PHYSICS POINT

NCERT Class 11 Physics Solutions

Chapter-Wise Complete Solutions (Session 2026-27)

Covers all 14 chapters of NCERT Physics Part I & Part II — concept summaries, key formulas, and fully worked, step-by-step solutions to representative in-text and end-of-chapter exercise questions.

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Note: Questions are presented in the faculty's own words as practice/solution material aligned to the NCERT Class 11 Physics syllabus (2026-27); please refer to the official NCERT textbook for the original question text.

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Chapter 1

Units and Measurement

Chapter Overview

This chapter deals with the International System (SI) of units, the idea of dimensions of physical quantities, dimensional analysis and its uses, significant figures in measured data, and the treatment of errors that creep into any measurement.

Key Concepts

- The SI system has seven base units: metre (length), kilogram (mass), second (time), ampere (current), kelvin (temperature), mole (amount of substance) and candela (luminous intensity).
- Every derived physical quantity can be expressed as a combination of the powers of the base quantities; this combination is called its dimensional formula.
- Dimensional analysis is used to check the correctness of an equation (principle of homogeneity of dimensions) and to derive relationships between physical quantities.
- The number of significant figures in a measured value indicates the precision of the measurement; rules govern how significant figures combine in addition, subtraction, multiplication and division.
- Error is the difference between the measured value and the true value. Absolute error, mean absolute error, relative error and percentage error describe the uncertainty in a measurement.
- When quantities are combined mathematically, errors also combine: errors add in sum/difference, and percentage errors add in product/quotient.

Important Formulas

Relative error = (mean absolute error) / (mean value)
Percentage error = Relative error × 100
If $Z = A^n$, then percentage error in Z = n × (percentage error in A)
If Z = A × B or Z = A / B, percentage error in Z = (percentage error in A) + (percentage error in B)
Dimensional formula of a quantity $Q = [M^a\ L^b\ T^c]$

Solved Questions (NCERT Exercise Pattern)

Q1. **A well-known unit of heat energy is defined such that the amount needed to raise the temperature of one gram of water by one degree Celsius is treated as one unit. Suppose a new system of units is adopted in which the unit of mass equals α kg, the unit of length equals β m, and the unit of time equals γ s. Show that this unit of heat, whose magnitude is 4.2 J in SI units, would have a numerical value of 4.2 α^{-1} β^{-2} γ^{2} in the new system.**

Solution:

1. The dimensional formula of energy (and hence of heat) is $[M\ L^{2}\ T^{-2}]$.
2. If n1 is the numerical value in the SI system (with units kg, m, s) and n2 is the numerical value in the new system (with units α kg, β m, γ s), the size of the physical quantity stays the same, so $n1[M1^{1}L1^{2}T1^{-2}] = n2[M2^{1}L2^{2}T2^{-2}]$.
3. Here n1 = 4.2, M1/M2 = $1/\alpha$, L1/L2 = $1/\beta$, T1/T2 = $1/\gamma$.
4. So $n2 = n1\ (M1/M2)^{1}(L1/L2)^{2}(T1/T2)^{-2} = 4.2 \times \alpha^{-1} \times \beta^{-2} \times \gamma^{2}$.

Answer: The unit of heat has magnitude 4.2 α^{-1} β^{-2} γ^{2} in the new system, confirming the relation follows directly from the dimensional formula of energy.

Q2. **State the number of significant figures in each of the following measured values: (a) 0.0075 m2, (b) 2.40 × 10^{4} kg, (c) 6.032 N m^{-2}, (d) 0.0006032 m3.**

Solution:

1. Leading zeros before the first non-zero digit are never significant; they only fix the position of the decimal point.
2. (a) 0.0075 has two significant figures (7 and 5); the leading zeros are not counted.
3. (b) 2.40 × 10^{4} has three significant figures (2, 4, 0); trailing zero after decimal in the coefficient is significant.
4. (c) 6.032 has four significant figures (6, 0, 3, 2), since zeros between non-zero digits are always significant.
5. (d) 0.0006032 has four significant figures (6, 0, 3, 2); the four leading zeros only locate the decimal point.

Answer: (a) 2, (b) 3, (c) 4, (d) 4 significant figures respectively.

Q3. **The resistance R of a wire is found using the formula R = V/I, where a voltage V = (100 ± 5) V produces a current I = (10 ± 0.2) A. Find the percentage error in R.**

Solution:

1. Percentage error in V = (5/100) × 100 = 5%.
2. Percentage error in I = (0.2/10) × 100 = 2%.
3. Since R = V/I is a quotient, percentage errors add: percentage error in R = 5% + 2% = 7%.
4. R itself = 100/10 = 10 Ω, so R = (10 ± 0.7) Ω.

Answer: The percentage error in R is 7%, so R = (10 ± 0.7) Ω.

Q4. **Using dimensional analysis, derive an expression for the time period T of a simple pendulum, given that T could depend on the mass m of the bob, the length l of the string, and the acceleration due to gravity g.**

Solution:

1. Assume $T = k\ m^{a}\ l^{b}\ g^{c}$, where k is a dimensionless constant.
2. Writing dimensions: $[T] = [M]^{a}[L]^{b}[LT^{-2}]^{c} = [M^{a}\ L^{b+c}\ T^{-2c}]$.
3. Comparing powers: for M, a = 0 (since T has no mass dimension); for T, -2c = 1 so c = -1/2; for L, b + c = 0 so b = 1/2.
4. Substituting back: $T = k\ m^{0}\ l^{1/2}\ g^{-1/2} = k\sqrt{(l/g)}$.

Answer: T = k$\sqrt{(l/g)}$; experiment shows k = 2π, giving the familiar formula T = 2$\pi\sqrt{(l/g)}$.

Q5. **The thickness of a coin is measured with a screw gauge of pitch 1 mm and 100 divisions on the circular scale. If the main scale reading is 3 mm and the circular scale reading is 35 divisions, with no zero error, find the thickness of the coin.**

Solution:

1. Least count of the screw gauge = pitch / number of circular divisions = 1 mm / 100 = 0.01 mm.
2. Circular scale reading contribution = 35 × 0.01 mm = 0.35 mm.
3. Total thickness = main scale reading + circular scale reading = 3 mm + 0.35 mm.

Answer: Thickness of the coin = 3.35 mm.

Q6. **Check the dimensional correctness of the equation v = u + at, where v and u are velocities, a is acceleration and t is time.**

Solution:

1. Dimension of v and u = $[L\ T^{-1}]$.
2. Dimension of a = $[L\ T^{-2}]$ and dimension of t = [T], so dimension of at = $[L\ T^{-2}][T] = [L\ T^{-1}]$.
3. Since every term (v, u, at) has the same dimension $[L\ T^{-1}]$, the equation is dimensionally consistent.

Answer: The equation v = u + at is dimensionally correct, as all terms reduce to $[L\ T^{-1}]$.

Chapter 2

Motion in a Straight Line

Chapter Overview

This chapter introduces one-dimensional motion: the ideas of position, path length and displacement, average and instantaneous speed and velocity, uniform and non-uniform acceleration, the kinematic equations for constant acceleration, and relative velocity.

Key Concepts

- Distance (path length) is a scalar and is always greater than or equal to the magnitude of displacement, which is a vector.
- Average velocity = total displacement / total time; average speed = total distance / total time; the two are only equal when motion is along a straight line without change of direction.
- Instantaneous velocity is the derivative of position with respect to time; instantaneous acceleration is the derivative of velocity with respect to time.
- For constant acceleration, the motion is completely described by the three standard kinematic equations.
- On a position-time graph, the slope gives velocity; on a velocity-time graph, the slope gives acceleration and the area under the graph gives displacement.
- Relative velocity of A with respect to B is the vector difference (velocity of A) minus (velocity of B).

Important Formulas

$v = u + at$
$s = ut + (1/2)at^2$
$v^2 = u^2 + 2as$
Average velocity = $\Delta x/\Delta t$; Average acceleration = $\Delta v/\Delta t$
Relative velocity: $v_{AB} = v_A - v_B$

Solved Questions (NCERT Exercise Pattern)

Q1. **A car starting from rest accelerates uniformly at 2 m/s2 for 10 seconds. Find (a) the velocity attained, and (b) the distance covered in this time.**

Solution:

1 Given u = 0, a = 2 m/s2, t = 10 s.
2 (a) Using v = u + at: v = 0 + 2 × 10 = 20 m/s.
3 (b) Using s = ut + (1/2)at2: s = 0 × 10 + (1/2)(2)(10)2 = 100 m.

Answer: The car attains a velocity of 20 m/s and covers a distance of 100 m.

Q2. **A ball is thrown vertically upward with a speed of 20 m/s from the ground. Taking g = 10 m/s2, find (a) the maximum height reached, (b) the time taken to reach that height, and (c) the total time of flight before it returns to the ground.**

Solution:

1. At maximum height, final velocity v = 0. Using v2 = u2 - 2gh: 0 = (20)2 - 2(10)h, giving h = 400/20 = 20 m.
2. Time to reach the top: using v = u - gt, 0 = 20 - 10t, so t = 2 s.
3. By symmetry of projectile motion under gravity, time to come back down equals time to go up, so total time of flight = 2 × 2 = 4 s.

Answer: Maximum height = 20 m, time to reach it = 2 s, and total time of flight = 4 s.

Q3. **Two trains 300 km apart move towards each other on the same track, one at 60 km/h and the other at 90 km/h. Starting at the same time, how long will they take to meet?**

Solution:

1. Since the trains move towards each other, their relative speed of approach = 60 + 90 = 150 km/h.
2. Time to cover the separating distance of 300 km at this relative speed: t = distance / relative speed = 300/150.

Answer: The trains meet after 2 hours.

Q4. **The position-time graph of a particle moving along a straight line shows the particle moving from x = 0 to x = 20 m in the first 4 s at constant slope, and then remaining at x = 20 m for the next 2 s. Describe the motion and find the velocity in each interval.**

Solution:

1. From t = 0 to t = 4 s, slope = (20 - 0)/(4 - 0) = 5 m/s, so the particle moves with a constant velocity of 5 m/s.
2. From t = 4 s to t = 6 s, the position does not change (the line is horizontal), so the slope is zero.
3. A zero slope on a position-time graph means the velocity is zero, i.e. the particle is at rest.

Answer: The particle moves at a constant 5 m/s for the first 4 s, then remains at rest for the next 2 s.

Q5. **A stone is dropped from the top of a tower 45 m high. Taking g = 10 m/s2, find the time it takes to reach the ground and its speed just before hitting the ground.**

Solution:

1. For a body dropped from rest, u = 0, and it falls a height h = 45 m.
2. Using h = (1/2)gt2: 45 = (1/2)(10)t2, so t2 = 9, giving t = 3 s.
3. Speed just before hitting the ground: v = u + gt = 0 + 10 × 3 = 30 m/s.

Answer: The stone takes 3 s to reach the ground, striking it with a speed of 30 m/s.

Q6. **Two buses A and B start from the same point and move in the same direction along a straight road, A at 40 km/h and B at 60 km/h, with B starting 1 hour after A. How far from the starting point will B catch up with A?**

Solution:

1. In the 1 hour head start, A covers a distance of 40 × 1 = 40 km.
2. Once B starts, the gap of 40 km closes at a relative speed of (60 - 40) = 20 km/h.
3. Time for B to close the gap: t = 40/20 = 2 h after B starts.
4. Distance covered by B in this time (from the common starting point) = 60 × 2 = 120 km.

Answer: Bus B catches up with bus A at a distance of 120 km from the starting point.

Chapter 3

Motion in a Plane

Chapter Overview

This chapter extends kinematics to two dimensions using vectors: vector addition and resolution, motion under gravity in two dimensions (projectile motion), and uniform circular motion.

Key Concepts

- A vector has both magnitude and direction and combines with other vectors using the triangle or parallelogram law.
- Any vector can be resolved into perpendicular (usually horizontal and vertical) components.
- In projectile motion, the horizontal component of velocity stays constant while the vertical component changes under gravity; the two motions are independent of each other.
- The path of a projectile launched at an angle is a parabola.
- In uniform circular motion, speed is constant but velocity changes direction continuously, producing a centripetal acceleration directed towards the centre.
- Relative velocity in two dimensions is found by vector subtraction of the two velocities involved.

Important Formulas

Range $R = u^2 \sin 2\theta / g$
Maximum height $H = u^2 \sin^2\theta / 2g$
Time of flight $T = 2u \sin\theta / g$
Centripetal acceleration $a = v^2/r = \omega^2 r$
Resolution: $A_x = A \cos\theta$, $A_y = A \sin\theta$

Solved Questions (NCERT Exercise Pattern)

Q1. A ball is projected with a speed of 20 m/s at an angle of 30° above the horizontal. Taking g = 10 m/s2, find the maximum height reached, the time of flight, and the horizontal range.

Solution:

1. u = 20 m/s, θ = 30°, so sinθ = 0.5, sin2θ = sin60° = 0.866.
2. Maximum height H = u2 sin2θ/(2g) = (20)2(0.5)2/(2 × 10) = 400 × 0.25/20 = 5 m.
3. Time of flight T = 2u sinθ/g = 2 × 20 × 0.5/10 = 2 s.
4. Range R = u2 sin2θ/g = 400 × 0.866/10 = 34.6 m.

Answer: Maximum height = 5 m, time of flight = 2 s, and horizontal range ≈ 34.6 m.

Q2. **A river flows due east at 3 km/h. A boatman rows the boat due north (relative to water) at 4 km/h to cross the river. Find the resultant velocity of the boat relative to the ground.**

Solution:

1. The boat's velocity relative to water (4 km/h, north) and the river's velocity relative to ground (3 km/h, east) are perpendicular, so they add as vectors at right angles.
2. Resultant speed = $\sqrt{(4^2 + 3^2)} = \sqrt{(16+9)} = \sqrt{25} = 5$ km/h.
3. Direction: $\tan\theta$ = (river speed)/(rowing speed) = 3/4, measured from the north (direction of rowing) towards east, $\theta = \tan^{-1}(3/4) \approx 37°$.

Answer: The resultant velocity of the boat is 5 km/h, directed at about 37° east of north.

Q3. **Two vectors A and B of magnitudes 6 units and 8 units act at right angles to each other. Find the magnitude and direction of the resultant vector.**

Solution:

1. Since the vectors are perpendicular, use the Pythagorean form of the parallelogram law: R = √(A2 + B2).
2. $R = \sqrt{(6^2 + 8^2)} = \sqrt{(36+64)} = \sqrt{100} = 10$ units.
3. Direction from A: $\tan\theta = B/A = 8/6 = 4/3$, so $\theta = \tan^{-1}(4/3) \approx 53°$.

Answer: The resultant has a magnitude of 10 units, inclined at about 53° to vector A.

Q4. **A stone tied to a 1 m long string is whirled in a horizontal circle at a constant speed of 2 m/s. Find the centripetal acceleration of the stone.**

Solution:

1. Given v = 2 m/s, r = 1 m.
2. Centripetal acceleration a = v2/r = (2)2/1 = 4 m/s2, directed towards the centre of the circle.

Answer: The centripetal acceleration is 4 m/s2, directed towards the centre.

Q5. **An aircraft flies horizontally at a height of 500 m with a speed of 100 m/s and releases a package. Taking g = 10 m/s2, find the time the package takes to hit the ground and the horizontal distance it travels.**

Solution:

1. The vertical motion is like free fall from rest (vertical component of the plane's velocity is zero): h = (1/2)gt2.
2. 500 = (1/2)(10)t2, so t2 = 100, giving t = 10 s.
3. Horizontal distance = horizontal speed × time = 100 × 10 = 1000 m, since the horizontal velocity stays unchanged during the fall.

Answer: The package takes 10 s to land and travels a horizontal distance of 1000 m.

Chapter 4

Laws of Motion

Chapter Overview

This chapter covers Newton's three laws of motion, the concepts of momentum and impulse, the law of conservation of momentum, friction (static and kinetic), and the dynamics of circular motion including banking of roads.

Key Concepts

- Newton's first law: a body continues in its state of rest or uniform motion unless acted upon by a net external force (law of inertia).
- Newton's second law: the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force, giving F = ma.
- Newton's third law: for every action there is an equal and opposite reaction, and these two forces act on different bodies.
- In the absence of an external force, the total momentum of an isolated system is conserved.
- Friction opposes relative sliding between two surfaces; static friction can take any value up to a maximum ($\mu_s N$) needed to keep the body from sliding, while kinetic friction ($\mu_k N$) acts once sliding begins.
- For a vehicle safely turning on a banked road, part of the normal reaction supplies the centripetal force needed to negotiate the turn.

Important Formulas

$F = ma = dp/dt$
$p = mv$
$f_{s(max)} = \mu_s N$, $f_k = \mu_k N$
$\tan\theta = v^2/rg$ (ideal banking angle, no friction)
Conservation of momentum: $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$

Solved Questions (NCERT Exercise Pattern)

Q1. **A block of mass 5 kg resting on a horizontal floor is pulled by a horizontal force of 20 N. If the coefficient of kinetic friction between the block and the floor is 0.2, find the acceleration of the block. (Take g = 10 m/s2.)**

Solution:

1. Normal reaction N = mg = 5 × 10 = 50 N.
2. Kinetic friction force $f = \mu_k N$ = 0.2 × 50 = 10 N, opposing the applied force.
3. Net force = applied force - friction = 20 - 10 = 10 N.
4. Acceleration a = net force / mass = 10/5 = 2 m/s2.

Answer: The block accelerates at 2 m/s2 in the direction of the applied force.

Q2. **Two blocks of masses 3 kg and 2 kg are connected by a light string passing over a frictionless pulley, with the 3 kg block hanging vertically and pulling the system. Find the acceleration of the system and the tension in the string, assuming the 2 kg block moves on a smooth horizontal surface. (Take g = 10 m/s2.)**

Solution:

1 Let a be the common acceleration and T the tension. For the hanging 3 kg block: $3g - T = 3a$.
2 For the 2 kg block on the smooth horizontal surface: $T = 2a$.
3 Adding the two equations: $3g = 5a$, so $a = 3g/5 = 3 \times 10/5 = 6$ m/s2.
4 Substituting back: $T = 2a = 2 \times 6 = 12$ N.

Answer: The system accelerates at 6 m/s2, and the tension in the string is 12 N.

Q3. **A bullet of mass 20 g moving at 300 m/s gets embedded in a stationary wooden block of mass 2 kg resting on a frictionless surface. Find the common velocity of the bullet and block immediately after impact.**

Solution:

1 This is a perfectly inelastic collision, so momentum is conserved: $m_{bullet}u_{bullet} + m_{block}u_{block} = (m_{bullet}+m_{block})v$.
2 Convert mass: 20 g = 0.02 kg.
3 $0.02 \times 300 + 2 \times 0 = (0.02 + 2)v$, so $6 = 2.02v$.
4 $v = 6/2.02 \approx 2.97$ m/s.

Answer: The bullet and block move together at approximately 2.97 m/s immediately after impact.

Q4. **A car of mass 1000 kg negotiates a curve of radius 50 m banked at an angle such that no friction is needed at a speed of 10 m/s. Find the angle of banking. (Take g = 10 m/s2.)**

Solution:

1 For an ideally banked curve (no friction required), $\tan\theta = v2/(rg)$.
2 $\tan\theta = (10)2/(50 \times 10) = 100/500 = 0.2$.
3 $\theta = \tan^{-1}(0.2) \approx 11.3°$.

Answer: The road must be banked at an angle of about 11.3°.

Q5. **A hockey ball of mass 200 g travelling at 10 m/s is struck by a stick and returns along the same line with a speed of 5 m/s. If the ball remains in contact with the stick for 0.01 s, find the impulse imparted to the ball and the average force exerted by the stick.**

Solution:

1 Take the initial direction of the ball as positive. Initial momentum = $0.2 \times 10 = 2$ kg m/s.
2 Since the ball returns along the same line, its final velocity is -5 m/s, so final momentum = $0.2 \times (-5) = -1$ kg m/s.
3 Impulse = change in momentum = final momentum - initial momentum = $-1 - 2 = -3$ kg m/s (magnitude 3 kg m/s, directed opposite to the initial motion).
4 Average force = impulse / time = $3 / 0.01 = 300$ N.

Answer: The impulse on the ball has magnitude 3 kg m/s (opposite to its initial direction), and the average force exerted by the stick is 300 N.

Chapter 5

Work, Energy and Power

Chapter Overview

This chapter introduces work done by a force, kinetic and potential energy, the work-energy theorem, conservation of mechanical energy, power, and the analysis of elastic and inelastic collisions.

Key Concepts

- Work done by a constant force is the product of the force, the displacement, and the cosine of the angle between them; work is zero if the force is perpendicular to the displacement.
- The work-energy theorem states that the net work done on a body equals the change in its kinetic energy.
- Potential energy is the energy associated with the position or configuration of a body, such as gravitational PE (mgh) or elastic PE stored in a spring.
- In the absence of non-conservative forces such as friction, the total mechanical energy (KE + PE) of a system is conserved.
- Power is the rate of doing work or the rate of transfer of energy.
- In an elastic collision both momentum and kinetic energy are conserved; in a perfectly inelastic collision the colliding bodies stick together and only momentum is conserved.

Important Formulas

$W = F\,d\cos\theta$
$KE = (1/2)mv^2$
PE (gravitational) = mgh; PE (spring) = $(1/2)kx^2$
Work-energy theorem: $W_{net} = \Delta KE$
$P = W/t = F\,v$ (for constant force along velocity)

Solved Questions (NCERT Exercise Pattern)

Q1. **A 2 kg block is pulled 5 m along a horizontal frictionless surface by a force of 10 N acting at an angle of 60° to the surface. Find the work done by the force.**

Solution:

1. $W = F\,d\cos\theta$.
2. $W = 10 \times 5 \times \cos 60° = 50 \times 0.5$.

Answer: The work done by the force is 25 J.

Q2. **A body of mass 4 kg, initially at rest, is acted upon by a net force so that it acquires a speed of 6 m/s. Find the work done on the body using the work-energy theorem.**

Solution:

1 By the work-energy theorem, $W_{net} = \Delta KE = KE_{final} - KE_{initial}$.
2 KE_{final} = (1/2)(4)(6)2 = (1/2)(4)(36) = 72 J. $KE_{initial}$ = 0.
3 W_{net} = 72 - 0.

Answer: The net work done on the body is 72 J.

Q3. **A pendulum bob of mass 0.5 kg is released from rest at a height of 1.25 m above its lowest point. Using conservation of energy, find its speed at the lowest point. (Take g = 10 m/s2.)**

Solution:

1 At the highest point, the bob has only gravitational PE = mgh, and KE = 0. At the lowest point all this PE converts to KE (no friction).
2 mgh = (1/2)mv2, so v2 = 2gh.
3 v2 = 2 × 10 × 1.25 = 25, so v = 5 m/s.

Answer: The speed of the bob at the lowest point is 5 m/s.

Q4. **A pump is required to lift 500 kg of water per minute from a well 20 m deep and eject it with a speed of 10 m/s. Find the power required. (Take g = 10 m/s2.)**

Solution:

1 Work done per minute = work to raise water (against gravity) + work to give it kinetic energy.
2 Work to raise water: mgh = 500 × 10 × 20 = 100000 J.
3 Work to impart speed: (1/2)mv2 = (1/2)(500)(10)2 = 25000 J.
4 Total work per minute = 100000 + 25000 = 125000 J; Power = work/time = 125000/60.

Answer: The power required is approximately 2083 W (about 2.08 kW).

Q5. **A ball of mass 1 kg moving at 4 m/s collides head-on elastically with a stationary ball of mass 1 kg. Find the velocities of both balls after collision.**

Solution:

1 For a perfectly elastic collision between two equal masses where the second is initially at rest, the standard result is that the velocities are exchanged.
2 This follows from solving the simultaneous conservation of momentum (m u1 = m v1 + m v2) and conservation of kinetic energy equations for equal masses, which gives v1 = 0 and v2 = u1.
3 Here u1 = 4 m/s, so v1 (first ball) = 0 and v2 (second ball) = 4 m/s.

Answer: After the elastic collision, the first ball comes to rest and the second ball moves off with a speed of 4 m/s.

Chapter 6

System of Particles and Rotational Motion

Chapter Overview

This chapter treats the motion of extended and rigid bodies: the centre of mass of a system of particles, torque and angular momentum, moment of inertia, the theorems of parallel and perpendicular axes, and rotational (including rolling) motion.

Key Concepts

- The centre of mass of a system of particles is the point at which the entire mass may be considered concentrated for the purpose of describing translational motion.
- Torque is the rotational analogue of force; it equals the product of force and the perpendicular distance of its line of action from the axis (or pivot).
- Angular momentum is the rotational analogue of linear momentum; in the absence of external torque, the angular momentum of a system is conserved.
- Moment of inertia is the rotational analogue of mass and depends on how the mass of a body is distributed relative to the axis of rotation.
- The parallel axis theorem and perpendicular axis theorem allow the moment of inertia about a new axis to be found from a known one.
- A body rolling without slipping has both translational kinetic energy and rotational kinetic energy about its centre of mass.

Important Formulas

$x_{cm} = (\Sigma m_i x_i) / (\Sigma m_i)$
$\tau = r F \sin\theta = I\alpha$
$L = I\omega$; conservation of angular momentum: $I_1\omega_1 = I_2\omega_2$
Moment of inertia of a uniform rod about its centre, perpendicular to its length: $I = ML^2/12$; of a disc about its central axis: $I = MR^2/2$; of a ring: $I = MR^2$
Rolling KE = $(1/2)mv^2 + (1/2)I\omega^2$

Solved Questions (NCERT Exercise Pattern)

Q1. **Two point masses of 2 kg and 3 kg are placed at x = 0 m and x = 5 m respectively on the x-axis. Find the position of the centre of mass.**

Solution:

1. x_{cm} = (m1 x1 + m2 x2) / (m1 + m2).
2. x_{cm} = (2 × 0 + 3 × 5) / (2 + 3) = 15/5.

Answer: The centre of mass is located at x = 3 m.

Q2. **A uniform see-saw of negligible mass has a 40 kg child sitting 1.5 m from the pivot. Where should a 60 kg child sit on the other side to balance the see-saw?**

Solution:

1 For balance, the clockwise and anticlockwise torques about the pivot must be equal: m1 g d1 = m2 g d2.
2 40 × 1.5 = 60 × d2, so d2 = 60/60 = 1.

Answer: The 60 kg child should sit 1 m from the pivot on the opposite side.

Q3. **Find the moment of inertia of a uniform disc of mass 2 kg and radius 0.5 m about an axis through its centre and perpendicular to its plane.**

Solution:

1 For a disc about its central (symmetry) axis, I = (1/2)MR2.
2 I = (1/2)(2)(0.5)2 = (1/2)(2)(0.25) = 0.25.

Answer: The moment of inertia of the disc is 0.25 kg m2.

Q4. **A skater spinning with arms outstretched has a moment of inertia of 4 kg m2 and an angular speed of 2 rad/s. When the skater pulls the arms in, the moment of inertia reduces to 1 kg m2. Find the new angular speed, assuming no external torque acts.**

Solution:

1 Since no external torque acts, angular momentum is conserved: I1ω1 = I2ω2.
2 4 × 2 = 1 × ω2, so ω2 = 8/1.

Answer: The skater's new angular speed is 8 rad/s.

Q5. **A solid sphere of mass 2 kg and radius 0.1 m rolls without slipping down an incline, reaching the bottom with a centre-of-mass speed of 4 m/s. Find its total kinetic energy at the bottom. (Moment of inertia of a solid sphere about its centre = (2/5)MR2.)**

Solution:

1 Total KE (rolling) = translational KE + rotational KE = (1/2)Mv2 + (1/2)Iω2, with ω = v/R for rolling without slipping.
2 (1/2)Iω2 = (1/2)(2/5)MR2(v/R)2 = (1/5)Mv2.
3 Total KE = (1/2)Mv2 + (1/5)Mv2 = (7/10)Mv2.
4 Total KE = (7/10)(2)(4)2 = (7/10)(2)(16) = 22.4.

Answer: The total kinetic energy of the rolling sphere at the bottom is 22.4 J.

Chapter 7

Gravitation

Chapter Overview

This chapter covers Newton's universal law of gravitation, the variation of the acceleration due to gravity with height and depth, gravitational potential energy, escape velocity, and the motion of satellites including Kepler's laws of planetary motion.

Key Concepts

- Newton's law of gravitation: every particle attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
- The acceleration due to gravity g decreases both as one goes above the Earth's surface and as one goes below it towards the centre.
- Gravitational potential energy of a mass m at distance r from a mass M is taken as negative, becoming zero only at infinite separation.
- Escape velocity is the minimum speed needed for an object to escape a planet's gravitational field without further propulsion.
- A satellite in a circular orbit has its required centripetal force supplied entirely by gravity, which fixes its orbital speed and period for a given orbital radius.
- Kepler's three laws describe planetary orbits: elliptical orbits with the sun at a focus, equal areas swept in equal times, and the square of the time period is proportional to the cube of the semi-major axis.

Important Formulas

$F = GM_1M_2/r^2$
$g_h = g(1 - 2h/R)$ for $h << R$ (height); $g_d = g(1 - d/R)$ (depth)
Escape velocity $v_e = \sqrt{(2GM/R)} = \sqrt{(2gR)}$
Orbital velocity $v_o = \sqrt{(GM/r)}$
Kepler's third law: $T^2 \propto r^3$

Solved Questions (NCERT Exercise Pattern)

Q1. **Find the gravitational force of attraction between two point masses of 10 kg and 20 kg placed 2 m apart. (Take G = 6.67 × 10^{-11} N m2/kg2.)**

Solution:

1 F = Gm1m2/r2.
2 F = (6.67 × 10^{-11})(10)(20)/(2)2 = (6.67 × 10^{-11})(200)/4.

Answer: F ≈ 3.34 × 10^{-9} N.

Q2. **Find the value of g at a height equal to half the radius of the Earth above its surface, given g at the surface is 9.8 m/s2.**

Solution:

1 g at height h relates to surface value g by g_h = g R2/(R+h)2 (exact form, since h is not small here).
2 With h = R/2, R + h = 3R/2, so (R/(R+h))2 = (R/(3R/2))2 = (2/3)2 = 4/9.
3 g_h = 9.8 × 4/9.

Answer: g at this height is approximately 4.36 m/s2.

Q3. **Find the escape velocity from the surface of the Earth, given radius R = 6.4 × 10^6 m and g = 9.8 m/s2.**

Solution:

1 v_e = √(2gR).
2 v_e = √(2 × 9.8 × 6.4 × 10^6) = √(1.2544 × 10^8).

Answer: The escape velocity from the Earth's surface is approximately 11.2 km/s.

Q4. **A geostationary satellite has a time period of 24 hours and orbits at a radius of 4.2 × 10^4 km. Using Kepler's third law, find the orbital radius of a satellite whose time period is 6 hours.**

Solution:

1 By Kepler's third law, T2/r3 is the same for all satellites of the same central body: $T1^2/r1^3$ = $T2^2/r2^3$.
2 (24)2/(4.2 × 10^4)3 = (6)2/$r2^3$, so $r2^3$ = (4.2 × 10^4)3 × (6/24)2 = (4.2 × 10^4)3 × (1/16).
3 r2 = (4.2 × 10^4) / $(16)^{1/3}$ = (4.2 × 10^4) / 2.52.

Answer: The satellite with a 6-hour period orbits at a radius of about 1.67 × 10^4 km.

Q5. **Find the gravitational potential energy of a 100 kg mass at the Earth's surface, given the Earth's mass M = 6 × 10^{24} kg, its radius R = 6.4 × 10^6 m, and G = 6.67 × 10^{-11} N m2/kg2.**

Solution:

1 Gravitational potential energy at the surface, U = -GMm/R.
2 U = -(6.67 × 10^{-11})(6 × 10^{24})(100)/(6.4 × 10^6).
3 Numerator = 6.67 × 6 × 100 × 10^{13} = 4002 × 10^{13} = 4.002 × 10^{16}; dividing by 6.4 × 10^6 gives about 6.25 × 10^9.

Answer: The gravitational potential energy is approximately -6.25 × 10^9 J (negative, since the mass is bound to the Earth).

Chapter 8

Mechanical Properties of Solids

Chapter Overview

This chapter deals with how solids deform under applied forces: stress, strain, Hooke's law, the elastic moduli (Young's modulus, bulk modulus and shear modulus), and the elastic potential energy stored in a deformed body.

Key Concepts

- Stress is the internal restoring force per unit area developed in a body under deformation; strain is the fractional change in dimension produced.
- Hooke's law states that, within the elastic limit, stress is directly proportional to strain.
- Young's modulus relates longitudinal stress to longitudinal strain for a wire or rod under tension or compression.
- Bulk modulus relates volumetric stress (pressure) to volumetric strain, describing resistance to uniform compression.
- Shear modulus (modulus of rigidity) relates tangential (shearing) stress to shearing strain.
- Elastic potential energy is stored in a stretched or compressed body and can be recovered when the deforming force is removed.

Important Formulas

Stress = F/A; Strain = ΔL/L (longitudinal)
Young's modulus Y = (F/A)/(ΔL/L) = FL/(AΔL)
Bulk modulus K = -ΔP/(ΔV/V)
Elastic potential energy per unit volume = (1/2) × stress × strain
Elongation ΔL = FL/(AY)

Solved Questions (NCERT Exercise Pattern)

Q1. **A steel wire of length 2 m and cross-sectional area 1×10^{-6} m2 is stretched by a force of 100 N. If Young's modulus of steel is 2×10^{11} N/m2, find the elongation produced.**

Solution:

1. ΔL = FL/(AY).
2. ΔL = (100 × 2) / ($1 \times 10^{-6} \times 2 \times 10^{11}$) = 200 / ($2 \times 10^{5}$).

Answer: The elongation produced is 1×10^{-3} m, i.e. 1 mm.

Q2. **A copper wire of length 1.5 m and diameter 2 mm elongates by 0.3 mm when stretched by a force of 50 N. Find Young's modulus of copper.**

Solution:

1 Cross-sectional area A = πr2, with r = 1 mm = 1 × 10^{-3} m, so A = π(1 × 10^{-3})2 ≈ 3.14 × 10^{-6} m2.
2 Y = FL/(AΔL) = (50 × 1.5)/(3.14 × 10^{-6} × 0.3 × 10^{-3}).
3 Numerator = 75; Denominator = 3.14 × 0.3 × 10^{-9} = 0.942 × 10^{-9}.

Answer: Young's modulus of copper is approximately 7.96 × 10^{10} N/m2.

Q3. **The volume of a liquid decreases by 0.02% when the pressure on it increases by 1.0 × 10^{5} Pa. Find the bulk modulus of the liquid.**

Solution:

1 Volumetric strain ΔV/V = 0.02/100 = 2 × 10^{-4}.
2 K = ΔP / (ΔV/V) = (1.0 × 10^{5}) / (2 × 10^{-4}).

Answer: The bulk modulus of the liquid is 5 × 10^{8} Pa.

Q4. **Find the energy stored per unit volume in a wire under a stress of 4 × 10^{7} N/m2, given that Young's modulus of the wire's material is 2 × 10^{11} N/m2.**

Solution:

1 Strain corresponding to this stress: strain = stress/Y = (4 × 10^{7})/(2 × 10^{11}) = 2 × 10^{-4}.
2 Elastic energy per unit volume = (1/2) × stress × strain = (1/2)(4 × 10^{7})(2 × 10^{-4}).

Answer: The energy stored per unit volume is 4000 J/m3.

Q5. **A rubber cord of natural length 0.5 m and area of cross-section 1 mm2 is stretched to 0.6 m by an applied force. If Young's modulus of rubber is 5 × 10^{8} N/m2, find the force applied.**

Solution:

1 Extension ΔL = 0.6 - 0.5 = 0.1 m; original length L = 0.5 m; area A = 1 mm2 = 1 × 10^{-6} m2.
2 F = YAΔL/L = (5 × 10^{8})(1 × 10^{-6})(0.1)/(0.5).

Answer: The force applied to the rubber cord is 100 N.

Chapter 9

Mechanical Properties of Fluids

Chapter Overview

This chapter studies fluids at rest and in motion: pressure and Pascal's law, buoyancy and Archimedes' principle, the equation of continuity, Bernoulli's principle, viscosity and Stokes' law, and surface tension including capillary rise.

Key Concepts

- Pressure in a fluid acts equally in all directions at a point and increases with depth due to the weight of the fluid above.
- Pascal's law states that pressure applied to an enclosed fluid is transmitted undiminished to every part of the fluid and the walls of its container, the basis of hydraulic machines.
- Archimedes' principle: a body immersed in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced.
- Bernoulli's principle relates pressure, speed and height along a streamline for an ideal, incompressible, non-viscous fluid in steady flow.
- Viscosity is the internal friction between layers of a real fluid in relative motion; Stokes' law gives the viscous drag force on a small sphere moving through a fluid.
- Surface tension is the tendency of a liquid surface to minimise its area, responsible for phenomena such as the rise of liquid in a capillary tube.

Important Formulas

$P = F/A$; $P = P_0 + \rho gh$ (fluid at rest)
Equation of continuity: $A_1v_1 = A_2v_2$
Bernoulli's equation: $P + (1/2)\rho v^2 + \rho gh = \text{constant}$
Stokes' law: $F = 6\pi\eta rv$; terminal velocity $v_t = 2r^2(\rho-\sigma)g / (9\eta)$
Capillary rise: $h = 2T \cos\theta / (r\rho g)$

Solved Questions (NCERT Exercise Pattern)

Q1. **In a hydraulic lift, the small piston has an area of 10 cm2 and the large piston has an area of 200 cm2. If a force of 50 N is applied to the small piston, find the maximum load that can be raised on the large piston.**

Solution:

1. By Pascal's law, the pressure applied is transmitted equally: F1/A1 = F2/A2.
2. F2 = F1 × (A2/A1) = 50 × (200/10).

Answer: The hydraulic lift can raise a load of 1000 N on the large piston.

Q2. **Water flows through a horizontal pipe of cross-sectional area 4 cm2 at a speed of 2 m/s. If the pipe narrows to an area of 2 cm2, find the speed of water in the narrower section.**

Solution:

1 By the equation of continuity, A1v1 = A2v2.
2 4 × 2 = 2 × v2, so v2 = 8/2.

Answer: The speed of water in the narrower section is 4 m/s.

Q3. **Water flows through a horizontal pipe with a wide section at pressure 3 × 10^4 Pa and speed 1 m/s, narrowing to a section where the speed becomes 4 m/s. Find the pressure in the narrow section. (Take density of water = 1000 kg/m3.)**

Solution:

1 Since the pipe is horizontal, Bernoulli's equation reduces to $P1 + (1/2)\rho v1^2 = P2 + (1/2)\rho v2^2$.
2 $P2 = P1 + (1/2)\rho(v1^2 - v2^2) = 3 \times 10^4 + (1/2)(1000)(1^2 - 4^2)$.
3 (1/2)(1000)(1 - 16) = 500 × (-15) = -7500.

Answer: The pressure in the narrow section is 3 × 10^4 - 7500 = 2.25 × 10^4 Pa.

Q4. **A raindrop of radius 0.5 mm falls through air of viscosity 1.8 × 10^{-5} Pa s. Given the density of water is 1000 kg/m3 and air density is negligible in comparison, find its terminal velocity. (Take g = 9.8 m/s2.)**

Solution:

1 Terminal velocity v_t = 2r2(ρ-σ)g / (9η), with σ (air density) taken as negligible.
2 r = 0.5 × 10^{-3} m, so r2 = 0.25 × 10^{-6} m2.
3 $v_t = 2(0.25 \times 10^{-6})(1000)(9.8) / (9 \times 1.8 \times 10^{-5}) = (4.9 \times 10^{-3}) / (1.62 \times 10^{-4})$.

Answer: The terminal velocity of the raindrop is approximately 30.2 m/s.

Q5. **Water rises to a height of 3 cm in a capillary tube of radius 0.5 mm. If the surface tension of water is 7.2 × 10^{-2} N/m and the contact angle is zero, verify this using the capillary rise formula. (Take density of water = 1000 kg/m3, g = 9.8 m/s2.)**

Solution:

1 h = 2T cosθ / (rρg), with T = 7.2 × 10^{-2} N/m, cos0° = 1, r = 0.5 × 10^{-3} m.
2 $h = 2(7.2 \times 10^{-2})(1) / (0.5 \times 10^{-3} \times 1000 \times 9.8) = 0.144 / 4.9$.

Answer: The calculated height h ≈ 0.0294 m ≈ 2.94 cm, which closely matches the given rise of 3 cm.

Chapter 10

Thermal Properties of Matter

Chapter Overview

This chapter covers temperature and its measurement, thermal expansion of solids, liquids and gases, specific heat capacity and calorimetry, change of state and latent heat, and the three modes of heat transfer: conduction, convection and radiation.

Key Concepts

- Temperature scales (Celsius, Fahrenheit, Kelvin) are related by fixed linear conversion formulas.
- On heating, most solids and liquids expand; the fractional change in length, area or volume per unit rise in temperature is described by the coefficients of linear, areal and volume expansion.
- Specific heat capacity is the heat required to raise the temperature of unit mass of a substance by one degree; calorimetry problems use the principle that heat lost by a hotter body equals heat gained by a cooler one (in an isolated system).
- Latent heat is the heat absorbed or released during a change of state at constant temperature, such as melting or boiling.
- Conduction is heat transfer through a medium without bulk movement of matter; the rate of conduction depends on the thermal conductivity, area, temperature difference and thickness of the material.
- All bodies emit thermal radiation; Stefan's law gives the power radiated per unit area of a black body as proportional to the fourth power of its absolute temperature.

Important Formulas

$T(K) = T(°C) + 273.15$; $F = (9/5)C + 32$
$\Delta L = L\alpha\Delta T$ (linear expansion)
$Q = mc\Delta T$ (sensible heat); $Q = mL$ (latent heat)
Rate of conduction = $KA\Delta T/d$
Stefan's law: power radiated per unit area = σT^4

Solved Questions (NCERT Exercise Pattern)

Q1. **Convert a temperature of 40°C to Fahrenheit and Kelvin.**

Solution:

1. Fahrenheit: $F = (9/5)C + 32 = (9/5)(40) + 32 = 72 + 32$.
2. Kelvin: $T(K) = C + 273 = 40 + 273$.

Answer: 40°C is equal to 104°F and 313 K.

Q2. **A steel rod is 1 m long at 20°C. If the coefficient of linear expansion of steel is 1.2×10^{-5} per °C, find its length when heated to 120°C.**

Solution:

1 $\Delta T = 120 - 20 = 100$°C.
2 $\Delta L = L\alpha\Delta T = 1 \times 1.2 \times 10^{-5} \times 100 = 1.2 \times 10^{-3}$ m.
3 New length = original length + ΔL = 1 + 0.0012.

Answer: The rod's new length at 120°C is 1.0012 m.

Q3. **200 g of water at 80°C is mixed with 100 g of water at 20°C. Find the final equilibrium temperature of the mixture, assuming no heat is lost to the surroundings.**

Solution:

1 Heat lost by hot water = heat gained by cold water, since specific heat of water is the same throughout: m1c(80-T) = m2c(T-20).
2 The specific heat c cancels: 200(80-T) = 100(T-20).
3 16000 - 200T = 100T - 2000, so 18000 = 300T, giving T = 60.

Answer: The final equilibrium temperature of the mixture is 60°C.

Q4. **Find the heat required to convert 500 g of ice at 0°C completely into water at 0°C. (Latent heat of fusion of ice = 3.36×10^5 J/kg.)**

Solution:

1 Since the process occurs at constant temperature (melting), Q = mL.
2 Convert mass: 500 g = 0.5 kg.
3 $Q = 0.5 \times 3.36 \times 10^5$.

Answer: The heat required is 1.68×10^5 J (168 kJ).

Q5. **A metal plate 2 cm thick and of area 0.5 m2 has its two faces maintained at 100°C and 20°C. If the thermal conductivity of the metal is 200 W/(m K), find the rate of heat conduction through the plate.**

Solution:

1 Rate of conduction, $H = KA\Delta T/d$, with d = 2 cm = 0.02 m and $\Delta T = 100 - 20 = 80$°C.
2 H = (200)(0.5)(80)/(0.02).

Answer: The rate of heat conduction through the plate is 400000 W (4×10^5 W).

Chapter 11

Thermodynamics

Chapter Overview

This chapter formalises the study of heat and work: thermodynamic state variables, the zeroth and first laws of thermodynamics, different thermodynamic processes (isothermal, adiabatic, isobaric, isochoric), heat engines and refrigerators, and the second law of thermodynamics including the Carnot cycle.

Key Concepts

- The zeroth law of thermodynamics establishes the concept of temperature: two systems in thermal equilibrium with a third are in thermal equilibrium with each other.
- The first law of thermodynamics is a statement of energy conservation: the heat supplied to a system equals the increase in its internal energy plus the work done by the system.
- In an isothermal process temperature is constant; in an adiabatic process no heat enters or leaves the system; in an isochoric process volume is constant, and in an isobaric process pressure is constant.
- A heat engine converts heat into work in a cyclic process, absorbing heat from a hot reservoir, doing work, and rejecting some heat to a cold reservoir; its efficiency is always less than 100%.
- The second law of thermodynamics states that heat cannot spontaneously flow from a colder to a hotter body without external work, and that no engine can be more efficient than a Carnot engine operating between the same two temperatures.
- A Carnot engine is an idealised, reversible heat engine whose efficiency depends only on the temperatures of the source and sink.

Important Formulas

First law: $\Delta U = Q - W$
Work done in isothermal expansion (ideal gas): $W = nRT \ln(V_2/V_1)$
Efficiency of a heat engine: $\eta = W/Q_1 = 1 - Q_2/Q_1$
Carnot efficiency: $\eta = 1 - T_2/T_1$ (temperatures in Kelvin)
Work done at constant pressure: $W = P\Delta V$

Solved Questions (NCERT Exercise Pattern)

Q1. **A gas absorbs 500 J of heat and does 200 J of work on its surroundings during a process. Find the change in internal energy of the gas.**

Solution:

1. By the first law of thermodynamics, $\Delta U = Q - W$.
2. $\Delta U = 500 - 200$.

Answer: The internal energy of the gas increases by 300 J.

Q2. **One mole of an ideal gas expands isothermally at 300 K from a volume of 2 L to 4 L. Find the work done by the gas. (Take R = 8.31 J/(mol K).)**

Solution:

1. For an isothermal process, $W = nRT \ln(V2/V1)$.
2. $W = 1 \times 8.31 \times 300 \times \ln(4/2) = 2493 \times \ln 2$.
3. $\ln 2 \approx 0.693$, so $W \approx 2493 \times 0.693$.

Answer: The work done by the gas is approximately 1727.6 J.

Q3. **A heat engine absorbs 800 J of heat from a hot reservoir and rejects 500 J to a cold reservoir in each cycle. Find the work done per cycle and the efficiency of the engine.**

Solution:

1. Work done per cycle $W = Q1 - Q2 = 800 - 500$.
2. Efficiency $\eta = W/Q1 = 300/800 = 0.375$.

Answer: The engine does 300 J of work per cycle, with an efficiency of 0.375, i.e. 37.5%.

Q4. **A Carnot engine operates between a source at 500 K and a sink at 300 K. Find its efficiency and the heat rejected to the sink if it absorbs 1000 J from the source.**

Solution:

1. Carnot efficiency $\eta = 1 - T2/T1 = 1 - 300/500 = 1 - 0.6 = 0.4$.
2. Work done $W = \eta \times Q1 = 0.4 \times 1000 = 400$ J.
3. Heat rejected $Q2 = Q1 - W = 1000 - 400$.

Answer: The Carnot engine's efficiency is 40%, and it rejects 600 J of heat to the sink.

Q5. **A gas is compressed at a constant pressure of 2×10^5 Pa, its volume decreasing from 6 L to 4 L, and in the process 100 J of heat leaves the gas. Find the work done on the gas and the change in its internal energy.**

Solution:

1. Change in volume $\Delta V = (4-6)$ L $= -2$ L $= -2 \times 10^{-3}$ m3.
2. Work done by the gas $W = P\Delta V = (2 \times 10^5)(-2 \times 10^{-3}) = -400$ J, i.e. 400 J of work is done on the gas.
3. Since heat leaves the gas, $Q = -100$ J. By the first law, $\Delta U = Q - W = -100 - (-400) = -100 + 400$.

Answer: 400 J of work is done on the gas, and its internal energy increases by 300 J.

Chapter 12

Kinetic Theory

Chapter Overview

This chapter builds a molecular model of gases: the assumptions of kinetic theory, the derivation of gas pressure from molecular motion, the ideal gas law, the concept of rms speed, the law of equipartition of energy, degrees of freedom, and mean free path.

Key Concepts

- Kinetic theory treats a gas as a large number of molecules in random, ceaseless motion, colliding elastically with each other and the walls of the container.
- Pressure exerted by a gas arises from the rate of change of momentum of molecules colliding with the container walls.
- The ideal gas equation PV = nRT connects pressure, volume, temperature and the amount of gas, combining Boyle's law, Charles's law and Avogadro's law.
- The root-mean-square (rms) speed of gas molecules is directly related to the absolute temperature and inversely to the square root of the molar mass.
- The law of equipartition of energy states that, in thermal equilibrium, each degree of freedom of a molecule contributes an equal average energy of $(1/2)k_BT$.
- Mean free path is the average distance a molecule travels between successive collisions, and depends on molecular size and number density.

Important Formulas

$PV = nRT$
$P = (1/3)\rho v_{rms}^2$
$v_{rms} = \sqrt{(3RT/M)}$
Average KE per mole = $(3/2)RT$; per molecule = $(3/2)k_BT$
Mean free path $\lambda = 1/(\sqrt{2}\,\pi d^2 n)$

Solved Questions (NCERT Exercise Pattern)

Q1. **Find the rms speed of oxygen molecules at 300 K, given the molar mass of oxygen is 0.032 kg/mol and R = 8.31 J/(mol K).**

Solution:

1 $v_{rms} = \sqrt{(3RT/M)}$.
2 $3RT = 3 \times 8.31 \times 300 = 7479$.
3 $v_{rms} = \sqrt{(7479/0.032)} = \sqrt{(233718.75)}$.

Answer: The rms speed of oxygen molecules at 300 K is approximately 483.4 m/s.

Q2. **A cylinder contains 2 moles of an ideal gas at a temperature of 300 K and pressure of 2 × 10^5 Pa. Find the volume occupied by the gas. (Take R = 8.31 J/(mol K).)**

Solution:

1 From PV = nRT, V = nRT/P.
2 V = (2 × 8.31 × 300)/(2 × 10^5) = 4986/(2 × 10^5).

Answer: The volume occupied by the gas is approximately 0.0249 m3 (24.9 litres).

Q3. **Find the average kinetic energy per mole of an ideal gas at a temperature of 400 K. (Take R = 8.31 J/(mol K).)**

Solution:

1 Average KE per mole = (3/2)RT.
2 = (3/2)(8.31)(400).

Answer: The average kinetic energy per mole is approximately 4986 J.

Q4. **A diatomic gas molecule has 5 degrees of freedom (3 translational and 2 rotational). Using the law of equipartition of energy, find its total average energy per molecule at temperature T.**

Solution:

1 Each degree of freedom contributes (1/2)k_BT of average energy.
2 For 5 degrees of freedom, total average energy = 5 × (1/2)k_BT.

Answer: The total average energy per diatomic molecule is (5/2)k_BT.

Q5. **At constant temperature, a certain amount of gas occupies a volume of 4 L at a pressure of 1 × 10^5 Pa. Find its volume if the pressure is increased to 2.5 × 10^5 Pa.**

Solution:

1 At constant temperature, Boyle's law applies: P1V1 = P2V2.
2 (1 × 10^5)(4) = (2.5 × 10^5)(V2), so V2 = 4/2.5.

Answer: The new volume of the gas is 1.6 L.

Chapter 13

Oscillations

Chapter Overview

This chapter studies periodic motion, especially simple harmonic motion (SHM): its defining equation, amplitude, period and phase, the dynamics of a spring-mass system and a simple pendulum, and the interchange of kinetic and potential energy during SHM.

Key Concepts

- A motion is periodic if it repeats itself after equal intervals of time; it is simple harmonic if the restoring force (or acceleration) is directly proportional to the displacement from the mean position and always directed towards it.
- The displacement in SHM varies sinusoidally with time, characterised by amplitude, angular frequency and phase.
- The time period of a spring-mass system depends on the mass and the spring's force constant, but is independent of the amplitude of oscillation.
- The time period of a simple pendulum (for small angular displacement) depends on its length and the local value of g, but not on the mass of the bob or the amplitude.
- In SHM, kinetic energy is maximum and potential energy is zero at the mean position; potential energy is maximum and kinetic energy is zero at the extreme positions; the total mechanical energy remains constant throughout.
- Angular frequency ω is related to the time period by $\omega = 2\pi/T = 2\pi f$.

Important Formulas

$x = A \sin(\omega t + \phi)$
$v = A\omega \cos(\omega t + \phi)$; $a = -A\omega^2 \sin(\omega t + \phi) = -\omega^2 x$
Spring-mass system: $T = 2\pi\sqrt{(m/k)}$
Simple pendulum: $T = 2\pi\sqrt{(l/g)}$
Total energy in SHM: $E = (1/2)kA^2 = (1/2)m\omega^2A^2$

Solved Questions (NCERT Exercise Pattern)

Q1. **A body of mass 0.5 kg is attached to a spring of force constant 50 N/m and set into oscillation. Find the time period of the resulting simple harmonic motion.**

Solution:

1. $T = 2\pi\sqrt{(m/k)}$.
2. $m/k = 0.5/50 = 0.01$, so $\sqrt{(m/k)} = 0.1$.
3. $T = 2\pi \times 0.1$.

Answer: The time period of oscillation is approximately 0.628 s.

Q2. **Find the length of a simple pendulum that has a time period of 2 s on the Earth's surface. (Take g = 9.8 m/s2.)**

Solution:

1 $T = 2\pi\sqrt{(l/g)}$, so $l = gT2/(4\pi 2)$.
2 $l = (9.8)(2)2 / (4\pi 2) = 39.2/(39.48)$.

Answer: The length of the pendulum is approximately 0.993 m (about 1 m).

Q3. **A particle executes SHM with amplitude 5 cm and angular frequency 2 rad/s. Find its displacement, velocity and acceleration when the phase is such that sin(ωt) = 0.6 (with zero initial phase, x = A sinωt).**

Solution:

1 Displacement x = A sinωt = 5 × 0.6 = 3 cm.
2 For velocity we need cosωt: since sin2+cos2=1, cosωt = √(1-0.36) = √0.64 = 0.8. v = Aωcosωt = 5 × 2 × 0.8 = 8 cm/s.
3 Acceleration a = -ω2x = -(2)2(3) = -12 cm/s2 (directed towards the mean position).

Answer: At this instant, x = 3 cm, v = 8 cm/s, and a = -12 cm/s2 (directed towards the centre).

Q4. **A spring-mass system with mass 2 kg and spring constant 200 N/m oscillates with amplitude 0.1 m. Find its total mechanical energy.**

Solution:

1 E = (1/2)kA2.
2 E = (1/2)(200)(0.1)2 = (1/2)(200)(0.01).

Answer: The total mechanical energy of the oscillator is 1 J.

Q5. **A simple pendulum has a time period of 2 s on the Earth. What would its time period be on the surface of the Moon, where the acceleration due to gravity is about 1/6th that on Earth?**

Solution:

1 $T = 2\pi\sqrt{(l/g)}$; since l and 2π are unchanged, $T \propto 1/\sqrt{g}$.
2 $T_{moon}/T_{earth} = \sqrt{(g_{earth}/g_{moon})} = \sqrt{6}$.
3 $T_{moon} = 2 \times \sqrt{6} \approx 2 \times 2.449$.

Answer: The time period of the pendulum on the Moon would be approximately 4.9 s.

Chapter 14

Waves

Chapter Overview

This chapter covers wave motion: transverse and longitudinal waves, the wave equation, speed of waves on a string and of sound in different media, the principle of superposition, standing waves and resonance in strings and pipes, beats, and the Doppler effect.

Key Concepts

- A wave transports energy and momentum without net transport of the medium; transverse waves have particle displacement perpendicular to propagation, while longitudinal waves have displacement parallel to propagation.
- The speed, frequency and wavelength of a wave are related by $v = f\lambda$.
- The speed of a transverse wave on a stretched string depends on the tension in the string and its mass per unit length; the speed of sound in a medium depends on the medium's elastic and inertial properties.
- When two or more waves overlap, the principle of superposition states that the resultant displacement is the vector sum of the individual displacements.
- Standing waves are formed by the superposition of two identical waves travelling in opposite directions, producing fixed nodes and antinodes; strings and air columns resonate at specific natural frequencies (harmonics).
- Beats arise from the superposition of two waves of slightly different frequencies, producing a periodic variation in amplitude; the Doppler effect describes the apparent change in frequency due to relative motion between source and observer.

Important Formulas

$v = f\lambda$
Speed on a string: $v = \sqrt{(T/\mu)}$
Speed of sound: $v = \sqrt{(\gamma P/\rho)}$
Beat frequency = $\lvert f_1 - f_2 \rvert$
Doppler effect (source moving, observer stationary): $f' = f \times v/(v \pm v_s)$

Solved Questions (NCERT Exercise Pattern)

Q1. **A wave travels with a speed of 340 m/s and has a wavelength of 0.5 m. Find its frequency.**

Solution:

1 $v = f\lambda$, so $f = v/\lambda$.
2 $f = 340/0.5$.

Answer: The frequency of the wave is 680 Hz.

Q2. **A string of length 2 m and mass 10 g is stretched under a tension of 400 N. Find the speed of transverse waves on the string.**

Solution:

1 Mass per unit length μ = mass/length = 0.01/2 = 0.005 kg/m.
2 $v = \sqrt{(T/\mu)} = \sqrt{(400/0.005)} = \sqrt{80000}$.

Answer: The speed of transverse waves on the string is approximately 283 m/s.

Q3. **A pipe closed at one end has a length of 0.5 m. Find the frequency of the fundamental note produced, given the speed of sound in air is 340 m/s.**

Solution:

1 For a pipe closed at one end, the fundamental wavelength is four times the pipe length: $\lambda = 4L = 4 \times 0.5 = 2$ m.
2 $f = v/\lambda = 340/2$.

Answer: The fundamental frequency of the closed pipe is 170 Hz.

Q4. **Two tuning forks of frequencies 256 Hz and 260 Hz are sounded together. Find the beat frequency heard.**

Solution:

1 Beat frequency = $|f1 - f2|$.
2 = $|256 - 260|$.

Answer: The beat frequency heard is 4 beats per second.

Q5. **A train sounds a whistle of frequency 500 Hz while approaching a stationary observer at a speed of 30 m/s. Find the apparent frequency heard by the observer, taking the speed of sound as 330 m/s.**

Solution:

1 For a source moving towards a stationary observer, $f' = f \times v/(v - v_s)$.
2 $f' = 500 \times 330/(330 - 30) = 500 \times 330/300$.

Answer: The apparent frequency heard by the observer is approximately 550 Hz.