ANSWERS

Chapter 1

1.1 (a)

1.2 (a)

1.3 (d)

1.4 (b)

1.5 (c)

1.6 (a)

1.7 (a)

1.8 (c), (d)

1.9 (b), (d)

1.10 (b), (d)

1.11 (c), (d)

1.12 (a), (c).

1.13 (a), (b), (c) and (d).

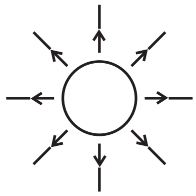
1.14 Zero.

1.15 (i) $\frac{-Q}{4\pi R_1^2}$ (ii) $\frac{Q}{4\pi R_2^2}$

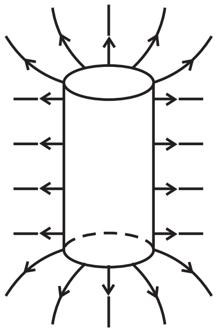
1.16 The electric fields bind the atoms to neutral entity. Fields are caused by excess charges. There can be no excess charge on the inter surface of an isolated conductor.

1.17 No, the field may be normal. However, the converse is true.

1.18



Top view



Side view

1.19 (i) $\frac{q}{8\varepsilon_0}$ (ii) $\frac{q}{4\varepsilon_0}$ (iii) $\frac{q}{2\varepsilon_0}$ (iv) $\frac{q}{2\varepsilon_0}$.

1.20 1 Molar mass M of Al has N_A = 6.023 × 10^{23} atoms.

$\therefore$ m = mass of Al paisa coin has $N = N_A \frac{m}{M}$ atoms

Now, Z_{Al} = 13, M_{Al} = 26.9815g

Hence $N = 6.02 \times 10^{23}$ atoms/mol $\times \frac{0.75}{26.9815\text{g/mol}}$

$= 1.6733 \times 10^{22}$ atoms

$\therefore q$ = +ve charge in paisa = N Ze

$= (1.67 \times 10^{22})(13)\ (1.60 \times 10^{-19}\text{C})$

$= 3.48 \times 10^4$ C.

q = 34.8 kC of ±ve charge.

This is an enormous amount of charge. Thus we see that ordinary neutral matter contains enormous amount of ± charges.

1.21 (i) $F_1 = \frac{|q|^2}{4\pi\varepsilon_0 r_1^2} = \left(8.99\times10^9 \frac{\text{Nm}^2}{\text{C}^2}\right)\frac{(3.48\times10^4\text{C})}{10^{-4}\text{m}^2} = 1.1\times10^{23}\text{N}$

(ii) $\frac{F_2}{F_1} = \frac{r_1^2}{r_2^2} = \frac{(10^{-2}\text{m})^2}{(10^2\text{m})^2} = 10^{-8} \Rightarrow F_2 = F_1\times10^{-8} = 1.1\times10^{15}\text{N}$

(iii) $\frac{F_3}{F_1} = \frac{r_1^2}{r_3^2} = \frac{(10^{-2}\text{m})^2}{(10^6\text{m})^2} = 10^{-16}$

$F_3 = 10^{-16} F_1 = 1.1 \times 10^7$ N.

Conclusion: When separated as point charges these charges exert an enormous force. It is not easy to disturb electrical neutrality.

1.22 (i) Zero, from symmetry.

(ii) Removing a +ve Cs ion is equivalent to adding singly charged -ve Cs ion at that location.
Net force then is

$$F = \frac{e^2}{4\pi\varepsilon_0 r^2}$$

where r = distance between the Cl ion and a Cs ion.

$$= \sqrt{(0.20)^2+(0.20)^2+(0.20)^2}\times10^{-9} = \sqrt{3(0.20)^2}\times10^{-9}$$

$$= 0.346 \times 10^{-9}\,\text{m}$$

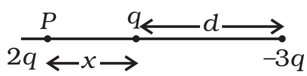
Hence, $F = \dfrac{(8.99\times10^9)(1.6\times10^{-19})^2}{(0.346\times10^{-9})^2} = 192\times10^{-11}$

$$= 1.92 \times 10^{-9}\,\text{N}$$

Ans 1.92×10^{-9} N, directed from A to Cl^-

1.23 At P: on $2q$, Force due to q is to the left and that due to $-3q$ is to the right.

$$\therefore \frac{2q^2}{4\pi\varepsilon_0 x^2} = \frac{6q^2}{4\pi\varepsilon_0 (d+x)^2}$$



$\therefore (d + x)^2 = 3x^2$

$\therefore 2x^2 - 2dx - d^2 = 0$

$$x = \frac{d}{2} \pm \frac{\sqrt{3}d}{2}$$

(–ve sign would be between q and $-3q$ and hence is unaceptable.)

$$x = \frac{d}{2} + \frac{\sqrt{3}d}{2} = \frac{d}{2}(1+\sqrt{3}) \text{ to the left of } q.$$

1.24 (a) Charges A and C are positive since lines of force emanate from them.

(b) Charge C has the largest magnitude since maximum number of field lines are associated with it.

(c) (i) near A. There is no neutral point between a positive and a negative charge. A neutral point may exist between two like charges. From the figure we see that a neutral point exists between charges A and C. Also between two like charges the neutral point is closer to the charge with smaller magnitude. Thus, electric field is zero near charge A.

1.25 (a) (i) zero (ii) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$ along $\overline{OA}$ (iii) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{2q}{r^2}$ along $\overline{OA}$

(b) same as (a).

1.26 (a) Let the Universe have a radius R. Assume that the hydrogen atoms are uniformly distributed. The charge on each hydrogen atom is $e_H = -(1 + y)\, e + e = -ye = |ye|$

The mass of each hydrogen atom is ~ m_p (mass of proton). Expansion starts if the Coulumb repulsion on a hydrogen atom, at R, is larger than the gravitational attraction.

Let the Electric Field at R be $\mathbf{E}$. Then

$$4\pi R^2 E = \frac{4}{3\varepsilon_o}\pi R^3 N|ye| \quad \text{(Gauss's law)}$$

$$\mathbf{E}\,(R) = \frac{1}{3}\frac{N|ye|}{\varepsilon_o} R\,\hat{\mathbf{r}}$$

Let the gravitational field at R be G_R. Then

$$-4\pi R^2 G_R = 4\pi G\, m_p \frac{4}{3}\pi R^3 N$$

$$G_R = -\frac{4}{3}\pi G m_\rho N R$$

$$\mathbf{G}_R(\mathbf{R}) = -\frac{4}{3}\pi G m_\rho N\, R\,\hat{\mathbf{r}}$$

Thus the Coulombic force on a hydrogen atom at R is

$$ye\mathbf{E}(R) = \frac{1}{3}\frac{Ny^2e^2}{\varepsilon_o} R\,\hat{\mathbf{r}}$$

The gravitational force on this atom is

$$m_p\mathbf{G}_R(R) = -\frac{4\pi}{3} G N m_p^2 R\,\hat{\mathbf{r}}$$

The net force on the atom is

$$\mathbf{F} = \left(\frac{1}{3}\frac{Ny^2e^2}{\varepsilon_o} R - \frac{4\pi}{3} G N m_p^2 R\right)\hat{\mathbf{r}}$$

The critical value is when

$$\frac{1}{3}\frac{Ny_c^2e^2}{\varepsilon_o} R = \frac{4\pi}{3} G N m_p^2 R$$

$$\Rightarrow y_c^2 = 4\pi\varepsilon_o G \frac{m_p^2}{e^2}$$

$$\square\ \frac{7\times10^{-11}\times1.8^2\times10^6\times81\times10^{-62}}{9\times10^9\times1.6^2\times10^{-38}}$$

$$\square\ 63\times10^{-38}$$

$$\therefore y_C\ \square\ 8\times10^{-19}\ \square\ 10^{-18}$$

(b) Because of the net force, the hydrogen atom experiences an acceleration such that

$$m_p \frac{d^2R}{dt^2} = \left(\frac{1}{3} \frac{Ny^2e^2}{e_o} R - \frac{4p}{3} GNm_p^2 R \right)$$

$$\text{Or, } \frac{d^2R}{dt^2} = a^2R \text{ where } \alpha^2 = \frac{1}{m_p}\left(\frac{1}{3} \frac{Ny^2e^2}{e_o} - \frac{4p}{3} GNm_p^2 \right)$$

This has a solution $R = Ae^{at} + Be^{-at}$

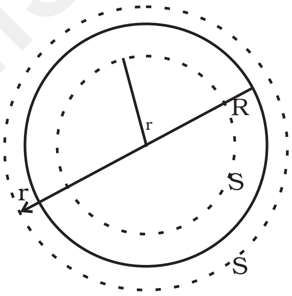
As we are seeking an expansion, $B = 0$.

$\therefore R = Ae^{\alpha t}$

$\Rightarrow \dot{R} = \alpha Ae^{\alpha t} = \alpha R$

Thus, the velocity is proportional to the distance from the centre.

1.27 (a) The symmetry of the problem suggests that the electric field is radial. For points $r < R$, consider a spherical Gaussian surfaces. Then on the surface



$$\oint \mathbf{E_r} . \mathbf{dS} = \frac{1}{\varepsilon_o} \int_V \rho dv$$

$$4\pi r^2 E_r = \frac{1}{\varepsilon_o} 4\pi k \int_o^r r'^3 dr'$$

$$= \frac{1}{\varepsilon_o} \frac{4\pi k}{4} r^4$$

$$\therefore E_r = \frac{1}{4\varepsilon_o} kr^2$$

$$\mathbf{E}(r) = \frac{1}{4\varepsilon_o} kr^2 \hat{\mathbf{r}}$$

For points $r > R$, consider a spherical Gaussian surfaces' of radius r,

$$\oint \mathbf{E}_r . d\mathbf{S} = \frac{1}{\varepsilon_o} \int_V \rho dv$$

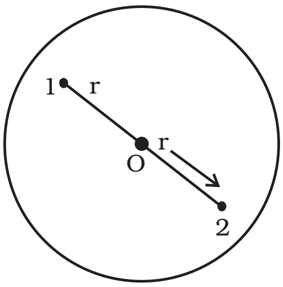
$$4\pi r^2 E_r = \frac{4\pi k}{\varepsilon_o} \int_o^R r^3 dr$$

$$= \frac{4\pi k}{\varepsilon_o} \frac{R^4}{4}$$

$$\therefore E_r = \frac{k}{4\varepsilon_o} \frac{R^4}{r^2}$$

$$\mathbf{E}(r) = (k / 4\varepsilon_o)(R^4 / r^2)\hat{\mathbf{r}}$$

(b) The two protons must be on the opposite sides of the centre along a diameter. Suppose the protons are at a distance r from the centre.



Now, $4\pi \int_o^R kr'^3 dr = 2e$

$$\therefore \frac{4\pi k}{4} R^4 = 2e$$

$$\therefore k = \frac{2e}{\pi R^4}$$

Consider the forces on proton 1. The attractive force due to the charge distribution is

$$-e\mathbf{E}_r = -\frac{e}{4\varepsilon_o} kr^2 \hat{\mathbf{r}} = -\frac{2e^2}{4\pi\varepsilon_o} \frac{r^2}{R^4} \hat{\mathbf{r}}$$

The repulsive force is $\dfrac{e^2}{4\pi\varepsilon_o} \dfrac{1}{(2r)^2} \hat{\mathbf{r}}$

Net force is $\left(\dfrac{e^2}{4\pi\varepsilon_o 4r^2} - \dfrac{2e^2}{4\pi\varepsilon_o} \dfrac{r^2}{R^4} \right) \hat{\mathbf{r}}$

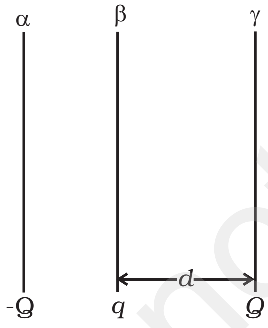
This is zero such that

$$\frac{e^2}{16\pi\varepsilon_o r^2} = \frac{2e^2}{4\pi\varepsilon_o} \frac{r^2}{R^4}$$

$$\text{Or, } r^4 = \frac{4R^4}{32} = \frac{R^4}{8}$$

$$\Rightarrow r = \frac{R}{(8)^{1/4}}$$

Thus, the protons must be at a distance $r = \dfrac{R}{\sqrt[4]{8}}$ from the centre.



1.28 (a) The electric field at γ due to plate α is $-\dfrac{Q}{S2\varepsilon_o} \hat{\mathbf{x}}$

The electric field at γ due to plate β is $\dfrac{q}{S2\varepsilon_o} \hat{\mathbf{x}}$

Hence, the net electric field is

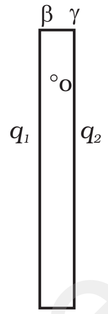
$$\mathbf{E}_1 = \frac{(Q-q)}{2\varepsilon_o S} (-\hat{\mathbf{x}})$$

(b) During the collision plates β & γ are together and hence must be at one potential. Suppose the charge on β is q_1 and on γ is q_2. Consider a point O. The electric field here must be zero.

Electric field at 0 due to $\alpha = -\dfrac{Q}{2\varepsilon_o S} \hat{\mathbf{x}}$

Electric field at 0 due to $\beta = -\dfrac{q_1}{2\varepsilon_o S}\hat{\mathbf{x}}$

Electric Field at 0 due to $\gamma = -\dfrac{q_2}{2\varepsilon_o S}\hat{\mathbf{x}}$



$$\therefore \frac{-(Q+q_2)}{2\varepsilon_o S} + \frac{q_1}{2\varepsilon_o S} = 0$$

$\Rightarrow q_1 - q_2 = Q$

Further, $q_1 + q_2 = Q + q$

$\Rightarrow q_1 = Q + q/2$

and $q_2 = q/2$

Thus the charge on β and γ are $Q + q/2$ and $q/2$, respectively.

(c) Let the velocity be v at the distance d after the collision. If m is the mass of the plate γ, then the gain in K.E. over the round trip must be equal to the work done by the electric field.
After the collision, the electric field at γ is

$$\mathbf{E}_2 = -\frac{Q}{2\varepsilon_o S}\hat{\mathbf{x}} + \frac{(Q+q/2)}{2\varepsilon_o S}\hat{\mathbf{x}} = \frac{q/2}{2\varepsilon_o S}\hat{\mathbf{x}}$$

The work done when the plate γ is released till the collision is $F_1 d$ where F_1 is the force on plate γ.
The work done after the collision till it reaches d is $F_2 d$ where F_2 is the force on plate γ.

$$F_1 = E_1 Q = \frac{(Q-q)Q}{2\varepsilon_o S}$$

and $F_2 = E_2 q/2 = \dfrac{(q/2)^2}{2\varepsilon_o S}$

∴ Total work done is

$$\frac{1}{2\varepsilon_o S}\left[(Q-q)Q + (q/2)^2\right]d = \frac{1}{2\varepsilon_o S}(Q - q/2)^2 d$$

$$\Rightarrow (1/2)mv^2 = \frac{d}{2\varepsilon_o S}(Q-q/2)^2$$

$$\therefore v = (Q - q/2)\left(\frac{d}{m\varepsilon_o S}\right)^{1/2}$$

1.29 (i) $F = \dfrac{Q_q}{r^2} = 1\,\text{dyne} = \dfrac{[1\,\text{esu of charge}]^2}{[1\,\text{cm}]^2}$

Or,

1 esu of charge = 1 $(\text{dyne})^{1/2}$ (cm)

Hence, [1 esu of charge] = $[F]^{1/2} L = [MLT^{-2}]^{1/2} L = M^{1/2} L^{3/2} T^{-1}$

[1 esu of charge] = $M^{1/2} L^{3/2} T^{-1}$

Thus charge in cgs unit is expressed as fractional powers (1/2) of M and (3/2) of L.

(ii) Consider the coloumb force on two charges, each of magnitude 1 esu of charge separated by a distance of 1 cm:
The force is then 1 dyne = 10^{-5} N.
This situation is equivalent to two charges of magnitude x C separated by 10^{-2}m.
This gives:

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{x^2}{10^{-4}}$$

which should be 1 dyne = 10^{-5} N. Thus

$$\frac{1}{4\pi\varepsilon_0} \cdot \frac{x^2}{10^{-4}} = 10^{-5} \Rightarrow \frac{1}{4\pi\varepsilon_0} = \frac{10^{-9}}{x^2} \frac{\text{Nm}^2}{\text{C}^2}$$

With $x = \frac{1}{[3] \times 10^9}$, this yields

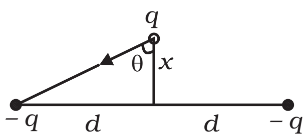
$$\frac{1}{4\pi\varepsilon_0} = 10^{-9} \times [3]^2 \times 10^{18} = [3]^2 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}$$

With [3] $\rightarrow$ 2.99792458, we get

$$\frac{1}{4\pi\varepsilon_0} = 8.98755....\times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \text{ exactly}$$

1.30 Net force F on q towards the centre O

$$F = 2\frac{q^2}{4\pi\varepsilon_0 r^2}\cos\theta = -\frac{2q^2}{4\pi\varepsilon_0 r^2} \cdot \frac{x}{r}$$



$$F = \frac{-2q^2}{4\pi\varepsilon_0} \frac{x}{(d^2 + x^2)^{3/2}}$$

$$\approx \frac{-2q^2}{4\pi\varepsilon_0 d^3} x = -kx \text{ for } x << d.$$

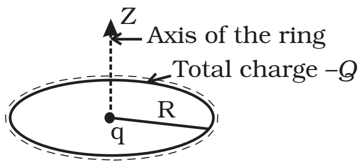
Thus, the force on the third charge q is proportional to the displacement and is towards the centre of the two other charges. Therefore, the motion of the third charge is harmonic with frequency

$$\omega = \sqrt{\frac{2q^2}{4\pi\varepsilon_0 d^3 m}} = \sqrt{\frac{k}{m}}$$

and hence $T = \frac{2\pi}{\omega}\left[\frac{8\pi^3\varepsilon_0 m d^3}{q^2}\right]^{1/2}$.

1.31 (a) Slight push on q along the axis of the ring gives rise to the situation shown in Fig (b). A and B are two points on the ring at the end of a diameter.

Force on q due to line elements $\frac{-Q}{2\pi R}$ at A and B is



(a)

$$F_{A+B} = 2.\frac{-Q}{2\pi R}.q.\frac{1}{4\pi\varepsilon_0}.\frac{1}{r^2}.\cos\theta$$

$$= \frac{-Qq}{\pi R.4\pi\varepsilon_0}.\frac{1}{(z^2+R^2)}.\frac{z}{(z^2+R^2)^{1/2}}$$

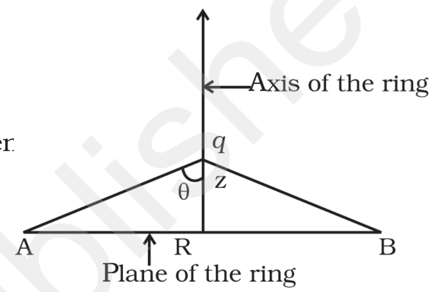
Total force due to ring on q = $(F_{A+B})(\pi R)$

$$= \frac{-Qq}{4\pi\varepsilon_0}\frac{z}{(z^2+R^2)^{3/2}}$$

$$\approx \frac{-Qq}{4\pi\varepsilon_0} \text{ for } z << R$$

Thus, the force is propotional to negative of displacement under such forces is harmonic.

(b) From (a)



$$m\frac{d^2z}{dt^2} = -\frac{Qqz}{4\pi\varepsilon_0 R^3} \text{ or } \frac{d^2z}{dt^2} = -\frac{Qq}{4\pi\varepsilon_0 mR^3}z$$

That is, $\omega^2 = \frac{Qq}{4\pi\varepsilon_0 mR^3}$. Hence $T = 2\pi\sqrt{\frac{4\pi\varepsilon_0 mR}{Qq}}$

(b)

Chapter 2

2.1 (d)

2.2 (c)

2.3 (c)

2.4 (c)

2.5 (a)

2.6 (c)

2.7 (b), (c), (d)

2.8 (a), (b), (c)

2.9 (b), (c)

2.10 (b), (c)

2.11 (a), (d)

2.12 (a), (b)

2.13 (c) and (d)

2.14 More.

2.15 Higher potential.

2.16 Yes, if the sizes are different.

2.17 No.

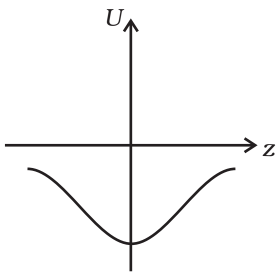
2.18 As electric field is conservative, work done will be zero in both the cases.

2.19 Suppose this were not true. The potential just inside the surface would be different from that at the surface resulting in a potential gradient. This would mean that there are field lines pointing inwards or outwards from the surface. These lines cannot at the other end be again on the surface, since the surface is equipotential. Thus, this is possible only if the other end of the lines are at charges inside, contradicting the premise. Hence, the entire volume inside must be at the same potential.

2.20 C will decrease

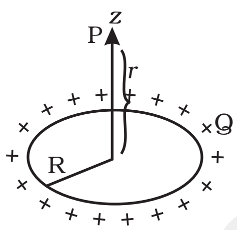
Energy stored = $\frac{1}{2}CV^2$ and hence will increase.

Electric field will increase.
Charge stored will remain the same.
V will increase.



2.21 Consider any path from the charged conductor to the uncharged conductor along the electric field. The potential will continually decrease along this path. A second path from the uncharged conductor to infinity will again continually lower the potential further. Hence this result.

2.22 $$U = \frac{-qQ}{4\pi\,\varepsilon_0 R\sqrt{1+z^2/R^2}}$$



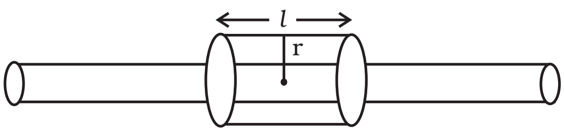
The variation of potential energy with z is shown in the figure.

The charge $-q$ displaced would perform oscillations. We cannot conclude anything just by looking at the graph.

2.23 $$V = \frac{1}{4\pi\varepsilon_0}\,\frac{Q}{\sqrt{R^2+z^2}}$$

2.24 To find the potential at distance r from the line consider the electric field. We note that from symmetry the field lines must be radially outward. Draw a cylindrical Gaussian surface of radius r and length l. Then

$$\oint \mathbf{E}.d\mathbf{S} = \frac{1}{\varepsilon_0}\lambda l$$



Or $E_r 2\pi r l = \frac{1}{\varepsilon_0}\lambda l$

$$\Rightarrow E_r = \frac{\lambda}{2\pi\varepsilon_0 r}$$

Hence, if r_0 is the radius,

$$V(r) - V(r_0) = -\int_{r_0}^{r} \mathbf{E}.d\mathbf{l} = \frac{\lambda}{2\pi\varepsilon_0} ln\frac{r_0}{r}$$

For a given V,

$$ln\frac{r}{r_0} = -\frac{2\pi\varepsilon_0}{\lambda}[V(r) - V(r_0)]$$

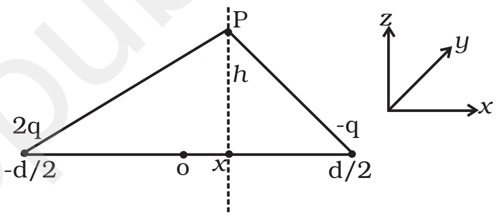
$$\Rightarrow r = r_0 e^{-2\pi\varepsilon_0 V r_0/\lambda} . e^{+2\pi\varepsilon_0 V(r)/\lambda}$$

The equipotential surfaces are cylinders of radius

$$r = r_0 e^{-2\pi\varepsilon_0 [V(r) - V(r_0)]/\lambda}$$

2.25 Let the plane be at a distance x from the origin. The potential at the point P is

$$\frac{1}{4\pi\varepsilon_0}\frac{q}{\left[(x+d/2)^2+h^2\right]^{1/2}} - \frac{1}{4\pi\varepsilon_0}\frac{q}{\left[(x-d/2)^2+h^2\right]^{1/2}}$$



If this is to be zero.

$$\frac{1}{\left[(x+d/2)^2+h^2\right]^{1/2}} = \frac{1}{\left[(x-d/2)^2+h^2\right]^{1/2}}$$

Or, $(x-d/2)^2 + h^2 = (x+d/2)^2 + h^2$

$$\Rightarrow x^2 - dx + d^2/4 = x^2 + dx + d^2/4$$

Or, $2dx = 0$

$\Rightarrow$ $x = 0$

The equation is that of a plane $x = 0$.

2.26 Let the final voltage be U. If C is the capacitance of the capacitor without the dielectric, then the charge on the capacitor is

$Q_1 = CU$

The capacitor with the dielectric has a capacitance εC. Hence the charge on the capacitor is

$$Q_2 = \varepsilon U \quad = \quad \alpha C U^2$$

The initial charge on the capacitor that was charged is

$Q_0 = CU_0$

From the conservation of charges,

$Q_0 = Q_1 + Q_2$

Or, $CU_0 = CU + \alpha CU^2$

$$\Rightarrow \alpha U^2 + U - u_0 = 0$$

$$\therefore U = \frac{-1 \pm \sqrt{1+4\alpha U_0}}{2\alpha}$$

$$= \frac{-1 \pm \sqrt{1+624}}{4}$$

$$= \frac{-1 \pm \sqrt{625}}{4} \text{ volts}$$

As U is positive

$$U = \frac{\sqrt{625}-1}{4} = \frac{24}{4} = 6\text{V}$$

2.27 When the disc is in touch with the bottom plate, the entire plate is a equipotential. A change q' is transferred to the disc.

The electric field on the disc is

$$= \frac{V}{d}$$

$$\therefore q' = -\varepsilon_0 \frac{V}{d} \pi r^2$$

The force acting on the disc is

$$-\frac{V}{d} \times q' = \varepsilon_0 \frac{V^2}{d^2} \pi r^2$$

If the disc is to be lifted, then

$$\varepsilon_0 \frac{V^2}{d^2} \pi r^2 = mg$$

$$\Rightarrow V = \sqrt{\frac{mgd^2}{\pi \varepsilon_0 r^2}}$$

2.28 $$\text{U} = \frac{1}{4\pi\varepsilon_0}\left\{\frac{q_d q_d}{r} - \frac{q_u q_d}{r} - \frac{q_u q_d}{r}\right\}$$

$$= \frac{9\times10^9}{10^{-15}}\left(1.6\times10^{-19}\right)^2 \{(1/3)^2 - (2/3)(1/3) - (2/3)(1/3)\}$$

$$= 2.304 \times 10^{-13} \left\{\frac{1}{9} - \frac{4}{9}\right\} = -7.68\times10^{-14}\text{J}$$

$= 4.8 \times 10^5$ eV $= 0.48$ MeV $= 5.11 \times 10^{-4}$ $(m_n c^2)$

2.29 Before contact

$$Q_1 = \sigma.4\pi R^2$$

$$Q_2 = \sigma.4\pi(2R^2) = 4\left(\sigma.4\pi R^2\right) = 4Q_1$$

After contact :

$$Q_1' + Q_2' = Q_1 + Q_2 = 5Q_1,$$

$$= 5(\sigma.4\pi R^2)$$

They will be at equal potentials:

$$\frac{Q_1'}{R}=\frac{Q_2'}{2R}$$

$$\therefore Q_2'=2Q'.$$

$$\therefore 3Q_1'=5(\sigma.4\pi R^2)$$

$$\therefore Q_1'=\frac{5}{3}(\sigma.4\pi R^2) \text{ and } Q_2'=\frac{10}{3}(\sigma.4\pi R^2)$$

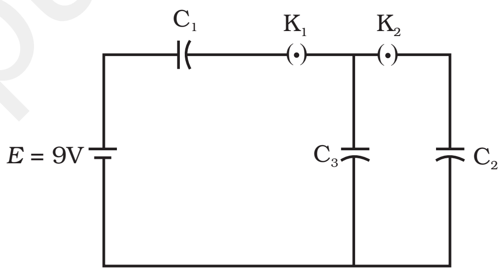
$$\therefore \ \sigma_1=5/3\,\sigma \quad \text{and} \quad \therefore \ \sigma_2=\frac{5}{6}\sigma.$$

2.30 Initially : $V\propto\frac{1}{C}$ and $V_1+V_2=E$

$$\Rightarrow V_1=3\text{V} \text{ and } V_2=6\text{V}$$

$$\therefore Q_1=C_1V_1=6\text{C}\times3=18\,\mu\text{C}$$

$$Q_2=9\,\mu\text{C} \text{ and } Q_3=0$$



Later : $Q_2=Q_2'+Q_3$

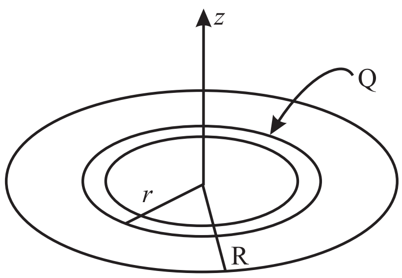
with $C_2V+C_3V=Q_2$ $\quad\Rightarrow V=\frac{Q_2}{C_2+C_3}=(3/2)\text{V}$

$$Q_2'=(9/2)\,\mu\text{C and } Q_3'=(9/2)\,\mu\text{C}$$

2.31 $\sigma=\frac{Q}{\pi R^2}$

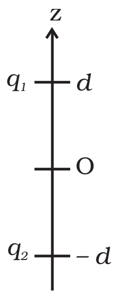
$$dU=\frac{1}{4\pi\varepsilon_0}\frac{\sigma.2\pi r\,dr}{\sqrt{r^2+z^2}}$$

$$\therefore U=\frac{\pi\sigma}{4\pi\varepsilon_0}\int_0^R\frac{2rdr}{\sqrt{r^2+z^2}}$$



$$= \frac{2\pi\sigma}{4\pi\varepsilon_0}\left[\sqrt{r^2+z^2}\right]_O^R = \frac{2\pi\sigma}{4\pi\varepsilon_0}\left[\sqrt{R^2+z^2}-z\right]$$

$$= \frac{2Q}{4\pi\varepsilon_0 R^2}\left[\sqrt{R^2+z^2}-z\right]$$



2.32
$$\frac{q_1}{\sqrt{x^2+y^2+(z-d)^2}} + \frac{q_2}{\sqrt{x^2+y^2+(z+d)^2}} = 0$$

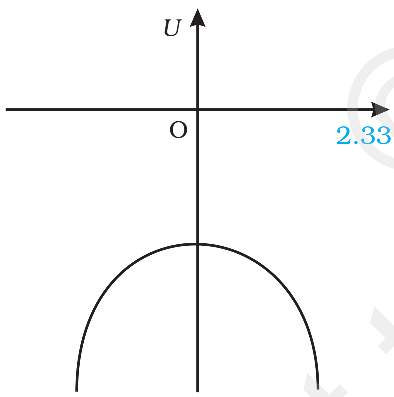
$$\therefore \frac{q_1}{\sqrt{x^2+y^2+(z-d)^2}} = \frac{-q_2}{\sqrt{x^2+y^2+(z+d)^2}}$$

Thus, to have total potential zero, q_1 and q_2 must have opposite signs. Squaring and simplifying, we get.

$$x^2+y^2+z^2+\left[\frac{(q_1/q_2)^2+1}{(q_1/q_2)^2-1}\right](2zd)+d^2=0$$

This is the equation of a sphere with centre at $\left(0,0,-2d\left[\frac{q_1{}^2+q_1{}^2}{q_1{}^2-q_1{}^2}\right]\right)$.

Note : if $q_1 = -q_2 \Rightarrow$ Then $z = 0$, which is a plane through mid-point.



$$U_0 = \frac{2q^2}{4\pi\varepsilon_0 d}$$

2.33
$$U = \frac{1}{4\pi\varepsilon_0}\left\{\frac{-q^2}{(d-x)} + \frac{-q^2}{(d-x)}\right\}$$

$$U = \frac{-q^2}{4\pi\varepsilon_0}\frac{2d}{(d^2-x^2)}$$

$$\frac{dU}{dx} = \frac{-q^2.2d}{4\pi\epsilon_0}\cdot\frac{2x}{(d^2-x^2)^2}$$

$$\frac{dU}{dx} = 0 \text{ at } x = 0$$

$x = 0$ is an equilibrium point.

$$\frac{d^2U}{dx^2} = \left(\frac{-2dq^2}{4\pi\epsilon_0}\right)\left[\frac{2}{(d^2-x^2)^2} - \frac{8x^2}{(d^2-x^2)^3}\right]$$

$$= \left(\frac{-2dq^2}{4\pi \in_0}\right)\frac{1}{(d^2-x^2)^3}\left[2\left(d^2-x^2\right)^2-8x^2\right]$$

At $x = 0$

$$\frac{d^2U}{dx^2} = \left(\frac{-2dq^2}{4\pi \in_0}\right)\left(\frac{1}{d^6}\right)(2d^2), \text{ which is} < 0.$$

Hence, unstable equilibrium.

Chapter 3

3.1 (b)

3.2 (a)

3.3 (c)

3.4 (b)

3.5 (a)

3.6 (a)

3.7 (b), (d)

3.8 (a), (d)

3.9 (a), (b)

3.10 (b), (c)

3.11 (a), (c)

3.12 When an electron approaches a junction, in addition to the uniform **E** that it normally faces (which keep the drift velocity $\boldsymbol{v}_d$ fixed), there are accumulation of charges on the surface of wires at the junction. These produce electric field. These fields alter direction of momentum.

3.13 Relaxation time is bound to depend on velocities of electrons and ions. Applied electric field affects the velocities of electrons by speeds at the order of 1mm/s, an insignificant effect. Change in T, on the other hand, affects velocities at the order of 10^2 m/s. This can affect τ significantly.

[$\rho = \rho(E,T)$ in which E dependence is ignorable for ordinary applied voltages.]

3.14 The advantage of null point method in a Wheatstone bridge is that the resistance of galvanometer does not affect the balance point and there is no need to determine current in resistances and galvanometer and the internal resistance of a galvanometer. $R_{unknown}$ can be calculated applying Kirchhoff's rules to the circuit. We would need additional accurate measurement of all the currents in resistances and galvanometer and internal resistance of the galvanometer.

3.15 The metal strips have low resistance and need not be counted in the potentiometer length l_1 of the null point. One measures only their lengths along the straight segments (of lengths 1 meter each). This is easily done with the help of centimeter rulings or meter ruler and leads to accurate measurements.

3.16 Two considerations are required: (i) cost of metal, and (ii) good conductivity of metal. Cost factor inhibits silver. Cu and Al are the next best conductors.

3.17 Alloys have low value of temperature co-efficient (less temperature sensitivity) of resistance and high resistivity.

3.18 Power wasted $P_C = I^2R_C$

where R_C is the resistance of the connecting wires.

$$P_C = \frac{P^2}{V^2}R_C$$

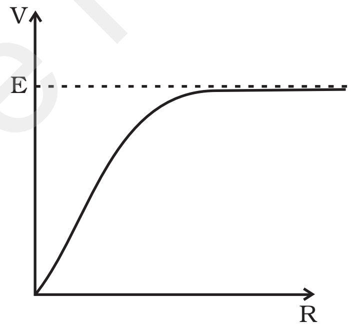
In order to reduce P_C, power should be transmitted at high voltage.

3.19 If R is increased, the current through the wire will decrease and hence the potential gradient will also decrease, which will result in increase in balance length. So J will shift towards B.

3.20 (i) Positive terminal of E_1 is connected at X and $E_1 > E$.

(ii) Negative terminal of E_1 is connected at X.

3.21



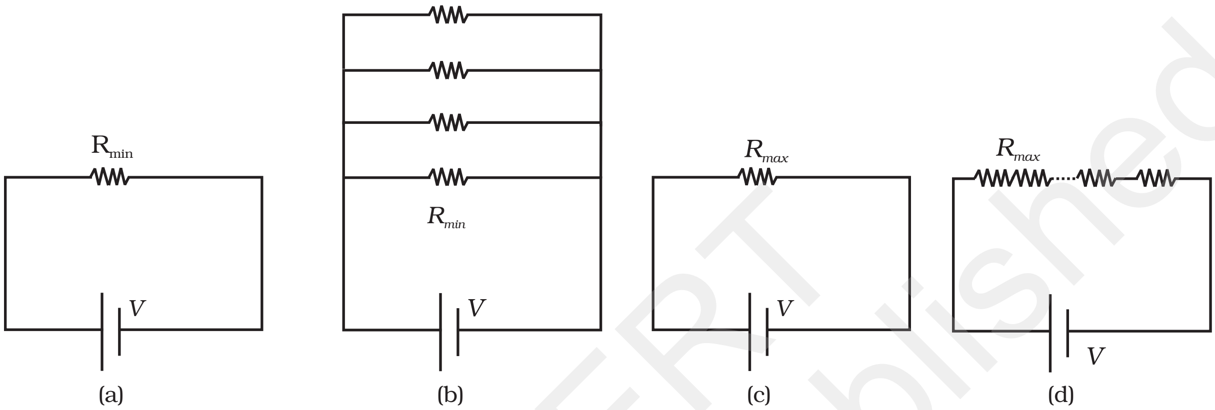
3.22 $$I = \frac{E}{R+nR};\ \frac{E}{R+\frac{R}{n}} = 10I$$

$$\frac{1+n}{1+\frac{1}{n}} = 10 = \frac{1+n}{n+1}n = n$$

$\therefore n = 10.$

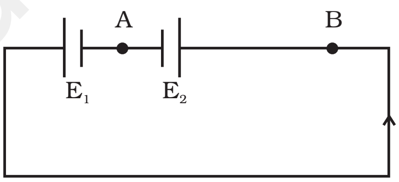
3.23 $$\frac{1}{R_p} = \frac{1}{R_1} + \ldots\ldots + \frac{1}{R_n},\quad \frac{R_{min}}{R_P} = \frac{R_{min}}{R_1} + \frac{R_{min}}{R_2} + \ldots\ldots + \frac{R_{min}}{R_n} > 1$$

and $R_s = R_1 + \ldots\ldots + R_n \geq R_{max}$.
In Fig. (b), R_{min} provides an equivalent route as in Fig. (a) for current. But in addition there are $(n-1)$ routes by the remaining $(n-1)$ resistors. Current in Fig.(b) > current in Fig. (a). Effective Resistance in Fig. (b) < R_{min}. Second circuit evidently affords a greater resistance. You can use Fig. (c) and (d) and prove $R_s > R_{max}$.



3.24 $I = \dfrac{6-4}{2+8} = 0.2\text{A}$

P.D. across $E_1 = 6 - 0.2 \times 2 = 5.6$ V
P.D. across $E_2 = V_{AB} = 4 + 0.2 \times 8 = 5.6$ V
Point B is at a higher potential than A



3.25 $I = \dfrac{E + E}{R + r_1 + r_2}$

$V_1 = E - Ir_1 = E - \dfrac{2E}{r_1 + r_2 + R} r_1 = 0$

or $E = \dfrac{2Er_1}{r_1 + r_2 + R}$

$1 = \dfrac{2r_1}{r_1 + r_2 + R}$

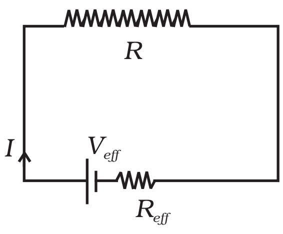
$r_1 + r_2 + R = 2r_1$
$R = r_1 - r_2$

3.26 $R_A = \dfrac{\rho l}{\pi(10^{-3} \times 0.5)^2}$

$R_B = \dfrac{\rho l}{\pi[(10^{-3})^2 - (0.5 \times 10^{-3})^2]}$

$\dfrac{R_A}{R_B} = \dfrac{(10^{-3})^2 - (0.5 \times 10^{-3})^2}{(.5 \times 10^{-3})^2} = 3 : 1$

3.27 We can think of reducing entire network to a simple one for any branch R as shown in Fig.



Then current through R is $I = \dfrac{V_{eff}}{R_{eff} + R}$

Dimensionally $V_{eff} = V_{eff}(V_1, V_2, \ldots\ldots V_n)$ has a dimension of voltage and $R_{eff} = R_{eff}(R_1, R_2, \ldots\ldots R_m)$ has a dimension of resistance.
Therefore if all are increased n-fold

$$V_{eff}^{new} = nV_{eff}, R_{eff}^{new} = n R_{eff}$$

and $R^{new} = nR$.
Current thus remains the same.

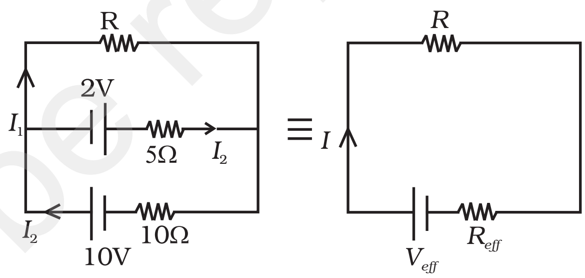
3.28 Applying Kirchhoff's junction rule:

$I_1 = I + I_2$
Kirchhoff's loop rule gives:
$10 = IR + 10I_1$....(i)
$2 = 5I_2 - RI = 5(I_1 - I) - RI$
$4 = 10I_1 - 10I - 2RI$..... (ii)

(i) – (ii) $\Rightarrow 6 = 3RI + 10I$ or, $2 = I\left(R + \dfrac{10}{3}\right)$

$2 = (R + R_{eff})I$ Comparing with $V_{eff} = (R + R_{eff})I$
and $V_{eff} = 2V$

$R_{eff} = \dfrac{10}{3}\Omega$.



3.29 Power consumption = 2units/hour = 2KW = 2000J/s

$I = \dfrac{P}{V} = \dfrac{2000}{220}$; 9 A

Power loss in wire = RI^2 J/s

$$= \rho \frac{l}{A} I^2 = 1.7 \times 10^{-8} \times \frac{10}{\pi \times 10^{-6}} \times 81 \text{ J/s}$$

≈ 4 J/s
= 0.2%

Power loss in Al wire = $4\dfrac{\rho_{Al}}{\rho_{Cu}} = 1.6 \times 4 = 6.4\text{J/s} = 0.32\%$

3.30 Let R' be the resistance of the potentiometer wire.

$$\frac{10 \times R'}{50 + R'} < 8 \Rightarrow \quad 10R' < 400 + 8R'$$

$2R' < 400$ or $R' < 200\Omega$.

$$\frac{10 \times R'}{10 + R'} > 8 \Rightarrow 2R' > 80 \Rightarrow R' > 40$$

$$\frac{10 \times \frac{3}{4}R'}{10 + R'} < 8 \Rightarrow 7.5R' < 80 + 8R'$$

$R' > 160 \Rightarrow 160 < R' < 200$.
Any R' between 160Ω and 200Ω will achieve.
Potential drop across 400 cm of wire > 8V.
Potential drop across 300 cm of wire < 8V.

$\phi \times 400 > 8V$ ($\phi \rightarrow$ potential gradient)
$\phi \times 300 < 8V$
$\phi > 2V/m$
$< 2\frac{2}{3}$ V/m.

3.31 (a) $I = \frac{6}{6} = 1 \text{ A} = nev_d A$

$$v_d = \frac{1}{10^{29} \times 1.6 \times 10^{-19} \times 10^{-6}} = \frac{1}{1.6} \times 10^{-4} \text{ m/s}$$

$$K.E = \frac{1}{2} m_e v_d^2 \times nAl$$

$$= \frac{1}{2} \times 9.1 \times 10^{-31} \times \frac{1}{2.56} \times 10^{-8} \times 10^{29} \times 10^{-6} \times 10^{-1} \simeq 2 \times 10^{-17} \text{J}$$

(b) Ohmic loss = $RI^2 = 6 \times 1^2 = 6$ J/s

All of KE of electrons would be lost in $\frac{2 \times 10^{-17}}{6} \text{s} \simeq 10^{-17} \text{s}$

Chapter 4

4.1 (d)

4.2 (a)

4.3 (a)

4.4 (d)

4.5 (a)

4.6 (d)

4.7 (a), (b)

4.8 (b), (d)

4.9 (b), (c)

4.10 (b), (c), (d)

4.11 (a), (b), (d)

4.12 For a charge particle moving perpendicular to the magnetic field:

$$\frac{mv^2}{R} = qvB$$

$$\therefore \frac{qB}{m} = \frac{v}{R} = \omega$$

$$\therefore [\omega] = \left[\frac{qB}{m}\right] = \left[\frac{v}{R}\right] = [T]^{-1}.$$

4.13 $dW = \mathbf{F}.d\mathbf{l} = 0$

$\Rightarrow \mathbf{F}.\mathbf{v}dt = 0$

$\Rightarrow \mathbf{F}.\mathbf{v} = 0$

F must be velocity dependent which implies that angle between **F** and **v** is 90°. If **v** changes (direction) then (directions) **F** should also change so that above condition is satisfied.

4.14 Magnetic force is frame dependent. Net acceleraton arising from this is however frame independent (non - relativistic physics)for inertial frames.

4.15 Particle will accelerate and decelerate altenatively. So the radius of path in the Dee's will remain unchanged.

4.16 At O_2, the magnetic field due to I_1 is along the y-axis. The second wire is along the y-axis and hence the force is zero.

4.17 $\mathbf{B} = \frac{1}{4}(\hat{\mathbf{i}}+\hat{\mathbf{j}}+\hat{\mathbf{k}})\frac{\mu_0 I}{2R}$

4.18 No dimensionless quantity $[T]^{-1} = [\omega] = \left[\frac{eB}{m}\right]$

4.19 $\mathbf{E} = E_0\hat{\mathbf{i}}, E_0 > 0, \mathbf{B} = B_0\hat{\mathbf{k}}$

4.20 Force due to $d\mathbf{l}_2$ on $d\mathbf{l}_1$ is zero.

Force due to $d\mathbf{l}_1$ on $d\mathbf{l}_2$ is non-zero.

4.21 $i_G(G + R_1) = 2$ for 2V range

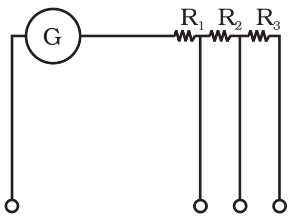
$i_G(G + R_1 + R_2) = 20$ for 20V range

and $i_G(G + R_1 + R_2 + R_3) = 200$ for 200V range

Gives $R_1 = 1990\Omega$

$R_2 = 18\ k\Omega$

and $R_3 = 180\ k\Omega$



4.22 $F = BIl \sin\theta = BIl$

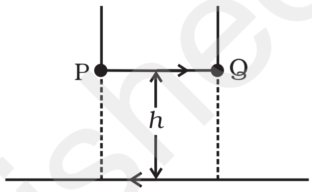
$$B = \frac{\mu_o I}{2\pi h}$$

$$F = mg = \frac{\mu_o I^2 l}{2\pi h}$$

$$h = \frac{\mu_o I^2 l}{2\pi mg} = \frac{4\pi\times10^{-7}\times250\times25\times1}{2\pi\times2.5\times10^{-3}\times9.8}$$

$= 51 \times 10^{-4}$

$h = 0.51$ cm



4.23 When the field is off $\sum\tau = 0$

$Mgl = W_{coil}\ l$

$500\ g\ l = W_{coil}\ l$

$W_{coil} = 500 \times 9.8$ N

When the magnetic field is switched on

$Mgl + mgl = W_{coil}\ l + IBL \sin 90° l$

$mgl = BIL\ l$

$$m = \frac{BIL}{g} = \frac{0.2\times4.9\times1\times10^{-2}}{9.8} = 10^{-3}\text{kg}$$

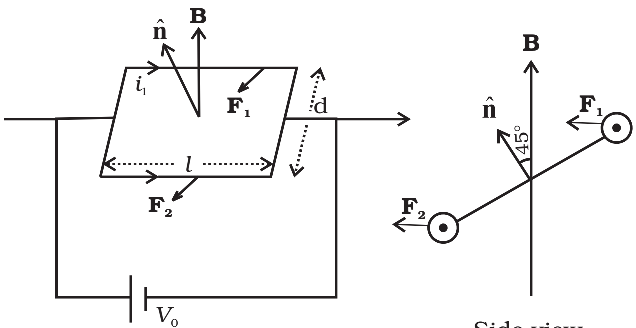
= 1 g

4.24 $F_1 = i_1 lB = \frac{V_0}{R} lB \quad \tau_1 = \frac{d}{2\sqrt{2}} F_1 = \frac{V_0 ldB}{2\sqrt{2}R}$

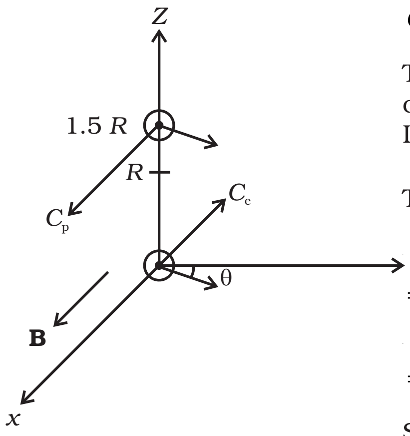
$F_2 = i_2 lB = \frac{V_0}{2R} lB \qquad \tau_2 = \frac{d}{2\sqrt{2}} F_2 = \frac{V_0 ldB}{4\sqrt{2}R}$

Net torque $\tau = \tau_1 - \tau_2$

$$\tau = \frac{1}{4\sqrt{2}} \frac{V_0 AB}{R}$$



4.25 As **B** is along the x axis, for a circular orbit the momenta of the two particles are in the y - z plane. Let $\mathbf{p}_1$ and $\mathbf{p}_2$ be the momentum of the electron and positron, respectively. Both of them define a circle of radius R. They shall define circles of opposite sense. Let $\mathbf{p}_1$ make an angle θ with the y axis $\mathbf{p}_2$ must make the same angle. The centres of the repective circles must be perpendicular to the momenta and at a distance R. Let the center of the electron be at Ce and of the positron at Cp. The coordinates of Ce is



The coordinates of Ce is

$Ce \equiv (0, -R\sin\theta,\ R\cos\theta)$

The coordinates of Cp is

$Cp \equiv (0, -R\sin\theta, \frac{3}{2}\ \text{R–R}\cos\theta)$

The circles of the two shall not overlap if the distance between the two centers are greater than $2R$.
Let d be the distance between Cp and Ce.

Then $d^2 = (2\text{RSin}\theta)^2 + \left(\frac{3}{2}\text{R} - 2\text{R}\cos\theta\right)^2$

$= 4R^2\text{Sin}^2\theta + \frac{9^2}{4}\ R - 6R^2\cos\theta + 4R^2\cos^2\theta$

$= 4R^2 + \frac{9}{4}R^2 - 6R^2\cos\theta$

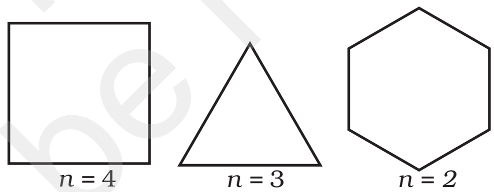
Since d has to be greater than $2R$
$d^2 > 4R^2$

$\Rightarrow 4R^2 + \frac{9}{4}R^2 - 6R^2\cos\theta > 4R^2$

$\Rightarrow \frac{9}{4} > 6\cos\theta$

Or, $\cos\theta < \frac{3}{8}$.

4.26



Area: $A = \frac{\sqrt{3}}{4}a^2$ $\qquad A = a^2$ $\qquad A = \frac{3\sqrt{3}}{4}a^2$

Current I is same for all
Magnetic moment $m = n\,I\,A$

$\therefore m = Ia^2\sqrt{3}$ $\qquad 3a^2I$ $\qquad 3\sqrt{3}a^2I$

(Note: m is in a geometric series)

4.27 (a) B (z) points in the same direction on z - axis and hence J (L) is a monotonically increasing function of L.

(b) J(L) + Contribution from large distance on contour $C = \mu_0 I$

$\therefore \text{as} L \to \infty$

Contribution from large distance $\to 0(\text{as}B$ □ $1/r^3)$

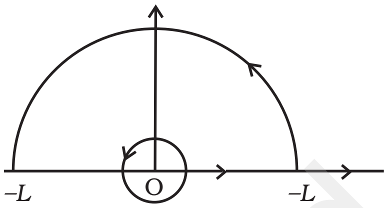
$J(\infty) - \mu_0 I$

(c) $B_z = \dfrac{\mu_0 I R^2}{2(z^2+R^2)^{3/2}}$

$$\int_{-\infty}^{\infty} B_z dz = \int_{-\infty}^{\infty} \frac{\mu_0 I R^2}{2(z^2+R^2)^{3/2}} dz$$

Put $z = R\tan\theta$ $\quad dz = R\sec^2\theta\, d\theta$

$$\therefore \int_{-\infty}^{\infty} B_z dz = \frac{\mu_0 I}{2}\int_{-\pi/2}^{\pi/2} \cos\theta d\theta = \mu_0 I$$



(d) $B(z)_{square} < B(z)_{circular\ coil}$

$\therefore \mathfrak{J}(L)_{square} < \mathfrak{J}(L)_{circular\ coil}$

But by using arguments as in (b)

$\mathfrak{J}(\infty)_{square} = \mathfrak{J}(\infty)_{circular}$

4.28 $i_G . G = (i_1 - i_G)(S_1 + S_2 + S_3)$ $\quad$ for $i_1 = 10$mA

$i_G (G + S_1) = (i_2 - i_G)(S_2 + S_3)$ $\quad$ for $i_2 = 100$mA

and $i_G (G + S_1 + S_2) = (i_3 - i_G)(S_3)$ $\quad$ for $i_3 = 1$A

gives $S_1 = 1\Omega$, $S_2 = 0.1\Omega$ and $S_3 = 0.01\Omega$

4.29 (a) zero

(b) $\dfrac{\mu_0}{2\pi}\dfrac{i}{R}$ perpendicular to AO towards left.

(c) $\dfrac{\mu_0}{\pi}\dfrac{i}{R}$ perpendicular to AO towards left.

Chapter 5

5.1 (c)

5.2 (a)

5.3 (c)

5.4 (b)

5.5 (b)

5.6 (a), (d)

5.7 (a), (d)

5.8 (a), (d)

5.9 (a), (c), (d)

5.10 (b), (c), (d)

5.11 $\mu_p \approx \dfrac{e\hbar}{2m_p}$ and $\mu_e \approx \dfrac{e\hbar}{2m_e}, \hbar = \dfrac{h}{2\pi}$

$\mu_e >> \mu_p$ because $m_p >> m_e$.

5.12 $Bl = \mu_0 M l = \mu_0 (I + I_M)$ and $H = 0 = I$

$Ml = I_M = 10^6 \times 0.1 = 10^5$ A.

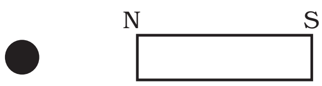
5.13 $x \propto \text{density}\,\rho$. Now $\dfrac{\rho_N}{\rho_{Cu}} = \dfrac{28g/22.4Lt}{8g/cc} = \dfrac{3.5}{22.4} \times 10^{-3} = 1.6 \times 10^{-4}$.

$\dfrac{x_N}{x_{Cu}} = 5 \times 10^{-4}$ (from given data).

Hence major difference is accounted for by density.

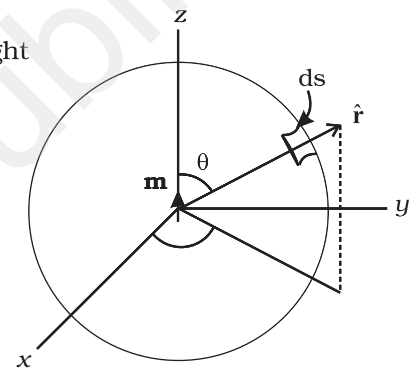
5.14 Diamagnetism is due to orbital motion of electrons developing magnetic moments opposite to applied field and hence is not much affected by temperature.

Paramagnetism and ferromagnetism is due to alignments of atomic magnetic moments in the direction of the applied field. As temperature increases, this aligment is disturbed and hence susceptibilities of both decrease as temperature increases.



5.15 (i) Away from the magnet.

(ii) Magnetic moment is from left to right



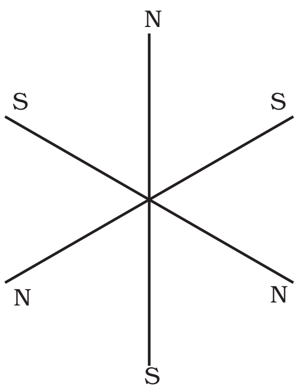
5.16 $\mathbf{B} = \dfrac{\mu_0}{4\pi}\dfrac{3\mathbf{m}.\hat{\mathbf{r}}}{r^3}, m = m\hat{\mathbf{k}}$

$d\mathbf{s} = \hat{\mathbf{r}}.\mathbf{r}^2 \sin\theta d\theta c$

$0 \le \theta \le \pi, 0 \le \phi \le$

$\oint \mathbf{B}.ds = \dfrac{\mu_0 m}{4\pi}\int \dfrac{3\cos\theta}{r^3} r^2 \sin\theta d6$

$= 0[\text{due to } \theta \text{ integral}]$.



5.17 Net $m = 0$. Only possibility is shown in Fig.

5.18 $E(r) = c\,B(r)$, $p = \dfrac{m}{c}$. Mass and moment of inertia of dipoles are equal.

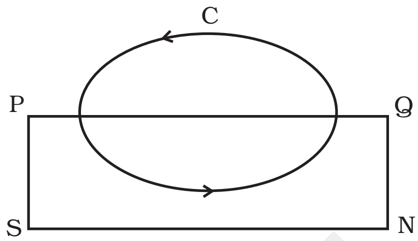
5.19 $T = 2\pi\sqrt{\dfrac{I}{mB}}$ $\quad I' = \dfrac{1}{2} \times \dfrac{1}{4} I$ and $m' = \dfrac{m}{2}$. $\quad T' = \dfrac{1}{2}T$

5.20 Consider a line of **B** through the bar magnet. It must be closed. Let C be the amperian loop.

$$\int_Q^P \mathbf{H}.d\mathbf{l} = \int_Q^P \frac{\mathbf{B}}{\mu_0}.d\mathbf{l} > 0$$

$$\oint_{PQP} \mathbf{H}.d\mathbf{l} = 0$$

$$\int_{p}^{Q} \mathbf{H}.d\mathbf{l} < 0$$



P → Q is inside the bar.
Hence **H** is making an obtuse angle with *d***l**.

5.21 (i) Along *z* axis

$$\mathbf{B} = \frac{\mu_0}{4\pi}\frac{2\mathbf{m}}{r^3}$$

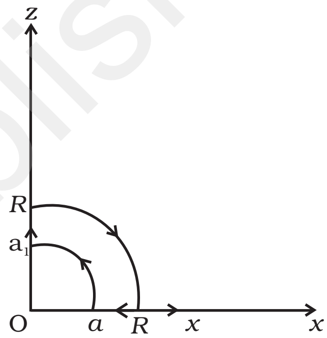
$$\int_a^R \mathbf{B}.d\mathbf{l} = \frac{\mu_0}{4\pi}2m\int_a^R \frac{dz}{z^3} = \frac{\mu_0 m}{2\pi}\left(-\frac{1}{2}\right)\left(\frac{1}{R^2}-\frac{1}{a^2}\right)$$

(ii) Along the quarter circle of radius *R*

$$B_\theta = \frac{\mu_0}{4\pi}\frac{-\mathbf{m}.\hat{\boldsymbol{\theta}}}{R^3} = \frac{-\mu_0}{4\pi}\frac{m}{R^3}(-\sin\theta)$$

$$\mathbf{B}.d\mathbf{l} = \frac{\mu_0 m}{4\pi R^2}\sin\theta d$$

$$\int_0^{\frac{\pi}{2}} \mathrm{B}.dl = \frac{\mu_0 m}{4\pi R^2}$$



(iii) Along *x*-axis

$$\mathbf{B} = \frac{\mu_0}{4\pi}\left(\frac{-m}{x^3}\right)$$

$$\int \mathbf{B}.d\mathbf{l} = 0$$

(iv) Along the quarter circle of radius *a*

$$\mathbf{B}.d\mathbf{l} = \frac{-\mu_0 m}{4\pi a^2}\sin\theta d\theta\ ,\quad \int \mathbf{B}.d\mathbf{l} = -\frac{-\mu_0 m}{4\pi a^2}\int_0^{\frac{\pi}{2}}\sin\theta d\theta = \frac{-\mu_0 m}{4\pi a^2}$$

Add $\oint_C \mathbf{B}.d\mathbf{l} = 0$

5.22 χ is dimensionless.

χ depends on magnetic moment induced when *H* is turned on. *H* couples to atomic electrons through its charge *e*. The effect on *m* is via current *I* which involves another factor of '*e*'. The combination "$\mu_0 e^2$" does not depend on the "charge" Q dimension.

$$\chi = \mu_0 e^2 m^\alpha v^\beta R^\gamma$$

$$\mu_0 c^2 = \frac{1}{c^2}\frac{e^2}{\varepsilon_0} \sim \frac{1}{c^2}\frac{e^2}{\varepsilon_0 R}.R \sim \frac{\text{Energy length}}{c^2}$$

$$[\chi] = M^0L^0T^0Q^0 = \frac{ML^3T^{-2}}{L^2T^{-2}} M^{\alpha}\left(\frac{L}{T}\right)^{\beta} L^{\gamma}Q^0$$

$$\alpha = -1, \beta = 0, \gamma = -1$$

$$\chi = \frac{\mu_0\, e^2}{mR} \sim \frac{10^{-6}\times 10^{-38}}{10^{-30}\times 10^{-10}} \sim 10^{-4}.$$

5.23 (i) $|\mathbf{B}| = \frac{\mu_0}{4\pi}\frac{m}{R^3}(4\cos^2\theta + \sin^2\theta)^{1/2}$

$$\frac{|\mathbf{B}|^2}{\left(\frac{\mu_0}{4\pi R^3}\right)^2 m^2} = 3\cos^2\theta + 1, \text{ minimum at } \theta = \frac{\pi}{2}.$$

$|\mathbf{B}|$ is minimum at magnetic equator.

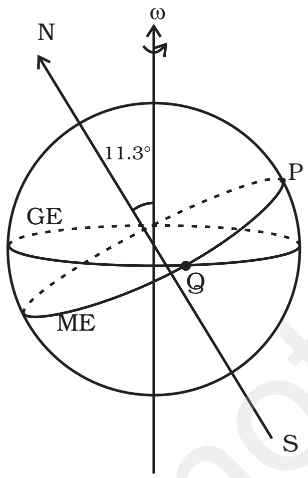
(ii) tan (dip angle) = $\frac{B_V}{B_H} = 2\cot$

at $\theta = \frac{\pi}{2}$ dip angle vanishes. Magnetic equator is again the locus.

(iii) Dip angle is ± 45° when $\left|\frac{B_V}{B_H}\right| = 1$

2 cot θ = 1

θ = $\tan^{-1}2$ is the locus.



5.24 Refer to the adjacent Fig.

1. P is in S (needle will point both north)

Declination = 0

P is also on magnetic equator.

∴ dip = 0

2. Q is on magnetic equator.

∴ dip = 0

but declination = 11.3°.

5.25 $n_1 = \frac{L}{2\pi R}$ $n_2 = \frac{L}{4a}$

$m_1 = n_1 IA$ $m_2 = n_2 IA_2$

$$= \frac{L}{2\pi R} I\pi R \qquad = \frac{L}{4a} Ia^2 = \frac{L}{4} Ia$$

$I_1 = \frac{MR^2}{2}$ (moment of inertia about an axis through the diameter)

$$I_2 = \frac{Ma^2}{12}$$

$$\omega_1^2 = \frac{m_1 B}{I_1} \qquad \omega_2^2 = \frac{m_2 B}{I_2}$$

$$\frac{m_1}{I_1} = \frac{m_2}{I_2}$$

$$\frac{LR}{2\pi} \times \frac{I}{\frac{MR^2}{2}} = \frac{\frac{L}{4} Ia}{\frac{Ma^2}{12}} \Rightarrow a = \frac{3\pi}{4} R.$$

Chapter 6

6.1 (c)

6.2 (b)

6.3 (a)

6.4 (d)

6.5 (a)

6.6 (b)

6.7 (a), (b), (d)

6.8 (a), (b), (c)

6.9 (a), (d)

6.10 (b), (c)

6.11 No part of the wire is moving and so motional e.m.f. is zero. The magnet is stationary and hence the magnetic field does not change with time. This means no electromotive force is produced and hence no current will flow in the circuit.

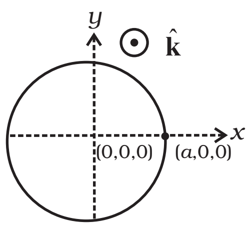
6.12 The current will increase. As the wires are pulled apart the flux will leak through the gaps. Lenz's law demands that induced e.m.f. resist this decrease, which can be done by an increase in current.

6.13 The current will decrease. As the iron core is inserted in the solenoid, the magnetic field increases and the flux increases. Lent's law implies that induced e.m.f. should resist this increase, which can be achieved by a decrease in current.

6.14 No flux was passing through the metal ring initially. When the current is switched on, flux passes through the ring. According to Lenz's law this increase will be resisted and this can happen if the ring moves away from the solenoid. One can analyse this in more detail (Fig 6.5). If the current in the solenoid is as shown, the flux (downward) increases and this will cause a counterclockwise current (as seen form the top in the ring). As the flow of current is in the opposite direction to that in the solenoid, they will repel each other and the ring will move upward.

6.15 When the current in the solenoid decreases a current flows in the same direction in the metal ring as in the solenoid. Thus there will be a downward force. This means the ring will remain on the cardboard. The upward reaction of the cardboard on the ring will increase.

6.16 For the magnet, eddy currents are produced in the metallic pipe. These currents will oppose the motion of the magnet. Therefore magnet's downward acceleration will be less than the acceleration due to gravity g. On the other hand, an unmagnetised iron bar will not produce eddy currents and will fall with an acceleration g. Thus the magnet will take more time.



6.17 Flux through the ring

$$\phi = B_o(\pi a^2)\cos\omega t$$

$$\varepsilon = B(\pi a^2)\omega \sin\omega t$$

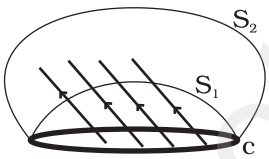
$$I = B(\pi a^2)\omega \sin\omega t / R$$

Current at

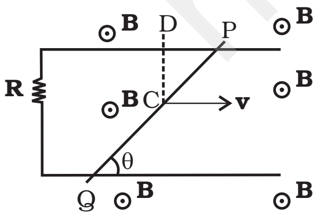
$$t = \frac{\pi}{2\omega};\ I = \frac{B(\pi a^2)\omega}{R} \text{ along } \hat{\mathbf{j}}$$

$$t = \frac{\pi}{\omega};\ I = ($$

$$t = \frac{3}{2}\frac{\pi}{\omega};\ I = \frac{B(\pi a^2)\omega}{R} \text{ along } -\hat{\mathbf{j}}.$$



6.18 One gets the same answer for flux. Flux can be throught of as the number of magnetic field lines passing through the surface (we draw dN = $B\,\Delta A$ lines in an area ΔA ⊥to **B**), As lines of of **B** cannot end or start in space (they form closed loops) number of lines passing through surface S_1 must be the same as the number of lines passing through the surface S_2.



6.19 Motional electric field E along the dotted line CD (⊥ to both **v** and **B** and along **v** × **B**) = vB

E.M.F. along PQ = (length PQ)×(Field along PQ)

$$= \frac{d}{\cos\theta} \times vB\cos\theta = dvB.$$

Therefore,

$$I = \frac{dvB}{R} \text{ and is independent of } q.$$

6.20 Maximum rate of change of current is in AB. So maximum back emf will be obtained between 5s < t <10s.

If $u = L\,1/5 \left(\text{for } t = 3\text{s}, \frac{dI}{dt} = 1/5\right)$ (L is a constant)

For 5s < t < 10s $u_1 = -L\frac{3}{5} = -\frac{3}{5}L = -3e$

Thus at t = 7 s, $u_1 = -3\ e$.

For 10s < t < 30s

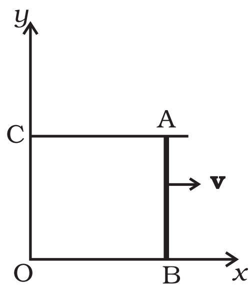
$$u_2 = L\frac{2}{20} = \frac{L}{10} = \frac{1}{2}e$$

For t > 30s $u_2 = 0$

6.21 Mutual inductance $= \frac{10^{-2}}{2} = 5\text{mH}$

Flux $= 5\times10^{-3}\times1 = 5\times10^{-3}$ Wb.

6.22 Let us assume that the parallel wires at are y = 0 and $y = d$. At t = 0, AB has x=0 and moves with a velocity $v\hat{\mathbf{i}}$.



At time t, wire is at $x(t) = vt$.

Motional e.m.f. $= (B_o \sin\omega t)vd(-\hat{\mathbf{j}})$

E.m.f due to change in field (along OBAC)

$$= -B_o\omega \cos\omega t\, x(t)d$$

Total e.m.f $= -B_o d[\omega x\cos(\omega t) + v\sin(\omega t)]$

Along OBAC, Current (clockwise) $= \frac{B_o d}{R}(\omega x\cos\omega t + v\sin\omega t)$

Force needed along $\hat{\mathbf{i}}$ $= \frac{B_o d}{R}(\omega x\cos\omega t + v\sin\omega t)\times d\times B_o \sin\omega t$

$$= \frac{B_o^2 d^2}{R}(\omega x\cos\omega t + v\sin\omega t)\sin\omega t.$$

6.23 (i) Let the wire be at $x = x(t)$ at time t.

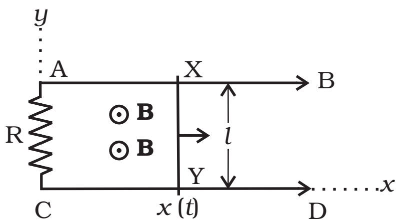
Flux = $B(t)\, l\, x(t)$

$$E = -\frac{d\phi}{dt} = -\frac{dB(t)}{dt}l\,x(t) - B(t)l.v(t) \text{ (second term due to motional emf)}$$

$$I = \frac{1}{R}E$$

$$\text{Force} = \frac{l\,B(t)}{R}\left[-\frac{dB}{dt}l\,x(t) - B(t)\,l\,v(t)\right]\hat{\mathbf{i}}$$

$$m\frac{d^2x}{dt^2} = -\frac{l^2B}{R}\frac{dB}{dt}x(t) - \frac{l^2B^2}{R}\frac{dx}{dt}$$



(ii) $\frac{dB}{dt} = 0, \qquad \frac{d^2x}{dt^2} + \frac{l^2B^2}{mR}\frac{dx}{dt} = 0$

$$\frac{dv}{dt} + \frac{l^2B^2}{mR}v = 0$$

$$v = A\exp\left(\frac{-l^2B^2t}{mR}\right)$$

At $t = 0$, $v = u$

$v(t) = u\exp(-l^2B^2t/mR)$.

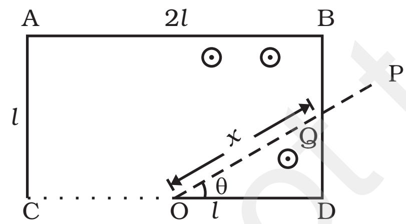
(iii) $I^2R = \frac{B^2l^2v^2(t)}{R^2} \times R = \frac{B^2l^2}{R}u^2\exp(-2l^2B^2t/mR)$

$$\text{Power lost} = \int_0^t I^2R\,dt = \frac{B^2l^2}{R}u^2\frac{mR}{2l^2B^2}\left[1 - e^{-(2l^2B^2t/mR)}\right]$$

$$= \frac{m}{2}u^2 - \frac{m}{2}v^2(t)$$

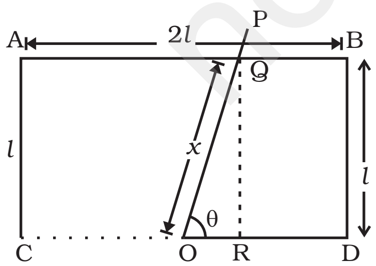
= decrease in kinetic energy.

6.24 Between time $t = 0$ and $t = \frac{\pi}{4\omega}$, the rod OP will make contact with the side BD. Let the length OQ of the contact at some time t such that $0 < t < \frac{\pi}{4\omega}$ be x. The flux through the area ODQ is



$$\phi = B\frac{1}{2}\text{QD}\times\text{OD} = B\frac{1}{2}l\tan\theta \times l$$

$$= \frac{1}{2}Bl^2\tan\theta \text{ where } \theta = \omega t$$



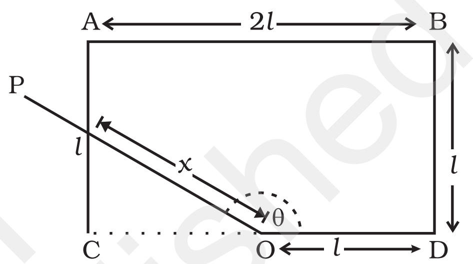
Thus the magnitude of the emf generated is $\varepsilon = \frac{d\phi}{dt} = \frac{1}{2}Bl^2\omega\sec^2\omega t$

The current is $I = \frac{\varepsilon}{R}$ where R is the resistance of the rod in contact.

$$R = \lambda x = \frac{\lambda l}{\cos \omega t}$$

$$\therefore \quad I = \frac{1}{2}\frac{Bl^2\omega}{\lambda l}\sec^2\omega t \cos\omega t = \frac{Bl\omega}{2\lambda\cos\omega t}$$

For $\frac{\pi}{4\omega} < t < \frac{3\pi}{\omega}$ the rod is in contact with the side AB. Let the length of the rod in contact (OQ) be x. The flux through OQBD is $\phi = \left(l^2 + \frac{1}{2}\frac{l^2}{\tan\theta}\right)B$ where θ = ωt



Thus the magnitude of emf generated is $\varepsilon = \frac{d\phi}{dt} = \frac{1}{2}Bl^2\omega\frac{\sec^2\omega t}{\tan^2\omega t}$

The current is $I = \frac{\varepsilon}{R} = \frac{\varepsilon}{\lambda x} = \frac{\varepsilon\sin\omega t}{\lambda l} = \frac{1}{2}\frac{Bl\omega}{\lambda\sin\omega t}$

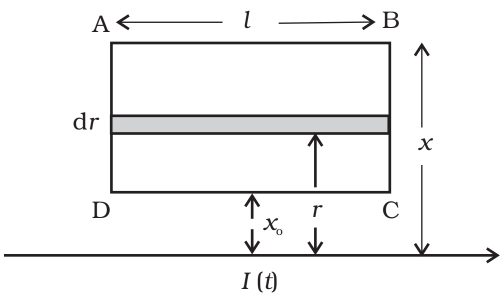
For $\frac{3\pi}{\omega} < t < \frac{\pi}{\omega}$ the rod will be in touch with OC. The Flux through OQABD is $\phi = \left(2l^2 - \frac{l^2}{2\tan\omega t}\right)B$

Thus the magnitude of emf

$$\varepsilon = \frac{d\phi}{dt} = \frac{B\omega l^2\sec^2\omega t}{2\tan^s\omega t}$$

$$I = \frac{\varepsilon}{R} = \frac{\varepsilon}{\lambda x} = \frac{1}{2}\frac{Bl\omega}{\lambda\sin\omega t}$$

6.25 At a distance r from the wire,



Field $B(r) = \frac{\mu_o I}{2\pi r}$ (out of paper).

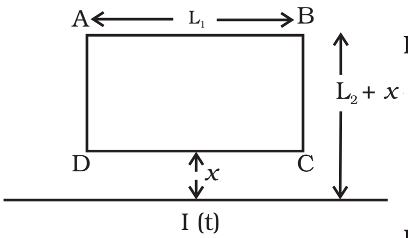
Total flux through the loop is

$$\text{Flux} = \frac{\mu_o I}{2\pi}l\int_{x_o}^{x}\frac{dr}{r} = \frac{\mu_o I}{2\pi}ln\frac{x}{x_o}$$

$$\frac{1}{R}\frac{dI}{dt} = \frac{\varepsilon}{R} = I = \frac{\mu_o l}{2\pi}\frac{\lambda}{R}\ln\frac{x}{x_0}$$

6.26 If $I(t)$ is the current in the loop.

$$I(t) = \frac{1}{R}\frac{d\phi}{dt}$$



If Q is the charge that passed in time t,

$$I(t) = \frac{dQ}{dt} \text{ or } \frac{dQ}{dt} = \frac{1}{R}\frac{d\phi}{dt}$$

Integrating $Q(t_1) - Q(t_2) = \frac{1}{R}[\phi(t_1) - \phi(t_2)]$

$$\phi(t_1) = L_1\frac{\mu_o}{2\pi}\int_x^{L_2+x}\frac{dx'}{x'}I(t_1)$$

$$= \frac{\mu_o L_1}{2\pi}I(t_1)\ln\frac{L_2+x}{x}$$

The magnitute of charge is

$$Q = \frac{\mu_o L_1}{2\pi}\ln\frac{L_2+x}{x}[I_o - 0]$$

$$= \frac{\mu_o L_1 I_1}{2\pi}\ln\left(\frac{L_2+x}{x}\right).$$

6.27 $2\pi bE = E.M.F = \frac{B.\pi a^2}{\Lambda t}$ where E is the electric field generated around the ring.

Torque $= b \times$ Force $= Q\,E\,b = Q\left[\frac{B\pi a^2}{2\pi b\Delta t}\right]b$

$$= Q\frac{Ba^2}{2\Delta t}$$

If ΔL is the change in angular momentum

$$\Delta L = \text{Torque} \times \Delta t = Q\frac{Ba^2}{2}$$

Initial angular momentum = 0

Final angular momentum $= mb^2\omega = \dfrac{QBa^2}{2}$

$$\omega = \frac{QBa^2}{2mb^2}.$$

6.28 $$m\frac{d^2x}{dt^2} = mg\sin\theta - \frac{B\cos\theta d}{R}\left(\frac{dx}{dt}\right)\times(Bd)\cos\theta$$

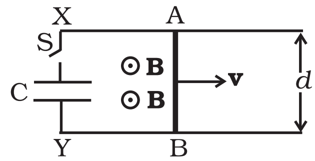
$$\frac{dv}{dt} = g\ \sin\theta - \frac{B^2d^2}{mR}(\cos\theta)^2 v$$

$$\frac{dv}{dt} + \frac{B^2d^2}{mR}(\cos\theta)^2 v = g\ \sin\theta$$

$$v = \frac{g\sin\theta}{\left(\dfrac{B^2d^2\cos^2\theta}{mR}\right)} + A\exp\left(-\frac{B^2d^2}{mR}(\cos^2\theta)t\right)$$ (A is a constant to be determine by initial conditions)

$$= \frac{mgR\sin\theta}{B^2d^2\cos^2\theta}\left(1 - \exp\left(-\frac{B^2d^2}{mR}(\cos^2\theta)t\right)\right)$$

6.29 If $Q(t)$ is charge on the capacitor (note current flows from A to B)



$$I = \frac{vBd}{R} - \frac{Q}{RC}$$

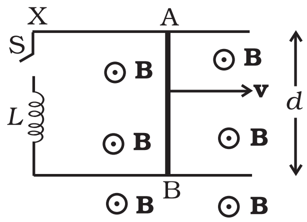
$$\Rightarrow \frac{Q}{RC} + \frac{dQ}{dt} = \frac{vBd}{R}$$

$$Q = vBdC + Ae^{-t/RC}$$

$$\therefore \Rightarrow Q = vBdC\left[1 - e^{-t/RC}\right]$$

(At time $t = 0$, $Q = 0 = A = -vBdc$). Differentiating, we get

$$I = \frac{vBd}{R}e^{-t/RC}$$



6.30 $$-L\frac{dI}{dt} + vBd = IR$$

$$L\frac{dI}{dt} + IR = vBd$$

$$I = \frac{vBd}{R} + A\,e^{-Rt/2}$$

At $\quad t = 0 \quad\quad I = 0 \Rightarrow A = -\frac{vBd}{R}$

$$I = \frac{vBd}{R}(1 - e^{-Rt/L}).$$

6.31 $\frac{d\phi}{dt}$ = rate of change in flux = $(\pi l^2)\, B_o\, l\, \frac{dz}{dt} = IR.$

$$I = \frac{\pi l^2 B_o \lambda}{R} v$$

Energy lost/second = $I^2 R = \frac{(\pi l^2 \lambda)^2 B_o{}^2 v^2}{R}$

This must come from rate of change in PE = $m\, g \frac{dz}{dt} = mgv$

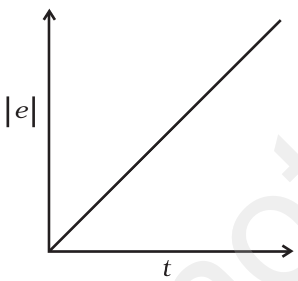
(as kinetic energy is constant for v= constant)

Thus, $mgv = \frac{(\pi l^2 \lambda B_0)^2 v^2}{R}$

Or, $v = \frac{mgR}{(\pi l^2 \lambda B_o)^2}$.

6.32 Magnetic field due to a solnoid S, $B = \mu_0 n I$

Magnetic flux in smaller coil $\phi = NBA$ where $A = \pi b^2$



So $e = \frac{-d\phi}{dt} = \frac{-d}{dt}$(NBA

$$= -N\pi b^2 \frac{d(B)}{dt} = -N\pi b^2 \frac{d}{dt}(\mu$$

$$= -N\pi b^2 \mu_0 n \frac{dI}{dt}$$

$$= -Nn\pi\mu_0 b^2 \frac{d}{dt}(mt^2 + C) = -\mu_0 N n \pi b^2 2mt$$

$e = -\mu_0 N n \pi b^2 2mt$

Negative sign signifies opposite nature of induced emf. The magnitude of emf varies with time as shown in the Fig.

Chapter 7

7.1 (b)

7.2 (c)

7.3 (c)

7.4 (b)

7.5 (c)

7.6 (c)

7.7 (a)

7.8 (a), (d)

7.9 (c), (d)

7.10 (a), (b), (d)

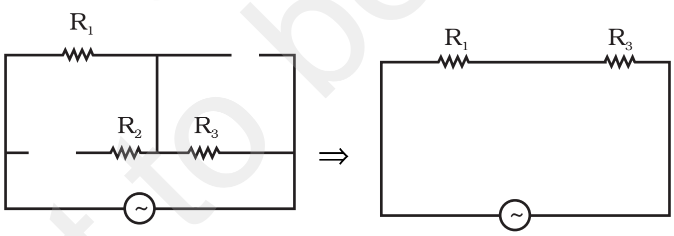
7.11 (a), (b), (c)

7.12 (c), (d)

7.13 (a), (d)

7.14 Magnetic energy analogous to kinetic energy and electrical energy analogous to potential energy.

7.15 At high frequencies, capacitor ≈ short circuit (low reactance) and inductor ≈ open circuit (high reactance). Therefore, the equivalent circuit $Z \approx R_1 + R_3$ as shown in the Fig.



7.16 (a) Yes, if rms voltage in the two circuits are same then at resonance, the rms current in *LCR* will be same as that in *R* circuit.

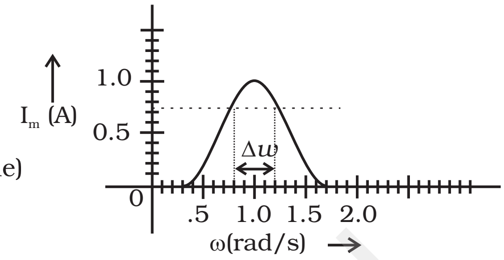
(d) No, because $R \le Z, \text{so}\, I_a \ge I_b$.

7.17 Yes, No.

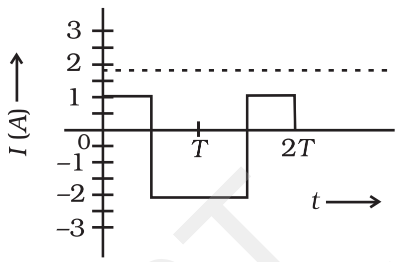
7.18 Bandwidth corresponds to frequencies at which $I_m = \frac{1}{\sqrt{2}} I_{max}$ $\approx 0.7 I_{max}$.

It is shown in the Fig.

$\Delta\omega = 1.2 - 0.8 = 0.4$ rad/s



7.19 $I_{rms} = 1.6$A (shown in Fig. by dotted line)



7.20 From negative to zero to positive; zero at resonant frequency.

7.21 (a) A

(b) Zero

(c) L or C or LC

7.22 An a.c current changes direction with the source frequency and the attractive force would average to zero. Thus, the a.c ampere must be defined in terms of some property that is independent of the direction of current. Joule's heating effect is such property and hence it is used to define rms value of a.c.

7.23 $X_L = \omega L = 2pfL$

$= 3.14\Omega$

$$Z = \sqrt{R^2 + L^2}$$

$$= \sqrt{(3.14)^2 + (1)^2} = \sqrt{10.86}$$

$; \ 3.3\Omega$

$$\tan\phi = \frac{\omega L}{R} = 3.14$$

$$\phi = \tan^{-1}(3.14)$$

$; \ 72°$

$$; \ \frac{72 \times \pi}{180} \text{rad.}$$

$$\text{Timelag } \Delta t = \frac{\phi}{\omega} = \frac{72 \times \pi}{180 \times 2\pi \times 50} = \frac{1}{250}\text{s}$$

7.24 $P_L = 60\text{W}, \ I_L = 0.54\text{A}$

$$V_L = \frac{60}{0.54} = 110\text{V}.$$

The transformer is step-down and have $\frac{1}{2}$ input voltage. Hence

$$i_p = \frac{1}{2} \times I_2 = 0.27\text{A}.$$

7.25 A capacitor does not allow flow of direct current through it as the resistance across the gap is infinite. When an alternating voltage is applied across the capacitor plates, the plates are alternately charged and discharged. The current through the capacitor is a result of this changing voltage (or charge). Thus, a capacitor will pass more current through it if the voltage is changing at a faster rate, i.e. if the frequency of supply is higher. This implies that the reactance offered by a capacitor is less with increasing frequency; it is given by $1/\omega C$.

7.26 An inductor opposes flow of current through it by developing a back emf according to Lenz's law. The induced voltage has a polarity so as to maintain the current at its present value. If the current is decreasing, the polarity of the induced emf will be so as to increase the current and vice versa. Since the induced emf is proportional to the rate of change of current, it will provide greater reactance to the flow of current if the rate of change is faster, i.e. if the frequency is higher. The reactance of an inductor, therefore, is proportional to the frequency, being given by ωL.

7.27 Power $P = \frac{V^2}{Z} \Rightarrow \frac{50,000}{2000} = 25 = Z$

$$Z^2 = R^2 + (X_C - X_L)^2 = 625$$

$$\tan\phi = \frac{X_C - X_L}{R} = -\frac{3}{4}$$

$$625 = R^2 + \left(-\frac{3}{4}R\right)^2 = \frac{25}{16}$$

$$R^2 = 400 \Rightarrow \text{R} = 20\Omega$$

$$X_C - X_L = -15\Omega$$

$$I = \frac{V}{Z} = \frac{223}{25} \approx 9\,\text{A}.$$

$$I_M = \sqrt{2} \times 9 = 12.6\,\text{A}.$$

If R, X_C, X_L are all doubled, tan ϕ does not change.

Z is doubled, current is halfed.

Power drawn is halfed.

7.28 (i) Resistance of Cu wires, R

$$= \rho \frac{l}{A} = \frac{1.7 \times 10^{-8} \times 20000}{\pi \times \left(\frac{1}{2}\right)^2 \times 10^{-4}} = 4\Omega$$

I at 220 V: $VI = 10^6$ W ; $I = \frac{10^6}{220} = 0.45 \times 10^4$ A

RI^2 = Power loss

$= 4 \times (0.45)^2 \times 10^8$ W

$> 10^6$ W

This method cannot be used for transmission

(ii) $V'I' = 10^6$ W $= 11000\ I'$

$$I' = \frac{1}{1.1} \times 10^2$$

$$RI'^2 = \frac{1}{1.21} \times 4 \times 10^4 = 3.3 \times 10^4 \text{ W}$$

$$\text{Fraction of power loss} = \frac{3.3 \times 10^4}{10^6} = 3.3\%$$

7.29 $Ri_1 = v_m \sin \omega t$ $\quad i_1 = \frac{v_m \sin \omega t}{R}$

$$\frac{q_2}{C} + L\frac{dq_2^2}{dt^2} = v_m \sin \omega t$$

Let $q_2 = q_m \sin(\omega t + \phi)$

$$q_m \left(\frac{1}{C} - L\omega^2\right) \sin(\omega t + \phi) = v_m \sin \omega t$$

$$q_m = \frac{v_m}{\frac{1}{C} - L\omega^2}, \phi = 0; \frac{1}{C} - \omega^2 L > 0$$

$$v_R = \frac{v_m}{Lw^2 - \frac{1}{C}}, \phi = \pi\, L\omega^2 - \frac{1}{C} > 0$$

$$i_2 = \frac{dq_2}{dt} = \omega q_m \cos(\omega t + \phi)$$

i_1 and i_2 are out of phase. Let us assume $\frac{1}{C} - \omega^2 L > 0$

$$i_1 + i_2 = \frac{v_m \sin\omega t}{R} + \frac{v_m}{L\omega - \frac{1}{c\omega}} \cos\omega t$$

Now A sin ωt + B cos ωt = C sin ($\omega t + \phi$)

C cos ϕ = A, C sin ϕ = B; $C = \sqrt{A^2 + B^2}$

Therefore, $i_1 + i_2 = \left[\frac{{v_m}^2}{R^2} + \frac{{v_m}^2}{[\omega l - 1/\omega C]^2}\right]^{\frac{1}{2}} \sin(\omega t + \phi)$

$$\phi = \tan^{-1}\frac{R}{X_L - X_C}$$

$$\frac{1}{Z} = \left\{\frac{1}{R^2} + \frac{1}{(L\omega - 1/\omega C)^2}\right\}^{1/2}$$

7.30 $Li\frac{di}{dt} + Ri^2 + \frac{qi}{c} = vi$; $Li\frac{di}{dt} = \frac{d}{dt}\left(\frac{1}{2}Li^2\right)$ = rate of change of energy stored in an inductor.

Ri^2 = joule heating loss

$\frac{q}{C}i = \frac{d}{dt}\left(\frac{q^2}{2C}\right)$ = rate of change of energy stored in the capacitor.

vi = rate at which driving force pours in energy. It goes into (i) ohmic loss and (ii) increase of stored energy.

$$\int_0^T dt \frac{d}{dt}\left(\frac{1}{2}i^2 + \frac{q^2}{C}\right) + \int_0^T Ri^2 dt = \int_0^T vidt$$

$$0+(+ve)=\int_0^T vidt$$

$\int_0^T vidt > 0$ if phase difference, a constant is acute.

7.31 (i) $L\frac{d^2q}{dt^2}+R\frac{dq}{dt}+\frac{q}{C}=v_m \sin \omega t$

Let $q = q_m \sin(\omega t + \phi) = -q_m \cos(\omega t + \phi)$

$i = i_m \sin(\omega t + \phi) = q_m\, \omega \sin(\omega t + \phi)$

$$i_m = \frac{v_m}{Z} = \frac{v_m}{\sqrt{R^2+(X_C-X_L)^2}}; \phi = \tan^{-1}\left(\frac{X_C-X_L}{R}\right)$$

(ii) $U_L = \frac{1}{2}Li^2 = \frac{1}{2}L\left[\frac{v_m}{\sqrt{R^2+X_C-X_L)^2}_0}\right]^2 \sin^2(\omega t_0+\phi)$

$$U_C = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2C}\left[\frac{v_m}{\sqrt{R^2+(X_C-X_L)^2}}\right]^2 \frac{1}{\omega^2}\cos^2(\omega t_0+\phi)$$

(iii) Left to itself, it is an *LC* oscillator. The capacitor will go on discharging and all energy will go to *L* and back and forth.

Chapter 8

8.1 (c)

8.2 (b)

8.3 (b)

8.4 (d)

8.5 (d)

8.6 (c)

8.7 (c)

8.8 (a), (d)

8.9 (a), (b), (c)

8.10 (b), (d)

8.11 (a), (c), (d)

8.12 (b), (d)

8.13 (a), (c), (d)

8.14 As electromagnetic waves are plane polarised, so the receiving antenna should be parallel to electric/magnetic part of the wave.

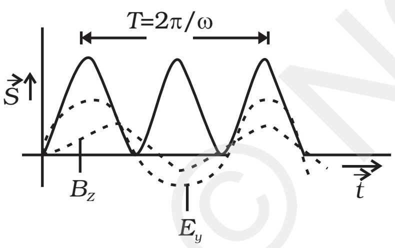
8.15 Frequency of the microwave matches the resonant frequency of water molecules.

8.16 $i_C = i_D = \dfrac{dq}{dt} = -2\pi q_0 \nu \sin 2\pi \nu t$.

8.17 On decreasing the frequency, reactance $X_c = \dfrac{1}{\omega C}$ will increase which will lead to decrease in conduction current. In this case $i_D = i_C$; hence displacement current will decrease.

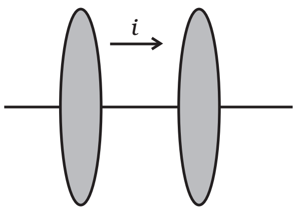
8.18 $I_{av} = \dfrac{1}{2} c \dfrac{B_0^2}{\mu_0} = \dfrac{1}{2} \times \dfrac{3\times10^8 \times (12\times10^{-8})^2}{1.26\times10^{-6}} = 1.71 W/m^2$.

8.19



8.20 EM waves exert radiation pressure. Tails of comets are due to solar solar radiation.

8.21 $B = \dfrac{\mu_0 2 I_D}{4\pi r} = \dfrac{\mu_0 1}{4\pi r} = \dfrac{\mu_0}{2\pi r} \varepsilon_0 \dfrac{d\phi_E}{dt}$



$$= \frac{\mu_0 \varepsilon_0}{2\pi r} \frac{d}{dt}(E\pi r^2)$$

$$= \frac{\mu_0 \varepsilon_0 r}{2} \frac{dE}{dt}.$$

8.22 (a) $\lambda_1 \rightarrow$ Microwave, $\lambda_2 \rightarrow$ UV

$\lambda_3 \rightarrow$ X rays, $\lambda_4 \rightarrow$ Infrared

(b) $\lambda_3 < \lambda_2 < \lambda_4 < \lambda_1$

(c) Microwave - Radar
UV - LASIK eye surgery
X-ray - Bone fracture identification (bone scanning)
Infrared - Optical communication.

8.23 $S_{av} = c^2\varepsilon_0|\mathbf{E}_0 \times \mathbf{B}_0|\frac{1}{T}\int_0^T \cos^2(kx - \omega t)dt$ as $\mathbf{S} = c^2\varepsilon_0(\mathbf{E} \times \mathbf{B})$

$$= c^2\varepsilon_0 E_0 B_0 \frac{1}{\not{T}} \times \frac{\not{T}}{2}$$

$$= c^2\varepsilon_0 E_0\left(\frac{E_0}{c}\right) \times \frac{1}{2} \quad \left(as\, c = \frac{E_0}{B_0}\right)$$

$$= \frac{1}{2}\varepsilon_0 E_0^2 c$$

$$= \frac{E_0^2}{2\mu_0 c} \quad as\left(c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}\right)$$

8.24 $i_D = C\frac{dV}{dt}$

$$1 \times 10^{-3} = 2 \times 10^{-6}\frac{dV}{dt}$$

$$\frac{dV}{dt} = \frac{1}{2} \times 10^3 = 5 \times 10 V/s$$

Hence, applying a varying potential difference of 5 × 10^2 V/s would produce a displacement current of desired value.

8.25 Pressure

$$P = \frac{Force}{Area} = \frac{F}{A} = \frac{1}{A}\frac{\Delta p}{\Delta t} \quad (F = \frac{\Delta p}{\Delta t} = \text{rate of change of momentum})$$

$$= \frac{1}{A}.\frac{U}{\Delta tc} \quad (\Delta pc = \Delta U = \text{energy imparted by wave in time} \Delta t)$$

$$= \frac{I}{c}\left(\text{intensity } I = \frac{U}{A\Delta t}\right.$$

8.26 Intensity is reduced to one fourth. Tis is beacause the light beam spreads, as it propogates into a spherical region of area $4\pi r^2$, but LASER does not spread and hence its intensity remains constant.

8.27 Electric field of an EM wave is an oscillating field and so is the electric force caused by it on a charged particle. This electric force averaged over an integral number of cycles is zero since its direction changes every half cycle. Hence, electric field is not responsible for radiation pressure.

8.28 $$\mathbf{E} = \frac{\lambda \hat{\mathbf{e}}_s}{2\pi\varepsilon_o a}\hat{\mathbf{j}}$$

$$\mathbf{B} = \frac{\mu_o i}{2\pi a}\hat{\mathbf{i}}$$

$$= \frac{\mu_o \lambda v}{2\pi a}\hat{i}$$

$$\mathbf{S} = \frac{1}{\mu_o}(\mathbf{E}\times\mathbf{B}) = \frac{1}{\mu_o}\left(\frac{\lambda \hat{\mathbf{j}}_s}{2\pi\varepsilon_o a}\hat{\mathbf{j}} \times \frac{\mu_o \lambda v}{2\pi a}\hat{\mathbf{i}}\right)$$

$$= \frac{-\lambda^2 v}{4\pi^2\varepsilon_0 a^2}\hat{\mathbf{k}}$$

8.29 Let the distance between the plates be d. Then the electric field $E = \frac{V_o}{d}\sin(2\pi\nu t)$. The conduction current density is given by the Ohm's law = E.

$$\Rightarrow J^c = \frac{1}{\rho}\frac{V_o}{d}\sin(2\pi\nu t) = \frac{V_0}{\rho d}\sin(2\pi\nu t)$$

$$= J_o^c \sin 2\pi\nu t$$

where $J_0^c = \frac{V_0}{\rho d}$.

The displacement current density is given as

$$J^d = \varepsilon\frac{\partial E}{dt} = \varepsilon\frac{\partial}{dt}\left\{\frac{V_o}{d}\sin(2\pi\nu t)\right\}$$

$$= \frac{\varepsilon 2\pi\nu V_o}{d}\cos(2\pi\nu t)$$

$= J_o^d \cos(2\pi\nu t)$, where $J_0^d = \frac{2\pi\nu\varepsilon V_0}{d}$

$$J_o^d / J_o^c = \frac{2\pi\nu\varepsilon V_o}{d} . \frac{\rho d}{V_o} = 2\pi\nu\varepsilon\rho = 2\pi\times 80\,\varepsilon_o\nu\times 0.25 = 4\pi\varepsilon_o\nu\times 10$$

$$= \frac{10\,\nu}{9\times 10^9} = \frac{4}{9}$$

8.30 (i) Displacement curing density can be found from the relation be $\mathbf{J}_D = \varepsilon_0 \frac{d\mathbf{E}}{dt}$

$$= \varepsilon_0\, \mu_0\, I_0\, \frac{\partial}{\partial t}\cos\,(2\pi\nu t).\ \ln\left(\frac{s}{a}\right)\hat{\mathbf{k}}$$

$$= \frac{1}{c^2} I_0 2\pi\nu^2 (-\sin(2\pi\nu t))\ln\left(\frac{s}{a}\right)\hat{\mathbf{k}}$$

$$= \left(\frac{\nu}{c}\right)^2 2\pi I_0 \sin(2\pi\nu t)\ln\left(\frac{a}{s}\right)\hat{k}$$

$$= \frac{2\pi}{\lambda^2} I_0 \ln\left(\frac{a}{s}\right)\sin(2\pi\nu t)\hat{\mathbf{k}}$$

(ii) $I^d = \int J_D s ds d\theta$

$$= \frac{2\pi}{\lambda^2} I_0 2\pi \int_{s=0}^{a} \ln\left(\frac{a}{s}\right).s ds \sin(2\pi\nu t)$$

$$= \left(\frac{2\pi}{\lambda}\right)^2 I_0 \int_{s=0}^{a} \frac{1}{2} ds^2 \ln\left(\frac{a}{s}\right).\sin(2\pi\nu t)$$

$$= \frac{a^2}{4}\left(\frac{2\pi}{\lambda}\right)^2 I_0 \int_{s=0}^{a} d\left(\frac{s}{a}\right)^2 ln\left(\frac{a}{s}\right)^2 .\sin(2\pi\nu t)$$

$$= -\frac{a^2}{4}\left(\frac{2\pi}{\lambda}\right)^2 I_0 \int_0^1 \ln\xi\, d\,\xi.\sin(2\pi\nu t)$$

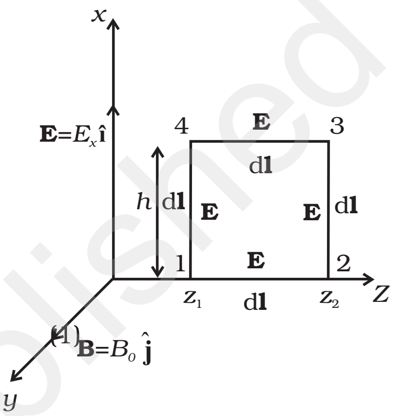
$$= +\left(\frac{a}{2}\right)^2\left(\frac{2\pi}{\lambda}\right)^2 I_0 \sin 2\pi\nu t$$ ($\therefore$ The integral has value –1)

(iii) The displacement current

$$I^d = \left(\frac{a}{2}.\frac{2\pi}{\lambda}\right)^2 I_0 \sin 2\pi\nu t = I_0^d \sin 2\pi\nu t$$

$$\frac{I_0^d}{I_0} = \left(\frac{a\pi}{\lambda}\right)^2.$$

8.31 (i) $\oint \mathbf{E}.d\mathbf{l} = \int_1^2 E.dl + \int_2^3 E.dl + \int_3^4 E.dl + \int_4^1 E.dl$

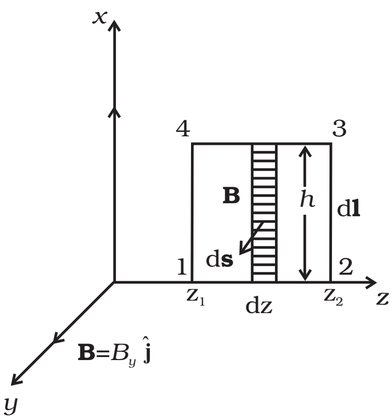


$$= \int_1^2 E.dl \cos 90° + \int_2^3 E.dl \cos 0 + \int_3^4 E.dl \cos 90° + \int_4^1 E.dl \cos 180°$$

$$= \mathbf{E}_0 h[\sin(kz_2 - \omega t) - \sin(kz_1 - \omega t)]$$

(ii) For evaluating $\int \mathbf{B.ds}$ let us consider the rectangle 1234 to be made of strips of area ds = $h\,dz$ each.

$$\int \mathbf{B.ds} = \int B ds \cos 0 = \int B ds = \int_{z_1}^{z_2} B_0 \sin(kz - \omega t) h dz$$



$$= \frac{-B_o h}{k}[\cos(kz_2 - \omega t) - \cos(kz_1 - \omega t)] \qquad (2)$$

(iii) $\oint \mathbf{E.dl} = \frac{-d\phi_B}{dt}$

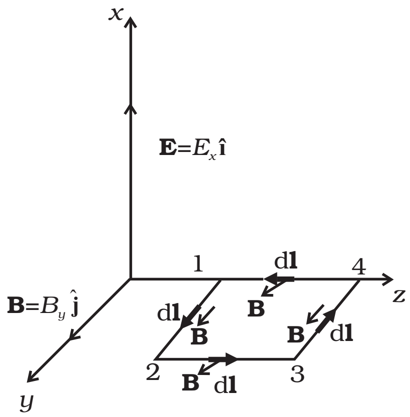
Using the relations obtained in Equations (1) and (2) and simplifiying, we get

$$E_0 h[\sin(kz_2 - \omega t) - \sin(kz_1 - \omega t)] = \frac{B_o h}{k}\omega[\sin(kz_2 - \omega t) - \sin(kz_1 - \omega t)]$$

$$E_0 = B_0 \frac{\omega}{k}$$

$$\frac{E_0}{B_0} = c$$

(iv) For evaluating $\oint \mathbf{B.dl}$, let us consider the loop 1234 in yz plane as shown in Fig.



$$\oint \mathbf{B.dl} = \int_1^2 \mathbf{B.dl} + \int_2^3 \mathbf{B.dl} + \int_3^4 \mathbf{B.dl} + \int_4^1 \mathbf{B.dl}$$

$$= \int_1^2 B\,dl\cos 0 + \int_2^3 B\,dl\cos 90° + \int_3^4 B\,dl\cos 180° + \int_4^1 B\,dl\cos 90°$$

$$= B_0 h[sin(kz_1 - \omega t) - sin(kz_2 - \omega t)] \qquad (3)$$

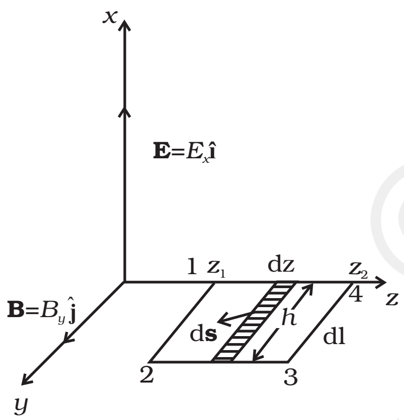
Now to evaluate $\phi_E = \int \mathbf{E.ds}$, let us consider the rectangle 1234 to be made of strips of area hdz each.

$$\phi_E = \int \mathbf{E.ds} = \int Eds\cos 0 = \int Eds = \int_{Z_1}^{Z_2} E_0 sin(kz_1 - \omega t)hdz$$

$$= \frac{-E_0 h}{k}[\cos(kz_2 - \omega t) - \cos(kz_1 -$$

$$\therefore \frac{d\phi_E}{dt} = \frac{E_0 h\omega}{k}[sin(kz_1 - \omega t) - sin(kz_2 - \omega t)]$$

(4)



In $\oint \mathbf{B.dl} = \mu_0 \left(I + \varepsilon_0 \frac{d\phi_E}{dt} \right)$, I = conduction current

= 0 in vacuum.

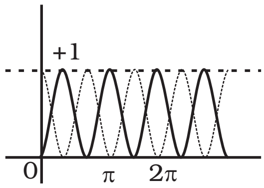
$$\therefore \oint \mathbf{B.dl} = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

Using relations obtained in Equations (3) and (4) and ssimplifying, we get

$$B_0 = E_0 \frac{\omega}{k} . \mu_0 \varepsilon_0$$

$$\frac{E_0}{B_0} \frac{\omega}{k} = \frac{1}{\mu_0 \varepsilon_0}$$ But E_0/B_0 = c, and $\omega = ck$

or $c.c = \frac{1}{\mu_0 \varepsilon_0}$ Therefore, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$.



8.32 (a) E - field contribution is $u_E = \frac{1}{2}\varepsilon_0 E^2$

B - field contribution is $u_B = \frac{1}{2}\frac{B^2}{\mu_0}$

Total energy density $u = u_E + u_B = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$ (1)

The values of E^2 and B^2 vary from point to point and from moment to moment. Hence, the effective values of E^2 and B^2 are their time averages.

$(E^2)_{av} = E_0^2[\sin^2(kz - \omega t)]_{av}$

$(B^2)_{av} = (B^2)_{av} = B_0^2[\sin^2(kz - \omega t)]_{av}$

The graph of $\sin^2\theta$ and $\cos^2\theta$ are identical in shape but shifted by $\pi/2$, so the average values of $\sin^2\theta$ and $\text{Cos}^2\theta$ are also equal over any integral multiple of π.

and also $\sin^2\theta + \cos^2\theta = 1$

So by symmetry the average of $\sin^2\theta$ = average of $\cos^2\theta = \frac{1}{2}$

$\therefore (E^2)_{av} = \frac{1}{2}E_0^2 \text{ and } (B^2)_{av} = \frac{1}{2}B_0^2$

Substuting in Equation (1),

$u = \frac{1}{4}\varepsilon_0 E^2 + \frac{1}{4}\frac{B_0^2}{\mu}$ (2)

(b) We know $\frac{E_0}{B_0} = c \text{ and } c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ $\therefore \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{E_0^2/c^2}{4\mu_0} = \frac{E_0^2}{4\mu_0}\mu_0\varepsilon_0 = \frac{1}{4}\varepsilon_0 E_0^2$.

Therefore, $u_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{2}\varepsilon_0 E_0^2, \text{and } I_{av} = u_{av}c = \frac{1}{2}\varepsilon_0 E_0^2$.

Chapter 9

9.1 (a)

9.2 (d)

9.3 (c)

9.4 (b)

9.5 (c)

9.6 (c)

9.7 (b)

9.8 (b)

9.9 (b)

9.10 (d)

9.11 (a)

9.12 (a), (b), (c)

9.13 (d)

9.14 (a), (d)

9.15 (a), (b)

9.16 (a), (b), (c)

9.17 As the refractive index for red is less than that for blue, parallel beams of light incident on a lens will be bent more towards the axis for blue light compared to red. Thus the focal length for blue light will be smaller than that for red.

9.18 The near vision of an average person is 25cm. To view an object with magnification 10,

$$m = \frac{D}{f} \Rightarrow f = \frac{D}{m} = \frac{25}{10} = 2.5 = 0.025\text{m}$$

$$P = \frac{1}{0.025} = 40 \text{ diopters.}$$

9.19 No. The reversibility of the lens makes equation.

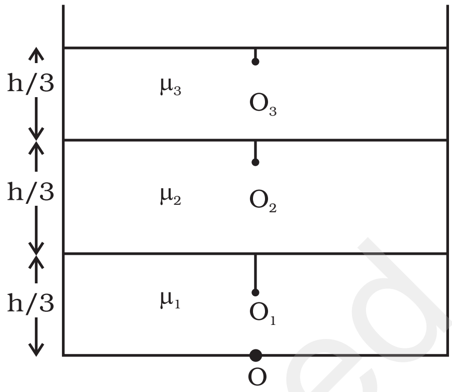
9.20 Let the apparent depth be O_1 for the object seen from μ_2 then

$$O_1 = \frac{\mu_2}{\mu_1}\frac{h}{3}$$

If seen from μ_3 the apparent depth is O_2.

$$O_2 = \frac{\mu_3}{\mu_2}\left(\frac{h}{3} + O_1\right) = \frac{\mu_3}{\mu_2}\left(\frac{h}{3} + \frac{\mu_2}{\mu_1}\frac{h}{3}\right) = \frac{h}{3}\left(\frac{\mu_3}{\mu_2} + \frac{\mu_3}{\mu_1}\right)$$

Seen from outside, the apparent height is



$$O_3 = \frac{1}{\mu_3}\left(\frac{h}{3}+O_2\right) = \frac{1}{\mu_3}\left[\frac{h}{3}+\frac{h}{3}\left(\frac{\mu_3}{\mu_2}+\frac{\mu_3}{\mu_1}\right)\right]$$

$$= \frac{h}{3}\left(\frac{1}{\mu_1}+\frac{1}{\mu_2}+\frac{1}{\mu_3}\right)$$

9.21 At minimum deviation

$$\mu = \frac{\sin\left[\frac{(A+D_m)}{2}\right]}{\sin\left(\frac{A}{2}\right)}$$

$\therefore$ Given $D_m = A$

$$\therefore\ \mu = \frac{\sin A}{\sin\frac{A}{2}} = \frac{2\sin\frac{A}{2}\cos\frac{A}{2}}{\sin\frac{A}{2}} = 2\cos\frac{A}{2}$$

$$\therefore\ \cos\frac{A}{2} = \frac{\sqrt{3}}{2} \text{ or } \frac{A}{2} = 30° \ \therefore\ A = 60°$$

9.22 Let the two ends of the object be at distance $u_1 = u - L/2$ and $u_2 = u + L/2$, respectively, so that $|u_1 - u_2| = L$. Let the image of the two ends be formed at v_1 and v_2, so that the image length would be $L' = |v_1 - v_2|$. Since $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ or $v = \frac{fu}{u-f}$ the image of the two ends will be at $v_1 = \frac{f(u-L/2)}{u-f-L/2}$, $v_2 = \frac{f(u+L/2)}{u-f+L/2}$

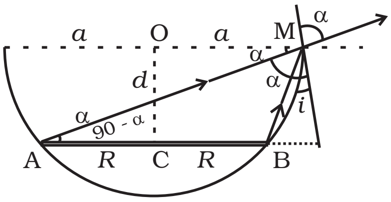
Hence

$$L' = |v_1 - v_2| = \frac{f^2 L}{(u-f)^2 \times L^2/4}$$

Since the object is short and kept away from focus, we have
$L^2/4 << (u-f)^2$
Hence finally

$$L' = \frac{f^2}{(u-f)^2} L.$$

9.23 Refering to the Fig., AM is the direction of incidence ray before liquid is filled. After liquid is filledm, BM is the direction of the incident ray. Refracted ray in both cases is same as that along AM.

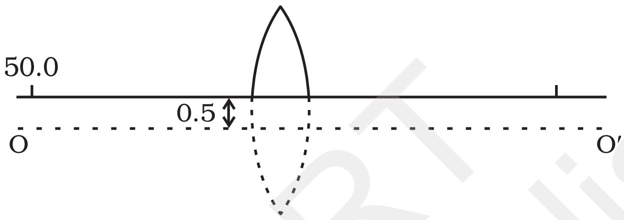


$$\frac{1}{\mu} = \frac{\sin i}{\sin r} = \frac{\sin i}{\sin \alpha}$$

$$\sin i = \frac{a - R}{\sqrt{d^2 + (a-R)^2}} \text{ and } \sin\alpha = \cos(90-\alpha) = \frac{a+R}{\sqrt{d^2+(a-R)^2}}$$

Substuting, we get $d = \dfrac{\mu(a^2 - R^2)}{\sqrt{(a+R)^2 - \mu(a-R)^2}}$

9.24



If there was no cut then the object would have been at a height of 0.5 cm from the principal axis 00′.
Consider the image for this case.

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

$$\therefore \frac{1}{v} = \frac{1}{u} + \frac{1}{f} = \frac{1}{-50} + \frac{1}{25} = \frac{1}{50}$$

$\therefore$ v = 50 cm.

Magnification is m = $\dfrac{v}{u} = -\dfrac{50}{50} = -1$.

Thus the image would have been formed at 50 cm from the pole and 0.5 cm below the principal axis.
Hence with respect to the X axis passing through the edge of the cut lens, the co-ordinates of the image are

(50 cm, –1 cm)

9.25 From the reversibility of u and v, as seen from the formula for lens,

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

It is clear that there are two positions for which there shall be an image on the screen.
Let the first position be when the lens is at O.
Given $-u + v = D$
$\Rightarrow u = -(D - v)$
Placing it in the lens formula

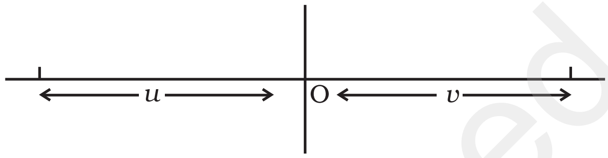
$$\frac{1}{D-v} + \frac{1}{v} = \frac{1}{f}$$

$$\Rightarrow \frac{v + D - v}{(D - v)v} = \frac{1}{f}$$

$$\Rightarrow v^2 - Dv + Df = 0$$

$$\Rightarrow v = \frac{D}{2} \pm \frac{\sqrt{D^2 - 4Df}}{2}$$

$$u = -(D - v) = -\left(\frac{D}{2} \pm \frac{\sqrt{D^2 - 4Df}}{2}\right)$$



Thus, if the object distance is $\frac{D}{2} - \frac{\sqrt{D^2 - 4Df}}{2}$ then the image is at $\frac{D}{2} + \frac{\sqrt{D^2 - 4Df}}{2}$

If the object distance is $\frac{D}{2} + \frac{\sqrt{D^2 - 4Df}}{2}$, then the image is at $\frac{D}{2} - \frac{\sqrt{D^2 - 4Df}}{2}$.

The distance between the poles for these two object distances is

$$\frac{D}{2} + \frac{\sqrt{D^2 - 4Df}}{2} - \left(\frac{D}{2} - \frac{\sqrt{D^2 - 4Df}}{2}\right) = \sqrt{D^2 - 4Df}$$

Let $d = \sqrt{D^2 - 4Df}$

If $u = \frac{D}{2} + \frac{d}{2}$ then the image is at $v = \frac{D}{2} - \frac{d}{2}$.

$\therefore$ The magnification $m_1 = \frac{D - d}{D + d}$

If $u = \frac{D - d}{2}$ then $v = \frac{D + d}{2}$

$\therefore$ The magnification $m_2 = \frac{D + d}{D - d}$. Thus $\frac{m_2}{m_1} = \left(\frac{D + d}{D - d}\right)^2$.

9.26 Let d be the diameter of the disc. The spot shall be invisible if the incident rays from the dot at O to the surface at $\frac{d}{2}$ are at the critical angle.

Let i be the angle of incidence.

Then $\sin i = \dfrac{1}{\mu}$

Now, $\dfrac{d/2}{h} = \tan i$

$$\Rightarrow \frac{d}{2} = h \tan i = h\left[\sqrt{\mu^2 - 1}\right]^{-1}$$

$$\therefore d = \frac{2h}{\sqrt{\mu^2 - 1}}.$$

9.27 (i) Let the power at the far point be P_f for the normal relaxed eye.

Then $P_f = \dfrac{1}{f} = \dfrac{1}{0.1} + \dfrac{1}{0.02} = 60$ D

With the corrective lens the object distance at the far point is ∞. The power required is

$$P_f' = \frac{1}{f'} = \frac{1}{\infty} + \frac{1}{0.02} = 50\,\text{D}$$

The effective power of the relaxed eye with glasses is the sum of the eye and that of the glasses P_g.

$\therefore P_f' = P_f + P_g$

$\therefore P_g = -10$ D.

(ii) His power of accomadation is 4 diopters for the normal eye. Let the power of the normal eye for near vision be P_n.

Then $4 = P_n - P_f$ or $P_n = 64$ D.

Let his near point be x_n, then

$$\frac{1}{x_n} + \frac{1}{0.02} = 64 \text{ or } \frac{1}{x_n} + 50 = 64$$

$$\frac{1}{x_n} = 14,$$

$$\therefore x_n = \frac{1}{14}; \quad 0.07\text{m}$$

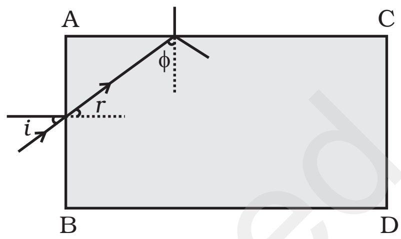
(iii) With glasses $P_n' = P_f' + 4 = 54$

$$54 = \frac{1}{x_n'} + \frac{1}{0.02} = \frac{1}{x_n'} + 50$$

$$\frac{1}{x_n'} = 4,$$

$$\therefore x_n' = \frac{1}{4} = 0.25\text{m}.$$

9.28 Any ray entering at an angle i shall be guided along AC if the angle the ray makes with the face AC (ϕ) is greater than the critical angle.



$$\Rightarrow \sin \geq \frac{1}{\mu}$$

$$\Rightarrow \cos r \geq \frac{1}{\mu}$$

$$\text{Or, } 1 - \cos^2 r \leq 1 - \frac{1}{\mu^2}$$

$$\text{i.e. } \sin^2 r \leq 1 - \frac{1}{\mu^2}$$

Since $\sin i = \mu \sin r$

$$\frac{1}{\mu^2}\sin^2 i \leq 1 - \frac{1}{\mu^2}$$

Or, $\sin^2 i \leq \mu^2 - 1$

The smallest angle ϕ shall be when $i = \frac{\pi}{2}$. If that is greater than the critical angle then all other angles of incidence shall be more than the critical angle.

Thus $1 \leq \mu^2 - 1$

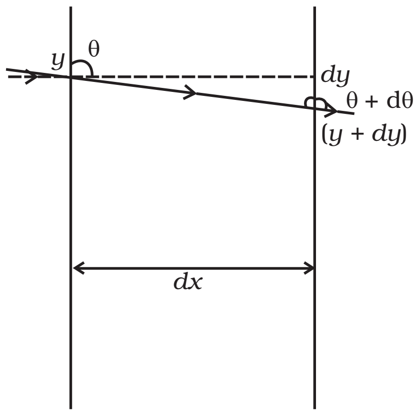
Or, $\mu^2 \geq 2$

$\Rightarrow \mu \geq \sqrt{2}$

9.29 Consider a portion of a ray between x and $x + dx$ inside the liquid. Let the angle of incidence at x be θ and let it enter the thin column at height y. Because of the bending it shall emerge at $x + dx$ with an angle θ + dθ and at a height $y + dy$. From Snell's law

$\mu(y) \sin\theta = \mu(y+dy) \sin(\theta + d\theta)$

$$\text{or } \mu(y)\sin\theta \simeq \left(\mu(y) + \frac{d\mu}{dy}dy\right)(\sin\theta\cos d\theta + \cos\theta \sin d\theta)$$



$$\simeq \mu(y)\sin\theta + \mu(y)\cos\theta d\theta + \frac{d\mu}{dy}dy\sin\theta$$

$$\text{or } \mu(y)\cos\theta d\theta \simeq \frac{-d\mu}{dy}dy\sin\theta$$

$$d\theta \simeq \frac{-1}{\mu}\frac{d\mu}{dy}dy\tan\theta$$

$$\text{But } \tan\theta = \frac{dx}{dy} \text{ (from the fig.)}$$

$$\therefore\ d\theta = \frac{-1}{\mu}\frac{d\mu}{dy}dx$$

$$\therefore\ \theta = \frac{-1}{\mu}\frac{d\mu}{dy}\int_{o}^{d} dx = \frac{-1}{\mu}\frac{d\mu}{dy}d$$

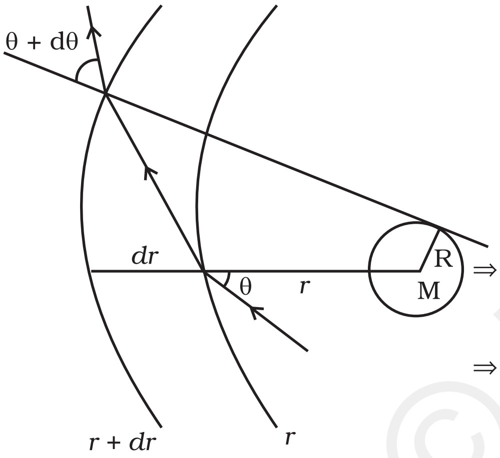
9.30 Consider two planes at r and $r + dr$. Let the light be incident at an angle θ at the plane at r and leave $r + dr$ at an angle $\theta + d\theta$

Then from Snell's law

$n(r)\sin\theta = n(r + dr)\sin(\theta + d\theta)$

$$\Rightarrow n(r)\sin\theta \simeq \left(n(r) + \frac{dn}{dr}dr\right)(\sin\theta\cos d\theta + \cos\theta\sin d\theta)$$

$$\simeq \left(n(r) + \frac{dn}{dr}dr\right)(\sin\theta + \cos\theta\, d\theta)$$



Neglecting products of differentials

$$n(r)\sin\theta \simeq n(r)\sin\theta + \frac{dn}{dr}dr\sin\theta + n(r)\cos\theta d\theta$$

$$\Rightarrow -\frac{dn}{dr}\tan\theta = n(r)\frac{d\theta}{dr}$$

$$\Rightarrow \frac{2GM}{r^2c^2}\tan\theta = \left(1 + \frac{2GM}{rc^2}\right)\frac{d\theta}{dr} \approx \frac{d\theta}{dr}$$

$$\therefore \int_0^{\theta_0} d\theta = \frac{2GM}{c^2}\int_{-\infty}^{\infty}\frac{\tan\theta dr}{r^2}$$

Now $r^2 = x^2 + R^2$ and $\tan\theta = \dfrac{R}{x}$

$2rdr = 2xdx$

$$\int_0^{\theta_0} d\theta = \frac{2GM}{c^2}\int_{-\infty}^{\infty}\frac{R}{x}\frac{xdx}{(x^2 + R^2)^{\frac{3}{2}}}$$

Put $x = R\tan\phi$

$dx = R\,\mathrm{Sec}^2\phi\, d\phi$

$$\therefore\quad \theta_0 = \frac{2GMR}{c^2}\int_{-\pi/2}^{\pi/2}\frac{R\sec^2\phi d\phi}{R^3\sec^3\phi}$$

$$= \frac{2GM}{Rc^2}\int_{-\pi/2}^{\pi/2}\cos\phi d\phi = \frac{4GM}{Rc^2}$$

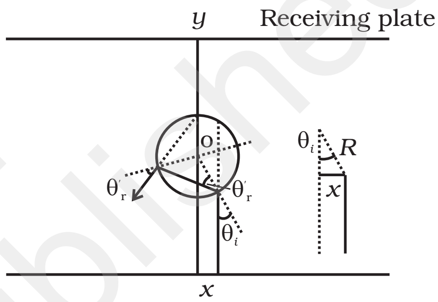
9.31 As the material is of refractive index –1, θ_r is negative and θ_r' positive.

Now $|\theta_i| = |\theta_r| = |\theta_r'|$

The total deviation of the outcoming ray from the incoming ray is $4\theta_i$. Rays shall not reach the receiving plate if

$$\frac{\pi}{2} \le 4\theta_i \le \frac{3\pi}{2} \quad \text{(angles measured clockwise from the } y \text{ axis)}$$

$$\frac{\pi}{8} \le \theta_i \le \frac{3\pi}{8}$$



Now $\sin\theta_i = \dfrac{x}{R}$

$$\frac{\pi}{8} \le \sin^{-1}\frac{x}{R} \le \frac{3\pi}{8}$$

Or, $\dfrac{\pi}{8} \le \dfrac{x}{R} \le \dfrac{3\pi}{8}$

Thus for $\dfrac{R\pi}{8} \le x \le \dfrac{R3\pi}{8}$ light emitted from the source shall not reach the receiving plate.

9.32 (i) The time required to travel from S to P_1 is

$$t_1 = \frac{SP_1}{c} = \frac{\sqrt{u^2+b^2}}{c}\ ; \ \frac{u}{c}\left(1+\frac{1}{2}\frac{b^2}{u^2}\right) \text{ assuming } b << u_0$$

The time required to travel from P_1 to O is

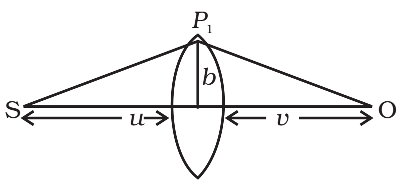
$$t_2 = \frac{P_1O}{c} = \frac{\sqrt{v^2+b^2}}{c}\ ; \ \frac{v}{c}\left(1+\frac{1}{2}\frac{b^2}{v^2}\right)$$

The time required to travel through the lens is

$$t_l = \frac{(n-1)w(b)}{c} \quad \text{where } n \text{ is the refractive index.}$$

Thus the total time is

$$t = \frac{1}{c}\left[u+v+\frac{1}{2}b^2\left(\frac{1}{u}+\frac{1}{v}\right)+(n-1)w(b)\right]. \text{ Put } \frac{1}{D}=\frac{1}{u}+\frac{1}{v}$$



Then $t = \dfrac{1}{c}\left(u+v+\dfrac{1}{2}\dfrac{b^2}{D}+(n-1)\left(w_0+\dfrac{b^2}{\alpha}\right)\right)$

Fermet's principle gives

$$\frac{dt}{db} = 0 = \frac{b}{CD} - \frac{2(n-1)b}{c\alpha}$$

$$\alpha = 2(n-1)D$$

Thus a convergent lens is formed if $\alpha = 2(n-1)D$. This is independant of b and hence all paraxial rays from S will converge at O (i.e. for rays $b << n$ and $b << v$).

Since $\frac{1}{D} = \frac{1}{u} + \frac{1}{v}$, the focal length is D.

(ii) In this case

$$t = \frac{1}{c}\left(u + v + \frac{1}{2}\frac{b^2}{D} + (n-1)k_1 ln\left(\frac{k_2}{b}\right)\right)$$

$$\frac{dt}{db} = 0 = \frac{b}{D} - (n-1)\frac{k_1}{b}$$

$\Rightarrow b^2 = (n-1)\, k_1 D$

$\therefore b = \sqrt{(n-1)k_1 D}$

Thus all rays passing at a height b shall contribute to the image. The ray paths make an angle

$$\beta ; \frac{b}{v} = \frac{\sqrt{(n-1)k_1 D}}{v^2} = \sqrt{\frac{(n-1)k_1 uv}{v^2(u+v)}} = \sqrt{\frac{(n-1)k_1 u}{(u+v)v}}.$$

Chapter 10

10.1 (c)

10.2 (a)

10.3 (a)

10.4 (c)

10.5 (d)

10.6 (a), (b), (d)

10.7 (b), (d)

10.8 (a), (b)

10.9 (a), (b)

10.10 Yes.

10.11 Spherical.

10.12 Spherical with huge radius as compared to the earth's radius so that it is almost a plane.

10.13 Sound wave have frequencies 20 Hz to 20 kHz. The corresponding wavelengths are 15m and 15mm, respectively. Diffraction effects are seen if there are slits of width a such that.

$\alpha : \lambda.$

For light waves, wavelengths $\sim 10^{-7}$m. Thus diffraction effects will show when

$a \sim 10^{-7}$ m.

whereas for sound they will show for

$15\text{mm} < a < 15\text{m}$.

10.14 The linear distance between two dots is $l = \frac{2.54}{300}\text{cm} \sim 0.84\times10^{-2}\text{cm}$.

At a distance of Z cm this subtends an angle.

$$\phi \sim l/z \therefore z = \frac{l}{\phi} = \frac{0.84\times10^{-2}\text{cm}}{5.8\times10^{-4}} \sim 14.5\text{cm}.$$

10.15 Only in the special cases when the pass axis of (III) is parollel to (I) or (II) there shall be no light emerging. In all other cases there shall be light emerging because the pass axis of (II) is no longer perpendicular to the pass axis of (III).

10.16 Polarisation by reflection occurs when the angle of incidence is the Brewster's angle i.e. $\tan\theta_B = \frac{n_2}{n_1}$ where $n_2 < n_1$.

When light travels in such a medium the critical angle is $\sin\theta_c = \frac{n_2}{n_1}$

where $n_2 < n_1$.

As $|\tan\theta_B| > |\sin\theta_c|$ for large angles, $\theta_B < \theta_C$.

Thus, polarisation by reflection shall definitely occur.

10.17 $$d_{\min} = \frac{1.22\lambda}{2\sin\beta}$$

where β is the angle subtended by the objective at the object.

For light of 5500 Å

$$d_{\min} = \frac{1.22\times5.5\times10^{-7}}{2\sin\beta}\text{m}$$

For electrons accelerated through 100V the deBroglie wavelength is

$$\lambda = \frac{h}{p} = \frac{1.227}{\sqrt{100}} = 0.13\text{nm} = 0.13\times10^{-9}\text{m}$$

$$\therefore d'_{\min} = \frac{1.22\times1.3\times10^{-10}}{2\sin\beta}$$

$$\therefore d'_{min} = \frac{1.22 \times 1.3 \times 10^{-10}}{2 \sin \beta}$$

$$\frac{d'_{min}}{d_{min}} = \frac{1.3 \times 10^{-10}}{5.5 \times 10^{-7}} : \ 0.2 \times 10^{-3}$$

10.18 $T_2P = D + x$, $T_1 P = D - x$

$$S_1P = \sqrt{(S_1T_1)^2 + (PT_1)^2}$$

$$= [D^2 + (D - x)^2]^{1/2}$$

$S_2P = [D^2 + (D + x)^2]^{1/2}$

Minima will occur when

$$[D^2 + (D + x)^2]^{1/2} - [D^2 + (D - x)^2]^{1/2} = \frac{\lambda}{2}$$

If $x = D$

$$(D^2 + 4D^2)^{1/2} = \frac{\lambda}{2}$$

$$(5D^2)^{1/2} = \frac{\lambda}{2}, \quad \therefore D = \frac{\lambda}{2\sqrt{5}}.$$

10.19 Without P:

$$A = A_\perp + A_{11}$$

$$A_\perp = A_\perp^1 + A_\perp^2 = A_\perp^0 \sin(kx - \omega t) + A_\perp^0 \sin(kx - \omega t + \phi)$$

$$A_{11} = A_{11}^{(1)} + A_{11}^{(2)}$$

$$A_{11} = A_{11}^0 [\sin(kx - wt) + \sin(kx - \omega t + \phi)]$$

where $A_\perp^0$, A_{11}^0 are the amplitudes of either of the beam in $\perp$ and 11 polarizations.

$\therefore$ Intensity =

$$= \left\{|A_\perp^0|^2 + |A_{11}^0|^2\right\}[\sin^2(kx - wt)(1 + \cos^2\phi + 2\sin\phi) + \sin^2(kx - \omega t)\ \sin^2\phi]_{average}$$

$$= \left\{|A_\perp^0|^2 + |A_{11}^0|^2\right\}\left(\frac{1}{2}\right).2(1 + \cos\phi)$$

$= 2|A_{\perp}^{0}|^2 .(1+\cos\phi) \text{ since } |A_{\perp}^{0}|_{average} = |A_{11}^{0}|_{average}$

With P:

Assume $A_{\perp}^{2}$ is blocked:

Intensity = $(A_{11}^{1} + A_{11}^{2})^2 + (A_{\perp}^{1})^2$

$= |A_{\perp}^{0}|^2 (1+\cos\phi) + |A_{\perp}^{0}|^2 . \frac{1}{2}$

Given: $I_o = 4|A_{\perp}^{0}|^2$ = Intensity without polariser at principal maxima.

Intensity at principal maxima with polariser

$$= |A_{\perp}^{0}|^2 \left(2 + \frac{1}{2}\right)$$

$$= \frac{5}{8} I_0$$

Intensity at first minima with polariser

$$= |A_{\perp}^{0}|^2 (1-1) + \frac{|A_{\perp}^{0}|^2}{2}$$

$$= \frac{I_0}{8}.$$

10.20 Path difference = $2d\sin\theta + (\mu - 1)l$

$\therefore$ For principal maxima,

$2d\sin\theta + 0.5l = 0$

$$\sin\theta_0 = \frac{-l}{4d} = \frac{-1}{16} \qquad \left(\because l = \frac{d}{4}\right)$$

$$\therefore \text{ OP} = D\tan\theta_0 \approx -\frac{D}{16}$$

For the first minima:

$$\therefore 2d\sin\theta_1 + 0.5l = \pm\frac{\lambda}{2}$$

$$\sin\theta_1 = \frac{\pm\lambda/2 - 0.5l}{2d} = \frac{\pm\lambda/2 - \lambda/8}{2\lambda} = \pm\frac{1}{4} - \frac{1}{16}$$

On the positive side: $\sin\theta^{+} = \frac{3}{16}$

On the negative side: $\sin\theta^{-} = -\frac{5}{16}$

The first principal maxima on the positive side is at distance

$$D\tan\theta^{+} = D\frac{\sin\theta^{+}}{\sqrt{1-\sin^2\theta}} = D\frac{3}{\sqrt{16^2 - 3^2}} \text{ above O.}$$

In the –ve side, the distance will be $D\tan\theta^{-} = \frac{5}{\sqrt{16^2 - 5^2}}$ below O.

10.21 (i) Consider the disturbances at R_1 which is a distance d from A. Let the wave at R_1 because of A be $Y_A = a\cos\omega t$. The path difference of the signal from A with that from B is $\lambda/2$ and hence the phase difference is π.

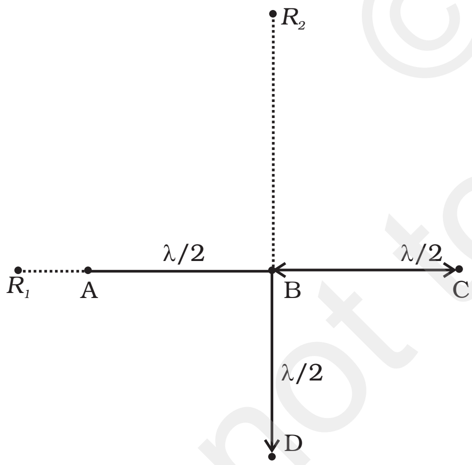
Thus the wave at R_1 because of B is

$$y_B = a\cos(\omega t - \pi) = -a\cos\omega t.$$

The path difference of the signal from C with that from A is λ and hence the phase difference is 2π.

Thus the wave at R_1 because of C is $y_c = a\cos\omega t$.

The path difference between the signal from D with that of A is



$$\sqrt{d^2 + \left(\frac{\lambda}{2}\right)^2} - (d - \lambda/2)$$

$$= d\left(1 + \frac{\lambda}{4d^2}\right)^{1/2} - d + \frac{\lambda}{2}$$

$$= d\left(1 + \frac{\lambda^2}{8d^2}\right)^{1/2} - d + \frac{\lambda}{2}$$

If $d >> \lambda$ the path difference : $\frac{\lambda}{2}$ and hence the phase difference is π.

$\therefore y_D = -a\cos\omega t$.

Thus, the signal picked up at R_1 is

$y_A + y_B + y_C + y_D = 0$

Let the signal picked up at R_2 from B be $y_B = a_1 \cos \omega t$.
The path difference between signal at D and that at B is λ/2.

$\therefore y_D = -a_1\cos\omega t$

The path difference between signal at A and that at B is

$$\sqrt{(d)^2+\left(\frac{\lambda}{2}\right)^2}-d = d\left(1+\frac{\lambda^2}{4d^2}\right)^{1/2}-d : \frac{1}{8}\frac{\lambda^2}{d^2}$$

$\therefore$ The phase difference is $\frac{2\pi}{8\lambda}.\frac{\lambda^2}{d^2}=\frac{\pi\lambda}{4d}=\phi :$ 0.

Hence, $y_A = a_1 \cos(\omega t\text{-}\phi)$
Similarly, $y_C = a_1 \cos(\omega t\text{-}\phi)$
$\therefore$ Signal picked up by R_2 is
$y_A + y_B + y_C + y_D = y = 2a_1 \cos(\omega t\text{-}\phi)$
$\therefore | y |^2 = 4a_1^2\cos^2(\omega t-\phi)$

$\therefore \langle I\rangle = 2a_1^2$

Thus R_1 picks up the larger signal.

(ii) If B is switched off,
R_1 picks up $y = a \cos \omega t$

$\therefore \langle I_{R_1}\rangle = \frac{1}{2}a^2$

R_2 picks up $y = a \cos \omega t$

$\therefore \langle I_{R_2}\rangle = \frac{1}{2}a_1^2$

Thus R_1 and R_2 pick up the same signal.

(c) If D is switched off.
R_1 picks up $y = a \cos \omega t$

$\therefore \langle I_{R_1}\rangle = \frac{1}{2}a^2$

R_2 picks up $y = 3a \cos \omega t$

$\therefore \langle I_{R_2}\rangle = \frac{1}{2}9a^2$

Thus R_2 picks up larger signal compared to R_1.

(iv) Thus a signal at R_1 indicates B has been switched off and an enhanced signal at R_2 indicates *D* has been switched off.

10.22 (i) Suppose the postulate is true, then two parallel rays would proceed as shown in Fig. 1. Assuming ED shows a wave front then all points on this must have the same phase. All points with the same optical path length must have the same phase.

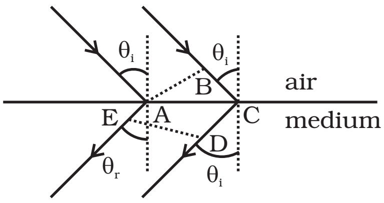


Fig. 1

Thus $-\sqrt{\varepsilon_r \mu_r}\ AE = \text{BC} - \sqrt{\varepsilon_r \mu_r}\ \text{CD}$

or $BC = \sqrt{\varepsilon_r \mu_r}\,(CD - AE)$

BC > 0, CD > AE

As showing that the postulate is reasonable. If however, the light proceeded in the sense it does for ordinary material (viz. in the fourth quadrant, Fig. 2)

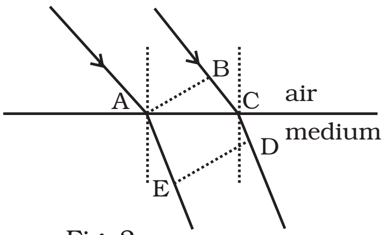


Fig. 2

Then $-\sqrt{\varepsilon_r \mu_r}\ AE = \text{BC} - \sqrt{\varepsilon_r \mu_r}\ \text{CD}$

or, $BC = \sqrt{\varepsilon_r \mu_r}\,(CD - AE)$

As AE > CD, BC < O

showing that this is not possible. Hence the postalate is correct.

(ii) From Fig. 1.

BC = AC sin θ_i and CD-AE = AC sin θ_r:

Since $-\sqrt{\varepsilon_r \mu_r}\,(AE - CD) = BC$

$-n \sin \theta_r = \sin \theta_i$.

10.23 Consider a ray incident at an angle *i*. A part of this ray is reflected from the air-film interface and a part refracted inside. This is partly reflected at the film-glass interface and a part transmitted. A part of the reflected ray is reflected at the film-air interface and a part transmitted as r_2 parallel to r_1. Of course succesive reflections and transmissions will keep on decreasing the amplitude of the wave. Hence rays r_1 and r_2 shall dominate the behavior. If incident light is to be transmitted through the lens, r_1 and r_2 should interfere destructively. Both the reflections at A and D are from lower to higher refractive index and hence there is no phase change on reflection. The optical path difference between r_2 and r_1 is
n (AD + CD) – AB.

If *d* is the thickness of the film, then

$$AD = CD = \frac{d}{\cos r}$$

$$AB = AC \sin i$$

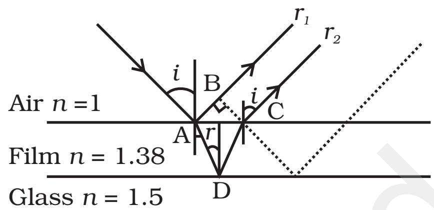
$$\frac{AC}{2} = d \tan r$$

$$\therefore AC = 2d \tan r$$

Hence, AB = 2d tan*r* sin*i*

Thus the optical path difference is

$$2n\frac{d}{\cos r} - 2d\tan r \sin i$$



$$= 2.\frac{\sin i}{\sin r}\frac{d}{\cos r} - 2d\frac{\sin r}{\cos r}\sin i$$

$$= 2d\sin\left[\frac{1-\sin^2 r}{\sin r\cos r}\right]$$

= 2nd cos$r$

For these waves to interefere destructively this must be λ/2.

$$\Rightarrow 2nd\cos r = \frac{\lambda}{2}$$

or nd cos r = λ/4

For a camera lens, the sources are in the vertical plane and hence $i \,\square\, r \,\square\, 0$

$$\therefore nd \; ; \; \frac{\lambda}{4}.$$

$$\Rightarrow d = \frac{5500\,\mathring{A}}{1.38\times 4} \; ; \; 1000\,\mathring{A}$$

Chapter 11

11.1 (d)

11.2 (b)

11.3 (d)

11.4 (c)

11.5 (b)

11.6 (a)

11.7 (a)

11.8 (c)

11.9 (c), (d)

11.10 (a), (c)

11.11 (b), (c)

11.12 (a), (b), (c)

11.13 (b), (d)

11.14 $\lambda_p / \lambda_d = p_x / p_p = \dfrac{\sqrt{2m_\alpha E_\alpha}}{\sqrt{2m_p E_p}} = \sqrt{8} : 1$

11.15 (i) $E_{max} = 2h\nu - \phi$

(ii) The probability of absorbing 2 photons by the same electron is very low. Hence such emissions will be negligible.

11.16 In the first case energy given out is less than the energy supplied. In the second case, the material has to supply the energy as the emitted photon has more energy. This cannot happen for stable substances.

11.17 No, most electrons get scattered into the metal. Only a few come out of the surface of the metal.

11.18 Total E is constant

Let n_1 and n_2 be the number of photons of X-rays and visible region

$n_1 E_1 = n_2 E_2$

$$n_1 \frac{hc}{\lambda_1} = n_2 \frac{hc}{\lambda_2}$$

$$\frac{n_1}{n_2} = \frac{\lambda_1}{\lambda_2}.$$

$$\frac{n_1}{n_2} = \frac{1}{500}.$$

11.19 The momentum is transferred to the metal. At the microscopic level, atoms absorb the photon and its momentum is transferred mainly to the nucleus and electrons. The excited electron is emitted. Conservation of momentum needs to be accounted for the momentum transferred to the nucleus and electrons.

11.20 Maximum energy = $h\nu - \phi$

$$\left(\frac{1230}{600} - \phi\right) = \frac{1}{2}\left(\frac{1230}{400} - \phi\right)$$

$$\phi = \frac{1230}{1200} = 1.02\text{eV}.$$

11.21 $\Delta x \Delta p \;;\; \text{h}$

$$\Delta p \;;\; \frac{\text{h}}{\Delta x} \;;\; \frac{1.05\times10^{-34}\,\text{Js}}{10^{-9}\,\text{m}} = 1.05\times10^{-25}$$

$$E = \frac{p^2}{2m} = \frac{(1.05\times10^{-25})^2}{2\times9.1\times10^{-31}} = \frac{1.05^2}{18.2}\times10^{-19}\text{J} = \frac{1.05^2}{18.2\times1.6}eV$$

$= 3.8 \times 10^{-2} eV$

11.22 $I = n_A n_A = n_B v_B$

$$\frac{n_A}{n_B} = 2 = \frac{v_B}{v_A}$$

The frequency of beam B is twice that of A.

11.23 $p_c = |p_A| + |p_B| = \frac{h}{\lambda_A} + \frac{h}{\lambda_B} = \frac{h}{\lambda_c} = \frac{h}{\lambda_c}$ if $p_A, p_B > 0$ or $p_A, p_B < 0$

or $\lambda_c = \frac{\lambda_A \lambda_B}{\lambda_A + \lambda_B}$

If $p_A > 0$, $p_B < 0$ or $p_A < 0$, $p_B > 0$

$$p_c = h\frac{\lambda_B - \lambda_A}{|\lambda_A.\lambda_B|} = \frac{h}{\lambda_c}$$

$$\lambda_c = \frac{\lambda_B.\lambda_A}{|\lambda_A - \lambda_B|}.$$

11.24 $2d \sin\theta = \lambda = d = 10^{-10}$ m.

$$p = \frac{h}{10^{-10}} = \frac{6.6\times10^{-34}}{10^{-10}} = 6.6\times10^{-21}\text{kg m/s}$$

$$E = \frac{(6.6\times10^{-24})^2}{2\times(1.7\times10^{-27})}\times1.6\times10^{-19} = \frac{6.6^2}{2\times1.7}\times1.6\times10^{-2}eV$$

$= 20.5 \times 10^{-2} eV = 0.21 eV$

11.25 6×10^{26} Na atoms weighs 23 kg.

Volume of target = $(10^{-4} \times 10^{-3}) = 10^{-7} m^3$

Density of sodium = (d) = 0.97 kg/m^3

Volume of 6×10^{26} Na atoms = $\frac{23}{0.97} m^3$ = 23.7 m^3

Volume occupied of 1 Na atom = $\frac{23}{0.97\times6\times10^{26}} m^3$ = $3.95 \times 10^{-26} m^3$

No. of sodium atoms in the target = $\frac{10^{-7}}{3.95\times10^{-26}}$ = 2.53×10^{18}

Number of photons/s in the beam for 10^{-4} m^2 = n

Energy per s $nh\nu = 10^{-4}$ J × 100 = 10^{-2} W

$$h\nu \text{ (for } \lambda = 660\text{nm)} = \frac{1234.5}{600}$$

$$= 2.05\text{eV} = 2.05 \times 1.6 \times 10^{-19} = 3.28 \times 10^{-19}\text{J}.$$

$$n = \frac{10^{-2}}{3.28\times10^{-19}} = 3.05\times10^{16}/\text{s}$$

$$n = \frac{1}{3.2}\times10^{17} = 3.1\times10^{16}$$

If P is the probability of emission per atom, per photon, the number of photoelectrons emitted/second

$$= P\times3.1\times10^{16}\times2.53\times10^{18}$$

Current = P × 3.1 × 10^{+16} × 2.53 × 10^{18} × 1.6 × 10^{-19} A

= P × 1.25 × 10^{+16} A

This must equal 100μA or

$$P = \frac{100\times10^{-6}}{1.25\times10^{+16}}$$

∴ $P = 8 \times 10^{-21}$

Thus the probability of photemission by a single photon on a single atom is very much less than 1. (That is why absorption of two photons by an atom is negligible).

11.26 Work done by an external agency $= +\frac{1}{4\pi\varepsilon_0}.\frac{1}{4}\int_d^\infty \frac{q^2}{x^2}dx = \frac{1}{4}.\frac{q^2}{4\pi\varepsilon_0 d}$

With d = 0.1nm, energy $= \frac{(1.6\times10^{-19})\times9\times10^{9}}{4(10^{-10})\times1.6\times10^{-19}}$eV

$$= \frac{1.6\times9}{4}\text{eV} = 3.6 \text{ eV}$$

11.27 (i) Stopping potential = 0 at a higher frequency for B. Hence it has a higher work function.

(ii) Slope $= \frac{h}{e} = \frac{2}{(10-5)\times10^{14}}$ for A.

$$= \frac{2.5}{(15-10)\times10^{14}} \text{ for B.}$$

$$h = \frac{1.6\times10^{-19}}{5}\times2\times10^{-14} = 6.04\times10^{-34}\text{Js for A}$$

$$= \frac{1.6\times10^{-19}\times2.5\times10^{-14}}{5} = 8\times10^{-34}\text{ Js for B.}$$

Since h works out differently, experiment is not consistent with the theory.

11.28 $m_A v = m_A v_1 + m_B v_2$

$$\frac{1}{2}m_A v^2 = \frac{1}{2}m_A v_1^2 + \frac{1}{2}m_B v_2^2$$

$$\therefore \frac{1}{2}m_A(v - v_1)(v_A + v_1) = \frac{1}{2}m_B v_B^2$$

$$\therefore v + v_1 = v_2$$

or $v = v_2 - v_1$

$$\therefore v_1 = \left(\frac{m_A - m_B}{m_A + m_B}\right)v, \qquad \text{and} \qquad v_2 = \left(\frac{2m_A}{m_A + m_B}\right)v$$

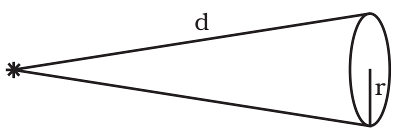
$$\therefore \lambda_{\text{initial}} = \frac{h}{m_A v}$$

$$\lambda_{\text{final}} = \frac{h}{m_A v} = \left|\frac{h(m_A + m_B)}{m_A(m_A - m_B)v}\right|$$

$$\therefore \Delta\lambda = \frac{h}{m_A v}\left[\left|\frac{m_A + m_B)}{m_A - m_B}\right| - 1\right]$$

11.29 (i) $\frac{dN}{dt} = \frac{P}{(hc/\lambda)} = 5\times10^{19}/s$

(ii) $\frac{hc}{\lambda} = 2.49\text{eV} > W_0$: Yes.



(iii) $P.\frac{\pi r^2}{4\pi d^2}\Delta t = W_0$, $\Delta t = 28.4\text{s}$

(iv) $N = \left(\frac{dN}{dt}\right)\times\frac{\pi r^2}{4\pi d^2}\times\Delta t = 2$

Chapter 12

12.1 (c)

12.2 (c)

12.3 (a)

12.4 (a)

12.5 (a)

12.6 (a)

12.7 (a)

12.8 (a), (c)

12.9 (a), (b)

12.10 (a), (b)

12.11 (b), (d)

12.12 (b), (d)

12.13 (c), (d)

12.14 Einstein's mass-energy equivalence gives $E = mc^2$. Thus the mass of a H-atom is $m_p + m_e - \frac{B}{c^2}$ where B ≈ 13.6eV is the binding energy.

12.15 Because both the nuclei are very heavy as compared to electron mass.

12.16 Because electrons interact only electromagnetically.

12.17 Yes, since the Bohr formula involves only the product of the charges.

12.18 No, because accoding to Bohr model, $E_n = -\frac{13.6}{n^2}$,

and electons having different energies belong to different levels having different values of n. So, their angular momenta will be different, as $mvr = \frac{nh}{2\pi}$.

12.19 The 'm' that occurs in the Bohr formula $E_n = -\frac{me^4}{8\varepsilon_0 n^2 h^2}$ is the reduced mass. For H-atom $m \approx m_e$. For positronium $m \approx m_e/2$. Hence for a positonium $E_1 \approx -6.8$eV.

12.20 For a nucleus with charge 2e and electrons of charge $-e$, the levels are $E_n = -\frac{4me^4}{8\varepsilon_0{}^2 n^2 h^2}$. The ground state will have two electrons each of energy E, and the total ground state energy would by $-(4\times13.6)$eV.

12.21 v = velocity of electron

a_0 = Bohr radius.

$\therefore$ Number of revolutions per unit time $= \frac{2\pi a_0}{v}$

$\therefore$ Current $= \frac{2\pi a_0}{v} e.$

12.22 $\nu_{mn} = cRZ^2\left[\frac{1}{(n+p)^2} - \frac{1}{n^2}\right],$

where $m = n + p$, (p = 1, 2, 3, ...) and R is Rydberg constant.

For $p \ll n$.

$$\nu_{mn} = cRZ^2\left[\frac{1}{n^2}\left(1+\frac{p}{n}\right)^{-2} - \frac{1}{n^2}\right]$$

$$\nu_{mn} = cRZ^2\left[\frac{1}{n^2} - \frac{2p}{n^3} - \frac{1}{n^2}\right]$$

$$\nu_{mn} = cRZ^2\frac{2p}{n^3}; \left(\frac{2cRZ^2}{n^3}\right)p$$

Thus, ν_{mn} are approximately in the order 1, 2, 3..........

12.23 H_γ in Balmer series corresponds to transition n = 5 to n = 2. So the electron in ground state n = 1 must first be put in state n = 5. Energy required = $E_1 - E_5$ = 13.6 – 0.54 = 13.06 eV.

If angular momentum is conserved, angular momentum of photon = change in angular momentum of electron

$= L_5 - L_2 = 5h - 2h = 3h = 3\times1.06\times10^{-34}$

$= 3.18 \times 10^{-34}$ kg m²/s.

12.24 Reduced mass for $H = \mu_H = \frac{m_e}{1+\frac{m_e}{M}}; \ m_e\left(1-\frac{m_e}{M}\right)$

Reduced mass for $D = \mu_D$; $m_e\left(1-\frac{m_e}{2M}\right) = m_e\left(1-\frac{m_e}{2M}\right)\left(1+\frac{m_e}{2M}\right)$

$h\nu_{ij} = (E_i - E_j)\alpha\mu$. Thus, $\lambda_{ij}\,\alpha\,\frac{1}{\mu}$

If for Hydrogen/Deuterium the wavelength is λ_H / λ_D

$$\frac{\lambda_D}{\lambda_H} = \frac{\mu_H}{\mu_D} ; \left(1+\frac{m_e}{2M}\right)^{-1} ; \left(1-\frac{1}{2\times 1840}\right)$$

$$\lambda_D = \lambda_H \times (0.99973)$$

Thus lines are 1217.7 Å , 1027.7 Å, 974.04 Å, 951.143 Å.

12.25 Taking into account the nuclear motion, the stationary state energies shall be, $E_n = -\frac{\mu Z^2 e^4}{8\varepsilon_0^2 h^2}\left(\frac{1}{n^2}\right)$. Let μ_H be the reduced mass of Hydrogen and μ_D that of Deutrium. Then the frequency of the 1st Lyman line in Hydrogen is $h\nu_H = \frac{\mu_H e^4}{8\varepsilon_0^2 h^2}\left(1-\frac{1}{4}\right) = \frac{3}{4}\frac{\mu_H e^4}{8\varepsilon_0^2 h^2}$. Thus the wavelength of the transition is $\lambda_H = \frac{3}{4}\frac{\mu_H e^4}{8\varepsilon_0^2 h^3 c}$. The wavelength of the transition for the same line in Deutrium is $\lambda_D = \frac{3}{4}\frac{\mu_D e^4}{8\varepsilon_0^2 h^3 c}$.

$$\therefore \Delta\lambda = \lambda_D - \lambda_H$$

Hence the percentage difference is

$$100\times\frac{\Delta\lambda}{\lambda_H} = \frac{\lambda_D - \lambda_H}{\lambda_H}\times 100 = \frac{\mu_D - \mu_H}{\mu_H}\times 100$$

$$= \frac{\frac{m_e M_D}{(m_e + M_D)} - \frac{m_e M_H}{(m_e + M_H)}}{m_e M_H / (m_e + M_H)}\times 100$$

$$= \left[\left(\frac{m_e + M_H}{m_e + M_D}\right)\frac{M_D}{M_H} - 1\right]\times 100$$

Since $m_e << M_H < M_D$

$$\frac{\Delta\lambda}{\lambda_H}\times 100 = \left[\frac{M_H}{M_D}\times\frac{M_D}{M_H}\left(\frac{1+m_e/M_H}{1+m_e/M_D}\right)-1\right]\times 100$$

$$= \left[(1+m_e/M_H)(1+m_e/M_D)^{-1}-1\right]\times 100$$

$$; \left[(1+\frac{m_e}{M_H}-\frac{m_e}{M_D}-1\right]\times 100$$

$$\approx m_e\left[\frac{1}{M_H}-\frac{1}{M_D}\right]\times 100$$

$$= 9.1\times 10^{-31}\left[\frac{1}{1.6725\times 10^{-27}}-\frac{1}{3.3374\times 10^{-27}}\right]\times 100$$

$$= 9.1\times 10^{-4}[0.5979-0.2996]\times 100$$

$$= 2.714 \times 10^{-2}\,\%$$

12.26 For a point nucleus in H-atom:

Ground state: $mvr = \hbar, \frac{mv^2}{r_B} = -\frac{e^2}{r_B{}^2}.\frac{1}{4\pi\varepsilon_0}$

$$\therefore m\frac{\hbar^2}{m^2 r_B{}^2}.\frac{1}{r_B} = +\left(\frac{e^2}{4\pi\varepsilon_0}\right)\frac{1}{r_B{}^2}$$

$$\therefore \frac{\hbar^2}{m}.\frac{4\pi\varepsilon_0}{e^2} = r_B = 0.51\,\text{Å}$$

Potential energy

$$-\left(\frac{e^2}{4\pi r_0}\right).\frac{1}{r_B} = -27.2\text{eV}; K.E = \frac{mv^2}{2} = \frac{1}{2}m.\frac{\hbar^2}{m^2 r_B^2} = \frac{\hbar}{2mr_B^2} = +13.6\text{eV}$$

For an spherical nucleus of radius R,

If $R < r_B$, same result.

If $R >> r_B$: the electron moves inside the sphere with radius r_B' (r_B' = new Bohr radius).

Charge inside $r_B'{}^4 = e\left(\frac{r_B'^3}{R^3}\right)$

$$\therefore r_B' = \frac{h^2}{m}\left(\frac{4\pi\varepsilon_0}{e^2}\right)\frac{R^3}{r_B'^3}$$

$$r_B'^4 = (0.51\,\overset{\circ}{A}).R^3. \qquad R = 10\,\overset{\circ}{A}$$

$$= 510(\overset{\circ}{A})^4$$

$$\therefore r_B' \approx (510)^{1/4}\,\overset{\circ}{A} < R.$$

$$K.E = \frac{1}{2}mv^2 = \frac{m}{2}.\frac{h}{m^2 r_B'^2} = \frac{h}{2m}.\frac{1}{r_B'^2}$$

$$= \left(\frac{h^2}{2mr_B{}^2}\right).\left(\frac{r_B^2}{r_B'^2}\right) = (13.6\text{eV})\frac{(0.51)^2}{(510)^{1/2}} = \frac{3.54}{22.6} = 0.16\text{eV}$$

$$P.E = +\left(\frac{e^2}{4\pi\varepsilon_0}\right).\left(\frac{r_B'^2 - 3R^2}{2R^3}\right)$$

$$= +\left(\frac{e^2}{4\pi\varepsilon_0}.\frac{1}{r_B}\right).\left(\frac{r_B(r_B'^2 - 3R^2}{R^3}\right)$$

$$= +(27.2\text{eV})\left[\frac{0.51(\sqrt{510} - 300)}{1000}\right]$$

$$= +(27.2\text{eV}).\frac{-141}{1000} = -3.83\text{eV}.$$

12.27 As the nucleus is massive, recoil momentum of the atom may be neglected and the entire energy of the transition may be considered transferred to the Auger electron. As there is a single valence electron in Cr, the energy states may be thought of as given by the Bohr model.

The energy of the nth state $E_n = -Z^2R\frac{1}{n^2}$ where R is the Rydberg constant and Z = 24.

The energy released in a transition from 2 to 1 is $\Delta E = Z^2R\left(1 - \frac{1}{4}\right) = \frac{3}{4}Z^2R.$ The energy required to eject a n = 4 electron is $E_4 = Z^2R\frac{1}{16}$.

Thus the kinetic energy of the Auger electron is

$$K.E = Z^2R\left(\frac{3}{4}-\frac{1}{16}\right) = \frac{1}{16}Z^2R$$

$$= \frac{11}{16}\times 24\times 24\times 13.6\,\text{eV}$$

= 5385.6 eV

12.28 $m_p c^2 = 10^{-6}\times$ electron mass $\times c^2$

$$\approx 10^{-6}\times 0.5\,\text{MeV}$$

$$\approx 10^{-6}\times 0.5\times 1.6\times 10^{-13}$$

$$\approx 0.8\times 10^{-19}\,\text{J}$$

$$\frac{h}{m_p c} = \frac{hc}{m_p c^2} = \frac{10^{-34}\times 3\times 10^{8}}{0.8\times 10^{-19}} \approx 4\times 10^{-7}\,\text{m} >> \text{Bohr radius.}$$

$$|\mathbf{F}| = \frac{e^2}{4\pi\varepsilon_0}\left[\frac{1}{r^2}+\frac{\lambda}{r}\right]\exp(-\lambda r)$$

where $\lambda^{-1} = \dfrac{\hbar}{m_p c} \approx 4\times 10^{-7}\,\text{m} >> r_B$

$$\therefore \lambda << \frac{1}{r_B}\ i.e\ \lambda r_B << 1$$

$$U(r) = -\frac{e^2}{4\pi\varepsilon_0}\cdot\frac{\exp(-\lambda r)}{r}$$

$$mvr = h \therefore v = \frac{h}{mr}$$

$$\text{Also}: \frac{mv^2}{r} =\approx \left(\frac{e^2}{4\pi\varepsilon_0}\right)\left[\frac{1}{r^2}+\frac{\lambda}{r}\right]$$

$$\therefore \frac{h^2}{mr^3} = \left(\frac{e^2}{4\pi\varepsilon_0}\right)\left[\frac{1}{r^2}+\frac{\lambda}{r}\right]$$

$$\therefore \frac{h^2}{m} = \left(\frac{e^2}{4\pi\varepsilon_0}\right)[r+\lambda r^2]$$

If $\lambda = 0; r = r_B = \frac{h}{m} \cdot \frac{4\pi\varepsilon_0}{e^2}$

$$\frac{h^2}{m} = \frac{e^2}{4\pi\varepsilon_0} . r_B$$

Since $\lambda^{-1} >> r_B$, put $r = r_B + \delta$

$\therefore r_B = r_B + \delta + \lambda(r_B^2 + \delta^2 + 2\delta r_B)$; negect δ^2

or $0 = \lambda r_B^2 + \delta(1 + 2\lambda r_B)$

$$\delta = \frac{-\lambda r_B^{\ 2}}{1 + 2\lambda r_B} \approx \lambda r_B^{\ 2}(1 - 2\lambda r_B) = -\lambda r_B^{\ 2} \text{ since } \lambda r_B << 1$$

$$\therefore V(r) = -\frac{e^2}{4\pi\varepsilon_0} . \frac{\exp(-\lambda\delta - \lambda r_B)}{r_B + \delta}$$

$$\therefore V(r) = -\frac{e^2}{4\pi\varepsilon_0} \frac{1}{r_B}\left[\left(1 - \frac{\delta}{r_B}\right).(1 - \lambda r_B)\right]$$

$\cong (-27.2\text{eV})$ remains unchanged.

$$K.E = -\frac{1}{2}mv^2 = \frac{1}{2}m.\frac{h^2}{mr^2} = \frac{h^2}{2(r_B + \delta)^2} = \frac{h^2}{2r_B^{\ 2}}\left(1 - \frac{2\delta}{r_B}\right)$$

$= (13.6\text{eV})[1 + 2\lambda r_B]$

Total energy $= -\frac{e^2}{4\pi\varepsilon_0 r_B} + \frac{h^2}{2r_B^{\ 2}}[1 + 2\lambda r_B]$

$= -27.2 + 13.6[1 + 2\lambda r_B]\text{eV}$

Change in energy $= 13.6 \times 2\lambda r_B \text{eV} = 27.2\lambda r_B \text{eV}$

12.29 Let $\varepsilon = 2 + \delta$

$F = \frac{q_1 q_2}{4\pi\varepsilon_0} . \frac{R_0^\delta}{r^{2+\delta}} = \wedge \frac{R_0^\delta}{r^{2+\delta}}$, where $\frac{q_1 q_2}{4\pi_0 \varepsilon} = \wedge$, $\wedge = (1.6 \times 10^{-19})^2 \times 9 \times 10^9$

$= 23.04 \times 10^{-29}$

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

$$v^2 = \frac{\wedge R_0^{\delta}}{m r^{1+\delta}}$$

(i) $mvr = n\text{h}$, $r = \frac{n\text{h}}{mv} = \frac{n\text{h}}{m}\left[\frac{m}{\wedge R_0^{\delta}}\right]^{1/2} r^{1/2+\delta/2}$

Solving this for r, we get $r_n = \left[\frac{n^2\hbar^2}{m \wedge R_0^{\delta}}\right]^{\frac{1}{1-\delta}}$

For $n = 1$ and substituting the values of constant, we get

$$r_1 = \left[\frac{\hbar^2}{m \wedge R_0^{\delta}}\right]^{\frac{1}{1-\delta}}$$

$$r_1 = \left[\frac{1.05^2 \times 10^{-68}}{9.1\times10^{-31} \times 2.3\times10^{-28} \times 10^{+19}}\right]^{\frac{1}{2.9}} = 8 \times 10^{-11} = 0.08 \text{ nm}$$

(< 0.1 nm)

(ii) $v_n = \frac{n\hbar}{mr_n} = n\hbar\left(\frac{m \wedge R_0^{\delta}}{n^2\hbar^2}\right)^{\frac{1}{1-\delta}}$. For $n = 1$, $v_1 = \frac{\hbar}{mr_1} = 1.44 \times 10^6$ m/s

(iii) K.E. $= \frac{1}{2}mv_1^2 = 9.43\times10^{-19}\text{J} = 5.9\text{eV}$

P.E. till $R_0 = -\frac{\wedge}{R_0}$

P.E. from R_0 to $r = + \wedge R_0^{\delta}\int_{R_0}^{r}\frac{dr}{r^{2+\delta}} = +\frac{\wedge R_0^{\delta}}{-1-\delta}\left[\frac{1}{r^{1+\delta}}\right]_{R_0}^{r}$

$$= -\frac{\wedge R_0^{\delta}}{1+\delta}\left[\frac{1}{r^{1+\delta}} - \frac{1}{R_0^{1+\delta}}\right]$$

$$= -\frac{\wedge}{1+\delta}\left[\frac{R_0^{\delta}}{r^{1+\delta}} - \frac{1}{R_0}\right]$$

$$P.E. = -\frac{\wedge}{1+\delta}\left[\frac{R_0^{\delta}}{r^{1+\delta}} - \frac{1}{R_0} + \frac{1+\delta}{R_0}\right]$$

$$P.E. = -\frac{\wedge}{-0.9}\left[\frac{R_0^{-1.9}}{r^{-0.9}} - \frac{1.9}{R_0}\right]$$

$$= \frac{2.3}{0.9} \times 10^{-18} [(0.8)^{0.9} - 1.9] \text{ J} = -17.3 \text{ eV}$$

Total energy is (–17.3 + 5.9) = –11.4 eV.

Chapter 13

13.1 (c)

13.2 (b)

13.3 (b)

13.4 (a)

13.5 (a)

13.6 (b)

13.7 (b)

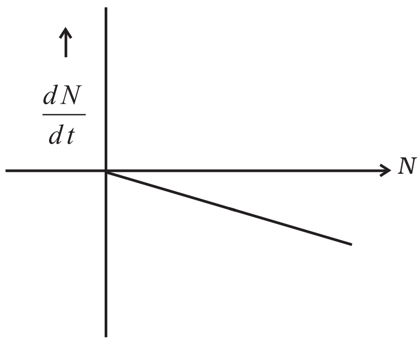
13.8 (a), (b)

13.9 (b), (d)

13.10 (c), (d)

13.11 No, the binding energy of H_1^3 is greater.

13.12



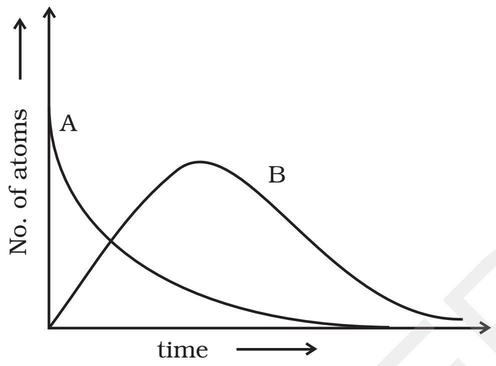
13.13 B has shorter mean life as λ is greater for B.

13.14 Excited electron because energy of electronic energy levels is in the range of eV, only not in MeV. as γ-radiation has energy in MeV.

13.15 2γ photons are produced which move in opposite directions to conserve momentum.

13.16 Protons are positively charged and repel one another electrically. This repulsion becomes so great in nuclei with more than 10 protons or so, that an excess of neutrons which produce only attractive forces, is required for stability.

13.17



At t = 0, N_A = N_O while N_B = 0. As time increases, N_A falls off exponentially, the number of atoms of B increases, becomes maximum and finally decays to zero at ∞ (following exponential decay law).

13.18 $t = \frac{1}{\lambda} \ln \frac{R_0}{R}$

$$= \frac{5760}{0.693} \ln \frac{16}{12} = \frac{5760}{0.693} \ln \frac{4}{3}$$

$$= \frac{5760}{0.693} \times 2.303 \log \frac{4}{3} = \quad 2391.12 \text{ years.}$$

13.19 To resolve two objects separated by distance d, the wavelength λ of the proving signal must be less than d. Therefore, to detect separate parts inside a nucleon, the electron must have a wavelength less than 10^{-15} m.

$$\lambda = \frac{h}{p} \text{ and } K \approx pc \Rightarrow K \approx pc = \frac{hc}{\lambda}$$

$$= \frac{6.63 \times 10^{34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 10^{-15}} \text{eV}$$

$= 10^9$ eV. = 1 GeV.

13.20 (a) ${}^{23}_{11}\text{Na}$: Z_1 = 11, N_1 = 12

$\therefore$ Mirror isobar of ${}^{23}_{11}\text{Na} = {}^{23}_{12}\text{Mg}$.

(b) Since $Z_2 > Z_1$, Mg has greater binding energy than Na.

13.21 $^{38}S \xrightarrow[2.48\,h]{} {}^{38}Cl \xrightarrow[0.62\,h]{} {}^{38}Ar$

At time *t*, Let ^{38}S have $N_1(t)$ active nuclei and ^{38}Cl have $N_2(t)$ active nuclei.

$$\frac{dN_1}{dt} = -\lambda_1 N_1 = \text{rate of formation of } Cl^{38}. \text{ Also}$$

$$\frac{dN_2}{dt} = -\lambda_1 N_2 + \lambda_1 N_1$$

But $N_1 = N_0 e^{-\lambda_1 t}$

$$\frac{dN_2}{dt} = -\lambda_1 N_0 e^{-\lambda_1 t} - \lambda_2 N_2$$

Multiplying by $e^{\lambda_2 t} dt$ and rearranging

$$e^{\lambda_2 t} dN_2 + \lambda_2 N_2 e^{\lambda_2 t} dt = \lambda_1 N_0 e^{(\lambda_2 - \lambda_1)t} dt$$

Integrating both sides.

$$N_2 e^{\lambda_2 t} = \frac{N_0 \lambda_1}{\lambda_2 - \lambda_1} e^{(\lambda_2 - \lambda_1)t} + C$$

Since at $t = 0$, $N_2 = 0$, $C = -\frac{N_0 \lambda_1}{\lambda_2 - \lambda_1}$

$$\therefore N_2 e^{\lambda_2 t} = \frac{N_0 \lambda_1}{\lambda_2 - \lambda_1}\left(e^{(\lambda_2 - \lambda_1)t} - 1\right)$$

$$N_2 = \frac{N_0 \lambda_1}{\lambda_2 - \lambda_1}\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right)$$

For maximum count, $\frac{dN_2}{dt} = 0$

On solving, $t = \left(\ln \frac{\lambda_1}{\lambda_2}\right) / (\lambda_1 - \lambda_2)$

$$= \ln \frac{2.48}{0.62} / (2.48 - 0.62)$$

$$= \frac{\ln 4}{1.86} = \frac{2.303 \log 4}{1.86}$$

$$= 0.745 \text{ s.}$$

13.22 From conservation of energy

$$E - B = K_n + K_p = \frac{p_n^2}{2m} + \frac{p_p^2}{2m} \qquad (1)$$

From conservation of momentum

$$p_n + p_p = \frac{E}{c} \qquad (2)$$

If $E = B$, the first equation gives $p_n = p_p = 0$ and hence the second equation cannot be satisfied, and the process cannot take place.

For the process to take place, Let $E = B + \lambda$, where λ would be $<<B$.

Then : substituting for p_n from Equation (2) into Equation (1),

$$\lambda = \frac{1}{2m}(p_p^2 + p_n^2) = \frac{1}{2m}\left(p_p^2 + (p_p - E/c)^2\right)$$

$$\therefore 2p_p^2 - \frac{2E}{c}p_p + \left(\frac{E^2}{c^2} - 2m\lambda\right) = 0$$

$$\therefore p_p = \frac{2E/c \pm \sqrt{4E^2/c^2 - 8\left(\frac{E^2}{c^2} - 2m\lambda\right)}}{4}$$

Since the determinant must be positive for p_p to be real :

$$\frac{4E^2}{c^2} - 8\left(\frac{E^2}{c^2} - 2m\lambda\right) = 0$$

Or, $16m\lambda = \frac{4E^2}{c^2}$, $\therefore \lambda = \frac{E^2}{4mc^2} \approx \frac{B^2}{4mc^2}$.

13.23 The binding energy in H atom $E = \frac{me^4}{8\varepsilon_0^2 h^2} = 13.6\,\text{eV}$. (1)

If proton and neutron had charge e' each and were governed by the same electrostatic force, then in the above equation we would need to replace electronic mass m by the reduced mass m' of proton-neutron and the electronic charge e by e'.

$$m' = \frac{M}{2} = \frac{1836m}{2} = 918m.$$

$\therefore$ Binding energy $= \frac{918m e'}{8\varepsilon_0^2 h^2} = 2.2\,\text{MeV}$ (given) (2)

Diving (2) by (1)

$$918\left(\frac{e'}{e}\right)^4 = \frac{2.2\text{MeV}}{13.6\text{eV}}$$

$$\Rightarrow \frac{e'}{e} \approx 11.$$

13.24 Before β decay, neutron is at rest. Hence $E_n = m_n c^2$, $p_n = 0$

After β decay, from conservation of momentum:

$$\mathbf{p}_n = \mathbf{p}_p + \mathbf{p}_e$$

Or $\mathbf{p}_p + \mathbf{p}_e = 0 \Rightarrow |\mathbf{p}_p| = |\mathbf{p}_e| = p$

Also, $E_p = (m_p{}^2c^4 + p_p{}^2c^2)^{\frac{1}{2}}$,

$$E_e = (m_e{}^2c^4 + p_e{}^2c^2)^{\frac{1}{2}} = (m_e{}^2c^4 + p_p c^2)^{\frac{1}{2}}$$

From conservation of energy:

$$(m_p{}^2c^4 + p^2c^2)^{\frac{1}{2}} + (m_e{}^2c^4 + p^2c^2)^{\frac{1}{2}} = m_n c^2$$

$$m_p c^2 \approx 936\text{MeV}, m_n c^2 \approx 938\text{MeV}, m_e c^2 = 0.51\text{MeV}$$

Since the energy difference between n and p is small, pc will be small, $pc << m_p c^2$, while pc may be greater than $m_e c^2$.

$$\Rightarrow m_p c^2 + \frac{p^2c^2}{2m_p{}^2c^4} ; \; m_n c^2 - pc$$

To first order $pc ; \; m_n c^2 - m_p c^2 = 938\text{MeV} - 936\text{MeV} = 2\text{MeV}$

This gives the momentum.

Then,

$$E_p = (m_p{}^2c^4 + p^2c^2)^{\frac{1}{2}} = \sqrt{936^2 + 2^2} ; \; 936\text{MeV}$$

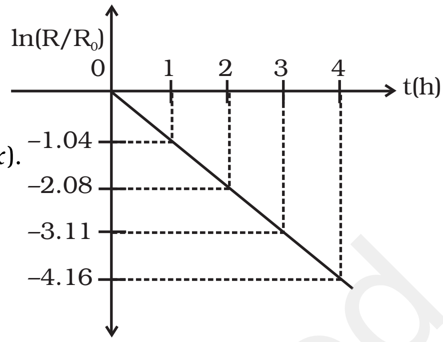
$$E_e = (m_e{}^2c^4 + p^2c^2)^{\frac{1}{2}} = \sqrt{(0.51)^2 + 2^2} ; \; 2.06\text{MeV}$$

13.25 (i) $t_{1/2}$ = 40 min (approx).

(ii) Slope of graph = $-\lambda$

So $\lambda = -\left(\frac{-4.16+3.11}{1}\right) = 1.05\text{h}$

So $t_{1/2} = \frac{0.693}{1.05} = 0.66\text{h} = 39.6\,\text{min}\,or\,40\,\text{min}\,(approx).$



13.26 (i) $S_{pSn} = (M_{119,70} + M_H - M_{120,70})c^2$

$= (118.9058 + 1.0078252 - 119.902199)c^2$

$= 0.0114362\ c^2$

$S_{pSb} = (M_{120,70} + M_H - M_{121,70})c^2$

$= (119.902199 + 1.0078252 - 120.903822)c_2$

$= 0.0059912\ c^2$

Since $S_{pSn} > S_{pSb}$, Sn nucleus is more stable than Sb nucleus.

(ii) It indicates shell structure of nucleus similar to the shell structure of an atom. This also explains the peaks in BE/nucleon curve.

Chapter 14

14.1 (d)

14.2 (b)

14.3 (b)

14.4 (d)

14.5 (b)

14.6 (c)

14.7 (b)

14.8 (c)

14.9 (a), (c)

14.10 (a), (c)

14.11 (b), (c), (d)

14.12 (b), (c)

14.13 (a), (b), (d)

14.14 (b), (d)

14.15 (a), (c), (d)

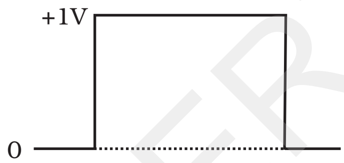
14.16 (a), (d)

14.17 The size of dopant atoms should be such as not to distort the pure semiconductor lattice structure and yet easily contribute a charge carrier on forming co-valent bonds with Si or Ge.

14.18 The energy gap for Sn is 0 eV, for C is 5.4 eV, for Si is 1.1 eV and for Ge is 0.7eV, related to their atomic size.

14.19 No, because the voltmeter must have a resistance very high compared to the junction resistance, the latter being nearly infinite.

14.20



14.21 (i) $10 \times 20 \times 30 \times 10^{-3} = 6V$

(ii) If dc supply voltage is 5V, the output peak will not exceed $V_{cc} = 5V$. Hence, $V_0 = 5V$.

14.22 No, the extra power required for amplified output is obtained from the DC source.

14.23 (i) ZENER junction diode and solar cell.

(ii) Zener breakdown voltage

(iii) Q- short circuit current

P- open circuit voltage.

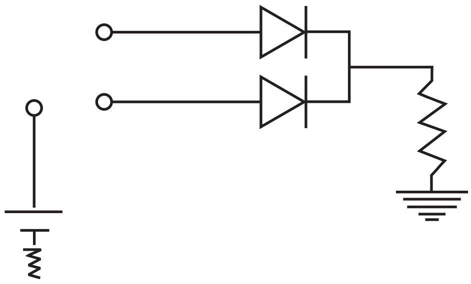
14.24 Energy of incident light photon

$$hv = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{6 \times 10^{-7} \times 1.6 \times 10^{-19}} = 2.06eV$$

For the incident radiation to be detected by the photodiode, energy of incident radiation photon should be greater than the band gap. This is true only for D2. Therefore, only D2 will detect this radiation.

14.25 $I_B = \frac{V_{BB} - V_{BE}}{R_1}$. If R_I is increased, I_B will decrease. Since $I_c = \beta I_b$, it will result in decrease in I_C i.e decrease in ammeter and voltmeter readings.

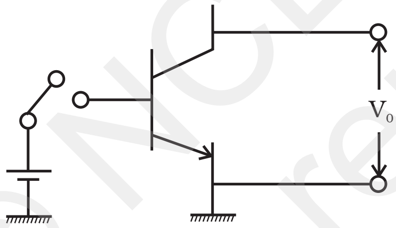
14.26



OR gate gives output according to the truth table.

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

14.27



Input	Output
A	A
0	1
1	0

14.28 Elemental semiconductor's band-gap is such that emissions are in IR region.

14.29 Truth table

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

AND Gate

14.30 $I_{Z\max} = \frac{P}{V_Z} = 0.2\text{A} = 200\,\text{mA}$

$$R_S = \frac{V_s - V_Z}{I_{Z\max}} = \frac{2}{0.2} = 10\,\Omega.$$

14.31 I_3 is zero as the diode in that branch is reverse bised. Resistance in the branch AB and EF are each (125 + 25) Ω = 150 Ω.

As AB and EF are identical parallel branches, their effective resistance is $\frac{150}{2} = 75\Omega$

∴ Net resistance in the circuit = (75 + 25) Ω = 100 Ω.

∴ Current $I_1 = \frac{5}{100} = 0.05\text{A}$.

As resistances of AB and EF are equal, and $I_1 = I_2 + I_3 + I_4$, $I_3 = 0$

$$\therefore I_2 = I_4 = \frac{0.05}{2} = 0.025\text{A}$$

14.32 As $V_{be} = 0$, potential drop across R_b is 10V.

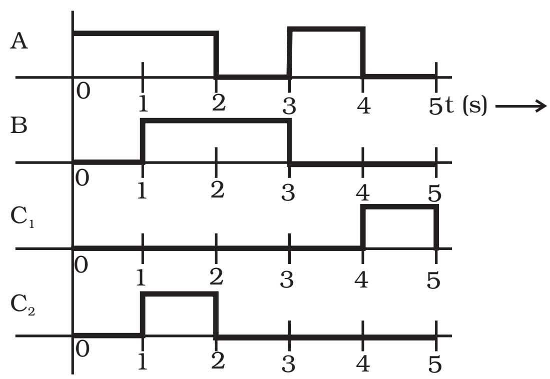
$$\therefore I_b = \frac{10}{400 \times 10^3} = 25\mu A$$

Since $V_{ce} = 0$, potential drop across R_c, i.e. $I_c R_c$ is 10V.

$$\therefore I_c = \frac{10}{3 \times 10^3} = 3.33 \times 10^{-3} = 3.33\text{m}A.$$

$$\therefore \beta = \frac{I_c}{I_b} = \frac{3.33 \times 10^{-3}}{25 \times 10^{-6}} = 1.33 \times 10^2 = 133.$$

14.33



14.34 From the output characteristics at point Q, V_{CE} = 8V & I_C = 4mA

$V_{CC} = I_C RC + V_{CE}$

$$R_c = \frac{V_{CC} - V_{CE}}{I_C}$$

$$R_c = \frac{16-8}{4\times10^{-3}} = 2\text{K}\Omega$$

Since,

$V_{BB} = I_B R_B + V_{BE}$

$$R_B = \frac{16-0.7}{30\times10^{-6}} = 510\text{K}\Omega$$

Now, $\beta = \dfrac{I_C}{I_B} = \dfrac{4\times10^{-3}}{30\times10^{-6}} = 133$

Voltage gain $= A_V = -\beta \dfrac{R_C}{R_B}$

$$= -133\times\frac{2\times10^3}{510\times10^3}$$

= 0.52

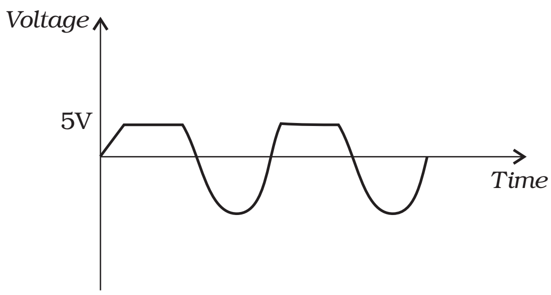
Power Gain = $A_p = \beta\times A_V$

$$= -\beta^2 \frac{R_C}{R_B}$$

$$= (133)^2 \times \frac{2\times10^3}{510\times10^3} = 69$$

14.35 When input voltage is greater than 5V, diode is conducting

When input is less than 5V, diode is open circuit



14.36 (i) In 'n' region; number of e^- is due to As:

$n_e = N_D = 1 \times 10^{-6} \times 5 \times 10^{28}$ atoms/m^3

$n_e = 5 \times 10^{22}$/m^3

The minority carriers (hole) is

$$n_h = \frac{n_i^2}{n_e} = \frac{(1.5\times10^{16})^2}{5\times10^{22}} = \frac{2.25\times10^{32}}{5\times10^{22}}$$

$n_h = 0.45 \times 10/m^3$

Similarly, when Boron is implanted a 'p' type is created with holes

$n_h = N_A = 200 \times 10^{-6} \times 5 \times 10^{28}$

$= 1 \times 10^{25}/m^3$

This is far greater than e^- that existed in 'n' type wafer on which Boron was diffused.

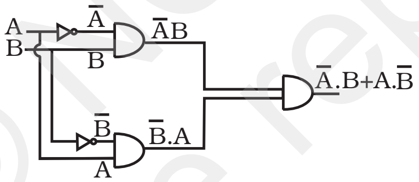
Therefore, minority carriers in created 'p' region

$$n_e = \frac{n_i^2}{n_h} = \frac{2.25\times10^{32}}{1\times10^{25}}$$

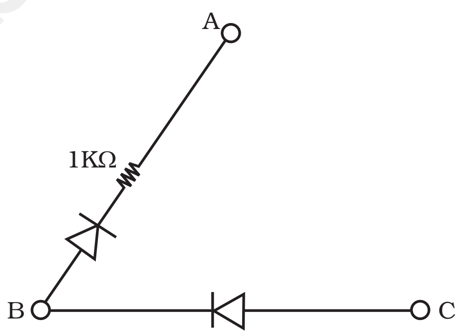
$= 2.25 \times 10^7/m^3$

(ii) Thus, when reverse biased $0.45 \times 10^{10}/m^3$, holes of '*n*' region would contribute more to the reverse saturation current than $2.25 \times 10^7/m^3$ minority e^- of p type region.

14.37



14.38



14.39 $I_C \approx I_E \therefore I_C(R_C + R_E) + V_{CE} = 12$ V

$R_E = 9 - R_C = 1.2$ KΩ

$\therefore\ V_E = 1.2$ V

$V_B = V_E + V_{BE} = 1.7$ V

$$I = \frac{V_B}{20K} = 0.085\,\text{mA}$$

$$R_B = \frac{12-1.7}{I_C/\beta + 0.085} = \frac{10.3}{0.01+1.085} = 108\,\text{K}\Omega$$

14.40 $I_E = I_C + I_B \qquad I_C = \beta\, I_B$ (1)

$I_C R_C + V_{CE} + I_E R_E = V_{CC}$ (2)

$R I_B + V_{BE} + I_E R_E = V_{CC}$ (3)

From (3) $I_e \approx I_C = \beta I_B$

$$(R + \beta R_E) = V_{CC} - V_{BE}, \quad I_B = \frac{V_{CC} - V_{BE}}{R + \beta R_E} = \frac{11.5}{200}\text{mA}$$

From (2)

$$R_C + R_E = \frac{V_{CC} - V_{CE}}{I_C} = \frac{V_{CC} - V_{CE}}{\beta I_B} = \frac{2}{11.5}(12-3)\text{K}\Omega = 1.56\text{K}\Omega$$

$$R_C = 1.56 - 1 = 0.56\text{K}\Omega$$

Chapter 15

15.1 (b)

15.2 (a)

15.3 (b)

15.4 (a)

15.5 (b)

15.6 (c)

15.7 (b)

15.8 (b)

15.9 (c)

15.10 (a), (b), (d)

15.11 (b), (d)

15.12 (b), (c), (d)

15.13 (a), (b), (c)

15.14 (b), (d)

15.15 (i) analog

(ii) analog

(iii) digital

(iv) digital

15.16 No, signals of frequency greater than 30 MHz will not be reflected by the ionosphere, but will penetrate through the ionosphere.

15.17 The refractive index increases with increase in frequency which implies that for higher frequency waves, angle of refraction is less, i.e. bending is less. Hence, the condition of total internal relection is atained after travelling larger distance (by 3MHz wave).

15.18 $A_c + A_m = 15,\ A_c - A_m = 3$

$\therefore\ 2A_c = 18,\ 2A_m = 12$

$$\therefore\ m = \frac{A_m}{A_c} = \frac{2}{3}$$

15.19 $$\frac{1}{2\pi\sqrt{LC}} = 1\text{MHz}$$

$$\sqrt{LC} = \frac{1}{2\pi \times 10^6}$$

15.20 In AM, the carrier waves instantaneous voltage is varied by modulating waves voltage. On transmission, noise signals can also be added and receiver assumes noise a part of the modulating signal.

However in FM, the carriers frequency is changed as per modulating waves instantaneous voltage. This can only be done at the mixing/ modulating stage and not while signal is transmitting in channel. Hence, noise doesn't effect FM signal.

15.21 Loss suffered in transmission path

$= -2\ \text{dB km}^{-1} \times 5\ \text{km} = -10\ \text{dB}$

Total amplifier gain = 10 dB + 20 dB

= 30 dB

Overall gain of signal = 30 dB – 10 dB

= 20 dB

$$10\log\left(\frac{P_o}{P_i}\right) = 12 \text{ or } P_o = P_i \times 10^2$$

$$= 1.01 \text{ mW} \times 100 = 101 \text{ mW.}$$

15.22 (i) Range = $\sqrt{2\times6.4\times10^6\times20}$ = 16 km

Area covered = 803.84 km^2

(ii) Range = $\sqrt{2\times6.4\times10^6\times20}+\sqrt{2\times6.4\times10^6\times25}$

= (16 + 17.9) km = 33.9 km

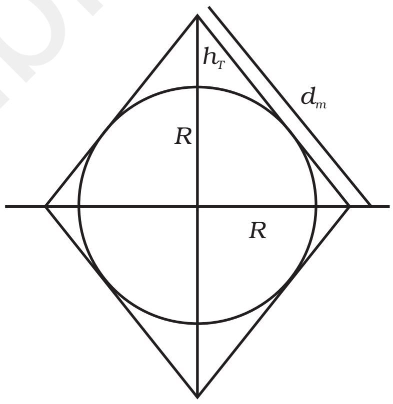
Area covered = 3608.52 km^2

∴ Percentage increase in area

$$= \frac{(3608.52 - 803.84)}{803.84}\times100$$

= 348.9%

15.23 $d_m^2 = 2(R+h_T)^2$



$8Rh_T = 2(R+h_T)^2$ $\qquad(\because dm = 2\sqrt{2Rh_T})$

$$4Rh_T = R^2 + h_T{}^2 + 2Rh_T$$

$(R - h_T)^2 = 0$

$R = h_T$

Since space wave frequency is used, $\lambda << h_T$, hence only tower height is taken to consideration.

In three diamensions, 6 antenna towers of $h_T = R$ would do.

15.24 For F_1 layer

$5 \times 10^6 = 9(N_{max})^{1/2}$ or $N_{max} = \left(\frac{5}{9}\times10^6\right)^2 = 3.086 \times 10^{11}$ m^{-3}

For F_2 layer
$8 \times 10^6 = 9\,(N_{max})^{1/2}$ or

$$N_{max} = \left(\frac{8}{9}\times10^6\right) = 7.9\times10^{11}\text{m}^{-3} = 7.9 \times 10^{11} \text{ m}^{-3}.$$

15.25 Of $\omega_c - \omega_m$, ω_c and $\omega_m + \omega_m$, only $\omega_c + \omega_m$ or $\omega_c - \omega_m$ contains information. Hence cost can be reduced by transmitting $\omega_c + \omega_m$, $\omega_c - \omega_m$, both $\omega_c + \omega_m$ & $\omega_c - \omega_m$

15.26 (i) $\frac{I}{I_o} = \frac{1}{4}$, so $\ln\left(\frac{1}{4}\right) = -\alpha x$

or $\ln 4 = \alpha x$ or $x = \left(\frac{\ln 4}{\alpha}\right)$

(ii) $10\log_{10}\frac{I}{I_o} = -\alpha x$ where α is the attunation in dB/km.

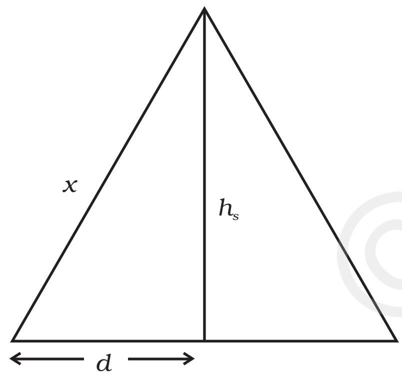
Here $\frac{I}{I_o} = \frac{1}{2}$

or $10\log\left(\frac{1}{2}\right) = -50\alpha$ or $\log 2 = 5\alpha$

or $\alpha = \frac{\log 2}{5} = \frac{0.3010}{5} = 0.0602 \text{dB/km}$

15.27 $\frac{2x}{\text{time}} = \text{velocity}$

$2x = 3 \times 10^8$ m/s $\times 4.04 \times 10^{-3}$s



$x = \frac{12.12 \times 10^5}{2}$ m $= 6.06 \times 10^5$m = 606 km

$d^2 = x^2 - h_s^2 = (606)^2 - (600)^2 = 7236$; $d = 85.06$ km

Distance between source and receiver = 2d ≅170 km

$d_m = 2\sqrt{2Rh_T}$, $2d = d_m$, $4d^2 = 8\,Rh_T$

$\frac{d^2}{2R} = h_T = \frac{7236}{2\times 6400} \approx 0.565$ km = 565m.

15.28 From the figure

$V_{max} = \frac{100}{2} = 50$V, $V_{min} = \frac{20}{2} = 10$ V.

(i) Percentage modulation

$$\mu(\%) = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} \times 100 = \left(\frac{50-10}{50+10}\right) \times 100 = \frac{40}{60} \times 100 = 66.67\%$$

(ii) Peak carrier voltage = $V_c = \frac{V_{\max} + V_{\min}}{2} = \frac{50+10}{2} = 30$V

(iii) Peak information voltage = $V_m = \mu V_c = \frac{2}{3} \times 30 = 20$V .

15.29 (a) $v(t) = A(A_{m_1}\sin\omega_{m_1}t + A_{m_2}\sin\omega_{m_2}t + A_c\sin\omega_c t)$

$$+ B(A_{m_1}\sin\omega_{m_1}t + A_{m_2}\sin\omega_{m_2}t + A_c\sin\omega_c t)^2$$

$$= A(A_{m_1}\sin\omega_{m_1}t + A_{m_2}\sin\omega_{m_2}t + A_c\sin\omega_c t)$$

$$+B((A_{m_1}\sin\omega_{m_1}t + A_{m_2}t)^2 + A_c^2\sin^2\omega_c t$$
$$+2A_c(A_{m_1}\sin\omega_{m1}t + A_{m_2}sin\omega_c t)$$

$$= A(A_1\sin\omega_{m_1}t + A_{m_2}\sin\omega_{m_2}t + A_c\sin\omega_c t)$$
$$+B[A_{m_1}^2\sin^2\omega_{m_1}t + A_{m_2}^2 sin^2\omega_{m_2}t + 2A_{m_1}A_{m_2}\sin\omega_{m_1}t\sin\omega_{m_2}t$$
$$+A_c^2\sin^2\omega_c t + 2A_c(A_{m_1}sin\omega_{m_1}t\sin\omega_c t + A_{m_2}\sin\omega_{m_2} + \sin\omega_c t]$$

$$= A(A_{m_1}\sin\omega_{m_1}t + A_{m_2}\sin\omega_{m_2}t + A_c\sin\omega_c t)$$
$$+B[A_{m1}^2\sin^2\omega_{m_1}t + A_{m_2}^2 sin^2\omega_{m_2}t + A_c^2\sin^2\omega_c t$$
$$+\frac{\cancel{2}A_{m_1}A_{m_2}}{\cancel{2}}[\cos(\omega_{m_2} - \omega_{m_1})t - \cos(\omega_{m_1} + \omega_{m_2})t]$$

$$+\frac{\cancel{2}A_c A_{m_2}}{\cancel{2}}[\cos(\omega_c - \omega_{m_1})t - \cos(\omega_c + \omega_{m_1})t]$$

$$+\frac{\cancel{2}A_c A_{m_1}}{\cancel{2}}[\cos(\omega_c - \omega_{m_2})t - \cos(\omega_c + \omega_{m_2})t]$$

∴ Frequencies present are

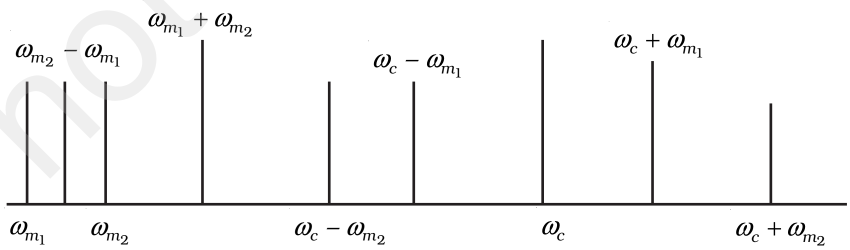
$\omega_{m_1}, \omega_{m_2}, \omega_c$

$(\omega_{m_2} - \omega_{m_1}), (\omega_{m_1} + \omega_{m_2})$

$(\omega_c - \omega_{m_1}), (\omega_c + \omega_{m_1})$

$(\omega_c - \omega_{m_2}), (\omega_c + \omega_{m_2})$

(i) Plot of amplitude versus ω is shown in the Figure.



(ii) As can be seen frequency spectrum is not symmetrical about ω_c. Crowding of spectrum is present for $\omega < \omega_c$.

(iii) Adding more modulating signals lead to more crowding in $\omega < \omega_c$ and more chances of mixing of signals.

(iv) Increase band-width and ω_c to accommodate more signals. This shows that large carrier frequency enables to carry more information (more ω_m) and which will in turn increase band-width.

15.30 f_m = 1.5kHz, $\frac{1}{f_m} = 0.7 \times 10^{-3}$ s

f_c = 20MHz, $\frac{1}{f_c} = 0.5 \times 10^{-7}$ s

(i) $RC = 10^3 \times 10^{-8} = 10^{-5}$ s

So, $\frac{1}{f_c} << RC < \frac{1}{f_m}$ is satisfied

So it can be demodulated.

(ii) $RC = 10^4 \times 10^{-8} = 10^{-4}$ s.

Here too $\frac{1}{f_c} << RC < \frac{1}{f_m}$.

So this too can be demodulated

(iii) $RC = 104 \times 10^{-12} = 10^{-8}$ s.

Here $\frac{1}{f_c} > RC$, so this cannot be demodulated.