JEE Advanced / Multidisciplinary PYQs with Answers and Solutions

CHAPTER 1 Units and Measurement

Q1 To find the distance d over which a signal can be seen clearly in foggy conditions, a railways engineer uses dimensional analysis and assumes that the distance depends on the mass density ρ of the fog, intensity (power/area) S of the light from the signal and its frequency f. The engineer finds that d is proportional to $S^{1/n}$. The value of n is _____.

(2014, PAPER 1)

Q2 Consider a Vernire callipers in which each 1 cm on the main scale is divided into 8 equal divisions and a screw gauge with 100 divisions on its circular scale. In the Vernier callipers, 5 divisions of the Vernier scale coincide with 4 divisions on the main scale and in the screw gauge, one complete rotation of the circular scale moves it by two divisions on the linear scale. Then:

(A) If the pitch of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.01 mm.

(B) If the pitch of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.005 mm.

(C) If the least count of the linear scale of the screw gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.01 mm.

(D) If the least count of the linear scale of the screw, gauge is twice the least count of the Vernier callipers, the least count of the screw gauge is 0.005 mm.

(2015, PAPER 1)

Q3 Planck's constant h, speed of light c and gravitational constant G are used to form a unit of length L and a unit of mass M. Then the correct option(s) is(are)

(A) $M \propto \sqrt{c}$ **(B)** $M \propto \sqrt{G}$

(C) $L \propto \sqrt{h}$ **(D)** $L \propto \sqrt{G}$

(2015, PAPER 1)

Q4 The energy of a system as a function of time t is given as $E(t) = A^2\exp(-\alpha t)$, where $\alpha = 0.2\ s^{-1}$. The measurement of A has an error of 1.25%. If the error m the measurement of time is 1.50%, the percentage error in the value of E(t) at t = 5 s is _____.

(2015, PAPER 2)

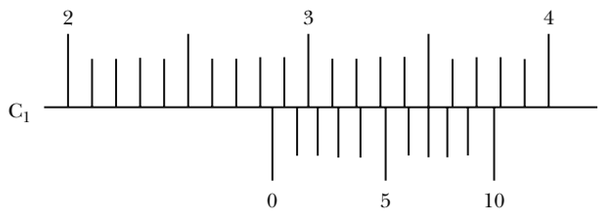
Q5 In terms of potential difference V, electric current I, permittivity ε_0, permeability μ_0 and speed of light c, the dimensionally correct equation(s) is(are) _____.

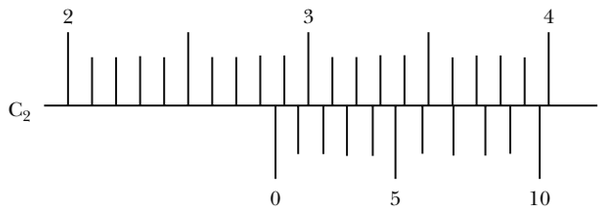
(A) $\mu_0 I^2 = \varepsilon_0 V^2$ **(B)** $\varepsilon_0 I = \mu_0 V$

(C) $I = \varepsilon_0 cV$ **(D)** $\mu_0 cI = \varepsilon_0 V$

(2015, PAPER 2)

Q6 There are two Vernier calipers both of which have 1 cm divided into 10 equal divisions on the main scale. The Vernier scale of one of the calipers (C_1) has 10 equal divisions that correspond to 9 main scale divisions. The Vernier scale of the odiet caliper (C_2) has 10 equal divisions that correspond to 11 main scale divisions. The readings of the two calipers are shown in the figure. The measured values (in cm) by calipers C_1 and C_2 respectively, are _____.





(A) 2.87 and 2.86 **(B)** 2.87 and 2.87

(C) 2.87 and 2.83 **(D)** 2.85 and 2.82

(2016, PAPER 2)

Q7 In an experiment to determine the acceleration due to gravity g, the formula used for the time period of a periodic motion is $T = 2\pi\sqrt{\frac{7(R-r)}{5g}}$. The values of R and r are measured to be (60 ± 1) nun and (10 ± 1) mm, respectively. In five successive measurements, the time period is found to be 0.52 s, 0.56 s, 0.57 s, 0.54 s and 0.59 s. The least count of the watch used for the measurement of time period is 0.01 s. Which of the following statement(s) is(are) true?

(A) The error in the measurement of r is 10%.
(B) The error in the measurement of T is 3.57%.
(C) The error in the measurement of T is 2%.
(D) The error in the determined value of g is 11%.

(2016, PAPER 2)

In electromagnetic theory, the electric and magnetic phenomena are related to each other. Therefore, the dimensions of electric and magnetic quantities must also be related to each other, in the questions below, $[E]$ and $[B]$ stand for dimensions of electric and magnetic fields respectively, while $[\epsilon_0]$ and $[\mu_0]$ stand for dimensions of the permittivity and permeability of free space respectively. $[L]$ and $[T]$ are dimensions of length and time respectively. All the quantities are given in SI units.

Q8 The relation between $[E]$ and $[B]$ is

(A) $[E] = [B]\,[L]\,[T]$
(B) $[E] = [B]\,[L]^{-1}\,[T]$
(C) $[E] = [B]\,[L]\,[T]^{-1}$
(D) $[E] = [B]\,[L]^{-1}\,[T]^{-1}$

Q9 The relation between $[\epsilon_0]$ and $[\mu_0]$ is

(A) $[\mu_0] = [\epsilon_0]\,[L]^2\,[T]^{-2}$
(B) $[\mu_0] = [\epsilon_0]\,[L]^{-2}\,[T]^2$
(C) $[\mu_0] = [\epsilon_0]^{-1}\,[L]^2\,[T]^{-2}$
(D) $[\mu_0] = [\epsilon_0]^{-1}\,[L]^{-2}\,[T]^2$

(2018, PAPER 1)

If the measurement errors in all the independent quantities are known, then it is possible to determine the error in any dependent quantity. This is done by the use of series expansion and truncating the expansion at the first power of the error. For example, consider the relation $z = x/y$. If the errors in x, y and z are Δx, Δy and Δz, respectively, then

$$z \pm \Delta z = \frac{x \pm \Delta x}{y \pm \Delta y} = \frac{x}{y}\left(1 \pm \frac{\Delta x}{x}\right)\left(1 \pm \frac{\Delta y}{y}\right)^{-1}.$$

The series expansion for $\left(1 \pm \frac{\Delta y}{y}\right)^{-1}$, to first power in $\Delta y/y$, is $1 \mp (\Delta y / y)$. The relative errors in independent variables are always added. So the error in z will be

$$\Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right).$$

The above derivation makes the assumption that $\Delta x/x \ll 1$, $\Delta y/y \ll 1$. Therefore, the higher powers of these quantities are neglected.

Q10 Consider the ratio $r = \frac{(1-a)}{(1+a)}$ to be determined by measuring a dimensionless quantity a. If the error in the measurement of a is Δa ($\Delta a/a \ll 1$), then what is the error Δr in determining r?

(A) $\frac{\Delta a}{(1+a)^2}$ **(B)** $\frac{2\Delta a}{(1+a)^2}$
(C) $\frac{2\Delta a}{(1-a^2)}$ **(D)** $\frac{2a\Delta a}{(1-a^2)}$

Q11 In an experiment the initial number of radioactive nuclei is 3000. It is found that 1000 ± 40 nuclei decayed in the first 1.0s. For $|x| \ll 1$, $\ln(1+x) = x$ up to first power in x. The error $\Delta\lambda$, in the determination of the decay constant λ, in s^{-1}, is _____.

(A) 0.04 **(B)** 0.03
(C) 0.02 **(D)** 0.01

(2018, PAPER 1)

Q12 A steel wire of diameter 0.5 mm and Young's modulus 2×10^{11} Nm^{-2} carries a load of mass M. The length of the wire with the load is 1.0 m. A vernier scale with 10 divisions is attached to the end of this wire. Next to the steel wire is a reference wire to which a main scale, of least count 1.0 mm, is attached. The 10 divisions of the vernier scale correspond to 9 divisions of the main scale. Initially, the zero of vernier scale coincides with the zero of main scale. If the load on the steel wire is increased by 1.2 kg, the vernier scale division which coincides with a main scale division is _____. Take g = 10 ms^{-2} and is $\pi = 3.2$.

(2018, PAPER 2)

Q13 Let us consider a system of units in which mass and angular momentum are dimensionless. If length has dimension of L, which of the following statement(s) is/are correct?

(A) The dimension of energy is L^{-2}.
(B) The dimension of force is L^{-3}.
(C) The dimension of power is L^{-5}.
(D) The dimension of linear momentum is L^{-1}.

(2019, PAPER 1)

Q14 Sometimes it is convenient to construct a system of units so that all quantities can he expressed in terms of only one physical quantity. In one such system, dimensions of different quantities are given in terms of a quantity X as follows: [positron] = $[X^{\alpha}]$; [Speed] = $[X^{\beta}]$; [acceleration] = $[X^{p}]$; [Linear momentum] = $[X^{q}]$; [force] = $[X^{1}]$. Then

(A) $\alpha + p = 2\beta$
(B) $p + q - r = \beta$
(C) $p - q + r = \alpha$
(D) $p + q + r = \beta$

(2020, PAPER 1)

Answer Key

1. (3)	**2.** (B,C)	**3.** (A,C,D)	**4.** (4)	**5.** (A,C)
6. (C)	**7.** (A,B,D)	**8.** (C)	**9.** (D)	**10.** (B)
11. (C)	**12.** (3.00)	**13.** (A,B,D)	**14.** (A,B)	

CHAPTER 2 Motion Along a Straight Line

Q1 The position vector $\vec{r}$ of a particle of mass in is given by the following equation $\vec{r}(t) = \alpha t^3\hat{i} + \beta t^2\hat{j}$, where $\alpha = 10/3$ ms^{-3}, $\beta = 5$ ms^{-2} and m = 0.1 kg. At t = 1 s, which of the following statement(s) is(are) true about the particle?

(A) The velocity $\vec{v}$ is given by $\vec{v} = (10\hat{i} + 10\hat{j})\,ms^{-1}$.

(B) The angular momentum $\vec{L}$ with respect to the origin is given by $\vec{L} = -(5/3)\hat{k}$ Nms.

(C) The force $\vec{F}$ is given by $\vec{F} = (\hat{i} + 2\hat{j})$ N.

(D) The torque $\vec{\tau}$ with respect to the origin is given by $\vec{\tau} = -(20/3)\hat{k}$ Nm.

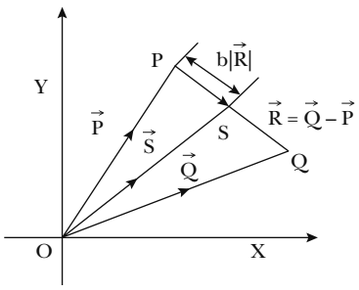
(2016, PAPER 1)

Answer Key

1. (A,B,D)

CHAPTER 3 Vectors

Q1 Three vectors $\vec{P}$, $\vec{Q}$ and $\vec{R}$ are shown in the figure. Let S be any point on the vector $\vec{R}$. The distance between the point P ad S is $b|\vec{R}|$. The general relation among vectors $\vec{P}$, $\vec{Q}$ and $\vec{S}$ is .



(A) $\vec{S} = (1-b)\vec{P} + b\vec{Q}$ **(B)** $\vec{S} = (b-1)\vec{P} + b\vec{Q}$

(C) $\vec{S} = (1-b^2)\vec{P} + b\vec{Q}$ **(D)** $\vec{S} = (1-b)\vec{P} + b^2\vec{Q}$

(2017, PAPER 2)

Q2 Two vectors $\vec{A}$ and $\vec{B}$ are defined as $\vec{A} = a\hat{i}$ and $\vec{B} = a(\cos\omega t\,\hat{i} + \sin\omega t\,\hat{j})$, where a is a constant and $\omega = \pi/6$ *rad* s^{-1}. If $|\vec{A} + \vec{B}| = \sqrt{3}|\vec{A} - \vec{B}|$ at time $t = \tau$ for the first time, the value of τ, in *seconds,* is _____.

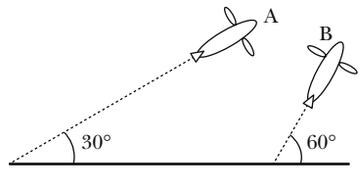
(2018, PAPER 1)

Answer Key

1. (A) **2.** (2.00)

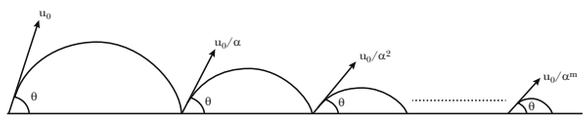
CHAPTER 4 Motion in Two and Three Dimensions

Q1 Airplanes A and B are flying with constant velocity in the same vertical plane at angles 30° and 60° with respect to the horizontal respectively as shown in the figure. The speed of A is $100\sqrt{3}$ ms^{-1}. At time t = 0 s, an observer in A finds B at a distance of 500 in. This observer sees B moving with a constant velocity perpendicular to the line of motion of A. If at $t = t_0$, A just escapes being hit by B. t_0 in seconds is _____.



(2014, PAPER 1)

Q2 A ball is thrown from ground at an angle θ with horizontal and with an initial speed u_0. For the resulting projectile motion, the magnitude of average velocity of the ball up to the point when it hits the ground for the first time is V_1. After hitting the ground, the ball rebounds at the same angle θ but with a reduced speed of u_0/α. Its motion continues for a long time as shown in figure. If the magnitude of average velocity of the ball for entire duration of motion is 0.8 V_1, the value of α is _____.



(2019, PAPER 2)

Q3 Starting at time $t = 0$ from the origin with speed 1 ms^{-1}, a particle follows a two-dimensional trajectory in the $x - y$ plane so that its coordinates are related by the equation $y = \frac{x^2}{2}$. The x and y components of its acceleration are denoted by a_x and a_y, respectively. Then

(A) $a_x = 1$ ms^{-2} implies that when the particle is at the origin, $a_y = 1$ ms^{-2}.

(B) $a_x = 0$ implies $a_y = 1$ ms^{-2} at all times.

(C) At $t = 0$, the particle's velocity points in the x-direction.

(D) $a_x = 0$ implies that at $t = 1$ s, the angle between the particle's velocity and the x axis is 45°.

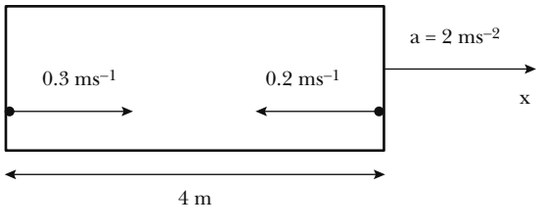
(2020, PAPER 2)

Answer Key

1. (5) **2.** (4) **3.** (A,B,C,D)

CHAPTER 5 Force and Motion – I

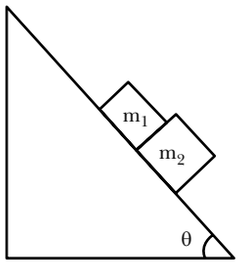
Q1 A rocker is moving in a gravity free space with a constant acceleration of 2 ms^{-2} along + x direction (see figure). The length of a chamber inside the rocket is 4 m. A ball is thrown from the left end of the chamber in + x direction with a speed of 0.3 ms^{-1} relative to the rocket. At the same time, another ball is thrown in –x direction with a speed of 0.2 ms^{-1} from its right end relative to the rocket. The time in seconds when the two balls hit each other is _____.



(2014, PAPER 1)

Q2 A block of mass m_1 = 1 kg another mass m_2 = 2kg, are placed together (see figure) on an inclined plane with angle of inclination θ. Various values of θ are given in List I. The coefficient of friction between the block m_1 and the plane is always zero. The coefficient of static and dynamic friction between the block m_2 and the plane are equal to $\mu = 0.3$. In List II expressions for the friction on the block m_2 are given. Match the correct expression of the friction in List II with the angles given in List I. and choose the correct option. The acceleration due to gravity is denoted by g.

[**Useful information:** tan (5.5°) ≈ 0.1; tan (11.5°) ≈ 0.2; tan (16.5°) ≈ 0.3]



	List–I		List–II
P.	$\theta = 5°$	**1.**	$m_2 g \sin\theta$
Q	$\theta = 10°$	**2.**	$(m_1 + m_2)\, g \sin\theta$
R.	$\theta = 15°$	**3.**	$\mu m_2 g \cos\theta$
S.	$\theta = 20°$	**4.**	$\mu(m_1 + m_2)\, g \cos\theta$

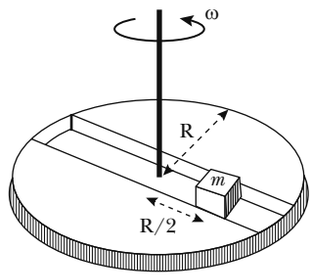
Code:
(A) P → 1, Q → 1, R → 1, S → 3
(B) P → 2, Q → 2, R → 2, S → 3
(C) P → 2, Q → 2, R → 2, S → 4
(D) P → 2, Q → 2, R → 3, S → 3

(2014, PAPER 2)

A frame of reference that is accelerated with respect to an inertial frame of reference is called a non-inertial frame of reference. A coordinate system fixed on a circular disc rotating about a fixed axis with a constant angular velocity ω is an example of a non-inertial frame of reference. The relationship between the force $\vec{F}_{rot}$ experienced by a particle of mass m moving on the rotating disc and the force $\vec{F}_{in}$ experienced by the particle in an inertial frame of reference is

$$\vec{F}_{rot} = \vec{F}_{in} + 2m(\vec{v}_{rot} \times \vec{\omega}) + m(\vec{\omega} \times \vec{r}) \times \vec{\omega},$$

where $\vec{v}_{rot}$ is the velocity of the particle in the rotating frame of reference and $\vec{r}$ is the position vector of the particle with respect to the centre of the disc.
Now consider a smooth slot along a diameter of a disc of radius R rotating counter-clockwise with a constant angular speed ω about its vertical axis through its center. We assign a coordinate system with the origin at the center of the disc, the x-axis along the slot, the y-axis perpendicular to the slot and the z-axis along the rotation axis ($\vec{\omega} = \omega\hat{k}$). A small block of mass m is gently placed in the slot at $\vec{r} = (R/2)\hat{i}$ at $t = 0$ and is constrained to move only along the slot.



Q3 The distance r of the block at time t is

(A) $\frac{R}{4}\left(e^{2\omega t} + e^{-2\omega t}\right)$

(B) $\frac{R}{2}\cos 2\omega t$

(C) $\frac{R}{2}\cos \omega t$

(D) $\frac{R}{2}\left(e^{\omega t} + e^{-\omega t}\right)$

Q4 The net reaction of the disc on the block is

(A) $-m\omega^2 R\cos\omega t\ \hat{j} - mg\hat{k}$

(B) $m\omega^2 R\sin\omega t\ \hat{j} - mg\hat{k}$

(C) $\frac{1}{2}m\omega^2 R\left(e^{\omega t} - e^{-\omega t}\right)\hat{j} + mg\hat{k}$

(D) $\frac{1}{2}m\omega^2 R\left(e^{2\omega t} - e^{-2\omega t}\right)\hat{j} + mg\hat{k}$

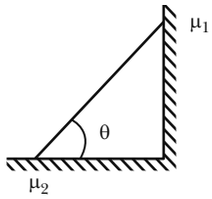
(2016, PAPER 2)

Answer Key

1. (2) **2.** (D) **3.** (D) **4.** (C)

CHAPTER 6 Force and Motion – II

Q1 In the figure, a ladder of mass m is shown leaning against a wall. It is in static equilibrium making an angle θ with the horizontal floor. The coefficient of friction between the wall and the ladder is μ_1 and that between the floor and the ladder is μ_2. The normal reaction of the wall on the ladder is N_1 and that of the floor is N_2. If the ladder is about to slip, then



(A) $\mu_1 = 0\ \mu_2 \neq 0$ and $N_2 \tan\theta = \frac{mg}{2}$

(B) $\mu_1 \neq 0\ \mu_2 = 0$ and $N_1 \tan\theta = \frac{mg}{2}$

(C) $\mu_1 \neq 0\ \mu_2 \neq 0$ and $N_2 = \frac{mg}{1+\mu_1\mu_2}$

(D) $\mu_1 = 0\ \mu_2 \neq 0$ and $N_1 \tan\theta = \frac{mg}{2}$ **(2014, PAPER 1)**

Q2 Put a uniform meter scale horizontally on your extended index fingers with the left one at 0.00 cm and the right one at 90.00 cm. When you attempt to move both the fingers slowly towards the center, initially only the left finger stops with respect to the scale and the right finger does not. After some distance, the left finger stops and the right one starts slipping. Then the right finger stops at a distance x_R from the center (50.00 cm) of the scale and the left one starts slipping again. This happens because of the difference in the frictional forces on the two fingers. If the coefficients of static and dynamic friction between the fingers and the scale are 0.40 and 0.32, respectively, the value of x_R (in cm) is _____.

(2020, PAPER 1)

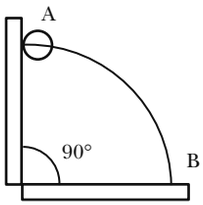
Answer Key

1. (C, D) **2.** (25.6)

CHAPTER 7 Circular Motion

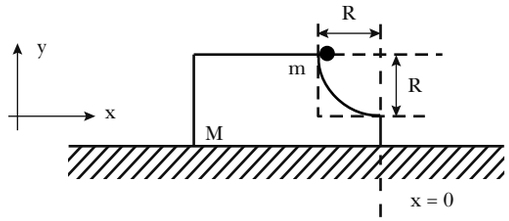
Q1 A wire, which passes through the hole in a small bead, is bent in the form of quarter of a circle. The wire is fixed vertically on ground as shown in the figure. The bead is released from near the top of the wire and it slides along the wire without friction. As the bead moves from A to B, the force it applies on the wire is

(A) always radially outwards.
(B) always radially inwards.
(C) radially outwards initially and radially inwards later.
(D) radially inwards initially and radially outwards later.



(2014, PAPER 2)

Q2 A block of mass M has a circular cut with a frictionless surface as shown. The block rests on the horizontal frictionless surface of a fixed table. Initially the right edge of the block is at x = 0, in a co-ordinate system fixed to the table. A point mass m is released from rest at the topmost point of the path as shown and it slides down. When the mass loses contact with the block, its position is x and the velocity is v. At that instant, which of the following options is/are correct?



(A) The x component of displacement of the center of mass of the block M is : $-\frac{mR}{M+m}$.

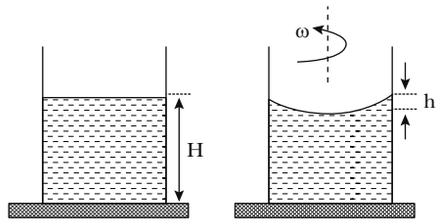
(B) The position of the point mass is : $x = -\sqrt{2}\frac{mR}{M+m}$.

(C) The velocity of the point mass m is : $v = \sqrt{\frac{2gR}{1+\frac{m}{M}}}$.

(D) The velocity of the block M is: $V = -\frac{m}{M}\sqrt{2gR}$.

(2017, PAPER 1)

Q3 A beaker of radius r is filled with water $\left(\text{refractive index}\ \frac{4}{3}\right)$ up to a height H as shown in the figure on the left. The beaker is kept on a horizontal table rotating with angular speed ω. This makes the water surface curved so that the difference in the height of water level at the center and at the circumference of the beaker is h(h << H, h << r), as shown in the figure on the right. Take this surface to be approximately spherical with a radius of curvature R. Which of the following is/are correct? (g is the acceleration due to gravity)



(A) $R = \frac{h^2 + r^2}{2h}$

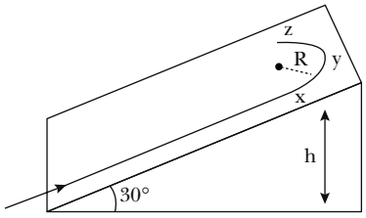
(B) $R = \frac{3r^2}{2h}$

(C) Apparent depth of the bottom of the beaker is close to $\frac{3H}{2}\left(1+\frac{\omega^2 H}{2g}\right)^{-1}$

(D Apparent depth of the bottom of the beaker is close to $\frac{3H}{4}\left(1+\frac{\omega^2 H}{4g}\right)^{-1}$

(2020, PAPER 2)

Q4 A student skates up a ramp that makes an angle 30° with the horizontal. He/she starts (as shown in the figure) at the bottom of the ramp with speed v_0 and wants to turn around over a semicircular path xyz of radius R during which he/she reaches a maximum height h (at point y) from the ground as shown in the figure. Assume that the energy loss is negligible and the force required for this turn at the highest point is provided by his/her weight only. Then (g is the acceleration due to gravity)



(A) $v_0^2 - 2gh = \frac{1}{2}gR$

(B) $v_0^2 - 2gh = \frac{\sqrt{3}}{2}gR$

(C) the centripetal force required at points x and z is zero

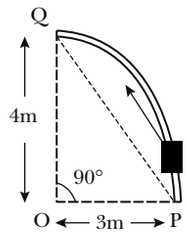
(D) the centripetal force required is maximum at points x and z **(2020, PAPER 2)**

Answer Key

1. (D) **2.** (A,C) **3.** (A,D) **4.** (A,D)

CHAPTER 8 Work, Power, and Energy

Q1 Consider an elliptically shaped rail PQ in the vertical plane with OP = 3 in and OQ = 4 m. A block of mass 1 kg is pulled along the rail from P to Q with a force of 18 N, which is always parallel to line PQ (see the figure given). Assuming no frictional losses, the kinetic energy of the block when it reaches Q is (n × 10) Joules. The value of n is (take acceleration due to gravity = 10 ms^{-2})



(2014, PAPER 1)

Q2 A particle of mass m is initially at rest at the origin. It is subjected to a force and starts moving along the x-axis. Its kinetic energy K changes with time as dK/dt = γt, where γ is a positive constant of appropriate dimensions. Which of the following statements is (are) true?

(A) The force applied on the particle is constant.

(B) The speed of the particle is proportional to time.

(C) The distance of the particle from the origin increases linearly with time.

(D) The force is conservative.

(2018, PAPER 2)

Q3 In the List–I below, four different paths of a particle are given as functions of time. In these functions, α and β are positive constants of appropriate dimensions and $\alpha \neq \beta$. In each case, the force acting on the particle is either zero or conservative. In List–II, five physical quantities of the particle are mentioned: $\vec{P}$ is the linear momentum, $\vec{L}$ is the angular momentum about the origin, K is the kinetic energy, U is the potential energy and E is the total energy. Match each path in List–I with those quantities in List–II. which are conserved for that path.

LIST–I	LIST–II
P. $\vec{r}(t) = \alpha t\,\hat{i} + \beta t\,\hat{j}$	**1.** $\vec{P}$
Q. $\vec{r}(t) = \alpha \cos \omega t\,\hat{i} + \beta \sin t\omega t\,\hat{j}$	**2.** $\vec{L}$
R. $\vec{r}(t) = \alpha(\cos \omega t\,\hat{i} + \sin t\omega t\,\hat{j})$	**3.** K
S. $\vec{r}(t) = \alpha t\,\hat{i} + \frac{\beta}{2}t^2\hat{j}$	**4.** U
	5. E

(A) P → 1, 2, 3, 4, 5; Q → 2,5; R → 2, 3, 4, 5; S → 5

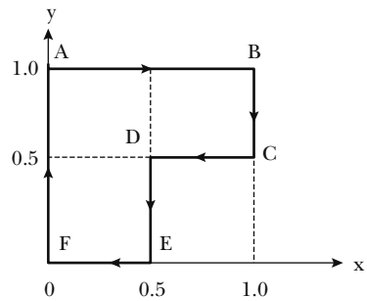
(B) P → 1, 2, 3, 4, 5; Q → 3, 5; R → 2, 3, 4, 5; S → 2, 5

(C) P → 2, 3, 4; Q → 5; R → 1, 2, 4; S → 2, 5

(D) P → 1, 2, 3, 5; Q → 2, 5; R → 2, 3, 4, 5; S → 2, 5

(2018, PAPER 2)

Q4 A particle is moved along a path AB–BC–CD–DE–EF–FA, as shown in figure, in presence of a force $\vec{F} = (\alpha y\hat{i} + 2\alpha x\hat{j})$N, where x and y are in meter and $\alpha = -1$ Nm^{-1}. The work done on the particle by this force $\vec{F}$ will be _____ Joule.



(2019, PAPER 1)

Answer Key

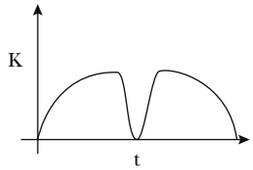
1. (5) **2.** (A, B, D) **3.** (A) **4.** (0.75)

CHAPTER 9 Center of Mass

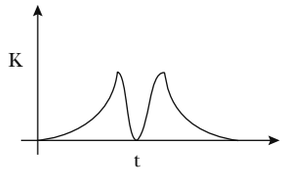
Q1 A tennis ball is dropped on a horizontal smooth surface. It bounces back to its original position after hitting the surface. The force on the ball during the collision is

proportional to the length of compression of the ball. Which one of the following sketches describes the variation of its kinetic energy K with time t most appropriately? The figures are only illustrative and not to the scale.

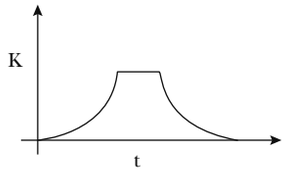
(A)



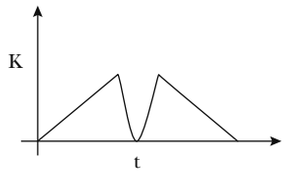
(B)



(C)



(D)



(2014, PAPER 2)

Q2 A solid horizontal surface is covered with a thin layer of oil. A rectangular block of mass m = 0.4 kg is at rest on this surface. An impulse of 1.0 Ns is applied to the block at time t = 0 so that it starts moving along the x-axis with a velocity $v(t) = v_0 e^{-t/\tau}$, where v_0 is a constant and $\tau = 4$ s. The displacement of the block, in meters, at $t = \tau$ is ____. Take $e^{-1} = 0.37$.

(2018, PAPER 2)

Q3 A ball is projected from the ground at an angle of 45° with the horizontal surface. It reaches a maximum height of 120 m and returns to the ground. Upon hitting the ground for the first time, it loses half of its kinetic energy. Immediately after the bounce, the velocity of the ball makes an angle of 30° with the horizontal surface. The maximum height it reaches after the bounce, in metres, is _____.

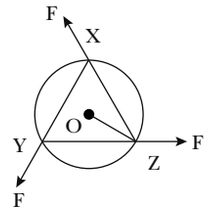
(2018, PAPER 2)

Answer Key

1. (B) **2.** (6.30) **3.** (30.00)

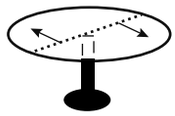
CHAPTER 10 Rigid Body Dynamics – I

Q1 A uniform circular disc of mass 1.5 kg and radius 0.5 m is initially at rest on a horizontal frictionless surface. Three forces of equal magnitude F = 0.5 N are applied simultaneously along the three sides of an equilateral triangle XYZ with its vertices on the perimeter of the disc (see figure). One second after applying the forces, the angular speed of the disc in rad s^{-1} is _____.



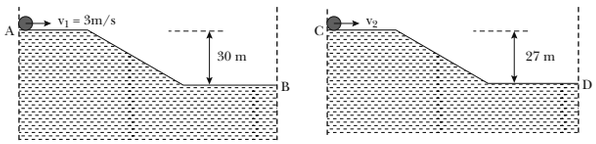
(2014, PAPER 1)

Q2 A horizontal circular platform of radius 0.5 m and mass 0.45 kg is free to rotate about its axis. Two massless spring toy-guns, each carrying a steel ball of mass 0.05 kg are attached to the platform at a distance 0.25 m from the centre on its either sides along its diameter (see figure). Each gun simultaneously fires the balls horizontally and perpendicular to the diameter in opposite directions. After leaving the platform, the balls have horizontal speed of 9 ms^{-1} with respect to the ground. The rotational speed of the platform in rad s^{-1} after the balls leave the platform is _____.



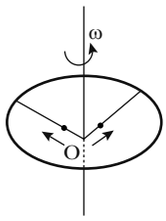
(2014, PAPER 1)

Q3 Two identical uniform discs roll without slipping on two different surfaces AB and CD (see figure) starting at A and C with linear speeds v_1 and v_2, respectively, and always remain in contact with the surfaces. If they reach B and D with the same linear speed and v_1 = 3 m/s, then v_2 in m/s is (g = 10 m/s^2)



(2015, PAPER 1)

Q4 A ring of mass M and radius R is rotating with angular speed ω about a fixed vertical axis passing through its centre O with two point masses each of mass $\frac{M}{8}$ at rest at O. These masses can move radially outwards along two massless rods fixed on the ring as shown in the figure. At some instant the angular speed of the system is $\frac{8}{9}\omega$ and one of the masses is at a distance of $\frac{3}{5}R$ from O. At this instant the distance of the other mass from O is _____.



(A) $\frac{2}{3}R$ **(B)** $\frac{1}{3}R$

(C) $\frac{3}{5}R$ **(D)** $\frac{4}{5}R$

(2015, PAPER 1)

Q5 The densities of two solid spheres A and B of the same radii R vary with radial distance r as $\rho_A(r) = k\left(\frac{r}{R}\right)$ and $\rho_B(r) = k\left(\frac{r}{R}\right)^5$, respectively, where k is a constant. The moments of inertia of the individual spheres about axes passing through their centres are I_A and I_B, respectively. If $\frac{I_B}{I_A} = \frac{n}{10}$, the value of n is _____.

(2015, PAPER 2)

Q6 A uniform wooden stick of mass 1.6 kg and length ℓ rests in an inclined manner on a smooth, vertical wall of height h ($<\ell$) such that a small portion of the stick extends beyond the wall. The reaction force of the wall on the stick is perpendicular to the stick. The stick makes an angle of 30° with the wall and the bottom of the stick is on a rough floor. The reaction of the wall on the stick is equal in magnitude to the reaction of the floor on the stick. The ratio h/ℓ and the frictional force f at the bottom of the stick are ($g = 10\ ms^{-2}$)

(A) $\frac{h}{\ell} = \frac{\sqrt{3}}{16}$, $f = \frac{16\sqrt{3}}{3}N$

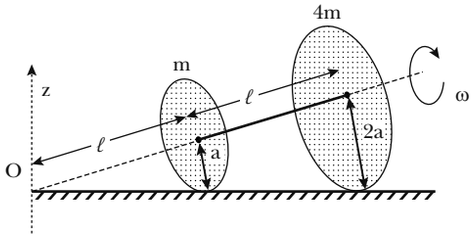
(B) $\frac{h}{\ell} = \frac{3}{16}$, $f = \frac{16\sqrt{3}}{3}N$

(C) $\frac{h}{\ell} = \frac{3\sqrt{3}}{16}$, $f = \frac{8\sqrt{3}}{3}N$

(D) $\frac{h}{\ell} = \frac{3\sqrt{3}}{16}$, $f = \frac{16\sqrt{3}}{3}N$

(2016, PAPER 1)

Q7 Two thin circular discs of mass m and 4m, having radii of a and 2a, respectively, are rigidly fixed by a massless, rigid rod of length $\ell = \sqrt{24}$ a through their centers. This assembly is laid on a firm and flat surface, and set rolling without slipping on the surface so that the angular speed about the axis of the rod is ω. The angular momentum of the entire assembly about the point 'O' is $\vec{L}$ (see the figure). Which of the following statement(s) is(are) true?



(A) The magnitude of angular momentum of the assembly about its center of mass is $17\ ma^2\omega/2$

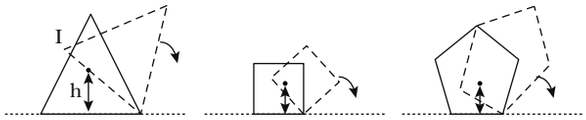
(B) The magnitude of the z-component of $\vec{L}$ is $55\ ma^2\omega$

(C) The magnitude of angular momentum of center of mass of the assembly about the point O is $81\ ma^2\omega$

(D) The center of mass of the assembly rotates about the z-axis with an angular speed of $\omega/5$

(2016, PAPER 2)

Q8 Consider regular polygons with number of sides n = 3, 4, 5, ….. as shown in the figure. The center of mass of all the polygons is at height h from the ground. They roll on a horizontal surface about the leading vertex without slipping and sliding as depicted. The maximum increase in height of the locus of the center of mass for each polygon is Δ. Then Δ depends on n and h as

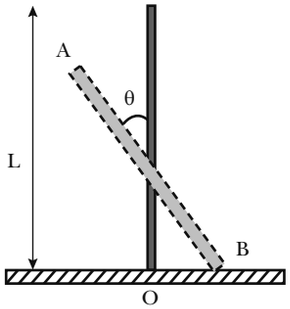


(A) $\Delta = h\sin^2\frac{\pi}{n}$ **(B)** $\Delta = h\left(\frac{1}{\cos\frac{\pi}{n}} - 1\right)$

(C) $\Delta = h\sin\left(\frac{2\pi}{n}\right)$ **(D)** $\Delta = h\tan^2\left(\frac{\pi}{2n}\right)$

(2017, PAPER 2)

Q9 A rigid uniform bar AB of length L is slipping from its vertical position on a frictionless floor (as shown in the figure). At some instant of time, the angle made by the bar with the vertical is θ. Which of the following statements about its motion is/are correct?



(A) The midpoint of the bar will fall vertically downward.

(B) The trajectory of the point A is a parabola.

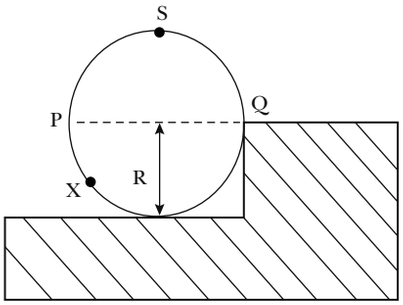
(C) Instantaneous torque about the point in contact with the floor is proportional to $\sin\theta$.

(D) When the bar makes an angle θ with the vertical, the displacement of its midpoint from the initial position is proportional to $(1-\cos\theta)$.

(2017, PAPER 2)

Q10 A wheel of radius R and mass M is placed at the bottom of a fixed step of height R as shown in the figure. A constant force is continuously applied on the surface of the wheel so that it just climbs the step without slipping. Consider the torque τ about an axis normal to the plane of the

paper passing through the point Q. Which of the following options is/are correct?



(A) If the force is applied at point P tangentially then τ decreases continuously as the wheel climbs
(B) If the force is applied normal to the circumference at point X then τ is constant
(C) If the force is applied normal to the circumference at point P then τ is zero
(D) If the force is applied tangentially at point S then $\tau \neq 0$ but the wheel never climbs the step

(2017, PAPER 2)

Q11 Consider a body of mass 1.0 *kg* at rest at the origin at time $t = 0$. A force $\vec{F} = (\alpha t\,\hat{i} + \beta\hat{j})$ is applied on the body, where $\alpha = 1.0 Ns^{-1}$ and $\beta = 1.0N$. The torque acting on the body about the origin at time $t = 1.0\ s$ is $\vec{\tau}$. Which of the following statements is (are) true?

(A) $|\vec{\tau}| = \frac{1}{3} Nm$.
(B) The torque $\vec{\tau}$ is in the direction of the unit vector $+\hat{k}$.
(C) The velocity of the body at $t = 1s$ is $\vec{v} = \frac{1}{2}(\hat{i} + 2\hat{j}) ms^{-1}$.
(D) The magnitude of displacement of the body at $t = 1\ s$ is $\frac{1}{6} m$.

(2018, PAPER 1)

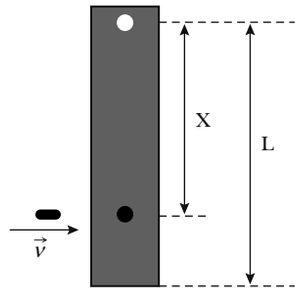
Q12 A thin and uniform rod of mass M and length L is held vertical on a floor with large friction. The rod is released from rest so that it falls by rotating about its contact–point with the floor without slipping. Which of the following statement(s) is/are correct, when the rod makes an angle 60° with vertical?

[g is the acceleration due to gravity]

(A) The radial acceleration of the rod's center of mass will be $\frac{3g}{4}$.
(B) The angular speed of the rod will be $\sqrt{\frac{3g}{2L}}$.
(C) The angular acceleration of the rod will be $\frac{2g}{L}$.
(D) The normal reaction force from the floor on the rod will be $\frac{Mg}{16}$.

(2019, PAPER 2)

Q13 A rod of mass in and length L, pivoted at one of its ends, is hanging vertically. A bullet of the same mass moving at speed v strikes the rod horizontally at a distance x from its pivoted end and gets embedded in it. The combined system now rotates with angular speed ω about the pivot. The maximum angular speed ω_M is achieved for $x = x_M$. Then



(A) $\omega = \frac{3vx}{L^2 + 3x^2}$
(B) $\omega = \frac{12vx}{L^2 + 12x^2}$
(C) $x_M = \frac{L}{\sqrt{3}}$
(D) $\omega_M = \frac{v}{2L}\sqrt{3}$

(2020, PAPER 2)

Answer Key

1. (2)	**2.** (4)	**3.** (7)	**4.** (D)
5. (6)	**6.** (NONE)	**7.** (A,D)	**8.** (B)
9. (A,C,D)	**10.** (A)	**11.** (A,C)	**12.** (A,B,D)
13. (A,C,D)			

CHAPTER 11 Rigid Body Dynamics – II

One twirls a circular ring (of mass M and radius R) near the tip of one's finger as shown in Figure 1. In the process the finger never loses contact with the inner run of the ring. The finger traces out the surface of a cone, shown by the dotted line. The radius of the path traced out by the point where the ring and the finger is in contact is r. The finger rotates with an angular velocity ω_0. The rotating ring *rolls without slipping* on the outside of a smaller circle described by the point where the ring and the finger is in contact (Figure 2). The coefficient of friction between the ring and the finger is μ and the acceleration due to gravity is g.

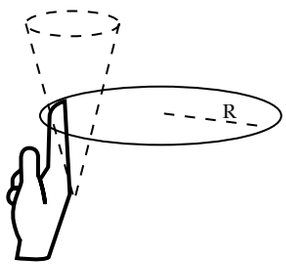


Figure 1

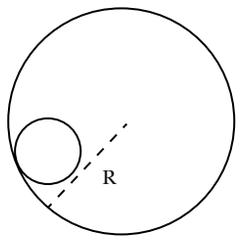


Figure 2

Q1 The total kinetic energy of the ring is

(A) $M\omega_0^2 R^2$
(B) $\frac{1}{2} M\omega_0^2 (R - r)^2$
(C) $M\omega_0^2 (R - r)^2$
(D) $\frac{3}{2} M\omega_0^2 (R - r)^2$

Q2 The minimum value of ω_0 below which the ring will drop down is

(A) $\sqrt{\dfrac{g}{\mu(R-r)}}$ **(B)** $\sqrt{\dfrac{2g}{\mu(R-r)}}$

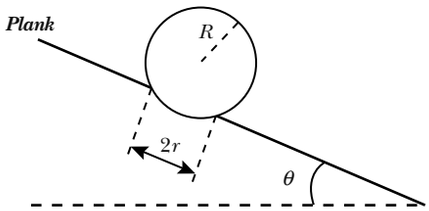
(C) $\sqrt{\dfrac{3g}{2\mu(R-r)}}$ **(D)** $\sqrt{\dfrac{g}{2\mu(R-r)}}$

(2017, PAPER 2)

Q3 A ring and a disc are initially at rest, side by side, at the top of an inclined plane which makes an angle 60° with the horizontal. They start to roll without slipping at the same instant of time along the shortest path. If the time difference between their reaching the ground is $(2-\sqrt{3})/\sqrt{10}\ s$, then the height of the top of the inclined plane, in *metres*, is ____. Take $g = 10\ ms^{-2}$.

(2018, PAPER 1)

Q4 A football of radius R is kept on a hole of radius r (r < R) made on a plank kept horizontally. One end of the plank is now lifted so that it gets tilted making an angle θ from the horizontal as shown in the figure below. The maximum value of θ so that the football does not start rolling down the plank satisfies (figure is schematic and not drawn to scale)

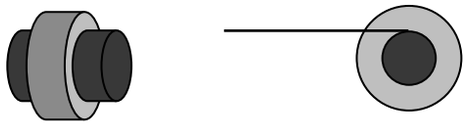


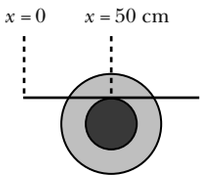
(A) $\sin\theta = \dfrac{r}{R}$ **(B)** $\tan\theta = \dfrac{r}{R}$

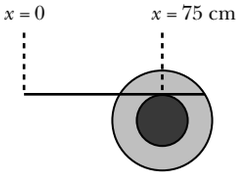
(C) $\sin\theta = \dfrac{r}{2R}$ **(D)** $\cos\theta = \dfrac{r}{2R}$

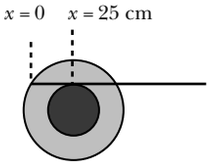
(2020, PAPER 1)

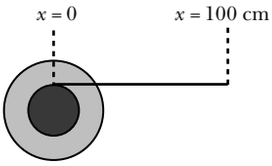
Q5 A small roller of diameter 20 cm has an axle of diameter 10 cm (see figure below on the left). It is on a horizontal floor and a meter scale is positioned horizontally on its axle with one edge of the scale on top of the axle (see figure on the right). The scale is now pushed slowly on the axle so that it moves without slipping on the axle, and the roller starts rolling without slipping. After the roller has moved 50 cm, the position of the scale will look like (figures are schematic and not drawn to scale)



(A)


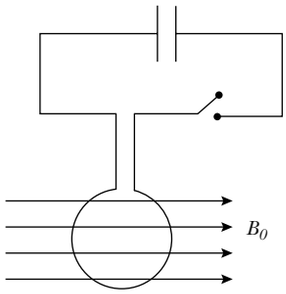
(B)


(C)


(D)


(2020, PAPER 1)

Q6 A circular coil of radius R and N turns has negligible resistance. As shown in the schematic figure, its two ends are connected to two wires and it is hanging by those wires with its plane being vertical. The wires are connected to a capacitor with charge Q through a switch. The coil is in a horizontal uniform magnetic field B_0 parallel to the plane of the coil. When the switch is closed, the capacitor gets discharged through the coil in a very short time. By the time the capacitor is discharged fully, magnitude of the angular momentum gained by the coil will be (assume that the discharge time is so short that the coil has hardly rotated during this time)



(A) $\dfrac{\pi}{2}NQB_0R^2$ **(B)** πNQB_0R^2

(C) $2\pi NQB_0R^2$ **(D)** $4\pi NQB_0R^2$

(2020, PAPER 1)

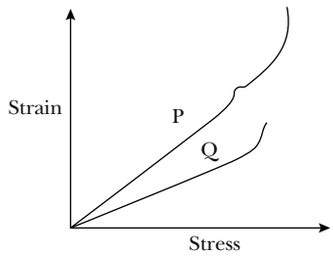
Answer Key

1. (C) **2.** (A) **3.** (0.75) **4.** (A) **5.** (B)
6. (B)

CHAPTER 12 Elasticity

Q1 In plotting stress versus strain curves for two materials P and Q, a student by mistake puts strain on the y-axis and

stress on the x–axis as shown in the figure. Then the correct statement(s) is(are) _____.

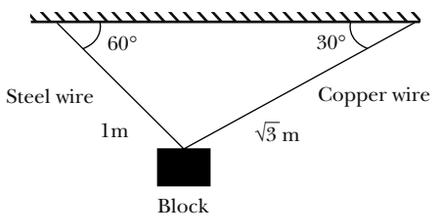


(A) P has more tensile strength than Q.
(B) P is more ductile than Q.
(C) P is more brittle than Q.
(D) The Young's modulus of P is more than that of Q.

(2015, PAPER 2)

Q2 A block of weight 100 N is suspended by copper and steel wires of same cross sectional area 0.5 cm^2 and length $\sqrt{3}$ m and 1 m, respectively. Their other ends are fixed on a ceiling as shown in figure. The angles subtended by copper and steel wires with ceiling are 30° and 60°, respectively. If elongation in copper wire is $(\Delta\ell_c)$ and elongation in steel wire is $(\Delta\ell_s)$, then the ratio $\frac{\Delta\ell_c}{\Delta\ell_s}$ is _____.

[Young's modulus for copper and steel are 1×10^{11} N/m^2 and 2×10^{11} N/m^2, respectively.]



(2019, PAPER 1)

Q3 A cubical solid aluminium (bulk modulus = $-V\frac{dP}{dv}$ = 70 GPa) block has an edge length of 1 m on the surface of the earth. It is kept on the floor of a 5 km deep ocean. Taking the average density of water and the acceleration due gravity to be 10^3 kg m^{-3} and 10 ms^{-2}, respectively, the change in the edge length of the block in mm is _____.

(2020, PAPER 2)

Answer Key

1. (A,B) **2.** (2) **3.** (0.238)

CHAPTER 13 Gravitation

Q1 A planet of radius $R = \frac{1}{10} \times$ (radius of Earth) has the same mass density as Earth. Scientists dig a well of depth $\frac{R}{5}$ on it and lower a wire of the same length and of linear mass density 10^{-3} kgm^{-1} into it. If the wire is not touching anywhere, the force applied at the top of the wire by a person holding it in place is (take the radius of Earth = 6×10^6 m and the acceleration due to gravity of Ear th is 10 ms^{-2})

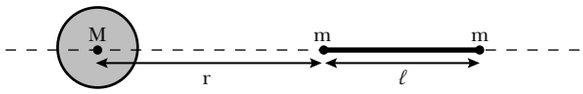
(A) 96 N **(B)** 108 N
(C) 120 N **(D)** 150 N

(2014, PAPER 2)

Q2 A bullet is fired vertically upwards with velocity v from the surface of a spherical planet. When it reaches its maximum height, its acceleration due to the planet's gravity is l/4th of its value at the surface of the planet. If the escape velocity from the planet is $V_{esc} = v\sqrt{N}$, then the value of N is _____. (ignore energy loss due to atmosphere)

(2015, PAPER 1)

Q3 A large spherical mass M is fixed at one position and two identical point masses m are kept on a line passing through the centre of M (see figure). The point masses are connected by a rigid massless rod of length ℓ and this assembly is free to move along the line connecting them. All three masses interact only through their mutual gravitational interaction. When the point mass nearer to M is at a distance $r = 3\ell$ from M. the tension in the rod is zero for $m = k\left(\frac{M}{208}\right)$. The value of k is



(2015, PAPER 2)

Q4 A rocket is launched normal to the surface of earth, away from the Sun. along the line joining the Sun and the Earth. The Sun is 3×10^5 times heavier than the Earth and is at a distance 2.5×10^4 times larger than the radius of the Earth. The escape velocity from Earth's gravitational field is v_e = 11.2 km s^{-1}. The minimum initial (v_s) required for the rocket to be able to leave the Sun–earth system is closest to

(Ignore the rotation and revolution of the Earth and the presence of any other planet)

(A) v_s = 22 km s^{-1} **(B)** v_s = 42 km s^{-1}
(C) v_s= 62 km s^{-1} **(D)** v_s = 72 km s^{-1}

(2017, PAPER 2)

Q5 A planet of mass M, has two natural satellites with masses m_1 and m_2. The radii of their circular orbits are R_1 and R_2 respectively. Ignore the gravitational force between the satellites. Define v_1, L_1, K_1 and T_1 to be, respectively, the orbital speed, angular momentum, kinetic energy and time period of revolution of satellite 1; and v_2, L_2, K_2, and T_2 to be the corresponding quantities of satellite 2. Given $m_1/m_2 = 2$ and $R_1 / R_2 = ¼$, match the ratios in List–I to the numbers in List–II.

LIST–I	LIST–II
P. $\frac{v_1}{v_2}$	**1.** $\frac{1}{8}$
Q. $\frac{L_1}{L_2}$	**2.** 1

LIST–I	LIST–II
R. $\frac{K_1}{K_2}$	**3.** 2
S. $\frac{T_1}{T_2}$	**4.** 8

(A) P → 4; Q → 2; R → 1; S → 3
(B) P → 3; Q → 2; R → 4; S → 1
(C) P → 2; Q → 3; R → 1; S → 4
(D) P → 2; Q → 3; R → 4; S → 1

(2018, PAPER 2)

Q6 Consider a spherical gaseous cloud of mass density $\rho(r)$ in free space where r is the radial distance from its center. The gaseous cloud is made of particles of equal mass m moving in circular orbits about the common center with the same kinetic energy K. The force acting on the particles is their mutual gravitational force. If $\rho(r)$ is constant in time, the particle number density $n(r) = \rho(r)/m$ is

[G is universal gravitational constant]

(A) $\frac{3K}{\pi r^2 m^2 G}$ **(B)** $\frac{K}{2\pi r^2 m^2 G}$

(C) $\frac{K}{6\pi r^2 m^2 G}$ **(D)** $\frac{K}{\pi r^2 m^2 G}$

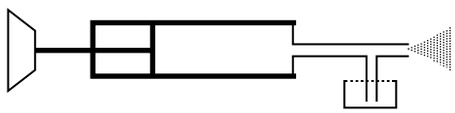
(2019, PAPER 1)

Answer Key

1. (B) **2.** (2) **3.** (7) **4.** (B) **5.** (B) **6.** (B)

CHAPTER 14 Fluids

A spray gun is shown in the figure where a piston pushes air out of a nozzle. A thin tube of uniform cross section is connected to the nozzle. The other end of the tube is in a small liquid container. As the piston pushes air through the nozzle, the liquid from the container rises into the nozzle and is sprayed out. For the spray gun shown, the radii of the piston and the nozzle are 20 mm and 1 mm respectively. The upper end of the container is open to the atmosphere.



Q1 If the piston is pushed at a speed of 5 mms $^{-1}$, the air comes out of the nozzle with a speed of

(A) 0.1 ms^{-1} **(B)** 1 ms^{-1}
(C) 2 ms^{-1} **(D)** 8 ms^{-1}

Q2 If the density of air is ρ_a and that of the liquid ρ_ℓ, then for a given piston speed the rate (volume per unit time) at which the liquid is sprayed will be proportional to

(A) $\sqrt{\frac{\rho_a}{\rho_\ell}}$ **(B)** $\sqrt{\rho_a \rho_\ell}$

(C) $\sqrt{\frac{\rho_\ell}{\rho_a}}$ **(D)** ρ_ℓ

(2014, PAPER 2)

Q3 A person in a lift is holding a water jar, which has a small hole at the lower end of its side. When the lift is at rest, the water jet coming out of the hole hits the floor of the lift at a distance d of 1.2 m from the person. In the following, state of the lift's motion is given in List–I and the distance where the water jet hits the floor of the lift is given in List–II. Match the statements from List–I with those in List–II and select the correct answer using the code given below the lists.

	List–I		List–II
P.	Lift is accelerating vertically up.	**1.**	d = 1.2 m
Q.	Lift is accelerating vertically down with an acceleration less than the gravitational acceleration.	**2.**	d > 1.2 m
R.	Lift is moving vertically up with constant speed.	**3.**	d < 1.2 m
S.	Lift is falling freely.	**4.**	No water leaks out of the jar

Code:
(A) P → 2, Q → 3, R → 2, S → 4
(B) P → 2, Q → 3, R → 1, S → 4
(C) P → 1, Q → 1, R → 1, S → 4
(D) P → 2, Q → 3, R → 1, S → 1

(2014, PAPER 2)

Q4 A spherical body of radius R consists of a fluid of constant density and is in equilibrium under its own gravity. If P(r) is the pressure at r(r < R), then the correct option(s) is(are) _____.

(A) $P(r = 0) = 0$ **(B)** $\frac{P(r = 3R/4)}{P(r = 2R/3)} = \frac{63}{80}$

(C) $\frac{P(r = 3R/5)}{P(r = 2R/5)} = \frac{16}{21}$ **(D)** $\frac{P(r = R/2)}{P(r = R/3)} = \frac{20}{27}$

(2015, PAPER 2)

Q5 Consider two solid spheres P and Q each of density 8 gm cm^{-3} and diameters 1cm and 0.5cm. respectively. Sphere P is dropped into a liquid of density 0.8 gm cm^{-3} and viscosity $\eta = 3$ poiseulles. Sphere Q is dropped into a liquid of density 1.6 gm cm^{-3} and viscosity $\eta = 2$ poiseulles. The ratio of the terminal velocities of P and Q is _____.

(2016, PAPER 1)

Q6 A flat plate is moving normal to its plane through a gas under the action of constant force *F*. The gas is kept at a very low pressure. The speed of the plate v is much less

than the average speed u of the gas molecules. Which of the following options is/are true?

(A) The resistive force experienced by the plate is proportional to v.

(B) The pressure difference between the leading and trailing faces of the plate is proportional to uv.

(C) The plate will continue to move with constant non-zero acceleration, at all times.

(D) At a later time the external force F balances the resistive force.

(2017, PAPER 1)

Q7 Consider a thin square plate floating on a viscous liquid in a large tank. The height h of the liquid in the tank is much less than the width of the tank. The floating plate is pulled horizontally with a constant velocity u_0. Which of the following statements is (are) true?

(A) The resistive force of liquid on the plate is inversely proportional to h.

(B) The resistive force of liquid on the plate is independent of the area of the plate.

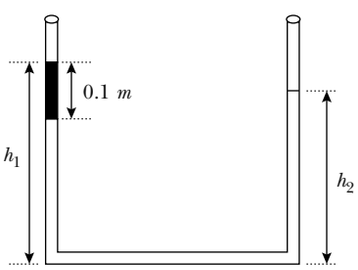
(C) The tangential (shear) stress on the floor of the tank increases with u_0.

(D) The tangential (shear) stress on the plate varies linearly with the viscosity η of the liquid.

(2018, PAPER 2)

Q8 An open-ended U-tube of uniform cross-sectional area contains water (density 10^3kg m^{-3}). Initially the water level stands at 0.29 m from the bottom in each arm. Kerosene oil (a water-immiscible liquid) of density 800 kg m^{-3} is added to the left aim until its length is 0.1 m, as shown in the schematic figure below.

The ratio $\left(\frac{h_1}{h_2}\right)$ of the heights of the liquid in the two anus is



(A) $\frac{15}{14}$ **(B)** $\frac{35}{33}$

(C) $\frac{7}{6}$ **(D)** $\frac{5}{4}$

(2020, PAPER 1)

Q9 A train with cross-sectional area S_t is mol ing with speed v_t inside a long tunnel of cross-sectional area S_0 ($S_0 = 4S_t$). Assume that almost all the air (density ρ) in front of the train flows back between its sides and the walls of the tunnel. Also, the air flow with respect to the train is steady and laminar. Take the ambient pressure and that inside the train to be p_0. If the pressure in the region between the sides of the train and the tunnel walls is p, then $p_0 - p = \frac{7}{2N}\rho v_t^2$. The value of N is _____.

(2020, PAPER 2)

Q10 A hot air balloon is carrying some passengers, and a few sandbags of mass 1 kg each so that its total mass is 480 kg. Its effective volume giving the balloon its buoyancy is V. The balloon is floating at an equilibrium height of 100 m. When N number of sandbags are thrown out, the balloon rises to a new equilibrium height close to 150 m with its volume V remaining unchanged. If the variation of the density of air with height h from the ground is $\rho(h) = \rho_0 e^{\frac{h}{h_0}}$, where $\rho_0 = 1.25$ kg m^{-3} and $h_0 = 6000$ m. the value of N is _____.

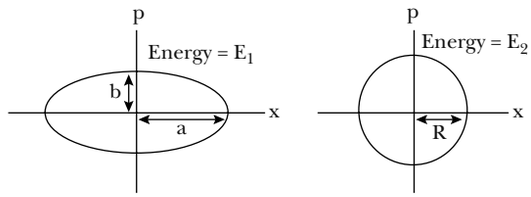
(2020, PAPER 2)

Answer Key

1. (C)	**2.** (A)	**3.** (C)	**4.** (B,C)	**5.** (3)
6. (A,B,D)	**7.** (A,C,D)	**8.** (B)	**9.** (9)	**10.** (4)

CHAPTER 15 Oscillations

Q1 Two independent harmonic oscillators of equal mass are oscillating about the origin with angular frequencies ω_1 and ω_2 and have total energies E_1 and E_2, respectively. The variations of then momenta p with positions x are shown in the figures. If $\frac{a}{b} = n^2$ and $\frac{a}{R} = n$, then the correct equation(s) is(are)



(A) $E_1\omega_1 = E_2\omega_2$

(B) $\frac{\omega_2}{\omega_1} = n^2$

(C) $\omega_1\omega_2 = n^2$

(D) $\frac{E_1}{\omega_1} = \frac{E_2}{\omega_2}$

(2015, PAPER 1)

Q2 A block with mass M is connected by a massless spring with stiffness constant k to a rigid wall and moves without friction on a horizontal stuface. The block oscillates with small amplitude A about an equilibrium position x_0. Consider two cases: (i) when the block is at x_0; and (ii) when the block is at $x = x_0 + A$. In both the cases, a particle with mass m (< M) is softly placed on the block after which they stick to each other. Which of the following statement(s) is (are) true about the motion after the mass m is placed on the mass M?

(A) The amplitude of oscillation in the first case changes by a factor of $\sqrt{\frac{M}{m+M}}$, whereas in the second case it remains unchanged.
(B) The final time period of oscillation in both the cases is same.
(C) The total energy decreases in both the cases.
(D) The instantaneous speed at x_0 of the combined masses decreases in both the cases.

(2016, PAPER 2)

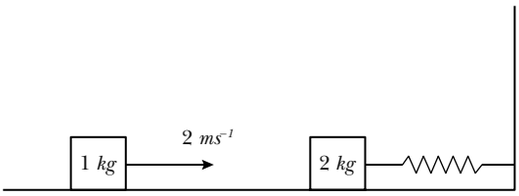
Q3 The potential energy of a particle of mass m at a distance r from a fixed point O is given by $V(r) = kr^2/2$, where k is a positive constant of appropriate dimensions. This particle is moving in a circular orbit of radius R about the point O. If v is the speed of the particle and L is the magnitude of its angular momentum about O, which of the following statements is (are) true?

(A) $v = \sqrt{\frac{k}{2m}}R$ **(B)** $v = \sqrt{\frac{k}{m}}R$

(C) $L = \sqrt{mk}R^2$ **(D)** $L = \sqrt{\frac{mk}{2}}R^2$

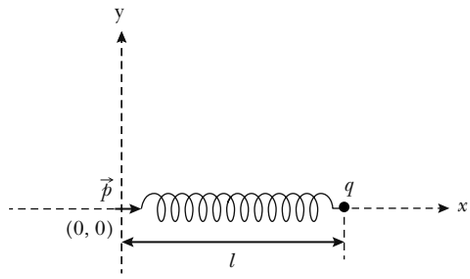
(2018, PAPER 1)

Q4 A spring-block system is resting on a frictionless floor as shown in the figure. The spring constant is 2.0 $N\ m^{-1}$ and the mass of the block is 2.0 kg. Ignore the mass of the spring. Initially the spring is in an unstretched condition. Another block of mass 1.0 kg moving with a speed of 2.0 ms^{-1} collides elastically with the first block. The collision is such that the 2.0 kg block does not hit the wall. The distance, in *metres*, between the two blocks when the spring returns to its unstretched position for the first time after the collision is___.



(2018, PAPER 1)

Q5 One end of a spring of negligible unstretched length and spring constant k is fixed at the origin (0,0). A point particle of mass in carrying a positive charge q is attached at its other end. The entire system is kept on a smooth horizontal surface. When a point dipole $\vec{p}$ pointing towards the charge q is fixed at the origin, the spring gets stretched to a length 1 and attains a new equilibrium position (see figure below). If the point mass is now displaced slightly by $\Delta l << l$ from its equilibrium position and released, it is found to oscillate at frequency $\frac{1}{\delta}\sqrt{\frac{k}{m}}$. The value of δ is_____.



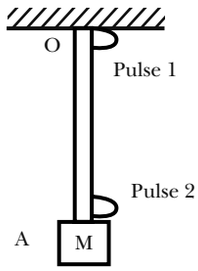
(2018, PAPER 1)

Answer Key

1. (B,D) **2.** (A,B,D) **3.** (B,C) **4.** (2.09) **5.** (3.14)

CHAPTER 16 Waves – I

Q1 A block M hangs vertically at the bottom end of a uniform rope of constant mass per unit length. The top end of the rope is attached to a fixed rigid support at O. A transverse wave pulse (Pulse 1) of wavelength λ_0 is produced at point O on the rope. The pulse takes time T_{OA} to reach point A. If the wave pulse of wavelength λ_0 is produced at point A (Pulse 2) without disturbing the position of M it takes time T_{AO} to reach point O. Which of the following options is/are correct?



(A) The time $T_{AO} = T_{OA}$
(B) The velocities of the two pulses (Pulse 1 and Pulse 2) are the same at the midpoint of rope.
(C) The wavelength of Pulse 1 becomes longer when it reaches point A.
(D) The velocity of any pulse along the rope is independent of its frequency and wavelength.

(2017, PAPER 1)

A musical instrument is made using four different metal strings, 1, 2, 3 and 4 with mass per unit length μ, 2μ, 3μ and 4μ respectively. The instrument is played by vibrating the strings by varying the free length in between the range L_0 and $2L_0$. It is found that in string-1 (μ) at free length L_0 and tension T_0 the fundamental mode frequency is f_0.

List–I gives the above four strings while list – II lists the magnitude of some quantity.

List–I		List–II	
(I)	String–1 (μ)	**(P)**	1
(II)	String–2 (2μ)	**(Q)**	1/2
(III)	String–3 (3μ)	**(R)**	$1/\sqrt{2}$
(IV)	String–4 (4μ)	**(S)**	$1/\sqrt{3}$
		(T)	3/16
		(U)	1/16

Q2 If the tension in each string is T_0, the correct match for the highest fundamental frequency in f_0 units will be _____.

Options

(A) $I \to P, II \to R, III \to S, IV \to Q$
(B) $I \to Q, II \to S, III \to R, IV \to P$
(C) $I \to P, II \to Q, III \to T, IV \to S$
(D) $I \to Q, II \to P, III \to R, IV \to T$

Q3. The length of the string 1, 2, 3 and 4 are kept fixed at $L_0, \frac{3L_0}{2}, \frac{5L_0}{2}$ and $\frac{7L_0}{2}$, respectively. Strings 1, 2, 3 and 4 are vibrated at their 1st, 3rd, 5th and 14th harmonics, respectively such that all the strings have same frequency. The correct match for the tension in the four strings in the units of T_o will be _____.

Options

(A) $I \to P, II \to Q, III \to T, IV \to U$
(B) $I \to P, II \to Q, III \to R, IV \to T$
(C) $I \to P, II \to R, III \to T, IV \to U$
(D) $I \to T, II \to Q, III \to R, IV \to U$

(2019, PAPER 2)

Answer Key

1. (A,B,D) **2.** (A) **3.** (A)

CHAPTER 17 Waves – II

Q1 A student is performing an experiment using a resonance column and a tuning fork of frequency 244 s^{-1}. He is told that the air in the tube has been replaced by another gas (assume that the column remains filled with the gas). If the minimum height at which resonance occurs is (0.350 ± 0.005)m, the gas in the tube is (**Useful information:** $\sqrt{167RT} = 640\ J^{1/2}mole^{-1/2}$; $\sqrt{140RT} = 590\ J^{1/2}mole^{-1/2}$. The molar masses M in grams are given in the options. Take the values of $\sqrt{\frac{10}{M}}$ for each gas as given there.)

(A) Neon $\left(M = 20, \sqrt{\frac{10}{20}} = \frac{7}{10}\right)$

(B) Nitrogen $\left(M = 28, \sqrt{\frac{10}{28}} = \frac{3}{5}\right)$

(C) Oxygen $\left(M = 32, \sqrt{\frac{10}{32}} = \frac{9}{16}\right)$

(D) Argon $\left(M = 36, \sqrt{\frac{10}{36}} = \frac{17}{32}\right)$

(2014, PAPER 1)

Q2 One end of a taut string of length 3m along the x axis is fixed at $x = 0$. The speed of the waves in the string is 100 ms^{-1}. The other end of the string is vibrating in the y direction so that stationary waves are set up in the string. The possible waveform(s) of these stationary waves is (are)

(A) $y(t) = A\sin\frac{\pi x}{6}\cos\frac{50\pi t}{3}$

(B) $y(t) = A\sin\frac{\pi x}{3}\cos\frac{100\pi t}{3}$

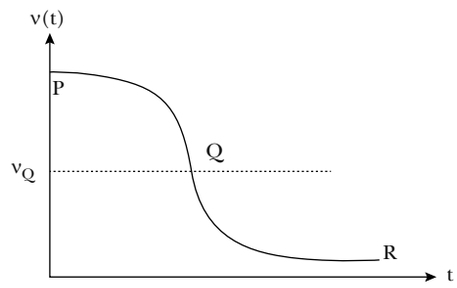
(C) $y(t) = A\sin\frac{5\pi x}{6}\cos\frac{250\pi t}{3}$

(D) $y(t) = A\sin\frac{5\pi x}{2}\cos 250\pi t$

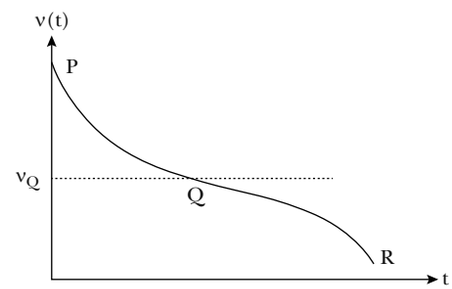
(2014, PAPER 1)

Q3 Two loudspeakers M and N are located 20 m apart and emit sound at frequencies 118 Hz and 121 Hz, respectively. A car is initially at a point P, 1800 m away from the mid-point Q of the line MN and moves towards Q constantly at 60 km/hr along the perpendicular bisector of MN. It crosses Q and eventually reaches a point R, 1800 m away from Q. Let $\nu(t)$ represent the beat frequency measured by a person sitting in the car at time t. Let ν_P, ν_Q and ν_R be the beat frequencies measured at locations P, Q and R, respectively. The speed of sound in air is 330 m s^{-1}. Which of the following statement(s) is(are) true regarding the sound heard by the person?

(A) $\nu_P + \nu_R = 2\nu_Q$.
(B) The rate of change in beat frequency is maximum when the car passes through Q.
(C) The plot below represents schematically the variation of beat frequency with time.



(D) The plot below represents schematically the variation of beat frequency with time.



(2016, PAPER 1)

Q4 A stationary source emits sound of frequency $f_0 = 492$ Hz. The sound is *reflected* by a large car *approaching* the source with a speed of 2 ms^{-1}. The reflected signal is received by the soruce and superposed with the original. What will be the beat frequency of the resulting signal in Hz? (Given that the speed of sound in air is 330 ms^{-1} and the car reflects the sound at the frequency *it* has received).

(2017, PAPER 1)

Q5 Two men are walking along a horizontal straight line in the same direction. The man in front walks at a speed 1.0 ms^{-1} and the man behind walks at a speed 2.0 ms^{-1}. A third man is standing at a height 12 *m* above the same horizontal line such that all three men are in a vertical plane. The two walking men are blowing identical whistles which emit a sound of frequency 1430 *Hz*. The speed of sound in air is 330 ms^{-1}. At the instant, when the moving men are 10 *m* apart, the stationary man is equidistant from them. The frequency of beats in *Hz,* heard by the stationary man at this instant, is___.

(2018, PAPER 1)

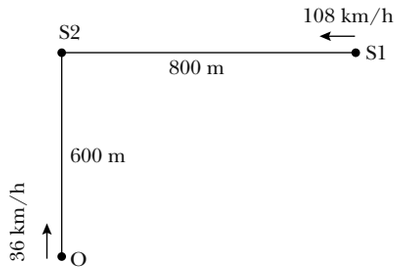
Q6 In an experiment to measure the speed of sound by a resonating air column, a tuning fork of frequency 500 Hz is used. The length of the air column is varied by changing the level of water in the resonance tube. Two successive resonances are heard at air columns of length 50.7 cm and 83.9 cm. Which of the following statements is (are) true?

(A) The speed of sound determined from this experiment is 332 ms^{-1}.
(B) The end correction in this experiment is 0.9 cm.
(C) The wavelength of the sound wave is 66.4 cm.
(D) The resonance at 50.7 cm corresponds to the fundamental harmonic.

(2018, PAPER 2)

Q7 A train S1, moving with a uniform velocity of 108 km/h, approaches another train S2 standing on a platform. An observer O moves with a uniform velocity of 36 km/h towards S2, as shown in figure. Both the trains are blowing whistles of same frequency 120 Hz. When O is 600 m away from S2 and distance between S1 and S2 is 800 m, the number of beats heard by O is _____.

[Speed of the sound = 330 m/s]



(2019, PAPER 1)

Q8 A stationary tuning fork is in resonance with an air column in a pipe. If the tuning fork is moved with a speed of 2 ms^{-1} in front of the open end of the pipe and parallel to it, the length of the pipe should be changed for the resonance to occur with the moving tuning fork. If the speed of sound in air is 320 ms^{-1}, the smallest value of the percentage change required in the length of the pipe is___.

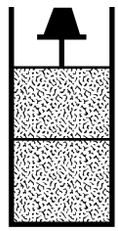
(2020, PAPER 1)

Answer Key

1. (D)	**2.** (A,C,D)	**3.** (A,B,C)	**4.** (6)
5. (5)	**6.** (A,C)	**7.** (8.13)	**8.** (0.62)

CHAPTER 18 Temperature, Zeroth Law of Thermodynamics and Thermal Expansion

In the figure a container is shown to have a movable (without friction) piston on top. The container and the piston are all made of perfectly insulating material allowing no heat transfer between outside and inside the container. The container is divided into two compartments by a rigid partition made of a thermally conducting material that allows slow transfer of heat. The lower compartment of the container is filled with 2 moles of an ideal monatomic gas at 700 K. and the upper compartment is filled with 2 moles of an ideal diatomic gas at 400 K. The heat capacities per mole of an ideal monatomic gas are $C_V = \frac{3}{2}R$, $C_P = \frac{5}{2}R$, and those for an ideal diatomic gas are $C_V = \frac{5}{2}R$, $C_P = \frac{7}{2}R$



Q1 Consider the partition to be rigidly fixed so that it does not move. When equilibrium is achieved, the final temperature of the gases will be _____.

(A) 550K **(B)** 525 K
(C) 513K **(D)** 490K

Q2 Now consider the partition to be free to move without friction so that the pressure of gases in both compartments is the same. Then total work done by the gases till the time they achieve equilibrium will be _____.

(A) 250R **(B)** 200R
(C) 100R **(D)** –100R

(2014, PAPER 2)

Q3 The ends Q and R of two thin wires. PQ and RS, are soldered (joined) together. Initially each of the wires has a length of 1 m at 10 °C. Now the end P is maintained at 10 °C, while the end S is heated and maintained at 400 °C. The system is thermally insulated from its surroundings. If the thermal conductivity of wire PQ is twice that of the wire RS and the coefficient of linear thermal expansion of PQ is $1.2 \times 10^{-5} K^{-1}$, the change in length of the wire PQ is _____.

(A) 0.78 mm **(B)** 0.90mm
(C) 1.56 mm **(D)** 2.34 mm

(2016, PAPER 2)

Q4 A drop of liquid of radius R = 10^{-2} m having surface tension $S = \frac{0.1}{4\pi} Nm^{-1}$ divides itself into K identical drops. In this process the total change in the surface energy $\Delta U = 10^{-3}$ J. If $K = 10^{\alpha}$ then the value of α is _____.

(2017, PAPER 1)

Q5 A uniform capillary tube of inner radius r is dipped vertically into a beaker filled with water. The water rises to a height h in the capillary tube above the water surface in the beaker. The surface tension of water is σ. The angle of contact between water and the wall of the capillary tube is θ. Ignore the mass of water in the meniscus. Which of the following statements is (are) true?

(A) For a given material of the capillary tube. h decreases with increase in r.

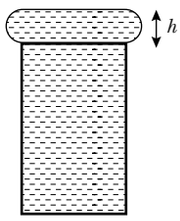
(B) For a given material of the capillary tube, h is independent of σ.

(C) If this experiment is performed in a lift going up with a constant acceleration, then h decreases.

(D) h is proportional to contact angle θ.

(2018, PAPER 1)

Q6 When water is filled carefully in a glass, one can fill it to a height h above the rim of the glass due to the surface tension of water. To calculate h just before water starts flowing, model the shape of the water above the rim as a disc of thickness h having semicircular edges, as shown schematically in the figure. When the pressure of water at the bottom of this disc exceeds what can be withstood due to the surface tension, the water surface breaks near the rim and water starts flowing from there. If the density of water, its surface tension and the acceleration due to gravity are 10^3 kg m^{-3}, 0.07 Nm^{-1} and 10 ms^{-2}, respectively, the value of h (in mm) is_____.



(2020, PAPER 1)

Answer Key

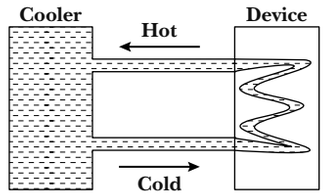
1. (D) **2.** (D) **3.** (A) **4.** (6) **5.** (A,C)
6. (3.75)

CHAPTER 19 Heat – Measurement and Transfer

Q1 Two spherical stars A and B emit blackbody radiation. The radius of A is 400 times that of B and A emits 10^4 times the power emitted from B. The ratio (λ_A/λ_B) of their wavelengths λ_A and λ_B at which the peaks occur in their respective radiation curves is _____.

(2015, PAPER 1)

Q2 A water cooler of storage capacity 120 litres can cool water at a constant rate of P watts. In a closed circulation system (as shown schematically in the figure), the water from the cooler is used to cool an external device that generates constantly 3 kW of heat (thermal load). The temperature of water fed into the device cannot exceed 30 °C and the entire stored 120 litres of water is initially cooled to 10 °C. The entire system is thermally insulated. The minimum value of P (in watts) for which the device can be operated for 3 hours is _____.



(Specific heat of water is 4.2 kJ kg^{-1} K^{-1} and the density of water is 1000 kg m^{-3})

(A) 1600 **(B)** 2067
(C) 2533 **(D)** 3933

(2016, PAPER 1)

Q3 A metal is heated in a furnace where a sensor is kept above the metal surface to read the power radiated (P) by the metal. The sensor has a scale that displays $\log_2(P/P_0)$, where P_0 is a constant. When the metal surface is at a temperature of 487°C, the sensor shows a value 1. Assume that the emissivity of the metallic surface remains constant. What is the value displayed by the sensor when the temperature of the metal surface is raised to 2767 °C? **(2016, PAPER 1)**

Q4 A gas is enclosed in a cylinder with a movable frictionless piston. Its initial thermodynamic state at pressure $P_i = 10^5$ Pa and volume $V_i = 10^{-3}$ m^3 changes to a final state at $P_f = (1/32) \times 10^5$ Pa and $V_f = 8 \times 10^{-3}$ m^3 in an adiabatic quasi-static process, such that P^3V^5 = constant. Consider another thermodynamic process that brings the system from the same initial state to the same final state in two steps: an isobaric expansion at P_i followed by an isochoric (isovolumetric) process at volume V_f. The amount of heat supplied to the system in the two-step process is approximately

(A) 112 J **(B)** 294 J
(C) 588 J **(D)** 813 J

(2016, PAPER 2)

Q5 A human body has a surface area of approximately 1 m^2. The normal body temperature is 10 K above the surrounding room temperature T_0. Take the room temperature to be $T_0 = 300$ K. For $T_0 = 300$ K. and the value of $\sigma T_0^4 = 460$ Wm^{-2} (where σ is the Stefan-Boltzmann constant). Which of the following option is/are correct?

(A) The amount of energy radiated by the body in 1 second is close to 60 Joules.

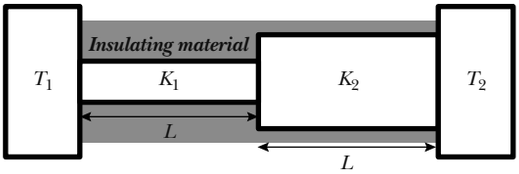
(B) If the surrounding temperature reduces by a small amount $\Delta T_0 << T_0$, then to maintain the same body temperature the same (living) human being needs to radiate $\Delta W = 4\sigma T_0^3 \Delta T_0$ more energy per unit time.

(C) Reducing the exposed surface area of the body (e.g by curling up) allows humans to maintain the same body temperature while reducing the energy lost by radiation.

(D) If the body temperature rises significantly then the peak in the spectrum of electromagnetic radiation emitted by the body would shift to longer wavelengths.

(2017, PAPER 1)

Q6 Two conducting cylinders of equal length but different radii are connected in series between two heat baths kept at temperatures T_1 = 300 K and T_2 = 100 K, as shown in the figure. The radius of the bigger cylinder is twice that of the smaller one and the thermal conductivities of the materials of the smaller and the larger cylinders are K_1 and K_2 respectively. If the temperature at the junction of the two cylinders in the steady state is 200 K, then K_1/K_2 = _____.



(2018, PAPER 1)

Q7 A current carrying wire heats a metal rod. The wire provides a constant power (P) to the rod. The metal rod is enclosed in an insulated container. It is observed that the temperature (T) in the metal rod changes with time (t) as

$$T(t) = T_0(1+\beta t^{1/4})$$

where β is a constant with appropriate dimension while T_0 is a constant with dimension of temperature The heat capacity of the metal is _____.

(A) $\dfrac{4P(T(t)-T_0)^4}{\beta^4 T_0^5}$ **(B)** $\dfrac{4P(T(t)-T_0)}{\beta^4 T_0^2}$

(C) $\dfrac{4P(T(t)-T_0)^2}{\beta^4 T_0^2}$ **(D)** $\dfrac{4P(T(t)-T_0)^3}{\beta^4 T_0^4}$

(2019, PAPER 1)

Q8 A liquid at 30°C is poured very slowly into a Calorimeter that is at temperature of 110°C. The boiling temperature of the liquid is 80°C. It is found that the first 5 gm of the liquid completely evaporates. After pouring another 80 gm of the liquid the equilibrium temperature is found to be 50°C. The ratio of the Latent heat of the liquid to its specific heat will be _____ °C.

[Neglect the heat exchange with surrounding]

(2019, PAPER 1)

Q9 The filament of light bulb has surface area 64 mm^2. The filament can be considered as a black body at temperature 2500 K emitting radiation like a point source when viewed from far. At night the light bulb is observed from a distance of 100 m. Assume the pupil of the eyes of the observer to be circular with radius 3 mm. Then

(Take Stefan-Boltzmann constant = 5.67 × 10^{-8} Wm^{-2}K^{-4}, Wien's displacement constant = 2.90 × 10^{-3} m-K, Planck's constant = 6.63 × 10^{-34} Js, speed of light in vacuum = 3.00 × 10^8 m/s)

(A) power radiated by the filament is in the range 642 W to 645 W

(B) radiated power entering into one eye of the observer is in the range 3.15 × 10^{-8} W to 3.25 × 10^{-8} W

(C) the wavelength corresponding to the maximum intensity of light is 1160 mm

(D) taking the average wavelength of emitted radiation to be 1740 nm. the total number of photons entering per second into one eye of the observer is in the range 2.75 × 10^{11} to 2.85 × 10^{11}

(2020, PAPER 1)

Q10 A container with 1 kg of water in it is kept in sunlight, which causes the water to get warmer than the surroundings The average energy per unit time per unit area received due to the sunlight is 700 Wm^{-2} and it is absorbed by the water over an effective area of 0.05 m^2. Assuming that the heat loss from the water to the surroundings is governed by Newton's law of cooling, the difference (in °C) in the temperature of water and the surroundings after a long time will be _____. (Ignore effect of the container, and take constant for Newton's law of cooling = 0.001 s^{-1}, Heat capacity of water = 4200 J kg^{-1} K^{-1})

(2020, PAPER 2)

Answer Key

1. (2)	**2.** (B)	**3.** (9)	**4.** (C)	**5.** (C)
6. (4)	**7.** (D)	**8.** (270)	**9.** (B,C,D)	**10.** (8.33)

CHAPTER 20 The Kinetic Theory of Gases

Q1 A container of fixed volume has a mixture of one mole of hydrogen and one mole of helium in equilibrium at temperature T. Assuming the gases are ideal, the correct statement(s) is(are) _____.

(A) The average energy per mole of the gas mixture is 2RT.

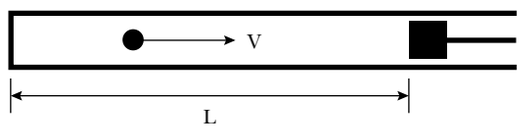
(B) The ratio of speed of sound in the gas mixture to that in helium gas is $\sqrt{6/5}$.

(C) The ratio of the rms speed of helium atoms to that of hydrogen molecules is 1/2.

(D) The ratio of the rms speed of helium atoms to that of hydrogen molecules is $1/\sqrt{2}$.

(2015, PAPER 1)

Q2 A small particle of mass in moving inside a heavy, hollow and straight tube along the tube axis undergoes elastic collision at two ends. The tube has no friction and it is closed at one end by a flat surface while the other end is fitted with a heavy movable flat piston as shown in figure. When the distance of the piston from closed end is L = L_0 the particle speed is v = v_0. The piston is moved inward at a very low speed V such that $v << \frac{dL}{L} v_0$, where dL is the infinitesimal displacement of the piston. which of the following statement(s) is/are correct?



(A) The particle's kinetic energy increases by a factor of 4 when the piston is moved inward from L_0 to $\frac{1}{2}L_0$.

(B) After each collision with the piston, the particle speed increases by 2V.

(C) If the piston moves inward by dL, the particle speed increases by $2v\frac{dL}{L}$.

(D) The rate at which the particle strikes the piston is v/L.

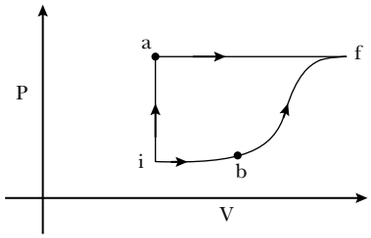
(2019, PAPER 2)

Answer Key

1. (A,B,D) **2.** (A,B)

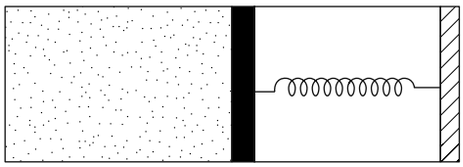
CHAPTER 21 The First Law of Thermodynamics

Q1 A thermodynamic system is taken from an initial state *i* with internal energy U_i = 100 J to the final state *f* along two different paths *iaf* and *ibf,* as schematically shown in the figure. The work done by the system along the paths *af*, *ib* and *bf* are W_{af} = 200 J, W_{ib} = 50 J and W_{bf} = 100 J respectively. The heat supplied to the system along the path iaf, ib and bf are Q_{iaf}, Q_{ib} and Q_{bf} respectively. If the internal energy of the system in the state b is U_b = 200 J and Q_{iaf} = 500 J, the ratio $\mathbf{Q_{bf}/Q_{ib}}$ is _____.



(2014, PAPER 1)

Q2 An ideal monoatomic gas is confined in a horizontal cylinder by a spring loaded piston (as shown in the figure). Initially the gas is at temperature T_1, pressure P_1 and volume V_1 and the spring is in its relaxed state. The gas is then heated very slowly to temperature T_2, pressure P_2 and volume V_2. During this process the piston moves out by a distance x. Ignoring the friction between the piston and the cylinder, the correct statement(s) is(are) _____.



(A) If $V_2 = 2V_1$ and $T_2 = 3T_1$, then the energy stored in the spring is $\frac{1}{4}P_1V_1$.

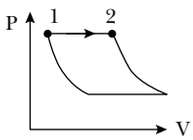
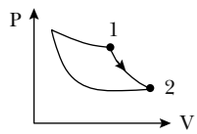
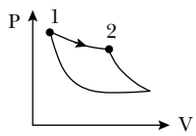
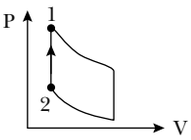
(B) If $V_2 = 2V_1$ and $T_2 = 3T_1$, then the change in internal energy is $3P_1V_1$.

(C) If $V_2 = 3V_1$ and $T_2 = 4T_1$, then the work done by the gas is $\frac{7}{3}P_1V_1$.

(D) If $V_2 = 3V_1$ and $T_2 = 4T_1$, then the heat supplied to the gas is $\frac{17}{6}P_1V_1$.

(2015, PAPER 2)

An ideal gas is undergoing a cyclic thermodynamic process in different ways as shown in the corresponding *P – V* diagrams in column 3 of the table. Consider only the path from state 1 to 2. *W* denotes the corresponding work done on the system. The equations and plots in the table have standard notations as used in thermodynamic processes. Here γ is the ratio of heat capacities at constant pressure and constant volume. The number of moles in the gas is *n*.

Column I	Column 2	Column 3
(I) $W_{1\to2} = \frac{1}{\gamma-1}(P_2V_2 - P_1V_2)$	**(i)** Isothermal	**(P)** 
(II) $W_{1\to2} = -PV_2 + PV_1$	**(ii)** isochoric	**(Q)** 
(III) $W_{1\to2} = 0$	**(iii)** Isobaric	**(R)** 
(IV) $W_{1\to2} = -nRT\ \ln\left(\frac{V_2}{V_1}\right)$	**(iv)** Adiabatic	**(S)** 

Q3 Which of the following options is the only correct representation of a process in which $\Delta U = \Delta Q - P\Delta V$?

(A) (II) (iv) (R) **(B)** (II) (iii) (P)
(C) (II) (iii) (S) **(D)** (III) (iii) (P)

Q4 Which one of the following options is the correct combination?

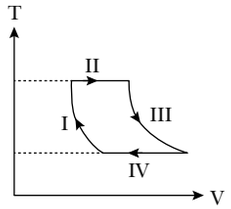
(A) (III) (ii) (S) **(B)** (II) (iv) (R)
(C) (II) (iv) (P) **(D)** (IV) (ii) (S)

Q5 Which one of the following options correctly represents a thermodynamic process that is used as a correction in the determination of the speed of sound in an ideal gas?

(A) (III) (iv) (R) **(B)** (I) (ii) (Q)
(C) (IV) (ii) (R) **(D)** (I) (iv) (Q)

(2017, PAPER 1)

Q6 One mole of a monatomic ideal gas undergoes a cyclic process as shown in the figure (where ***V*** is the volume and ***T*** is the temperature). Which of the statements below is (are) true?



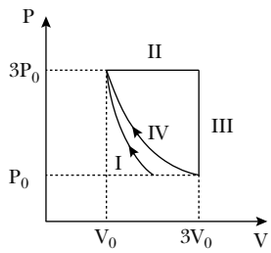
(A) Process I is an isochoric process.
(B) In process II, gas absorbs heat.
(C) In process IV, gas releases heat.
(D) Processes I and III are not isobaric.

(2018, PAPER 1)

Q7 One mole of a monatomic ideal gas undergoes an adiabatic expansion in which its volume becomes eight times its initial value. If the initial temperature of the gas is 100 K and the universal gas constant R = 8.0 J $mol^{-1}K^{-1}$, the decrease in its internal energy, in Joule, is_____.

(2018, PAPER 2)

Q8 One mole of a monatomic ideal gas undergoes four thermodynamic processes as shown schematically in the PV-diagram below. Among these four processes, one is isobaric, one is isochoric, one is isothermal and one is adiabatic. Match the processes mentioned in List-1 with the corresponding statements in List-II.



LIST-I	LIST-II
P. In process I	**1.** Work done by the gas is zero.
Q. In process II	**2.** Temperature of the gas remains unchanged.
R. In process III	**3.** No heat is exchanged between the gas and its surroundings.
S. In process IV	**4.** Work done by the gas is $6P_0V_0$.

(A) **P** → 4; **Q** → 3; **R** → 1; **S** → 2
(B) **P** → 1; **Q** → 3; **R** → 2; **S** → 4
(C) **P** → 3; **Q** → 4; **R** → 1; **S** → 2
(D) **P** → 3; **Q** → 4; **R** → 2; **S** → 1

(2018, PAPER 2)

Q9 A mixture of ideal gas contains 5 moles of monatomic gas and 1 mole of rigid diatomic gas is initially at pressure P_0, volume V_0, and temperature T_0. If the gas mixture is adiabatically compressed to a volume $\frac{V_0}{4}$, then the correct statement(s) is /are. (Given $2^{1.2} = 2.3$; $2^{3.2} = 9.2$; R is gas constant)

(A) Adiabatic constant of the gas mixture is 1.6
(B) The final pressure of the gas mixture after compression is in between $9P_0$ and $10P_0$
(C) The work |W| done during the process is $13RT_0$
(D) The average kinetic energy of the gas mixture after compression is in between $18RT_0$ and $19RT_0$

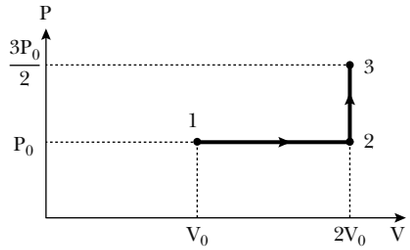
In a thermodynamic process on an ideal monatomic gas, the infinitesimal heat absorbed by the gas is given by $T\Delta X$, where T is temperature of the system and ΔX is the infinitesimal change in a thermodynamic quantity X of the system. For a mole of monatomic ideal gas $X = \frac{3}{2}R\ln\left(\frac{T}{T_A}\right) + R\ln\left(\frac{V}{V_A}\right)$.

Here, R is gas constant, V is volume of gas T_A and V_A are constants.

The List-I below gives some quantities involved in a process and List-II gives some possible values of these quantities.

List-I		List-II	
(I)	Work done by the system in process $1 \to 2 \to 3$	**(P)**	$\frac{1}{3}RT_0\ln 2$
(II)	Change in internal energy in process $1 \to 2 \to 3$	**(Q)**	$\frac{1}{3}RT_0$
(III)	Heat absorbed by the system in process $1 \to 2 \to 3$	**(R)**	RT_0
(IV)	Heat absorbed by the system in process $1 \to 2$	**(S)**	$\frac{4}{3}RT_0$
		(T)	$\frac{1}{3}RT_0(3+\ln 2)$
		(U)	$\frac{5}{6}RT_0$

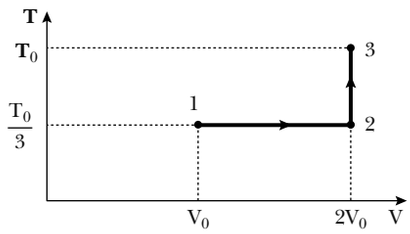
Q10 If The process carried out on one mole of monatomic ideal gas is as shown in figure in the PV-diagram with $P_0V_0 = \frac{1}{3}RT_0$, the correct match is _____.



Options

(A) I → Q, II → R, III → S, IV → U
(B) I → Q, II → S, III → R, IV → U
(C) I → Q, II → R, III → P, IV → U
(D) I → S, II → R, III → Q, IV → T

Q11 If the process on one mole of monatomic ideal gas is as shown in the TV-diagram with $P_0V_0 = \frac{1}{3}RT_0$, the correct match is _____.



Options

(A) I → P, II → T, III → Q, IV → T
(B) I → S, II → T, III → Q, IV → U
(C) I → P, II → R, III → T, IV → S
(D) I → P, II → R, III → T, IV → P

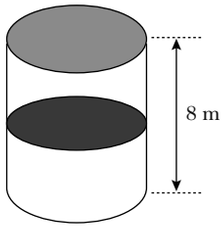
(2019, PAPER 2)

Q12 Consider one mole of helium gas enclosed in a container at initial pressure P_1 and volume V_1. It expands isothermally to volume $4V_1$. After this, the gas expands adiabatically and its volume becomes $32\ V_1$. The work done by the gas during isothermal and adiabatic expansion processes are W_{iso} and W_{adia}, respectively.

If the ratio $\frac{W_{iso}}{W_{adia}} = f\ \ln 2$, then f is _____.

(2020, PAPER 1)

Q13 A thermally isolated cylindrical closed vessel of height 8 m is kept vertically. It is divided into two equal parts by a diathermic (perfect thermal conductor) frictionless partition of mass 8.3 kg. Thus the partition is held initially at a distance of 4 m from the top, as shown in the schematic figure below. Each of the two parts of the vessel contains 0.1 mole of an ideal gas at temperature 300 K. The partition is now released and moves without any gas leaking from one part of the vessel to the other. When equilibrium is reached, the distance of the partition from the top (in m) will be _____ (take the acceleration due to gravin = 10 ms^{-2} and the universal gas constant = 8.3 J $mol^{-1}K^{-1}$).



(2020, PAPER 2)

Q14 A spherical bubble inside water has radius R. Take the pressure inside the bubble and the water pressure to be p_0. The bubble now gets compressed radially in an adiabatic manner so that its radius becomes (R − a), for a << R the magnitude of the work done in the process is given by $(4\pi p_0 R a^2)X$, where X is a constant and $\gamma = C_p/C_V = 41/30$. The value of X is _____.

(2020, PAPER 2)

Answer Key

1. (2)	**2.** (A,B,C)	**3.** (B)	**4.** (A)
5. (D)	**6.** (B,C,D)	**7.** (900)	**8.** (C)
9. (A,B,C)	**10.** (A)	**11.** (D)	**12.** (1.77)
13. (NONE)	**14.** (2.05)		

ANSWERS WITH EXPLANATION

CHAPTER 1 Units and Measurement

A1 Using dimensional analysis

$$d \propto S^{1/n} P^a f^b$$

Expanding dimension

$$L = (MT^{-3})^{1/n}(ML^{-3})^a(T^{-1})^b$$

$$L = M^{1/n+a} L^{-3a} T^{-3/n-b}$$

Equating exponents

For M: $1/n + a = 0 \Rightarrow a = -1/n$

For L: $-3a = 1 \Rightarrow a = -1/3$

For T: $-3/n-b = 0 \Rightarrow b = -3/n$

From the first and second equation

$$-1/n = -1/3 \Rightarrow n = 3$$

A2 For vernier calipers

Main scale division = 1/8cm

Vernier scale division = 1/10cm

Least count = 1/40cm

For Screw Gauge.

Pitch = 2 main scale divisions

Least count = P/100

A3 $L \propto h^a c^b G^c$, $M \propto h^x c^y G^z$

Finding M in terms of C and G

Assume $M \propto C^x G^y$:

$$[M] = [LT^{-1}]^x [M^{-1}L^3T^{-2}]^y$$

Expanding dimensions:

$$M = M^{-y} L^x L^{3y} T^{-x} T^{-2y}$$

Equating dimension for M

$$1 = -y \Rightarrow y = -1$$

For L

$$0 = x + 3(-1) \Rightarrow x - 3 = 0 \Rightarrow x = 3$$

Thus

$$M \propto C^3G^{-1}$$

Finding L in terms of h and G

Assume $L \propto h^a G^b$

$$[L] = [ML^2T^{-1}]^a [M^{-1} L^3 T^{-2}]^b$$

Expanding dimensions

$$L = M^a L^{2a} T^{-a} M^{-b} L^{3b} T^{-2b}$$

Equating for M

$$0 = a - b \Rightarrow a = b$$

For L

$$1 = 2a + 3b \Rightarrow 1 = 2a + 3a \Rightarrow 1 = 5a$$

$$a = 1/5, b = 1/5$$

Thus

$$L \propto h^{1/5} G^{1/5}$$

A4 Given

$$E(t) = A^2e^{-\propto t}$$

Differentiating

$$dE = -\propto A^2 e^{-\propto t} dt + 2AdAe^{-\propto t}$$

For maximum error

$$\frac{dE}{E} + \frac{4}{100}$$

Hence % error is 4

A5 Starting with

$$BI\lambda_c = VI$$

$$\mu_0 I^2 c = VI$$

$$\mu_0 I_c = V$$

Squaring both side

$$\propto_0^2 I^2c^2 = V^2$$

Rearranging

$$\mu_0 I^2 = \varepsilon_0 v^2$$

$$\varepsilon_0 cv = I$$

A6 For the first case

Main scale reading = 2.8cm

Vernier scale reading $= 7 \times \frac{1}{10} = 0.07$cm

Total reading = 2.8 + 0.07 = 2.87cm

For the second case

Main scale reading = 2.8cm

Vernier scale correction $= 7 \times \frac{0.1}{10} = 0.07$cm

Total reading = 2.80 + 0.10 − 0.07 = 2.83cm

A7 Error in r

Given r = 10 ± 1mm

$$\% \text{ error} = \left(\frac{1}{10} \times 100\right) = 10\%$$

Error in T

Given time period measurement

0.52, 0.56, 0.57, 0.54, 0.59

Mean value

$$T_{avg} = \frac{0.52 + 0.56 + 0.57 + 0.54 + 0.59}{5}$$

$$= 0.556 \text{ sec}$$

Absolute error

$$\Delta T = \frac{\text{max deviation from mean}}{T_{avg}} \times 100$$

$$= \frac{0.59 - 0.556}{0.556} \times 100 \approx 3.57\%$$

Error in g:

Using error propagation

$$\frac{\Delta g}{g} = \frac{2\Delta T}{T} + \frac{\Delta R}{R-r} + \frac{\Delta r}{R-r}$$

Given R = 60 ± 1mm, r = 10 ± 1mm

$$\frac{\Delta R}{R-r} = \frac{1}{50} = 2\%, \frac{\Delta r}{R-r} = \frac{1}{50} = 2\%$$

$$\frac{\Delta g}{g} = 2(3.57\%) + 2\% + 2\% = 11.14\%$$

A8 Given $E = \frac{F}{q} = VB$

Using dimensional analysis

$$[E] = [B]\,[V]$$

Since $[B] = MT^{-2}A^{-1}$ and $[V] = LT^{-1}$

$$[E] = MLT^{-3}A^{-1}$$

A9 From the equation

$$C^2 = \frac{1}{\mu_0 \epsilon_0}$$

Dimensional formula

$[C] = [LT^{-1}]$

Squaring both side

$$[L^2T^{-2}] = [\mu_0]^{-1}[\varepsilon_0]^{-1}$$

A10 $\Delta r = \frac{1-a}{1+a}\left[\frac{\Delta a}{1-a} + \frac{\Delta a}{1+a}\right]$

$$\Delta r = \frac{2\Delta a}{(1+a)^2}$$

A11 $N_d = N_0(1 - e^{-\lambda t})$

$1000 = 3000\,(1 - e^{-\lambda t}) \Rightarrow e^{\lambda} = 3/2$

$\Delta N_d = N_0 - e^{-\lambda t}\Delta\lambda$

$40 = 3000 \times 2/3 \times \Delta\lambda$

$\Delta\lambda = 0.02$

A12 Calculation of extension $\Delta\lambda$

$$\Delta\lambda = \frac{F\lambda}{Ay} = \frac{4F\lambda}{\pi d^2 y}$$

$$\Delta\lambda = \frac{4 \times 25 \times 10^8 \times 11}{\pi \times (12 \times 10^{-2})^2 \times 10^{12}}$$

$$\Delta\lambda = 0.3\text{mm}$$

Least count calculation

Given

10 vernier scale Division = 9 main scale Division

$$VSD = \frac{9}{10}MSD$$

Least count = 1MSD – 1VSD

$$= 1 - \frac{9}{10} = \frac{1}{10}MSD = 0.1\text{mm}$$

A13 $[M^0L^0T^0] = [ML^2T^{-1}]$

$[L^2] = [T]$

Energy = $L^{-2} = [MLT^{-2}L]$

Force = $L^{-3} = [MLT^{-2}]$

Power = $L^{-4} = [MLT^{-2}LT^{-1}]$

Linear momentum = $MLT^{-1} = L^{-1}$

A14 Verify option

(A) $\propto + \rho = 2\beta$

Substituting $\rho = \propto - 2$

$\propto + (\propto - 2) = 2\beta$

$2\propto - 2 = 2\beta$

$\propto - 1 = \beta$

(B) $p + q - r = \beta$

Using $q = m + \beta$ and $r = m + p$ we get

$p + (m + \beta) - (m + p) = \beta$

$p + m + \beta - m - p = \beta$

$\beta = \beta$

CHAPTER 2 Motion Along a Straight Line

A1 $v(t) = \frac{dr}{dt} = (3\alpha t^2)\hat{i} + (2\beta t)\hat{j}$

At t = 1s

$$v(1) = \left(3 \times \frac{10}{3} \times 1^2\right)\hat{i} + (2 \times 5 \times 1)\hat{j}$$

$$= (10\hat{i} + 10\hat{j})\text{ m/s}$$

(A) is correct

L = m (r × v)

Position at t = 1s

$$r(1) = \left(\frac{10}{3} \times 1^3\right)\hat{i} + (5 \times 1^2)\hat{j} = \left(\frac{10}{3}\hat{i} + 5\hat{j}\right)\text{m}$$

Cross product

$$r \times v = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 10/3 & 5 & 0 \\ 10 & 10 & 0 \end{vmatrix}$$

$$L = \left(\frac{-5}{3}\hat{k}\right)\text{Nms}$$

(B) is correct.

$\tau = r \times f$

$$r \times f = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 10/3 & 5 & 0 \\ 2 & 1 & 0 \end{vmatrix}$$

$$\tau = \left(\frac{-20}{3}\hat{k}\right)$$

(D) is correct

CHAPTER 3 Vectors

A1 Given vectors

P, Q and R

S is a point on R such that the distance from P to S is b |R|

Since R = Q – P, any point S along R

$\therefore$ s = P + b (Q – P)

or s = P + b Q – b P

s = (1 – b) P + b Q

$\therefore$ Option (A) is correct

A2 Given vectors

$A = a\hat{i}, B = a(\cos \omega t\, \hat{i} + \sin \omega t\, \hat{j})$

With $\omega = \frac{\pi}{6}$

Condition A + B = 3 (A – B)

Equating i – components

$1 + \cos \omega t = 3\,(1 - \cos \omega t)$

$4 \cos \omega t = 2 \Rightarrow \cos \omega t = \frac{1}{2}$

$\omega t = \frac{\pi}{3}, t = \frac{\pi}{3} \div \frac{\pi}{6} = 2\,\text{sec}$

CHAPTER 4 Motion in Two and Three Dimensions

A1 The relative velocity of B w.r.t A is $\perp$ to the line of motion of A.

$$V_B \cos 30° = V_A$$

$$V_B = \frac{V_A}{\cos 30°}$$

Given $V_A = 200\text{m/s}$

$V_B = 200\text{m/s}$

Time taken

$$t_0 = \frac{\text{Relative distance}}{\text{Relative velocity}}$$

$$t_0 = \frac{500}{V_B \sin 30°}$$

$$t_0 = \frac{500}{200 \times \frac{1}{2}} = 5\text{sec}$$

A2 Given

$$T = \frac{2u_0 \sin \theta}{g}, u_0 \cos \theta = V_1$$

Average velocity

$$\frac{u_0T + u_0T + 2u_0 \cos \theta T(\cos \propto + \cos \propto + \cos \propto + \cos \propto)}{T + T}$$

$$= \frac{2u_0 \cos \theta T(1 + \cos \propto + \cos \propto + \cos \propto + \cos \propto)}{2T}$$

$$= V_1 \frac{1 + \cos \propto + \cos \propto + \cos \propto + \cos \propto}{1 + 1}$$

Since $\propto = 4$

Average velocity = $0.8V_1$

A3 $Y = x^2/2$

$V_y = xV_x$

$a_y = xa_x + V_x^2$

$x = 0 \Rightarrow a_y = ax^2 = 1\text{m/s}^2$ for any value of a_x

$a_x = 0 \Rightarrow a_y = V_x^2 = 1$

$a_x = 0$

$$\tan \theta = \frac{V_x}{V_y} = x = 1(x = V_x t = 1)$$

CHAPTER 5 Force and Motion – I

A1 The maximum displacement of the left ball from the left wall of the chamber is 2.25 cm. This means the right ball needs to travel nearly the entire length of the chamber (4m) to collide with the left ball, As a result, the time taken by the right ball to reach the left ball is approximately 1.9 seconds.

A2 For $\theta = 5°$ and $\theta = 10°$

$f = (m_1 + m_2)g \sin \theta$

For $\theta = 15°$

$f = \mu m_2 g \cos \theta$

For $\theta = 20°$

$f = \mu\,(m_1 + m_2)\, g \cos \theta$

A3 $V\frac{dv}{dr} = \omega^2 r$

$$\int_o^v v dv = \omega^2 \int_{R/2}^r r\, dr$$

$$\Rightarrow v = \omega\sqrt{r^2 - \frac{R^2}{4}}$$

$$\int_{R/2}^r \frac{dr}{\sqrt{r^2 - \frac{R^2}{4}}} = \omega \int_o^t dt$$

$$r = \frac{R}{4}(e^{\omega t} + e^{-\omega t})$$

A4 The block moves radially with

$$r(t) = \frac{R}{2}(e^{\omega t} + e^{-\omega t})$$

The centrifugal force is

$$r(t) = \frac{R}{2}(e^{\omega t} + e^{-\omega t})$$

$$\frac{-m\omega^2 R}{2}(e^{\omega t} + e^{-\omega t})\hat{j}$$

The gravitational force is –mgk

Summing these gives the net reaction force

$$f_{reaction} = \frac{m\omega^2 R}{2}(e^{\omega t} + e^{-\omega t})\hat{j} + mgk$$

CHAPTER 6 Force and Motion – II

A1 Ladder about to slip → Friction at the wall is zero ($\mu_1 = 0$), but floor has friction ($\mu_2 \neq 0$)

Force & Torque Equilibrium

$$N_1 = \mu_2 N_2, N_2 = mg$$

Torque balance given $N_2 = mg/(1 + \mu_1 \mu_2)$

If both friction are zero, $N_1 \tan\theta = mg/2$.

∴ (C, D) is correct.

A2 The meter scale is uniform, meaning its center of mass is at 50cm.

The friction force determines when each finger sticks or slips.

Static friction ($\mu_s = 0.40$) holds the scale initially, but as the force increase, one finger slips white the other nods.

The fingers alternate stopping and slipping as the normal force distribution shifts.

Friction balance equation and solving for X_R we get $X_R = 25.6$ cm

CHAPTER 7 Circular Motion

A1 The bead applies a radially inward force on the wire initially (when it's at the top), and as it speeds up while sliding down, the force becomes radially outward later (towards the bottom).

∴ D is correct

A2 Applying energy conservation

$$Mg\,R = \frac{1}{2}mv^2 + \frac{1}{2}MV^2$$

$$V = \sqrt{\frac{2gR(M+m)}{M}} \quad \therefore \text{C is correct}$$

Using momentum conservation

$$MV + MV_x = 0$$

From circular motion at the point of losing contact, the horizontal velocity of m is

$$V_x = V\cos\theta = V \cdot 1 = V$$

$$MV = -mv$$

By substituting V above

$$V = -m\sqrt{\frac{2gR}{M+m}}$$

∴ D is correct.

A3 Finding Radius of curvature R

$$h = \frac{w^2 r^2}{2g}$$

$$R = \frac{r^2 + h^2}{2h} \quad \therefore \text{A is correct}$$

Apparent Depth calculation

$$dapp = \frac{H}{\mu\ \text{water}}$$

$$dapp \approx \frac{3H}{4}\left(1 - \frac{w^2}{g}H\right) \quad \therefore \text{D is correct.}$$

A4 Using energy conservation

$$V_0^2 = g\,(2h + R)$$

Centripetal force analysis

At y weight provides centripetal force.

At x and Z, velocity is highest → centripetal force

Is maximum (not zero)

∴ A and D is correct

CHAPTER 8 Work, Power, and Energy

A1 Work Done by Applied force

$$PQ = \sqrt{OP^2 + OQ^2} = \sqrt{3^2 + 4^2} = 5m$$

$W_{applied} = F \times d = 18 \times 5 = 90$ J

Work Done Against Gravity

$\Delta h = OQ - OP = 4 - 3 = 1m$

$W_{gravity} = mg\Delta h = 1 \times 10 \times 1 = 10J$

Kinetic energy at Q

Using work – energy theorem

Net Work = $W_{applied} - W_{gravity}$

$K{\cdot}E_Q = 90 - 40 = 50J$

Comparing with n × 10

We get n = 5

A2 Finding velocity

$$mv = \frac{dv}{dt}\gamma t$$

Separating variable and integrating

$$\int v dv = \frac{\gamma}{m}\int t dt$$

$$\frac{v^2}{2} = \frac{\gamma}{2m}t^2$$

$$v = \sqrt{\frac{\gamma}{m}t}$$

Since the force is denied from a time-dependent kinetic energy function and has no explicit dependence on velocity, it can be considered conservative in this case.

A3 Path P $(r(t) = \propto t\,\hat{i} + B\,t\hat{j}) \rightarrow$ All conserved

Path Q $(r(t)) = \propto \cos(wt)\hat{i} + B\sin(wt)\hat{j}) \rightarrow$

Angular momentum & Total energy conserved)

Path R $(r(t) = \propto(\cos(wt)\hat{i} + \sin(wt)\hat{j} \rightarrow$

Angular momentum KE, PE, Total energy conserved).

Path S $(r(t) = \propto t^2\hat{i} + B\,t^2\hat{j}) \rightarrow$ Angular momentum & Total energy conserved $\therefore$ A is correct

A4 Given force field

$$F = (y\hat{i} + 2x\hat{j})\propto$$

Where $\propto = -1\text{Nm}^{-1}$

Calculate work done using

$$W = \oint F\cdot dv$$

Since the force is conservative the work

Over a closed path is

$$W = \oint f\cdot dv = O.$$

Total work done

$W = W_{AB} + W_{BC} + W_{CD} + W_{DE} + W_{EF} + W_{FA}$

$W = 0 + (-2) + 0.375 + 0.5 + (-0.5) + 2.375$

$W = 0.75J$

CHAPTER 9 Center of Mass

A1 The graph that most accurately depicts the variation of K·E with time t for this scenario would be (B) as parabolic segments connected by sharp, narrow dips at the moments of collision.

A2 $J = mV_0$

$V_0 = \frac{J}{m} = \frac{1}{0.4} = 2.5$ m/s

$v = V_0 e^{-t/\tau}$

$\int dx = V_0 \int_0^{\tau} e^{\frac{-t}{\tau}} dt$

$\Delta x = V_0\tau[1 - e^{-t/\tau}]$

at $t = \tau$sec

$\Delta x = 6.30$m

A3 Given

$H = \frac{2V_0^2}{4g}$

$\Rightarrow V_0^2 = \frac{120}{4g}$

Using energy conversion

$$V^2 = 2V_0^2$$

height

$$H = \left(\frac{V_0 \sin 30°}{2g}\right)^2 = \frac{V_0^2}{8g} = \frac{30}{1} = 30\text{m}$$

CHAPTER 10 Rigid Body Dynamics – I

A1 Using the torque equation

$$\tau = I\propto$$

Given that $\tau = 3FR\sin 30°$ and $I = \frac{1}{2}MR^2$

$$3FR \times \frac{1}{2} = \frac{1}{2}MR^2 \propto$$

$$\propto = 2\text{rad/s}^2$$

Using the Kinetic equation

$$\omega = \omega_0 + \propto t$$

For initial velocity $\omega_0 = 0$

$$\omega = 2\text{rad/s}$$

A2 Since the net torque about the center of rotation is zero, we apply the conservation of angular momentum

$L_i = L_f$

$$O = I\omega + 2mv\left(\frac{r}{2}\right)$$

Comparing magnitudes

$0.45 \times 0.5^2 \times \omega = 0.05 \times 9 \times 0.5 \times 2 = \omega$

$\omega = 4$

A3 The kinetic energy of a purely rolling disc with center of mass velocity is

$K \cdot E = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

Since $I = \frac{1}{2}mR^2$ and $\omega\frac{V}{R}$

$K \cdot E = \frac{1}{2}mv^2 + \frac{1}{2}\left(\frac{1}{2}mR^2\right)\left(\frac{V^2}{R^2}\right)$

$K \cdot E = \frac{1}{2}mv^2 + \frac{1}{4}mv^2 = \frac{3}{4}mv^2$

Applying energy conservation

$\frac{3}{4}m(3)^2 + mg(30) = \frac{3}{4}mv^2 + mg(27)$

$\frac{27}{4}m + 30mg = \frac{3}{4}mv^2 + 27mg$

$\frac{3}{4}mv^2 = 3mg$

$V^2 = 7$ m/s

A4 Using the conservation of angular momentum

$$\frac{MR^2}{9}\omega + \frac{mR^2}{8}\omega + \frac{8m(9R)}{25}\omega = \frac{8mx^2}{9}\omega$$

Solving for x

$$X = \frac{4R}{5}$$

A5 $I_A = \int \rho \times r^2 r^2 dr = \frac{2}{3} r^4$

$I_B \propto \int r^5 dr$

$\frac{I_B}{I_A} = \frac{6}{10}$

Comparing with $\frac{I_B}{I_A} = \frac{n}{10}$

n is 6

A6 On the basis of given data it is not possible for the rod to stay at rest.

A7 To solve this question, we first consider the masses and radii of the given disc Next, we determine the angular speed and calculate the velocity of the center of the lower disc. Then, we find the angular velocity of the C.O.M and finally compute the angular momentum

A8 For a regular polygon with n sides, the angle subtended by each side at the center is $\frac{2\pi}{n}$. The height of the C.M From the ground increases by

$$\Delta = h\left(1 - \cos\frac{\pi}{n}\right)$$

Correct match is B

A9 No horizontal force on the rod → c.m falls vertically. Net torque about point B: $\tau = mgL\sin\theta$

Midpoint displacement: $\frac{L}{2} - \frac{L}{2}\cos\theta$

A10 Net torque

$\tau_{net} = R\cos\theta\,(2F - mg)$

Since θ increases, τ_{net} decreases

Applying force creates friction at the bottom, generating a nonzero torque about point Q.

A11 $\alpha = t\hat{i} + \hat{j}(m/s^2)$

$V = \int a dt = \frac{t^2}{2}\hat{i} + \hat{j}(m/s)$

$R = \int V dt = \frac{t^3}{6}\hat{i} + \frac{t^2}{2}\hat{j}(m)$

Torque

$t = r \times F$

$\tau = \left(\frac{t^3}{6}\hat{i} + \frac{t^2}{2}\hat{j}\right) \times (t\hat{i} + \hat{j})$

$= \left(\frac{t^3}{6}\hat{i} \times t\hat{i}\right) + \left(\frac{t^3}{6}\hat{i} \times \hat{j}\right) + \left(\frac{t^2}{2}\hat{j} \times t\hat{i}\right) + \left(\frac{t^2}{2}\hat{j} \times \hat{j}\right)$

Since $\hat{i} \times \hat{i} = 0$ and $\hat{j} \times \hat{j} = 0$

$\tau = \left(\frac{t^3}{6} \times \hat{i} \times \hat{j}\right) + \left(\frac{t^2}{2}\ t \times \hat{j} \times \hat{i}\right)$

$= \left(\frac{t^3}{6}\hat{k}\right) - \left(\frac{t^3}{2}\hat{k}\right)$

$= \left(\frac{t^3}{6} - \frac{t^3}{2}\right)\hat{k}$

$= -\frac{t^3}{3}\hat{k}$

This $\tau = -\frac{t^3}{3}\hat{k}$ (Nm)

A12 $W = \sqrt{\frac{3g}{2L}}$

$\omega^2 \frac{L}{2} = \frac{3g}{4}$

$Mg\frac{1}{2}\sin 60 = \frac{1}{3}ML^2 \propto$

$\propto = \frac{3g}{2L}\sin 60°$

$a_{cm}tang = \propto \frac{L}{2} = \frac{3g}{4}\sin 60°$

$Mg - N = (a_{cm}rudral\cos 60° + a_{cmtang}\sin 60°)$

$= Mx\left(\frac{3g}{8} + \frac{9g}{16}\right)$

$N = \frac{Mg}{16}$

A13 $mvx = \left(\frac{ML^2}{3} + mx^2\right)\omega$

$\omega = \frac{3V_x}{L^2 + 3x^2}$

For ω to be maximum

$\frac{d\omega}{dx} = 0$, this given $x = \frac{L}{\sqrt{3}}$ and $\omega_{max} = \frac{\sqrt{3}v}{2L}$

CHAPTER 11 Rigid Body Dynamics – II

A1 The ring has rotational and translational Kinetic energy Rotation about its center

$KE_{rot} = \frac{1}{2}MR^2\omega_0^2$

Translational of Center of mass

$K \cdot E_{trans} = \frac{1}{2}M\,(R - r)^2\omega_0^2$

Total energy

$K \cdot E = M\omega_0^2(R^2 - rR)$

A2 Friction provides the required centripetal force.

Equating forces

$M\omega_0^2(R - r) = \mu Mg$

Solving for ω_0

$$\omega_0 = \sqrt{\frac{g}{\mu(R-r)}}$$

A3 $\sin^2\theta = \dfrac{1}{1+\dfrac{hgt^2I}{MR^2}}$

Given Values

h = 10/3 = 10/2

h = 0.75 m

A4 At the verge of toppling $N_1 = 0$

$mg\sin\theta \cdot h = mg\cos\theta \cdot r$

Since $\cos\theta = \dfrac{h}{R}$, we substitute

$mg\sin\theta \cdot h = mg\dfrac{h}{R} \cdot r$

Canceling mg and h

$\sin\theta = \dfrac{r}{R}$

A5 $V - wR = 0$

$V_p = v + Wr$

$= v + \dfrac{V}{R}r$

$= v\left(1+\dfrac{r}{R}\right)$

So, $\Delta xp = 50\left(1+\dfrac{5}{10}\right) = 75\text{cm}$

A6 Torque experienced by circular

100p = MXB

Where, M is magnetic moment and B is magnetic field.

$\tau = i\,\pi R^2 NB_0$

$\tau_{dt} = dL = i\,\pi R^2 NB_0 dt$

$\therefore$ (idt = Q)

$= Q\pi R^2\, NB_0$

CHAPTER 12 Elasticity

A1 Material with a sleeper slope in this incorrect plot means it has a lower Young's modulus. E.

Material P reaches a higher stress value before failure → Higher tensile strength.

Material P has more strain before fracture. More ductile.

Material Q has more strain before breaking. More brittle.

A2 Force Balance.

Vertical: $T_c \sin 30° + T_s \sin 60° = 100$

$\Rightarrow T_c + \sqrt{3}\,T_s = 200$

Horizontal: $T_c \cos 30° = T_s \cos 60°$

$\Rightarrow \sqrt{3}\,T_c = T_s$

$\Rightarrow T_c = \dfrac{T_s}{\sqrt{3}}$

Elongation formula.

$\lambda\Delta = \dfrac{TL}{AY}$

Ratio $\dfrac{\Delta\lambda_c}{\Delta\lambda_s} = \dfrac{T_c \times 3}{T_s \times 1} \times \dfrac{2}{1}$

$\dfrac{T_c}{T_s} \times 6 = \dfrac{1}{\sqrt{3}} \times 6 = 2$

A3 Pressure at 5 km depth.

$P = \rho gh = (10^3)\,(10)\,(5000) = 5 \times 10^7 P_a$

Bulk Modulus Formula.

$\Delta V = \dfrac{VP}{B} = \dfrac{(1^3)(5\times10^7)}{70\times10^9} = 7.14 \times 10^{-4}\ m^3$

Change in Edge length ΔL

$\dfrac{\Delta V}{V} = 3\dfrac{\Delta V}{L}$

$\Delta L = \dfrac{7.14\times10^{-4}}{3} = 0.238\text{mm}$

CHAPTER 13 Gravitation

A1 Inside the planet.

Gravitational acceleration.

$g = g_s\dfrac{r}{R} = \dfrac{4\pi G\rho r}{3}$

Force required to keep the wire at rest.

F = weight of the wire.

$F = \int_0^{4R/5} \lambda g dr$

$= \lambda \int_0^{4R/5} \dfrac{4G\pi\rho r}{3} dr$

$= \lambda \dfrac{4G\pi\rho r}{3} \times \dfrac{(4R/5)^2}{2}$

Given

$\rho = \dfrac{3Me}{4\neq R^3}$ and $R = \dfrac{10Re}{2}$

Substituting value.

F = 108N

A2 At a height R from the surface of the planet, the acceleration due to gravity is $\dfrac{1}{4}$ of its surface value.

Using energy conservation.

$\dfrac{GM_m}{R} - \dfrac{1}{2}mv^2 = \dfrac{GM_m}{2R}$

Escape velocity condition.

$\dfrac{GM_m}{R} - \dfrac{1}{2}mv_{esc}^2 = 0$

Solving for $v_{esc} = v\sqrt{2}$

A3 For m closer to M.

$$\frac{GM_m}{\lambda^2} - \frac{Gm}{\lambda^2} = ma$$

$$a = \frac{GM_m}{9\lambda^2} _____ 1$$

For the other m.

$$\frac{Gm}{\lambda^2} + \frac{GM_m}{\lambda^2} = ma$$

$$a = \frac{GM_m}{16\lambda^2} _____ 2$$

From both equation solving for K.

K = 7

A4 $\frac{1}{2}mv_{es}^2 - \frac{GM_m}{R} - \frac{G(3\times10^5 m)\times m}{2.5\times10^4 R} = 0$

Hence $V_{es} = \sqrt{13}\ V_e = 40.3$ Km/s

The closest answer choice is $V_s \approx 42$ Km/s

A5 Using kepler's laws and orbital mechanics.

Velocity ratio $V \propto \frac{1}{\sqrt{R}} \rightarrow \frac{V_1}{V_2} = 2$

Angular momentum $L \propto mvR \rightarrow \frac{L_1}{L_2} = 1$

Kinetic energy $k \propto mv^2 \rightarrow \frac{K_1}{K_2} = 8$

Time period $T \propto R^{3/2} \rightarrow \frac{T_1}{T_2} = 1/8.$

A6 The density ρ is given by.

$$\rho = \frac{1}{4\pi G}\frac{d}{dr}(gr^2)$$

Since $\frac{mv^2}{r} = mg$, we get

$$k = \frac{1}{2}mv^2 = \frac{1}{2}mgr$$

Substituting into the density equation.

$$\rho = \frac{1}{4\pi G}\cdot\frac{d}{dr}\left(\frac{2kr}{m}\right)$$

$$\rho = \frac{K}{2\pi Gmr}$$

CHAPTER 14 Fluids

A1 $A_1V_1 = A_2V_2$

$\pi \times (20)^2 \times 5 = \pi\,(1)^1 \times V_2$

$V_2 = 2m/s^2$

A2 $\frac{1}{2}\rho_a V_a^2 = \frac{1}{2}\rho_\ell V_\ell^2$

$$V_\ell \propto \sqrt{\frac{\rho_a}{\rho_\ell}}$$

A3 At point P, Q and R, no horizontal velocity is given to the falling water so the distance d remain unchanged. At point S, since it is in free fall the effective acceleration $a_{eff} = 0$, meaning the liquid will no fall relative to the lift.

A4 Using the hydrostatic equilibrium, equation and the gravitational field inside a uniform sphere.

$$P(r) = \frac{2}{3}\pi G\rho^2(R^2 - r^2)$$

At different points.

$$P(o) = \frac{2}{3}\pi G\rho^2R^2$$

$$P(3R/4) = 14/24\pi G\rho^2R^2$$

$$P(2R/3) = \frac{10}{15}\pi G\rho^2R^2$$

$$P(3R/5) = \frac{16}{25}\pi G\rho^2R^2$$

$$P(2R/5) = \frac{21}{30}\pi G\rho^2R^2$$

$$P(R/2) = \frac{20}{30}\pi G\rho^2R^2$$

$$P(R/3) = \frac{27}{40}\pi G\rho^2R^2$$

A5 Use terminal velocity formula.

$$V_T = \frac{2r^2g(\rho - \sigma)}{g\eta}$$

For P and Q $\frac{V_P}{V_Q} = \frac{r_P^2(\rho_P - \sigma)}{r_Q^2(\rho_Q - \sigma)}$

A6 a) The resistive force $F_r \propto V$, since at low speed, the number of collision per unit time is proportional to V.

b) The pressure difference $\Delta P \propto uv$, as it depends on both the molecular speed u and the plate speed V.

d) Eventually F balance F_r leading to terminal velocity.

A7 a) The resistive force $F = \eta\frac{U_0}{h}A$ is inversely proportional to h.

c) The shear stress at the floor $\tau = \eta\frac{U_0}{h}$ increases with μ_0 since shear stress depends directly on velocity.

d) Since $\tau = \eta\frac{U_0}{h}$ the shear stress on the plate varies linearly with viscosity h.

A8 $800 \times 0.1 + 100 \times x = 1000 \times (0.58 - x)$

$2000x = 500$

$X = 0.25m$

$h_1 = 0.35$ m, $h_2 = 0.33$m

ratio $= \frac{h_1}{h_2} = \frac{35}{33}$

A9 Using continuity.

$$V_a = \frac{Vt}{3}$$

Applying Bernoulli's equation.

$$\rho_0 - p = \frac{1}{2}\rho V_a^2 = \frac{\rho v_t^2}{18}$$

Given equation.

$$P_0 - p = \frac{2}{N}\rho V_t^2$$

Comparing

$$\frac{2}{N} = \frac{1}{18} \Rightarrow N = 9$$

A10 $(480 - N)\rho_1 = 480\,\rho_2$

$$\frac{480 - N}{480} = \frac{\rho_1}{\rho_2}$$

$$1 - \frac{N}{480} = e^{-\left(\frac{150-100}{6000}\right)}$$

$$1 - \frac{N}{480} = 1 - \frac{5}{600}$$

$N = 4$

CHAPTER 15 Oscillations

A1 For Ist oscillation.

$$\frac{1}{2} mw_1^2 a^2 = E_1$$

$P = mv = mw_1 a = b$

Hence $\frac{a}{b} = \frac{1}{mw_1}$____a

For IInd oscillation

$$\frac{1}{2} mw_2^2 R^2 = E_2$$

and $mw_2 = 1$ _____b

$$\left(\frac{a}{b}\right) = \frac{w_2}{w_1} = n^2$$

$$\frac{E_1}{w_1^2 a^2} = \frac{E_2}{w_2^2 R^2} \Rightarrow \frac{E_1}{W_1} = \frac{E_2}{W_2}$$

A2

Case-I	Case-II
Angular frequency. $W' = \sqrt{\frac{K}{M+m}}$	$W' = \sqrt{\frac{K}{M+m}}$
Amplitude. $A' = A\frac{m}{M+m}$	remain the same.
Energy. $E' = \frac{1}{2} KA^2 \frac{m}{M+m}$	remain the same.
Velocity. $V' = V\frac{m}{M+m}$	$V' = A\sqrt{\frac{K}{M+m}}$

A3 $V = \frac{Kr^2}{2}$

$$F = \frac{-dv}{dr} = -kr$$

$$\therefore \frac{mv^2}{r} = kr$$

$$V = \sqrt{\frac{K}{M}R}$$

Angular momentum.

$L = mvr$

$$L = m\sqrt{\frac{K}{m}R^2}$$

$$= \sqrt{mk}\,R^2$$

A4 For the collision.

Using the center of mass equation.

$1 \times 2 = 1 \times 4 + 2 \times V$

Using the coefficient of restitution equation.

$2 = -u + v$

Solving, we get.

$$u = \frac{-2}{3}\text{m/s}, V = \frac{4}{3}\text{m/s}$$

Time taken for the block to reach the unpstretched position of the spring for the first time.

$$t = \frac{\pi m}{K}\text{ sec}$$

Distance between blocks.

$$d = 2 \times \frac{2.09}{3}\pi \approx 2.09\text{m}$$

A5 At equilibrium.

$$K\ell = \frac{C}{\ell^4}$$

Effective stiffness. Considering dipole force contribution.

$$K_{eff} = K + 4\frac{K}{\ell}$$

Oscillation frequency.

$$\omega = \sqrt{\frac{K_{eff}}{m}} = \sqrt{\frac{(1 + 4/\ell)K}{m}}$$

Comparing with $\omega = \sqrt{\frac{\delta K}{m}}$ we get

$\delta = 3.14$.

CHAPTER 16 Waves – I

A1 Velocities at the Midpoint.

At the midpoint, the tension is the same for both pulses.

Since wave speed depends only on tension, both pulse have the same speed at the midpoint.

Velocity Independence.

The velocity of a wave depends only on the medium's properties (tension and mass per unit length μ) not frequency or wavelengths.

A2 Calculating the relative tensions.

$$T_1 \propto \left(\frac{2L_0}{1}\right)^2 = 4L_0^2$$

$$T_2 \propto \left(\frac{2\times 3/2L_0}{3}\right)^2 = \left(\frac{3L_0}{3}\right)^2 = (L_0)^2$$

$$T_3 \propto \left(\frac{2\times 5/2L_0}{5}\right)^2 = \left(\frac{3L_0}{3}\right)^2 = (L_0)^2$$

$$T_4 \propto \left(\frac{2\times 7/2L_0}{14}\right)^2 = \left(\frac{7L_0}{14}\right)^2 = \left(\frac{L_0}{2}\right)^2 = \frac{L_0^2}{4}$$

the tensions are proportional to.

$$T_1 : T_2 : T_3 : T_4 = 4 : 1 : 1 : \frac{1}{4}$$

Expressing in terms of T_0 we get.

$$T_1 = T_0, T_2 = \frac{T_0}{4}, T_3 = \frac{T_0}{3}, T_4 = \frac{T_0}{16}$$

A3 Using the frequency formula $f_n = \frac{n}{2L} = \sqrt{\frac{T}{\propto}}$ and equaling for all strings.

String 1: $T_1 = T_0$

String 2: $T_2 = 2T_0$

String 3: $T_3 = 3T_0$

String 4: $T_4 = 4T_0$

∴ A is correct.

CHAPTER 17 Waves – II

A1 The calculation for 1 RT for the gasses given in option A, B, C and D yield the following values.

A: 0.459m, B: 0.363m, C: 0.340m, D: 0.348m

Since λ = (0.350 ± 0.005)m.

The correct option is D.

A2 Taking y(t) = A f(x) g(t) and applying the given conditions.

Boundary conditions

x = 3m is an antinode

x = 0 is a node

Possible frequencies.

Only odd multiples of the fundamental frequency are allowed.

Fundamental frequency.

$$V_{fundamental} = \frac{V}{4\times 3} = \frac{V}{12}$$

Given V = 300m/s

$$V_{fundamental} = \frac{300}{12} = 25 \text{ Hz}$$

A3 $V = \left(\frac{V - V_D}{V}\right) \cos \propto$

$V_Q = 121 - 118 = 3\text{Hz}$

Since

$V_P + V_R = 2V_Q$

Now for V (between P and Q).

$$V = \left(\frac{V + V_D\cos\theta}{V}\right)^3$$

For D : $dv = \frac{av}{dv} \sin\theta$

Since sin θ = 1 at Q (maximum).

The rate of change in beat frequency is maximum at Q.

A4 Frequency received by the approaching car.

$$f_1 = f_0\left(\frac{330+V}{330}\right)$$

Frequency received by the source again.

$$f_2 = f_1\left(\frac{330}{330-V}\right)$$

Beat frequency calculation.

$f_B = f_2 - f_0 = 6\text{Hz}$

A5 Using the Doppler Effect formula.

Frequency heard from the man in front.

$f_1' \approx 1434.35$ Hz

Frequency heard from the man behind

$f_2' \approx 1438.72$ Hz

Beat frequency

$f_B = |f_2' - f_1'| = 5\text{Hz}$

A6 λ/2 = 83.9 – 50.7 = 33.2

λ = 66·4cm

$$V = n\lambda = \frac{500\times 66.4}{100} = 332\text{m/s}$$

e = – 0.9cm

A7 $f_1 = 120 \times \left(\frac{330+10\cos 53°}{330-30\cos 37°}\right)$

$$f_2 = 120 \times \left(\frac{330+10}{330}\right)$$

$f_B = f_1 - f_2 = 8.128$ Hz ≈ 8.13 Hz

A8 $f_0 = f \times \frac{320}{320-2} = f \times \frac{320}{318}$

$\Delta f = \frac{2f_0}{318}$ .....(1)

Since

$$f_0 = \frac{(2n+1)V}{4L}$$

$\Delta L = \frac{2L}{318}$

$\Delta L = \frac{100 \times L}{318} = 200 \times 0.62983 \approx 0.63$

CHAPTER 18 Temperature, Zeroth Law of Thermodynamics and Thermal Expansion

A1 Heat given by the lower compartment

$Q_1 = \frac{2}{3} R (700 - T)$

Heat obtained by the upper compartment

$Q_2 = \frac{2}{7} R(T - 400)$

Equating

$3(700 - T) = 7(T - 400)$

Solving

$2100 - 3T = 7T - 2800$

$4900 = 10T$

$T = 490K$

A2 Heat given by the lower compartment

$Q_1 = \frac{2}{5} R (700 - T)$

Heat obtained by the upper compartment

$Q_2 = \frac{2}{7} R (T - 400)$

Equating

$5(700 - T) = 7(T - 400)$

Solving

$3000 - 5T = 7T - 2800$

$6300 = 12T \Rightarrow T = 525K$

Work done by lower gas

$W_1 = nR\Delta T = -350R$

Work done by upper gas

$W_2 = nR\Delta T = +250R$

Net work done

$W_{net} = -100R$

A3 Given data

$\frac{PQ}{RS} = \frac{R_1}{R_2}$

Temperature equation

$T \sim 10 = \frac{400 - T}{2}$

Solving

$T = 140°C$

Temperature as a function of x

$T(x) = 10 + 130x$

Temperature difference

$\Delta T(x) = 130x$

Small element extension

$d\lambda = \propto \Delta T(x)dx = 130\propto x\, dx$

Net extension

$\Delta\lambda = 130\propto \int_0^1 x\, dx$

$= 130 \times 1.2 \times 10^{-5} \times \frac{1}{2}$

$\Delta\lambda = 0.78mm$

A4 $\Delta U = U_f - U_i$

$= S \times 4\pi R^2 \left(\frac{K^{1/3} - 1}{1}\right)$

Given

$\frac{\Delta U}{4\pi R^2 S} = \frac{1}{3}(K^{1/3} - 1) = 101$

Solving for K

$K^{1/3} \approx 104$

$K \approx 10^6$

A5 $h = \frac{2\sigma \cos\theta}{r\rho g_{eff}}$ (ρ is density of water)

A6 $S(2R) = \left(\frac{\rho gh}{2}\right) h\,(2R)$

$h = 3.75 \times 10^{-3}mm$

CHAPTER 19 Heat – Measurement and Transfer

A1 $\left[\frac{dQ}{dt}\right]_A = 10^4 \times \left[\frac{dQ}{dt}\right]_B$

$[400]^2\, T_A^4 = 10^4\left[R^2 T_B^4\right]$

$2T_A = T_B$ and $\frac{\lambda_A}{\lambda_B} = \frac{T_B}{T_A} = 2$

A2 $(P_{heater} - P_{cooler}) \times t = mS\Delta T$

$(3 \times 10^3 - P) \times 3 \times 3600 = 120 \times 4.2 \times 10^3 \times 20$

$P = 2067$

A3 Using the Stefan–Boltzmann law

$P = e\sigma AT^4$

Power at 487°c

$P_1 = e\,\sigma\, A(760)^4$ ————————1

Given

$\log\frac{P_1}{P_0} = 1 \Rightarrow \frac{P_1}{P_0} = 10$

Power at 2767°c

$P_2 = e\,\sigma\, A\,(3040)^4$

Ratio of Powers

$\log\left(\frac{P_1}{P_0}\right) = \log\left(\frac{(3040)^2}{(3040)^4}\right)$

$= \log(4^4) = \log(256)$

$= 4\log 2 = 4 \times 0.301 = 1.204$

$= 9$

A4 Given monoatomic gas $Y = \frac{5}{3}$

Using the first law of Thermodynamics

$H = W + \Delta U$

work done $W = 700J$

Change in internal energy

$$\Delta U = \frac{-900}{8} = -112.5 \text{ J}$$

Enthalpy change

$H = 700 - 112.5 = 588J$

A5 The heat radiated by the body remains unchanged despite a change in room temperature.

The energy lost due to radiation depends on the surface area of the body

According to Wien's law

$\lambda\, m\, T = \text{Constant}.$

A6 In the steady state, the heat current in both material remains the same

$$K_1 A \frac{(300-200)}{L} = K_2 A \frac{(200-100)}{L}$$

Simplifying

$K_1 \times 100 = K_2 \times 100$

$$\frac{K_1}{K_2} = 4$$

A7 At equilibrium

$$C\frac{dT}{dt} = 3P$$

or

$$\frac{dT}{dt} = \frac{3P}{C}$$

Given

$$\frac{dT}{dt} = \beta(T_0 - 4T)$$

Thus the heat capacity is

$$C = \frac{3P}{3\beta(T_0 - T)}$$

From given equation

$$\frac{T_0 - 4T}{T_0 - T} = \beta t$$

$$\text{So } \frac{(T_0 - 4T)}{T_0 - T} = \beta t$$

$$\text{Thus } C = \frac{4P}{4\beta(T_0 - T)}$$

A8 From the given equation

5(s) (50) + 5L = C (30) ————————1

80 (s) (20) = C (30) ————————2

Divided equation 1 by 2

$$\frac{5(s)(50) + 5L}{80(s)(20)} = \frac{C(30)}{C(30)}$$

Solving for L

$$L = \frac{270C}{S}$$

$L = 270.00$

A9 Radiated power

Using Stefan-Boltzmann law

$P = A\,\sigma\,T^4$

$P = (64 \times 10^{-6}) \times (5.67 \times 10^{-8}) \times (2500)^4$

≈ 140 w

Power Entering the Eye

$$\frac{140}{4\pi(100)^2}$$

$$= \frac{140}{4 \times 3.14 \times 10^4} \approx 3.15 \times 10^{-8} \text{w}$$

Wavelength Calculation

From Wien's law

$$\lambda = \frac{2.93 \times 10^{-6} \times 2500}{1160}$$

$\lambda = 1740\text{nm}$

Number of Photon

$$n = \frac{1240 \times 3.15 \times 10^{-8}}{1740 \times 1.6 \times 10^{-19}}$$

$n \approx 2.75 \times 10^{11}$

A10 At steady state, the energy received per unit time is equal to the energy lost per unit time.

$$700 \times 0.05 = \frac{msdT}{dt}$$

Rearranging

$$\frac{dT}{dt} = -b\Delta T$$

Solving for ΔT

$\Delta T = 8.33K$

CHAPTER 20 The Kinetic Theory of Gases

A1 $$(KE_{qr})_{mix/mol} = \frac{\frac{5}{1}(1)RT + \frac{3}{2}(1)RT}{2}$$

$$V_{sound} = \sqrt{\frac{\gamma RT}{M}}$$

Here

$$\gamma_{mix} = \frac{\left(1\times\frac{5}{2}\right)+\left(1\times\frac{7}{2}\right)}{\left(1\times\frac{3}{2}\right)+\left(1\times\frac{5}{2}\right)} = \frac{3}{2}$$

$$\frac{V_{mix}}{V_{He}} = \sqrt{\frac{\gamma_{mix}}{\gamma_{He}}} \times \sqrt{\frac{M_{He}}{M_{mix}}}$$

$$= \sqrt{\frac{6}{5}}$$

A2 The collision rule of the particle with the piston is $\frac{V}{2L}$

After collision the particle speed increases by V + 2V

For a piston moving in word by dℓ the particle speed charge

$$dv = \frac{2V}{L} vd\ell$$

$$K = \frac{1}{2} mv^2$$

Differentiating $\frac{dK}{K} = -\frac{2d\ell}{\ell}$

Integrating $K\ell^2$ = constant

Hence $K_f = 4K_i$

CHAPTER 21 The First Law of Thermodynamics

A1 Calculate Q_{ib}

For path i_b

$\Delta U = U_b - U_i = 200J - 100J = 100J$

$Q_{ib} = \Delta U + W_{ib} = 100J + 50J + 150J$

Calculate Q_{bf}

For path b_f

$\Delta U = U_f - U_b = U_f - 200J$

Full path i_{af}

$Qi_{af} = \Delta U + \omega_{af}$

$500J = (U_f - 100J) + 200J$

$U_f = 400J$

For path b_f

$\Delta U = 400J - 200J = 200J$

$Q_{bf} = \Delta U + \omega_{bf}$

$= 200J + 100J = 300J$

Ratio $\frac{Q_{bf}}{Q_{ib}} = \frac{300J}{150J} = 2$

A2 Pressure $P = P_1 + \frac{Kx}{A}$

Work done: $W = P_1 (V_2 - V_1) + \frac{Kx}{2} (V_2 - V_1)$

Internal Energy Change $\Delta U = \frac{3}{2} (P_2V_2 - P_1V_1)$

Heat Supplied $Q = W + \Delta U$

Case I

$\Delta U = 3P_1V_1, W = \frac{5}{4} P_1V_1$

$Q = \frac{17}{4} P_1V_1, U_{spring} = \frac{1}{4} P_1V_1$

Case II

$\Delta U = \frac{9}{2} P_1V_1, W = \frac{7}{3} P_1V_1$

$Q = \frac{41}{6} P_1V_1, U_{spring} = \frac{1}{3} P_1V_1$

A3 The process must occur at constant pressure (isobaric) (B)

A4 The correct combination corresponds to an isochoric process. (A)

A5 The process must be adiabatic, as applied in Laplace's correction to Newton's law for the speed of sound in air (D)

A6 Process II is an isothermal expansion process IV is an isothermal compression

In an isobaric process, volume is directly promotional to temperature.

A7 $\frac{T_f}{T_i} = \left(\frac{V_i}{V_f}\right)\gamma - 1 = \left(\frac{1}{8}\right) 2/3$

$T_f = \frac{T_i}{4} = \frac{100}{4} = 25k$

$\Delta U = nC_v (T_f - T_i)$

= 900 Joule.

A8 Process 1 is an adiabatic process so Q = 0

Process 2 is an isobaric process, thus

$W = P.\Delta V = 6 P_0V_0$

Process 3 is an isochoric process

So W = 0

Process 4 is an isothermal Process

A9 $\frac{5+1}{\gamma_m - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$

$$\frac{6}{\gamma_m - 1} = \frac{5}{\frac{5}{3} - 1} + \frac{1}{\frac{7}{5} - 1} = 10$$

$\gamma_m = 1.6$

$$P_0 V_0^{\gamma m} = P\left(\frac{V_0}{4}\right)^{\gamma m} \Rightarrow P = P_0 \times 2^{3.2} = 9.2P_0$$

$$\frac{W = P_0V_0 - (9.2\, P_0)\times V_0/4}{0.6}$$

$$= \frac{-1.3P_0V_0}{0.6}$$

$= 13/6\ .6RT_0$

$= 13\ RT_0$.

$T_0V_0^{\gamma_{m-1}} = 7V^{7m-1}$

$\Rightarrow T = T_0\left(\frac{V_0}{V}\right)\gamma^{m-1}$

$= T_0(4)^{0.6} = 2.3\,T_0$

Avg K · E of the gas mixture $5 \times \frac{3}{2}\ RT + 1 \times \frac{5}{2}\ RT$

$= 10\ RT$

$= 23\ RT_0$

A10 $W_{1\to2\to3} = P_0V_0 = \frac{1}{3}\ RT_0$

$\Delta U_{1\to2\to3} = n\ C_v(T_f - T_i)$

$= 1 \times \frac{3}{2}\ (3P_0\ (3P_0V_0 - P_0V_0\ ) = RT_0$

$\Delta Q_{1\to2\to3} = \Delta U + W = \frac{4}{3}\ RT_0$

$\Delta Q_{1\to2} = nCp\Delta T = \frac{5}{2}\ (2P_0V_0 - P_0V_0) = \frac{5}{6}\ RT_0$

A11 $W_{1\to2\to3} = W_{1\to2} + W_{2\to3}$

$\Delta U_{1\to2\to3} = \Delta U_{1\to2} + \Delta U_{2\to3}$

$= 0 + 1 \times \frac{3R}{2} \times \frac{2T_0}{2} = RT_0$

$\Delta Q_{1\to2} = \int Tdx = O + RT\ln 2$

$\Delta Q_{2\to3} = \int Tdx = RT_0$

$\Delta Q_{1\to2\to3} = \frac{1}{2}\ RT_0\ (3 + \ln 2)$

A12 The ratio of work done in isothermal and adiabatic expansion is given by

$\frac{W_{iso}}{W_{adia}} = f\ln 2$

for helium gas Y = 5/3

Isothermal work $W_{iso} = 2RJ\ln_2$

Adiabatic work $W_{adia} \approx 1.13\ RT$

$f = \frac{2}{1.13} \approx 1.77$

A13 NONE

A14 In adiabatic process

$Q2\ \frac{dp}{p} = Y\frac{dv}{V}$

$dp = -p\ (4R\alpha)\ \frac{Y}{V}$

Work done in the process

$W = \int dP_{avg}\ dv = -\frac{dp \cdot dv}{2}$

$= \frac{P_0(4R\alpha)(4R\alpha)}{2V_0} = \frac{4\pi P_0R\alpha^2}{30} \times 41$

$= (2.05)\ (4\pi p_0R\alpha^2)$

Hence $\chi = 2.05$

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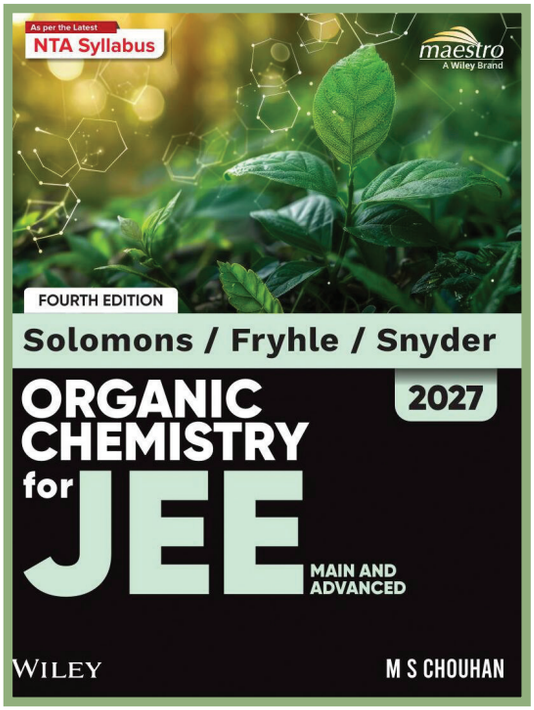

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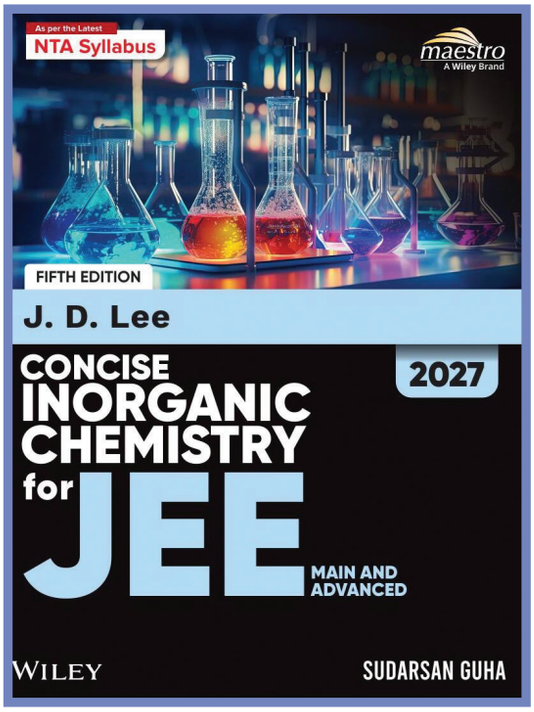

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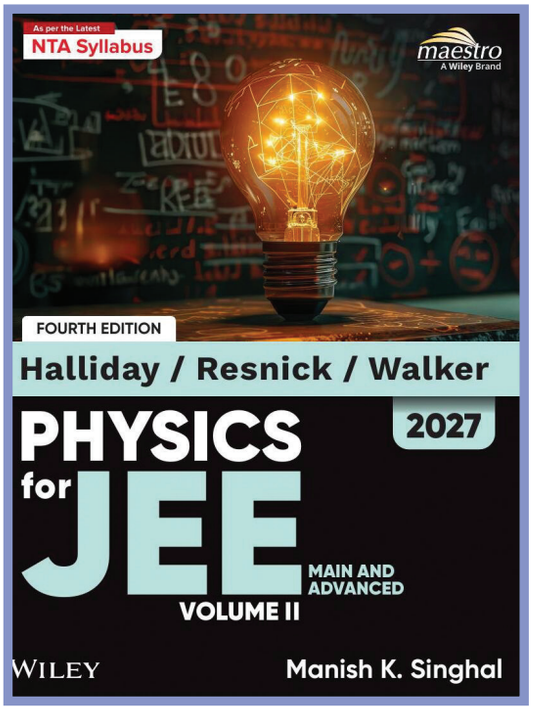

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