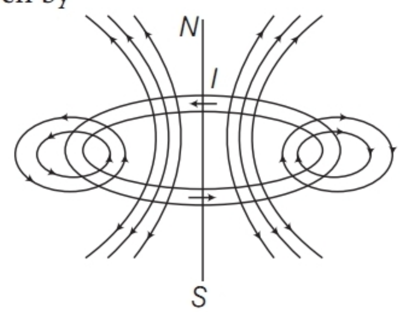
Explanations

1. Magnetic field lines due to a current carrying loop are given by



(1)

2. Refer to Sol. 4 on pages 121 and 122. **(2)**

3. To calculate net magnetic field at point O, first of all, calculate the magnetic field at point O due to both coils separately, with direction. By vector addition of these two magnetic fields, net magnetic field can be obtained.

Magnetic field at O due to two rings will be in same direction ($Q \to P$, along the axis) and of equal magnitude. **(1/2)**

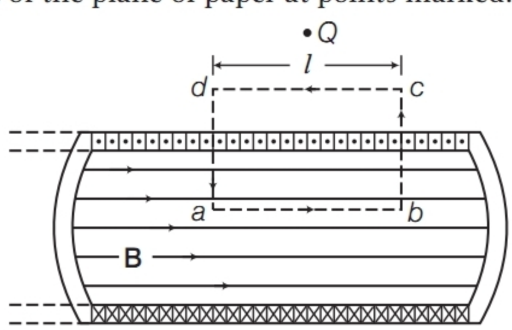
$$B = B_1 + B_2 \text{ but } B_2 = B_1$$

$$\Rightarrow \quad B = 2B_1 = 2\left[\frac{\mu_0 Ir^2}{2(r^2 + r^2)^{3/2}}\right]$$ **(1/2)**

$$B = \frac{\mu_0 Ir^2}{(2r^2)^{3/2}} = \frac{\mu_0 Ir^2}{2^{3/2} r^3}$$ **(1/2)**

$$B = \frac{\mu_0 I}{2^{3/2} r}$$ **(1/2)**

4. Figure shows the longitudinal sectional view of long current carrying solenoid. The current comes out of the plane of paper at points marked.



Let $\mathbf{B}$ be the magnetic field at any point inside the solenoid.

Considering the rectangular closed path *abcda*.
Applying Ampere's circuital law over loop *abcda*.

$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \times$ (Total current passing through loop *abcda*)

$$\int_a^b \mathbf{B} \cdot d\mathbf{l} + \int_b^c \mathbf{B} \cdot d\mathbf{l} + \int_c^d \mathbf{B} \cdot d\mathbf{l} + \int_d^a \mathbf{B} \cdot d\mathbf{l} = \mu_0 \left(\frac{N}{L} lI\right)$$

(1)

where, $\frac{N}{L}$ = number of turns per unit length and $ab = cd = l$ = length of rectangle.

$$\int_a^b Bdl \cos 0° + \int_b^c Bdl \cos 90° + 0 + \int_d^a Bdl \cos 90° = \mu_0 \left(\frac{N}{L}\right) lI$$

$$B\int_a^b dl = \mu_0 \left(\frac{N}{L}\right) lI$$

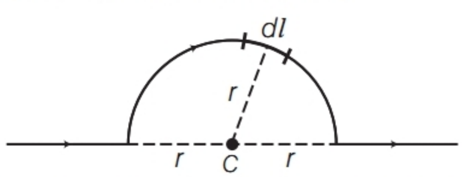
$$\Rightarrow \quad Bl = \mu_0 \left(\frac{N}{L}\right) lI$$

$$\Rightarrow \quad B = \mu_0 (N/L) I$$

or $\quad B = \mu_0 nI$

where, n = number of turns per unit length.
This is the required expression for magnetic field inside the long current carrying solenoid. **(1)**

5. When a straight wire is bent into semi-circular loop, then there are two parts which can produce the magnetic field at the centre, one is circular part and other is straight part due to which magnetic field is zero i.e. net magnetic field at C is only due to semi-circular loop.



$\because$ Length L is bent into semi-circular loop.
Length of wire = Circumference of semi-circular wire

$$\Rightarrow \quad L = \pi r \Rightarrow r = \frac{L}{\pi} \qquad \ldots(\text{i})$$

Considering a small element dl on current loop. The magnetic field dB due to small current element Idl at centre C. Using Biot-Savart's law, we have

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl \sin 90°}{r^2} \quad [\because Idl \perp \mathbf{r}, \therefore \theta = 90°]$$ **(1/2)**

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl}{r^2}$$

$\therefore$ Net magnetic field at C due to semi-circular loop,

$$B = \int_{\text{semicircle}} \frac{\mu_0}{4\pi} \frac{Idl}{r^2}$$

$$\Rightarrow \quad B = \frac{\mu_0}{4\pi} \frac{I}{r^2} \int_{\text{semicircle}} dl$$

(1/2)

$$B = \frac{\mu_0}{4\pi} \cdot \frac{I}{r^2} L$$

But, $r = L/\pi$

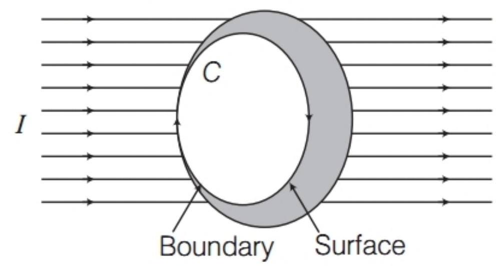
$$B = \frac{\mu_0}{4\pi} \cdot \frac{IL}{(L/\pi)^2} = \frac{\mu_0}{4\pi} \times \frac{IL}{L^2} \times \pi^2$$

$$\Rightarrow \quad B = \frac{\mu_0 I\pi}{4L}$$

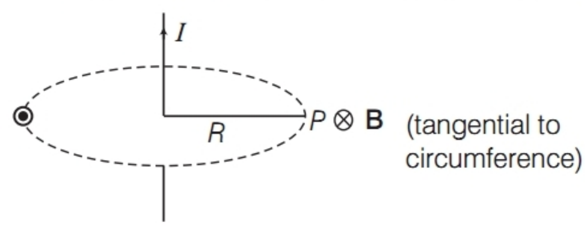
This is the required expression. **(1)**

6. Ampere's circuital law As, Ampere's circuital law states that the line integral of magnetic field $\mathbf{B}$ around any closed loop is equal to μ_0 times the total current threading through the loop. **(1)**

i.e. $\quad \oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I$



Derivation To explain the Ampere's circuital law consider an infinitely long conductor wire carrying a steady current I as shown in the figure.



In order to determine the magnetic field at point P which is situated at a distance R from the centre of the circular loop around the conductor wire, $\mathbf{B}$ (magnetic field) is tangential to circumference of the loop.

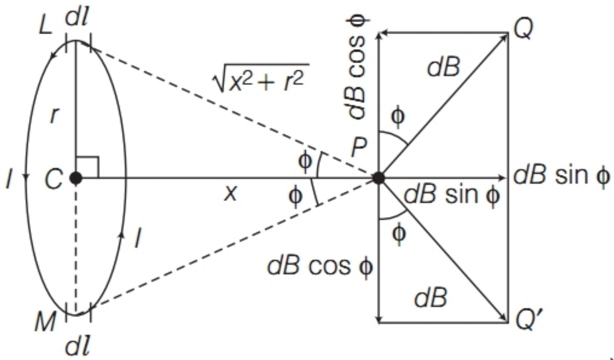
Now, $\oint \mathbf{B} \cdot d\mathbf{l} = \int B\, dl = B\, 2\pi R = \mu_0 I$

$\Rightarrow \quad B = \mu_0 I / 2\pi R$ [from Ampere's circuital law]

The direction of magnetic field will be determined by right hand rule. **(1)**

7. (i) Refer to text on pages 117 and 118 (Biot-Savart's law). **(1)**

(ii) Let us consider a circular loop of radius r with centre C. Let the plane of the coil be perpendicular to the plane of the paper and current I be flowing in the direction as shown in the figure. Suppose P is any point on the axis at a direction x from the centre.



Now, consider a current element Idl on top (L) where current comes out of paper normally, whereas at bottom (M) enters into the plane of paper normally.

$\because \quad LP \perp Idl$

Also, $\quad MP \perp Idl$

$\because \quad LP = MP = \sqrt{x^2 + r^2}$

The magnetic field at point P due to current element Idl. According to Biot-Savart's law,

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl \sin 90^\circ}{(x^2 + r^2)}$$

where, r = radius of circular loop,

x = distance of point P from centre along the axis.

The direction of dB is perpendicular to LP and along PQ, where $PQ \perp LP$. Similarly, the same magnitude of magnetic field is obtained due to current element Idl at the bottom and direction is along PQ', where $PQ' \perp MP$.

Now, resolving dB due to current element at L and M, $dB \cos\phi$ components balance each other and net magnetic field is given by

$$B = \oint dB \sin\phi = \oint \frac{\mu_0}{4\pi}\left(\frac{Idl}{x^2 + r^2}\right) \cdot \frac{a}{\sqrt{x^2 + r^2}}$$

$$\left[\because \text{In } \Delta PCL,\ \sin\phi = \frac{a}{\sqrt{x^2 + r^2}}\right]$$

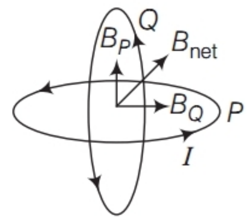
$$= \frac{\mu_0}{4\pi} \frac{Ia}{(x^2 + r^2)^{3/2}} \oint dl = \frac{\mu_0}{4\pi} \frac{Ia}{(x^2 + r^2)^{3/2}} (2\pi r)$$

or $B = \dfrac{\mu_0 I a^2}{2(x^2 + r^2)^{3/2}}$

For N turns, $B = \dfrac{\mu_0 N I r^2}{2(x^2 + r^2)^{3/2}}$ T **(1)**

8. (i) Refer to text on pages 117 and 118. (Biot-Savart's law). **(1)**

(ii)



Magnitude of magnetic field due to circular wire P,

$$B_P = \frac{\mu_0}{4\pi} \times \frac{2\pi I_1}{R} \text{ (along vertically upwards)}$$

$$= \mu_0 I_1 / 2R$$

Magnitude of magnetic field due to circular wire Q,

$$B_Q = \mu_0 / 4\pi \times 2\pi I_2 / R$$

(along horizontal towards left)

$$= \mu_0 I_2 / 2R$$ **(1)**

Net magnitude of magnetic field at the common centre of the two coils,

$$B = \sqrt{B_P^2 + B_Q^2}$$

$$\Rightarrow B = \sqrt{\left(\frac{\mu_0 I_1}{2R}\right)^2 + \left(\frac{\mu_0 I_2}{2R}\right)^2}$$

$$B = \sqrt{\left(\frac{\mu_0}{2R}\right)^2 (I_1^2 + I_2^2)} \Rightarrow B = \frac{\mu_0}{2R}\sqrt{I_1^2 + I_2^2}$$

$$B = \frac{4\pi \times 10^{-7}}{2 \times R}\sqrt{(1)^2 + (\sqrt{3})^2}$$

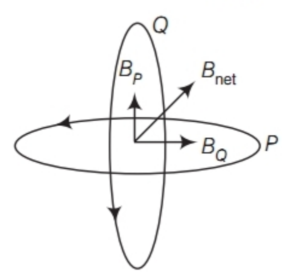
$$B = 4\pi \times 10^{-7} / R \text{ T}$$

Resultant magnetic field makes an angle θ with direction of B_Q, which is given by

$$\tan\theta = B_P / B_Q = 1/\sqrt{3} \Rightarrow \theta = 30^\circ$$ **(1)**

9. Magnetic field due to circular loop P,

$$B_P = \frac{\mu_0 I_P}{2r}$$



Magnetic field due to circular loop Q,

$$B_Q = \mu_0 I_Q / 2r$$ **(1)**

So, net magnetic field at the common centre of the loop is,

$$B_{net} = \sqrt{B_P^2 + B_Q^2}$$

$$= \sqrt{(\mu_0 I_P/2r)^2 + (\mu_0 I_Q/2r)^2}$$

$$= \frac{\mu_0}{2r}\sqrt{I_P^2 + I_Q^2} = \frac{4\pi\times10^{-7}}{2\times5\times10^{-2}}\times\sqrt{3^2+4^2}$$

$$= 2\pi\times10^{-5}\ \text{T}$$ **(1)**

Resultant magnetic field makes an angle θ with B_Q which is given by,

$$\tan\theta = \frac{B_P}{B_Q} = \frac{I_P}{I_Q} = \frac{3}{4} \Rightarrow \theta = \tan^{-1}\left(\frac{3}{4}\right)$$ **(1)**

10. Refer to Sol. 7 (ii) on pages 122 and 123. **(3)**

11. (i) Refer to Sol. 6 on page 122. **(1)**

(ii) According to Ampere's circuital law, the net magnetic field is given by $B = \mu_0 n \hat{\mathbf{i}}$

(a) The net magnetic field is given by

$$B_{\text{net}} = B_2 - B_1$$
$$= \mu_0 n_2 I_2 - \mu_0 n_1 I_1 \qquad [\because I_2 = I_1 = I]$$
$$= \mu_0 I (n_2 - n_1)$$

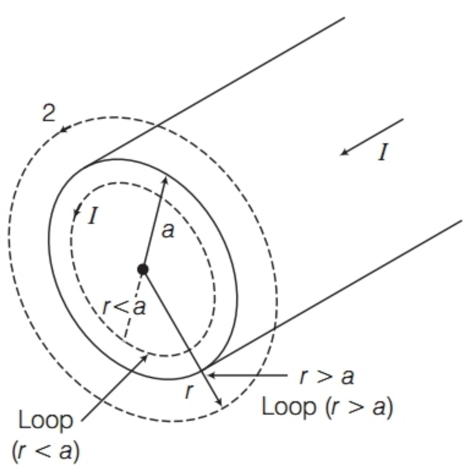
The direction is from B to A. **(1)**

(b) As the magnetic field due to S_1 is confined solely inside S_1 and the solenoids are assumed to be very long so, there is no magnetic field outside S_1 due to current in S_1. Similarly there is no field outside S_2.

$\therefore\ B_{\text{net}} = 0$ **(1)**

12. In these types of questions, first of all we have to calculate the current per unit area of cross-section, so that we can calculate the current in each loop, then only we can find the magnetic field.

As, the current is distributed uniformly across the cross-section of radius a.



$\therefore$ Current passes per unit cross-section $= I/\pi a^2$

$\therefore$ Current passes through the cross-section of radius r is,

$$I' = \left(\frac{I}{\pi a^2}\times\pi r^2\right) = \frac{Ir^2}{a^2} \qquad \text{...(i)}$$ **(1/2)**

(i) Consider a loop of radius r whose centre lies at the axis of wire where, $r < a$ as shown in figure inside the wire.

Applying Ampere's circuital law,

$$\oint \mathbf{B}\cdot d\mathbf{l} = \mu_0 I'$$ **(1/2)**

$$\oint Bdl\cos 0° = \mu_0 (Ir^2/a^2) \qquad \text{[From Eq. (i)]}$$

$$B\oint dl = \mu_0\frac{Ir^2}{a^2} \Rightarrow B\times 2\pi r = \frac{\mu_0 Ir^2}{a^2}$$

$$\Rightarrow \quad B = \frac{\mu_0 Ir}{2\pi a^2} \Rightarrow B \propto r$$ **(1)**

(ii) Considering a loop of radius r whose centre lies at the axis of wire and $(r > a)$ as shown in outer dotted line.

$\therefore$ Current I threads the loops.

Applying Ampere's circuital law,

$$\oint \mathbf{B}\cdot d\mathbf{l} = \mu_0 I$$

$$\oint Bdl\cos 0° = \mu_0 I \Rightarrow B\oint dl = \mu_0 I$$

$$B\times 2\pi r = \mu_0 I \Rightarrow B = \mu_0 I/2\pi r \Rightarrow B \propto 1/r$$

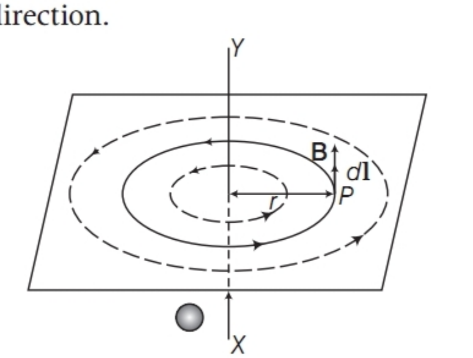
Thus, the field **B** is proportional to r as we move from the axis of cylinder towards its surface and then decreases as $1/r$. **(1)**

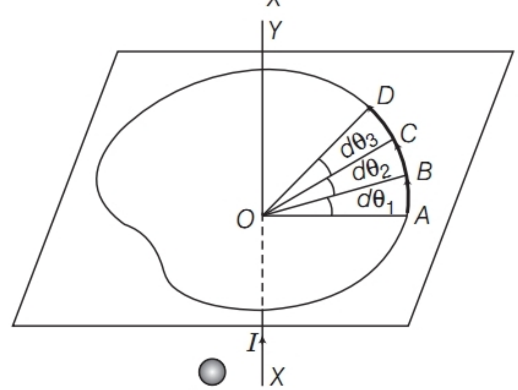
13. Refer to Sol. 12 on page 124. **(3)**

14. (i) **For Biot-Savart's law** Refer to text on pages 117 and 118.

For magnetic field due to a current carrying loop on its axis Refer to Sol. 7 (ii) on pages 122 and 123. **(1+1 ½)**

(ii) When current in the coil is in anti-clockwise direction.





Consider any arbitrary closed path perpendicular to the plane of paper around a long straight conductor XY carrying current from X to Y, lying in the plane of paper.

Let, the closed path be made of large number of small elements, where

$$AB = d\mathbf{l}_1,\ BC = d\mathbf{l}_2,\ CD = d\mathbf{l}_3$$

Let $d\theta_1, d\theta_2, d\theta_3$, be the angles subtended by the various elements at point O through which conductor is passing. Then

$$d\theta_1 + d\theta_2 + d\theta_3 + \ldots = 2\pi$$

Suppose these small elements $AB, BC, CD, \ldots$ are small circular arcs of radii $r_1, r_2, r_3, \ldots$ respectively.

Then, $d\theta_1 = \frac{d\mathbf{l}_1}{r_1}, d\theta_2 = \frac{d\mathbf{l}_2}{r_2}, d\theta_3 = \frac{d\mathbf{l}_3}{r_3}$

If $\mathbf{B}_1, \mathbf{B}_2, \mathbf{B}_3$ are the magnetic field induction at a point along the small elements $d\mathbf{l}_1, d\mathbf{l}_2, d\mathbf{l}_3 \ldots\ldots$ then from Biot-Savart's law we know that for the conductor of infinite length, magnetic field is given by

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I}{r_1};\ B_2 = \frac{\mu_0}{4\pi}\frac{2I}{r_2};\ B_3 = \frac{\mu_0}{4\pi}\frac{2I}{r_3} \ldots$$

In case of each elements, the magnetic field induction $\mathbf{B}$ and current element vector $d\mathbf{l}$ are in the same direction. Line integral of $\mathbf{B}$ around closed path is

$$\oint \mathbf{B}\cdot d\mathbf{l} = \mathbf{B}_1\cdot d\mathbf{l}_1 + \mathbf{B}_2\cdot d\mathbf{l}_2 + \mathbf{B}_3\cdot d\mathbf{l}_3 + \ldots$$

$$= B_1(dl_1) + B_2(dl_2) + B_3(dl_3) + \ldots$$

$$= \frac{\mu_0}{4\pi}\frac{2I}{r_1}dl_1 + \frac{\mu_0}{4\pi}\frac{2I}{r_2}dl_2 + \frac{\mu_0}{4\pi}\frac{2I}{r_3}dl_3 + \ldots$$

$$= \frac{\mu_0 2I}{4\pi}\left[\frac{dl_1}{r_1} + \frac{dl_2}{r_2} + \frac{dl_3}{r_3} + \ldots\right]$$

$$= \frac{\mu_0 2I}{4\pi}[d\theta_1 + d\theta_2 + d\theta_3 + \ldots] = \frac{\mu_0}{4\pi}2I \times 2\pi = \mu_0 I$$

$\Rightarrow \oint B\cdot dl = \mu_0 I$, which is an expression of

Ampere's circuital law. **(2½)**

15. The magnetic field at a point due to a circular loop is given by $B = \frac{\mu_0}{4\pi}\cdot\frac{2\pi I a^2}{(a^2 + r^2)^{3/2}}$ **(1)**

where, I = current through the loop

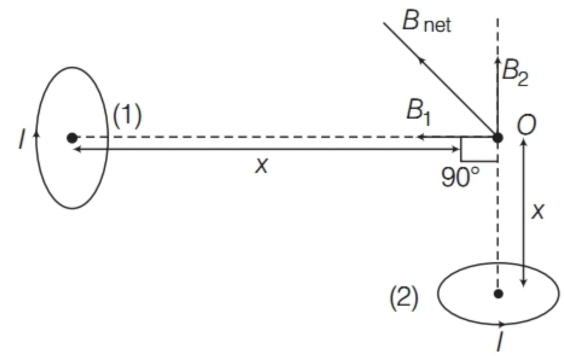
a = radius of the loop

and r = distance of O from the centre of the loop.

Since I, a and $r = x$ are the same for both the loops, the magnitude of B will be the same and is given by **(1)**

$$B_1 = B_2 = \frac{\mu_0}{4\pi}\cdot\frac{2\pi I a^2}{(a^2 + x^2)^{3/2}}$$

The direction of magnetic field due to loop (1) will be away from O and that of the magnetic field due to loop (2) will be towards O as shown. The direction of the net magnetic field will be as shown below: **(1)**



(1)

The magnitude of the net magnetic field is given by

$$B_{\text{net}} = \sqrt{B_1^2 + B_2^2} \Rightarrow B_{\text{net}} = \frac{\mu_0}{4\pi}\frac{2\sqrt{2}\,\pi I a^2}{(a^2 + x^2)^{3/2}}$$ **(1)**

16. For the statement of Biot-Savart's law Refer to text on pages 117 and 118. **(1)**

For field at axial point of a circular coil Refer to Sol. 7 (ii) on pages 122 and 123. **(2)**

Magnetic field induction at the centre of the circular coil carrying current is,

$$B_1 = \frac{\mu_0}{4\pi}\cdot\frac{2\pi I}{a}$$

and magnetic field induction at an axial point is

$$B_2 = \frac{\mu_0}{4\pi}\cdot\frac{2\pi a^2 I}{(a^2 + d^2)^{3/2}}$$

$$\frac{B_2}{B_1} = \frac{a^2 \times a}{(a^2 + d^2)^{3/2}} = \frac{a^3}{(a^2 + d^2)^{3/2}}$$

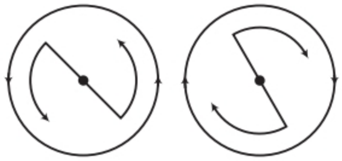
$$\frac{B_2}{B_1} = \frac{a^3}{(a^2 + 3a^2)^{3/2}} \qquad [\because d = a\sqrt{3}]$$

$$= \frac{a^3}{(4a^2)^{3/2}} = \frac{a^3}{8a^3} \Rightarrow \frac{B_2}{B_1} = \frac{1}{8}$$ **(2)**

17. For Biot-Savart's law Refer to text on pages 117 and 118. **(2)**

For the magnetic field due to a circular coil carrying current at a point along its axis Refer to Sol. 7 (ii) on pages 122 and 123. **(1)**

As current carrying loop has the magnetic field lines around it which exerts a force on a moving charge. Thus, it behaves as a magnet with two mutually opposite poles. **(1)**

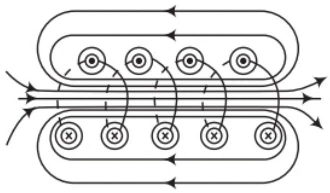


The anti-clockwise flow of current behaves like a North pole, whereas clockwise flow as South pole. Hence, loop behaves as a magnet. **(1)**

18. (i) **For statement of Ampere's circuital law**
Refer to Sol. 6 on page 122. **(1)**

(ii) Refer to Sol. 4 on pages 121 and 122. **(2)**

(iii) Magnetic field lines for a finite solenoid has been shown below **(2)**



All the magnetic field lines are necessarily closed loops, whereas electric lines of force are not closed.

19. (i) Refer to Sol. 7 (ii) on pages 122 and 123. **(2)**

(ii) Refer to Sol. 1 on page 121. **(1)**

(iii) (a) Magnetic field due to straight part

$$B = \int \frac{\mu_0}{4\pi} \frac{I d\mathbf{l} \times \mathbf{r}}{r^3}$$ **(1/2)**

For point O, $d\mathbf{l}$ and r for each element of the straight segments AB and DE are parallel. Therefore, $d\mathbf{l} \times \mathbf{r} = 0$. Hence, magnetic field due to straight segments is zero.

(b) Magnetic field at the centre due to circular point

$$= \frac{\text{Magnetic field at the centre of circular coil}}{2}$$

[∵ Here, coil is half]

$$= \frac{1}{2}\left(\frac{\mu_0 I}{2r}\right) = \frac{\mu_0 I}{4r}$$

$$B = \frac{\mu_0 I}{4r} = \frac{(4\pi \times 10^{-7}) \times 12}{4 \times 2 \times 10^{-2}}$$

$$= 6\pi \times 10^{-5}\ \text{T}$$ **(1½)**

Explanations

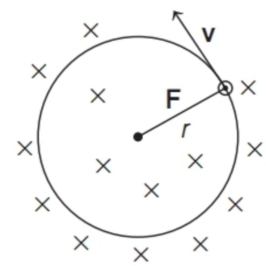
1. The magnetic force acting on the electron is given as

$$\mathbf{F} = e(\mathbf{v} \times \mathbf{B}) = evB\sin\theta$$

If the electron moves along $+x$-direction and $\mathbf{B}$ is directed along $-z$ direction, then $\theta = 90°$.

$\Rightarrow \quad F = evB$

So, the trajectory followed by the electron after entering the field will be circular as shown below



[1]

2. When a charged particle q moves with velocity $\mathbf{v}$ in a uniform magnetic field $\mathbf{B}$, then the force acting on it is given by

$$\mathbf{F} = q\,(\mathrm{v} \times \mathrm{B})$$ **(1)**

3. $F_{\text{lorentz}} = F_{\text{electric}} + F_{\text{magnetic}}$

$$= q\mathbf{E} + q\,(\mathbf{v} \times \mathbf{B}) = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$ **(1)**

4. First proton has circular trajectory and second has helical. **(1)**

5. As we know that in a circular path, frequency of a charged particle is given by

$$\nu = \frac{qB}{2\pi m} \quad \text{or} \quad \nu \propto \frac{1}{m}$$

Since, $m_p > m_e$, therefore electron will move in circular path with higher frequency. **(1)**

6. The expression in vector form is given by

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$ **(1/2)**

where, q is the charged particle.

The direction of the magnetic force is in the direction of $\mathbf{v} \times \mathbf{B}$, i.e. perpendicular to the plane containing $\mathbf{v}$ and $\mathbf{B}$. **(1/2)**

7. For the given momentum of charge particle, radius of circular paths depends on charge and magnetic field as

$$r = mv/qB \qquad [\because qvB = mv^2/r]$$

For constant momentum, $r \propto (1/qB)$

$\therefore \; r_{\text{proton}} : r_{\text{deuteron}} = q_{\text{deuteron}} : q_{\text{proton}} = 1:1$ **(1)**

8. Ratio of forces acting on the two particles,

$$\frac{F_A}{F_B} = \frac{qv_1 B \sin 90^\circ}{(2q)\, v_2 B \sin 90^\circ} = \frac{1}{2}$$

[Given, $B_1 = B_2 = B$]

$\Rightarrow \quad v_1/v_2 = 1 \Rightarrow v_1 : v_2 = 1:1$ **(1)**

9. Velocity of α-particles

$\mathbf{v} = v\hat{\mathbf{i}}$ [Projected along X-axis]

Magnetic force on α-particles,

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

As, $\mathbf{F}_m = F_m\,\hat{\mathbf{j}}$ [Oriented along Y-axis]

$\Rightarrow \quad F_m\,\hat{\mathbf{j}} = q\,(v\hat{\mathbf{i}} \times \mathbf{B}) \Rightarrow \mathbf{B} = -B\hat{\mathbf{k}} = B(-\hat{\mathbf{k}})$

The direction of magnetic field must be along $-Z$-axis. **(1)**

10. Given, $\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B}) \Rightarrow F = qvB \sin\theta$

where, θ is the angle between **v** and **B**.

$\Rightarrow \quad B = F/qv\sin\theta$

If $q = 1\text{ C}, v = 1\text{ ms}^{-1}, \theta = 90^\circ$

The magnetic field at any point can be given by

$$B = \frac{1\text{ N}}{[(1\text{ C})\,(1\text{ ms}^{-1})\sin 90^\circ]} = 1\text{ N/A-m} = 1\text{ T}$$

$\therefore$ SI unit of magnetic field = 1 T

Thus, the 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 ms^{-1} experiences a force of 1 N at that point. **(1)**

11. The kinetic energy of proton due to potential V is given by

$K = eV$

where, e = charge on proton.

The radius of circular path of proton in a magnetic field is

$$r = \frac{\sqrt{2mK}}{qB} = \frac{\sqrt{2meV}}{qB}$$ **(1)**

If potential is doubled, i.e.

$V' = 2V$, then

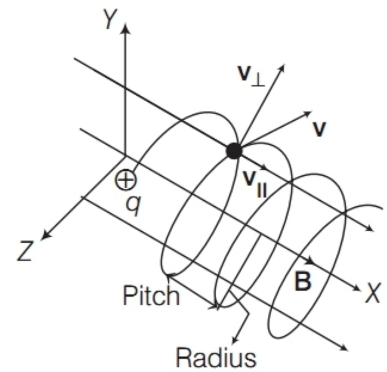
$$r' = \frac{\sqrt{2me \times 2V}}{qB} = \sqrt{2}\,r$$

Thus, radius becomes $\sqrt{2}$ times of previous value. **(1)**

12. When an charged particle q enters a uniform magnetic field at an angle of 30°, then its path becomes helix of radius

$$r = \frac{mv \sin 30^\circ}{eB} = \frac{mv}{2eB}$$ **(1)**

For diagram and discription If a charged particle has a velocity not perpendicular to **B,** then component of velocity along **B** remains unchanged as the motion along the magnetic field will not be affected by the magnetic field. Then, the motion of the particle in a plane perpendicular to **B** is as before a circular one, thereby producing a helical motion.



(1)

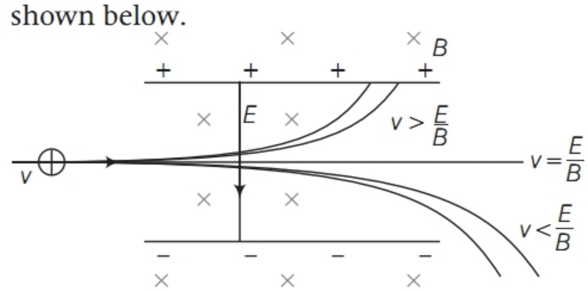
13. If we adjust the value of electric field (E) and magnetic field (B), such that the magnitude of two forces are equal, then the total force on the charge is zero. Also, the charge will move in the fields undeflected. This happens, when

Electric force (F_e) = Magnetic force (F_m)

$\Rightarrow \quad qE = qvB$ or $v = E/B$

The above condition can be used to select a charged particle of a particular velocity from the charges moving with different speeds.

A diagram in which particle has being deflected in the presence of magnetic and electric field is shown below. **(1)**



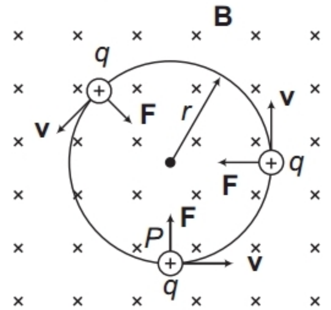
(1)

14. One tesla is defined as the field which produces a force of 1 newton when a charge of 1 coulomb moves perpendicularly in the region of the magnetic field at a velocity of 1 ms^{-1}.

As, $F = qvB \Rightarrow B = F/qv$

$\Rightarrow \quad 1\text{ T} = 1\text{ N}/(1\text{C})\,(1\text{ ms}^{-1})$ **(2)**

15. A charge q projected perpendicular to the uniform magnetic field **B** with velocity **v**. The perpendicular force, $F = qvB$, acts like a centripetal force perpendicular to the magnetic field. Then, the path followed by charge is circular as shown in the figure. **(1)**



$$qvB = \frac{mv^2}{r} \quad \text{or} \quad r = \frac{mv}{qB}$$

where, r = radius of the circular path followed by charge projected perpendicular to a uniform magnetic field. **(1)**

16. Lorentz force always acts along the direction perpendicular to the direction of velocity of the particle.

Magnetic Lorentz force,

$$\mathbf{F}_m = q\,(\mathbf{v} \times \mathbf{B}) \quad \textbf{(1)}$$

$\because$ $\quad \mathbf{F} \perp \mathbf{v}$

$\Rightarrow$ Force is perpendicular to displacement made by charged particle.

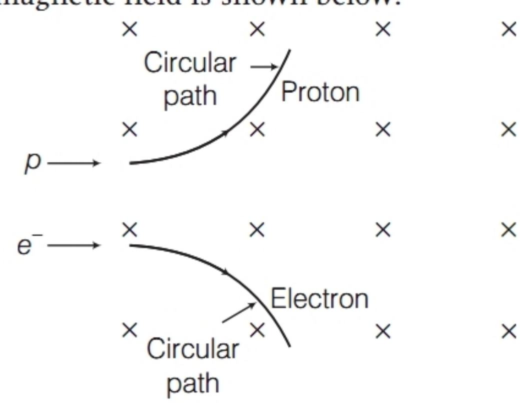
$\therefore$ $W = Fd \cos 90° = 0$

[$\because$ Force F and displacement d are perpendicular to each other]

$\Rightarrow$ $\quad W = 0$

Hence, no work is done by magnetic Lorentz force on the charged particle. **(1)**

17. When a charged particle enters in the magnetic field at right angle, then the particle follows a circular path. The trajectory of the two particles in the magnetic field is shown below.



Radius of the circular path, $r = \dfrac{mv}{qB}$

For same speed v, magnitude of charge q and magnetic field B

$$r \propto m \Rightarrow \frac{r_e}{r_p} = \frac{m_e}{m_p} \quad \textbf{(1)}$$

where, m_e and m_p are masses of electron and proton, respectively

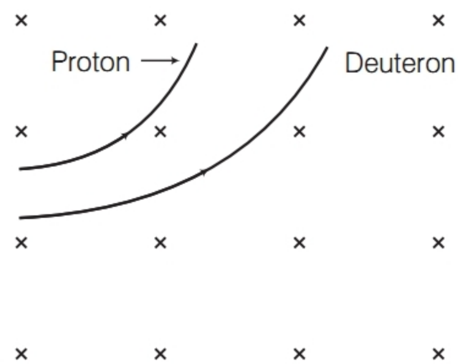
$\because$ $\quad m_e < m_p$

(Proton is much heavier than electron)

$\Rightarrow$ $\quad r_e < r_p$

The radius of curvature of path of proton is much more than radius of curvature of path of electron. Hence, curvature of path of electron is more than curvature of path of electron **(1)**

18. The trajectory of the two particles in the magnetic field is shown below. **(1)**



$\because$ $\quad \dfrac{r_d}{r_p} = \dfrac{m_d}{m_p}$

$\because$ $\quad m_d = 2m_p \Rightarrow r_d = 2r_p$

or $\quad r_d : r_p = 2:1$ **(1)**

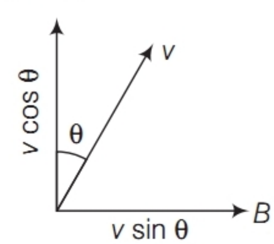
NOTE Smaller the radius, greater the curvature and *vice-versa*. This is why, proton's path has got greater curvature.

19. (i) Force acting on the particle, $F = Bqv$

In vector form, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

where, $\mathbf{B}$ is uniform magnetic field and $\mathbf{v}$ is velocity with which particle is moving.

From this equation, it is clear that direction of force is perpendicular to the plane containing both $\mathbf{v}$ and $\mathbf{B}$. In other words, force acts perpendicular to both $\mathbf{v}$ and $\mathbf{B}$. When velocity becomes perpendicular to force, the path of the object becomes circular. **(1)**



In this case, $\mathbf{B}$ is assumed to act perpendicular to $\mathbf{v}$.

In case, **B** is not perpendicular to **v**, a component of **v** remains perpendicular to **B** creates circular path. The component of **v** parallel to **B** will create linear path.

Here, the particle will have circular path due to $v\cos\theta$ and linear path due to $v\sin\theta$. Both when combined gives helical path. **(1)**

(ii) Since, force always adjusts itself in a direction which becomes perpendicular to velocity, so only direction of velocity is changed not the magnitude. Hence, the kinetic energy of the particle always remains constant. **(1)**

20. (i) When a charged particle (q) moves with velocity (**v**) inside a uniform magnetic field **B**, then force acting on it is, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$ **(1)**

(ii) The direction of force on the charged particle is given by $(\mathbf{v} \times \mathbf{B})$ with the sign of charged particle, i.e. for α-particle, charge is positive and direction of **v** is $+\hat{\mathbf{i}}$ and direction of **B** is $-\hat{\mathbf{k}}$.

So, direction of force is $+(\hat{\mathbf{i}} \times -\hat{\mathbf{k}})$, i.e. $+\hat{\mathbf{j}}$.

For α-particle

It describes a circle with anti-clockwise motion.

For neutron

It is a neutral particle so, it goes undeviated.

As $\mathbf{F} = q(\mathbf{v} \times \mathbf{B}) = 0$

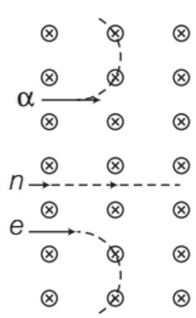
For electron

Force is given by $\mathbf{F} = -e(\mathbf{v} \times \mathbf{B})$

So, direction $= -\hat{\mathbf{i}} \times -\hat{\mathbf{k}} \Rightarrow -\hat{\mathbf{j}}$

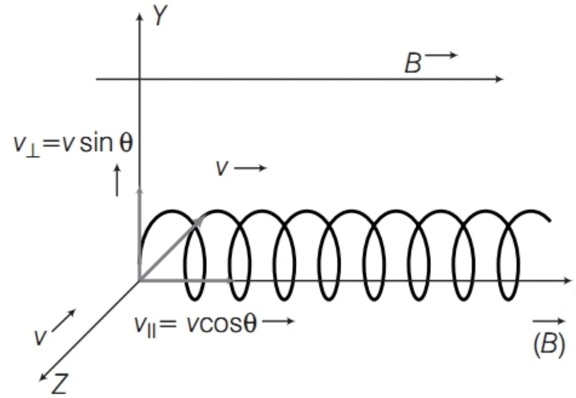
e^- describes a circle with clockwise motion.

Path of the particles in the presence of magnetic field is shown below.



(2)

21. The path of the charged particle will be helix. As, the charge moves linearly in the direction of the magnetic field with velocity $v\cos\theta$ and also describe the circular path due to velocity $v\sin\theta$.



(1)

Time taken by the charge to complete one circular rotation, $T = 2\pi r / v_\perp$

$\Rightarrow \quad F = qv_\perp B \quad \ldots(\text{i})$

and centripetal force = magnetic force

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

$\Rightarrow \quad mv_\perp^2 / r = qv_\perp B \quad \ldots(\text{ii})$

$\Rightarrow \quad v_\perp m/qB = r \Rightarrow T = 2\pi v_\perp m/qB \cdot v_\perp$

$\Rightarrow \quad T = 2\pi m/Bq$ **(1)**

Distance moved by the particle along the magnetic field in one rotation (pitch of the helix path)

$= v_{||} \times T \quad [\because v_{||} = v_{\text{parallel}}]$

$= v\cos\theta \times 2\pi m/Bq \Rightarrow P = 2\pi m v\cos\theta / qB$ **(1)**

22. Force experienced by the charged particle in the presence of electric and magnetic field is the sum of electric force and magnetic force acting on it.

As, electric force, $\mathbf{F}_e = q\mathbf{E}$

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

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

$= q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$ **(2)**

For a charged prticle moves undeflected through these field, $\mathbf{F} = 0$

$q(\mathbf{E} + (\mathbf{v} \times \mathbf{B})] = 0$ **(1)**

or $\quad \mathbf{E} + (\mathbf{v} \times \mathbf{B}) = 0$

$\mathbf{E} = -(\mathbf{v} \times \mathbf{B}) = (\mathbf{B} \times \mathbf{v})$

$\Rightarrow \quad |\mathbf{E}| = |\mathbf{B}|\,|\mathbf{v}|\sin\theta$ **(1)**

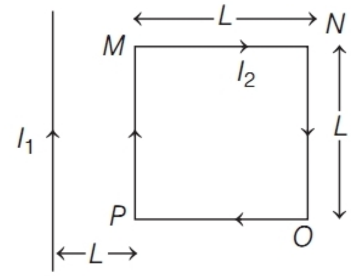
It is maximum, when $\theta = 90°$

$\Rightarrow \quad |\mathbf{v}| = |\mathbf{B}|/|\mathbf{E}|$

The above condition can be used to select a charged particle of a particular velocity from charges moving with different speed for a condition of the particle undeflected through the field. **(1)**

Explanations

1. The given loop can be shown below as



The force acting on the arms MN and PO of the given loop are equal, mutually opposite and collinear. Hence, they balance each other.

Force on arm PM,

$$F_1 = \frac{\mu_0 I_1 I_2 L}{2\pi L}$$

$$= \frac{\mu_0 I_1 I_2}{2\pi}, \text{ attractive in nature} \quad \ldots \text{(i)}$$

Force on arm NO,

$$F_2 = \frac{\mu_0 I_1 I_2 L}{2\pi(2L)}$$

$$= \frac{\mu_0 I_1 I_2}{4\pi}, \text{ repulsive in nature} \quad \ldots \text{(ii)}$$

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

$$F_{\text{net}} = F = F_1 - F_2 = \frac{\mu_0 I_1 I_2}{2\pi} - \frac{\mu_0 I_1 I_2}{4\pi}$$

$$= \frac{\mu_0 I_1 I_2}{4\pi}, \text{ attractive in nature} \quad \ldots \text{(iii)}$$

So, from Eqs. (ii) and (iii), we can conclude that the magnitude of the force on side NO of the loop is $F = \left(\frac{\mu_0 I_1 I_2}{4\pi}\right)$ which is repulsive when the net force F is towards the wire. **[1]**

2. Current sensitivity of the galvanometer is the deflection per unit current flowing through it.

It is given as, $I_S = \frac{\theta}{I} = \frac{NAB}{k}$

where, k is the restoring torque per unit twist of phosphor bronze strip. **[1]**

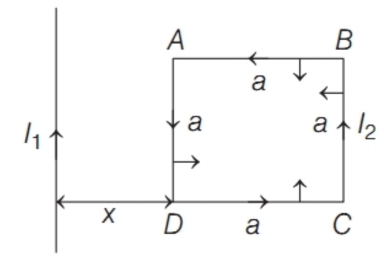
3. The principle of moving coil galvanometer is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque. **(1)**

4. One ampere is the current which flows through each of two parallel uniform long linear conductors, which are placed in free space at a distance of 1 m from each other and which attract or repel each other with a force of 2×10^{-7} N/m of length. **(1)**

5. No, steady current is not the only source of magnetic field. As, magnetic field can be produced by other sources also, for example, alternating current, moving charged particle, permanent magnets, etc. **(1)**

6. According to right-hand screw rule, force on AD is

$$F_1 = \frac{\mu_0 I_1 I_2 a}{2\pi x} \text{ (toward right)}$$



Force on BC is

$$F_2 = \frac{\mu_0 I_1 I_2 a}{2\pi(x + a)} \text{ (toward left)}$$ **(1)**

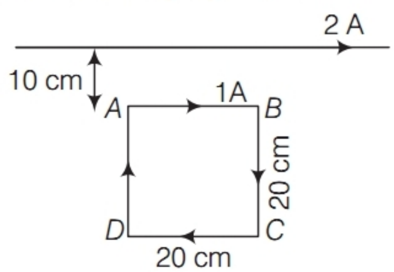
The forces on AB and DC are equal and opposite, so they will cancel each other.

Thus, net force on loop is

$$F_R = \frac{\mu_0 I_1 I_2 a}{2\pi}\left(\frac{1}{x} - \frac{1}{x + a}\right)$$

$$= \frac{\mu_0 I_1 I_2 a^2}{2\pi x(x + a)} \text{ (towards right)}$$ **(1)**

7. According to the question, as the loop is square, its sides are parallel. So, force between two parallel current carrying wires,



$$F = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

Force on arm AB, $F_{AB} = \dfrac{\mu_0 \times 2 \times 1 \times 20 \times 10^{-2}}{2\pi \times 10 \times 10^{-2}}$ **(1)**

$= \dfrac{2\mu_0}{\pi}$ newton (Attractive, towards the wire)

Force on arm CD, $F_{CD} = \dfrac{\mu_0 \times 2 \times 1 \times 20 \times 10^{-2}}{2\pi \times 30 \times 10^{-2}}$

$= \dfrac{2\mu_0}{3\pi}$ newton (Repulsive, away from the wire)

Force on arms BC and DA are equal and opposite. So, they cancel out each other.

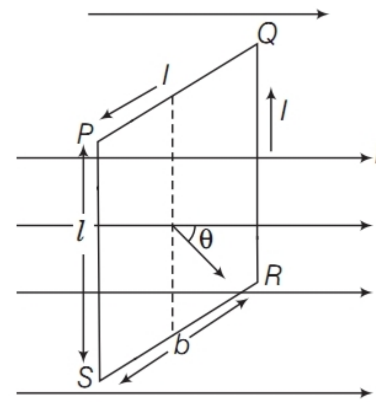
Net force on the loop is $F = F_{AB} - F_{CD} = \dfrac{\mu_0}{\pi}\left[2 - \dfrac{2}{3}\right]$

$$= \frac{4\mu_0}{3\pi} = \frac{4 \times 4\pi \times 10^{-7}}{3\pi}$$

$$= 5.33 \times 10^{-7} \text{ N}$$

(Attractive, towards the wire) **(1)**

8. A rectangular coil $PQRS$ is placed in a uniform magnetic field as shown in the figure below.



Forces on arm PQ and RS are equal and opposite and they cancel each other as they are collinear.

Force on SP is F_1 and force on QR is F_2

and $F_1 = F_2 = IlB$ **(1)**

Thus, magnitude of torque due to these forces on the coil will be given as

$$\tau = IlbB\sin\theta = IAB\sin\theta$$

where, $A = lb$ (area of coil)

or in vector form, $\tau = MB\sin\theta\,\hat{\mathbf{n}} = \mathbf{M} \times \mathbf{B}$

where , $\mathbf{M} = NI\mathbf{A}$, is the magnetic moment of the coil.

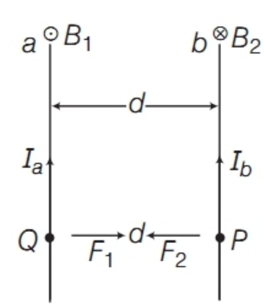
Since, according to the question,

$\theta = 0°$ (as plane of coil is perpendicular to the field).

Thus, $\tau = 0$

Torque acting on the coil will be zero. **(1)**

9. (i) Let a and b be two long straight parallel conductors, I_a and I_b are the current flowing through them and separated by a distance d.



Magnetic field induced at a point P on a conductor b due to current I_a passing through a is

$$B_1 = \frac{\mu_0 2I_a}{4\pi d}$$

Now, unit length of b will experience a force as $F_2 = B_1 I_b \times 1 = B_1 I_b$

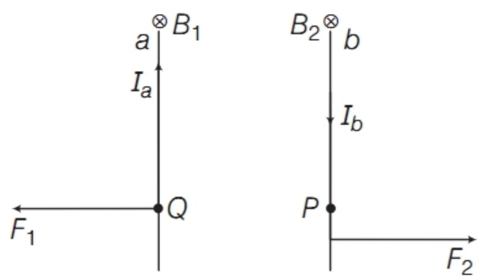
$$\therefore \quad F_2 = \frac{\mu_0}{4\pi} \frac{2I_a I_b}{d}$$

Conductor a also experiences the same amount of force directed towards b. Hence, a and b attract each other.

$\therefore$ The force between two current carrying parallel conductors per unit length is

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2I_a I_b}{d}$$ **(1)**

(ii)



Now, let the direction of current in conductor b be reversed. The magnetic field B_2 at point P due to current I_a flowing through a will be downwards. Similarly, the magnetic field B_1 at point Q due to current I_b passing through b will also be downward as shown. The force on a will be, therefore towards the left. Also, the force on b will be towards the right. Hence, the two conductors will repel each other by equal amount of force as shown above. **(1)**

10. According to the question,

$$2\pi r = 4a \Rightarrow a = \frac{\pi r}{2} \quad ..(i)$$ **(1)**

Thus, the ratio of magnetic moment of square coil and circular coil is given as

$$\frac{M_s}{M_c} = \frac{NIA_s}{NIA_C} = \frac{NI(a)^2}{NI\pi r^2} = \frac{NI(\pi r/2)^2}{NI\pi r^2}$$

[$\because$ from Eq. (i)]

$$= \pi/4$$

$$\Rightarrow \quad M_s : M_c = \pi : 4$$ **(1)**

11. (i) Magnetic field at centre due to circular current carrying coil, $B = \mu_0 NI/2r$ **(1)**

(ii) Magnetic moment, $M = NIA = NI\,(\pi r^2)$

$$M = \pi\, NIr^2$$

where, r is the radius of circular coil, μ_0 is permeability of free space and N is number of turns. **(1)**

12. The length of wire will be same in two cases as the same coil is unwound and rewound.

Length of the wire is same

$$\therefore \quad N_1 \times (2\pi R) = N_2 \times 2\pi\,(R/2)$$

[N_1 and N_2 = number of turns in two coils]

$$N_2 = 2N_1$$ **(1/2)**

Now, the ratio of magnetic moments is given by

$$\frac{M_1}{M_2} = \frac{N_1 I A_1}{N_2 I A_2} = \frac{N_1 \times \pi R_1^2}{N_2 \times \pi R_2^2}$$ **(1/2)**

$$\frac{M_1}{M_2} = \left(\frac{N_1}{2N_1}\right) \times \left(\frac{R}{R/2}\right)^2$$

$$= \frac{1}{2} \times 4 = 2$$ **(1/2)**

$$M_1 : M_2 = 2:1$$ **(1/2)**

13. The length of wire will be same in two cases as the same coil in unwound and rewound.

Length of wire of coil 1 = Length of wire of coil 2

$$N_1 \times \pi d_1 = N_2 \times \pi d_2$$

$$N_1 \times \pi d = N_2 \times \pi \times 2d$$

$$N_2 = \frac{N_1}{2} \qquad \text{[where, } N_1 = N\text{]}$$

$$\Rightarrow \quad N_2 : N_1 = 1:2$$

$$\Rightarrow \quad N_1 : N_2 = 2:1$$ **(1)**

Magnetic moment, $M = NIA$

$$\therefore \quad \frac{M_1}{M_2} = \frac{N_1 I A_1}{N_2 I A_2} = \frac{N_1 \pi d^2}{N_2 \pi (2d)^2}$$

$$\frac{M_1}{M_2} = \left(\frac{N_1}{N_2}\right) \times \frac{1}{4} = 2 \times \frac{1}{4} = \frac{1}{2}$$

$$\frac{M_1}{M_2} = \frac{1}{2}$$

$$\Rightarrow \quad M_1 : M_2 = 1:2$$ **(1)**

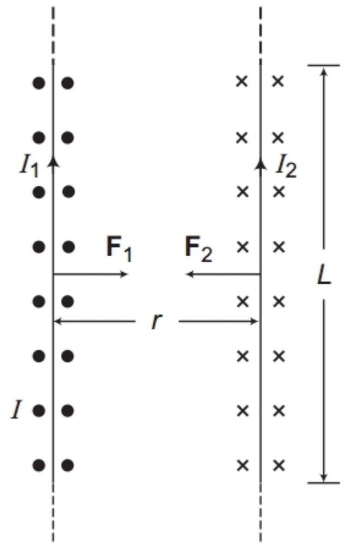
14. In these types of questions, we are calculating force on a wire in the field produced by the other current carrying wire.

To find expression of force between two parallel wires. Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction.

Magnetic field B_1 due to first wire on seconds, i.e. **(1/2)**

$$B_1 = \frac{\mu_0}{4\pi} \frac{2I_1}{r} = \frac{\mu_0 I_1}{2\pi r} \quad ...(i)$$ **(1/2)**

The magnetic field is perpendicular to the plane of paper and directed inwards.



Now, magnetic force on length L of second wire is given by **(1/2)**

$$F_2 = I_2 B_1 \; L \sin 90°$$

$$\Rightarrow \qquad F_2 = I_2 \left(\frac{\mu_0}{4\pi} \cdot \frac{2I_1}{r} \right) L$$

$$\Rightarrow \qquad \frac{F_2}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 \, I_2}{r} = \frac{\mu_0 I_1 I_2}{2\pi r} \qquad \text{...(ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on Ist wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2\, I_1 \, I_2}{r} \qquad \text{... (iii)}$$

$$\mathbf{F}_1 = -\mathbf{F}_2$$

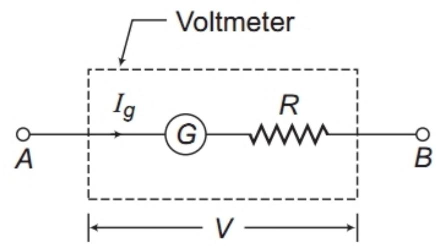
The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductors have the same direction of flow of currents attracting each other. **(1/2)**

15. The resistance of an ideal voltmeter is infinity or very high in practical condition. So, to convert a galvanometer into voltmeter, its resistance needs to be increased, which can be done by connecting a high resistance in series with it.

A galvanometer can be converted into a voltmeter by connecting a very high resistance R in series with it. This is done, so that there is no potential drop across it. **(1/2)**

Let R is so chosen that current I_g gives full deflection in the galvanometer where I_g is the range of galvanometer.



(1/2)

Let galvanometer of resistance G, range I_g is to be converted into voltmeter of range V (volt). Now,

$$V = I_g \, (G + R)$$

$$\Rightarrow \qquad R + G = \frac{V}{I_g}$$

$$\Rightarrow \qquad R = \frac{V}{I_g} - G$$

The appropriate scale need to be graduated to measure potential difference. **(1)**

16. Here, area of coil, $A = 10 \times 10 = 100 \text{ cm}^2 = 10^{-2} \text{ m}^2$

Number of turns, $N = 20$ turns

Current, $I = 12$ A

Coil makes an angle with magnetic field $= \theta = ?$

Magnetic field, $B = 0.8$ T

Torque, $\tau = 0.96$ N-m **(1/2)**

$\because$ Torque (τ) experienced by current carrying coil in the magnetic field is

$$\tau = NIAB \sin \theta \qquad \textbf{(1)}$$

$$0.96 = 20 \times 12 \times 10^{-2} \times 0.8 \times \sin \theta$$

$$\Rightarrow \qquad \sin \theta = \frac{0.96}{1.92} = \frac{1}{2}$$

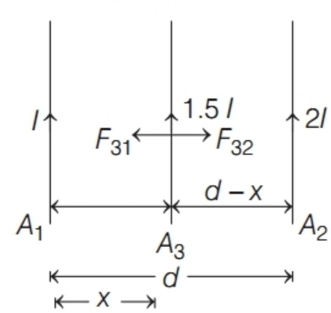
$$\Rightarrow \qquad \theta = \frac{\pi}{6} \text{ rad}$$

(1/2)

17. Refer to Sol. 9(i) on pages 140 and 141. **(1½)**

Refer to Sol. 4 on page 139. **(1½)**

18. Let the current in the third wire A_3 be in same direction as that of A_1 and A_2. So, it will experience attractive force due to both.



The force on A_3 due to A_1 is $F_{31} = \dfrac{\mu_0}{2\pi} \cdot \dfrac{I \times 1.5\, I \times l}{x}$

where, l = unit length of conductor wire A_2

and x = distance between A_1 and A_3. **(1½)**

Similarly, force on A_3 due to A_2 is

$$F_{32} = \frac{\mu_0}{2\pi} \cdot \frac{1.5I \times 2I \times l}{(d - x)}$$

According to question, $F_{31} = F_{32}$

$$\Rightarrow \quad \frac{\mu_0}{2\pi} \cdot \frac{1.5I^2 l}{x} = \frac{\mu_0}{2\pi} \frac{3I^2}{(d - x)} l$$

$$\Rightarrow \quad \frac{1.5}{x} = \frac{3}{d - x}$$

$$\Rightarrow \quad d - x = 2x \quad \text{or} \quad x = \frac{d}{3}$$

Yes, the net force acting on A_3 depends on the current flowing through it. **(1½)**

19. (i) Refer to Sol. 8 on page 140. **(2)**

(ii) In a radial magnetic field, the magnetic torque remains maximum for all positions of the coils. **(1)**

20. (i) Refer to Sol. 3 on page 139. **(1)**

(ii) The galvanometer cannot be used to measure the current because

(a) all the currents to be measured passes through coil and it gets damaged easily.

(b) its coil has considerable resistance because of length and it may affect original current. **(1)**

(iii) **Current sensitivity** of the galvanometer is the deflection per unit current flowing through it.

It is given by $I_S = \frac{\theta}{I} = \frac{NAB}{k}$

Its unit is rad/A or div/A.

Voltage sensitivity is the deflection per unit voltage.

It is given by

$$V_S = \frac{\theta}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V}$$

or $$V_S = \frac{NAB}{k} \times \frac{I}{IR} = \frac{NAB}{kR}$$

[$\because$ according to Ohm's law, $V = IR$]

Its unit is rad/V or div/V. **(1)**

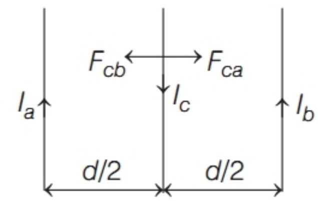
21. (i) Refer to Sol. 4 on page 139. **(1)**

(ii) Refer to Sol. 9(i) on pages 140 and 141. **(1)**

When a third conductor of current I_c is placed in between them having current in opposite direction, then the forces will be

Force on C due to current I_a is

$$F_{ca} = \frac{\mu_0}{4\pi} \frac{2I_a I_c}{d/2} \text{ (toward right)}$$



Force on C due to current I_b is

$$F_{cb} = \frac{\mu_0}{4\pi} \frac{2I_b I_c}{d/2} \text{ (toward left)}$$

Then net force,

$$F = F_{ca} - F_{cb} = \frac{\mu_0}{4\pi} \frac{4I_c}{d} (I_a - I_b) \text{ (toward right)}$$ **(1)**

22. **For the expression of force** Refer to Sol. 14 on pages 141 and 142. **(1½)**

For the definition of one ampere Refer to Sol. 4 on page 139. **(1½)**

23. **For principle of galvanometer** Refer to Sol. 3 on page 139. **(1)**

A high resistance is connected in series with the galvanometer to convert into voltmeter. The value of the resistance is given by $R = \frac{V}{I_g} - G$ **(1)**

where, V = potential difference across the terminals of the voltmeter, I_g = current through the galvanometer and G = resistance of the galvanometer.

When resistance R_1 is connected in series with the galvanometer, then $R_1 = (V/I_g) - G$ ...(i)

When resistance R_2 is connected in series with the galvanometer, then $R_2 = \frac{V}{2I_g} - G$ ...(ii)

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

$$R_1 - R_2 = V/2I_g \text{ and } G = R_1 - 2R_2$$

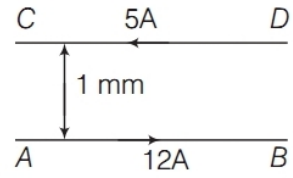
The resistance R_3 required to convert the given galvanometer into voltmeter of range 0 to 2V is given by $R_3 = (2V/I_g) - G$

$$\Rightarrow \quad R_3 = 4(R_1 - R_2) - (R_1 - 2R_2)$$
$$= 3R_1 - 2R_2$$

G in terms of R_1 and R_2 is given by

$$G = R_1 - 2R_2$$ **(1)**

24. Force per unit length between two parallel current carrying wires separated by a distance r is given as $\frac{F}{l} = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{r}$



It is repulsive, if the current in the wires is in opposite direction; (otherwise attractive)

The magnetic force of repulsion on the upper wire (CD) should be balancing its own weight in order to remain suspended. **(1)**

Thus, to remain suspended at its position in equilibrium,

magnetic force on CD due to

AB = weight of CD

$$\therefore \quad \frac{\mu_0 I_1 I_2}{2\pi r} l = mg \qquad (g = 10 \text{ m/s}^2)$$

$$m/l = 2\times10^{-7}\frac{I_1 I_2}{rg}$$

$$m/l = \frac{2\times10^{-7}\times12\times5}{10^{-3}\times10}$$

$$= 1.2\times10^{-3} \text{ kgm}^{-1}$$

$\therefore$ Mass per unit length of wire CD is 1.2×10^{-3} kgm^{-1}

Current in CD should be in opposite direction to that in AB. **(2)**

25. There will be force of attraction between the straight wire and 4 cm long arm of loop nearer to the straight conductor. Thus,

$$F_1 = \frac{\mu_0}{4\pi}\frac{2\times2\times1}{(1\times10^{-2})}\times(4\times10^{-2})$$

$F_1 = 16\times10^{-7}$N [towards straight wire] ...(i) **(1)**

Similarly, force on other 4 cm arm of loop, away from the straight conductor,

$$F_2 = \frac{\mu_0}{4\pi}\times\frac{2\times2\times1}{(3.5\times10^{-2})}\times(4\times10^{-2})$$

$F_2 = 4.57\times10^{-7}$N [away from straight wire] ...(ii)

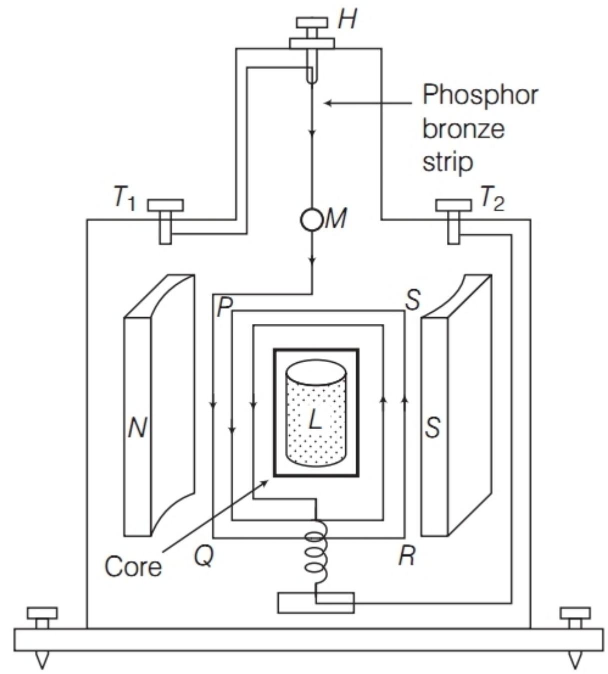
(i) Since, F_1 and F_2 are of different magnitudes, therefore they do not form couple and hence Torque, $\tau = 0$ **(1)**

(ii) The magnitude of net force on loop,

$$F = F_1 - F_2$$
$$F = 16\times10^{-7} - 4.57\times10^{-7}$$
$$\Rightarrow \quad F = 11.43\times10^{-7}\text{N}$$

The direction of the force would be towards the straight wire. **(1)**

26. The labelled diagram of moving coil galvanometer is shown below.



(1)

Working

Suppose, the coil $PQRS$ is suspended freely in the magnetic field.

Let l = length PQ or RS of the coil,

b = breadth QR or SP of the coil

and n = number of turns in the coil

Area of each turns of the coil, $A = l\times b$

Let B = strength of the magnetic field in which coil is suspended and I = current passing through the coil in the direction of $PQRS$.

Let at any instant of time, α be the angle which the normal drawn on the plane of the coil makes with the direction of magnetic field. The rectangular current carrying coil when placed in the magnetic field experiences a torque whose magnitude is given by $\tau = NIBA\sin\alpha$ **(1)**

Due to this deflecting torque, the coil rotates and suspended wire gets twisted. A restoring torque is set up in the suspension wire.

Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and k be the restoring torque per unit twist of the phosphor bronze strip.

Then, total restoring torque produced = $k\theta$

In equilibrium position of the coil,

Deflecting torque = Restoring torque

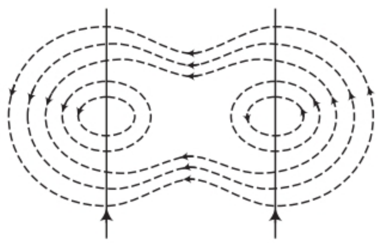
$\therefore \quad NIBA = k\theta$ or $I = \frac{k}{NBA}\theta = G\theta$

where, $\frac{k}{NBA} = G$ [constant for a galvanometer]

It is known as **galvanometer constant.**

The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field, i.e. the angle between the plane of the coil and the magnetic field is zero for all the orientations of the coil. **(1)**

27. Magnetic field lines due to straight long parallel conductors carrying currents I_1 and I_2 in the same direction is shown below.



Magnetic field lines due to both conductors

(1)

For deduction of the force acting between two long parallel conductors Refer to Sol. 14 on pages 141 and 142. **(1)**

As, the current carrying conductors has same direction of flow of current, so the force between them will be attractive. **(1)**

28. Principle The current carrying coil placed in normal magnetic field experiences a torque which is given by

$$\tau = NIAB$$

where, N = number of turns,

I = current, A = area of coil

and B = magnetic field **(1)**

The galvanometer cannot be used to measure the current because

(i) all the currents to be measured has to be, then passes through coil which would gets damaged as it is a hair line spring or

(ii) its coil has considerable resistance because of length and it may affect original current.

[½×2=1]

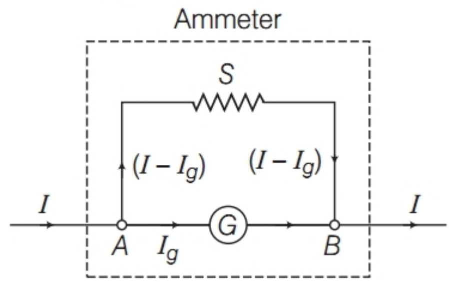
Current sensitivity of galvanometer can be increased by

(i) increasing the magnetic field and

(ii) decreasing the value of torsional constant. **(1)**

29. The resistance of an ideal ammeter is zero or very low in practical condition, so to convert a galvanometer into ammeter its resistance needs to be decreased which can be done by connecting a low resistance in its parallel order.

A moving coil galvanometer of range I_g and resistance G can be converted into ammeter by connecting a very low shunt resistance (S) in parallel with galvanometer.



(1)

This is done, so that the potential difference across the combination is same.

$\therefore$ PD across galvanometer = PD across shunt S

$$I_g G = I_s S$$ **(1)**

But $\quad I_s + I_g = I$

$\Rightarrow \quad I_s = I - I_g \Rightarrow I_g G = (I - I_g) S$

$\Rightarrow \quad S = \frac{I_g G}{I - I_g}$ **(1)**

30. The magnetic moment of a current carrying loop

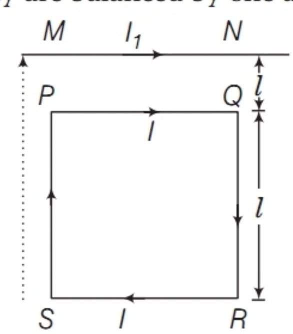
$$\mathbf{M} = I\mathbf{A}$$

where, $\mathbf{A}$ = area of the loop (square)

$\therefore \quad \mathbf{A} = l^2 \hat{\mathbf{n}}$

Here, $\hat{\mathbf{n}}$ is a unit vector normal to the direction of area vector.

The forces acting on the arms QR and SP of given loop are equal, mutually opposite and collinear. Hence, they are balanced by one another. **(1)**



Force on arm PQ, $F_1 = B_1 \cdot Il = \frac{\mu_0 I_1}{2\pi l} Il = \frac{\mu_0 I_1 I}{2\pi}$

Since, the direction of the current in the arm PQ and the wire is same, so F_1 is of the attractive nature and directed towards MN.

Again, force on arm RS,

$$F_2 = B_2 I l = \frac{\mu_0 I_1 I l}{2\pi(2l)} = \frac{\mu_0 I_1 I}{4\pi}$$ **(1)**

F_2 is perpendicular to wire RS and directed away from the conductor MN.

$\therefore$ Net force on loop $PQRS$,

$$\Rightarrow \quad \mathbf{F}_{net} = \mathbf{F}_1 - \mathbf{F}_2 = \frac{\mu_0 I_1 I}{2\pi} - \frac{\mu_0 I_1 I}{4\pi}$$

or $\quad F_{net} = \dfrac{\mu_0 I_1 I}{4\pi}$ [attractive]

As, $\mathbf{F}_1$ and $\mathbf{F}_2$ are collinear, hence they do not produce torque on the loop $PQRS$. **(1)**

31. **For Principle of galvanometer** Refer to Sol. 3. on page 139. **(2)**

For figure and working Refer to Sol. 26 on pages 144 and 145.

For current and voltage sensitivity Refer to Sol. 20 (iii) on page 143.

Current sensitivity, $I_s = \dfrac{NAB}{k}$

and voltage sensitivity, $V_s = \dfrac{NAB}{kR}$

Since, the resistance of the coil may vary, it implies an increase in current sensitivity may not necessarily increase voltage sensitivity. **(3)**

32. (i) Refer to Sol. 26 on page 144 and 145. **(2)**

(ii) (a) It is necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer because it increases its magnetic field. Thus, its sensitivity increases and magnetic field becomes radial. So, angle between the plane of coil and magnetic line of force is zero in all orientations of coil. **(1)**

(b) Refer to Sol. 31 on page 146. **(2)**

33. (i) Refer to Sol. 26 on pages 144 and 145. **(3)**

(ii) **For converting galvanometer into ammeter** Refer to Sol. 34(i)(b) on page 146.

In the case, when galvanometer is converted into voltmeter, its resistance needs to be increased, so that there is no potential drop across it because of high resistance no current passes through it. Hence, a high resistance is connected in series with the galvanometer. **(2)**

34. (i) A galvanometer of range I_g and resistance G can be converted into

(a) a voltmeter of range V by connecting a high resistance R in series with it whose value is given by $R = \dfrac{V}{I_s} - G$

(b) an ammeter of range I by connecting a very low resistance (shunt) in parallel with galvanometer whose value is given by

$$S = I_g G / (I - I_g) \quad \textbf{(4)}$$

(ii) Refer to Sol. 9(i) on pages 140 and 141. **(1)**

35. Refer to Sol. 8 on page 140. **(1)**

36. (i) Torque on rectangular loop,

$$\tau = NIAB \sin\theta \quad \ldots(i)$$

Also, torque on the loop can be expressed in terms of magnetic moment of the coil and the magnetic field as

$$\tau = MB \sin\theta \quad \ldots(ii)$$

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

The magnetic dipole moment,

$$M = NIA$$

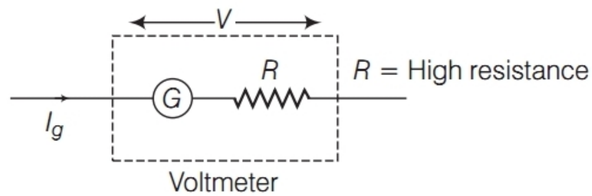
Also, $\mathbf{M}$ is along $\mathbf{A}$.

$$\Rightarrow \quad \mathbf{M} = NI\mathbf{A} \quad \textbf{(1)}$$

(ii) Refer to Sol. 8 on page 140. **(2)**

(iii) Given, $G = 50\ \Omega$,

$$I_g = 5 \times 10^{-3}\ \text{A},\ V = 15\ \text{V}$$



$$\because \quad V = I_g (G + R)$$

$$\Rightarrow \quad \boxed{R = \frac{V}{I_g} - G}$$

$$\Rightarrow \quad \frac{15}{5 \times 10^{-3}} - 50$$

$$\Rightarrow \quad R = 2950\ \Omega$$

A resistance $R = 2950\Omega$ is to be connected in series with galvanometer to convert it into a desired voltmeter. **(2)**

37. (i) Refer to Sol. 26 on pages 144 and 145. **(2)**

(ii) Refer to Sol. 26 on pages 144 and 145. **(2)**

(iii) Refer to Sol. 33 (ii) on page 146. **(1)**

38. (i) Refer to Sol. 9 (i) on pages 140 and 141. **(2)**

(ii) As, $\dfrac{F}{L} = \dfrac{\mu_0}{4\pi} \dfrac{2 I_1 I_2}{r}$

$$\Rightarrow \quad I_1 = I_2 = 1\ \text{A},\ r = 1\text{m}$$

$$\frac{F}{L} = 2 \times 10^{-7}\ \text{Nm}^{-1}$$

For definition Refer to Sol. 4 on page 139. **(1)**

(iii) Here, magnetic field due to the current carrying conductor at a distance d from it is given by

$$B = \frac{\mu_0}{4\pi} \frac{2I}{d} \quad \textbf{(1/2)}$$

∴ Force on proton,

$$F = (e)\,(v)\,B \sin 90°$$

$$\Rightarrow \quad F = evB$$

$$F = ev\left(\frac{\mu_0}{4\pi}\frac{2I}{d}\right)$$

$$F = \frac{\mu_0}{4\pi}\cdot\frac{2Iev}{d}$$ **(1)**

The proton is directed perpendicular to straight conductor and away from it. **(1/2)**

39. (i) Refer to Sol. 9 on pages 140 and 141. **(3)**

(ii) (a) The direction of the magnetic moment of the current loop is perpendicular to the plane of the paper and directed inward. **(1)**

(b) When angle between area vector of coil and magnetic field is 90°, then maximum torque experienced by the coil.

When $\theta = 0°$ or 180°, then torque will be minimum, i.e. zero. **(1)**