JEE Advanced / Multidisciplinary PYQs with Answers and Solutions

ANSWERS WITH EXPLANATION

CHAPTER 1 Units and Measurement

A1 Least count $= 1 - \frac{0.1 \times 9}{10} = 0.01\text{cm}$

Zero error = –0.1 + 0.06 = – 0.04cm
Final reading = 3.1 + (0.01 × 1) = 3.11cm
Correct measurement = 3.11 + 0.04
= 3.15cm

A2 Using dimensional analysis for

$$B = [e]^{\alpha}[m_e]^{\beta}[h]^{\gamma}[k]^{\delta}$$

Equation from dimensions
$\beta + \gamma + \delta = 1$ (Mass M)
$2\gamma + 3\delta = 0$ (Length L)
$\alpha - \gamma - 4\delta = -2$ (Time T)
$\alpha - 2\delta = -1$ (Current A)
Solving for exponents

$$\delta = \frac{2}{3}, \gamma = -1, \beta = \frac{4}{3}, \alpha = \frac{1}{3}$$

Summering up $\alpha + \beta + \gamma + \delta = 4$

A3 least count

$$LC = \frac{0.5}{100} = 0.005 \text{ mm}$$

Zero error $= 4 \times 0.005$
$= 0.02$ mm

Corrected readings

Attempt - 1

$(4 \times 0.5 + 20 \times 0.005) - 0.02 = 2.08$ mm

Attempt - 2

$(4 \times 0.5 + 16 \times 0.005) - 0.02 = 2.06$ mm

Mean diameter

$$d = \frac{2.08 + 2.06}{2} = 2.07 \approx 2.14 \text{ mm}$$

Maximum error

$\Delta d = \pm 0.02$ mm

Radius $r = 1.14 \pm 0.02$ mm

Cross Sectional Area

$A = \pi r^2 = \pi(1.14 \pm 0.02)$ mm^2

A4 Given $Y = C^{\alpha} h^{\beta} G^{\gamma}$ comparing dimension
1 For M: $\beta - \gamma = 1$
2 For L: $\alpha + 2\beta + 3\gamma = -1$
3 For T: $\alpha + \beta + 2\gamma = 2$
Solving equations
$\gamma = -2 \quad \beta = -1 \quad \alpha = 7$

A5 The correct dimensionless relation is

$$e^{\alpha}\epsilon_0^{\beta}h^{r}c^{\delta} = \text{dimensionless}$$

Solving for dimensions of M, L, T, A, we get
$\alpha = 2n \quad \gamma = -n$
$\beta = -n \quad \delta = -n$

A6 Percentage error in volume

$$\frac{\Delta V}{V} \times 100 = 2\frac{\Delta d}{d} \times 100 + \frac{\Delta h}{h}$$

$$\times 100\left(\frac{\Delta d}{d} = \frac{\Delta h}{h} = \frac{1}{100}\right)\frac{\Delta V}{V} \times 100 = 3\%$$

A7 Given

10 Vernier Scale Divisions = 7 Main Scale Divisions

$$1\text{ MSD} = \frac{1}{10}\text{ cm} = 0.1\text{ cm}$$

$$1\text{ VSD} = \frac{7}{10} \times 1\text{ MSD} = \frac{7}{10} \times 0.1\text{ cm}$$
$$= 0.07\text{ cm}$$

Least Count

LC = 1 MSD – 1 VSD

= 0.1 cm – 0.07 cm = 0.03 cm

Main Scale reading = 1 × MSD = 0.1 cm

Vernier Scale reading = 1 × LC = 0.03 cm

Total reading = 0.1 cm + 0.03 cm = 0.13 cm

A8 Given

length, $\lambda = 10.5$ cm (3 significant figures)

width, b = 0.05 mm = 0.005 cm (1 significant figure)

Height, h = 6.0×10^{-4} cm (2 significant figures)

$$\text{Volume} = \lambda \times b \times h$$
$$= 10.5\text{ cm} \times 0.005\text{ cm} \times 6.0 \times 10^{-4}\text{ cm}$$
$$= 3.15 \times 10^{-5}\text{ cm}^3$$
$$\approx 3 \times 10^{-5}\text{ cm}^3$$

A9 S(thermoelectric power)

$$[S] = \frac{[\text{Voltage}]}{[\text{Temperature}]} = \frac{[ML^2T^{-3}I^{-1}]}{[K]}$$
$$= [ML^2T^{-3}I^{-1}K^{-1}]$$

σ (electrical conductivity)

$$[K] = \frac{[\text{Power}]}{[\text{Area} \times \text{Temperature gradient}]}$$
$$= [MLT^{-3}K^{-1}]$$
$$[S^2] = [M^2L^4T^{-6}I^{-2}K^{-2}]$$
$$[S^2\sigma] = [M^2L^4T^{-6}I^{-2}K^{-2}] \cdot [M^{-1}L^{-3}T^3I^2]$$
$$= [M^1L^1T^{-3}K^{-2}]$$

$$Z = \frac{S^2\sigma}{K} = \frac{[M^1L^1T^{-3}K^{-2}]}{[MLT^{-3}K^{-1}]} = [M^0L^0T^0I^0K^{-1}]$$

CHAPTER 2 Motion Along a Straight Line

A1 From the geometry

$$\frac{H}{x+s} = \frac{h}{s}$$

Substituting values

$$\frac{4}{x+s} = \frac{1.6}{s}$$

After solving we get

$$s = \frac{2}{3}x$$

Differentiate w.r.t time 't'

$$\frac{ds}{dt} = \frac{2}{3}\frac{dx}{dt}$$

$$\because \frac{dx}{dt} = 0.6\text{m/s}$$

$$\therefore \frac{ds}{dt} = \frac{2}{3} \times 0.6 = 0.4\text{m/s} = 40\text{cm/s}$$

CHAPTER 4 Motion in Two and Three Dimensions

A1 After the split, the first mass take 0.5 seconds to reach the ground. Since both masses have the same initial velocity in the vertical direction at the highest point and their displacement and acceleration in the vertical direction are identical the second mass will also take 0.5 second to reach the ground.

A2 The velocity of the projectile at the highest point is 5m/s $\hat{i}$ since no external force acts in the horizontal direction, applying the conservation of momentum

$$m(5) = m(0) + m(v)$$

$$2v = 10 \Rightarrow v = 10\text{m/s}\ \hat{i}$$

The distance covered by the second mass before landing is

$$\text{Range} + 10(t) = 7.5\text{m}$$

A3 $\theta = \frac{1}{2}\ \alpha\ t^2$

$= 60°$

$V_{cm} = \alpha t$

Net velocity of point P is V

$= \alpha t$ at an angle 60°

With horizontal

$U_Y = \propto t \sin 60°$

$$Y_{max} = \frac{1}{2} + \frac{uy^2}{2g} = \frac{1}{2} + \frac{\alpha^2 t^2}{20}\frac{3}{4}$$

$$= \frac{1}{2} + \frac{\pi}{60}$$

$x = 0.52$

A4 $d' = \frac{d}{2} + \sqrt{\frac{2H}{g'}} V \cos\theta$

$$= \frac{d}{2} + \sqrt{\frac{2}{g'}\frac{V^2 \sin^2\theta}{2g}} V \cos\theta$$

$$d' = \frac{d}{2} + \frac{V^2 \sin\theta \cos\theta}{\sqrt{g\frac{g}{0.81}}} = \frac{d}{2} + \frac{d}{2}\left(\frac{9}{10}\right) = \frac{19d}{20}$$

$d' = 0.g5d \qquad n = 0.g5$

A5 C is correct

I→S, II→T, III→P, IV→R

A6 Initial velocity $\mu_0 = \sqrt{2gh}\ \hat{x}$

Horizontal velocity $V_x = \sqrt{2gh}$

Vertical velocity $V_z = \sqrt{6gh}$

Angle $\theta = 60°$

Velocity rector $V = \sqrt{2gh}(\hat{x} + \hat{z})$

Rebound height $h_1 = h$

Time to hit ground $t = \frac{\sqrt{6h}}{g}$

Range $d = 2\sqrt{3h}$

A7 Case I

Given $V_0 = V_0$ and $\theta_0 = \theta_1$ we get

$$\Delta t_1 = T_1 = \frac{L}{V_0}\left(\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right) = \frac{L\sqrt{2}}{V_0}$$

$$\Delta V_1 = V_1 = V_0\left(\frac{1}{2} + \frac{1}{2}\right) = \frac{V_0}{2}$$

Case II

Given $V_0 = \sqrt{3}V_0$ and $\theta_1 = 3\theta_0$ we get

$$\Delta t_2 = T_2 = \frac{L}{\sqrt{3}V_0}, \frac{\sqrt{3}}{2} + \frac{V_0}{2} = \frac{L}{2V_0}$$

$$\Delta V_2 = V_2 = \sqrt{3}V_0, \frac{3}{2} + \frac{V_0}{2} = \frac{V_0}{2}$$

Taking ratio

$$\left(\frac{T_1}{T_2}\right)^2 = \left(\sqrt{2}\right)^2 = 2$$

CHAPTER 5 Force and Motion – I

A1 The acceleration is

$$a = \frac{dv}{dt}$$

Velocity given

$$v = (\alpha yx^2)\ \hat{i} + (\alpha yx)\ \hat{j}$$

Differentiating ω.r.t time

$$a_x = \frac{d}{dt}(\alpha yx^2) = \alpha(2x\dot{x}y + x^2\dot{y})$$

$$a_y = \frac{d}{dt}(\alpha yx) = \alpha(\dot{x}y + x\dot{y})$$

Newton's second law F = ma

$F = m\ (2\alpha xy\ \hat{i} + \alpha x^2\ \hat{j}\ )$

CHAPTER 6 Force and Motion – II

A1 Height of the elevator

$$y = 8\left[1 - \sin\left(\frac{2\pi t}{T}\right)\right]$$

$T = 40\pi s$

Angular frequency $\omega = \frac{2\pi}{T} = \frac{1}{20}$ rad/s

Acceleration of the elevator

$$a = \frac{d^2y}{dt^2} = 8\omega^2 \sin(\omega t) = 0.02 \sin(\omega t) m/s^2$$

Acceleration varies between
$-0.02 m/s^2$ and $0.02 m/s^2$
Weight $W = m(g + a)$
$m = 50kg \quad g = 10 m/s^2$
$W_{max} = 50(10 + 0.02) = 501N$
$W_{min} = 50(10 - 0.02) = 499N$
$W_{max} - W_{min} = 2N$

CHAPTER 9 Center of Mass

A1 $L_i = L_f$

$$m \times 5 \times \frac{L}{2} = \frac{ML^2}{3} \times W - mv \times \frac{L}{2}$$

$$5 = \frac{4w}{3} - v$$

$$v_2 - v_1 = e\,(u_1 - u_2)$$

$$\frac{L}{2} w - (-u) = 1(5 - 0)$$

$$\frac{W}{10} + v = 5$$

W = 6.98 rad/sec
V = 4.3 m/s

A2 $a = -\dfrac{20x + 10}{5} = -4x + 2$

$$a = \frac{vdx}{dx} = -4x + 2$$

Hence

$$\int_0^v v dv = \int_1^x (-4x + 2) dx$$

$$\frac{v^2}{2} = [-2x^2 + 2x]_1^x$$

$V = -2\sqrt{x - x^2}$ (as particle starts moving in –ve x direction)

$$\frac{dx}{dt} = -2\sqrt{x - x^2} \Rightarrow \int_{x=1}^{x=x} \frac{dx}{\sqrt{x - x^2}} = -2\int_0^{\pi/4} dt$$

$$\sin^{-1}[2x - 1]^x, \frac{-\pi}{2}$$

$$x = \frac{1}{2} = 0.5m$$

Also momentum = mv

$$\therefore 5(V)_{x=\frac{1}{2}} = -5kg - m/s$$

A3 $u_2 = aw$ towards left after collision velocity will exchange

$V_2 = \dfrac{aw}{2}$ towards right

$u_1 = aw$ towards right

$$V_{cm} = \frac{3aw}{4}$$

$$\frac{V_{cm}}{aw} = \frac{3}{4} = 0.75$$

A4 After collision $V_2 = \dfrac{aw}{2}$ towards right

$u_1 = 0$

$\therefore V_{cm} = \dfrac{aw}{4}$ towards right

$$V = W\sqrt{A^2 - x^2}$$

$$\frac{aw}{4} = W\sqrt{A^2 - a^2}$$

$$\frac{a^2}{16} + a^2 = A^2$$

$$\frac{17}{16} a^2 = A^2 = b^2$$

$$\therefore b^2 = \frac{17}{16} a^2$$

$$\frac{4b^2}{a^2} = \frac{17}{4}$$

= 4.25

A5 In an elastic collision where a particle of mass 2m strikes a stationary particle of mass m, the maximum scattering angle θ of the heavier particle is given by

$$\sin\theta_{max} = \frac{m}{2m} = \frac{1}{2}$$

$\theta_{max} = \dfrac{\pi}{6}$ radians

CHAPTER 10 Rigid Body Dynamics – I

A1 Time taken to travel from $(-\lambda, -h)$ to $(\lambda, -h)$

$$\lambda = \frac{1}{2}at^2$$

Given a = 10, Solving for τ

$$\tau = 2 \text{ sec}$$

Angular momentum

$$L = muh\hat{k}$$

Substituting values

$$L = (0.2)(10)(2)(1)\ \hat{k} = 4\hat{k}$$

Torque

$$\tau = \frac{dL}{dt} = m_a h\hat{k}$$

Substituting values

$$\tau = (0.2)(10)(1)\ \hat{k} = 2\hat{k}$$

This $L = 4\hat{k}$, $\tau = 2\hat{k}$ (always)

A2 The angular momentum of the disc about O is

$$L_{DO} = M\left(\frac{3a}{4} \times \frac{3a\Omega}{4}\right) + M\left(\frac{a}{2} \times 4\Omega\right)$$

The angular momentum of the rod about O is

$$L_{Ro} = Ma^2 \frac{\Omega}{3}$$

Total angular momentum about O

$$L_O = L_{Do} + L_{Ro} = \frac{49}{48}(Ma^2\Omega)$$

This n = 49.

A3 The given force

$$F = -K(x\hat{i} + y\hat{j}) \text{ with } K = 1$$

This represents a central force, which conserves angular momentum L about the again. The conserved quantity is

$$Lz = xVy - yVx$$

At t = 0

$$Lz = \left(\frac{1}{2} \times 2\right) - \left(\frac{2}{2} \times (-2/\pi)\right)$$
$$= 1 + 4/\pi$$

Since L_z is conserved, its value remains constant at Z = 0.5

Then $xv_y - yv_x = 3$.

A4 $$L = \left(\frac{MR^2}{2}\right)\omega_0 + M \times 2R\omega \times 2R$$

$$= \frac{MR^2}{2} \times 2\omega + 4MR^2\omega$$

$L = 5MR^2\omega$

$\therefore$ n = 5

A5 Given $J = MV_{cm}$ _____ (1)

$$J = \frac{MR^2}{2}W \text{ _____ (2)}$$

From (1)

$$V_{cm} = \frac{J}{M}$$

Time taken to reach back to the initial point

$$T = \frac{2V_{cm}}{g} = \frac{2J}{gm}$$

Angle rotated in time T

$$\theta = wt = \frac{2J}{MR^2} \times \frac{MR^2}{4} \times \frac{2J}{Mg}$$

$$\theta = \frac{60\pi}{A}$$

$$n = \frac{60}{2} = 30$$

A6 Conserving angular momentum of the system (bigger disc + smaller disc) about the symmetric axis of bigger disc

$$\frac{MR^2}{2}\omega' + M \cdot R\omega' \cdot R + M\frac{(R/z)^2}{2}\ \omega = 0$$

Where w′ is the required angular speed

$$\frac{3}{2}MR^2\ \omega' = \frac{-MR^2\omega}{8}$$

$$\omega' = \frac{-\omega}{12}$$

n = 12

A7 linear impulse $\int Fdt = \Delta$ momentum

$$= m(V_{cm} - O)$$

$$P = m(wr_{cm}) = mw\left(L + \frac{L}{2}\right)$$

$$P = mw\left(\frac{3L}{2}\right) \text{_____ (1)}$$

Angular impulse $\int \tau dt = \Delta$ angular momentum

$$\int r \times Fdt = \Delta L$$

$r \times \int Fdt = I\ (w - 0)$, and I is moment of inertia about the axis of rotation

$$\left(L + \frac{L}{2} + x\right) \times P = (I_{cm} + md^2)\ w$$

$$= \left(\frac{mL^2}{12} + m\left(L + \frac{L}{2}\right)^2\right)w$$

$$\left(\frac{3L}{2} + x\right) P = mL^2\left(\frac{1}{12} + \left(\frac{3}{2}\right)^2\right)w$$

$$\left(\frac{3L}{2} + x\right) P = mL^2\left(\frac{7}{3}\right)w \text{_____(2)}$$

Divide equation (1) and (2)

$$\left(\frac{3L}{2} + x\right) = \frac{L\left(\frac{7}{3}\right)}{\left(\frac{3}{2}\right)}$$

$$\frac{3L}{2} + x = L\left(\frac{14}{9}\right)$$

$$X = \frac{L}{18}$$

A8 Case I : Restoring torque

When rod is rotated by θ

$$\tau = kl\theta \cdot l + \left(k\frac{l}{2}\theta\right)\frac{l}{2}$$

$$\tau = \frac{5}{4}kl^2\theta$$

$$\tau = \frac{-ml^2}{3}\alpha$$

$$\alpha = \frac{-15k}{4m}\theta$$

The frequency is

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{15k}{4m}} \qquad \text{(A)}$$

Case II: Restoring torque

$$\tau = \left(2k\frac{l}{2}\theta\right)\frac{l}{2} = \frac{kl^2\theta}{2}$$

$$\frac{kl^2\theta}{2} = -I_0\alpha = -\frac{ml^2}{3}\alpha$$

$$\alpha = -\frac{3k}{2m}\theta$$

The frequency is

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{3k}{2m}} \qquad \text{(B)}$$

$$\frac{f_1}{f_2} = \sqrt{\frac{5}{2}}$$

CHAPTER 11 Rigid Body Dynamics – II

A1 For a rolling object Equation of motion

$$F - f = ma$$

Torque about the C.O.M

$$fR = I\alpha$$

Pure rolling condition

$$a = R\alpha$$

For a hollow cylinder

$$\alpha = \frac{F}{2m}, f = \frac{F}{2}$$

For a solid cylinder

$$\alpha = \frac{2F}{3m}, f = \frac{F}{3}$$

Since $F \le \mu$ mg, for a solid cylinder

$$\alpha \le \frac{2\mu g}{3}$$

A2 Using force equilibrium

Horizontal force

$$R_1 = T\cos 45° = \frac{T}{\sqrt{2}}$$

Vertical force

$R_2 + T\sin 45° = W + \alpha w$

$R_2 + \frac{T}{\sqrt{2}} = w\,(1 + \alpha)$

Using torque equilibrium

$W\frac{L}{2} + \alpha w\,\frac{L}{2} = TL$

$T = W\,\frac{(\alpha + 1)}{2}$

Substituting vertical equilibrium equation

$R_2 = w\,\frac{(\alpha + 1)}{2} = w\,(1 + \alpha)$

$R_2 = \frac{W}{2}$

A3 Using torque equation

$mg\sin\theta \times R + R \times \frac{1}{2} - 3R \times \frac{1}{2} = I\alpha$

Substituting $I = \frac{7}{5}mR^2$

$10 \times \frac{1}{2} + 1 - 3 = \frac{7}{5}MR^2\alpha$

$\frac{5}{2} - 3 = \frac{7}{5}\alpha$

$\frac{5}{2} - \frac{6}{2} = \frac{7}{5}\alpha$

$\frac{-1}{2} = \frac{7}{5}\alpha$

$\alpha = \frac{20}{7}$

A4 Correct statement are:

A. when $\mu \neq 0$ and $a \to 0$, the mass distribution approaches that of a solid disk leading to $hm = \frac{b}{2}$

B. When $\mu \neq 0$ and $a \to b$, the disk becomes a thin ring, giving $hm = b$

C. When $h = h_m$, the initial angular velocity depends only on the other radius b, not one

D. If $\mu = 0$ and $h = 0$, there is no torque about the centre, so the Disk slides without rolling.

A5 The horizontal motion is governed by

$mv_x = -cv_x$

giving $v_x(t) = v_{0x}e^{-(c/m)t}$

with $v_{0x} = 270 \cos 60°$

$= 135$ m/s

Integrating the horizontal distance

$x(t) = \frac{mv_{0x}}{C}(1 - e^{-(c/m)t})$

Given

$m = 0.2$ kg $\quad c = 0.1$ kg/s

$c/m = 0.5\ s^{-1}$

At $t = 2$ sec

$e^{-(c/m)t} = e^{-1} = 1/2.7$

$x(2) = \frac{0.2 \times 135}{0.1}\left(1 - \frac{1}{2.7}\right)$

$= 270 \times \frac{1.7}{2.7}$

$= 170$ m

CHAPTER 13 Gravitation

A1 Both masses revolve around their common C.O.M

$x_5 = \frac{3m \times 9R}{6M + 3M} = 3R$

Using the gravitational force balance.

$\frac{G \cdot 6M \cdot 3M}{(9R)^2} = 6m\,(\omega^2 x_s)$

Solving for ω.

$\omega = \frac{\sqrt{2GM}}{9R}$

The time period.

$T_s^2 = \frac{4\pi^2 (9R)^3}{GM} = 81T^2$

$T_s \to$ all

A2 Given that.

$M_B = 2M_A$ we also have $\rho_B = 2\rho_A$

After mass transfer.

$$M'_A = \frac{4}{3}\pi\rho A\left(\frac{7R}{8}\right)^3$$

$$M'_B = \frac{4}{3}\pi\,(\rho_A + 2\rho_A)\left(\frac{7R}{8}\right)^3$$

New outer radius.

$$R' = \left(\frac{15}{8}\right)^{1/3} R$$

Velocities.

$$V'_A = \sqrt{\frac{GM^1_A}{R^1}}$$

$$V'_B = \sqrt{\frac{G \cdot 4/3\pi(\rho_A + 2\rho_A)R^{-3}}{R^1}}$$

Taking the ratio.

$$\frac{V_B}{V_A} = \frac{\sqrt{2.3}}{(15/8)^{1/3}}$$

$n = 2.30$

A3 Given

$$g = \frac{GM}{R^2}$$

At point Q

$$g_Q = \left(\frac{GM}{R + h_Q}\right)^2$$

At point P

$$\frac{36g}{25} = \frac{GM}{(R + h_Q)^2}$$

Substituting.

$$g = \frac{GM}{R^2}$$

$$\frac{36}{25} \cdot \frac{1}{R^2} = \frac{1}{(R + h_Q)^2}$$

Taking square root

$$\frac{6}{5R} = \frac{1}{R + h_Q}$$

Solving for h_Q

$$R + h_Q = \frac{5R}{6}$$

$$h_Q = \frac{5R}{6} - R = \frac{3R}{5}$$

A4 $$\frac{GM_m}{r_0^2} = m\omega^2 r_0$$

$$\omega = \sqrt{\frac{Gm}{r_0^3}}$$

$$T_0^2 = 4\pi^2\left(\frac{r_0^3}{GM}\right)$$

$$F = -\frac{dv_c(r)}{dv} \qquad \text{_____ 1}$$

$$F = \frac{3m\pi}{r^4}$$

Net force.

$$\frac{GM_m}{r_0^2} - \frac{3m\pi}{r_0^4} = m\omega^2 r_0$$

$$\omega^2 = \frac{GM}{r_0^3} - \frac{3\alpha}{r_0^5}$$

we know $\omega = \dfrac{2\pi}{T_1}$

$$\frac{4\pi^2}{T_1^2} = \frac{GM}{r_0^3} - \frac{3\alpha}{r_0^5}$$

$$T_1^2 = \frac{4\pi^2}{\frac{GM}{r_0^3} - \frac{3\alpha}{r_0^5}} \qquad \text{_____ 2}$$

from equation 1 and 2

$$\frac{T_1^2 - T_0^2}{T_1^2} = \frac{3\alpha}{GMr_0^2}$$

A6 The synodic period T_{rel} between the geostationary satellite and second satellite is

$$T_{rel} = \frac{T_1 T_2}{T_1 + T_2}$$

Using Kepler's third law

$T_2 = T_1(r_2/r_1)^{3/2}$

Given $r_1 = 1.21r_2$ we have $r_2/r_1 = 1/1.21$

cr = 100/121

$$T_2 = 24\left(\frac{100}{121}\right)^{3/2} = 24\left(\frac{10}{11}\right)^3 = 24 \times \frac{1000}{2331} \text{ hr}$$

Given $T_{rel} =$ 24/p hr

$$\frac{24}{p} = 24 \times \frac{1000}{2331}$$

$$p = \frac{2331}{1001} = 2.331$$

$$p = 2.33$$

CHAPTER 14 Fluids

A1 $(P_1 - P_2)\, ds = \rho_{dsd}\,(g \sin 45° - a)$

$(P_1 - P_2) = \rho_d\,(g - a\sqrt{2})$

$$\beta = \frac{(p_1 - p_2)}{\rho g d} = 1 - \frac{a\sqrt{2}}{g}$$

For $a = \frac{g}{2}$

$\beta = 0$

For $a = \frac{g}{2}$ $\beta = \frac{2 - \sqrt{2}}{2}$

A2 For equilibrium of the test tube.

Weight of tube + weight of air = Buoyant force.

$$W + mg = (V + V_{air})\,\rho_g$$

Substituting values.

$$5 = 5 + V_{air} \times \frac{1}{2.5}$$

$V_{air} = 3cc$

Thus $\Delta v = 0.3cc$

A3 For the isothermal process.

$$(10^5) \times (3.3) = P \times (3)$$

Solving for P

$$P = \frac{10^5 \times 3.3}{3} = 1.1 \times 10^5 \text{Pa}$$

Change in pressure

$\Delta p = (1.1 - 1) \times 10^5 = 10 \times 10^3$ Pa

A4 Using the given equations.

$P_1 - YT^Y = \text{cost.}$

Given $P_2 = 150$ Pa

$m = \rho_1 A_1 V_1$

$V_1 = 40$m/s

$$\rho = \frac{PM}{RJ}, \rho_2 = 0.1 \text{ kg/m}^3$$

$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

$V_2 = 20$ m/s

From work energy theorem.

$P_1 A_1 V_1\, dt - P_2 A_2 V_2\, dt + \rho_1 A_1 V_1 dt \cdot g(0)$
$- \rho_2 A_2 V_2\, dt \cdot g(h)$

$= \frac{1}{2}\rho_2 A_2 V_2\, dt \cdot V_1^2 - \frac{1}{2}\rho_1 A_1 V_1\, dt \cdot V_1^2$
$+ [P_2 A_2 V_2\, dt - P_1 A_1 V_1] \Rightarrow h = 360$m

A5 Using P_a as constant.

$\rho_a T_a = \rho T$

Solving for ρ.

$$P = \frac{p_a T_a}{T} = \frac{1.2 \times 300}{360} = 1 \text{kg/m}^3.$$

Applying Bernoulli's equation.

$$P_a + 0 + 0 = P_a - \rho_a g\,(10) + \rho_g\,(10) + \frac{1}{2}\rho V^2$$

Solving for V

$$V = \sqrt{2g(10)\frac{\rho_a - \rho}{\rho}} = \sqrt{(2)(0.2)(100)}$$
$$= 40\text{m/s}$$

Mass flow rate Q

$$Q = \frac{\pi}{4}(0.1)^2\,(40)(10^3) = 49.61 \text{ g/s}$$

A6 Using the given equation.

$P_a = P_{inside} + \rho_g\,(10)$

$P_{inside} = P_a - \rho_g\,(10)$

$P_{outside} = P_a - \rho_{ag}\,(10)$

Pressure difference

$\Delta P = P_{inside} - P_{outside}$
$= (\rho_a - \rho)g \times 10$

$\Delta P = 20$ N/m^2

A7 A) $W_{ext} + W_g + W_B = \Delta K$

$W_{ext} + mgh - \rho_{vgh} = 0$

$W_{ext} = \rho_\ell Vgh - mgh$

$= gh(\rho_g v - m)$

$= 10 \times 0.7\,[10^3 \times \frac{4}{3}\pi\,(1.5 \times 10^{-2})^3 - \pi \times 10^{-3}]$

$= 0.77J$

B) $w_g + w_B = \frac{1}{2}MV^2 - 0$

$0.77 = \frac{1}{2}\left(\frac{22}{7} \times 10^{-3}\right)V^2 = V = 7m/s$

C) $H = \frac{v^2}{2g} = \frac{(7)^2}{2 \times 10} = 2.45$ m

D) Ratio $= \left|\frac{\rho_\ell V_g - M_g}{6\pi nrv}\right| = \frac{500}{9}J$

CHAPTER 15 Oscillations

A1 Velocity of the Bob after impulse.

$P = mv$

$V = \frac{P}{m} = \frac{0.2}{0.1} = 2m/s$

Angular momentum Before Lift off.

$J = mvr$

$J = 0.1 \times 2 \times 0.9 = 0.18$ kg m²/s

A2 Velocity component perpendicular to string.

$V\perp = V \times \frac{R}{L} = 2 \times \frac{0.9}{1} = 1.8$ m/s

Kinetic Energy After Lift off

$K = \frac{1}{2}m\,v_\perp^2$

$K = \frac{1}{2}(0.1)(1.8)^2$

$K = \frac{1}{2}(0.1)(3.24)$

$K = 0.162 \approx 0.16$ J

A3 For $\lambda > \lambda_0$, the oscillation frequency is.

$F_1 = \frac{1}{2\pi}\sqrt{\frac{K_1}{m}}$

For $\lambda < \lambda_0$, the oscillation frequency is.

$F_2 = \frac{1}{2\pi}\sqrt{\frac{K_2}{m}}$

Thus time period is

$T = \pi\left(\sqrt{\frac{m}{K_1}} + \sqrt{\frac{m}{K_2}}\right)$

Substituting Value

$T = \pi\left(\sqrt{\frac{0.1}{70}} + \sqrt{\frac{0.1}{6}}\right)$

$T = \pi(0.038 + 0.129) = \pi(0.167)$

Approx.

$T \approx 6\pi$

Since $T = n\pi$ we get

$n = 6$

A4 The time period of oscillation is given by.

$T = 2\pi\sqrt{\frac{I}{K}}$

Calculating I

$I = (30 \times 16) + (20 \times 36) = 12 \times 10^{-5}$kgm²

Substituting in the formula.

$T = 2\pi\sqrt{\frac{1.2 \times 10^{-5}}{1.2 \times 10^{-8}}}$

$T = 200\pi$ sec

Angular frequency.

$W = \frac{2\pi}{T} = 10 \times 10^{-3}$ rad/s

$n = 10$

A5 Restoring force $= qE\sin\left(\frac{\theta}{2}\right)$

Therefore

$\tau = qE\sin\left(\frac{\theta}{2}\right)R = I\alpha$

$E = \frac{Kq}{\left(2R\cos\left(\frac{\theta}{2}\right)\right)^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{4R^2\cos^2\left(\frac{\theta}{2}\right)}$

$= \frac{1}{4\pi\varepsilon_0}\frac{qR}{4R^2\cos^2\left(\frac{\theta}{2}\right)}\sin\left(\frac{\theta}{2}\right)q = mR^2\alpha$

For θ: which is very small.

$$\frac{+q^2}{32\pi\varepsilon_0 R^3 m}\theta = \alpha$$

A6 The disk rolls without slipping inside the ring, with its center moving on a circle of radius R – r. For small angular displacement θ from the equilibrium position (bottom of the ring) the K·E is $T = \frac{3}{4}$ m $(R - r)^2\ \theta^2$, accounting for both translational and rotational motion

The gravitational P·E

$$Ug = \frac{1}{2}\ mg(R - r)\ \theta^2$$

Spring P·E

$$Us = \frac{1}{2}\ k(R - r)^2\ \theta^2$$

$$\frac{3}{2}\ m(R - r)^2\theta = -\ [mg(R - r) + k(R - r)^2]\theta$$

$$\theta + \left(\frac{2g}{3(R - r)} + \frac{2k}{3m}\right)\theta = 0$$

The angular frequency

$$\omega^2 = \frac{2}{3}\left(\frac{g}{R - r} + \frac{k}{m}\right)$$

$$\omega = \sqrt{\frac{2}{3}\left(\frac{g}{R - r} + \frac{k}{m}\right)}$$

CHAPTER 16 Waves – I

A1 Using the harmonic frequency formula.

$$fn = \frac{n}{2L} = \sqrt{\frac{T}{\mu}}$$

Rearrange for T

$$T = \left(\frac{2Lfn}{n}\right)^2 \mu$$

Substituting $f_3 = 750$Hz, L = 1m, and

$$\mu = \frac{2 \times 10^{-5}}{1} = 2 \times 10^{-5}\text{kg/m}$$

$$T = \left(\frac{2 \times 1 \times 750}{3}\right)^2 (2 \times 10^{-5})$$

$$T = \left(\frac{1500}{3}\right)^2 (2 \times 10^{-5})$$

$$T = (500)^2\ (2 \times 10^{-5})$$

$$T = 25000 \times 2 \times 10^{-5}$$

$$T = 5\text{N}$$

A2 The minimum frequency with a node at O is V_0, as both segments must resonate together. A is correct.

An antinode at O is not possible due to differing wave speeds. B is incorrect.

With a node at O, there are 6 nodes in total C is correct.

No vibrational mode with an antinode at O is possible D is correct.

A3 → No phase change occurs during transmission of a wave from one medium to another.

→ Reflection from a denser medium introduces a phase change of π.

→ The angular frequency ω remains unchanged when the wave crosses into a different medium.

→ The wavelength λ changes by the same factor as the wave speed V when the medium changes.

→ The wave speed on a string is given by $V = \sqrt{\frac{T}{\mu}}$ where T is the tension and μ is the linear mass density.

CHAPTER 17 Waves – II

A1 (A) $u = 0{\cdot}8V$, $f_s = f_0$

$$f' = f_0 \times \frac{V}{V - 0 \cdot 8V} = f_0 \times \frac{V}{0 \cdot 2V} = 5f_0$$

Since 5 f_0 is an odd multiple of f_0 resonance occure.

(D) $u = 0 \cdot 5V$, $f_s = 1 \cdot 5f_0$

$$f' = 1 \cdot 5f_0 \times \frac{V}{V - 0 \cdot 5V} = 1 \cdot 5f_0 \times \frac{V}{0 \cdot 5V} = 3f_0$$

Since $3f_0$ is an odd multiple of f_0 resonance occurs.

A2 The apparent frequency is given by the Doppler Effect formula

$$f' = f_s \times \frac{V}{V + V_s \cos 45°}$$

Substituting the given values

$$f' = 324 \times \frac{656}{324 + 4\sqrt{2}}$$

Since $V_s = 4\sqrt{2}$ m/s

$$f' = 324 \times \frac{656}{328}$$

$f' = 648$Hz

Apparent frequency f'

A3 Using the Doppler Effect formula

$$f_1 = f_s \times \frac{V}{V - V_s'}$$

Given $V_s' = 4$m/s

$$f_1 = 656 \times \frac{324}{320}$$

$f_1 = 664{\cdot}2$Hz

Apparent frequency f_2

For $0 = 90°$, $\cos 90° = 0$, so

$f_2 = f_0 = 656$Hz

Beat frequency calculation

$f_b = |f_1 - f_2|$

$f_b = |664{\cdot}2 - 656|$

$f_b = 8{\cdot}2$Hz

A4 (i) f_0 = 240Hz (moving towards each other)

Using the Doppler Effect formula.

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

(Moving away from each other)

(ii) $288 = \left(\frac{V + u}{V - u}\right) 240 \Rightarrow \frac{V + u}{V - u} = \frac{6}{5}$

$V = 11u$

$$f_2 = \left(\frac{V - u}{V + u}\right) f_0$$

$$f_2 = \frac{6}{5} \times 240 = 200\text{Hz}$$

A5 $\frac{1}{2} mv^2 = mg\,(L - L\cos\theta)$

$v = \sqrt{2gL(1 - \cos\theta)}$

$v = \sqrt{2 \times 10 \times 8(1 - 0.9)}$

$= \sqrt{16}$

$= 4$ m/s

$$f = f_0 \left(\frac{v - v_O}{v - v_s}\right)$$

$$f_{max} = 660\left(\frac{330 + 4}{330 - 4}\right) = 676.20 \text{ Hz}$$

$$f_{min} = 660\left(\frac{330 - 4}{330 + 4}\right) = 644.19 \text{ Hz}$$

Maximum variation

$f_{max} - f_{min}$

$676.20 - 644.19 = 32.01$ Hz

CHAPTER 18 Temperature, Zeroth Law of Thermodynamics and Thermal Expansion

A1 Isothermal process (T = constant)

$PV = \text{constant} \Rightarrow P_1V_1 = P_2V_2$

$$\left(P_1 + \frac{4T}{R}\right)\frac{4\pi R^3}{3} = \left(P_2 + \frac{4T}{R}\right)\frac{4\pi R^3}{3}$$

$$\frac{P_1 + \frac{4T}{R}}{P_2 + \frac{4T}{R}} = 1$$

Adiabatic process ($PV^{\gamma} = \text{constant}$)

$PT^{-5/2} = \text{constant}$

$$\frac{P_1}{P_2} = \left(\frac{T_2}{T_1}\right)^{5/2}$$

$$\frac{P_1 + 4T/R}{P_2 + 4T/R} = \left(\frac{T_2}{T_1}\right)^{5/2}$$

A2 Given $P_0V_0 = P_A\left(\frac{100V}{101}\right)$

Solving for P_A:

$$P_A = P_0\frac{101}{100}$$

Since $P_A = P_D$ we get

$$P_D = P_0\frac{101}{100}$$

Also

$$P_B - P_C = \frac{2T}{r}$$

Since $P_B = P_0$

$$P_C = P_0 - \frac{2T}{r}$$

For P_D:

$P_D = P_C + pgh$

Substituting values

$$P_0\frac{101}{100} = P_0 - \frac{2T}{r} + pgh$$

Solving for h

$h = 0.25m = 25cm$

A3 The Carnot engine has an efficiency of $\eta = 0.4$ with a hot reservoir at $T_{H1} = 1000$ K. Using $\eta = 1 - \frac{Tc_1}{T_{H1}}$ The cold reservoir temperature

$Tc_1 = 600$ K So statement (B) is correct.

The work extracted per cycle is

$W = \eta\, Q_{H1} = 0.4 \times 150$ J $= 60$ J

Statement (A) is correct.

This work drives a heat pump with a coefficient of performance = 10 and a hot reservoir at $T_{H2} = 300$ K

Assuming the heat pump is Carnot

$$COP = \frac{T_{H_2}}{T_{H_2} - Tc_2} \text{ gives } Tc_2 = 270 \text{ K}$$

Statement (C) is correct.

The heat supplied to the hot reservoir is $Q_{H2} = COP \times W = 10 \times 60$ J $= 600$ J not 540 J, statement (D) is incorrect.

A4 Given

$V_w = 64$ cm³, $V_X = 125$ cm³ and $V_Y = 250$ cm³ and Assuming WX is adiabatic and XY is isobaric, the temperature at X and Y are

$$T_X = T_W\left(\frac{V_W}{V_X}\right)^{Y-1} = T_W\left(\frac{64}{125}\right)^{2/3} = \frac{16}{25}T_W$$

$$T_Y = T_X\frac{V_Y}{V_X} = \frac{16}{25}T_W \times \frac{250}{125} = \frac{32}{25}T_W$$

The temperature difference is $\Delta T = T_Y - T_X = \frac{16}{25}T_W$ for a monoatomic gas $C_p = \frac{5}{2}R$

The heat absorbed along the isobaric process XY is

$$Q_{XY} = nC_p\Delta T$$

$$= n \cdot \frac{5}{2}R \cdot \frac{16}{25}T_W$$

$$= \frac{5}{2} \cdot \frac{16}{25}nRT_W$$

$\because$ nRTw = 1 J (given)

$$Q_{XY} = \frac{5}{2} \cdot \frac{16}{25} \cdot 1$$

$$= \frac{8}{5}\text{ J}$$

$$= 1.6 \text{ J}$$

CHAPTER 19 Heat – Measurement and Transfer

A1 Using stefan – Boltzmann's law and integrating.

$$\frac{t_2}{t_1} = 9$$

A2 For an isobaric process, the work done is.

$W = (n_1 + n_2)\, R\Delta T$

Given

$W = 3R\Delta T = 66$

$R\Delta T = 22$

Change in internal energy

$$\Delta U = \frac{f_1}{2}n_1 R\Delta T + \frac{f_2}{2}n_2 R\Delta T$$

Degree of freedom

$$f = \frac{2}{Y-1}$$

Substituting values

$$\frac{3}{2}R\Delta T + \frac{5}{2}R\Delta T = \frac{11}{2}R\Delta T$$

$$\Delta U = \frac{11}{2} \times 22 = 121 \text{ Joules.}$$

A3 P(2000K) → (3): Radiation at peak emission wavelength (1450nm) is infrared which causes the widest central maximum in single-slit diffraction.

A (3000K) → (4): from Stefan-Boltzmann's law, power emitted per unit area varies as T^4 since $5000^4/6000^4 = 1/16$

R (5000K) → (2): Peak wavelength (580nm) is in the visible spectrum so the radiation is visible to the human eye.

S (10000K) → (1): Peak wavelength (290nm) is UV radiation which can cause. Photoelectron emission for metals with work function 4ev.

A4 $dQ = mSdT$

$\int dQ = \Delta 1 \cdot kTdT$

$\Delta Q = K\int_{200}^{300} TdT$

$$\Delta Q = \frac{K}{2}\left[T^2\right]_{200}^{300}$$

$$\Delta Q = \frac{K}{2} \times (9-4) \times 10^4$$

$\Delta Q = 25000$ K

$n = 25000$K

A5 The radiative heat transfer per unit area is

$$W_0 = \sigma\left(T_P^4 - T_Q^4\right)$$

For the three gap

$$\sigma\left(T_P^4 - T_1^4\right) = W_s, \ \sigma\left(T_1^4 - T_2^4\right) = W_s$$

$$\sigma\left(T_2^4 - T_Q^4\right) = W_s$$

Adding above equations

$$\sigma\left(T_P^4 - T_Q^4\right) = \frac{3Ws}{\sigma}$$

Substituting $W_0 = \sigma\,(T_P^4 - T_Q^4)$

$W_0 = 3W_s$

$$\frac{W_0}{W_S} = 3$$

CHAPTER 20 The Kinetic Theory of Gases

A1 $U_n = \frac{n}{2}RT; U_n \alpha n$

Where n is degree of freedom

As n → increases; Un increases

$$V_n = \sqrt{\frac{\left(1+\frac{2}{n}RT\right)}{M}}$$

As n increases; V_n decreases

A2 (P) JK ⇒ $\Delta W_{JK} = nR\Delta T$

$= 1 \cdot R(3T_0 - T_0) = 2RT_0$

LM ⇒ $\Delta W_{LM} = P\Delta V = nR\Delta T$

$= 1 \cdot R(T_0 - 3T_0) = -2RT_0$

KL ⇒ $\Delta W_{KL} = nRln\left(\frac{p_i}{p_f}\right)$

$= R3T_0 ln\left(\frac{p_0}{2p_0}\right)$

$= -3RT_0 ln2$

MJ ⇒ $\Delta W_{MJ} = nRTln\left(\frac{p_i}{p_f}\right)$

$= RT_0 ln\left(\frac{2p_0}{p_0}\right) = RT_0 ln2$

Total work done

$\Delta W = -2RT_0 ln2$

(Q) $\Delta U_{JK} = nC_V\Delta T = 1 \cdot \frac{3}{2}R(3T_0 - T_0)$

$= 3RT_0$

(R) $\Delta Q_{KL} = \Delta W_{KL} + \Delta U_{KL} = \Delta W_{KL} + 0$

$= -3RTln2$

(S) $\Delta U_{MJ} = nC_V\Delta T = 0$

CHAPTER 21 The First Law of Thermodynamics

A1. $\Delta Q_1 = nCp\ \Delta T > O$

$\Delta Q_2 = nCv\ \Delta T < O$

$\Delta Q_3 = nCv\ \Delta T < O$

$\Delta Q_4 = nCv\ \Delta T > O$

A2 When $FeSO_4$ reacts with $K_4[Fe\ (CN)_6]$ in the absence of air, it forms a while precipitate of f_{errors} ferro cynide $(K_2Fe(CN)_6])$ which turns blue when exposed to air due to oxidation, forming Prussian Blue ($Fe_4[Fe(CN)_6]_3$)

A3 $[Fe(NO)(H_2O)_5]^{2-}$, as it is responsible for the characteristic brown ring in the brown ring test for nitrates.

A4 (B) $I \to S, II \to P, III \to T, IV \to P$

A5 Volume of gas at B is

$$V_B = \left(\frac{100}{300}\right)^{3/5} \times (0.8) = (0.4)m^3$$

$$W_{A\to B} = \frac{P_A V_A - P_B V_B}{Y-1} = -60 \text{ Joule}$$

$$W_B \to C = P_B V_B L_{n2} = 84 \text{ Kilo Joule}$$

$$W_C \to A = O$$

A6 $TV^{\gamma-1} = T_0\ 0^{\gamma-1}$

$\Rightarrow T_A\ V_0^{\gamma-1} = V_f(5V_0)^{\gamma-1}$

$$\Rightarrow \frac{T_A}{T_f} = 5^{\gamma-1}$$

Since $T_f = T_B$

$$\Rightarrow \frac{T_A}{T_A} = 5^{\gamma-1}$$

A7 Work done in cycle I

$W_I = 4\ P_0\ V_0 + 8\ P_0\ V_0 \ln 2 - 6P_0\ V_0$

Work done in cycle II

$W_{II} = 4\ P_0\ V_0 \ln 2 - P_0\ V_0$

Ratio Work done

$$\frac{W_I}{W_{II}} = 2$$

A8 In equilibrium, the piston is at a distance $\frac{L}{2}$ from both ends, so the volumes of both compartments are $V = \frac{AL}{2}$

Spring is stretched by $\Delta x = \frac{L}{2} - \frac{2L}{5} = \frac{L}{10}$

Force $F = k\ \Delta x = \frac{KL}{10}$

$$P_{left}\ A = P_{right}\ A + \frac{KL}{10}$$

The ideal gas law for both compartments at common temperature T

$$P_{left} \cdot \frac{AL}{2} = \frac{3}{2} RT$$

$$P_{right} \cdot \frac{AL}{2} = RT$$

$$\frac{P_{left}}{P_{right}} = \frac{3}{2}$$

Substituting the value

$$\frac{3}{2} P_{right} = P_{right} + \frac{kL}{10A}$$

$$\frac{1}{2} P_{right} = \frac{KL}{10A}$$

$$P_{right} = \frac{KL}{5A}$$

$\alpha = 1/5$

$\alpha = 0.2$

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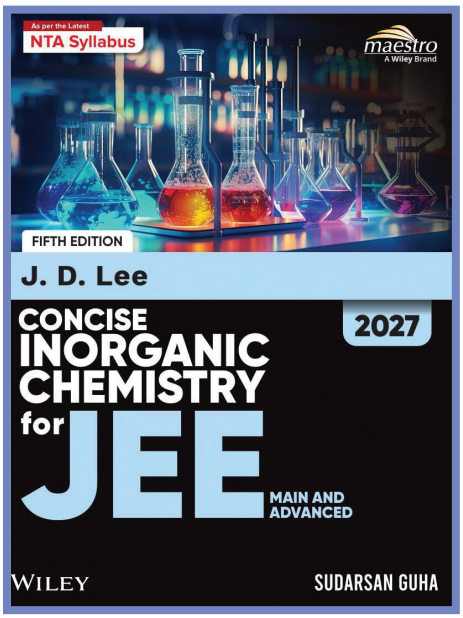

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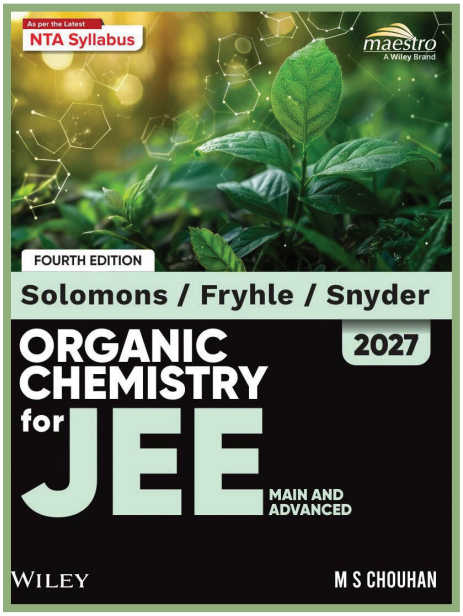

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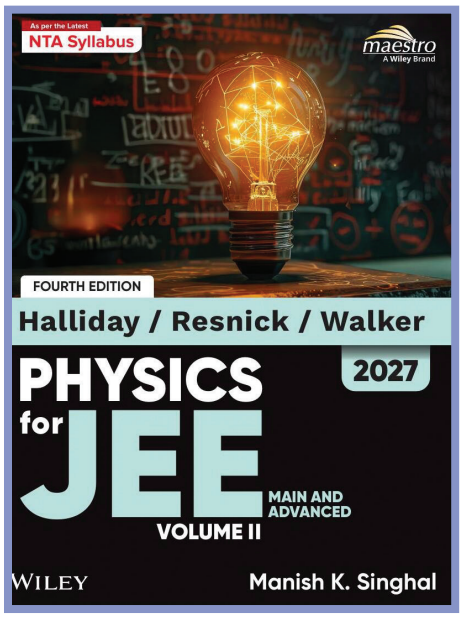

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