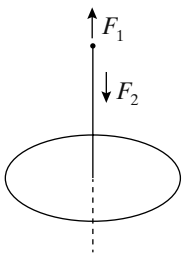
# JEE Advanced / Multidisciplinary PYQs with Answers and Solutions

## ANSWERS WITH EXPLANATION

### *CHAPTER 22 Electric Charges and Fields*

**A1**




$$\vec{F}_1 = \frac{\sigma q}{2\varepsilon_0}\left(1 - \frac{Z}{\sqrt{Z^2 + R^2}}\right)\hat{K}$$

$$\vec{F}_2 = -c\hat{k}$$

$$ß = \frac{1}{4} \text{ Also } \frac{1}{4} = \frac{2c\varepsilon_0}{\sigma q} \text{ (given)}$$

$$\frac{\sigma q}{2\varepsilon_0} = 4c \qquad \text{(A)}$$

Considering Equilibrium at $Z = Z_0$

$F_1 = F_2$

$$= \frac{\sigma q}{2\varepsilon_0}\left(1 - \frac{Z}{\sqrt{Z^2 + R^2}}\right) = C$$

from equation A

$$\left(1 - \frac{Z}{\sqrt{Z^2 + R^2}}\right) = \frac{1}{4}$$

$$\frac{Z}{\sqrt{R^2 + Z^2}} = \frac{3}{4}$$

$$Z = \sqrt{\frac{9}{7}}R \simeq 1.13\,R$$

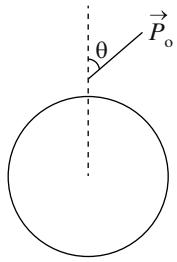
$Z > 1.13\,R, F_2 > F_1$

Particle reaches origin

$Z < 1.13\,R, F_1 > F_2$

Particle reaches back to $Z = Z_0$

**A2**




Restoring torque

$\tau = -P_0\,E \sin\theta$ for small $\theta$

$\tau = -(P_0E)\theta\ \alpha - \theta$

$\tau = -P_0E\theta$ (A)

$\because\ \tau = I\alpha$

for angular S.H.M

$\propto = -\omega^2\theta$

$\tau = -I\omega^2\theta$ (B)

from equation (A) and (B)

$-P_0E_\theta = -I\omega^2\theta$

$$\omega = \sqrt{\frac{P_0E}{I}}$$

Angular S.H.M

$$\omega = \sqrt{\frac{P_0 E}{I}} = \sqrt{\frac{P_0 \sigma R^2}{I \in_0 r^2}}$$

$$\because\ E = \frac{1}{4\pi \in_0}\ \frac{q}{r^2},\ q = \sigma 4\pi R^2$$

for r = 10R

$$\omega = \sqrt{\frac{\sigma P_0}{100\ \varepsilon_0 I}}$$

**A3** The electric field $\vec{E}$ due to a dipole at a point is given by : On the axial line (along the dipole axis) : $E_{axial} = \frac{2kp}{r^3}$ (along the dipole moment) when $K = \frac{1}{4\pi \in_0}$

On the equatorial line (perpendicular bisector): Equatorial = $\frac{-kp}{r^3}$

(P) $E = \frac{-2kp}{r^3}\hat{j} = -\frac{p}{2\pi\varepsilon_0 r^3}\hat{j}$ P → (2)

(Q) E = 0 Q → (1)

(R) $E = \frac{2kp}{r^3}\hat{i} - \frac{kp}{r^3}\hat{j}$ R → (4)

(S) $E = \frac{4kp}{r^3}\hat{i}$ S → (5)

## CHAPTER 23 Gauss' Law

**A1** Flux through cone = $\frac{q}{2\epsilon_0} = \frac{nq}{6\epsilon_0}$

n = 3

**A2** $E_{net} = 0 \Rightarrow q_{net} = 0 \Rightarrow r = \frac{\sqrt{3}}{2}$

$$V = \frac{KQ_{net}}{r} = \frac{1}{4\pi\varepsilon_0}\frac{\pi K\left(4r^2 - 3\right)}{r}$$

$$V = \frac{K}{4\varepsilon_0}\left[4r - \frac{3}{r}\right]$$

$$= \frac{K}{4\varepsilon_0}\left[4 \times \frac{3}{2} - \frac{3 \times 2}{3}\right] = \frac{K}{\varepsilon_0}$$

**A3** $\phi_1 = q/\varepsilon_0 - q/\varepsilon_0\left(\frac{1-\cos 30°}{2}\right) \times 2$

$$= q/\varepsilon_0\left[1 - 1 + \frac{\sqrt{3}}{2}\right] = \frac{\sqrt{3}}{2}\frac{q}{\varepsilon_0}$$

$$\phi_2 = q/\varepsilon_0\left(\frac{1-\cos 60°}{2}\right) \times 2$$

$$= \frac{1}{2}q/\varepsilon_0$$

$$\frac{\phi_2}{\phi_1} = \frac{1/2}{\sqrt{3}/2} = \frac{1}{\sqrt{3}}$$

$$\phi_2 = \frac{\phi_1}{\sqrt{3}}$$

**A4** In the dielectric, $\vec{D}$ (electric displacement field) obeys Gauss's law: total flux over the full cylindrical surface = Q

Electric field flux: $\phi_E = \frac{1}{k}$ × corresponding-free space value

Given plane at radius R intercept $\frac{1}{12}$ of the total cylindrical flux

$\because k = 5$

$$\therefore \phi = \frac{1}{12}\cdot\frac{Q}{k\varepsilon_0} = \frac{1}{12}\cdot\frac{Q}{5\varepsilon_0} = \frac{Q}{60\varepsilon_0}$$

## CHAPTER 24 Electric Potential

**A1** The radius is given by the distance from b = 1.5 to either charge Using the definition of the radius

$$R = \sqrt{(b-0)^2}$$

$$R = \sqrt{(1.5-0)(1.5-2)}$$

$R = \sqrt{3} \approx 1.73$ meters.

**A2** b = a + radius

$$= \frac{2\sqrt{3}}{\sqrt{3}+1} + \sqrt{3}$$

$$= \frac{2\sqrt{3}+3+\sqrt{3}}{1+\sqrt{3}}$$

$$= \frac{2\sqrt{3}+3}{1+\sqrt{3}} = 3$$

**A3** When $x = q$, the electric field at 0 is zero. when $x = -q$, the electric field at 0 is

$$E = \frac{2q}{4\pi\varepsilon_0 (3a)^2} = \frac{2q}{6\pi\varepsilon_0 a^2}$$

when $x = 2q$ He potential at 0 is

$$v = \frac{7q}{4\pi\varepsilon_0 (3a)}$$

when $x = -3q$ the potential at 0 is

$$v = \frac{2q}{4\pi\varepsilon_0 (3a)}$$

**A4** Initial dipole configuration

Dipole moment p = q (4mm) along y axis

Potential at P (100,100) : $V_0$ (given)

New Dipole configuration

The charges are shifted symmetrically along the $x$ axis to (–1, 2)mm and (1, –2) mm new dipole moment remains in the same direction but with a reduced magnitude.

Effect on potential at P

The effective dipole moment decreases by a factor of 2

Since, dipole potential $V \alpha P$, the new potential becomes $V_0/2$

**A5** $(V_P - V_R) = 2k\lambda \ln \frac{r_R}{r_P} = 126V$ for line charge

$(V_P - V_R) = kq\left(\frac{1}{1} - \frac{1}{r_R}\right) = \frac{kq}{2} = 45V$ for sphere

$V_P - V_R = 126 + 45 = 171V$

**A6** Given:

$q = 10^{-8}$ C, sphere radius R = 10 cm = 0.1 m

Initial distance of charge from center = 20 cm = 0.2 m

$$\frac{1}{4\pi\varepsilon_0} = 9\times10^9$$

(A) Potential of neutral sphere before grounding

Potential of sphere due to external charge

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} = 9\times10^9 \cdot \frac{10^{-8}}{0.2} = 450V$$

(B) Grounding the sphere

for a grounded conducting sphere with external charge q at distance a, induced charge on sphere

$$Q = -q\frac{R}{a}$$

$$Q = -10^{-8} \cdot \frac{0.1}{0.2} = -5\times10^{-9}C$$

Charge that flows to ground = $-5 \times 10^{-9}$ C

(C) After removing grounding charge remains on sphere

$$Q = -5 \times 10^{-9} C$$

**A7** (A) In configuration I, the electric field due to the infinite sheets cancel in region 4, so the net electric field is zero.

## CHAPTER 25 Capacitance

**A1** Energy $U = 1/2\ CV^2$, for $C = 4\mu F$

$V = 2V$, $U = 1/2 \times 4 \times 4 = 8\ \mu J$

**A2** Parallel $C_{eq} = C_1 + C_2$, If $C_1 = C$, $C_2 = 2C$

$C_{eq} = 3C$.

**A3** Field in dielectric

$E = \frac{\sigma}{K\epsilon_0}$, in air $E = \sigma/\varepsilon_0$

For K = 2, field ratio 1/2

**A4** Dielectric (K = 3) full area : $C' = 3\varepsilon_0 A/d$

If partial, adjust area ratio.

## CHAPTER 26 Current and Resistance

**A1** $R_{A0} = \int_0^{1/2} \frac{\rho}{\pi} \frac{dx}{(r+4rx)^2} = \frac{2\rho}{3\pi r^2}$

$R_{0B} = \int_{1/2}^{1} \frac{\rho}{\pi} \frac{dx}{(r+4rx)^2} = \frac{2\rho}{15\pi r^2}$

$$(x)\ \frac{2\rho}{15\pi r^2} = (1)\ \frac{2\rho}{3\pi r^2} \Rightarrow x = 5$$

**A2** For a 6v voltage source

Power $P \alpha \frac{1}{R}$ (since voltage is constant)

If $R_1 > R_2$ then $P_1 < P_2$

For a 2A correct source

Power $P \alpha R$ (since current is constant)

If $R_2 > R_1$ then $P_2 < P_1$

Given $P = \frac{6}{16} \times \frac{11}{1}$

$$Q = \frac{6}{5} \times \frac{11}{1}$$

Since $Q_1 > P_1$ and $Q_2 < Q_1$, the power and heat dissipation increases with resistance in the current source case.

## CHAPTER 27 Circuits

**A1** Two loops $\mathcal{E} = 4V, R_1 = 3\Omega, R_2 = 2\Omega$
Solve current I = 1.33 A in a branch

**A2** Discharging: $V = V_0 e^{-t/RC}$
At t = RC

$V/V_0 = e^{-1} \approx 0.67$

**A3** Voltmeter reading $V = I\,\Omega$
If R voltmeter high
ideal reading
For I = 1A, R = 3Ω, and V = 3V

**A4** Kirchhoff law: solve for current/voltage in two loops.

**A5** RC charging/discharging

V, I, and Q behaviors: exponential growth/decay, time constant, or final values.

## CHAPTER 28 Magnetic Force

**A1** A → Correct → The magnetic field B $(x, y)$ is always perpendicular to the plane

B → Correct → The magnitude $|B(x, y)|$ depends only on the radial distance $r = \sqrt{x^2 + y^2}$

**A2** Magnetic field of solenoid

$$\vec{B} = \mu_0 m I \hat{n}$$

Induced emf in loop

$$\in = \frac{-AdB}{dt} = -\mu_0 m I A \frac{d\hat{n}}{dt}$$

Induced current

$$i = \frac{\in}{R}$$

Magnetic moment of loop

$$\vec{\mu} = iA\hat{n}$$

Torque on loop

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

At

$$t = \frac{\pi}{6\omega}, \sin \omega t = \frac{1}{2}, \cos \omega t = \frac{\sqrt{3}}{2}$$

Using

$$\alpha = \frac{\mu_0^2 m^2 I^2 A^2 \omega}{2R}$$

Evaluate $\vec{\tau}$ for each given $\hat{n}(t)$

I → Q  II → P  III → S  IV → R

## CHAPTER 29 Magnetic Fields Due to Currents

**A1** $r_\alpha = \frac{\sqrt{2m_\alpha q_\alpha v}}{q_{\alpha B}}, r_s = \frac{\sqrt{2m_s q_s v}}{q_{sB}}$

$$\frac{r_s}{r_\alpha} = \sqrt{\frac{m_s}{q_s} \cdot \frac{q_\alpha}{m_\alpha}} = \sqrt{\left(\frac{32}{1}\right) \cdot \left(\frac{2}{4}\right)} = 4$$

**A2** $\vec{B}_{net} = \vec{B}_{AB} + \vec{B}_{BC} + \vec{B}_{CD} + \vec{B}_{DE} + \vec{B}_{EF} + \vec{B}_{FG}$

$$\overrightarrow{B_{AB}} = \overrightarrow{B_{DE}} = \overrightarrow{B_{FG}} = 0$$

$$\overrightarrow{B_{AB}} = \frac{\mu_0 I}{4\pi L} \sin 45° \left[-\hat{K}\right]$$

$$\overrightarrow{B_{CD}} = \frac{\mu_0 I}{4\left[\frac{L}{2}\right]} \left[-\hat{K}\right]$$

$$\overrightarrow{B_{EF}} = \frac{\mu_0 I}{8\left[\frac{L}{2}\right]}\left[-\hat{K}\right]$$

**A3** $\oint \vec{B}\cdot\vec{dl} = \int_0^i \vec{B}\cdot\vec{dl} + \int_i^f \vec{B}\cdot\vec{dl} + \int_f^0 \vec{B}\cdot\vec{dl}$

$$= \mu_0 \frac{I}{2\pi}\frac{7\pi}{12}$$

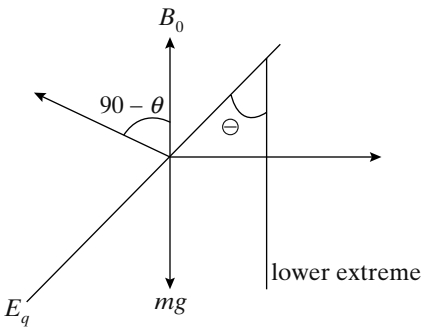
$$= \frac{7\mu_0 I}{24}$$

**A4** $l\,\pi r^2 = \vec{M}$

$\tau = MB\cos\theta$

$l\pi r^2 B_0 \cos\theta = mgr\sin\theta$

$$\tan\theta = \frac{l\pi r B_0}{mg}$$




**A5** $x = 2R$

$$= 2\frac{mv}{qB}$$

$$= \frac{\sqrt[2]{2m(e\Delta v)}}{qB}$$

for $H^+$ ion

$x = 3.91$cm

$= 4$cm

For $m = 144(mp)$

$= 12(\times H^+)$

$= 48$ cm

For $1 \le Am \le 196$

$= (x_1 - x_0)\min = 2R_{196} - 2R$

$= (14 \times 4) - 4$

$= 52$cm.

For $Am = 196$

$W_{min} = R196 = 28$cm

**A6** For a conducting spherical shell

$$\frac{\mu}{L} = \frac{Q}{2M}$$

for a conducting solid sphere, the charge resides on the surface, so the magnetic moment is same as that of a shell

$$\mu = \frac{Q\omega R^2}{3}$$

The angular momentum of a solid sphere is

$$L = I\omega = \frac{2}{5}MR^2\omega$$

$$\frac{\mu}{L} = \frac{\frac{Q\omega R^2}{3}}{\frac{2}{5}MR^2\omega} = \frac{5Q}{6M}$$

Comparing with

$$\frac{\mu}{L} = \alpha\frac{Q}{M}$$

$$\alpha = \frac{5}{3} \approx 1.67$$

## CHAPTER 31 Electromagnetic Induction

**A1** $\varepsilon = Blv$

$A \rightarrow$ EMF proportional to v

$C \rightarrow$ current depends on resistance

**A2** Induced current opposes flux change

If flux increases, current flow to decrease it.

**A3** Growth $I = (V/R)(1 - e^{-t/\tau})$

At $t = \tau$, $I = 0.63V/R$

**A4** E-field

$E = (r/2)\,dB/dt$ (inside charging B-field)

$D \rightarrow$ field magnitude or direction.

**A5** $U = 1/2LI^2$

For $L = 2H$, $I = 2A$

$U = 1/2 \times 2 \times 4 = 4J$

**A6** $\varepsilon = -d\phi/dt$, if loop rotates in B-field $\Phi$

$\phi = BACos\ wt$

**A7** Magnetic field exist only for $y \geq 0$ and varies as $B(t) = B_0 \cos(\omega t)$

As the loop rotates, flux changes only when the loop is in the field region otherwise flux is zero

Because B(t) itself changes sign with time, the induced emf alternates in sign during successive intervals when the loop is in the field.

This produces alternating positive and negative emf pulses with zero in between, matching plot 'A'.

**A8** (B) When the loop is completely inside the uniform magnetic field, the magnetic flux is constant; no induced current; net force is zero.

(D) For $V_0 = 3kL$, the loop enters completely into the magnetic field at the given time expression.

## *CHAPTER 32 Electromagnetic Oscillations and Alternating Current*

**A1** $Z_c = \frac{1}{wc}$ where $w = 2\pi f = 100\pi$

$$Z_c = \sqrt{Z^2 - R^2} = \sqrt{40^2 - 20^2} = \sqrt{1600 - 400}$$

$$= \sqrt{1200} \approx 35\Omega$$

$$C = \frac{1}{wZ_c} = \frac{1}{100\pi \times 35} \approx 100\mu F$$

**A2** $\cos\phi = \frac{R}{z} = \frac{20}{40} = 0.5$

$\phi = 60°$

**A3** The induced current oscillates with a maximum value given by

$$I_{max} = \frac{\varepsilon}{WL}$$

$$I_{max} = \frac{0.04}{(100 \times 0.1)}$$

$$I_{max} = \frac{0.04}{10} = 0.004A = 4mA$$

**A4** $\Delta w = \frac{w_0}{Q} = \frac{10^5}{400} = 250$ rad/s

$R \rightarrow 4$ (Bandwidth = 250 rad/s)

$$P_{max} = \frac{v^2 rms}{R} = \frac{\left(\frac{45}{\sqrt{2}}\right)^2}{12.5}$$

$$P_{max} = \frac{2025}{25} = 81w$$

$S \rightarrow 2$ (peak Power = 18w)

$$R = \frac{W_0 L}{Q} = \frac{10^5 \times 50 \times 10^{-3}}{400} = 12.5\Omega$$

$$I_0 = \frac{45}{12.5} = 3.6A = 3600mA$$

$P \rightarrow 3(3600mA = 3.6A)$

**A5** (P) At $t = 0, I_1 = 0$

(Q) At $t \rightarrow 00, I_2 = \frac{20}{5} = 4amp$

(R) $w_0 \frac{1}{\sqrt{Lc}} = 2$ kilo – rad/sec

(S) $\frac{1}{2} LI_2^2 = \frac{1}{2} CV_0^2$

$V_0 = 200$ volts

**A6** Given:

$$V = 300 \sin(400t)$$

Purely Resistive Circuit

$\rightarrow$ Resistance $R = 30\ \Omega$

$\rightarrow$ Impedance $Z = R = 30\ \Omega$

$\rightarrow$ Phase difference $\phi = 0$

$$I_0 = \frac{V_0}{Z} = \frac{300}{30} = 10A$$

$$i = 10\sin(400t)$$

Series R – L Circuit

$\rightarrow$ Inductive reactance

$X_L = \omega L = 400 \times 100 \times 10^{-3} = 40\ \Omega$

$\rightarrow$ Impedance

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{30^2 + 40^2} = 50\ \Omega$$

→ Current amplitude

$$I_0 = \frac{300}{50} = 6A$$

→ Phase angle

$$\tan\phi = \frac{X_L}{R} = \frac{40}{30} = \frac{4}{3}$$

$$\phi = \tan^{-1}\left(\frac{4}{3}\right)$$

$$i = 6\sin\left(400t - \tan^{-1}\frac{4}{3}\right)$$

At t = 0

$$i(0) = -6\sin\left(\tan^{-1}\frac{4}{3}\right) = -6\times\frac{4}{5} = -4.8\,A$$

## CHAPTER 33 Electromagnetic Waves

**A1** Given the physical quantity

$$S = \frac{E\times B}{\mu_0}$$

$$S = \frac{\text{Power}}{\text{Area}} = \left[\frac{M}{T^3}\right]$$

Dimension of S

$$S = \frac{\left[\frac{ML}{T^3A}\right]\times\left[\frac{M}{T^2A}\right]}{\left[\frac{ML}{T^2A^2}\right]} = \left[\frac{M}{T^3}\right]$$

Compare with

$$\frac{\text{Force}}{\text{Length}\times\text{Time}} = \left[\frac{M}{T^3}\right]$$

**A2** Initial ratio $r = \frac{I_A}{I_B} = 2$

First polaroid: $I'_B = \frac{IB}{2}$

Second polaroid at 45° = $I''_B$

$= I'_B \cos^2 45° = \frac{I_B}{4}$

New ratio $r' = \frac{I_A}{I''_B} = 4\times 2 = 8$

**A3** Number of photon

$$N = 35\times 10^7 = 3.5\times 10^8$$

Energy of one photon

$E = h\nu = (6\times 10^{-34})(10^{15}) = 6\times 10^{-19}$ J

Total energy in unit volume

$U = NE = (3.5\times 10^8)(6\times 10^{-19})$

$= 2.1\times 10^{-10}$ J/m$^3$

For an electromagnetic wave

$$u = \frac{B_0^2}{2\mu_0}$$

So,

$$B_0 = \sqrt{2\mu_0 u}$$

$$\mu_0 = 4\pi\times 10^{-7} = \frac{88}{7}\times 10^{-7} = 1.26\times 10^{-6}$$

$$B_0 = \sqrt{2(1.26\times 10^{-6})(2.1\times 10^{-10})}$$

$$\approx \sqrt{5.28\times 10^{-16}}$$

$$\approx 2.3\times 10^{-8}\ T$$

$$B_0 = 23\times 10^{-9}\ T$$

$$\alpha = 23$$

## CHAPTER 34 Geometrical Optics: Reflection

**A1** The given plane equation is

$x + y + z = 1$

Using the mirror image formula

$$\alpha = 10 - 2\frac{(10+15+20-1)}{1+1+1}$$

$$\beta = 15 - 2\frac{(10+15+20-1)}{1+1+1}$$

$$\gamma = 20 - 2\frac{(10+15+20-1)}{1+1+1}$$

Calculating the term inside the fraction

$2(10 + 15 + 20 - 1) = 2(44) = 88$

$$\frac{88}{3} = 29.33$$

the coordinates of the mirror image are

$\alpha = 10 - 29.33 = -58/3$

$\beta = 15 - 29.33 = -43/3$

$\gamma = 20 - 29.33 = -28/3$

Final values

**A2** Using the mirror formula

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$1/v = 1/10 - 1/30 = 2/30 = 1/15$$

$$v = 15\text{cm}$$

Differentiating the mirror equation

$$d/dt(1/v + 1/u) = 0$$

$$\frac{-dv}{v^2} = \frac{-du}{u^2}$$

$$dv = \left(\frac{v^2}{u^2}\right)du$$

$$dv = 15^2/30^2\ du = \frac{225}{900}du = \frac{1}{4}du$$

Since $du/dt = v_0 - v_m$, we get

$$v_i = \frac{1}{4}(v_0 - v_m)$$

for the image to be at rest

$0 = 1/4\ (15 - v_m)$

$4v_m + v_m = 15$

$v_m = 30_m/5$

$v_m = 3^{cm}/\text{sec}$

**A3** Using Snell's law at the glass-air interface

$$3\sin\alpha = 1 \times \sin 60°$$

$$\sin\alpha = \frac{1}{2}$$

$$\alpha = 30°$$

In triangle $\Delta OAB$

$$\frac{\sin 120°}{R} = \frac{\sin\theta}{\frac{3R}{2}}$$

$$\sin\theta = \frac{3}{4} = 0.75$$

**A4** For the image to be formed back on the source S, the round-trip optional path between the mirror must satisfy the self imaging condition of concave mirrors

The glass slab introduces an additional optical path of $(n_0 - 1)$ t.

This condition is satisfied when the mirror separation are equals, hence A and B.

## *CHAPTER 35 Geometrical Optics: Refraction*

**A1** $\text{Sin}\theta_C = 1/n$, for $n = 1.5$, $\theta_C \approx 41.8°$

**A2** For $u > f$, real inverted image

B → real C → inverted D → magnification varies.

**A3** Deviation $\delta = (n - 1)A$

B → depends on n

C → emergent ray bends are true

**A4** $1/f = 1/f_1 + 1/f_2$

For $f_1 = 20\text{cm}$, $f_2 = -40\text{cm}$

$f = 40\text{cm}$.

**A5** $M = f_0/f_e$, for $f_0 = 100\text{cm}$, $f_e = 10\text{cm}$

$M = 10$.

**A6** $\text{Sin}60° = \frac{\sqrt{3}}{2}r$

$r = 45°$

$\frac{\sqrt{3}}{2}\ \text{Sin}45° = \sqrt{3}\ \text{Sin}\ r_2$

$r_2 = 30$.

$$\left(\frac{1}{\sqrt{3}} + \frac{(\sqrt{3}-1)}{2} + \frac{(\sqrt{3}-1)}{2\sqrt{3}}\right) \times n = \frac{8}{\sqrt{3}}$$

$n = 4$

**A7** $\theta_C = \text{Sin}^{-1}\left(\frac{1}{n}\right)$, for $n = \sqrt{2}$, $\theta_C = 45°$

A, C, D match TIR condition.

**A8** $1/v = 1/f + 1/u$, reflect back

Possible image distances are 220, 80 or 150mm.

**A9** $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

$$\frac{\Delta f}{f^2}=\pm\left(\frac{\Delta v}{v^2}+\frac{\Delta u}{u^2}\right)$$

$$\frac{\Delta f}{f}=\pm\left(\frac{\Delta v}{v^2}+\frac{\Delta u}{u^2}\right)f$$

$$=\pm\left(\frac{0.2}{(20)^2}+\frac{0.1}{(10)^2}\right)\times\frac{20}{3}$$

$$\frac{\Delta f}{f}=\pm 0.01$$

$$\frac{\Delta f}{f}\times 100\%=\pm 1\%$$

**A10** For u > f, real image

B → real D → Since varies hold

**A11** $-\frac{1}{f_{net}}=2\left(\frac{1}{f_{liq}}\right)+2\left(\frac{1}{f_{lens}}\right)+2\left(\frac{1}{f_{mirror}}\right)-(1)$

$$-\frac{1}{f_{net}}=2\left(\frac{n-1}{-9}\right)+2\left(\frac{0.6}{9}\right)+2\left(\frac{-1}{\infty}\right)-(2)$$

from equation (1) and (2)

$$h=\frac{9}{(1.6-n)}$$

**A12** $\alpha=(\theta_0-\phi_0)+(\pi-2\phi_0)+(\theta_0-\phi_0)$

$\alpha=\pi+2\phi_0-4\phi_0-(1)$

$\text{Sin}\,\theta_0=n\text{Sin}\theta_0-(2)$

for P

$n=2, \alpha=180$

If $\alpha=\pi, 2\theta_0-4\theta_0=0$

$\theta_0=2\theta_0$

$\text{Sin}\theta_0=2\text{Sin}\left(\frac{\theta_0}{2}\right)$

P → 5

for Q, $n=\sqrt{3}, \alpha=180$

$\theta_0=2\theta_0$

A = (2)

$\text{Sin}\theta_0=\sqrt{3}\,\text{Sin}\left(\frac{\theta_0}{2}\right)$

$\theta_0=60,0$

**A13** At C, $1\text{Sin}\alpha=\sqrt{3}\text{Sin}30°$

$\alpha=60°$

At B, $\sqrt{\frac{3}{2}}\,\text{sin}r_2=1\ \text{Sin}\alpha r_2=45°$

At A, $1\text{Sin}\theta=\sqrt{\frac{3}{2}}\,\text{Sin}15°$

$$\theta=\text{Sin}^{-1}\left[\sqrt{\frac{3}{2}}\text{Sin}\left(\frac{\pi}{12}\right)\right]$$

## *CHAPTER 36 Interference and Diffraction*

**A1** $\Delta r=(MB+BN)-Ac$

$$\Delta r=(n_1\times\sin i+n_2\,d\cos\theta)-\frac{n_2 d}{\cos\theta}$$

$$\Delta r=n_1\,(d\tan\theta)\,\frac{n_2}{n_1}\,\sin\theta+n_2\,d\cos\theta-\frac{n_2 d}{\cos\theta}$$

$$\Delta r=\frac{n_2 d\sin^2\theta}{\cos\theta}+n_2 d\cos\theta-\frac{n_2 d}{\cos\theta}$$

$$\Delta r=\frac{n_2 d\left[\sin^2\theta+\cos^2\theta-1\right]}{\cos\theta}=0$$

**A2** $\Delta y=\frac{8\lambda D}{(0.8-0.04)\times10^{-3}}-\frac{8\lambda D}{(0.8+0.04)\times10^{-3}}$

$=60.15\mu m$

**A3** $y=\frac{8\times6000\times10^{-10}\times1}{(0.8+0.04\sin wt)\times10^{-3}}$

$$y=\frac{48\times10^{-4}}{(0.8+0.04\sin wt)}$$

$$\left|\frac{d_y}{d_t}\right|=\frac{48\times10^{-4}}{(0.8+0.04\sin wt)^2}(0.04w\cos wt)$$

$T=0, v=v_{max}$

$$V_{max}=\frac{48\times10^{-4}\times0.04\times0.08}{(0.8)^2}$$

$=24\times10^{-6}$ m/s = 24μm/s

**A4** Given

$$b=\frac{\lambda D}{d}m$$

$\lambda = 600$ nm, $m = 3$, $d = 5$ mm $= 5 \times 10^{-3}$ m

$D = 1$ m

Errors

least count in D = 1 cm = 0.01 m

$\Delta D = 0.01$ m

least count in d = 1 mm = $10^{-3}$ m

$\Delta d = 10^{-3}$ m

from these value

$$b = \frac{600 \times 10^{-9} \times 1 \times 3}{5 \times 10^{-3}} = 3.6 \times 10^{-4} \text{ m}$$

Error propagation

$$\frac{\Delta b}{b} = \frac{\Delta D}{D} + \frac{\Delta d}{d}$$

$$= 0.01 + \frac{10^{-3}}{5 \times 10^{-3}}$$

$$= 0.01 + 0.2$$

$$= 0.21$$

$$\Delta b = 0.21 \times 3.6 \times 10^{-4} = 7.56 \times 10^{-5} \text{ m}$$

$$\Delta b = 75.6\ \mu\text{m}$$

**A5** $\tan\theta = \frac{\lambda}{L}$

Given $L = d + 2\lambda = 2 + 2 = 4$ mm

From geometry of wedges

$$\frac{t_1}{t_2} = \frac{1}{3} \Rightarrow t_2 = 3t_1$$

and

$$t_1 + t_2 = 12\ \mu\text{m} \Rightarrow 4t_1 = 12$$

$$t_1 = 3\ \mu\text{m}, \qquad t_2 = 9\ \mu\text{m}$$

Optical path

From slit $S_1$

$$L_1 = S_1P + t_1(n_B - 1) + t_2(n_A - 1)$$

From slit $S_2$

$$L_2 = S_2P + t_2(n_B - 1) + t_1(n_A - 1)$$

Path difference

$$\Delta L = L_2 - L_1 = S_2P - S_1P + (n_A - n_B)(t_1 - t_2)$$

For central maximum $\Delta L = 0$

$$d \sin\theta + (n_A - n_B)(t_1 - t_2) = 0$$

Using $\sin\theta = \frac{y}{D}$

$$\frac{dy}{D} + (1.7 - 1.5)(3 - 9) \times 10^{-6} = 0$$

Substitute $d = 2 \times 10^{-3}$ m, $\quad D = 2$ m

$$\frac{2 \times 10^{-3}}{2} y = 0.2 \times 6 \times 10^{-6}$$

$$y = 1.2 \times 10^{-3} \text{ m}$$

$$= 1.2 \text{ mm}$$

## CHAPTER 38 Photons and Matter Waves

**A1** Convert $\lambda$ into meters.

$\lambda = 200 \times 10^{-9}$ m

$$E = \frac{(6.626 \times 10^{-34})(3 \times 10^{8})}{200 \times 10^{-9}}$$

$$E = \frac{1.9878 \times 10^{-25}}{2 \times 10^{-7}}$$

$E = 9.939 \times 10^{-19}$ J

Convert to electron volts

$1\text{ev} = 1.6 \times 10^{-19}$ J

$$E = \frac{9.939 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$E \approx 6$ ev

**A2** Schrödinger wave equation describes quantum particles.

The time-independent equation:

$$-\frac{h^2}{2m}\frac{d^2\Psi}{dx^2} + \sqrt{\Psi} = E\Psi$$

**A3** Compute momentum uncertainty

$$\Delta P \geq \frac{6.626 \times 10^{-34}}{4\pi \times 10^{-10}}$$

$$\Delta P \geq \frac{6.626 \times 10^{-34}}{12.566 \times 10^{-10}}$$

$$\Delta P \geq 5.27 \times 10^{-25} \text{ Kg m/s}$$

Compute velocity uncertainty using $P = mv$

For an electron $m = 9.11 \times 10^{-31}$kg

$$\Delta V \geq \frac{5.27 \times 10^{-25}}{9.11 \times 10^{-31}}$$

$$\Delta V \geq 5.79 \times 10^{5} \text{ m/s}$$

Approx Closest integer: 3

## CHAPTER 39 Hydrogen Atom

**A1** The correct statement are A and D

**(A)** The ratio of the longests to shortest wavelength in the Balmer series is indeed 9/5.

**(D)** The Lyman series lies entirely in the ultraviolet (wavelength ≤ 121.6 nm) while the Balmer series starts at 364.6 nm, so they do not overlap.

**A2** For a circular orbit under the central force F(r) = –Kr, the centripetal force condition i,

$$\frac{mv^2}{r} = Kr \Rightarrow mv^2 = Kr^2$$

Bohr's quantization condition for angular momentum

$$L = mvr = n\hbar$$

**(A)** $r^2 = n\hbar/\sqrt{mK}$

Squaring the quantization : $v = n\hbar/mr$ substituting into $mv^2 = Kr^2$ yields

$$m\left(\frac{n\hbar}{mr}\right)^2 = Kr^2 \Rightarrow \frac{n^2\hbar^2}{mr^2} = Kr^2 \Rightarrow r^4 = \frac{n^2\hbar^2}{mK}$$

Hence $r^2 = \dfrac{n\hbar}{\sqrt{mK}}$

**(B)** $V^2 = n\hbar\sqrt{K/m^3}$

From $V = n\hbar/(mv)$ and $r^2 = n\hbar/\sqrt{mK}$ we get

$$r = \sqrt{\frac{n\hbar}{(mK)^{1/4}}} \Rightarrow V^2 = \frac{n^2\hbar^2}{m^2r^2}$$

$$= \frac{n^2\hbar^2}{m^2} \cdot \frac{\sqrt{mK}}{n\hbar} = n\hbar\sqrt{\frac{K}{m^3}}$$

**(C)** $L/(mr^2) = \sqrt{k/m}$

Direct substitution yields

$$\frac{L}{mr^2} = \frac{n\hbar}{mr^2} = \frac{n\hbar}{m} \cdot \frac{\sqrt{mK}}{n\hbar} = \sqrt{\frac{K}{m}}$$

**A3** Correct option is (C)

**(A)** $E \propto Z^2 \rightarrow$ (5) Energy of radiation due to electronic transitions from hydrogen like atom.

**(B)** $E \propto (Z-1)^2 \rightarrow$ (1) Energy of characteristic X-rays (Moseley's law)

**(C)** $E \propto Z(Z-1) \rightarrow$ (2) Electrostatic part of the nuclear binding energy for stable nuclei with mass numbers 30 –170 (Coulomb repulsion).

**(D)** E practically independent of Z → (4) Average nuclear binding energy per nucleon for stable nuclei with mass numbers 30 – 170 (saturation property).

**A4** $hv_1 = E_{ion} + k_e$

$$hV_1 = 13.6\text{eV} + 10\text{eV} = 23.6\text{eV}$$

So Energy of the first photon $hV_1 = 23.6\text{eV}$

for hydrogen : $\mu H \approx me$

for positronium : $\mu_{Ps} = \dfrac{m_e \cdot m_e}{m_e + m_e} = \dfrac{m_e}{2}$

$$E_{ps} = \frac{1}{2} \times 13.6\text{eV} = 6.8 \text{ eV}$$

So Binding energy of the positronium

$$E_{ps} = 6.8 \text{ eV}$$

$$K_e + K_p = K_{cm} + (-E_{ps}) + hV_2$$

$$10 + 0 = 5 - 6.8 + hV_2$$

$$hV_2 = 10 - 5 + 6.8 = 11.8\text{eV}$$

Energy of the second photon (hV2)

$$hV_2 = 11.8 \text{ eV}$$

$$\Delta E = |hV_1 - hV_2|$$

$$\Delta E = |23.6 - 11.8| = 11.8\text{eV}$$

## CHAPTER 40 All About Atoms

**A1** $$\frac{\lambda \text{cut off, K}\alpha(z=46)}{\lambda \text{cut off, K}\alpha(z=41)} = \frac{\frac{1}{(46-1)^2}}{\frac{1}{(41-1)^2}}$$

$$\Rightarrow \frac{2}{x} = \frac{(40)^2}{(45)^2}$$

$$\Rightarrow x = 2.53$$

**A2** de brogli wavelength of electron in H-like atom

$$\lambda_e = \frac{2\pi n a_0}{Z}$$

for n = 3

$$\lambda_e = \frac{6\pi a_0}{Z}$$

Thermal de broglie wavelength of neutron

$$\lambda_n = \frac{h}{\sqrt{2m_N k_B T}}$$

Given $\lambda_e = \lambda_n$

$$\frac{h}{\sqrt{2m_N k_B T}} = \frac{6\pi a_0}{Z}$$

Solving for T

$$T = \frac{Z^2 n^2}{72\pi^2 a_0^2 m_N k_B}$$

Compare with mentioned equation

$$\alpha = 72$$

## CHAPTER 41 The Nucleus

**A1** Fusion (e.g. $^2H + {}^3H \rightarrow {}^4H_e$) releases energy.

**A2** Decay types: α reduces A, β changes Z, γ releases energy.

**A3** $t = T_{1/2} \log_2 (N_0/N)$

If $N/N_0 = 1/5$ $t = T_{1/2}$ 2.32 (approx)

**A4** Models (liquid drop, shell) explain stability.

**A5** From $^{238}U$ to $^{234}Th$, 2 alpha decays

**A6** Fusion (e.g. $^4He$ formation) powers stars.

**A7** Fission of $^{238}U$ releases ~ 2.5 neutrons

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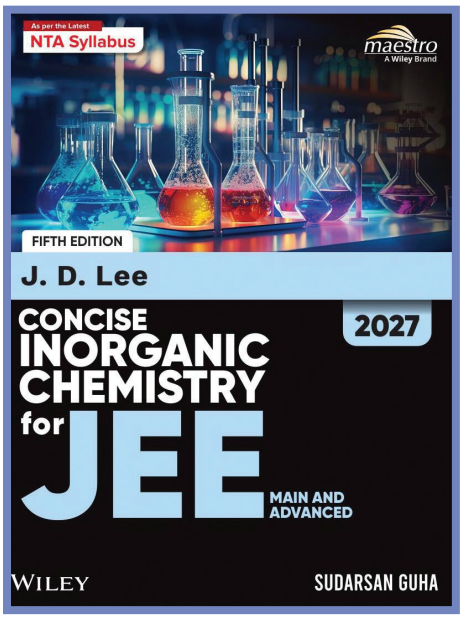


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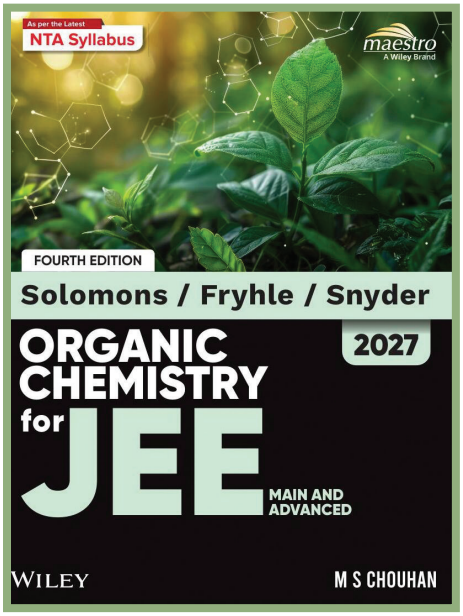


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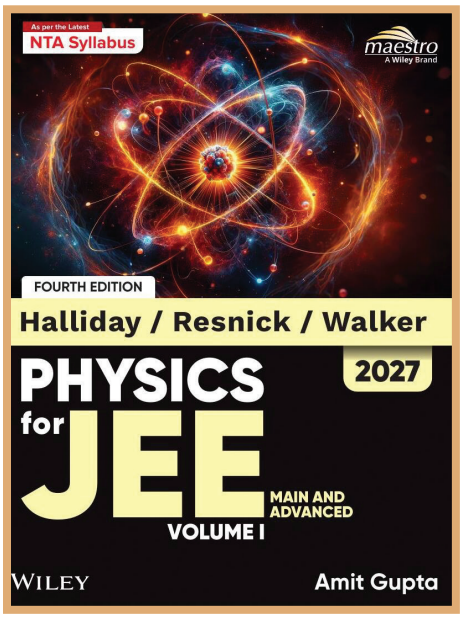


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