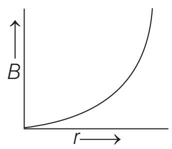
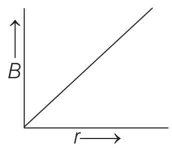
18

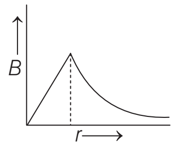
Moving Charges and Magnetism

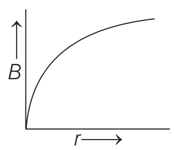
TOPIC 1
Biot Savart's Law and Ampere's Circuital Law

1 A thick current carrying cable of radius R carries current I uniformly distributed across its cross-section. The variation of magnetic field B due to the cable with the distance r from the axis of the cable is represented by **[NEET 2021]**

(a) 

(b) 

(c) 

(d) 

Ans. *(c)*

Magnetic field inside the conducting cylindrical cable,

$$B = \frac{\mu_0 I}{2\pi R^2} r$$

Here, R is the radius of the cylindrical cable,

r is the distance from the axis of the cylinder,

I is the current carrying in the cylindrical cable.

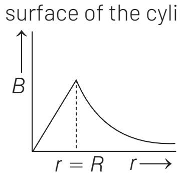
$\Rightarrow \quad B \propto r$

$\therefore$ The graph of magnetic field B with r is a straight line passing through origin.

For a point outside the cylinder,

$$B = \frac{\mu_0 I}{2\pi R} \Rightarrow B \propto \frac{1}{R}$$

The graph of magnetic field (B) with r is a rectangular hyperbola passing through the outer surface of the cylinder.



$\therefore$ The variation of the magnetic field B due to the cable with the distance r from the axis of the cylindrical cable is as shown in the figure.

2 A long solenoid of 50 cm length having 100 turns carries a current of 2.5 A. The magnetic field at the centre of solenoid is (Take, $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}) **[NEET (Sep.) 2020]**

(a) 3.14×10^{-4} T (b) 6.28×10^{-5} T
(c) 3.14×10^{-5} T (d) 6.28×10^{-4} T

Ans. *(d)*

Given, $l = 50$ cm $= 0.5$ m, $N = 100$ turns and $I = 2.5$ A

$\therefore$ Magnetic field at the centre of solenoid is

$$= \mu_0 n I = \mu_0 \left(\frac{N}{l}\right) \cdot I$$

$$= 4\pi \times 10^{-7} \times \frac{100}{0.5} \times 2.5$$

$$= 6.28 \times 10^{-4} \text{ T}$$

Hence, correct option is (d).

3 Two toroids 1 and 2 have total number of turns 200 and 100 respectively with average radii 40 cm and 20 cm respectively. If they carry same current i, the ratio of the magnetic fields along the two loops is **[NEET (Odisha) 2019]**

(a) 1 : 1 (b) 4 : 1
(c) 2 : 1 (d) 1 : 2

Ans. *(a)*

The magnetic field within the turns of toroid is

$$B = \frac{\mu_0 N I}{2\pi r}$$

where, N = number of turns, I = current in loops and

r = radius of each turn

Here, $N_1 = 200$, $N_2 = 100$, $r_1 = 40$ cm, $r_2 = 20$ cm

and current I is same, then

$$\frac{B_1}{B_2} = \frac{\mu_0 N_1 I}{2\pi r_1} \times \frac{2\pi r_2}{\mu_0 N_2 I}$$

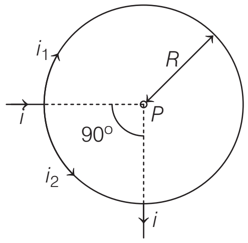
Substituting the given values in the above relation, we get

$$\frac{B_1}{B_2} = \left(\frac{N_1}{N_2}\right)\left(\frac{r_2}{r_1}\right)$$

$$= \left(\frac{200}{100}\right)\left(\frac{20}{40}\right) = 2 \times \frac{1}{2} = 1$$

$\therefore \quad B_1 : B_2 = 1:1$

4 A straight conductor carrying current i splits into two parts as shown in the figure. The radius of the circular loop is R. The total magnetic field at the centre P at the loop is **[NEET (Odisha) 2019]**

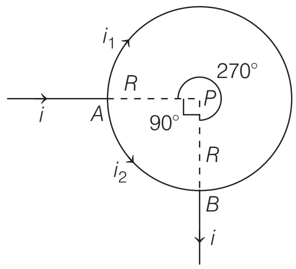


(a) Zero
(b) $3\mu_0 i / 32$ R, outward
(c) $3\mu_0 i / 32$R, inward
(d) $\frac{\mu_0 i}{2R}$, inward

Ans. ***(a)***

The magnetic field at the centre of an arc subtended at an angle θ is given by

$$B = \frac{\mu_0 i}{2R} \times \frac{\theta}{2\pi}$$



Then, the magnetic field due to larger arc AB is

$$B_1 = \frac{\mu_0 i_1}{2R} \times \frac{270}{2\pi} \quad \text{...(i)}$$

which acts in inward direction according to right hand thumb rule. And magnetic field due to smaller arc AB is

$$B_2 = \frac{\mu_0 i_2}{2R} \times \frac{90}{2\pi} \quad \text{...(ii)}$$

which acts in outward direction.

The resultant magnetic field

$B_R = B_1 + B_2$

$$= -\frac{\mu_0 i_1 \times 270}{4\pi R} + \frac{\mu_0 i_2 \times 90}{4\pi R} \text{[From Eq. (i) and (ii)]} \quad \text{...(iii)}$$

which acts in inward direction as $B_1 > B_2$.

Two arcs can also be seen as the two resistances in parallel combination.

So, the potential across them will be same i.e.

$$V_1 = V_2$$

$$i_1 R_1 = i_2 R_2 \quad \text{...(iv)}$$

where, R_1 and R_2 = Resistance of respective segments

The wire is uniform so

$$\frac{R_1}{R_2} = \frac{L_1}{L_2} = \frac{R \times 270}{R \times 90}$$

[$\because$ length of arc = radius × angle]

From Eq. (iv), we get

$$\Rightarrow \quad \frac{i_1}{i_2} = \frac{R_2}{R_1} = \frac{90}{270} = \frac{1}{3}$$

or $\quad 3i_1 = i_2 \quad$ ...(v)

From Eq. (iii) and (v), we get

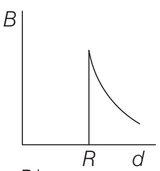
$$B_R = \frac{\mu_0}{4\pi R}(-270 i_1 + 90 i_2)$$

$$= \frac{\mu_0}{4\pi R}[-270 i_1 + 90(3i_1)]$$

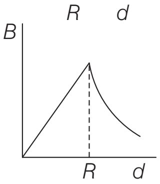
$$= \frac{\mu_0}{4\pi R}(-270 i_1 + 270 i_1) = 0$$

5 A cylindrical conductor of radius R is carrying a constant current. The plot of the magnitude of the magnetic field B with the distance d from the centre of the conductor, is correctly represented by the figure **[NEET (National) 2019]**

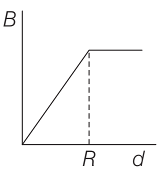
(a)



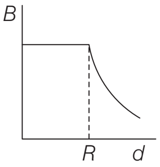
(b)



(c)

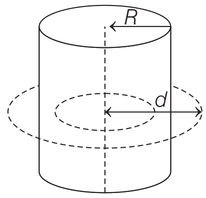


(d)



Ans. ***(b)***

The cylinder can be considered to be made from concentric circles of radius R.



(i) The magnetic field at point outside cylinder, i.e. $d > R$.

From Ampere's circuital law,

$$\oint B \cdot dl = \mu_0 I$$

$$\Rightarrow \quad B\int dl = \mu_0 I$$

$$B(2\pi d) = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi d}$$

where, μ_0 = permeability of free space.

(ii) The magnitude field at surface, i.e. $d = R$

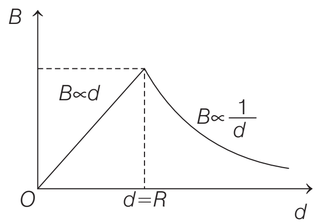
$$B = \frac{\mu_0 I}{2\pi R}$$

(iii) The magnetic field at inside point. The current for a point inside the cylinder is given by I' = current per unit cross-sectional area of cylinder × cross-section of loop

$$= \frac{I}{\pi R^2} \pi d^2 = \frac{I d^2}{R^2}$$

$$\therefore \quad B = \frac{\mu_0 I'}{2\pi d} = \frac{\mu_0 I d^2}{2\pi R^2 d} = \frac{\mu_0 I}{2\pi R^2} d$$

So, the variation of magnetic field can be plotted as



6 A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields **B** and **B′** at radial distances $\frac{a}{2}$ and $2a$ respectively, from the axis of the wire is **[NEET 2016]**

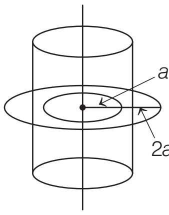
(a) $\frac{1}{2}$ (b) 1

(c) 4 (d) $\frac{1}{4}$

Ans. *(b)*

Consider two amperian loops of radius $\frac{a}{2}$ and $2a$ as shown in the diagram.

Applying Ampere's circuital law for these loops we get,



$$\oint \mathbf{B} \cdot \mathbf{d}L = \mu_0 I_{enclosed}$$

For the smaller loop

$$\Rightarrow \quad B \times 2\pi \frac{a}{2} = \mu_0 \times \frac{I}{\pi a^2} \times \pi \left(\frac{a}{2}\right)^2$$

$$= \mu_0 I \times \frac{1}{4} = \frac{\mu_0 I}{4}$$

$$\Rightarrow \quad B_I = \frac{\mu_0 I}{4\pi a}, \text{at distance } \frac{a}{2} \text{ from}$$

the axis of the wire.

Similarly, for bigger amperian loop.

$B' \times 2\pi(2a) = \mu_0 I$ [total current enclosed by Amperian loop is 2]

$$\Rightarrow \quad B' = \frac{\mu_0 I}{4\pi a},$$

at distance $2a$ from the axis of the wire.

So, ratio of, $\frac{B}{B'} = \frac{\mu_0 I}{4\pi a} \times \frac{4\pi a}{\mu_0 I} = 1$

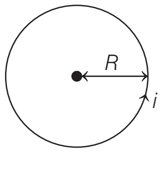
7 A long wire carrying a steady current is bent into a circular loop of one turn. The magnetic field at the centre of the loop is B. It is then bent into a circular coil of n turns. The magnetic field at the centre of this coil of n turns will be **[NEET 2016]**

(a) nB (b) n^2B
(c) $2nB$ (d) $2n^2B$

Ans. *(b)*

Key Idea $B_{centre} = \frac{n \cdot \mu_0 i}{2R}$ (For a circular coil)

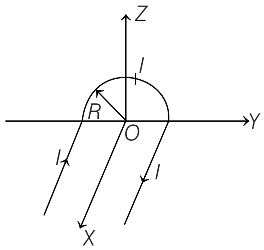
where, n : Number of turns in circular coil



$$B = \frac{\mu_0 i}{2R} = \frac{\mu_0 i(2\pi)}{2(l)} = \frac{\mu_0 \pi i}{l}$$

$$= \frac{\mu_0 n i}{2\left(\frac{l}{2n\pi}\right)} = \frac{n^2 \mu_0 \pi i}{l} = n^2 B$$

8 A wire carrying current I has the shape as shown in adjoining figure. Linear parts of the wire are very long and parallel to X-axis while semicircular portion of radius R is lying in Y-Z plane. Magnetic field at point O is **[CBSE AIPMT 2015]**



(a) $\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} + 2\hat{\mathbf{k}})$

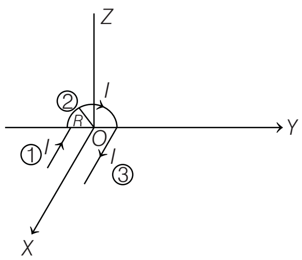
(b) $\mathbf{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} - 2\hat{\mathbf{k}})$

(c) $\mathbf{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} + 2\hat{\mathbf{k}})$

(d) $\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} - 2\hat{\mathbf{k}})$

Ans. *(a)*

The magnetic field in the different regions is given by



$$\mathbf{B}_1 = \frac{\mu_0}{4\pi} \times \frac{I}{R}(-\hat{\mathbf{k}})$$

$$\mathbf{B}_3 = \frac{\mu_0 I}{4\pi R}(-\hat{\mathbf{k}})$$

$$\mathbf{B}_2 = \frac{\mu_0 I}{4\pi R}(-\hat{\mathbf{i}})$$

The net magnetic field at the centre O is

$$\mathbf{B} = \mathbf{B}_1 + \mathbf{B}_2 + \mathbf{B}_3$$

$$= \frac{\mu_0 I}{4\pi R}(-2\hat{\mathbf{k}}) + \frac{\mu_0 I}{4R}(-\hat{\mathbf{i}})$$

$$= -\frac{\mu_0 I}{4\pi R}(2\hat{\mathbf{k}} + \pi\hat{\mathbf{i}})$$

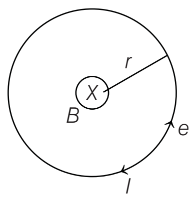
9 An electron moving in a circular orbit of radius r makes n rotations per second. The magnetic field produced at the centre has magnitude **[CBSE AIPMT 2015]**

(a) $\frac{\mu_0 ne}{2\pi r}$ (b) zero

(c) $\frac{\mu_0 n^2 e}{r}$ (d) $\frac{\mu_0 ne}{2r}$

Ans. *(d)*

As $I = \frac{q}{t}$. So, for an electron revolving in a circular orbit of radius r



$$q = e \text{ and } t = T$$

$$\Rightarrow$$

$$I = \frac{e}{T} = \frac{e}{2\pi/\omega} = \frac{\omega e}{2\pi} = \frac{2\pi ne}{2\pi} = ne$$

The magnetic field produced at the centre is

$$B = \frac{\mu_0 I}{2R} = \frac{\mu_0 ne}{2r}$$

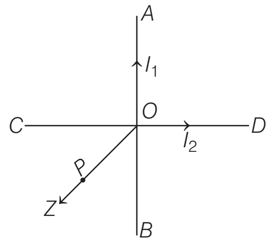
10 Two identical long conducting wires AOB and COD are placed at right angle to each other, such that one is above the other and O is their common point. The wires carry I_1 and I_2 currents, respectively. Point P is lying at distance d from O along a direction perpendicular to the plane containing the wires. The magnetic field at the point P will be **[CBSE AIPMT 2014]**

(a) $\frac{\mu_0}{2\pi d}\left(\frac{I_1}{I_2}\right)$ (b) $\frac{\mu_0}{2\pi d}(I_1 + I_2)$

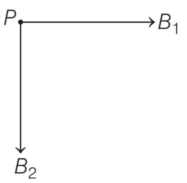
(c) $\frac{\mu_0}{2\pi d}(I_1^2 - I_2^2)$ (d) $\frac{\mu_0}{2\pi d}(I_1^2 + I_2^2)^{1/2}$

Ans. *(d)*

As from question



The point P is lying at a distance d along the Z-axis.



As magnetic field B_1 is given by $= \frac{\mu_0}{2\pi}\frac{I_1}{d}$

and magnetic field B_2 is given by $= \frac{\mu_0}{2\pi}\frac{I_2}{d}$

B_1 and B_2 are $\perp$ to each other

So, B_{net} is given by

$$B_{net} = \sqrt{B_1^2 + B_2^2},$$

$$B_{net} = \frac{\mu_0}{2\pi}\frac{1}{d}(I_1^2 + I_2^2)^{1/2}$$

11 When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards West. When it is projected towards North with a speed v_0 it moves with an initial acceleration $3a_0$ towards West. The electric and magnetic fields in the room are **[NEET 2013]**

(a) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ up

(b) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ down

(c) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ up

(d) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ down

Ans. *(b)*

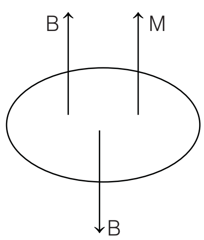
Initial acceleration is given by

$$a_0 = \frac{eE}{m} \qquad (F = eE)$$

$$\Rightarrow \quad E = \frac{a_0 m}{e} \qquad \text{...(i)}$$

$$\therefore \quad \frac{ev_0 B + eE}{m} = 3a_0$$

or $\quad ev_0 B + eE = 3a_0 m$



$\therefore \quad ev_0 B = 3ma_0 - eE$

$\Rightarrow \quad = 3\,ma_0 - ma_0 \qquad$ [from Eq. (i)]

$\therefore B = \frac{2ma_0}{ev_0}$, in vertically downward direction

12 Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and $2I$, respectively. The resultant magnetic field induction at the centre will be **[CBSE AIPMT 2012]**

(a) $\frac{\sqrt{5}\mu_0 I}{2R}$ (b) $\frac{3\mu_0 I}{2R}$

(c) $\frac{\mu_0 I}{2R}$ (d) $\frac{\mu_0 I}{R}$

Ans. *(a)*

The magnetic field (B) at the centre of circular current carrying coil of radius R and current I is $B = \frac{\mu_0 I}{2R}$

Similarly, if current is $2I$, then

Magnetic field $= \frac{\mu_0 2I}{2R} = 2B$

So, resultant magnetic field

$$= \sqrt{B^2 + (2B)^2} = \sqrt{5B^2}$$

$$= \sqrt{5}B = \frac{\mu_0 I\sqrt{5}}{2R}$$

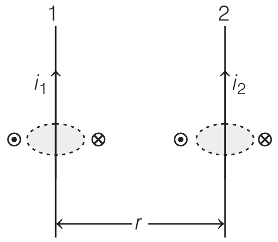
13 Two wires are held perpendicular to the plane of paper and are 5 m apart. They carry currents of 2.5 A and 5 A in same direction. Then, the magnetic field strength $(\mathbf{B})$ at a point midway between the wires will be **[CBSE AIPMT 2008]**

(a) $\frac{\mu_0}{4\pi}$ T (b) $\frac{\mu_0}{2\pi}$ T

(c) $\frac{3\mu_0}{2\pi}$ T (d) $\frac{3\mu_0}{4\pi}$ T

Ans. *(b)*

According to Maxwell's right handed screw rule, the magnetic field at right hand of wire 1 is perpendicular to the current carrying wire in plane of paper going inwards shown by ⊗. Similarly, the magnetic field at left hand of wire 2 is perpendicular to current carrying wire in plane of paper opposite to first wire shown by ⊙. Thus, the two fields are opposite to each other.



Therefore, net magnetic field

$$B = B_1 - B_2 = \frac{\mu_0 i_1}{2\pi r_1} - \frac{\mu_0 i_2}{2\pi r_2}$$

At mid-point, $r_1 = r_2 = \frac{r}{2} = \frac{5}{2} = 2.5\,\text{cm}$

Hence, $B = \frac{\mu_0}{2\pi}\left(\frac{i_1}{r/2} - \frac{i_2}{r/2}\right)$

$$= \frac{\mu_0}{2\pi}\left(\frac{5}{2.5} - \frac{2.5}{2.5}\right)$$

$$= \frac{\mu_0}{2\pi}(2-1) = \frac{\mu_0}{2\pi}\text{ T}$$

14 Two circular coils 1 and 2 are made from the same wire but the radius of the 1st coil is twice that of the 2nd coil. What is the ratio of potential difference applied across them so that the magnetic field at their centres is the same ? **[CBSE AIPMT 2006]**

(a) 3 (b) 4 (c) 6 (d) 2

Ans. *(b)*

Magnetic field at the centre of a circular coil is

$$B = \frac{\mu_0}{2\pi} \times \frac{i}{r}$$

where, i is current flowing in the coil and r is radius of coil.

At the centre of coil-1,

$$B_1 = \frac{\mu_0}{2\pi} \times \frac{i_1}{r_1} \qquad \text{...(i)}$$

At the centre of coil-2

$$B_2 = \frac{\mu_0}{2\pi} \times \frac{i_2}{r_2} \qquad \text{...(ii)}$$

but $\quad B_1 = B_2$

$$\therefore \quad \frac{\mu_0}{2\pi}\frac{i_1}{r_1} = \frac{\mu_0}{2\pi}\frac{i_2}{r_2}$$

or $\quad \frac{i_1}{r_1} = \frac{i_2}{r_2}$

As given $\quad r_1 = 2\,r_2$

$$\therefore \quad \frac{i_1}{2r_2} = \frac{i_2}{r_2} \text{ or } i_1 = 2i_2 \qquad \text{...(iii)}$$

Now, ratio of potential differences

$$\frac{V_2}{V_1} = \frac{i_2 \times R_2}{i_1 \times R_1} = \frac{i_2 \times R_2}{2i_2 \times 2R_2} = \frac{1}{4} \qquad [R \propto r]$$

$\therefore \quad \frac{V_1}{V_2} = \frac{4}{1}$

Note If wires are made of same material, then resistance of coil is proportional to the radius of coil i.e., $R \propto l$ so, $R \propto 2\pi r$

15 A long solenoid carrying a current produces a magnetic field B along its axis. If the current is doubled and the number of turns per cm is halved, the new value of the magnetic field is **[CBSE AIPMT 2003]**

(a) $2B$ (b) $4B$ (c) $\frac{B}{2}$ (d) B

Ans. *(d)*

For a solenoid magnetic field is given by $B = \mu_0 ni$

where, n = number of turns per unit length and i = current through the coil

or so for two different cases $B \propto ni$

$$\therefore \quad \frac{B_1}{B_2} = \frac{n_1 i_1}{n_2 i_2}$$

Here, $n_1 = n,\ n_2 = \frac{n}{2},$

$i_1 = i,\ i_2 = 2i,\ B_1 = B$

Hence, $\frac{B}{B_2} = \frac{n}{n/2} \times \frac{i}{2i} = 1$ or $B_2 = B$

16 The magnetic field of a given length of wire carrying a current for a single turn circular coil at centre is B, then its value for two turns for the same wire when same current passing through it is **[CBSE AIPMT 2002]**

(a) $\frac{B}{4}$ (b) $\frac{B}{2}$ (c) $2B$ (d) $4B$

Ans. *(d)*

Magnetic field at the centre of circular coil carrying current i with N number of turns is given by

$$B = \frac{\mu_0 Ni}{2r}$$

Case I $\quad N = 1, L = 2\pi r \Rightarrow r = \frac{L}{2\pi}$

$$\therefore \quad B = \frac{\mu_0 \times 1 \times i}{2r} = \frac{\mu_0 i}{2r}$$

Case II $N = 2, L = 2 \times 2\pi r'$

$\Rightarrow r' = \frac{L}{4\pi} = \frac{r}{2} \quad \therefore \quad B' = \frac{\mu_0 \times 2 \times i}{2r'}$

Putting the value of r'

$$B' = \frac{\mu_0 \times 2i}{2 \times (r/2)} = \frac{4\mu_0 i}{2r} = 4B$$

Note Magnetic field at the centre of circular coil is maximum and decreases as we move away from the centre (on the axis of coil).

17 Magnetic field due to 0.1A current flowing through a circular coil of radius 0.1m and 1000 turns at the centre of the coil is **[CBSE AIPMT 1999]**

(a) 0.2 T (b) 2×10^{-4} T (c) 6.28×10^{-4} T (d) 9.8×10^{-4} T

Ans. *(c)*

At the centre of current carrying, circular coil, the magnetic field is,

$$B = \frac{\mu_0 Ni}{2r}$$

where, N = number of turns in the coil
i = current flowing
r = radius of the coil

Given, $N = 1000$, $i = 0.1$ A, $r = 0.1$ m

Substituting the values, we have

$$B = \frac{4\pi \times 10^{-7} \times 1000 \times 0.1}{2 \times 0.1} = 2\pi \times 10^{-4} = 6.28 \times 10^{-4} \text{ T}$$

18 If a long hollow copper pipe carries a current, then magnetic field is produced **[CBSE AIPMT 1999]**

(a) inside the pipe only
(b) outside the pipe only
(c) both inside and outside the pipe
(d) no where

Ans. *(b)*

According to Ampere's circuital law,

$$\int B \cdot dl = \mu_0 i_{\text{enclosed}}$$

So, $\quad B(2\pi r) = \mu_0 \times 0 \quad [i_{\text{enclosed}} = 0]$

$\therefore \quad B = 0$

So, inside a hollow metallic (copper) pipe there is no current inside the Ampere's surface so, the magnetic field is zero. But for external points, the whole current behaves as if it were concentrated at the axis only, so outside

$$B_0 = \frac{\mu_0 i}{2\pi r}$$

Thus, the magnetic field is produced outside the pipe only.

19 A coil of one turn is made of a wire of certain length and then from the same length a coil of two turns is made. If the same current is passed in both the cases, then the ratio of the magnetic induction at their centres will be **[CBSE AIPMT 1998]**

(a) 2 : 1 (b) 1 : 4 (c) 4 : 1 (d) 1 : 2

Ans. *(b)*

Magnetic induction at the centre of current carrying coil of N turns carrying current is given by

$$B = \frac{\mu_0 Ni}{2r} \quad \text{...(i)}$$

Suppose the length of the wire be L.

Case I For coil of one turn, let radius be r_1.

$\therefore \quad L = 2\pi r_1 \times N$

or $\quad r_1 = \frac{L}{2\pi \times N} = \frac{L}{2\pi} \quad (\because N = 1)$

Case II For coil of two turns, let radius be r_2.

$\therefore \quad L = 2\pi r_2 \times N$

or $\quad r_2 = \frac{L}{2\pi \times N} = \frac{L}{2\pi \times 2} \quad (\because N = 2)$

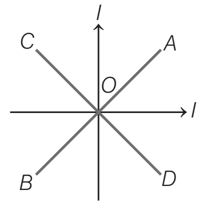
or $\quad r_2 = \frac{r_1}{2}$

By comparing two different cases from Eq. (i),

$$\frac{B_1}{B_2} = \frac{N_1}{r_1} \times \frac{r_2}{N_2} \text{ or } \frac{B_1}{B_2} = \frac{1 \times \frac{r_1}{2}}{r_1 \times 2}$$

$$\therefore \quad \frac{B_1}{B_2} = \frac{1}{4}$$

20 Two equal electric currents are flowing perpendicular to each other as shown in the figure. AB and CD are perpendicular to each other and symmetrically placed w.r.t the currents, where do we expect the resultant magnetic field to be zero ? **[CBSE AIPMT 1996]**



(a) On AB
(b) On CD
(c) On both AB and CD
(d) On both OD and BO

Ans. *(a)*

Applying right hand grip rule and considering AB, the direction of magnetic field due to one current is upwards and that due to other is downwards. Both the magnetic fields cancel out each other and the resultant magnetic field is zero.

Considering *CD* and applying right hand grip rule for the two currents, the direction of magnetic field is in the same direction in both the cases giving non-zero resultant.

21 The magnetic field **dB** due to a small element at a distance $\mathbf{r}$ and carrying current *i* is **[CBSE AIPMT 1996]**

(a) $\mathbf{dB} = \frac{\mu_0}{4\pi} i \left(\frac{\mathbf{dl} \times \mathbf{r}}{r}\right)$

(b) $\mathbf{dB} = \frac{\mu_0}{4\pi} i^2 \left(\frac{\mathbf{dl} \times \mathbf{r}}{r^2}\right)$

(c) $\mathbf{dB} = \frac{\mu_0}{4\pi} i^2 \left(\frac{\mathbf{dl} \times \mathbf{r}}{r}\right)$

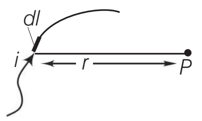
(d) $\mathbf{dB} = \frac{\mu_0}{4\pi} i \left(\frac{\mathbf{dl} \times \mathbf{r}}{r^3}\right)$

Ans. *(d)*

According to Biot-Savart law, the magnetic field induction **dB** (also called magnetic flux density) at a point *P* due to current element depends upon the factors as stated below.

(i) $dB \propto i$ (ii) $dB \propto dl$

(iii) $dB \propto \sin\theta$ (iv) $dB \propto \frac{1}{r^2}$



Combining these factors, we get magnitude of **dB**

i.e., $\mathbf{dB} = \frac{\mu_0}{4\pi} \cdot \frac{i\, dl \sin\theta}{r^2}$

In vector form,

$$\mathbf{dB} = \frac{\mu_0}{4\pi} i \frac{(\mathbf{dl} \times \mathbf{r})}{r^3} \quad \left[\frac{\mu_0}{4\pi} = 10^{-7}\ \text{T-m/A}\right]$$

22 At what distance from a long straight wire carrying a current of 12 A will the magnetic field be equal to $3 \times 10^{-5}\ \text{Wb/m}^2$? **[CBSE AIPMT 1995]**

(a) 8×10^{-2} m (b) 12×10^{-2} m

(c) 18×10^{-2} m (d) 24×10^{-2} m

Ans. *(a)*

Total magnetic field due to current carrying straight wire at any point *P* is given by

$$B = \frac{\mu_0 i}{4\pi r}(\sin\phi_1 + \sin\phi_2)$$

When the conductor is of infinite length and point *P* lies near the centre of conductor, then $\phi_1 = \phi_2 = 90°$

$\therefore$ $B = \frac{\mu_0 i}{4\pi r}(\sin 90° + \sin 90°)$

$= \frac{\mu_0}{4\pi} \cdot \frac{2i}{r} \Rightarrow r = \frac{\mu_0 i}{2\pi B}$

Here, current $(i) = 12$ A,

magnetic field $(B) = 3 \times 10^{-5}\ \text{Wb/m}^2$

$\therefore$ Perpendicular distance from wire to the point, $r = \frac{4\pi \times 10^{-7} \times 12}{2 \times \pi \times (3 \times 10^{-5})}$

$= 8 \times 10^{-2}$ m

23 A straight wire of diameter 0.5 mm carrying a current of 1 A is replaced by another wire of 1 mm diameter carrying same current. The strength of magnetic field far away is **[CBSE AIPMT 1995]**

(a) twice the earlier value

(b) same as the earlier value

(c) one-half of the earlier value

(d) one-quarter of the earlier value

Ans. *(b)*

Magnetic field due to straight wire is given by

$$B = \frac{\mu_0}{4\pi} \frac{2i}{r}$$

From above expression magnetic field due to current carrying conductor doesn't depends on the diameter of wire, it only depends on distance of wire from the point and current in the wire so, magnetic field reamaining same for both wires.

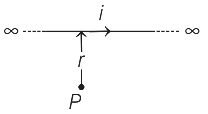
24 The magnetic field at a distance *r* from a long wire carrying current *i* is 0.4 T. The magnetic field at a distance 2*r* is **[CBSE AIPMT 1992]**

(a) 0.2 T (b) 0.8 T

(c) 0.1 T (d) 1.6 T

Ans. *(a)*

Magnetic field due to a long current carrying wire at distance *r* at point *P* is given by



$$B = \frac{\mu_0}{4\pi} \cdot \frac{2i}{r}$$

So, $B \propto \frac{1}{r}$

when *r* is doubled, the magnetic field becomes halved.

i.e., $B' = \frac{B}{2} \Rightarrow B' = \frac{0.4}{2} = 0.2$ T

25 The magnetic induction at a point *P* which is at the distance of 4 cm from a long current carrying wire is 10^{-3} T. The field of induction at a distance 12 cm from the current will be **[CBSE AIPMT 1990]**

(a) 3.33×10^{-4} T (b) 1.11×10^{-4} T

(c) 3×10^{-3} T (d) 9×10^{-3} T

Ans. *(a)*

Magnetic field due to a long straight conductor carrying current *i* at a distance *r* is given by

$$B = \frac{\mu_0}{4\pi} \frac{2i}{r}$$

Given, $r_1 = 4\,\text{cm}$, $r_2 = 12\,\text{cm}$.

As $B \propto \frac{1}{r}$

and distance becomes 3 times, field is reduced to its one-third value.

Hence, $B' = \frac{B}{3} = \frac{10^{-3}}{3} = 3.33 \times 10^{-4}$ T

26 Tesla is the unit of **[CBSE AIPMT 1988]**

(a) magnetic flux

(b) magnetic field

(c) magnetic induction

(d) magnetic moment

Ans. *(c)*

SI unit of magnetic induction is tesla (T). Magnetic field induction at a point is said to be one tesla if a charge of one coulomb while moving at right angle to a magnetic field, with a velocity of $1\ \text{ms}^{-1}$ experiences a force of 1 N, at that point.

$\therefore$ $1\text{T} = 1\text{NA}^{-1}\ \text{m}^{-1}$

TOPIC 2

Magnetic Force on Charged Particle in Magnetic Field

27 In the product

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$
$$= q\mathbf{v} \times (B\hat{\mathbf{i}} + B\hat{\mathbf{j}} + B_0\hat{\mathbf{k}})$$

For $q = 1$ and $\mathbf{v} = 2\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + 6\hat{\mathbf{k}}$ and

$\mathbf{F} = 4\hat{\mathbf{i}} - 20\hat{\mathbf{j}} + 12\hat{\mathbf{k}}$

What will be the complete expression for **B**? **[NEET 2021]**

(a) $-8\hat{\mathbf{i}}-8\hat{\mathbf{j}}-6\hat{\mathbf{k}}$

(b) $-6\hat{\mathbf{i}}-6\hat{\mathbf{j}}-8\hat{\mathbf{k}}$

(c) $8\hat{\mathbf{i}}+8\hat{\mathbf{j}}-6\hat{\mathbf{k}}$

(d) $6\hat{\mathbf{i}}+6\hat{\mathbf{j}}-8\hat{\mathbf{k}}$

Ans. *(b)*

Given, velocity, $\mathbf{v}=2\hat{\mathbf{i}}+4\hat{\mathbf{j}}+6\hat{\mathbf{k}}$

Force, $\mathbf{F}=4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}$

As we know,

$$\mathbf{F}=q(\mathbf{v}\times\mathbf{B})$$

Here, $q=1$ (given)

Substituting the values in the above equation, we get

$$4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}=(1)[(2\hat{\mathbf{i}}+4\hat{\mathbf{j}}+6\hat{\mathbf{k}})\times(B\hat{\mathbf{i}}+B\hat{\mathbf{j}}+B_0\hat{\mathbf{k}})]$$

$$4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}=\begin{pmatrix}\hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}}\\ 2 & 4 & 6\\ B & B & B_0\end{pmatrix}$$

$$\Rightarrow 4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}=\hat{\mathbf{i}}(4B_0-6B)-\hat{\mathbf{j}}(2B_0-6B)+\hat{\mathbf{k}}(2B-4B)$$

Comparing the LHS and RHS of the above equation, we get

$\hat{\mathbf{i}}$ terms:

$$4B_0-6B=4 \quad \text{...(i)}$$

$\hat{\mathbf{j}}$ terms:

$$2B_0-6B=20 \quad \text{...(ii)}$$

$\hat{\mathbf{k}}$ terms:

$$2B-4B=12$$

$$\Rightarrow \quad B=-6$$

Substituting the value of B in the Eq. (ii), we get

$$2B_0-6(-6)=20 \Rightarrow B_0=-8$$

Thus, the magnetic field vector,

$$B=-6\hat{\mathbf{i}}-6\hat{\mathbf{j}}-8\hat{\mathbf{k}}$$

28 Ionised hydrogen atoms and α-particles with same momenta enters perpendicular to a constant magnetic field, B. The ratio of their radii of their paths $r_H : r_\alpha$ will be **[NEET (National) 2019]**

(a) 1 : 2 (b) 4 : 1

(c) 1 : 4 (d) 2 : 1

Ans. *(d)*

The centripetal force required for circular motion is provided by magnetic force

$$\Rightarrow \frac{mv_p^2}{r}=Bqv_p$$

$$\Rightarrow r=\frac{mv_p}{qB} \quad \text{...(i)}$$

where, v_p = perpendicular velocity of particle and

q = charge on particle.

As, momentum, $p=mv_p$

$$\therefore \quad r=\frac{p}{qB} \quad \text{[from Eq. (i)]}$$

According to the question, moment of both particle is same.

$$\Rightarrow r\propto\frac{1}{q}$$

For ionised hydrogen atom, $q_H=e$ and for α-particle, $q_\alpha=2e$

$$\Rightarrow \frac{r_H}{r_\alpha}=\frac{q_\alpha}{q_H}=\frac{2e}{e}=\frac{2}{1} \text{ or } 2:1$$

29 An electron is moving in a circular path under the influence of a transverse magnetic field of 3.57×10^{-2} T. If the value of e/m is 1.76×10^{11} C/kg, the frequency of revolution of the electron is **[NEET 2016]**

(a) 1 GHz (b) 100 MHz

(c) 62.8 MHz (d) 6.28 MHz

Ans. *(a)*

As we know that, radius of a charged particle in a magnetic field B is given by

$$r=\frac{mv}{qB} \quad \text{...(i)}$$

where, r = charge on the particle

v = speed of the particle

$\therefore$ The time taken to complete the circle,

$$T=\frac{2\pi r}{v}\Rightarrow\frac{T}{2\pi}=\frac{m}{qB} \quad \text{[from Eq. (i)]}$$

$$\therefore \quad \omega=\frac{2\pi}{T}=\frac{qB}{m}$$

$$\because \quad q=e \text{ and } \frac{e}{m}=1.76\times10^{11}\text{ C/kg}$$

$$B=3.57\times10^{-2}\text{ T}$$

$$\Rightarrow \frac{2\pi}{T}=\frac{eB}{m}\, f=\frac{1}{2\pi}\frac{e}{m}B \quad \left(\because\frac{1}{T}=f\right)$$

$$=\frac{1}{2\pi}\times1.76\times10^{11}\times3.57\times10^{-2}$$

$$=1.0\times10^9\text{ Hz}=1\text{ GHz}$$

30 An alternating electric field of frequency ν, is applied across the dees (radius $=R$) of a cyclotron that is being used to accelerate protons (mass $=m$). The operating magnetic field (B) used in the cyclotron and the kinetic energy (K) of the proton beam, produced by it, are given by **[CBSE AIPMT 2012]**

(a) $B=\frac{m\nu}{e}$ and $K=2m\pi^2\nu^2R^2$

(b) $B=\frac{2\pi m\nu}{e}$ and $K=m^2\pi\nu R^2$

(c) $B=\frac{2\pi m\nu}{e}$ and $K=2m\pi^2\nu^2R^2$

(d) $B=\frac{m\nu}{e}$ and $K=m^2\pi\nu R^2$

Ans. *(c)*

Frequency, $\nu=\frac{eB}{2\pi m}$

$$\text{KE}=\frac{1}{2}m\nu^2 \quad\text{and}\quad \text{radius } R=\frac{m\nu}{eB}$$

Here, velocity, $v=\frac{\pi R}{T/2}=\frac{2\pi R}{T}=2\pi R\nu$

$$\therefore \quad \text{Radius, } R=\frac{m(2\pi R\nu)}{eB}$$

Magnetic field, $B=\frac{2\pi m\nu}{e}$

$$\text{Kinetic energy, } K=\frac{1}{2}m(2\pi R\nu)^2=2m\pi^2\nu^2R^2$$

31 A uniform electric field and a uniform magnetic field are acting along the same direction in a certain region. If an electron is projected in the region such that its velocity is pointed along the direction of fields, then the electron **[CBSE AIPMT 2011]**

(a) speed will decrease

(b) speed will increase

(c) ill turn towards left of direction of motion

(d) will turn towards right of direction of motion

Ans. *(a)*

Magnetic field (B) will not apply any force. Only electric field **E** will apply a force opposite to velocity of the electron hence, speed decreases.

32 A beam of cathode rays is subjected to crossed electric (E) and magnetic fields (B). The fields are adjusted such that the beam is not deflected. The specific charge of the cathode rays is given by **[CBSE AIPMT 2010]**

(a) $\frac{B^2}{2VE^2}$ (b) $\frac{2VB^2}{E^2}$

(c) $\frac{2VE^2}{B^2}$ (d) $\frac{E^2}{2VB^2}$

Ans. *(d)*

As the electron beam is not deflected, then $F_m = F_e$ or $Bev = Ee$

or $v = \dfrac{E}{B}$ ...(i)

As the electron moves from cathode to anode, its potential energy at the cathode appears as its kinetic energy at the anode. If V is the potential difference between the anode and cathode, then potential energy of the electron at cathode $= eV$. Also, kinetic energy of the electron at anode $= \frac{1}{2} mv^2$. According to law of conservation of energy,

$$\frac{1}{2} mv^2 = eV \text{ or } v = \sqrt{\frac{2eV}{m}} \quad ...(ii)$$

From Eqs. (i) and (ii), we have

$$\sqrt{\frac{2eV}{m}} = \frac{E}{B} \text{ or } \frac{e}{m} = \frac{E^2}{2VB^2}$$

33 The magnetic force acting on a charged particle of charge $-2\mu C$ in a magnetic field of 2 T acting in y-direction, when the particle velocity is $(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) \times 10^6 \text{ ms}^{-1}$ is

(a) 8 N in z-direction **[CBSE AIPMT 2009]**
(b) 4 N in z-direction
(c) 8 N in y-direction
(d) 8 N in z-direction

Ans. *(a)*

Magnetic Lorentz force, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

$$= -2 \times 10^{-6} \{(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) \times 10^6 \times 2\hat{\mathbf{j}}\}$$
$$= -2 \times 10^{-6} [2 \times 2 \times 10^6 \hat{\mathbf{k}}]$$
$$= 8 \text{ N along negative } Z\text{-axis}$$

34 A particle of mass m, charge q and kinetic energy T enters a transverse uniform magnetic field of induction $\mathbf{B}$. After 3 s, the kinetic energy of the particle will be **[CBSE AIPMT 2008]**

(a) $3T$ (b) $2T$
(c) T (d) $4T$

Ans. *(c)*

Magnetic field can never increase the energy of a charged particle so, its kinetic energy will remain same.

35 A beam of electrons passes undeflected through mutually perpendicular electric and magnetic fields. If the electric field is switched OFF and the same magnetic field is maintained, the electrons move **[CBSE AIPMT 2007]**

(a) in an elliptical orbit
(b) in a circular orbit
(c) along a parabolic path (d) along a straight line

Ans. *(b)*

If both electric and magnetic fields are present and are perpendicular to each other and the particle is moving perpendicular to both of them with $F_e = F_m$. In this situation $\mathbf{E} \neq 0$ and $\mathbf{B} \neq 0$ and $F_e + F_m = 0$.

But if electric field becomes zero, then only force due to magnetic field exists. And $\mathbf{E}$ is perpendicular to the $\mathbf{B}$ so the charge moves along a circle.

36 Under the influence of a uniform magnetic field a charged particle is moving in a circle of radius R with constant speed v. The time period of the motion **[CBSE AIPMT 2007]**

(a) depends on v and not on R
(b) depends on both R and v
(c) is independent of both R and v
(d) depends on R and not on v

Ans. *(c)*

When magnetic field is perpendicular to motion of charged particle, then particle performs circular motion.
So, centripetal force = magnetic force

i.e. $\dfrac{mv^2}{R} = Bqv$ or $R = \dfrac{mv}{Bq}$

Further, time period of the motion

$$T = \frac{2\pi R}{v} = \frac{2\pi\left(\frac{mv}{Bq}\right)}{v} \text{ or } T = \frac{2\pi m}{Bq}$$

37 When a charged particle moving with velocity $\mathbf{v}$ is subjected to a magnetic field of induction $\mathbf{B}$, the force on it is non-zero. This implies that **[CBSE AIPMT 2006]**

(a) angle between $\mathbf{v}$ and $\mathbf{B}$ is necessarily 90°
(b) angle between $\mathbf{v}$ and $\mathbf{B}$ can have any value other than 90°
(c) angle between $\mathbf{v}$ and $\mathbf{B}$ can have any value other than zero and 180°
(d) ngle between $\mathbf{v}$ and $\mathbf{B}$ is either zero or 180°

Ans. *(c)*

When a charged particle q is moving in a uniform magnetic field $\mathbf{B}$ with velocity $\mathbf{v}$ such that angle between $\mathbf{v}$ and $\mathbf{B}$ is θ, then the charge q experiences a force which is given by

$$F = q(\mathbf{v} \times \mathbf{B}) = qvB \sin\theta$$

If $\theta = 0°$ or $180°$, then $\sin\theta = 0$

$\therefore \quad F = qvB \sin\theta = 0$

Since, force on charged particle is non-zero, so angle between $\mathbf{v}$ and $\mathbf{B}$ can have any value other than 0° and 180°.

Note Force experienced by the charged particle is the Lorentz force.

38 An electron moves in a circular orbit with a uniform speed v. It produces a magnetic field B at the centre of the circle. The radius of the circle is proportional to **[CBSE AIPMT 2005]**

(a) $\dfrac{B}{v}$ (b) $\dfrac{v}{B}$ (c) $\sqrt{\dfrac{v}{B}}$ (d) $\sqrt{\dfrac{B}{v}}$

Ans. *(c)*

The time period of electron moving in a circular orbit,

$$T = \frac{\text{Circumference of circular path}}{\text{Speed}} = \frac{2\pi r}{v}$$

Now, equivalent current due to flow of electron is given by

$$i = \frac{q}{T} = \frac{e}{(2\pi r/v)} = \frac{ev}{2\pi r} \quad [q = e]$$

Magnetic field at centre of circle

$$B = \frac{\mu_0 i}{2r} = \frac{\mu_0 ev}{4\pi r^2} \quad \left(i = \frac{eV}{2\pi r}\right)$$

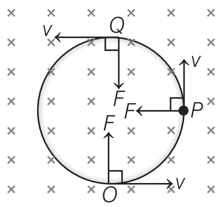
$$\Rightarrow \quad r \propto \sqrt{\frac{v}{B}}$$

39 A charged particle moves through a magnetic field in a direction perpendicular to it. Then, the **[CBSE AIPMT 2003]**

(a) acceleration remains unchanged
(b) velocity remains unchanged
(c) speed of the particle remains unchanged
(d) direction of the particle remains unchanged

Ans. *(c)*

When a charged particle moves through a perpendicular magnetic field, then a magnetic force acts on it which changes the direction of particle but does not alter the magnitude of its velocity (i.e., speed).



So, speed of charged particle remains unchanged i.e., of velocity magnitude remains constant.

Note If a charged particle moves at 45° to magnetic field, then path of the particle will be a helix whose circular part has radius according to relation, $r = \dfrac{mv \sin\theta}{qB}$.

40 A charge q moves in a region where electric field $\mathbf{E}$ and magnetic field $\mathbf{B}$ both exist, then the force on it is **[CBSE AIPMT 2002]**

(a) $q(\mathbf{v} \times \mathbf{B})$ (b) $q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$
(c) $q\mathbf{B} + q(\mathbf{B} \times \mathbf{v})$ (d) $q\mathbf{B} + q(\mathbf{E} \times \mathbf{v})$

Ans. *(b)*

If $\mathbf{E}$ is the electric field strength and $\mathbf{B}$ is the magnetic field strength and q is the charge on a particle, then electric force on the charge

$$\mathbf{F}_e = q\mathbf{E}$$

and magnetic force on the charge

$$\mathbf{F}_m = q(\mathbf{v} \times \mathbf{B})$$

The net force on the charge

$$\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$$

Alternative

According to Lorentz force if a charged particle is in both electric field ($\mathbf{E}$) and magnetic field ($\mathbf{B}$), force is given by

$$\mathbf{F} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

41 A charged particle of charge q and mass m enters perpendicularly in a magnetic field $\mathbf{B}$. Kinetic energy of the particle is E, then frequency of rotation is **[CBSE AIPMT 2001]**

(a) $\dfrac{qB}{m\pi}$ (b) $\dfrac{qB}{2\pi m}$ (c) $\dfrac{qBE}{2\pi m}$ (d) $\dfrac{qB}{2\pi E}$

Ans. *(b)*

Magnetic force = centripetal force

i.e. $qvB = \dfrac{mv^2}{r}$

or $qvB = mr\omega^2$ $(v = r\omega)$

or $\omega^2 = \dfrac{qvB}{mr} = \dfrac{q(r\omega)B}{mr}$

Angular frequency, $\omega = \dfrac{qB}{m}$

If ν is the frequency of rotation, then

$$\omega = 2\pi\nu \Rightarrow \nu = \frac{\omega}{2\pi}$$

$$\therefore \quad \nu = \frac{qB}{2\pi m}$$

Note In the resultant expression $\dfrac{q}{m}$ is known as specific charge. It is sometimes denoted by α. So, in terms of α, the above formula can be written as

$$\omega = B\alpha \quad \text{and} \quad \nu = \frac{B\alpha}{2\pi}$$

42 A positively charged particle moving due east enters a region of uniform magnetic field directed vertically upwards. The particle will **[CBSE AIPMT 1997]**

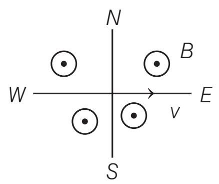
(a) continue to move due East
(b) move in a circular orbit with its speed unchanged
(c) move in a circular orbit with its speed increased
(d) gets deflected vertically upwards

Ans. *(b)*

According to the question, the magnetic field is perpendicular to the direction of motion of charged particle.

Force on the charged particle is given by $F = qvB \sin\theta = q(\mathbf{v} \times \mathbf{B})$

where, q = charge on charged particle
v = velocity of charged particle
B = magnetic field
θ = angle between $\mathbf{v}$ and $\mathbf{B} = 90°$



According to Fleming's left hand rule, the force acts perpendicular to the velocity of the particle. This force in magnitude remains same but the direction of charged particle goes on changing and always perpendicular to the velocity of the particle, so the particle will move in a circular orbit. The magnetic force does not make any change in its kinetic energy which implies that speed is constant or unchanged.

43 A beam of electrons is moving with constant velocity in a region having simultaneous perpendicular electric and magnetic fields of strength 20 Vm^{-1} and 0.5 T, respectively at right angles to the direction of motion of the electrons. Then, the velocity of electrons must be **[CBSE AIPMT 1996]**

(a) 8 m/s (b) 20 m/s
(c) 40 m/s (d) $\dfrac{1}{40}$ m/s

Ans. *(c)*

According to Lorentz force,

$$\mathbf{F}_{net} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

When $\mathbf{v}$, $\mathbf{E}$ and $\mathbf{B}$ are mutually perpendicular to each other, in this situation if $\mathbf{E}$ and $\mathbf{B}$ are such that $\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = 0$, then acceleration in the particle, $\mathbf{a} = \dfrac{\mathbf{F}}{m} = 0$. It means particle will pass undeflected.

Here, $F_e = F_m$

So, $qE = qvB$ $\quad \begin{bmatrix} F_e = qE \\ F_M = qvB \end{bmatrix}$

or $v = \dfrac{E}{B}$

Given, $E = 20\ Vm^{-1}$
$B = 0.5$ T

$\therefore$ $v = \dfrac{20}{0.5} = 40$ m/s

44 A 10 eV electron is circulating in a plane at right angle to a uniform field of magnetic induction 10^{-4} Wb/m^2 (= 1.0 gauss). The orbital radius of the electron is **[CBSE AIPMT 1996]**

(a) 12 cm (b) 16 cm
(c) 11 cm (d) 18 cm

Ans. *(c)*

If charged particle is moving perpendicular to the direction of $\mathbf{B}$, it experiences a maximum force which acts perpendicular to the direction of $\mathbf{B}$ as well as $\mathbf{v}$. Hence, this force will provide the required centripetal force and the charged particle will describe a circular path in the magnetic field of radius r and is given by

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

Now, KE of electron = 10 eV

$\Rightarrow$ $\dfrac{1}{2}mv^2 = 10$ eV

$\therefore$ $\dfrac{1}{2} \times (9.1 \times 10^{-31}) v^2 = 10 \times 1.6 \times 10^{-19}$

$\Rightarrow$ $v^2 = \dfrac{2 \times 10 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}$

$\Rightarrow$ $v^2 = 3.52 \times 10^{12}$

or $v = 1.88 \times 10^6$ m

Now, radius of circular path,

$$r = \frac{mv}{qB} = \frac{9.1 \times 10^{-31} \times 1.88 \times 10^{6}}{1.6 \times 10^{-19} \times 10^{-4}} = 11 \text{ cm}$$

45 An electron enters a region where magnetic field (B) and electric field (E) are mutually perpendicular, then **[CBSE AIPMT 1994]**

(a) it will always move in the direction of B

(b) it will always move in the direction of E

(c) it always possess circular motion

(d) it can go undeflected also

Ans. *(d)*

The force experienced by a charged particle moving in space where both electric and magnetic fields exist is called Lorentz force.

Due to both electric and magnetic fields, the total force experienced by the charged particle will be given by,

$$\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$$
$$= q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

When $\mathbf{v}$, $\mathbf{E}$ and $\mathbf{B}$ are mutually perpendicular to each other. In this situation, if $\mathbf{E}$ and $\mathbf{B}$ are such that $\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = 0$, then acceleration in the particle, $\mathbf{a} = \frac{\mathbf{F}}{m} = 0$.

It means particle will go undeflected.

46 A charge moving with velocity v in x-direction is subjected to a field of magnetic induction in negative x-direction. As a result, the charge will **[CBSE AIPMT 1993]**

(a) remain unaffected

(b) start moving in a circular y-z plane

(c) retard along x-axis

(d) move along a helical path around x-axis

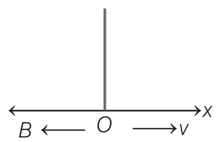
Ans. *(a)*

Force on a charged particle in the magnetic field is

$$|\mathbf{F}| = q\,|\mathbf{v} \times \mathbf{B}| \quad \text{or} \quad F = qvB \sin\theta$$

when angle between velocity v and magnetic induction B is 180° or 0°, then

$$F = qvB \sin 180° = 0$$
$$[\text{as } \sin 180° \text{ or } \sin 0° = 0]$$



So, the charged particle remains unaffected.

47 A uniform magnetic field acts right angles to the direction of motion of electrons. As a result, the electron moves in a circular path of radius 2 cm. If the speed of electrons is doubled, then the radius of the circular path will be **[CBSE AIPMT 1991]**

(a) 2.0 cm (b) 0.5 cm

(c) 4.0 cm (d) 1.0 cm

Ans. *(c)*

The force F on the charged particle due to external magnetic field provides the required centripetal force $(= mv^2/r)$ necessary for motion along the circular path of radius r.

So, $qvB = \frac{mv^2}{r}$ or $r = \frac{mv}{qB}$

$\therefore \quad r \propto v \quad \left[\frac{m}{qB} = \text{constant}\right]$

As v is doubled, the radius also becomes double. Hence, radius $= 2 \times 2 = 4$ cm.

48 A deutron of kinetic energy 50 keV is describing a circular orbit of radius 0.5 m in a plane perpendicular to magnetic field B. The kinetic energy of the proton that describes a circular orbit of radius 0.5 m in the same plane with the same magnetic field B is **[CBSE AIPMT 1991]**

(a) 25 keV (b) 50 keV

(c) 200 keV (d) 100 keV

Ans. *(d)*

When charged particle move on circular path, the force F on the charged particle due to magnetic field provides the required centripetal force $(= mv^2/r)$ necessary for motion along the circular path.

So, $\frac{mv^2}{r} = qvB$

where, m = mass of particle
v = velocity of particle
q = charge on particle
B = external magnetic field
r = radius of circular path

$$mv^2 = Bqvr$$

$\therefore$ Kinetic energy $E_K = \frac{1}{2}mv^2 = \frac{1}{2}Bqvr$

$$= Bq \cdot \frac{r}{2}\frac{Bqr}{m} = \frac{B^2q^2r^2}{2m}$$

For deutron, $E_1 = \frac{B^2q^2r^2}{2 \times (2m)}$ (mass $= 2m$)

For proton, $E_2 = \frac{B^2q^2r^2}{2m}$ (mass $= m$)

$\therefore \quad \frac{E_1}{E_2} = \frac{1}{2} \Rightarrow \frac{50 \text{ keV}}{E_2} = \frac{1}{2}$

or $\quad E_2 = 100$ keV

TOPIC 3

Force and Torque on Current Carrying Conductor

49 A metallic rod of mass per unit length 0.5 kg m^{-1} is lying horizontally on a smooth inclined plane which makes an angle of 30° with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25 T is acting on it in the vertical direction. The current flowing in the rod to keep it stationary is **[NEET 2018]**

(a) 14.76 A (b) 5.98 A

(c) 7.14 A (d) 11.32 A

Ans. *(d)*

Key Concept *Firstly, make a free body diagram of the system and indicate the magnitude and direction of all the forces acting on the body. Then, choose any two mutually perpendicular axes say X and Y in the plane of forces in case of coplanar forces.*

As, the system is in equilibrium,

$$\Sigma F_x = 0$$

or $\quad mg \sin\theta = F \cos\theta \quad$ ...(i)

where, F is the magnitude of force experienced by the rod when placed in a magnetic field and current I is flowing through it.

But the force experienced by the given rod in a uniform magnetic field is

$$F = ILB$$

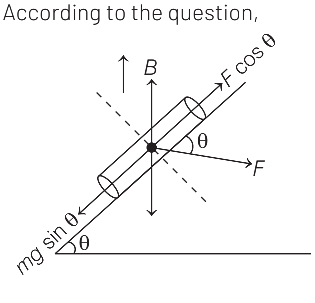
$\therefore$ Eq. (i) becomes,

$$mg \sin\theta = ILB \cos\theta$$

$\Rightarrow \quad I = \frac{mg \sin\theta}{LB \cos\theta} = \frac{mg}{LB}\tan\theta$

$I = \left(\frac{m}{L}\right)\frac{g \tan\theta}{B} \quad$ ...(ii)

According to the question,



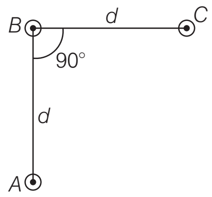
Here, $\frac{m}{L} = 0.5 \text{ kg m}^{-1}$, $g = 9.8 \text{ ms}^{-2}$,

$\theta = 30°$, $B = 0.25$ T

Substituting the given values in Eq. (ii), we get

$$I = \frac{0.5 \times 9.8}{0.25} \tan 30°$$
$$= \frac{0.5 \times 9.8}{0.25} \times \frac{1}{\sqrt{3}}$$
$$= 11.32 \text{ A}$$

50 An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current *I* along the same direction is shown in figure. Magnitude of force per unit length on the middle wire *B* is given by **[NEET 2017]**

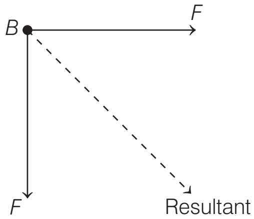


(a) $\frac{\mu_0 i^2}{2\pi d}$ (b) $\frac{2\mu_0 i^2}{\pi d}$

(c) $\frac{\sqrt{2}\mu_0 i^2}{\pi d}$ (d) $\frac{\mu_0 i^2}{\sqrt{2}\, \pi d}$

Ans. *(d)*

As force on wire *B* due to *A* and *C* are attractive, so we have following condition



$$F = \frac{\mu_0 I^2}{2\pi d}$$

Resultant force on *B*

$$= \sqrt{F_1^2 + F_2^2} = \sqrt{2}\, F = \sqrt{2} \times \frac{\mu_0 I^2}{2\pi d} = \frac{\mu_0 I^2}{\sqrt{2}\pi d}$$

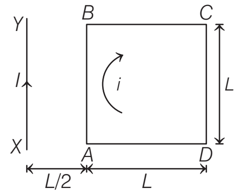
51 A square loop *ABCD* carrying a current *i*, is placed near and coplanar with a long straight conductor *XY* carrying a current *I*, the net force on the loop will be **[NEET 2016]**

(a) $\frac{\mu_0 Ii}{2\pi}$ (b) $\frac{2\mu_0 IiL}{3\pi}$

(c) $\frac{\mu_0 IiL}{2\pi}$ (d) $\frac{2\mu_0 Ii}{3\pi}$

Ans. *(d)*

Consider the given figure,



From the above figure, it can be seen that the direction of currents in a long straight conductor *XY* and arm *AB* of a square loop *ABCD* are in the same direction. So, there exist a force of attraction between the two, which will be experienced by F_{BA} as

$$F_{BA} = \frac{\mu_0 IiL}{2\pi\left(\frac{L}{2}\right)}$$

In the case of *XY* and arm *CD*, the direction of currents are in the opposite direction. So, there exist a force of repulsion which will be experienced by *CD* as $F_{CD} = \frac{\mu_0 IiL}{2\pi\left(\frac{3L}{2}\right)}$

Therefore, net force on the loop *ABCD* will be

$$F_{\text{loop}} = F_{BA} - F_{CD} = \frac{\mu_0 IiL}{2\pi}\left[\frac{1}{(L/2)} - \frac{1}{(3L/2)}\right]$$
$$F_{\text{loop}} = \frac{2\mu_0 iI}{3\pi}$$

52 A rectangular coil of length 0.12 m and width 0.1 m having 50 turns of wire is suspended vertically in a uniform magnetic field of strength 0.2 Wb/m^2. The coil carries a current of 2 A. If the plane of the coil is inclined at an angle of 30° with the direction of the field, the torque required to keep the coil in stable equilibrium will be **[CBSE AIPMT 2015]**

(a) 0.15 Nm (b) 0.20 Nm

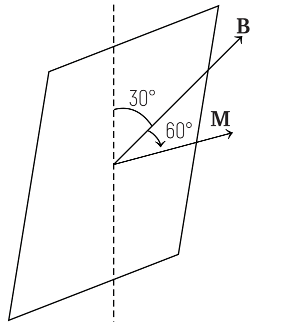
(c) 0.24 Nm (d) 0.12 Nm

Ans. *(b)*

Given, $N = 50$

$B = 0.2 \text{ Wb/m}^2$, $I = 2$ A

$\theta = 60°$, $A = 0.12 \times 0.1 = 0.012 \text{ m}^2$



Thus, torque required to keep the coil in stable equilibrium, i.e.

$$\tau = NIAB \sin\theta$$
$$= 50 \times 2 \times 0.012 \times 0.2 \times \sin 60°$$
$$= 50 \times 2 \times 0.12 \times 0.2 \times \frac{\sqrt{3}}{2} = 0.20$$

Nm

53 A current loop in a magnetic field **[NEET 2013]**

(a) experiences a torque whether the field is uniform or non-uniform in all orientations

(b) can be in equilibrium in one orientation

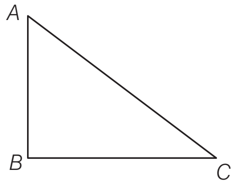
(c) can be in equilibrium in two orientations, both the equilibrium states are unstable

(d) can be in equilibrium in two orientations, one stable while other is unstable

Ans. *(d)*

For parallel, **M** is stable and for antiparallel, it is unstable.

54. A current carrying closed loop in the form of a right angled isosceles Δ *ABC* is placed in a uniform magnetic field acting along *AB*. If the magnetic force on the arm *BC* is **F**, the force on the arm *AC* is **[CBSE AIPMT 2011]**



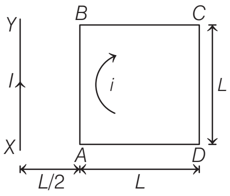
(a) $-\mathbf{F}$ (b) $\mathbf{F}$

(c) $\sqrt{2}$ F (d) $-\sqrt{2}$ F

Ans. *(a)*

Force on *AB* is given by, $\mathbf{F}_{AB} = 0$

According to the question,



$$\mathbf{F}_{AB} = 0$$

$$\Rightarrow \quad \mathbf{F}_{AB} + \mathbf{F}_{BC} + \mathbf{F}_{CA} = 0$$

$$\mathbf{F}_{BC} + \mathbf{F}_{CA} = 0$$

$$\mathbf{F}_{CA} = -\mathbf{F}_{BC} = -\mathbf{F}$$

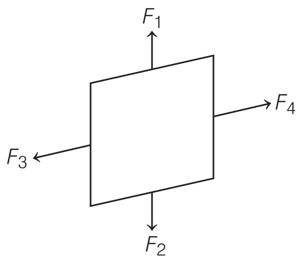
55 A square current carrying loop is suspended in a uniform magnetic field acting in the plane of the loop. If the force on one arm of the loop is **F**, the net force on the remaining three arms of the loop is **[CBSE AIPMT 2010]**

(a) 3F (b) –F (c) –3F (d) F

Ans. *(b)*

When a current carrying loop is placed in a magnetic field, the coil experiences a torque given by $\tau = NBi\,A\sin\theta$. Torque is maximum when $\theta = 90°$, i.e., the plane of the coil is parallel to the field.

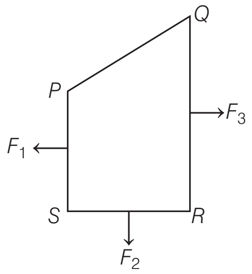
$$\tau_{max} = NBiA$$



Forces $\mathbf{F}_1$ and $\mathbf{F}_2$ acting on the coil are equal in magnitude and opposite in direction. As the forces $\mathbf{F}_1$ and $\mathbf{F}_2$ have the same line of action, their resultant effect on the coil is zero.

The two forces $\mathbf{F}_3$ and $\mathbf{F}_4$ are equal in magnitude and opposite in direction. As the two forces have different lines of action, they constitute a torque. Thus, if the force on one arc of the loop is **F**, the net force on the remaining three arms of the loop is –**F**.

56 A closed loop *PQRS* carrying a current is placed in a uniform magnetic field. If the magnetic forces on segments *PS*, *SR* and *RQ* are F_1, F_2 and F_3 respectively and are in the plane of the paper and along the directions shown in figure, the force on the segment *QP* is **[CBSE AIPMT 2008]**



(a) $F_3 - F_1 - F_2$

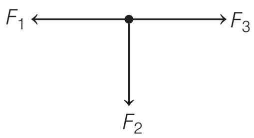
(b) $\sqrt{(F_3 - F_1)^2 + F_2^2}$

(c) $\sqrt{(F_3 - F_1)^2 - F_2^2}$

(d) $F_3 - F_1 + F_2$

Ans. *(b)*

As the net force on closed loop is equal to zero. So, force on *QP* will be equal and opposite to sum of forces on other 3 sides.



So, from vector laws,

$$F_{QP} = \sqrt{(F_3 - F_1)^2 + F_2^2}$$

57 A coil in the shape of an equilateral triangle of side *l* is suspended between the pole pieces of a permanent magnet such that **F** is in plane of the coil. If due to a current *i* in the triangle a torque τ acts on it, the side *l* of the triangle is **[CBSE AIPMT 2005]**

(a) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{Bi}\right)^{1/2}$ (b) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{Bi}\right)$

(c) $2\left(\frac{\tau}{\sqrt{3}Bi}\right)^{1/2}$ (d) $\frac{1}{\sqrt{3}}\frac{\tau}{Bi}$

Ans. *(c)*

Torque acting on equilateral triangle in a magnetic field **B** is

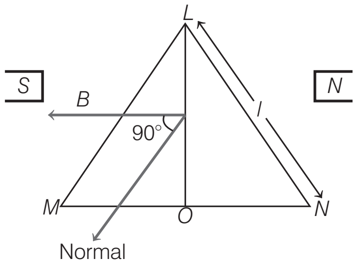
$$\tau = \mathbf{M} \times \mathbf{B},\ \tau = i\,AB\sin\theta \qquad [iA = \mathbf{M}]$$

Area of ΔLMN

$$A = \frac{\sqrt{3}}{4}l^2 \text{ and } \theta = 90°$$

$[l = \text{sides of triangle}]$

Substituting the given values in the expression for torque, we have



$$\tau = i \times \frac{\sqrt{3}}{4}l^2\ B\sin 90° = \frac{\sqrt{3}}{4}il^2\ B$$

$(\because \sin 90° = 1)$

Hence, $\quad l = 2\left(\frac{\tau}{\sqrt{3}\,Bi}\right)^{1/2}$

58 Current is flowing in a coil of area *A* and number of turns *N*, then magnetic moment of the coil, *M* is equal to **[CBSE AIPMT 2001]**

(a) NiA (b) $\frac{Ni}{A}$

(c) $\frac{Ni}{\sqrt{A}}$ (d) N^2Ai

Ans. *(a)*

If there are *N* turns in a coil, *i* is the current flowing and *A* is the area of the coil, then magnetic dipole moment or simply magnetic moment of the coil is

$$M = NiA$$

As we know when velocity of charged particle entering to magnetic field region is perpendicular to **B**, then it follows circular path.

59 Two long parallel wires are at a distance of 1 m. Both of them carry 1A of current. The force of attraction per unit length between the two wires is **[CBSE AIPMT 1998]**

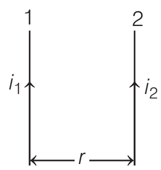
(a) 2×10^{-7} N/m (b) 2×10^{-8} N/m

(c) 5×10^{-8} N/m (d) 10^{-7} N/m

Ans. *(a)*

Magnetic force between parallel wires per unit length is given by

$$\frac{F}{l} = \frac{\mu_0}{2\pi} \times \frac{i_1 i_2}{r}$$



where, i_1 and i_2 are the currents in wires 1 and 2 respectively and *r* is the distance between them. Since, it is given that between two wires there is a force of attraction, so, the direction of currents in both will be the same.

Given, $i_1 = i_2 = 1\,\text{A}$, $r = 1\,\text{m}$,

$\mu_0 = 4\pi \times 10^{-7}$ T-m/A

$\therefore \quad \frac{F}{l} = \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{1\times 1}{1} = 2\times 10^{-7}$ N/m

Note When current is in same direction in both the wires there will be attraction and if current in opposite direction there is repulsion.

60 A straight wire of length 0.5 m and carrying a current of 1.2 A is placed in uniform magnetic field of induction 2 T. The magnetic field is perpendicular to the length of the wire. The force on the wire is **[CBSE AIPMT 1992]**

(a) 2.4 N (b) 1.2 N (c) 3.0 N (d) 2.0 N

Ans. ***(b)***

Force on a current carrying conductor placed in a magnetic field is given by

$F = i(\mathbf{l} \times \mathbf{B}) = il\,B\sin\theta$

where, θ = angle between current elements and magnetic field.

If linear conductor carrying current is placed perpendicular to the direction of magnetic field, ($\theta = 90°$) it will experience maximum force.

i.e., $F_{\max} = ilB$

Given, $i = 1.2$ A, $l = 0.5$ m and $B = 2$ T

$\therefore \quad F = 2 \times 1.2 \times 0.5 = 1.2$ N

61 A current carrying coil is subjected to a uniform magnetic field. The coil will orient so that its plane becomes **[CBSE AIPMT 1988]**

(a) inclined at 45° to the magnetic field
(b) inclined at any arbitrary angle to the magnetic field
(c) parallel to the magnetic field
(d) perpendicular to magnetic field

Ans. ***(c)***

The coil must orient so that its magnetic moment becomes parallel to the field. So that the magnetic force on the coil is zero.

TOPIC 4
Moving Coil Galvanometer

62 Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity (angular deflection per unit voltage applied) is 20 div/V. The resistance of the galvanometer is **[NEET 2018]**

(a) 250 Ω (b) 25 Ω
(c) 40 Ω (d) 500 Ω

Ans. ***(a)***

Current sensitivity of a moving coil galvanometer is the deflection (θ) per unit current (I) flowing through it, i.e.

$$I_S = \frac{\theta}{I} = \frac{NAB}{k} \quad \text{...(i)}$$

where, N = number of turns in the coil,
A = Area of each turn of coil,
B = magnetic field
k = restoring torque per unit twist of the fibre strip.

Similarly, voltage sensitivity is the deflection per unit voltage, i.e.

$$V_S = \frac{\theta}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V} = \frac{NAB}{kR_G} \quad \text{...(ii)}$$

where, R_G is the resistance of the galvanometer.

From Eqs. (i) and (ii), we get

$$R_G = \frac{I_S}{V_S} \quad \text{...(iii)}$$

Here, $I_S = 5$ div/mA $= 5 \times 10^{-3}$ div/A

and $V_S = 20$ div/V

Substituting the given values in Eq. (iii), we get

$$R_G = \frac{5\times 10^3}{20} = 250$$

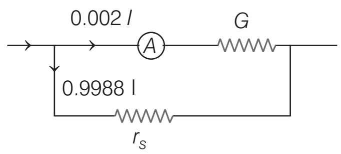
$\therefore$ The resistance of the galvanometer is 250 Ω.

63 In an ammeter 0.2% of main current passes through the galvanometer. If resistance of galvanometer is G, the resistance of ammeter will be **[CBSE AIPMT 2014]**

(a) $\frac{1}{499}G$ (b) $\frac{499}{500}G$
(c) $\frac{1}{500}G$ (d) $\frac{500}{499}G$

Ans. ***(c)***

For ammeter,



$0.002\text{I} \times G = 0.998\text{I} \times r_s$

$r_s = \frac{0.002}{0.998}G$

$\Rightarrow \quad r_s = 0.002004\,G = \frac{1}{499} \times G$

Equivalent resistance of ammeter,

$$\frac{1}{R} = \frac{1}{G} + \frac{1}{r_s}$$

$$\therefore \quad \frac{1}{R} = \frac{1}{G} + \frac{1}{G/499} \Rightarrow R = \frac{G}{500}$$

64 A millivoltmeter of 25 mV range is to be converted into an ammeter of 25 A range. The value (in ohm) of necessary shunt will be **[CBSE AIPMT 2012]**

(a) 0.001 (b) 0.01
(c) 1 (d) 0.05

Ans. ***(a)***

The full scale deflection current

$$i_g = \frac{25\,\text{mV}}{G}\,\text{A}$$

where, G is the resistance of the meter.

The value of shunt required for converting it into ammeter of range 25 A

is $S = \frac{i_g G}{i - i_g} \Rightarrow S = i_g \frac{G}{i}$ (as $i >> i_g$)

So that,

$$S \approx \frac{25\,mV}{G}\cdot\frac{G}{i} = \frac{25\,mV}{25} = 0.001\,\Omega$$

65 The resistance of an ammeter is 13 Ω and its scale is graduated for a current upto 100 A. After an additional shunt has been connected to this ammeter it becomes possible to measure currents upto 750 A by this meter. The value of shunt resistance is **[CBSE AIPMT 2007]**

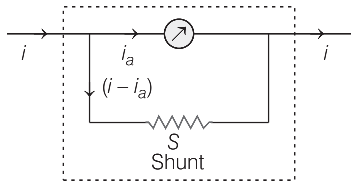
(a) 20 Ω (b) 2 Ω (c) 0.2 Ω (d) 2 kΩ

Ans. ***(b)***

Let i_a be the current flowing through ammeter and i be the total current. So, a current $i - i_a$ will flow through shunt resistance.

Potential difference across ammeter and shunt resistance is same.

i.e. $\quad i_a \times R = (i - i_a) \times S$



High reading ammeter

or $\quad S = \frac{i_a R}{i - i_a} \quad \text{...(i)}$

Given, $i_a = 100\,A, i = 750\,A, R = 13\,\Omega$

Hence, $S = \frac{100 \times 13}{750 - 100} = 2\,\Omega$