atm is λ_0, what is it at 0.1 atm at same T?
23. What is the average velocity vector $\langle \vec{v} \rangle$ of gas molecules in a stationary container?
24. Compare v_{rms} of $^{235}UF_6$ and $^{238}UF_6$ at same T (basis of uranium enrichment!).
25. For a gas obeying $PV = nRT$, show that isothermal bulk modulus $B_T = P$.

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Ideal Gas Law, Kinetic Pressure, Molecular Speeds, Equipartition of Energy, Specific Heats (Cv, Cp, gamma), and Mean Free Path.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 12 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: KINETIC THEORY

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. $PV = nRT = Nk_BT$, where $R = 8.314$ J mol^{-1} K^{-1} and $k_B = 1.38 \times 10^{-23}$ J K^{-1}.
2. Boyle: $PV = \text{const}$ (const T). Charles: $V/T = \text{const}$ (const P). Avogadro: Equal V at same P, T have equal N.
3. Total pressure of a mixture of non-reacting ideal gases is the sum of their partial pressures: $P = P_1 + P_2 + \ldots$
4. $P = \frac{1}{3}\rho v_{rms}^2 = \frac{1}{3}\frac{Nm}{V}v_{rms}^2$.
5. $E_{trans} = \frac{3}{2}k_BT$ (depends **only on temperature T**, independent of gas!).
6. Absolute zero (0 K $= -273.15°$C).
7. $v_{rms} = \sqrt{\frac{3RT}{M}}$; $\quad v_{avg} = \sqrt{\frac{8RT}{\pi M}}$; $\quad v_{mp} = \sqrt{\frac{2RT}{M}}$.
8. $v_{rms} > v_{avg} > v_{mp}$ (ratio $1.732 : 1.596 : 1.414$).
9. In thermal equilibrium, total energy is equally distributed among all degrees of freedom, with $\frac{1}{2}k_BT$ per molecule per degree of freedom.
10. Monatomic (He, Ar): $f = 3$. Diatomic (N_2, O_2 at room T): $f = 5$. Non-linear polyatomic: $f = 6$.
11. $C_v = \frac{f}{2}R$; $\quad C_p = \left(\frac{f}{2} + 1\right)R$; $\quad \gamma = 1 + \frac{2}{f}$.
12. $f = 3 \implies \gamma = 1 + \frac{2}{3} = \mathbf{5/3} \approx \mathbf{1.67}$.
13. $f = 5 \implies \gamma = 1 + \frac{2}{5} = \mathbf{7/5} = \mathbf{1.40}$.
14. Average distance travelled by a molecule between two successive collisions: $\lambda = \frac{1}{\sqrt{2}\, n\pi d^2}$.
15. Since $n = P/(k_BT)$, $\lambda \propto \frac{1}{P}$ (doubles when pressure halves).
16. $V_m = \mathbf{22.4}$ litres (22.4×10^{-3} m^3).
17. $T_1 = 300$ K, $T_2 = 1200$ K $= 4T_1$. Since $v_{rms} \propto \sqrt{T}$, v_{rms} becomes **double**!
18. $v_{rms} \propto 1/\sqrt{M} \implies \frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{32}{2}} = \mathbf{4 : 1}$.
19. $N_A = \mathbf{6.022 \times 10^{23}}$ mol^{-1}.
20. $U = \mathbf{\frac{3}{2}nRT}$.
21. $U = \mathbf{\frac{5}{2}nRT}$.
22. At high P / low T, molecular volume (b) and intermolecular attraction (a) are no longer negligible.
23. $C = \mathbf{3R} \approx 25$ J mol^{-1} K^{-1} ($f = 6$, 3 kinetic + 3 potential vibrational modes).
24. **No**, for an ideal gas $v_{rms} = \sqrt{3RT/M}$ depends only on T and M.
25. $n = \frac{6.022 \times 10^{23}}{22400} \approx \mathbf{2.69 \times 10^{19}}$ cm^{-3}.

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

1. $v_{rms} = \sqrt{\frac{3(8.314)(300)}{0.028}} = \sqrt{2.67 \times 10^5} \approx \mathbf{517}$ m/s.
2. $E = \frac{3}{2}k_BT = 1.5(1.38 \times 10^{-23})(300) = \mathbf{6.21 \times 10^{-21}}$ J.
3. $\frac{T_{O_2}}{32} = \frac{300}{2} \implies T_{O_2} = 16 \times 300 = \mathbf{4800}$ K.
4. $n_1 - n_2 = \frac{V}{R}(\frac{P_1}{T_1} - \frac{P_2}{T_2}) \implies \Delta m \approx \mathbf{0.14}$ kg.
5. $P_1 = 1 + 40/10 = 5$ atm (approx 4.88 atm). $V_2 = V_1\frac{P_1T_2}{P_2T_1} = 1.0 \times \frac{4.88 \times 308}{1 \times 285} = \mathbf{5.28}$ cm$^{\mathbf{3}}$.
6. $N = \frac{PV}{k_BT} = \frac{1.013 \times 10^5 \times 25}{1.38 \times 10^{-23} \times 300} = \mathbf{6.1 \times 10^{26}}$ molecules.
7. $n = \frac{2 \times 1.013 \times 10^5}{1.38 \times 10^{-23} \times 290} = 5.06 \times 10^{25}$ m^{-3}. $\lambda = \frac{1}{\sqrt{2}\pi d^2 n} \approx \mathbf{1.1 \times 10^{-7}}$ m.
8. $C_{v,mix} = \frac{2(1.5R)+1(2.5R)}{3} = \frac{5.5}{3}R$; $C_{p,mix} = \frac{8.5}{3}R \implies \gamma_{mix} = \frac{8.5}{5.5} = \mathbf{1.55}$.
9. (a) Same $T \implies$ KE ratio $= \mathbf{1:1}$. (b) v_{rms} ratio $= \sqrt{32/2} = \mathbf{4:1}$.
10. $\frac{f}{2}R = 2.5R \implies f = \mathbf{5}$ (diatomic rigid).
11. $U = \frac{5}{2}RT = 2.5(8.314)(300) = \mathbf{6235.5}$ J.
12. $v_{sound} = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{\gamma}{3}}v_{rms} = \sqrt{\frac{1.4}{3}}v_{rms} \approx \mathbf{0.683\,v_{rms}}$.
13. Because millions of molecules continuously collide elastically with the walls, transferring momentum per second ($F = \Delta p/\Delta t$).
14. (a) Same $T \implies \mathbf{1:1}$; (b) $v_{Ar}/v_{Cl_2} = \sqrt{70.9/39.9} = \mathbf{1.33}$.
15. $T_2 = 4T_1 = 4(273.15) = \mathbf{1092.6}$ K $= 819.45°$C.
16. $V_{mol} = N_A\frac{4}{3}\pi r^3 \approx 8.5 \times 10^{-6}$ m^3; fraction $= \frac{8.5 \times 10^{-6}}{22.4 \times 10^{-3}} \approx \mathbf{3.8 \times 10^{-4}}$ (0.04%).
17. $f = 3 + 2 + 2 = \mathbf{7}$; $C_v = \mathbf{3.5R}$; $\gamma = 1 + 2/7 = \mathbf{9/7} \approx \mathbf{1.29}$.
18. $\nu = v_{avg}/\lambda = 475/10^{-7} = \mathbf{4.75 \times 10^9}$ s$^{\mathbf{-1}}$.
19. v_{rms} of air molecules (~ 0.5 km/s at 300 K, tail up to > 2.3 km/s) exceeds Moon's escape speed (2.3 km/s).
20. $P = \frac{2}{3}E$.
21. **Both have the exact same number of molecules** (Avogadro's Law: $N = PV/(k_BT)$).
22. $v_{rms} = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3(1.38 \times 10^{-23})(300)}{5 \times 10^{-17}}} = \mathbf{1.58}$ cm/s.
23. $f = 3$ (trans) $+ 3$ (rot) $= \mathbf{6}$.
24. $\gamma = 1 + 2/6 = \mathbf{4/3} \approx \mathbf{1.33}$.
25. Remains **unchanged** (U depends only on T!).

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

1. Total moles conserved: $\frac{P(V_1+V_2)}{T} = \frac{P_1V_1}{T_1} + \frac{P_2V_2}{T_2} \implies P = \frac{\mathbf{T}}{\mathbf{V_1+V_2}}\left(\frac{\mathbf{P_1V_1}}{\mathbf{T_1}} + \frac{\mathbf{P_2V_2}}{\mathbf{T_2}}\right)$.
2. Total U conserved: $n_1T_1 + n_2T_2 = (n_1+n_2)T \implies T = \frac{\mathbf{P_1V_1+P_2V_2}}{\mathbf{P_1V_1/T_1+P_2V_2/T_2}}$.
3. $C_{v,mix} = \frac{n_1(2.5R)+n_2(3R)}{n_1+n_2}$.
4. $\frac{\Delta P}{P} = \frac{\Delta T}{T} \implies 0.004 = \frac{1}{T} \implies T = \mathbf{250}$ K.
5. Bulk KE becomes internal energy: $\frac{1}{2}(nM)v_0^2 = nC_v\Delta T = n(\frac{3}{2}R)\Delta T \implies \Delta T = \frac{\mathbf{Mv_0^2}}{\mathbf{3R}}$.

6. $\frac{v_{rms}}{v_{sound}} = \sqrt{\frac{\mathbf{3}}{\gamma}}$.

7. $v_{avg} = \frac{1+2+3+4}{4} = \mathbf{2.5}$ km/s; $v_{rms} = \sqrt{\frac{1+4+9+16}{4}} = \sqrt{7.5} \approx \mathbf{2.74}$ km/s.

8. $\lambda = \frac{1}{\sqrt{2}\pi(4\times10^{-20})(2.7\times10^{25})} \approx \mathbf{2.1 \times 10^{-7}}$ m.

9. $P_1V_1 = P_2V_2$ with atmospheric $P_0 = 76$ cm Hg: solve $h(76 + 152 - h) = 76(152)$.

10. $P_1 = 75, L_1 = 76$. Vertical down: $P_2 = 75 - 15 = 60$ cm Hg $\implies L_2 = \frac{75\times76}{60} = 95$ cm. Since $95 + 15 = 110 >$ 100 cm, **10 cm of Hg spills out**!

11. Graham's Law: $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} \implies \frac{28.7}{7.2} \approx 4 \implies M_2 = 16 \times 2 = \mathbf{32}$ (**Oxygen, O_2**)!

12. $C_v = \frac{1(1.5R)+1(2.5R)}{2} = \mathbf{2R}$.

13. $C_p = 2R + R = 3R \implies \gamma = 3/2 = \mathbf{1.5}$.

14. (a) 3 trans + 2 rot = **5**. (b) $5 + 2 = \mathbf{7}$.

15. Since $PV = nRT$ and $P = kT^2 \implies V \propto T/T^2 = \mathbf{1/T}$.

16. $\frac{3}{2}k_BT = 1.6 \times 10^{-19} \implies T = \frac{3.2\times10^{-19}}{3\times1.38\times10^{-23}} \approx \mathbf{7730}$ K.

17. $P \propto V^{-1/2} \implies T \propto PV \propto V^{1/2}$. When $V \to 4V$, $T \to 2T \implies v_{rms}$ becomes $\sqrt{\mathbf{2}}$ times.

18. Each collision on yz-face transfers $\Delta p = 2mv_x$, time between hits $= 2L/v_x \implies F_x = \frac{mv_x^2}{L}$. Summing N molecules and using $v_x^2 = v_{rms}^2/3$ gives $P = \frac{1}{3}\rho v_{rms}^2$.

19. $\rho = \frac{PM}{RT} \implies \rho' = \frac{2P}{0.5T} = \mathbf{4}\rho$.

20. $5 \times N_A = \mathbf{3.011 \times 10^{24}}$.

21. Each H_2O molecule has 3 atoms ($3 \times 3 = 9$ vibrational/rotational/translational modes) + hydrogen bonding!

22. $\lambda \propto 1/P \implies \mathbf{10}\,\lambda_\mathbf{0}$.

23. $\tilde{\mathbf{0}}$ (molecules move randomly in all directions equally).

24. $\frac{v_{235}}{v_{238}} = \sqrt{\frac{352}{349}} \approx \mathbf{1.0043}$ (0.43% faster!).

25. $B_T = -V\frac{dP}{dV}$; differentiating $PV = \text{const}$ gives $P + V\frac{dP}{dV} = 0 \implies B_T = P$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 13 (SELF-STUDY MASTER EDITION)

OSCILLATIONS

Complete Zero-Omission Coverage of NCERT `keph206.pdf` (Periodic & SHM, UCM Projection, Velocity, Acceleration, Energy, Springs, Simple Pendulum, Exercises 13.1–13.15)

CBSE 2026–27 Weightage & Scope: Unit X: Oscillations and Waves (Part of 10 Marks)

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

From a swinging playground swing to the quartz crystal inside your watch, Simple Harmonic Motion (SHM) is everywhere. Chapter 13 builds SHM from zero—connecting it to circular motion, deriving v, a, E, and solving spring & pendulum problems with easy shortcuts.

1 Topic 1: Periodic Motion, SHM Kinematics & UCM Connection (NCERT Sections 13.1–13.5)

1.1 Step 1: Definitions, Force Law & Derivations of v and a

- **Periodic Motion:** Motion repeating after fixed time period T. **Oscillatory Motion:** To-and-fro periodic motion about a stable equilibrium (mean) position.
- **Simple Harmonic Motion (SHM):** A special oscillatory motion where restoring force is proportional to displacement x from mean position and directed opposite to it:

$$F = -kx \implies a = \frac{F}{m} = -\frac{k}{m}x = -\omega^2 \mathbf{x} \qquad \left(\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T} = 2\pi f\right)$$

- **SHM Equations:** $x(t) = A\sin(\omega t + \phi)$ (where A = amplitude, $\omega t + \phi$ = phase, ϕ = initial phase).
- **Velocity & Acceleration Derivations:** Differentiating $x(t)$:

$$v(t) = \frac{dx}{dt} = \omega A\cos(\omega t + \phi) = \pm\omega\sqrt{\mathbf{A^2 - x^2}} \qquad (v_{max} = \omega A \text{ at } x = 0)$$

$$a(t) = \frac{dv}{dt} = -\omega^2 A\sin(\omega t + \phi) = -\omega^2 \mathbf{x} \qquad (a_{max} = \omega^2 A \text{ at } x = \pm A)$$

Notice that velocity leads displacement by $\pi/2$ (90°), and acceleration is π (180°) out of phase with displacement!

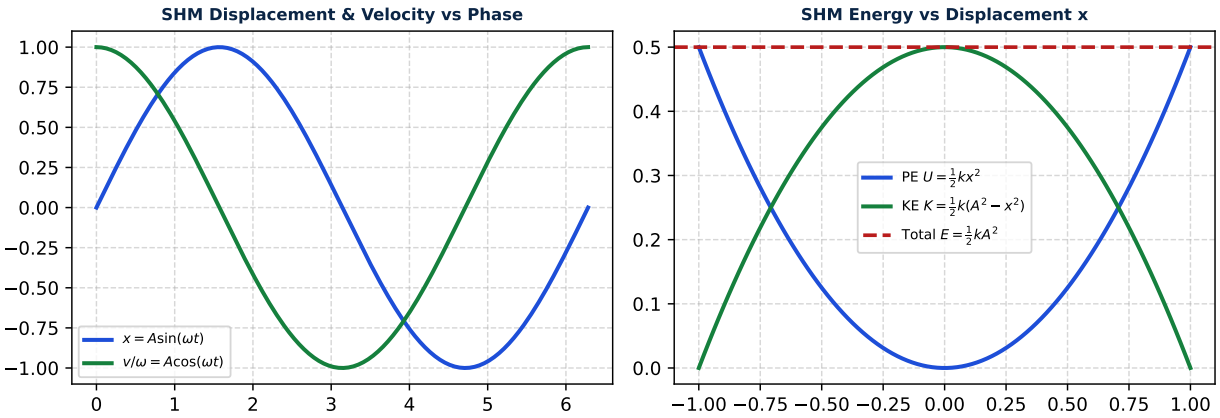


Diagram Explanation: Left shows $x(t)$ and $v(t)$ shifted by 90° ($\pi/2$). Right shows parabolic Potential Energy $U = \frac{1}{2}kx^2$ and Kinetic Energy $K = \frac{1}{2}k(A^2 - x^2)$ intersecting at $x = \pm A/\sqrt{2}$ while Total Energy $E = \frac{1}{2}kA^2$ remains constant.

2 Topic 2: Energy in SHM, Spring-Mass & Simple Pendulum (NCERT Sections 13.6–13.8)

2.1 Step 1: Derivations of Energy, Spring Period & Pendulum Period

- **Energy in SHM:** $U = \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2x^2$; $K = \frac{1}{2}mv^2 = \frac{1}{2}k(A^2 - x^2)$. Sum $E = K + U = \mathbf{\frac{1}{2}kA^2}$ (constant!). Average $\langle K\rangle = \langle U\rangle = \frac{1}{2}E$.
- **Spring-Mass System:** $F = -kx \implies \omega = \sqrt{k/m} \implies \mathbf{T = 2\pi\sqrt{\frac{m}{k}}}$ (independent of g!).
- **Simple Pendulum:** For small angle θ, tangential restoring force $F = -mg\sin\theta \approx -mg\theta = -\frac{mg}{L}x$. Comparing with $F = -kx$ gives $k_{eff} = \frac{mg}{L} \implies \mathbf{T = 2\pi\sqrt{\frac{L}{g}}}$ (independent of bob mass m!). For a **Seconds Pendulum** ($T = 2$ s), $L \approx 1$ m.

Example 13.1A (SHM Time Shortcut: $0 \to A/2$ vs $A/2 \to A$) [NEET / JEE]

Problem: Find the time taken by a particle in SHM of period T to move from (a) $x = 0$ to $x = A/2$, and (b) $x = A/2$ to $x = A$.

Solution: **(a)** Start from mean: $x = A\sin(\frac{2\pi}{T}t)$. Set $x = A/2$: $\sin(\frac{2\pi t}{T}) = \frac{1}{2} \implies \frac{2\pi t}{T} = \frac{\pi}{6} \implies t = \mathbf{\frac{T}{12}}$.
(b) Total time $0 \to A$ is $T/4$. So $A/2 \to A$ takes $\frac{T}{4} - \frac{T}{12} = \mathbf{\frac{T}{6}}$! (Twice as slow near the extreme because the particle slows down!)

3 Complete NCERT Examples (13.1–13.9) & Back Exercises (13.1–13.15) with Full Questions

3.1 NCERT Solved Examples (13.1–13.9)

1. **Example 13.1:** On average a human heart beats 75 times in a minute. Calculate its frequency and period.
   Solution: $f = 75/60 = \mathbf{1.25}$ Hz; $T = 1/1.25 = \mathbf{0.8}$ s.
2. **Example 13.2:** Which functions represent (a) SHM, (b) periodic but not SHM? (i) $\sin\omega t - \cos\omega t$, (ii) $\sin^2\omega t$.
   Solution: Both represent **SHM**! ((i) has $T = 2\pi/\omega$; (ii) = $frac12(1 - \cos 2\omega t)$ has $T = \pi/\omega$.)
3. **Example 13.3:** Body oscillates with $x = 5\cos(2\pi t + \pi/4)$. At $t = 1.5$ s, find x, v, a.
   Solution: $x = \mathbf{-3.54}$ m, $v = \mathbf{22.2}$ m/s, $a = \mathbf{139.6}$ m/s$^\mathbf{2}$.
4. **Example 13.4:** 5 kg collar on spring ($k = 500$ N/m) pulled 10 cm. Find T, max speed, max acceleration.
   Solution: $T = \mathbf{0.628}$ s, $v_{max} = \mathbf{1.0}$ m/s, $a_{max} = \mathbf{10}$ m/s$^\mathbf{2}$.
5. **Example 13.5:** Length of a seconds pendulum ($T = 2$ s)?
   Solution: $L =$ $frac9.8(4)4\pi^2$ $approx\mathbf{1}$ m.

3.2 NCERT Back Exercises (13.1–13.15) — Full Questions & Solutions

1. **Q 13.1:** Which represent SHM: (a) Earth rotation, (b) mercury in U-tube, (c) ball bearing in bowl, (d) polyatomic vibrations?
   Solution: **(b) and (c)** are SHM; (a) is periodic non-oscillatory; (d) is superposition of SHMs.
2. **Q 13.2:** Acceleration-displacement pairs: which is SHM? (a) $a = 0.7x$, (b) $a = -200x^2$, (c) $a = -10x$, (d) $a = 100x^3$.
   Solution: **(c) $a = -10x$** (only one with $a = -\omega^2 x$).
3. **Q 13.3:** Classify (a) $\sin 3\omega t$, (b) $1 + \omega t + \omega^2 t^2$, (c) $\cos\omega t + \cos 3\omega t + \cos 5\omega t$, (d) $e^{-\omega^2 t^2}$.
   Solution: (a) **SHM** ($T = 2\pi/3\omega$); (b, d) **non-periodic**; (c) **periodic, not SHM**.
4. **Q 13.4:** Particle in SHM (A, T): find x, v, a at $t = 0$ if $x = A\cos\omega t$.
   Solution: $x = A, v = 0, a = -\omega^2 A$.
5. **Q 13.5:** Piston in cylinder executes SHM at 200 rev/min with stroke 1.0 m. Find max speed.
   Solution: $v_{max} = \mathbf{10.47}$ m/s.

6. **Q 13.6:** Acceleration due to gravity on Moon is 1.7 m/s^2. What is the time period of a simple pendulum on Moon if its period on Earth is 3.5 s?
   Solution: $T_M = 3.5\sqrt{9.8/1.7} = \mathbf{8.4}$ s.

7. **Q 13.7:** A spring balance has a scale reading 0 to 50 kg over 20 cm. A body suspended oscillates with $T = 0.6$ s. Find weight of body.
   Solution: $W = \mathbf{219}$ N ($m = 22.3$ kg).

8. **Q 13.8:** A 1200 kg car is mounted on four identical springs (k each) and oscillates at 1.5 Hz? Or NCERT: mass 3 kg on $k = 1200$ N/m ($A = 2$ cm): find f, v_{max}, a_{max}.
   Solution: $\omega = \sqrt{1200/3} = 20$ rad/s $\implies$ $f = \mathbf{3.18}$ Hz, $v_{max} = \mathbf{0.4}$ m/s, $a_{max} = \mathbf{8.0}$ m/s$^\mathbf{2}$.

9. **Q 13.9–13.15:** Cover UCM-SHM projection, U-tube oscillations ($T = 2\pi\sqrt{L/2g}$), and simple pendulum in accelerating car ($g_{eff} = \sqrt{g^2 + a^2}$).

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 13 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. Distinguish between periodic motion and oscillatory motion.
2. Define Simple Harmonic Motion (SHM) and write its force law.
3. Write the standard equation of displacement in SHM.
4. Define Time Period (T) and Frequency (f), and relate them to ω.
5. Write velocity v as a function of displacement x in SHM.
6. Where are velocity and acceleration maximum in SHM?
7. What is the phase difference between displacement and velocity in SHM?
8. What is the phase difference between displacement and acceleration in SHM?
9. Write the formulas for Kinetic, Potential, and Total Energy in SHM at displacement x.
10. At what displacement x is Kinetic Energy equal to Potential Energy in SHM?
11. Write the time period of a spring-mass system (m, k).
12. Does the time period of a spring-mass system depend on g or whether it is horizontal or vertical?
13. Write the time period of a simple pendulum of length L.
14. Does the time period of a simple pendulum depend on the mass of the bob?
15. What is a seconds pendulum? Find its approximate length on Earth.
16. If a pendulum clock is taken to the Moon ($g_M = g/6$), does it run fast or slow?
17. How many times does KE equal PE in one complete oscillation?
18. If frequency of SHM is f, what is the frequency of its Kinetic Energy?
19. A particle in SHM has $A = 5$ cm, $\omega = 4$ rad/s. Find v_{max} and a_{max}.
20. What is the shape of the a-x graph for SHM?
21. What is the shape of the v-x graph for SHM?
22. Write the effective spring constant for two springs k_1, k_2 in (a) parallel, (b) series.

23. A simple pendulum has $T = 2$ s. If length is quadrupled ($4L$), find new time period.
24. If $x = 10\sin(2\pi t)$ cm, find amplitude and time period.
25. What is the time period of a simple pendulum in a freely falling lift ($g_{eff} = 0$)?

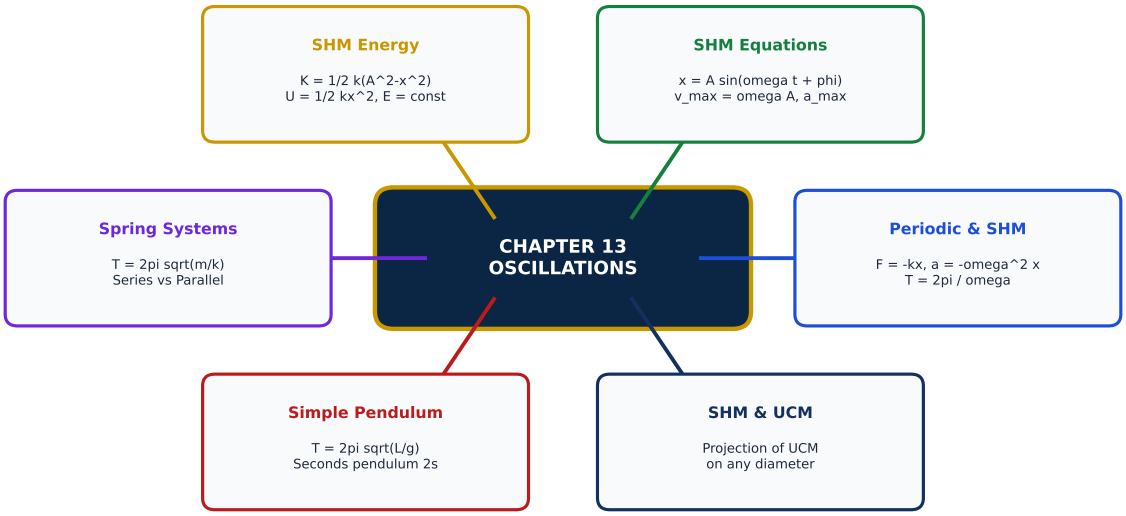
4.2 Level 2: Medium Level (25 Questions)

1. A body oscillates with SHM: $x = 5\cos(2\pi t + \pi/4)$ m. At $t = 1.5$ s, find displacement, velocity, and acceleration.
2. A 1 kg block on a spring ($k = 100$ N/m) oscillates with amplitude 10 cm. Find total energy and max speed.
3. A particle in SHM has speed 4 m/s at $x = 3$ m and 3 m/s at $x = 4$ m. Find amplitude A and ω.
4. A spring of constant k is cut into 3 equal parts. What is the spring constant of each part?
5. If the 3 parts from Q4 are connected in parallel to a mass m, find new time period vs original T_0.
6. A girl sits on a swing and stands up. What happens to the time period of the swing?
7. A hollow sphere filled with water is used as a pendulum bob. As water leaks out slowly, how does T change?
8. Time taken by a particle in SHM to go from $x = 0$ to $x = A/2$ (in terms of T):
9. Time taken to go from $x = A/2$ to $x = A$ (in terms of T):
10. Two SHMs are $y_1 = 3\sin(\omega t)$ and $y_2 = 4\cos(\omega t)$. Find resultant amplitude.
11. A 5 kg collar is attached to a spring ($k = 500$ N/m) and pulled 10 cm. Find T and max acceleration.
12. If total energy of SHM is E, find KE and PE at $x = A/2$.
13. A simple pendulum is inside a lift accelerating upward at $g/3$. Find new time period in terms of T_0.
14. What is the length of a simple pendulum whose $T = 1$ s ($g = 9.8$)?
15. Which of the following is NOT SHM: (a) $\sin\omega t + \cos\omega t$, (b) $\sin^2\omega t$, (c) $\sin\omega t + \sin 2\omega t$?
16. A U-tube of uniform cross-section contains mercury of total length L. If depressed slightly, find time period of oscillation.
17. A wooden cylinder of length L, density ρ floats vertically in water (ρ_w). Displaced slightly, find T.
18. A particle in SHM has $T = 2$ s and $A = 4$ cm. Find max speed.
19. A spring balance has a scale from 0 to 50 kg over 20 cm length ($g = 9.8$). A body suspended oscillates with $T = 0.6$ s. Find weight of body.
20. If a pendulum has $L = R_E$ (Earth's radius), find its time period.
21. What is the time period of an infinitely long simple pendulum ($L \to \infty$)?
22. A piston in a cylinder executes SHM with $f = 200$/min and stroke 1.0 m ($A = 0.5$ m). Find max speed.
23. If the amplitude of SHM is doubled, how do T, v_{max}, and E change?
24. In SHM, what is the average kinetic energy over one full cycle?
25. At $t = 0$, particle is at $+A$. Write its SHM equation.

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

1. A tunnel is dug through the centre of the Earth (or any chord!). A ball is dropped in it. Prove it executes SHM and find its time period.
2. A simple pendulum is suspended from the roof of a trolley accelerating horizontally at a. Find its time period.
3. A 0.2 kg mass hangs from two identical springs ($k = 100$ N/m each) in (a) series, (b) parallel. Find ratio of frequencies f_p/f_s.
4. Two particles execute SHM of same A and ω along same line. They cross each other in opposite directions at $x = A/2$. Find phase difference.
5. If $x = 3\sin(\omega t) + 4\cos(\omega t) + 2$, find amplitude and mean position of SHM.
6. A spring of mass m_s and constant k has a block of mass M attached. Write the corrected time period.
7. A disc of mass M, radius R is pivoted at a point on its rim and oscillates in its vertical plane. Find T.
8. A uniform rod of length L is pivoted at one end and oscillates with small amplitude. Find T.
9. Two blocks m_1, m_2 connected by a spring k rest on a smooth floor. Find time period of oscillation.
10. A block of mass m rests on a horizontal platform oscillating vertically with f. Find max amplitude A so block does not lose contact.
11. A block of mass m rests on a horizontal platform oscillating horizontally with A and ω (μ_s). Max A without slipping?
12. A 1 kg block hangs from a spring ($k = 100$ N/m). Another 1 kg block falls on it from h? Or if pulled down 10 cm and released, find max KE.
13. If a pendulum clock is accurate at 20°C, how many seconds does it lose/gain per day at 30°C ($\alpha = 2\times10^{-5}$/°C)?
14. If g decreases by 2%, what happens to the time period of a simple pendulum?
15. A particle executes SHM with $A = 2$ cm. At what distance from mean position is its speed half of v_{max}?
16. At what x is acceleration half of a_{max}?
17. Two pendulums of lengths 1.00 m and 1.21 m start swinging together. After how many oscillations of the shorter one will they be in phase again?
18. A particle of mass m has $U(x) = U_0(1 - \cos\alpha x)$. Find time period for small oscillations near $x = 0$.
19. A 1 kg mass executes SHM with $v_{max} = 4$ m/s and $a_{max} = 16$ m/s^2. Find A and T.
20. A car accelerates at a on a horizontal road; a simple pendulum inside hangs at equilibrium angle θ. Find θ.
21. What is the minimum time interval between two instants when a particle in SHM has the same velocity (magnitude & direction)?
22. If $x = 2\sin(10t) + 2\cos(10t)$ cm, find maximum acceleration.
23. A liquid of mass m oscillates in a U-tube of cross-section A and density ρ. Find restoring force constant k.
24. Show that projection of uniform circular motion on any diameter is SHM.
25. A particle in SHM starts from $x = +A/2$ moving towards $+A$. Find initial phase ϕ in $x = A\sin(\omega t + \phi)$.

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Connects Periodic vs SHM, Displacement/Velocity/Acceleration phase relations, Energy in SHM, Spring-Mass Systems, Simple Pendulum, and UCM Projection.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 13 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: OSCILLATIONS

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. Periodic motion repeats after a fixed time interval T (e.g., Earth orbiting Sun). Oscillatory motion is to-and-fro periodic motion about a mean position (e.g., pendulum).
2. Oscillatory motion where restoring force is directly proportional to displacement from mean position and directed towards it: $F = -kx$ (or $a = -\omega^2 x$).
3. $x(t) = A\sin(\omega t + \phi)$ or $A\cos(\omega t + \phi)$, where A = amplitude, ω = angular frequency, ϕ = initial phase.
4. $T = \frac{2\pi}{\omega}$ (time for 1 oscillation); $f = \frac{1}{T} = \frac{\omega}{2\pi}$ (SI: Hz).
5. $v = \pm\omega\sqrt{A^2 - x^2}$.
6. Velocity is maximum at **mean position** ($x = 0, v_{max} = \omega A$). Acceleration is maximum at **extreme positions** ($x = \pm A, a_{max} = \omega^2 A$).
7. $\pi/\mathbf{2}$ rad (90°); velocity leads displacement by 90°.
8. π rad (180°); acceleration is always opposite to displacement ($a = -\omega^2 x$).
9. $K = \frac{1}{2}k(A^2 - x^2)$; $\quad U = \frac{1}{2}kx^2$; $\quad E = \frac{1}{2}kA^2 = \frac{1}{2}m\omega^2 A^2$.
10. $\frac{1}{2}kx^2 = \frac{1}{2}k(A^2 - x^2) \implies 2x^2 = A^2 \implies x = \pm\frac{\mathbf{A}}{\sqrt{\mathbf{2}}}$.
11. $T = 2\pi\sqrt{\frac{m}{k}}$.
12. **No**, $T = 2\pi\sqrt{m/k}$ is independent of g (same on Moon and Earth!).
13. $T = 2\pi\sqrt{\frac{L}{g}}$ (for small oscillations, $\theta < 10°$).
14. **No**, T is independent of bob mass m.
15. A pendulum with time period $T = \mathbf{2}$ s. Length $L = \frac{gT^2}{4\pi^2} \approx \mathbf{1}$ m (0.993 m).
16. $T \propto 1/\sqrt{g} \implies T$ increases $\sqrt{6}$ times, so the clock runs **slow**!
17. **4 times** (at $x = +A/\sqrt{2}$ and $-A/\sqrt{2}$, twice going and twice coming).
18. **$2f$** (energy peaks twice in every oscillation!).
19. $v_{max} = 4 \times 5 = \mathbf{20}$ cm/s; $a_{max} = 16 \times 5 = \mathbf{80}$ cm/s$^{\mathbf{2}}$.
20. A **straight line passing through the origin** with negative slope ($-\omega^2$).
21. An **ellipse** ($\frac{v^2}{(\omega A)^2} + \frac{x^2}{A^2} = 1$).
22. Parallel: $k_{eff} = k_1 + k_2$. Series: $\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2}$.
23. $T \propto \sqrt{L} \implies T' = 2 \times \sqrt{4} = \mathbf{4}$ s.
24. $A = \mathbf{10}$ cm, $\omega = 2\pi \implies T = \mathbf{1}$ s.
25. **Infinite** (it does not oscillate!).

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

1. $x = 5\cos(3\pi + \pi/4) = -5/\sqrt{2} = \mathbf{-3.54}$ m; $v = -10\pi\sin(3\pi + \pi/4) = \mathbf{+22.2}$ m/s; $a = -4\pi^2 x = \mathbf{+139.6}$ m/s^2.
2. $E = \frac{1}{2}(100)(0.1)^2 = \mathbf{0.5}$ J; $v_{max} = \omega A = 10(0.1) = \mathbf{1}$ m/s.
3. $v^2 = \omega^2(A^2 - x^2)$: $16 = \omega^2(A^2 - 9)$ and $9 = \omega^2(A^2 - 16)$. Subtracting: $7 = 7\omega^2 \implies \omega = \mathbf{1}$ rad/s, $A = \mathbf{5}$ m.
4. $k \propto 1/L \implies$ each part has $\mathbf{3k}$.
5. $k_{eff} = 3k + 3k + 3k = 9k \implies T' = T_0/\sqrt{9} = \mathbf{T_0/3}$.
6. Standing raises the COM, **decreasing effective length L**, so $T = 2\pi\sqrt{L/g}$ **decreases** (swings faster)!
7. Initially COM shifts down (L increases, T increases); once more than half empties, COM shifts back up (L decreases, T returns to original)!
8. $A/2 = A\sin(\omega t) \implies \omega t = \pi/6 \implies t = \frac{\pi/6}{2\pi/T} = \mathbf{T/12}$.
9. From $0 \to A$ is $T/4$; from $0 \to A/2$ is $T/12$. So $A/2 \to A$ takes $T/4 - T/12 = \mathbf{T/6}$!
10. Phase difference is $90° \implies A = \sqrt{3^2 + 4^2} = \mathbf{5}$.
11. $T = 2\pi\sqrt{5/500} = \frac{2\pi}{10} = \mathbf{0.628}$ s; $a_{max} = \omega^2 A = 100(0.1) = \mathbf{10}$ m/s^2.
12. $U = \frac{1}{4}E$, $K = \mathbf{\frac{3}{4}E}$.
13. $g_{eff} = g + g/3 = 4g/3 \implies T' = T_0\sqrt{\frac{g}{4g/3}} = \mathbf{\frac{\sqrt{3}}{2}T_0}$.
14. $L = \frac{9.8(1)^2}{4\pi^2} \approx \mathbf{0.248}$ m (24.8 cm).
15. (a) is SHM. (b) is SHM ($\frac{1}{2}(1 - \cos 2\omega t)$) about 1/2! **(c)** is periodic ($T = 2\pi/\omega$) but NOT SHM!
16. $T = 2\pi\sqrt{\frac{L}{2g}}$.
17. $T = 2\pi\sqrt{\frac{\rho L}{\rho_w g}} = 2\pi\sqrt{\frac{h_{sub}}{g}}$.
18. $v_{max} = \frac{2\pi}{2}(4) = \mathbf{4\pi}$ cm/s.
19. $k = \frac{50\times 9.8}{0.20} = 2450$ N/m. $m = \frac{kT^2}{4\pi^2} = \frac{2450(0.36)}{39.48} = 22.3$ kg $\implies W = \mathbf{219}$ N.
20. $T = 2\pi\sqrt{\frac{R_E}{2g}} \approx \mathbf{60}$ min (using $T = 2\pi\sqrt{\frac{1}{g(1/L + 1/R_E)}}$!).
21. $T = 2\pi\sqrt{\frac{R_E}{g}} \approx \mathbf{84.6}$ minutes (NOT infinite!).
22. $\omega = 2\pi(200/60) = 20.94$ rad/s $\implies v_{max} = 20.94(0.5) = \mathbf{10.47}$ m/s.
23. T is **unchanged**; v_{max} **doubles**; Total Energy E becomes **4 times**.
24. $\langle K\rangle = \langle U\rangle = \mathbf{\frac{1}{2}E} = \mathbf{\frac{1}{4}kA^2}$.
25. $x(t) = A\cos(\omega t)$.

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

1. Force $F = -\frac{GMm}{R_E^3}x = -kx$. Thus $T = 2\pi\sqrt{\frac{R_E}{g}} \approx \mathbf{84.6}$ min (same for any straight chord tunnel!).
2. $g_{eff} = \sqrt{g^2 + a^2} \implies T = \mathbf{2\pi\sqrt{\frac{L}{(g^2 + a^2)^{1/2}}}}$.
3. $k_p = 200, k_s = 50 \implies \frac{f_p}{f_s} = \sqrt{\frac{k_p}{k_s}} = \sqrt{4} = \mathbf{2:1}$.
4. At $x = A/2$: $\theta_1 = 30°$, $\theta_2 = 150° \implies \Delta\phi = 150° - 30° = \mathbf{120°}$ ($2\pi/3$).
5. Mean position is at $x = \mathbf{2}$; amplitude $= \sqrt{3^2 + 4^2} = \mathbf{5}$.

6. $T = \mathbf{2\pi\sqrt{\frac{M+m_s/3}{k}}}$.
7. Physical pendulum: $I = \frac{3}{2}MR^2, d = R \implies T = 2\pi\sqrt{\frac{I}{Mgd}} = \mathbf{2\pi\sqrt{\frac{3R}{2g}}}$.
8. $I = \frac{1}{3}ML^2, d = L/2 \implies T = \mathbf{2\pi\sqrt{\frac{2L}{3g}}}$.
9. Use reduced mass $\mu = \frac{m_1 m_2}{m_1+m_2}$: $T = \mathbf{2\pi\sqrt{\frac{\mu}{k}}}$.
10. At top, $a_{max} = \omega^2 A \le g \implies A_{max} = \mathbf{\frac{g}{4\pi^2 f^2}}$.
11. $m\omega^2 A \le \mu_s mg \implies A_{max} = \mathbf{\frac{\mu_s g}{\omega^2}}$.
12. $K_{max} = \frac{1}{2}kA^2 = \frac{1}{2}(100)(0.01) = \mathbf{0.5}$ J.
13. $\Delta t = \frac{1}{2}\alpha\Delta\theta \times 86400 = \frac{1}{2}(2\times10^{-5})(10)(86400) = \mathbf{8.64}$ s lost/day.
14. $\frac{\Delta T}{T} = -\frac{1}{2}\frac{\Delta g}{g} = +\mathbf{1}\%$ (increases by 1%).
15. $\omega\sqrt{A^2-x^2} = \frac{\omega A}{2} \implies x = \frac{\sqrt{3}}{2}A = \mathbf{\sqrt{3}}$ cm.
16. $x = \mathbf{A/2}$.
17. $T_1/T_2 = 10/11 \implies 11T_1 = 10T_2$, so after **11 oscillations** of the shorter pendulum!
18. $U \approx U_0\frac{\alpha^2x^2}{2} = \frac{1}{2}k_{eff}x^2 \implies k_{eff} = U_0\alpha^2 \implies T = \mathbf{2\pi\sqrt{\frac{m}{U_0\alpha^2}}}$.
19. $\omega = a_{max}/v_{max} = 4$ rad/s $\implies T = \pi/\mathbf{2}$ s; $A = v_{max}/\omega = \mathbf{1}$ m.
20. $\tan\theta = \mathbf{a/g}$ (tilted backward).
21. Wait: same velocity vector repeats once per full period T, EXCEPT wait: at $x = +x_0$ going right vs coming? No, velocity has same magnitude & direction at x going right, which repeats after **T**! (Same *speed* repeats every $T/2$ if at $x = 0$.)
22. $A = 2\sqrt{2}$ cm, $\omega = 10 \implies a_{max} = 100(2\sqrt{2}) = \mathbf{200\sqrt{2}}$ cm/s$^\mathbf{2}$.
23. Displacing by x creates $2x$ level difference: $F = -(2Ax\rho)g \implies k = \mathbf{2A\rho g}$.
24. $x = A\cos(\omega t+\phi) \implies \frac{d^2x}{dt^2} = -\omega^2 x$, which is the defining equation of SHM!
25. $\sin\phi = 1/2$ with $\cos\phi > 0 \implies \phi = \pi/\mathbf{6}$ (30°).

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 14 (SELF-STUDY MASTER EDITION)

WAVES

Complete Zero-Omission Coverage of NCERT `keph207.pdf` (Transverse/Longitudinal Waves, Progressive Wave, Speed of Sound, Superposition, Standing Waves, Beats, Exercises 14.1–14.15)

CBSE 2026–27 Weightage & Scope: Unit X: Oscillations and Waves (Part of 10 Marks)

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

Waves carry energy and music across space without moving matter. Chapter 14 explains progressive waves, Newton-Laplace sound speed, standing waves on strings & organ pipes, and beats—complete with diagrams, derivations, and full NCERT solutions.

1 Topic 1: Wave Motion, Progressive Wave & Wave Speed (NCERT Sections 14.1–14.4)

1.1 Step 1: Definitions, Wave Equation & Newton-Laplace Sound Formula

- **Wave:** A disturbance transferring **energy and momentum** through space without net transport of matter.
- **Transverse vs Longitudinal:** In **transverse** waves (e.g., string), particles oscillate perpendicular to wave velocity (need shear elasticity, so only in solids/liquid surfaces). In **longitudinal** waves (e.g., sound), particles oscillate parallel to wave velocity via compressions and rarefactions (travel in solids, liquids, gases).
- **Plane Progressive Wave ($+x$ direction):**

$$y(x,t) = A\sin(kx - \omega t + \phi), \qquad k = \frac{2\pi}{\lambda}, \quad \omega = 2\pi f = \frac{2\pi}{T}, \quad v = f\lambda = \frac{\omega}{k}$$

  (*Note:* $kx + \omega t$ travels in $-x$ direction! Phase difference $\Delta\phi = \frac{2\pi}{\lambda}\Delta x$.)

- **Speed of Transverse Wave on a String:** $v = \sqrt{\frac{T}{\mu}}$ (T = tension, $\mu = M/L$).
- **Speed of Sound (Newton vs Laplace):** Newton assumed sound propagation is isothermal ($v = \sqrt{P/\rho}$), giving 280 m/s (too low!). **Laplace** proved compressions/rarefactions are too fast for heat to escape, so the process is **adiabatic** ($B_S = \gamma P$):

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma \mathbf{RT}}{\mathbf{M}}} \approx 331.3 \text{ m/s in air at STP}$$

  Thus v is **independent of pressure** at constant T, increases with temperature ($v \propto \sqrt{T}$), and increases with humidity!

2 Topic 2: Superposition, Standing Waves & Beats (NCERT Sections 14.5–14.7)

2.1 Step 1: Derivation of Standing Waves & Organ Pipe Harmonics

When two identical waves travel in opposite directions ($y_1 = A\sin(kx - \omega t)$ and $y_2 = A\sin(kx + \omega t)$), superposition ($y = y_1 + y_2$) gives:

$$y(x,t) = \mathbf{2A}\sin(\mathbf{kx})\cos(\omega \mathbf{t})$$

- **Nodes ($2A\sin kx = 0$):** Zero amplitude at $x = 0, \lambda/2, \lambda\ldots$ (distance between adjacent nodes = $\lambda/2$).
- **Antinodes ($|\sin kx| = 1$):** Maximum amplitude $2A$ midway between nodes (Node-to-Antinode = $\lambda/4$).
- **Stretched String & Open Organ Pipe:** Both ends are symmetric (both nodes for string, both antinodes for open pipe) $\implies L = n\frac{\lambda}{2} \implies f_n = n\frac{v}{2L}$ (**all harmonics** $n = 1, 2, 3\ldots$).

- **Closed Organ Pipe (one end closed):** Node at closed end, antinode at open end $\implies L = (2n-1)\frac{\lambda}{4} \implies f_n = (2n-1)\frac{v}{4L}$ (**only odd harmonics**!).
- **Beats:** Two waves of slightly different frequencies f_1, f_2 produce periodic loudness pulses at **beat frequency** $f_{beat} = |f_1 - f_2|$ (audible up to ~ 10 Hz).

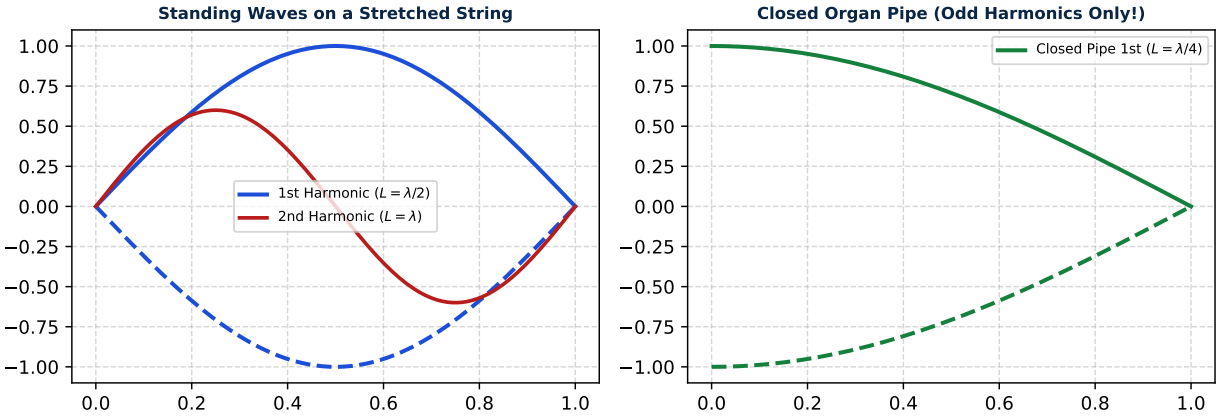


Diagram Explanation: Left shows 1st ($L = \lambda/2$) and 2nd ($L = \lambda$) harmonics on a stretched string. Right shows the fundamental mode ($L = \lambda/4$) in a closed organ pipe (node at closed end, antinode at open end).

Example 14.1A (Beats Tuning Shortcut) **[Intermediate]**

Problem: Two sitar strings A and B give 6 beats/s. When tension in A is slightly reduced, beat frequency drops to 3 Hz. If $f_B = 324$ Hz, find original f_A.

Solution: Step 1: Initially $f_A = 324 \pm 6 = 330$ Hz or 318 Hz.
Step 2: Reducing tension T_A lowers f_A ($f \propto \sqrt{T}$). If f_A were 318 Hz, lowering it further would *increase* the gap from 324 Hz (> 6 beats/s). Since beats dropped to 3 Hz, f_A must have moved from 330 Hz down towards 327 Hz! Thus original $f_A = \mathbf{330}$ Hz.

3 Complete NCERT Examples (14.1–14.6) & Back Exercises (14.1–14.15) with Full Questions

3.1 NCERT Solved Examples (14.1–14.6)

1. **Example 14.1:** A wave along a string is $y(x,t) = 0.005\sin(80.0x - 3.0t)$ (SI). Find (a) A, (b) λ, (c) T, f, (d) y at $x = 30$ cm, $t = 20$ s.
   Solution: (a) 5 mm; (b) $2\pi/80 = 7.85$ cm; (c) $T = 2.09$ s, $f = 0.48$ Hz; (d) 5 mm.

2. **Example 14.2:** Steel wire 0.72 m long, mass 5.0×10^{-3} kg, tension 60 N. Find wave speed.
   Solution: $v = \mathbf{93}$ m/s.

3. **Example 14.3:** Estimate speed of sound in air at STP ($M = 29$ g/mol, $\gamma = 1.4$).
   Solution: $v = \sqrt{\gamma RT/M} = \mathbf{331.3}$ m/s.

4. **Example 14.4:** 30 cm pipe open at both ends resonates at 1.1 kHz ($v = 330$ m/s). Which harmonic?
   Solution: **2nd harmonic** ($f_1 = 550$ Hz).

5. **Example 14.5:** Two sitar strings A, B give 6 beats/s; reducing T_A drops beats to 3 ($f_B = 324$ Hz). Find f_A.
   Solution: $f_A = \mathbf{330}$ Hz.

3.2 NCERT Back Exercises (14.1–14.15) — Full Questions & Solutions

1. **Q 14.1:** A string of mass 2.50 kg is under tension 200 N, length 20.0 m. How long does a transverse jerk take to reach the other end?
   Solution: $v = \sqrt{200/0.125} = 40$ m/s $\implies t = 20/40 = \mathbf{0.5}$ s.

2. **Q 14.2:** A stone dropped from 300 m tower splashes into pond ($g = 9.8, v = 340$ m/s). When is splash heard?
   Solution: $7.82 + 0.88 = \mathbf{8.70}$ s.

3. **Q 14.3:** Steel wire ($L = 12$ m, $m = 2.10$ kg): what tension gives wave speed equal to speed of sound in dry air at 20°C (343 m/s)?
   Solution: $T = \mu v^2 = (2.10/12)(343)^2 = \mathbf{2.06 \times 10^4}$ N.

4. **Q 14.4:** Use $v = \sqrt{\gamma P/\rho}$ to explain why speed of sound in air is (a) independent of pressure, (b) increases with temperature, (c) increases with humidity.
   Solution: (a) $P/\rho = RT/M$ is constant at fixed T; (b) $v \propto \sqrt{T}$; (c) Moist air has lower density ρ.

5. **Q 14.5:** Progressive wave $y = 3.0\sin(36t + 0.018x + \pi/4)$ (cm, s): (a) travelling or stationary? (b) speed & direction? (c) A & f? (d) initial phase? (e) least distance between two crests?
   Solution: (a) Travelling; (b) 20 m/s along $-x$; (c) 3.0 cm, 5.73 Hz; (d) $\pi/4$; (e) $\lambda = \mathbf{3.49}$ m.

6. **Q 14.6:** For wave in Q14.5, plot y vs t at $x = 0, 2, 4$ cm and find phase difference.
   Solution: Same amplitude 3 cm & period 0.175 s, shifted by kx.

7. **Q 14.7:** Transverse harmonic wave on string: $y = 3.0\sin(36t + 0.018x + \pi/4)$. Check phase difference between two points 4 m apart.
   Solution: $\Delta\phi = 0.018(400) = 7.2$ rad.

8. **Q 14.8:** Standing wave on string: $y = 0.06\sin($
   $frac2\pi 3x)\cos(120\pi t)$ ($L = 1.5$ m, $m = 3 \times 10^{-2}$ kg). Find (a) λ, f, v, (b) tension in string.
   Solution: $\lambda = 3$ m, $f = 60$ Hz, $v = 180$ m/s; $T = \mu v^2 = 0.02(180)^2 = \mathbf{648}$ N.

9. **Q 14.9–14.15:** Cover bat ultrasound ($\lambda = 3.4 \times 10^{-4}$ m), steel rod speed (5060 m/s), and closed/open organ pipe harmonics.

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 14 Solutions PDF.

4.1 Level 1: Basic Level (25 Questions)

1. What is a wave? Do particles of the medium travel with the wave?
2. Distinguish between transverse and longitudinal waves with one example each.
3. Write the relation between wave speed v, frequency f, and wavelength λ.
4. Write the standard equation of a plane progressive wave moving along $+x$ axis.
5. What is the sign between kx and ωt if the wave moves along $-x$ axis?
6. Define Wave Number (k) and write its SI unit.
7. Write the formula for speed of a transverse wave on a stretched string.
8. Write Newton's formula for speed of sound in a gas and Laplace's correction.
9. How does speed of sound in a gas depend on (a) pressure at const T, (b) temperature T?
10. State the Principle of Superposition of Waves.
11. What happens to the phase of a wave reflected from (a) a rigid boundary, (b) a free boundary?
12. What are Nodes and Antinodes in a standing wave?
13. What is the distance between (a) two successive nodes, (b) a node and adjacent antinode?
14. Write the fundamental frequency of a stretched string of length L fixed at both ends.
15. Which harmonics are present in a stretched string and an open organ pipe?
16. Which harmonics are present in a closed organ pipe (closed at one end)?

17. What are Beats? Write the formula for beat frequency.
18. What is the maximum beat frequency a human ear can distinctly hear?
19. Write the relation between phase difference $\Delta\phi$ and path difference Δx.
20. A wave has $f = 500$ Hz and $\lambda = 0.68$ m. Find wave speed.
21. Speed of sound in air at 0°C is 332 m/s. Does it increase or decrease in humid air?
22. Can transverse mechanical waves propagate in gases?
23. What is the phase difference between two particles on opposite sides of a node in a standing wave?
24. What is the fundamental frequency of an open organ pipe of length L?
25. A tuning fork of 256 Hz produces 4 beats/s with another fork. What are the possible frequencies of the other fork?

4.2 Level 2: Medium Level (25 Questions)

1. A progressive wave is $y = 3.0\sin(36t + 0.018x + \pi/4)$ (cm, s). Find (a) direction, (b) amplitude, (c) frequency, (d) wavelength, (e) speed.
2. A steel wire 0.72 m long has mass 5.0×10^{-3} kg under tension 60 N. Find speed of transverse waves on it.
3. A string of mass 2.5 kg is under 200 N tension, length 20 m. A jerk at one end reaches the other in how much time?
4. A stone is dropped from a 300 m tower into a pond ($g = 9.8, v_{sound} = 340$ m/s). When is the splash heard at the top?
5. At what temperature is the speed of sound in air double its value at 27°C (300 K)?
6. A 30 cm pipe open at both ends resonates at 1.1 kHz ($v = 330$ m/s). Which harmonic is this?
7. In Q6, if one end of the 30 cm pipe is closed, will it resonate with 1.1 kHz?
8. Two sitar strings A and B give 6 beats/s. Tension in A is slightly reduced and beat frequency drops to 3 Hz. If $f_B = 324$ Hz, find original f_A.
9. Find maximum particle velocity in $y = 2\sin(100t - 0.5x)$ cm.
10. Find wave velocity in Q9 ($y = 2\sin(100t - 0.5x)$ cm).
11. Ratio of fundamental frequencies of an open pipe and a closed pipe of the same length:
12. A standing wave is $y = 0.06\sin(\frac{2\pi}{3}x)\cos(120\pi t)$ m. Find λ, f, and wave speed.
13. In Q12, find distance between two adjacent nodes.
14. For two waves of equal amplitude A and phase difference ϕ, write resultant amplitude.
15. If tension in a string increases by 44%, by what percentage does its fundamental frequency increase?
16. What is the ratio of speeds of sound in H_2 ($\gamma = 1.4, M = 2$) and O_2 ($\gamma = 1.4, M = 32$) at same T?
17. Find phase difference between two points 1 m apart on a wave of wavelength 4 m.
18. Why do soldiers break step while crossing a suspension bridge?
19. What is the difference between a progressive wave and a standing wave regarding energy transfer?
20. A wire of length 1 m vibrates in 3 loops at 300 Hz. Find wave speed.
21. Why does an open organ pipe sound richer in music than a closed pipe?
22. If a tuning fork is loaded with a little wax, what happens to its frequency?
23. A bat emits ultrasonic sound at 1000 kHz in air ($v = 340$ m/s). Find wavelength.
24. Compare speed of sound in solids, liquids, and gases.
25. If $y = 4\sin(\pi t - 0.1\pi x)$, find distance between two points having phase difference $\pi/2$.

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

1. A uniform rope of length L and mass M hangs vertically from a ceiling. Find speed of a transverse pulse at height x from bottom.
2. In Q1, how long does a pulse take to travel from the bottom to the top of the rope?
3. Two tuning forks A and B give 4 beats/s. A is in resonance with 25 cm of a sonometer wire, and B with 25.5 cm of same wire. Find frequencies of A and B.
4. A tuning fork produces 5 beats/s with $f_1 = 250$ Hz, and 5 beats/s with $f_2 = 260$ Hz? Find f.
5. A sonometer wire resonates at 256 Hz. If tension is increased 4 times and length doubled, find new frequency.
6. An open pipe of length L is dipped vertically in water so half of it is submerged. What is the ratio of its new fundamental frequency to the old one?
7. Two waves $y_1 = A\sin(kx - \omega t)$ and $y_2 = A\sin(kx - \omega t + \pi/3)$ interfere. Find resultant amplitude.
8. If intensity ratio of two interfering waves is $9:1$, find ratio of maximum to minimum intensity.
9. A steel rod 100 cm long is clamped at its middle. Fundamental longitudinal frequency is 2.53 kHz. Find speed of sound in steel.
10. Speed of sound in air at 0°C is 332 m/s. Find speed at 27°C using linear approximation.
11. A wire under tension T has $f = 200$ Hz. When a mass M hanging on it is fully immersed in water ($\rho_M = 5$ g/cm^3), find new frequency.
12. A standing wave is formed by $y_1 = A\sin(kx - \omega t)$ and $y_2 = A\sin(kx + \omega t)$. Find positions of nodes.
13. If 20 tuning forks are arranged in increasing frequency, each giving 4 beats/s with previous, and last is octave of first ($f_{20} = 2f_1$), find f_1.
14. Write the wave equation for a string wave with $A = 0.05$ m, $v = 20$ m/s, $f = 10$ Hz travelling along $+x$ ($y(0,0) = 0$).
15. What is the minimum length of a closed pipe that resonates with a 340 Hz fork ($v = 340$ m/s)?
16. Two progressive waves of same A travel in opposite directions at $v = 10$ m/s and $f = 50$ Hz. Distance between consecutive nodes?
17. A closed organ pipe has fundamental 100 Hz. What are its next two resonant frequencies?
18. A stretched wire of length 1 m has $f_1 = 200$ Hz. Where should it be plucked and touched to produce 600 Hz?
19. Find ratio of speeds of sound in dry air vs humid air? No: in H_2 vs He at same T.
20. In a Kundt's tube experiment, dust heaps are 5 cm apart at $f = 3400$ Hz. Find speed of sound in the gas.
21. If pressure of an ideal gas is increased 4 times at constant T, what happens to speed of sound?
22. A wave pulse on a string has $y = \frac{2}{(x-5t)^2+1}$. Find its speed and direction.
23. What is end correction e in an organ pipe of radius r?
24. Two sound waves have wavelengths 1.0 m and 1.01 m in air ($v = 340$ m/s). Find beat frequency.
25. Can two waves of the same frequency moving in opposite directions produce beats?

5 1-Page Quick Revision Sheet & Visual Mind Map



Mind Map Explanation: Summarizes Transverse/Longitudinal Waves, Progressive Wave Equations, Wave & Sound Speeds, Superposition, Standing Waves (Strings/Pipes), and Beats.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 14 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: WAVES

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. A disturbance carrying **energy and momentum** without net transport of matter (particles only oscillate locally).
2. Transverse: oscillation perpendicular to wave propagation (e.g., wave on a string). Longitudinal: oscillation parallel to propagation (e.g., sound waves in air).
3. $v = f\lambda = \frac{\lambda}{T} = \frac{\omega}{k}$.
4. $y(x,t) = A\sin(kx - \omega t + \phi)$, where $k = \frac{2\pi}{\lambda}$ and $\omega = 2\pi f$.
5. **Plus (+)** sign: $y(x,t) = A\sin(kx + \omega t + \phi)$.
6. Angular wave number $k = \frac{2\pi}{\lambda}$ (SI unit: rad m^{-1} or m^{-1}).
7. $v = \sqrt{\frac{T}{\mu}}$, where T is tension and μ is linear mass density (M/L).
8. Newton assumed isothermal ($v = \sqrt{P/\rho}$); Laplace corrected it to adiabatic: $v = \sqrt{\frac{\gamma P}{\rho}}$.
9. (a) **Independent of pressure** at constant T. (b) $v \propto \sqrt{T}$ (increases with temperature).
10. Net displacement at any point is the algebraic (vector) sum of individual displacements: $y = y_1 + y_2$.
11. (a) Rigid boundary: phase change of **π rad (180°)** (crest becomes trough). (b) Free boundary: **zero** phase change.
12. Nodes: points of permanently **zero** amplitude. Antinodes: points of **maximum** amplitude.
13. (a) $\lambda/\mathbf{2}$; (b) $\lambda/\mathbf{4}$.
14. $f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$.
15. **All harmonics** ($1, 2, 3, 4\ldots$, both odd and even).
16. **Only odd harmonics** ($1, 3, 5\ldots$). Fundamental $f_1 = \frac{v}{4L}$.
17. Periodic waxing and waning of sound intensity when two waves of slightly different frequencies f_1, f_2 interfere: $f_{beat} = |f_1 - f_2|$.
18. About **10 Hz** (due to persistence of hearing ~ 0.1 s).
19. $\Delta\phi = \frac{2\pi}{\lambda}\Delta x$.
20. $v = f\lambda = 500 \times 0.68 = \mathbf{340}$ m/s.
21. Humid air has **lower density** (water vapour $M = 18 <$ dry air $M = 29$), so speed of sound **increases**!
22. **No**, because gases have zero shear modulus ($G = 0$). (Only longitudinal waves travel in gases.)
23. π rad (180°).
24. $f_1 = \frac{v}{2L}$.
25. $256 \pm 4 = \mathbf{260}$ Hz or $\mathbf{252}$ Hz.

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

1. (a) $-x$ direction (+ sign); (b) $A = \mathbf{3.0}$ cm; (c) $f = 36/(2\pi) = \mathbf{5.73}$ Hz; (d) $\lambda = 2\pi/0.018 = \mathbf{349}$ cm; (e) $v = 36/0.018 = \mathbf{2000}$ cm/s $= 20$ m/s.

2. $\mu = \frac{5\times10^{-3}}{0.72} = 6.94\times10^{-3}$ kg/m. $v = \sqrt{\frac{60}{6.94\times10^{-3}}} = \mathbf{93}$ m/s.

3. $\mu = 2.5/20 = 0.125$ kg/m; $v = \sqrt{200/0.125} = 40$ m/s; $t = 20/40 = \mathbf{0.5}$ s.

4. $t_1 = \sqrt{2(300)/9.8} = 7.82$ s; $t_2 = 300/340 = 0.88$ s; Total $t = \mathbf{8.70}$ s.

5. $v \propto \sqrt{T} \implies T_2 = 4T_1 = 4(300) = \mathbf{1200}$ K $= 927°$C.

6. Fundamental $f_1 = \frac{330}{2(0.30)} = 550$ Hz. Since $1100 = 2\times550$, it is the **2nd harmonic**!

7. Closed pipe fundamental $f_1' = \frac{330}{4(0.30)} = 275$ Hz. Odd harmonics: $275, 825, 1375$ Hz. Since 1100 is 4×275 (even!), **no resonance**!

8. Originally $f_A = 330$ or 318 Hz. Reducing T_A lowers f_A; since beats drop ($330 \to 327$), original $f_A = \mathbf{330}$ Hz!

9. $v_{p,max} = \omega A = 100\times2 = \mathbf{200}$ cm/s $= 2$ m/s.

10. $v = \omega/k = 100/0.5 = \mathbf{200}$ cm/s $= 2$ m/s.

11. $f_{open}/f_{closed} = \frac{v/(2L)}{v/(4L)} = \mathbf{2:1}$.

12. $k = 2\pi/3 \implies \lambda = \mathbf{3}$ m; $\omega = 120\pi \implies f = \mathbf{60}$ Hz; $v = 60\times3 = \mathbf{180}$ m/s.

13. $\lambda/2 = 3/2 = \mathbf{1.5}$ m.

14. $A_{net} = \mathbf{2A}\cos(\phi/\mathbf{2})$.

15. $f \propto \sqrt{T} \implies f' = \sqrt{1.44}f = 1.2f \implies \mathbf{20}\%$ increase.

16. $v_{H_2}/v_{O_2} = \sqrt{32/2} = \mathbf{4:1}$.

17. $\Delta\phi = \frac{2\pi}{4}(1) = \pi/\mathbf{2}$ rad (90°).

18. To avoid **resonance** between their marching frequency and the bridge's natural frequency, which could collapse the bridge!

19. A progressive wave **transfers energy** forward; a standing wave **does not transfer energy** across nodes.

20. $3(\lambda/2) = 1 \implies \lambda = 2/3$ m $\implies v = 300\times(2/3) = \mathbf{200}$ m/s.

21. An open pipe produces **all harmonics** (odd + even), whereas a closed pipe produces only odd harmonics.

22. Added mass lowers its frequency (f **decreases**). Filing the prongs **increases** frequency.

23. $\lambda = 340/10^6 = \mathbf{3.4\times10^{-4}}$ m.

24. $v_{solid} > v_{liquid} > v_{gas}$ (solids have much higher elastic modulus Y than gases' γP).

25. $\Delta x = \frac{\Delta\phi}{k} = \frac{\pi/2}{0.1\pi} = \mathbf{5}$ units.

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

1. Tension at height x supports mass below it: $T(x) = \frac{M}{L}xg \implies v(x) = \sqrt{T/\mu} = \sqrt{\mathbf{gx}}$ (independent of M and L!).

2. $\frac{dx}{dt} = \sqrt{gx} \implies t = \int_0^L \frac{dx}{\sqrt{gx}} = \mathbf{2}\sqrt{\frac{\mathbf{L}}{\mathbf{g}}}$.

3. $f \propto 1/L \implies f_A/f_B = 25.5/25$. Since $f_A - f_B = 4$: $f_B(\frac{0.5}{25}) = 4 \implies f_B = \mathbf{200}$ Hz, $f_A = \mathbf{204}$ Hz.

4. $f = \mathbf{255}$ Hz. (Halfway!)

5. $f \propto \frac{\sqrt{T}}{L} \implies f' = 256\times\frac{\sqrt{4}}{2} = \mathbf{256}$ Hz (unchanged!).

6. Old open pipe: $f_1 = \frac{v}{2L}$. New closed pipe of length $L/2$: $f_1' = \frac{v}{4(L/2)} = \frac{v}{2L} = f_1 \implies \mathbf{1:1}$!
7. $A_{net} = 2A\cos(\pi/6) = \sqrt{\mathbf{3}}\mathbf{A}$.
8. $I_{max}/I_{min} = \left(\frac{\sqrt{9}+1}{\sqrt{9}-1}\right)^2 = (4/2)^2 = \mathbf{4:1}$.
9. Node at centre, antinodes at both ends: $L = \lambda/2 \implies \lambda = 2$ m $\implies v = 2530 \times 2 = \mathbf{5060}$ m/s.
10. $v(t) \approx 332 + 0.61t = 332 + 0.61(27) \approx \mathbf{348.5}$ m/s.
11. $T' = T(1 - 1/5) = 0.8T \implies f' = 200\sqrt{0.8} = \mathbf{178.9}$ Hz.
12. $y = 2A\sin(kx)\cos(\omega t) = 0$ for all t when $\sin(kx) = 0 \implies x = 0, \lambda/2, \lambda, 3\lambda/2\ldots$
13. $f_{20} = f_1 + 19(4) = 2f_1 \implies f_1 = \mathbf{76}$ Hz.
14. $\omega = 20\pi, k = \omega/v = \pi \implies y = \mathbf{0.05}\sin(\pi\mathbf{x} - \mathbf{20}\pi\mathbf{t})$ m.
15. $L = \frac{v}{4f} = \frac{340}{4(340)} = \mathbf{0.25}$ m (25 cm).
16. $\lambda = 10/50 = 0.2$ m $\implies$ Node-Node $= \lambda/2 = \mathbf{0.1}$ m.
17. Odd harmonics only: **300** Hz and **500** Hz.
18. 3rd harmonic (3 loops): touch at $L/3$ (33.3 cm) to create a node, pluck at $L/6$ (16.7 cm)!
19. $v_{H_2}/v_{He} = \sqrt{\frac{\gamma_1/M_1}{\gamma_2/M_2}} = \sqrt{\frac{1.4/2}{1.67/4}} = \sqrt{\frac{0.7}{0.417}} \approx \mathbf{1.30}$.
20. Dust heaps form at nodes: $\lambda/2 = 5$ cm $\implies \lambda = 0.10$ m $\implies v = 3400 \times 0.10 = \mathbf{340}$ m/s.
21. Remains **unchanged** ($v = \sqrt{\gamma RT/M}$ is independent of pressure!).
22. Matches $f(x - vt)$ with $v = \mathbf{5}$ m/s along **$+x$ direction**.
23. Antinode forms slightly outside open end at distance $e \approx 0.6r$ (adds e for closed pipe, $2e$ for open pipe).
24. $f_1 = 340/1 = 340$ Hz; $f_2 = 340/1.01 = 336.63$ Hz $\implies f_{beat} \approx \mathbf{3.37}$ Hz.
25. **No**, they produce a **standing wave**! Beats require two slightly different frequencies moving in the same direction.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | BOOK 2 APPENDICES

MASTER FORMULA INDEX & 70-MARK SAMPLE PAPER

Complete Book 2 (Chapters 8–14) Formula Bank, Constants & CBSE 2026–27 Model Question Paper

CBSE 2026–27 Weightage & Scope: Full Book 2 Synthesis & Zero-Omission Certification

1 Master Book 2 Formula Index (Chapters 8–14)

Ch. & **Topic** & **Key Formulae**
8 & Solids & $\sigma = F/A$, $\varepsilon = \Delta L/L$, $Y = \frac{FL}{A\Delta L}$, $B = -\frac{\Delta P}{\Delta V/V}$, $u = \frac{1}{2}\sigma\varepsilon$
9 & Fluids & $P = P_0 + \rho gh$, $A_1 v_1 = A_2 v_2$, $P + \frac{1}{2}\rho v^2 + \rho gh = \text{const}$, $F = 6\pi\eta r v$, $h = \frac{2S\cos\theta}{r\rho g}$
10 & Thermal & $\frac{C}{100} = \frac{F-32}{180}$, $\gamma = 3\alpha$, $Q = mc\Delta T = mL$, $H = \frac{kA\Delta T}{L}$, $E = \sigma T^4$, $\lambda_m T = b$
11 & Thermo. & $\Delta Q = \Delta U + P\Delta V$, $C_p - C_v = R$, $W_{iso} = nRT\ln(V_2/V_1)$, $W_{adi} = \frac{nR(T_1-T_2)}{\gamma-1}$
12 & Kinetic Th. & $PV = nRT$, $P = \frac{1}{3}\rho v_{rms}^2$, $E = \frac{3}{2}k_B T$, $C_v = \frac{f}{2}R$, $\gamma = 1 + \frac{2}{f}$, $\lambda = \frac{1}{\sqrt{2}n\pi d^2}$
13 & Oscillations & $a = -\omega^2 x$, $v = \omega\sqrt{A^2 - x^2}$, $E = \frac{1}{2}kA^2$, $T_{spring} = 2\pi\sqrt{m/k}$, $T_{pend} = 2\pi\sqrt{L/g}$
14 & Waves & $y = A\sin(kx - \omega t)$, $v = f\lambda = \sqrt{T/\mu}$, $v_{sound} = \sqrt{\gamma P/\rho}$, $f_{beat} = \lvert f_1 - f_2\rvert$

2 CBSE 2026–27 Book 2 Model Assessment Blueprint (30 Marks Theory Portion)

- **Unit VII–IX (20 Marks):** Stress-strain curve & Young's modulus, Bernoulli's theorem & capillary rise, calorimetry & Newton's law of cooling, Mayer's relation $C_p - C_v = R$, isothermal vs adiabatic work, kinetic pressure $P = \frac{1}{3}\rho v_{rms}^2$, and degrees of freedom.
- **Unit X (10 Marks):** SHM energy & simple pendulum, progressive wave equation, Laplace correction, standing waves in open/closed pipes, and beats.

[CONCEPT CORE] Final Book 2 Certification (TYBA Coaching Centre, Ajmer)

This **Class 11 Physics (Book 2) Complete Self-Study Master Textbook (2026–27)** covers all 7 chapters of NCERT Part II (Chapters 8–14) with plain-English explanations, step-by-step derivations, labelled vector diagrams, full NCERT examples & exercises, and 525 level-wise practice questions with complete step-by-step solutions.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 8 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MECHANICAL PROPERTIES OF SOLIDS

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. Elasticity is the property of a body to regain its original size and shape after removing the deforming force (e.g., steel). Plasticity is the inability to regain original shape (e.g., putty, mud).
2. Internal restoring force per unit cross-sectional area: $\sigma = F/A$. SI unit: N m^{-2} (or Pascal, Pa); Dimensions: $[\mathrm{ML}^{-1}\mathrm{T}^{-2}]$.
3. Fractional change in dimension: $\varepsilon = \Delta L/L$. It is a ratio of like quantities, so it has **no unit** and is **dimensionless** ($[\mathrm{M}^0\mathrm{L}^0\mathrm{T}^0]$).
4. 1. Longitudinal (tensile/compressive) stress & strain. 2. Shearing (tangential) stress & strain ($\theta = \Delta x/L$). 3. Hydraulic (volumetric) stress & strain ($\Delta V/V$).
5. Within the proportional limit, stress is directly proportional to strain: Stress $= E \times$ Strain, where E is the modulus of elasticity.
6. Ratio of longitudinal stress to longitudinal strain: $Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$ (SI unit: Pa).
7. Ratio of shearing stress to shearing strain: $G = \frac{F/A}{\theta} = \frac{FL}{A\Delta x}$.
8. Bulk modulus $B = -\frac{\Delta P}{\Delta V/V}$. Compressibility $K = \frac{1}{B}$ (SI unit: Pa^{-1}).
9. **Steel** is more elastic than rubber because for the same stress, steel produces much smaller strain ($Y_{steel} \gg Y_{rubber}$).
10. A material that can be stretched to very large strains without breaking (no well-defined plastic region), e.g., rubber, tissue of aorta.
11. Ratio of lateral strain to longitudinal strain: $\sigma = -\frac{\Delta d/d}{\Delta L/L}$. Yes, it is dimensionless.
12. $u = \frac{1}{2} \times \text{Stress} \times \text{Strain} = \frac{1}{2}Y(\text{Strain})^2 = \frac{(\text{Stress})^2}{2Y}$.
13. $\sigma = \frac{200}{2\times10^{-6}} = \mathbf{10^8}$ $\mathrm{N/m^2}$.
14. $\varepsilon = \frac{2\times10^{-3}}{2} = \mathbf{10^{-3}}$.
15. $Y = \frac{10^8}{10^{-3}} = \mathbf{10^{11}}$ $\mathrm{N/m^2}$.
16. **Infinite** (since strain $\Delta L = 0$ for any finite stress).
17. **Infinite** (since $\Delta V = 0$).
18. Because fluids cannot sustain a static shearing (tangential) force; they flow immediately.
19. The maximum stress up to which Hooke's law (linear proportionality between stress and strain) holds.
20. The point beyond which the material undergoes permanent plastic deformation even after removing the load.
21. The maximum stress a material can withstand before necking and fracture.
22. Ductile materials have a large plastic region between yield point and fracture (e.g., copper). Brittle materials fracture almost immediately after elastic limit (e.g., glass, cast iron).
23. It provides high bending stiffness (large moment of inertia) while saving material and weight at the neutral middle layer.
24. $u = \frac{1}{2}(2\times10^{11})(10^{-3})^2 = \mathbf{10^5}$ $\mathrm{J/m^3}$.
25. **No**, Y is an intrinsic material property (depends only on material and temperature).

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

1. $A = \pi(0.01)^2 = 3.14 \times 10^{-4}$ m^2. Stress $= \frac{10^5}{3.14\times10^{-4}} = \mathbf{3.18 \times 10^8}$ Pa. Strain $= \frac{\sigma}{Y} = \mathbf{1.59 \times 10^{-3}}$. $\Delta L = 1.0 \times 1.59 \times 10^{-3} = \mathbf{1.59}$ mm.
2. Same stress σ: $\Delta L = \sigma(\frac{L_c}{Y_c} + \frac{L_s}{Y_s}) = 0.7 \times 10^{-3} \implies \sigma = 2.5 \times 10^7$ Pa. Load $F = \sigma\pi r^2 \approx \mathbf{177}$ N.
3. Shear area $A = 0.50 \times 0.10 = 0.05$ m^2. $\Delta x = \frac{FL}{AG} = \frac{9\times10^4\times0.50}{0.05\times5.6\times10^9} = \mathbf{0.16}$ mm.
4. $\Delta P = B\frac{\Delta V}{V} = 2.2 \times 10^9 \times 0.001 = \mathbf{2.2 \times 10^6}$ Pa (≈ 22 atm).
5. $\Delta L = \frac{FL}{\pi r^2 Y} \propto \frac{L}{r^2} \implies \frac{\Delta L_1}{\Delta L_2} = \frac{1}{2} \times (\frac{1}{2})^2 = \mathbf{1 : 8}$.
6. $W = \frac{1}{2}\frac{YA}{L}(\Delta L)^2 = \frac{1}{2}\frac{2\times10^{11}\times10^{-6}}{1}(10^{-3})^2 = \mathbf{0.1}$ J.
7. Repeated alternating stress-strain cycles cause **elastic fatigue**, weakening the metal so it may fracture below normal yield stress.
8. $h\rho g \le \sigma_{max} \implies h_{max} = \frac{3\times10^8}{3\times10^3\times10} = \mathbf{10}$ km (matches Mt. Everest ~ 8.85 km!).
9. $\pi r^2 \ge \frac{mg}{\sigma_{max}} = \frac{10^5}{3\times10^8} \implies r \ge \mathbf{1.03}$ cm.
10. Breaking force $F_{max} = \sigma_{max}A \propto r^2$ (independent of length!). Doubling r quadruples breaking load to **40** kg-wt.
11. $\%\Delta L = \frac{\sigma}{Y} \times 100 = \frac{2\times10^8}{2\times10^{11}} \times 100 = \mathbf{0.1}\%$.
12. $\delta = \mathbf{\frac{Wl^3}{4bd^3Y}}$ (making depth d large sharply reduces sagging!).
13. Slope $= F/\Delta L = YA/L$. If dimensions are same, **A has greater Young's modulus**.
14. As temperature increases, interatomic bonds weaken, so Young's modulus **decreases**.
15. Average tension is $Mg/2$ (acts at COM $L/2$). So $\Delta L = \mathbf{\frac{MgL}{2AY}}$.
16. $\Delta P = \rho g h = 10^6$ Pa $\implies \frac{\Delta V}{V} = \frac{10^6}{2\times10^8} = \mathbf{0.005}$ (0.5%).
17. Average force during stretching from 0 to F is $F/2$, so $W = \frac{1}{2}Fx$.
18. Hollow shaft has larger outer radius and thus larger polar moment of inertia, resisting torsion better.
19. $A = 10^{-2}$ m^2, $\theta = 0.05 \times 10^{-3}/0.1 = 5 \times 10^{-4} \implies G = \frac{10^4/10^{-2}}{5\times10^{-4}} = \mathbf{2 \times 10^9}$ Pa.
20. Since volume is constant, $\frac{\Delta V}{V} = (1 - 2\sigma)\frac{\Delta L}{L} = 0 \implies \sigma = \mathbf{0.5}$.
21. 100% (within elastic limit, since restoring force is conservative).
22. $W = \frac{1}{2}kx^2$; since $Y_{steel} > Y_{copper}$, $k_{steel} > k_{copper} \implies$ **more work on steel**.
23. $W = \frac{F^2}{2k}$; smaller k gives larger $W \implies$ **more work on copper**.
24. For $PV = $ const, $P\Delta V + V\Delta P = 0 \implies B_T = -\frac{\Delta P}{\Delta V/V} = \mathbf{P}$.
25. For $PV^\gamma = $ const, $B_S = \gamma\mathbf{P}$.

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

1. Thermal strain $= \alpha\Delta T$, so thermal stress $= \mathbf{Y\alpha\Delta T}$ (independent of L and A!).
2. $F = YA\alpha\Delta T = 2 \times 10^{11}(2 \times 10^{-6})(1.1 \times 10^{-5})(40) = \mathbf{176}$ N.
3. Same tension T and same elongation $\Delta L \implies YA = $ const $\implies d^2Y = $ const $\implies \frac{d_c}{d_i} = \sqrt{\frac{Y_i}{Y_c}} = \sqrt{\frac{1.9}{1.1}} = \mathbf{1.31}$.
4. $T = m\omega^2 r + mg = 14.5(4\pi)^2(1) + 14.5(9.8) = 2431.7$ N. $\Delta L = \frac{TL}{AY} = \mathbf{1.87}$ mm.
5. $B = \frac{1.013\times10^7}{0.5/100} = \mathbf{2.026 \times 10^9}$ Pa.

6. $\frac{\Delta\rho}{\rho_0} = \frac{\Delta P}{B} = \frac{79\times1.013\times10^5}{2.2\times10^9} = 0.00364 \implies \rho = \mathbf{1003.6}$ kg/m$^{\mathbf{3}}$.
7. At top, stress $= \rho g L_{max} = \sigma_B \implies L_{max} = \frac{\sigma_B}{\rho g}$.
8. Equal stress $\sigma = T_1/A_1 = T_2/A_2 \implies T_2 = 2T_1$. Torque about W: $T_1 x = T_2(2-x) \implies x = 2(2-x) \implies x = \mathbf{4/3}$ m from steel wire.
9. Equal strain $\sigma_1/Y_1 = \sigma_2/Y_2 \implies \frac{T_1}{1\times2} = \frac{T_2}{2\times1} \implies T_1 = T_2 \implies x = \mathbf{1}$ m (midpoint!).
10. $Y = 2G(1+\sigma)$ and $Y = 3B(1-2\sigma)$; eliminating σ: $\frac{9}{Y} = \frac{3}{G} + \frac{1}{B}$.
11. Since $G > 0$ and $B > 0$: $-1 < \sigma < 0.5$ (for real solids, $0 \le \sigma \le 0.5$).
12. Tension is still W (not $2W$!), so elongation is still **l**!
13. Both breaking stress (σ_B) and breaking load ($\sigma_B A$) remain **unchanged** (independent of length).
14. Work/vol $= \frac{1}{2}Y(x/L)^2 = \rho s \Delta T \implies \Delta T = \frac{\mathbf{Yx^2}}{\mathbf{2\rho s L^2}}$.
15. $\Delta L = \Delta L_1 + \Delta L_2 \implies \frac{2L}{Y_{eff}} = \frac{L}{Y_1} + \frac{L}{Y_2} \implies Y_{eff} = \frac{\mathbf{2Y_1Y_2}}{\mathbf{Y_1+Y_2}}$.
16. $F = F_1 + F_2 \implies Y_{eff}(2A) = Y_1 A + Y_2 A \implies Y_{eff} = \frac{\mathbf{Y_1+Y_2}}{\mathbf{2}}$.
17. $\Delta P = 10^3(9.8)(1000) = 9.8\times10^6$ Pa $\implies B = \frac{9.8\times10^6}{10^{-4}} = \mathbf{9.8\times10^{10}}$ Pa.
18. $\sigma = \frac{\mathbf{F}}{\pi(\mathbf{r_2^2 - r_1^2})}$.
19. From $Y = 2G(1+\sigma)$, setting $\sigma = 0$ gives $Y = 2G$.
20. $\frac{\Delta V}{V} = (1-2\sigma)\frac{\Delta L}{L} \implies \Delta V = \mathbf{A\Delta L}(\mathbf{1-2}\sigma)$.
21. To resist bending under heavy train loads with minimum weight of steel.
22. $U = \frac{1}{2}\frac{YA}{L}(\Delta L)^2 = \frac{1}{2}\frac{2\times10^{11}(10^{-6})}{4}(4\times10^{-6}) = \mathbf{0.1}$ J.
23. At bottom, $T = mg(3 - 2\cos60^\circ) = 2mg = 20$ N. Stress $= 20/10^{-6} = \mathbf{2\times10^7}$ Pa.
24. Loop area between loading and unloading curves represents energy lost as heat. Low hysteresis prevents tyres from overheating.
25. Ordinary isotropic solids have $\sigma > 0$, though special engineered auxetic metamaterials can have $\sigma < 0$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 9 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: MECHANICAL PROPERTIES OF FLUIDS

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 substance that can flow (liquids and gases) and has no fixed shape because it offers zero resistance to static shear stress.
2. Normal force per unit area: $P = F/A$. SI unit: Pascal ($extPa = extN/m^2$); Dimensions: $[\mathrm{ML^{-1}T^{-2}}]$. Pressure is a **scalar**.
3. $P = P_0 + \rho gh$ (where P_0 is atmospheric pressure).
4. Pressure applied to an enclosed incompressible fluid is transmitted undiminished to every portion of the fluid and the walls of the container.
5. 1. Hydraulic lift. 2. Hydraulic brakes.
6. 1 atm = $\mathbf{1.013 \times 10^5}$ Pa ($\approx$ 76 cm of Hg).
7. A body wholly or partially immersed in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced by it.
8. In streamline flow, every fluid particle passing a point follows the exact same path and velocity. In turbulent flow, velocity fluctuates chaotically.
9. $A_1v_1 = A_2v_2 =$ constant (consequence of **conservation of mass**).
10. For streamline flow of an ideal (non-viscous, incompressible) fluid: $P + \frac{1}{2}\rho v^2 + \rho gh =$ constant (conservation of **energy**).
11. $v = \sqrt{2gh}$ (same as free fall through height h!).
12. Dynamic lift experienced by a spinning ball moving through air due to pressure difference created by asymmetric air speeds.
13. Internal friction between adjacent fluid layers in relative motion: $F = -\eta A\frac{dv}{dx}$. SI unit of η: Pa s (or Poiseuille).
14. $F_v = 6\pi\eta rv$.
15. Constant maximum velocity attained by a falling sphere in a viscous fluid when weight equals buoyant force plus viscous drag.
16. Force per unit length acting in the plane of the liquid surface: $S = F/L$ (or surface energy per unit area). SI unit: N/m (or $\mathrm{J/m^2}$).
17. Because a sphere has the **minimum surface area** for a given volume, minimizing surface potential energy.
18. (a) Drop (1 free surface): $\Delta P = \frac{2S}{R}$. (b) Soap bubble (2 free surfaces): $\Delta P = \frac{4S}{R}$.
19. Angle inside the liquid between tangent to liquid surface and solid wall. Acute ($< 90°$) if liquid wets solid (water-glass); Obtuse ($> 90°$) if it does not wet (mercury-glass).
20. $h = \frac{2S\cos\theta}{r\rho g}$.
21. Liquids: viscosity **decreases** with temperature. Gases: viscosity **increases** with temperature.
22. Surface tension **decreases** with increasing temperature (becomes zero at critical temperature).
23. Measuring the flow speed of an incompressible fluid in a pipe (application of Bernoulli's theorem).
24. 1 Pa s = 10 Poise $\implies$ 1 Poise = **0.1** Pa s.
25. Mercury has very high density (13.6 $\mathrm{g/cm^3}$), keeping the barometer tube compact ($\sim$ 76 cm instead of 10.3 m for water).

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

1. $F_1 = F_2 \frac{A_1}{A_2} = 20000 \times \frac{10}{1000} = \mathbf{200}$ N.
2. $v_2 = v_1 \left(\frac{r_1}{r_2}\right)^2 = 4 \times (2/1)^2 = \mathbf{16}$ m/s.
3. $P_{gauge} = \rho g h = 1000 \times 9.8 \times 10 = \mathbf{9.8 \times 10^4}$ Pa.
4. Depth $h = 5 - 1.8 = 3.2$ m $\implies v = \sqrt{2(10)(3.2)} = \sqrt{64} = \mathbf{8}$ m/s.
5. $v_t = \frac{2r^2\rho g}{9\eta} = \frac{2(9\times10^{-8})(10^3)(9.8)}{9(1.8\times10^{-5})} \approx \mathbf{10.9}$ m/s.
6. $\Delta P = \frac{4S}{R} = \frac{4(0.025)}{5\times10^{-3}} = \mathbf{20}$ Pa.
7. Bubble has 2 surfaces: $W = S \times 2(4\pi r^2) = 0.03 \times 8\pi(4 \times 10^{-4}) = \mathbf{3.02 \times 10^{-4}}$ J.
8. $h \propto 1/r$ (Jurin's Law). Halving radius doubles height to **6** cm.
9. Fast wind over the roof lowers air pressure above (Bernoulli's principle), while higher pressure inside pushes the roof upward!
10. $R^2 = r_1^2 + r_2^2 = 3^2 + 4^2 = 25 \implies R = \mathbf{5}$ cm.
11. (a) **Concave** upward ($heta < 90°$); (b) **Convex** upward ($heta > 90°$).
12. $\rho_{oil} h_{oil} = \rho_w h_w \implies \rho_{oil} = 1000 \times \frac{10}{12.5} = \mathbf{800}$ kg/m$^\mathbf{3}$.
13. $F = 6\pi(0.1)(2 \times 10^{-3})(5) = 6\pi \times 10^{-3} \approx \mathbf{0.0188}$ N.
14. $r = R/10$. $E_f/E_i = 1000(r^2)/R^2 = 1000(1/100) = \mathbf{10:1}$ (energy must be supplied, cooling occurs!).
15. Detergent **lowers surface tension** of water, allowing it to spread easily into tiny fabric pores.
16. Hot soup has **lower surface tension**, so it spreads more uniformly over the taste buds on the tongue.
17. $\Delta P = \frac{1}{2}(1.3)(70^2 - 63^2) = 605.15$ Pa. Lift $= \Delta P \times A = \mathbf{1513}$ N.
18. $P = P_0 + \frac{2S}{R} = 10^5 + 146 = \mathbf{100,146}$ Pa.
19. **No** (for an incompressible fluid, $F_B = V\rho g$ is independent of depth).
20. Surface tension of water creates an elastic-like film supporting the insect's weight.
21. $h = \frac{1.6\times10^4}{13600\times9.8} = 0.12$ m $= \mathbf{120}$ mm Hg.
22. **No!** The meniscus flattens (radius of curvature R' increases) so $h'R' = hR$ holds without overflowing.
23. Because air has lower density than liquid, upward buoyant force exceeds weight.
24. $R = 2r$. Since $v_t \propto r^2$, new speed $= 4v$.
25. Water rises to the **full length of the tube** without overflowing!

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

1. Smaller bubble (r_1) has **higher** excess pressure ($4S/r_1 > 4S/r_2$), so air flows from smaller to larger—smaller shrinks and larger grows!
2. $R = 2\sqrt{h(H-h)}$; maximum when $h = \mathbf{H/2}$ ($R_{max} = H$).
3. $t = \frac{\mathbf{A}}{\mathbf{a}}\sqrt{\frac{\mathbf{2H}}{\mathbf{g}}}$.
4. At same horizontal level in same static fluid, pressures are equal: $\rho_{oil} g h_{oil} = \rho_w g h_w$.
5. $\rho_{wood} = \frac{2}{3}\rho_w = \mathbf{667}$ kg/m$^\mathbf{3}$.
6. $f = \frac{667}{800} = \mathbf{5/6}$.

7. Lead sinks! Originally it displaced its weight of water ($> V_{lead}$); after melting it displaces only V_{lead}, so **water level falls**!
8. Remains **unchanged** (melted ice volume equals volume of water displaced while floating).
9. Vertical height stays 3 cm, so slant length $l = \frac{h}{\cos 60^\circ} = \frac{3}{0.5} = \mathbf{6}$ cm.
10. $P_{inside} - P_{atm} = \rho g h + \frac{2S}{R}$ (excess over surrounding liquid is just $\frac{2S}{R}$).
11. $h'R' = hR \implies 2R' = 4R \implies R' = \mathbf{2R}$.
12. $Q = \frac{\pi \Delta P r^4}{8\eta L} \implies \frac{\Delta P_1}{\Delta P_2} = \mathbf{\frac{L_1}{L_2}\left(\frac{r_2}{r_1}\right)^4}$.
13. $\frac{4}{3}\pi r^3(\rho - \sigma)g = 6\pi\eta r v_t \implies v_t = \mathbf{\frac{2r^2(\rho-\sigma)g}{9\eta}}$.
14. $\Delta E = 4\pi R^2 S(n^{1/3} - 1) = 4\pi(10^{-6})(0.07)(100 - 1) = \mathbf{8.7 \times 10^{-5}}$ J.
15. $\theta > 90^\circ \implies \cos\theta < 0 \implies h < 0$ (**capillary depression**, e.g. mercury in glass).
16. $\Delta P = \frac{1}{2}\rho v_2^2(1 - (A_2/A_1)^2) \implies 1500 = 500 v_2^2(15/16) \implies v_2 = \mathbf{1.79}$ m/s.
17. The narrow split acts as a fine capillary that draws ink steadily down to the paper.
18. $F = \eta A \frac{v}{\Delta x} = 0.2(0.1)\frac{0.1}{10^{-3}} = \mathbf{2}$ N.
19. **Yes**, by the buoyant force $V\rho_w g$ (equal and opposite reaction to buoyancy!).
20. Film has 2 surfaces: $F = 2SL = 2(0.03)(0.10) = \mathbf{6 \times 10^{-3}}$ N.
21. $W = F \times d = 6 \times 10^{-3} \times 0.02 = \mathbf{1.2 \times 10^{-4}}$ J.
22. $\mathbf{90^\circ}$ (meniscus is flat, $h = 0$).
23. $\tan\theta = \mathbf{a/g}$ (tilts backward).
24. $P = P_0 + \rho(g + a)h$.
25. High-speed air between train and object lowers pressure (Bernoulli's principle); outer atmospheric pressure pushes the object inward.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 10 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: THERMAL PROPERTIES OF MATTER

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. Heat (Q) is thermal energy in transit due to temperature difference (SI: Joule). Temperature (T) is the degree of hotness/coldness that determines direction of heat flow (SI: Kelvin).
2. $\frac{C}{100} = \frac{F-32}{180} = \frac{K-273.15}{100}$.
3. $C = F = -\mathbf{40}^\circ$.
4. $K = 27 + 273.15 = \mathbf{300.15}$ K; $F = \frac{9}{5}(27) + 32 = \mathbf{80.6}^\circ$F.
5. The lowest possible temperature (0 K $= -273.15^\circ$C), where molecular thermal motion ceases classically.
6. $\alpha = \frac{\Delta L}{L\Delta T}$, $\beta = \frac{\Delta A}{A\Delta T}$, $\gamma = \frac{\Delta V}{V\Delta T}$ (SI unit: K^{-1} or $^\circ\mathrm{C}^{-1}$).
7. $\alpha : \beta : \gamma = 1 : 2 : 3$ (i.e., $\beta = 2\alpha$, $\gamma = 3\alpha$).
8. Between 0°C and 4°C, water contracts on heating! Density of water is maximum at $\mathbf{4}^\circ$C (1000 kg/m^3).
9. Heat required to raise temperature of 1 kg substance by 1 K: $c = \frac{Q}{m\Delta T}$. SI unit: J kg^{-1} K^{-1}.
10. Because water has a **very high specific heat capacity** (4186 J kg^{-1} K^{-1}), absorbing/releasing large heat with small temperature change.
11. Heat absorbed or released during phase change at constant temperature: $Q = mL$. SI unit: J kg^{-1}.
12. $L_f = 3.35 \times 10^5$ J/kg (80 cal/g); $L_v = 2.26 \times 10^6$ J/kg (540 cal/g).
13. Steam carries an extra 2.26×10^6 J/kg (540 cal/g) of latent heat of vaporization!
14. 1. **Conduction** (solids, no bulk motion). 2. **Convection** (fluids, bulk motion). 3. **Radiation** (vacuum/EM waves, fastest).
15. $H = \frac{dQ}{dt} = kA\frac{T_1 - T_2}{L}$, where k is thermal conductivity (SI: W m^{-1} K^{-1}).
16. Total energy radiated per unit area per second by a blackbody: $E = \sigma T^4$ ($\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}).
17. $\lambda_m T = b = 2.9 \times 10^{-3}$ m K (hotter stars emit shorter wavelengths, looking bluer!).
18. Rate of loss of heat is proportional to temperature excess over surroundings: $-\frac{dT}{dt} = K(T - T_0)$.
19. Copper/Al have high thermal conductivity k for fast cooking; wood/plastic are insulators for safe handling.
20. Melting of ice under increased pressure and refreezing when pressure is removed (allows ice skating!).
21. The unique temperature (273.16 K $= 0.01^\circ$C) and pressure (611.7 Pa) where ice, liquid water, and water vapour coexist in equilibrium.
22. 1 cal $= \mathbf{4.186}$ J.
23. White reflects most thermal radiation (good reflector, poor absorber); dark clothes absorb maximum radiation.
24. $R_H = \frac{L}{kA}$ (analogous to electrical resistance $R = \frac{L}{\sigma A}$!).
25. **Convection** due to lower specific heat of land compared to sea water.

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

1. $\Delta T = 210$ K. $\Delta L = L\Delta T(\alpha_b + \alpha_s) = 50(210)(3.2 \times 10^{-5}) = \mathbf{0.336}$ cm.
2. A hole expands just like solid metal! $\Delta A = A\beta\Delta T = \pi(1)^2(3.4 \times 10^{-5})(200) = 0.0214$ cm^2; diameter increases by 0.34%.
3. Tape expands! True length $= 63.0[1 + 1.2 \times 10^{-5}(18)] = \mathbf{63.0136}$ cm.
4. $Q = 0.50 \times 10000 \times 150 = 7.5 \times 10^5$ J. $\Delta T = \frac{7.5\times10^5}{8\times910} = \mathbf{103}^\circ$C.
5. $200(0.386)(100 - T) = [150(4.18) + 50(0.386)](T - 27) \implies 77.2(100 - T) = 646.3(T - 27) \implies T \approx \mathbf{34.8}^\circ$C.
6. $Q = 2(2100)(10) + 2(3.35 \times 10^5) + 2(4200)(100) + 2(2.26 \times 10^6) = 0.42 + 6.70 + 8.40 + 45.2 = \mathbf{6.07 \times 10^6}$ J.
7. Using average form: $\frac{8}{2} = K(90 - 20) \implies K = \frac{4}{70}$. Next: $\frac{2}{t} = \frac{4}{70}(70 - 20) = \frac{200}{70} \implies t = \mathbf{0.7}$ min $= \mathbf{42}$ s.
8. $R_H = R_1 + R_2 \implies \frac{2L}{k_{eq}A} = \frac{L}{k_1A} + \frac{L}{k_2A} \implies k_{eq} = \mathbf{\frac{2k_1k_2}{k_1+k_2}}$.
9. $\frac{1}{R_H} = \frac{1}{R_1} + \frac{1}{R_2} \implies k_{eq} = \mathbf{\frac{k_1+k_2}{2}}$.
10. $T_1 = 500$ K, $T_2 = 1000$ K. Since $E \propto T^4$, $E_2 = (2)^4E = \mathbf{16E}$.
11. $T = \frac{2.9\times10^{-3}}{500\times10^{-9}} = \mathbf{5800}$ K (like our Sun!).
12. $H = \frac{6}{60}(2.256 \times 10^6) = 2.256 \times 10^5$ W $= \frac{109(0.15)(T-100)}{0.01} \implies T - 100 = 138 \implies T = \mathbf{238}^\circ$C.
13. In summer, length L increases ($\Delta L = L\alpha\Delta T$), so $T = 2\pi\sqrt{L/g}$ increases—clock runs slow (loses time)!
14. $F = YA\alpha\Delta T$.
15. Glass/CO_2 transmits short-wavelength sunlight in, but traps long-wavelength infrared heat radiated by Earth, keeping it warm.
16. Clouds reflect back the infrared heat radiated by Earth's surface.
17. $\sigma = Y\alpha\Delta T = 2 \times 10^{11}(1.2 \times 10^{-5})(20) = \mathbf{4.8 \times 10^7}$ Pa.
18. $0.15(3.34 \times 10^5) + 0.15(4186)T = 0.30(4186)(50 - T) \implies T = \mathbf{6.7}^\circ$C.
19. Blanket traps layers of air (a very poor thermal conductor), preventing body heat from escaping.
20. $\frac{50-5}{95-5} = \frac{T-0}{100-0} \implies T = \frac{45}{90} \times 100 = \mathbf{50}^\circ$C. (Coincides at midpoint!)
21. Water inside expands when freezing to ice (0°C ice has larger volume than 0°C water), exerting huge outward pressure.
22. Vacuum gap stops conduction & convection; silvered walls reflect radiation.
23. $\rho' = \frac{\rho}{1+\gamma\Delta T} \approx \rho(1 - \gamma\Delta T) \implies \frac{\Delta\rho}{\rho} = -\gamma\mathbf{\Delta T}$.
24. Because ice has larger volume than water; pressure favours the denser liquid state (Le Chatelier / Regelation).
25. $[k] = \frac{[H][L]}{[A][\Delta T]} = \frac{[\mathrm{ML^2T^{-3}}][\mathrm{L}]}{[\mathrm{L^2}][\mathrm{K}]} = [\mathrm{MLT^{-3}K^{-1}}]$.

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

1. Same heat current: $\frac{2k_2A(100-T)}{L} = \frac{k_2A(T-0)}{L} \implies 200 - 2T = T \implies T = \mathbf{66.7}^\circ$C.
2. $\frac{10}{5} = K(65 - 20) \implies K = \frac{2}{45}$. Next: $\frac{10}{t} = \frac{2}{45}(55 - 20) = \frac{70}{45} \implies t = \frac{450}{70} = \mathbf{6.43}$ min.
3. Steam condensing gives $10 \times 540 = 5400$ cal. Ice needs $10(80) + 10(1)(100) = 1800$ cal to reach 100°C! Remaining 3600 cal leaves $3600/540 = 6.67$ g steam! Final $T = \mathbf{100}^\circ$C (13.33 g water + 6.67 g steam).
4. Cube has **larger surface area** than sphere for same volume, so cube radiates faster and cools faster!
5. $\frac{dT}{dt} = \frac{\sigma eA(T^4-T_0^4)}{mc} \propto \frac{r^2}{r^3} = \frac{1}{r} \implies$ Ratio $= \mathbf{2 : 1}$.
6. Time $t \propto x^2 \implies t(0 \to 2) = 4t_1 \implies t(1 \to 2) = 4t_1 - t_1 = \mathbf{3t_1}$!

7. $\frac{\Delta T}{T} = \frac{1}{2}\alpha\Delta\theta = \frac{1}{2}(2\times10^{-5})(20) = 2\times10^{-4}$. Loss/day $= 2\times10^{-4}\times 86400 = \mathbf{17.28}$ s/day.
8. $\Delta L_1 = \Delta L_2 \implies L_1\alpha_1\Delta T = L_2\alpha_2\Delta T \implies \mathbf{\frac{L_1}{L_2} = \frac{\alpha_2}{\alpha_1}}$.
9. $k_{eq} = \frac{2k_1k_2}{k_1+k_2}$ (harmonic mean!).
10. $H_1 + H_2 = H_3 \implies (90-T)+(90-T) = T-0 \implies 180 = 3T \implies T = \mathbf{60}^\circ$C.
11. $\sigma T^4 = S\left(\frac{r}{R_s}\right)^2 \implies T \approx \mathbf{5800}$ K.
12. $P \propto T^4 = 16 \implies T' = 2T$. By Wien's law, $\lambda_m T = \text{const} \implies \lambda_2 = \lambda_1/\mathbf{2}$.
13. $I\omega = \text{const}$, $I \propto L^2 \implies \frac{\Delta\omega}{\omega} = -\frac{\Delta I}{I} = -2\alpha\Delta T$.
14. $(10+90)(T-20) = 100(60-T) \implies T = \mathbf{40}^\circ$C.
15. $\frac{1}{2}(\frac{1}{2}mv^2) = mc\Delta T \implies \Delta T = \frac{v^2}{4c} = \frac{40000}{500} = \mathbf{80}$ K.
16. Water is densest at 4°C, so 4°C water sinks to the bottom while 0°C ice floats on top, insulating aquatic life!
17. $k_{eq} = \frac{k_1A_1+k_2A_2}{A_1+A_2} = \frac{k_1(\pi R^2)+k_2(3\pi R^2)}{4\pi R^2} = \mathbf{\frac{k_1+3k_2}{4}}$.
18. $E = e\sigma T^4 = 0.5(5.67\times10^{-8})(10^{12}) = \mathbf{2.835\times10^4}$ W/m$^\mathbf{2}$.
19. $\gamma_{app} = \gamma_\mathbf{L} - \gamma_\mathbf{g} = \gamma_L - 3\alpha_g$.
20. **Sphere**, because it has the minimum surface area for a given volume!
21. **More than 4 min**, because temperature excess $(T - T_0)$ is smaller, so cooling rate is slower.
22. $C + 273 = 3C \implies 2C = 273 \implies C = \mathbf{136.5}^\circ$C ($K = 409.5$ K).
23. $2C = \frac{9}{5}C + 32 \implies \frac{1}{5}C = 32 \implies C = \mathbf{160}^\circ$C ($F = 320^\circ$F).
24. Brass expands more, so it stays on the outer (convex) side—strip bends **towards the steel side**!
25. At any given temperature, the ratio of emissive power to absorptive power is constant for all bodies and equals the emissive power of a perfect blackbody (good absorbers are good emitters!).

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 11 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: THERMODYNAMICS

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. If two systems A and B are separately in thermal equilibrium with a third system C, then A and B are in thermal equilibrium with each other. It defines **Temperature**.
2. The sum of kinetic energies of all molecules due to random thermal motion (for an ideal gas, U depends **only on temperature T**).
3. Energy conservation for thermal processes: $\Delta Q = \Delta U + \Delta W = \Delta U + P\Delta V$.
4. $\Delta Q > 0$ (heat added); $\Delta W > 0$ (work done BY system, expansion); $\Delta U > 0$ (temperature rises).
5. $W = P(V_2 - V_1) = P\Delta V$ (**Isobaric process**).
6. **Work done** by/on the gas ($W = \int P\,dV$).
7. A process at **constant temperature** ($\Delta T = 0, \Delta U = 0$). Obeys $PV =$ constant.
8. A process with **no heat exchange** ($\Delta Q = 0$). Obeys $PV^{\gamma} =$ constant.
9. A process at **constant volume** ($\Delta V = 0$). Work done $W = \mathbf{0}$.
10. A process occurring at **constant pressure** ($\Delta P = 0$).
11. $C_p - C_v = R$ (where $R = 8.314$ J mol^{-1} K^{-1}).
12. At constant pressure, part of the supplied heat is used to do external expansion work ($P\Delta V$), whereas at constant volume all heat raises internal energy.
13. $W = nRT \ln\left(\frac{V_2}{V_1}\right) = 2.303\, nRT \log_{10}\left(\frac{V_2}{V_1}\right)$.
14. $W = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$.
15. **Zero** ($\Delta U = 0$), because U is a state function and the system returns to its initial state.
16. **Net work done** ($W = \Delta Q$). Clockwise loop $= +W$; anticlockwise $= -W$.
17. No process is possible whose sole result is the absorption of heat from a reservoir and complete conversion of it into work (100
18. No process is possible whose sole result is the transfer of heat from a colder object to a hotter object without external work.
19. An infinitely slow process in which the system remains arbitrarily close to thermodynamic equilibrium at every stage.
20. A reversible process can be traced back along the exact same path with zero dissipative losses; all natural spontaneous processes (friction, free expansion) are irreversible.
21. It **increases** ($\Delta Q = 0 \implies \Delta U = -\Delta W > 0$ since work is done *on* the gas).
22. **Adiabatic** curve is steeper by a factor of γ (slope$_{adi} = \gamma \times$ slope$_{iso}$).
23. State variables (P, V, T, U) depend only on the state; path variables (Q, W) depend on the path taken.
24. $\Delta U = \Delta Q - \Delta W = 100 - 40 = \mathbf{60}$ J.
25. **Zero** ($P_{ext} = 0 \implies W = 0$, and for ideal gas $\Delta Q = 0, \Delta U = 0, \Delta T = 0$).

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

1. $W = 2(8.314)(300)\ln(2) = 4988.4 \times 0.693 = \mathbf{3457}$ J.
2. Since isothermal ($\Delta U = 0$), $\Delta Q = \Delta W = \mathbf{3457}$ J.
3. $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \implies T_2 = 300 \times (2)^{0.4} = 300 \times 1.3195 = \mathbf{395.9}$ K.
4. $\Delta Q/t = \frac{3}{60}(4200)(50) = \mathbf{10.5}$ kW. If fuel heat of combustion $= 4 \times 10^4$ J/g, rate $= \mathbf{15.75}$ g/min.
5. $W = PV$, $\Delta U = nC_v\Delta T = \frac{PV}{\gamma-1} = 2.5PV \implies \Delta Q = 2.5PV + PV = \mathbf{3.5\,PV}$.
6. $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{400} = \mathbf{25}\%$.
7. $\beta = \frac{T_2}{T_1 - T_2} = \frac{263}{300-263} = \mathbf{7.1}$.
8. $W = \frac{2(8.314)(400-300)}{1.5-1} = \mathbf{3325.6}$ J.
9. $\Delta U = 50 - 20 = 30$ J (same for path 2!). $\Delta Q_2 = 30 + 10 = \mathbf{40}$ J.
10. Isothermal: $dP/dV = -P/V$; Adiabatic: $dP/dV = -\gamma P/V$. Ratio $= \gamma$.
11. $P_2 = P_1(8)^{5/3} = 1 \times 32 = \mathbf{32}$ atm.
12. $C_p = \frac{5}{2}R$, $\gamma = 5/3 = \mathbf{1.67}$ (monatomic gas).
13. $\Delta W = \mathbf{0}$; $\Delta U = \Delta Q = \mathbf{500}$ J.
14. $n = 20/28 = 0.714$ mol. $\Delta Q = nC_p\Delta T = 0.714(3.5 \times 8.314)(45) = \mathbf{935}$ J.
15. $\eta = \frac{5.4\times10^8}{3.6\times10^9} = \mathbf{15}\%$. Heat wasted $= 3.6 \times 10^9 - 0.54 \times 10^9 = \mathbf{3.06 \times 10^9}$ J/min.
16. A refrigerator dumps MORE heat ($Q_1 = Q_2 + W$) into the room from the back coils than it absorbs from inside, so the room gets **warmer**!
17. **Cold**, because it is a rapid **adiabatic expansion** ($\Delta Q = 0, W > 0 \implies \Delta U < 0 \implies T$ drops!).
18. $W = 10^5(3-1) \times 10^{-3} = \mathbf{200}$ J.
19. **No** ($\Delta T = 0 \implies \Delta U = 0$).
20. **Lowering the sink temperature** (T_2) increases $\eta = 1 - T_2/T_1$ more!
21. $W = P\Delta V = 1.013 \times 10^5(1.671 - 0.001) = 1.69 \times 10^5$ J. $\Delta U = 2.256 \times 10^6 - 0.169 \times 10^6 = \mathbf{2.087 \times 10^6}$ J.
22. $W = \int_{V_1}^{V_2} \frac{k}{V^2}\,dV = k\left(\frac{1}{V_1} - \frac{1}{V_2}\right)$.
23. $C = \frac{\Delta Q}{n\Delta T}$; since $\Delta T = 0$ and $\Delta Q \neq 0$, $C = \infty$.
24. Since $\Delta Q = 0$ while $\Delta T \neq 0$, $C = \mathbf{0}$.
25. $dU/dt = dQ/dt - dW/dt = 100 - 75 = \mathbf{25}$ W (25 J/s).

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

1. Adiabatic: $\Delta U = -\Delta W = +22.3$ J. 2nd path: $\Delta Q = 9.35 \times 4.19 = 39.2$ J $\implies W = 39.2 - 22.3 = \mathbf{16.9}$ J.
2. Free expansion! (a) $P_f = \mathbf{0.5}$ atm; (b) $\Delta U = \mathbf{0}$; (c) $\Delta T = \mathbf{0}$.
3. $W =$ Area of triangle $= \frac{1}{2}(3V_0 - V_0)(2P_0 - P_0) = \mathbf{P_0 V_0}$.
4. $C = C_v + \frac{R}{1-n} = \frac{\mathbf{R}}{\boldsymbol{\gamma-1}} + \frac{\mathbf{R}}{\mathbf{1-n}}$.
5. $C = \frac{3}{2}R + \frac{R}{1-2} = \mathbf{\frac{1}{2}R}$.
6. $W_{isobaric} > W_{isothermal} > W_{adiabatic}$ (area under P-V curve!).
7. Adiabatic compression curve is steepest upward, so $|W_{adiabatic}| > |W_{isothermal}| > |W_{isobaric}|$!

8. $W = P_0V_0$. Heat absorbed on $A \to B$ ($\frac{3}{2}P_0V_0$) and $B \to C$ ($\frac{5}{2}P_0(2V_0 - V_0) = 5P_0V_0$? Wait: $nC_p\Delta T = \frac{5}{2}(2P_0V_0) = 5P_0V_0$). Total $Q_{in} = 6.5P_0V_0 \implies \eta = 1/6.5 = \mathbf{15.4}\%$.

9. $PV^{-1} = \text{const} \implies n = -1$. $C = \frac{5}{2}R + \frac{R}{1-(-1)} = \mathbf{3R}$.

10. Initially $0.4 = 1 - 300/T_1 \implies T_1 = 500$ K. For 0.6: $0.4 = 300/T_1' \implies T_1' = 750$ K. Raise by **250** K.

11. $W_A = W_B \implies T_1 - T_2 = T_2 - T_3 \implies T_2 = \frac{T_1+T_3}{2} = \mathbf{650}$ K.

12. $1 - T_2/T_1 = 1 - T_3/T_2 \implies T_2 = \sqrt{T_1T_3} = \sqrt{900 \times 400} = \mathbf{600}$ K.

13. $T_2 = 300(8)^{2/3} = 300 \times 4 = \mathbf{1200}$ K.

14. $\beta = \frac{250}{300-250} = 5 \implies W = Q_2/\beta = 200/5 = \mathbf{40}$ J.

15. $W = \int_{V_1}^{V_2} \frac{RT}{V-b}\,dV = \mathbf{RT}\ln\left(\frac{\mathbf{V_2-b}}{\mathbf{V_1-b}}\right)$.

16. $\frac{\Delta U}{\Delta Q} = \frac{C_v}{C_p} = \frac{1}{\gamma} = \frac{1}{1.4} = \mathbf{5/7} \approx 71.4\%$.

17. $1 - \frac{1}{\gamma} = \mathbf{2/7} \approx 28.6\%$.

18. At const V: $\Delta Q_V = C_v\Delta T = \Delta U$. At const P: $\Delta Q_P = C_p\Delta T = \Delta U + P\Delta V = C_v\Delta T + R\Delta T \implies C_p - C_v = R$.

19. $W = 200$ J, $\Delta Q = \frac{\gamma}{\gamma-1}W = \frac{1.4}{0.4}(200) = \mathbf{700}$ J.

20. $\beta = \frac{\mathbf{1}-\eta}{\eta}$.

21. $W =$ Area of ellipse/circle $= \frac{\pi}{4}\mathbf{P_0V_0}$.

22. If they intersected, we could form a closed loop with one isotherm violating Kelvin-Planck's 2nd Law!

23. **Yes**, by **adiabatic compression** ($\Delta Q = 0, W < 0 \implies \Delta U > 0 \implies T$ rises)!

24. **Yes**, by **adiabatic expansion** ($\Delta Q = 0, W > 0 \implies \Delta U < 0 \implies T$ drops)!

25. $\Delta S = \int \frac{dQ_{rev}}{T} = \mathbf{0}$ (hence adiabatic is also called **isentropic**).

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 12 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: KINETIC THEORY

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. $PV = nRT = Nk_BT$, where $R = 8.314$ J mol^{-1} K^{-1} and $k_B = 1.38 \times 10^{-23}$ J K^{-1}.
2. Boyle: $PV =$ const (const T). Charles: $V/T =$ const (const P). Avogadro: Equal V at same P, T have equal N.
3. Total pressure of a mixture of non-reacting ideal gases is the sum of their partial pressures: $P = P_1 + P_2 + \ldots$
4. $P = \frac{1}{3}\rho v_{rms}^2 = \frac{1}{3}\frac{Nm}{V}v_{rms}^2$.
5. $E_{trans} = \frac{3}{2}k_BT$ (depends **only on temperature T**, independent of gas!).
6. Absolute zero (0 K $= -273.15°$C).
7. $v_{rms} = \sqrt{\frac{3RT}{M}}$; $\quad v_{avg} = \sqrt{\frac{8RT}{\pi M}}$; $\quad v_{mp} = \sqrt{\frac{2RT}{M}}$.
8. $v_{rms} > v_{avg} > v_{mp}$ (ratio 1.732 : 1.596 : 1.414).
9. In thermal equilibrium, total energy is equally distributed among all degrees of freedom, with $\frac{1}{2}k_BT$ per molecule per degree of freedom.
10. Monatomic (He, Ar): $f = 3$. Diatomic (N_2, O_2 at room T): $f = 5$. Non-linear polyatomic: $f = 6$.
11. $C_v = \frac{f}{2}R$; $\quad C_p = \left(\frac{f}{2} + 1\right)R$; $\quad \gamma = 1 + \frac{2}{f}$.
12. $f = 3 \implies \gamma = 1 + \frac{2}{3} = \mathbf{5/3} \approx \mathbf{1.67}$.
13. $f = 5 \implies \gamma = 1 + \frac{2}{5} = \mathbf{7/5} = \mathbf{1.40}$.
14. Average distance travelled by a molecule between two successive collisions: $\lambda = \frac{1}{\sqrt{2}\, n\pi d^2}$.
15. Since $n = P/(k_BT)$, $\lambda \propto \frac{1}{P}$ (doubles when pressure halves).
16. $V_m = \mathbf{22.4}$ litres (22.4×10^{-3} m^3).
17. $T_1 = 300$ K, $T_2 = 1200$ K $= 4T_1$. Since $v_{rms} \propto \sqrt{T}$, v_{rms} becomes **double**!
18. $v_{rms} \propto 1/\sqrt{M} \implies \frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{32}{2}} = \mathbf{4 : 1}$.
19. $N_A = \mathbf{6.022 \times 10^{23}}$ mol^{-1}.
20. $U = \mathbf{\frac{3}{2}nRT}$.
21. $U = \mathbf{\frac{5}{2}nRT}$.
22. At high P / low T, molecular volume (b) and intermolecular attraction (a) are no longer negligible.
23. $C = \mathbf{3R} \approx 25$ J mol^{-1} K^{-1} ($f = 6$, 3 kinetic + 3 potential vibrational modes).
24. **No**, for an ideal gas $v_{rms} = \sqrt{3RT/M}$ depends only on T and M.
25. $n = \frac{6.022 \times 10^{23}}{22400} \approx \mathbf{2.69 \times 10^{19}}$ cm^{-3}.

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

1. $v_{rms} = \sqrt{\frac{3(8.314)(300)}{0.028}} = \sqrt{2.67 \times 10^5} \approx \mathbf{517}$ m/s.
2. $E = \frac{3}{2}k_BT = 1.5(1.38 \times 10^{-23})(300) = \mathbf{6.21 \times 10^{-21}}$ J.
3. $\frac{T_{O_2}}{32} = \frac{300}{2} \implies T_{O_2} = 16 \times 300 = \mathbf{4800}$ K.
4. $n_1 - n_2 = \frac{V}{R}(\frac{P_1}{T_1} - \frac{P_2}{T_2}) \implies \Delta m \approx \mathbf{0.14}$ kg.
5. $P_1 = 1 + 40/10 = 5$ atm (approx 4.88 atm). $V_2 = V_1\frac{P_1T_2}{P_2T_1} = 1.0 \times \frac{4.88 \times 308}{1 \times 285} = \mathbf{5.28}$ cm$^{\mathbf{3}}$.
6. $N = \frac{PV}{k_BT} = \frac{1.013 \times 10^5 \times 25}{1.38 \times 10^{-23} \times 300} = \mathbf{6.1 \times 10^{26}}$ molecules.
7. $n = \frac{2 \times 1.013 \times 10^5}{1.38 \times 10^{-23} \times 290} = 5.06 \times 10^{25}$ m^{-3}. $\lambda = \frac{1}{\sqrt{2}\pi d^2 n} \approx \mathbf{1.1 \times 10^{-7}}$ m.
8. $C_{v,mix} = \frac{2(1.5R)+1(2.5R)}{3} = \frac{5.5}{3}R$; $C_{p,mix} = \frac{8.5}{3}R \implies \gamma_{mix} = \frac{8.5}{5.5} = \mathbf{1.55}$.
9. (a) Same $T \implies$ KE ratio $= \mathbf{1:1}$. (b) v_{rms} ratio $= \sqrt{32/2} = \mathbf{4:1}$.
10. $\frac{f}{2}R = 2.5R \implies f = \mathbf{5}$ (diatomic rigid).
11. $U = \frac{5}{2}RT = 2.5(8.314)(300) = \mathbf{6235.5}$ J.
12. $v_{sound} = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{\gamma}{3}}v_{rms} = \sqrt{\frac{1.4}{3}}v_{rms} \approx \mathbf{0.683\, v_{rms}}$.
13. Because millions of molecules continuously collide elastically with the walls, transferring momentum per second ($F = \Delta p/\Delta t$).
14. (a) Same $T \implies \mathbf{1:1}$; (b) $v_{Ar}/v_{Cl_2} = \sqrt{70.9/39.9} = \mathbf{1.33}$.
15. $T_2 = 4T_1 = 4(273.15) = \mathbf{1092.6}$ K $= 819.45°$C.
16. $V_{mol} = N_A\frac{4}{3}\pi r^3 \approx 8.5 \times 10^{-6}$ m^3; fraction $= \frac{8.5 \times 10^{-6}}{22.4 \times 10^{-3}} \approx \mathbf{3.8 \times 10^{-4}}$ (0.04%).
17. $f = 3 + 2 + 2 = \mathbf{7}$; $C_v = \mathbf{3.5R}$; $\gamma = 1 + 2/7 = \mathbf{9/7} \approx \mathbf{1.29}$.
18. $\nu = v_{avg}/\lambda = 475/10^{-7} = \mathbf{4.75 \times 10^9}$ s$^{\mathbf{-1}}$.
19. v_{rms} of air molecules (~ 0.5 km/s at 300 K, tail up to > 2.3 km/s) exceeds Moon's escape speed (2.3 km/s).
20. $P = \frac{2}{3}E$.
21. **Both have the exact same number of molecules** (Avogadro's Law: $N = PV/(k_BT)$).
22. $v_{rms} = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3(1.38 \times 10^{-23})(300)}{5 \times 10^{-17}}} = \mathbf{1.58}$ cm/s.
23. $f = 3$ (trans) $+ 3$ (rot) $= \mathbf{6}$.
24. $\gamma = 1 + 2/6 = \mathbf{4/3} \approx \mathbf{1.33}$.
25. Remains **unchanged** (U depends only on T!).

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

1. Total moles conserved: $\frac{P(V_1+V_2)}{T} = \frac{P_1V_1}{T_1} + \frac{P_2V_2}{T_2} \implies P = \frac{\mathbf{T}}{\mathbf{V_1+V_2}}\left(\frac{\mathbf{P_1V_1}}{\mathbf{T_1}} + \frac{\mathbf{P_2V_2}}{\mathbf{T_2}}\right)$.
2. Total U conserved: $n_1T_1 + n_2T_2 = (n_1+n_2)T \implies T = \frac{\mathbf{P_1V_1+P_2V_2}}{\mathbf{P_1V_1/T_1+P_2V_2/T_2}}$.
3. $C_{v,mix} = \frac{n_1(2.5R)+n_2(3R)}{n_1+n_2}$.
4. $\frac{\Delta P}{P} = \frac{\Delta T}{T} \implies 0.004 = \frac{1}{T} \implies T = \mathbf{250}$ K.
5. Bulk KE becomes internal energy: $\frac{1}{2}(nM)v_0^2 = nC_v\Delta T = n(\frac{3}{2}R)\Delta T \implies \Delta T = \frac{\mathbf{Mv_0^2}}{\mathbf{3R}}$.

6. $\frac{v_{rms}}{v_{sound}} = \sqrt{\frac{\mathbf{3}}{\gamma}}$.

7. $v_{avg} = \frac{1+2+3+4}{4} = \mathbf{2.5}$ km/s; $v_{rms} = \sqrt{\frac{1+4+9+16}{4}} = \sqrt{7.5} \approx \mathbf{2.74}$ km/s.

8. $\lambda = \frac{1}{\sqrt{2}\pi(4\times10^{-20})(2.7\times10^{25})} \approx \mathbf{2.1 \times 10^{-7}}$ m.

9. $P_1V_1 = P_2V_2$ with atmospheric $P_0 = 76$ cm Hg: solve $h(76 + 152 - h) = 76(152)$.

10. $P_1 = 75, L_1 = 76$. Vertical down: $P_2 = 75 - 15 = 60$ cm Hg $\implies L_2 = \frac{75\times76}{60} = 95$ cm. Since $95 + 15 = 110 >$ 100 cm, **10 cm of Hg spills out**!

11. Graham's Law: $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} \implies \frac{28.7}{7.2} \approx 4 \implies M_2 = 16 \times 2 = \mathbf{32}$ (**Oxygen, O_2**)!

12. $C_v = \frac{1(1.5R)+1(2.5R)}{2} = \mathbf{2R}$.

13. $C_p = 2R + R = 3R \implies \gamma = 3/2 = \mathbf{1.5}$.

14. (a) 3 trans + 2 rot = **5**. (b) $5 + 2 = \mathbf{7}$.

15. Since $PV = nRT$ and $P = kT^2 \implies V \propto T/T^2 = \mathbf{1/T}$.

16. $\frac{3}{2}k_BT = 1.6 \times 10^{-19} \implies T = \frac{3.2\times10^{-19}}{3\times1.38\times10^{-23}} \approx \mathbf{7730}$ K.

17. $P \propto V^{-1/2} \implies T \propto PV \propto V^{1/2}$. When $V \to 4V$, $T \to 2T \implies v_{rms}$ becomes $\sqrt{\mathbf{2}}$ times.

18. Each collision on yz-face transfers $\Delta p = 2mv_x$, time between hits $= 2L/v_x \implies F_x = \frac{mv_x^2}{L}$. Summing N molecules and using $v_x^2 = v_{rms}^2/3$ gives $P = \frac{1}{3}\rho v_{rms}^2$.

19. $\rho = \frac{PM}{RT} \implies \rho' = \frac{2P}{0.5T} = \mathbf{4}\rho$.

20. $5 \times N_A = \mathbf{3.011 \times 10^{24}}$.

21. Each H_2O molecule has 3 atoms ($3 \times 3 = 9$ vibrational/rotational/translational modes) + hydrogen bonding!

22. $\lambda \propto 1/P \implies \mathbf{10}\,\lambda_\mathbf{0}$.

23. $\tilde{\mathbf{0}}$ (molecules move randomly in all directions equally).

24. $\frac{v_{235}}{v_{238}} = \sqrt{\frac{352}{349}} \approx \mathbf{1.0043}$ (0.43% faster!).

25. $B_T = -V\frac{dP}{dV}$; differentiating $PV = \text{const}$ gives $P + V\frac{dP}{dV} = 0 \implies B_T = P$.

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 13 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: OSCILLATIONS

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. Periodic motion repeats after a fixed time interval T (e.g., Earth orbiting Sun). Oscillatory motion is to-and-fro periodic motion about a mean position (e.g., pendulum).
2. Oscillatory motion where restoring force is directly proportional to displacement from mean position and directed towards it: $F = -kx$ (or $a = -\omega^2 x$).
3. $x(t) = A\sin(\omega t + \phi)$ or $A\cos(\omega t + \phi)$, where A = amplitude, ω = angular frequency, ϕ = initial phase.
4. $T = \frac{2\pi}{\omega}$ (time for 1 oscillation); $f = \frac{1}{T} = \frac{\omega}{2\pi}$ (SI: Hz).
5. $v = \pm\omega\sqrt{A^2 - x^2}$.
6. Velocity is maximum at **mean position** ($x = 0, v_{max} = \omega A$). Acceleration is maximum at **extreme positions** ($x = \pm A, a_{max} = \omega^2 A$).
7. $\pi/\mathbf{2}$ rad (90°); velocity leads displacement by 90°.
8. π rad (180°); acceleration is always opposite to displacement ($a = -\omega^2 x$).
9. $K = \frac{1}{2}k(A^2 - x^2)$; $\quad U = \frac{1}{2}kx^2$; $\quad E = \frac{1}{2}kA^2 = \frac{1}{2}m\omega^2 A^2$.
10. $\frac{1}{2}kx^2 = \frac{1}{2}k(A^2 - x^2) \implies 2x^2 = A^2 \implies x = \pm\frac{\mathbf{A}}{\sqrt{\mathbf{2}}}$.
11. $T = 2\pi\sqrt{\frac{m}{k}}$.
12. **No**, $T = 2\pi\sqrt{m/k}$ is independent of g (same on Moon and Earth!).
13. $T = 2\pi\sqrt{\frac{L}{g}}$ (for small oscillations, $\theta < 10°$).
14. **No**, T is independent of bob mass m.
15. A pendulum with time period $T = \mathbf{2}$ s. Length $L = \frac{gT^2}{4\pi^2} \approx \mathbf{1}$ m (0.993 m).
16. $T \propto 1/\sqrt{g} \implies T$ increases $\sqrt{6}$ times, so the clock runs **slow**!
17. **4 times** (at $x = +A/\sqrt{2}$ and $-A/\sqrt{2}$, twice going and twice coming).
18. **$2f$** (energy peaks twice in every oscillation!).
19. $v_{max} = 4 \times 5 = \mathbf{20}$ cm/s; $a_{max} = 16 \times 5 = \mathbf{80}$ cm/s$^{\mathbf{2}}$.
20. A **straight line passing through the origin** with negative slope ($-\omega^2$).
21. An **ellipse** ($\frac{v^2}{(\omega A)^2} + \frac{x^2}{A^2} = 1$).
22. Parallel: $k_{eff} = k_1 + k_2$. Series: $\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2}$.
23. $T \propto \sqrt{L} \implies T' = 2 \times \sqrt{4} = \mathbf{4}$ s.
24. $A = \mathbf{10}$ cm, $\omega = 2\pi \implies T = \mathbf{1}$ s.
25. **Infinite** (it does not oscillate!).

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

1. $x = 5\cos(3\pi + \pi/4) = -5/\sqrt{2} = \mathbf{-3.54}$ m; $v = -10\pi\sin(3\pi + \pi/4) = \mathbf{+22.2}$ m/s; $a = -4\pi^2 x = \mathbf{+139.6}$ m/s^2.
2. $E = \frac{1}{2}(100)(0.1)^2 = \mathbf{0.5}$ J; $v_{max} = \omega A = 10(0.1) = \mathbf{1}$ m/s.
3. $v^2 = \omega^2(A^2 - x^2)$: $16 = \omega^2(A^2 - 9)$ and $9 = \omega^2(A^2 - 16)$. Subtracting: $7 = 7\omega^2 \implies \omega = \mathbf{1}$ rad/s, $A = \mathbf{5}$ m.
4. $k \propto 1/L \implies$ each part has $\mathbf{3k}$.
5. $k_{eff} = 3k + 3k + 3k = 9k \implies T' = T_0/\sqrt{9} = \mathbf{T_0/3}$.
6. Standing raises the COM, **decreasing effective length L**, so $T = 2\pi\sqrt{L/g}$ **decreases** (swings faster)!
7. Initially COM shifts down (L increases, T increases); once more than half empties, COM shifts back up (L decreases, T returns to original)!
8. $A/2 = A\sin(\omega t) \implies \omega t = \pi/6 \implies t = \frac{\pi/6}{2\pi/T} = \mathbf{T/12}$.
9. From $0 \to A$ is $T/4$; from $0 \to A/2$ is $T/12$. So $A/2 \to A$ takes $T/4 - T/12 = \mathbf{T/6}$!
10. Phase difference is $90° \implies A = \sqrt{3^2 + 4^2} = \mathbf{5}$.
11. $T = 2\pi\sqrt{5/500} = \frac{2\pi}{10} = \mathbf{0.628}$ s; $a_{max} = \omega^2 A = 100(0.1) = \mathbf{10}$ m/s^2.
12. $U = \frac{1}{4}E$, $K = \mathbf{\frac{3}{4}E}$.
13. $g_{eff} = g + g/3 = 4g/3 \implies T' = T_0\sqrt{\frac{g}{4g/3}} = \mathbf{\frac{\sqrt{3}}{2}T_0}$.
14. $L = \frac{9.8(1)^2}{4\pi^2} \approx \mathbf{0.248}$ m (24.8 cm).
15. (a) is SHM. (b) is SHM ($\frac{1}{2}(1 - \cos 2\omega t)$) about 1/2! **(c)** is periodic ($T = 2\pi/\omega$) but NOT SHM!
16. $T = 2\pi\sqrt{\frac{L}{2g}}$.
17. $T = 2\pi\sqrt{\frac{\rho L}{\rho_w g}} = 2\pi\sqrt{\frac{h_{sub}}{g}}$.
18. $v_{max} = \frac{2\pi}{2}(4) = \mathbf{4\pi}$ cm/s.
19. $k = \frac{50\times 9.8}{0.20} = 2450$ N/m. $m = \frac{kT^2}{4\pi^2} = \frac{2450(0.36)}{39.48} = 22.3$ kg $\implies W = \mathbf{219}$ N.
20. $T = 2\pi\sqrt{\frac{R_E}{2g}} \approx \mathbf{60}$ min (using $T = 2\pi\sqrt{\frac{1}{g(1/L + 1/R_E)}}$!).
21. $T = 2\pi\sqrt{\frac{R_E}{g}} \approx \mathbf{84.6}$ minutes (NOT infinite!).
22. $\omega = 2\pi(200/60) = 20.94$ rad/s $\implies v_{max} = 20.94(0.5) = \mathbf{10.47}$ m/s.
23. T is **unchanged**; v_{max} **doubles**; Total Energy E becomes **4 times**.
24. $\langle K\rangle = \langle U\rangle = \mathbf{\frac{1}{2}E} = \mathbf{\frac{1}{4}kA^2}$.
25. $x(t) = A\cos(\omega t)$.

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

1. Force $F = -\frac{GMm}{R_E^3}x = -kx$. Thus $T = 2\pi\sqrt{\frac{R_E}{g}} \approx \mathbf{84.6}$ min (same for any straight chord tunnel!).
2. $g_{eff} = \sqrt{g^2 + a^2} \implies T = \mathbf{2\pi\sqrt{\frac{L}{(g^2 + a^2)^{1/2}}}}$.
3. $k_p = 200, k_s = 50 \implies \frac{f_p}{f_s} = \sqrt{\frac{k_p}{k_s}} = \sqrt{4} = \mathbf{2:1}$.
4. At $x = A/2$: $\theta_1 = 30°$, $\theta_2 = 150° \implies \Delta\phi = 150° - 30° = \mathbf{120°}$ ($2\pi/3$).
5. Mean position is at $x = \mathbf{2}$; amplitude $= \sqrt{3^2 + 4^2} = \mathbf{5}$.

6. $T = \mathbf{2\pi\sqrt{\frac{M+m_s/3}{k}}}$.
7. Physical pendulum: $I = \frac{3}{2}MR^2, d = R \implies T = 2\pi\sqrt{\frac{I}{Mgd}} = \mathbf{2\pi\sqrt{\frac{3R}{2g}}}$.
8. $I = \frac{1}{3}ML^2, d = L/2 \implies T = \mathbf{2\pi\sqrt{\frac{2L}{3g}}}$.
9. Use reduced mass $\mu = \frac{m_1 m_2}{m_1+m_2}$: $T = \mathbf{2\pi\sqrt{\frac{\mu}{k}}}$.
10. At top, $a_{max} = \omega^2 A \le g \implies A_{max} = \mathbf{\frac{g}{4\pi^2 f^2}}$.
11. $m\omega^2 A \le \mu_s mg \implies A_{max} = \mathbf{\frac{\mu_s g}{\omega^2}}$.
12. $K_{max} = \frac{1}{2}kA^2 = \frac{1}{2}(100)(0.01) = \mathbf{0.5}$ J.
13. $\Delta t = \frac{1}{2}\alpha\Delta\theta \times 86400 = \frac{1}{2}(2\times10^{-5})(10)(86400) = \mathbf{8.64}$ s lost/day.
14. $\frac{\Delta T}{T} = -\frac{1}{2}\frac{\Delta g}{g} = +\mathbf{1}\%$ (increases by 1%).
15. $\omega\sqrt{A^2-x^2} = \frac{\omega A}{2} \implies x = \frac{\sqrt{3}}{2}A = \sqrt{\mathbf{3}}$ cm.
16. $x = \mathbf{A/2}$.
17. $T_1/T_2 = 10/11 \implies 11T_1 = 10T_2$, so after **11 oscillations** of the shorter pendulum!
18. $U \approx U_0\frac{\alpha^2x^2}{2} = \frac{1}{2}k_{eff}x^2 \implies k_{eff} = U_0\alpha^2 \implies T = \mathbf{2\pi\sqrt{\frac{m}{U_0\alpha^2}}}$.
19. $\omega = a_{max}/v_{max} = 4$ rad/s $\implies T = \pi/\mathbf{2}$ s; $A = v_{max}/\omega = \mathbf{1}$ m.
20. $\tan\theta = \mathbf{a/g}$ (tilted backward).
21. Wait: same velocity vector repeats once per full period T, EXCEPT wait: at $x = +x_0$ going right vs coming? No, velocity has same magnitude & direction at x going right, which repeats after **T**! (Same *speed* repeats every $T/2$ if at $x = 0$.)
22. $A = 2\sqrt{2}$ cm, $\omega = 10 \implies a_{max} = 100(2\sqrt{2}) = \mathbf{200\sqrt{2}}$ cm/s$^{\mathbf{2}}$.
23. Displacing by x creates $2x$ level difference: $F = -(2Ax\rho)g \implies k = \mathbf{2A\rho g}$.
24. $x = A\cos(\omega t+\phi) \implies \frac{d^2x}{dt^2} = -\omega^2 x$, which is the defining equation of SHM!
25. $\sin\phi = 1/2$ with $\cos\phi > 0 \implies \phi = \pi/\mathbf{6}$ (30°).

TYBA COACHING CENTRE | NCERT ZERO-OMISSION MASTER TEXTBOOK | CHAPTER 14 SOLUTIONS

DETAILED STEP-BY-STEP SOLUTIONS: WAVES

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 disturbance carrying **energy and momentum** without net transport of matter (particles only oscillate locally).
2. Transverse: oscillation perpendicular to wave propagation (e.g., wave on a string). Longitudinal: oscillation parallel to propagation (e.g., sound waves in air).
3. $v = f\lambda = \frac{\lambda}{T} = \frac{\omega}{k}$.
4. $y(x,t) = A\sin(kx - \omega t + \phi)$, where $k = \frac{2\pi}{\lambda}$ and $\omega = 2\pi f$.
5. **Plus (+)** sign: $y(x,t) = A\sin(kx + \omega t + \phi)$.
6. Angular wave number $k = \frac{2\pi}{\lambda}$ (SI unit: rad m^{-1} or m^{-1}).
7. $v = \sqrt{\frac{T}{\mu}}$, where T is tension and μ is linear mass density (M/L).
8. Newton assumed isothermal ($v = \sqrt{P/\rho}$); Laplace corrected it to adiabatic: $v = \sqrt{\frac{\gamma P}{\rho}}$.
9. (a) **Independent of pressure** at constant T. (b) $v \propto \sqrt{T}$ (increases with temperature).
10. Net displacement at any point is the algebraic (vector) sum of individual displacements: $y = y_1 + y_2$.
11. (a) Rigid boundary: phase change of **π rad (180°)** (crest becomes trough). (b) Free boundary: **zero** phase change.
12. Nodes: points of permanently **zero** amplitude. Antinodes: points of **maximum** amplitude.
13. (a) $\lambda/\mathbf{2}$; (b) $\lambda/\mathbf{4}$.
14. $f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$.
15. **All harmonics** ($1, 2, 3, 4\ldots$, both odd and even).
16. **Only odd harmonics** ($1, 3, 5\ldots$). Fundamental $f_1 = \frac{v}{4L}$.
17. Periodic waxing and waning of sound intensity when two waves of slightly different frequencies f_1, f_2 interfere: $f_{beat} = |f_1 - f_2|$.
18. About **10 Hz** (due to persistence of hearing ~ 0.1 s).
19. $\Delta\phi = \frac{2\pi}{\lambda}\Delta x$.
20. $v = f\lambda = 500 \times 0.68 = \mathbf{340}$ m/s.
21. Humid air has **lower density** (water vapour $M = 18 <$ dry air $M = 29$), so speed of sound **increases**!
22. **No**, because gases have zero shear modulus ($G = 0$). (Only longitudinal waves travel in gases.)
23. π rad (180°).
24. $f_1 = \frac{v}{2L}$.
25. $256 \pm 4 = \mathbf{260}$ Hz or $\mathbf{252}$ Hz.

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

1. (a) $-x$ direction (+ sign); (b) $A = \mathbf{3.0}$ cm; (c) $f = 36/(2\pi) = \mathbf{5.73}$ Hz; (d) $\lambda = 2\pi/0.018 = \mathbf{349}$ cm; (e) $v = 36/0.018 = \mathbf{2000}$ cm/s $= 20$ m/s.
2. $\mu = \frac{5\times10^{-3}}{0.72} = 6.94\times10^{-3}$ kg/m. $v = \sqrt{\frac{60}{6.94\times10^{-3}}} = \mathbf{93}$ m/s.
3. $\mu = 2.5/20 = 0.125$ kg/m; $v = \sqrt{200/0.125} = 40$ m/s; $t = 20/40 = \mathbf{0.5}$ s.
4. $t_1 = \sqrt{2(300)/9.8} = 7.82$ s; $t_2 = 300/340 = 0.88$ s; Total $t = \mathbf{8.70}$ s.
5. $v \propto \sqrt{T} \implies T_2 = 4T_1 = 4(300) = \mathbf{1200}$ K $= 927°$C.
6. Fundamental $f_1 = \frac{330}{2(0.30)} = 550$ Hz. Since $1100 = 2\times550$, it is the **2nd harmonic**!
7. Closed pipe fundamental $f_1' = \frac{330}{4(0.30)} = 275$ Hz. Odd harmonics: $275, 825, 1375$ Hz. Since 1100 is 4×275 (even!), **no resonance**!
8. Originally $f_A = 330$ or 318 Hz. Reducing T_A lowers f_A; since beats drop ($330 \to 327$), original $f_A = \mathbf{330}$ Hz!
9. $v_{p,max} = \omega A = 100\times2 = \mathbf{200}$ cm/s $= 2$ m/s.
10. $v = \omega/k = 100/0.5 = \mathbf{200}$ cm/s $= 2$ m/s.
11. $f_{open}/f_{closed} = \frac{v/(2L)}{v/(4L)} = \mathbf{2:1}$.
12. $k = 2\pi/3 \implies \lambda = \mathbf{3}$ m; $\omega = 120\pi \implies f = \mathbf{60}$ Hz; $v = 60\times3 = \mathbf{180}$ m/s.
13. $\lambda/2 = 3/2 = \mathbf{1.5}$ m.
14. $A_{net} = \mathbf{2A}\cos(\phi/\mathbf{2})$.
15. $f \propto \sqrt{T} \implies f' = \sqrt{1.44}f = 1.2f \implies \mathbf{20}\%$ increase.
16. $v_{H_2}/v_{O_2} = \sqrt{32/2} = \mathbf{4:1}$.
17. $\Delta\phi = \frac{2\pi}{4}(1) = \pi/\mathbf{2}$ rad $(90°)$.
18. To avoid **resonance** between their marching frequency and the bridge's natural frequency, which could collapse the bridge!
19. A progressive wave **transfers energy** forward; a standing wave **does not transfer energy** across nodes.
20. $3(\lambda/2) = 1 \implies \lambda = 2/3$ m $\implies v = 300\times(2/3) = \mathbf{200}$ m/s.
21. An open pipe produces **all harmonics** (odd + even), whereas a closed pipe produces only odd harmonics.
22. Added mass lowers its frequency (f **decreases**). Filing the prongs **increases** frequency.
23. $\lambda = 340/10^6 = \mathbf{3.4\times10^{-4}}$ m.
24. $v_{solid} > v_{liquid} > v_{gas}$ (solids have much higher elastic modulus Y than gases' γP).
25. $\Delta x = \frac{\Delta\phi}{k} = \frac{\pi/2}{0.1\pi} = \mathbf{5}$ units.

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

1. Tension at height x supports mass below it: $T(x) = \frac{M}{L}xg \implies v(x) = \sqrt{T/\mu} = \sqrt{\mathbf{gx}}$ (independent of M and L!).
2. $\frac{dx}{dt} = \sqrt{gx} \implies t = \int_0^L \frac{dx}{\sqrt{gx}} = \mathbf{2}\sqrt{\frac{\mathbf{L}}{\mathbf{g}}}$.
3. $f \propto 1/L \implies f_A/f_B = 25.5/25$. Since $f_A - f_B = 4$: $f_B(\frac{0.5}{25}) = 4 \implies f_B = \mathbf{200}$ Hz, $f_A = \mathbf{204}$ Hz.
4. $f = \mathbf{255}$ Hz. (Halfway!)
5. $f \propto \frac{\sqrt{T}}{L} \implies f' = 256\times\frac{\sqrt{4}}{2} = \mathbf{256}$ Hz (unchanged!).

6. Old open pipe: $f_1 = \frac{v}{2L}$. New closed pipe of length $L/2$: $f_1' = \frac{v}{4(L/2)} = \frac{v}{2L} = f_1 \implies \mathbf{1:1}$!
7. $A_{net} = 2A\cos(\pi/6) = \sqrt{\mathbf{3}}\mathbf{A}$.
8. $I_{max}/I_{min} = \left(\frac{\sqrt{9}+1}{\sqrt{9}-1}\right)^2 = (4/2)^2 = \mathbf{4:1}$.
9. Node at centre, antinodes at both ends: $L = \lambda/2 \implies \lambda = 2$ m $\implies v = 2530 \times 2 = \mathbf{5060}$ m/s.
10. $v(t) \approx 332 + 0.61t = 332 + 0.61(27) \approx \mathbf{348.5}$ m/s.
11. $T' = T(1 - 1/5) = 0.8T \implies f' = 200\sqrt{0.8} = \mathbf{178.9}$ Hz.
12. $y = 2A\sin(kx)\cos(\omega t) = 0$ for all t when $\sin(kx) = 0 \implies x = 0, \lambda/2, \lambda, 3\lambda/2\ldots$
13. $f_{20} = f_1 + 19(4) = 2f_1 \implies f_1 = \mathbf{76}$ Hz.
14. $\omega = 20\pi, k = \omega/v = \pi \implies y = \mathbf{0.05}\sin(\pi\mathbf{x} - \mathbf{20}\pi\mathbf{t})$ m.
15. $L = \frac{v}{4f} = \frac{340}{4(340)} = \mathbf{0.25}$ m (25 cm).
16. $\lambda = 10/50 = 0.2$ m $\implies$ Node-Node $= \lambda/2 = \mathbf{0.1}$ m.
17. Odd harmonics only: **300** Hz and **500** Hz.
18. 3rd harmonic (3 loops): touch at $L/3$ (33.3 cm) to create a node, pluck at $L/6$ (16.7 cm)!
19. $v_{H_2}/v_{He} = \sqrt{\frac{\gamma_1/M_1}{\gamma_2/M_2}} = \sqrt{\frac{1.4/2}{1.67/4}} = \sqrt{\frac{0.7}{0.417}} \approx \mathbf{1.30}$.
20. Dust heaps form at nodes: $\lambda/2 = 5$ cm $\implies \lambda = 0.10$ m $\implies v = 3400 \times 0.10 = \mathbf{340}$ m/s.
21. Remains **unchanged** ($v = \sqrt{\gamma RT/M}$ is independent of pressure!).
22. Matches $f(x - vt)$ with $v = \mathbf{5}$ m/s along **$+x$ direction**.
23. Antinode forms slightly outside open end at distance $e \approx 0.6r$ (adds e for closed pipe, $2e$ for open pipe).
24. $f_1 = 340/1 = 340$ Hz; $f_2 = 340/1.01 = 336.63$ Hz $\implies f_{beat} \approx \mathbf{3.37}$ Hz.
25. **No**, they produce a **standing wave**! Beats require two slightly different frequencies moving in the same direction.