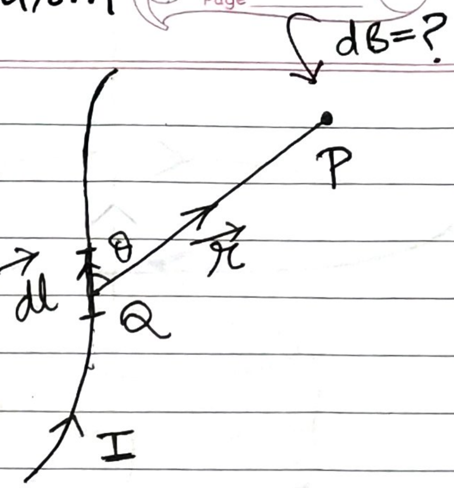
Unit-3 – Magnetic Effect of Current & Magnetism



Biot-Savart's Law:—

According to this law, magnetic field at point P due to current element at Q can be given by

$$dB \propto I \quad \text{—(i)}$$
$$dB \propto dl \quad \text{—(ii)}$$
$$dB \propto \sin\theta \quad \text{—(iii)}$$
$$dB \propto \frac{1}{r^2} \quad \text{—(iv)}$$

Combining (i) to (iv), we get

$$dB \propto \frac{I\,dl \sin\theta}{r^2}$$

$$dB = \frac{\mu_0}{4\pi} \times \frac{I\,dl \sin\theta}{r^2}$$

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

In vector form,

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I\,\vec{dl} \times \vec{r}}{r^3}$$

Right hand thumb rule:—

→ According to this rule if we hold a current carrying conductor with our right hand in such a way that the thumb denotes the direction of current then the curling of the fingers will denote the direction of magnetic field.

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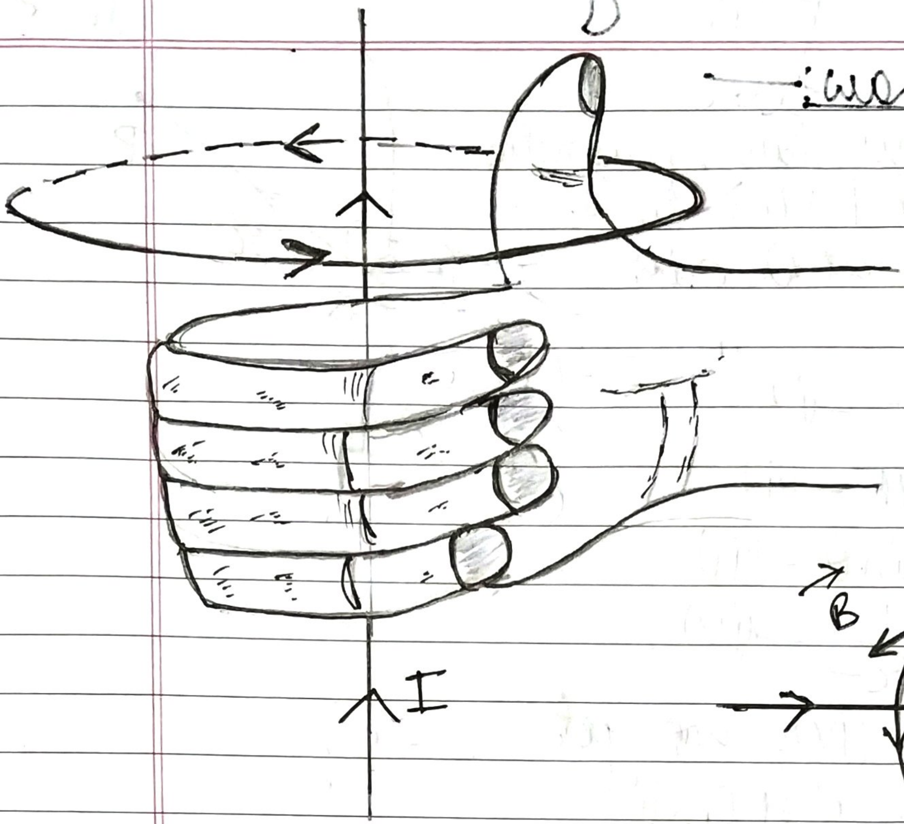
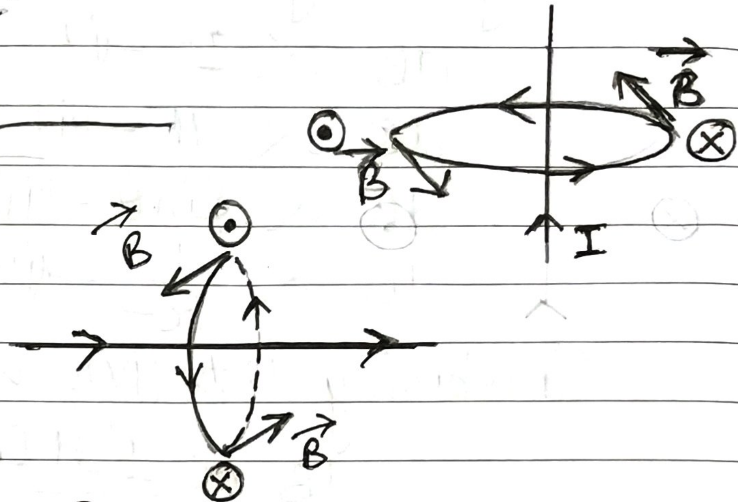
Biot-Savart's law:-

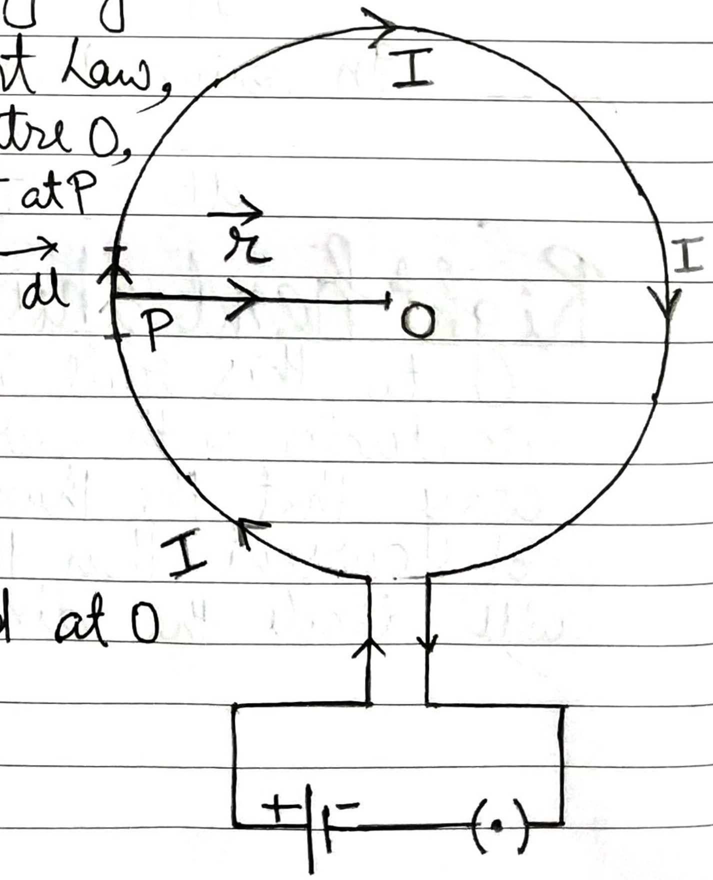




Applications of Biot-Savart Law:→

(A) Magnetic field at the centre of a current carrying circular coil:→

According to Biot-Savart Law, magnetic field at the centre O, due to current element at P can be given by



$$dB = \frac{\mu_0}{4\pi}\frac{I\,dl\,\sin 90^\circ}{r^2}$$

$$= \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}$$

Now, net magnetic field at O can be given by

$$B = \int_{l=0}^{l=2\pi r} dB$$

$$= \int_0^{2\pi r} \frac{\mu_0}{4\pi} \times \frac{I\,dl}{r^2}$$

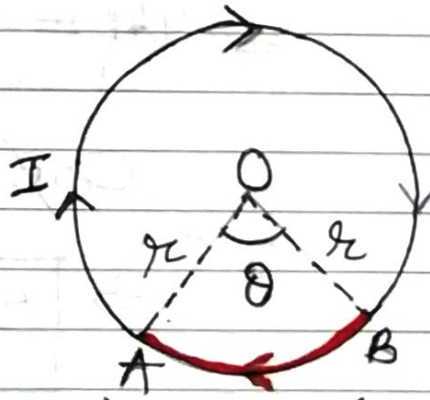
$$= \frac{\mu_0}{4\pi} \times \frac{I}{r^2} \int_0^{2\pi r} dl$$

$$= \frac{\mu_0}{4\pi} \times \frac{I}{r^2} \Big[l \Big]_0^{2\pi r}$$

$$= \frac{\mu_0}{4\pi} \times \frac{I}{r^2} \Big[2\pi r - 0 \Big]$$

$$= \frac{\mu_0}{\cancel{4\pi}_{\,2}} \times \frac{I}{r^{\cancel{2}}} \cancel{\times 2\pi r}$$

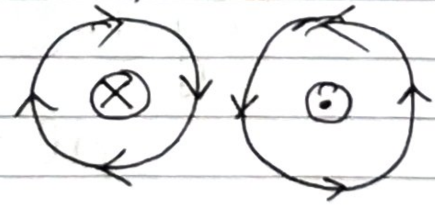
$$\boxed{B = \frac{\mu_0}{2} \times \frac{I}{r}} \quad \otimes$$



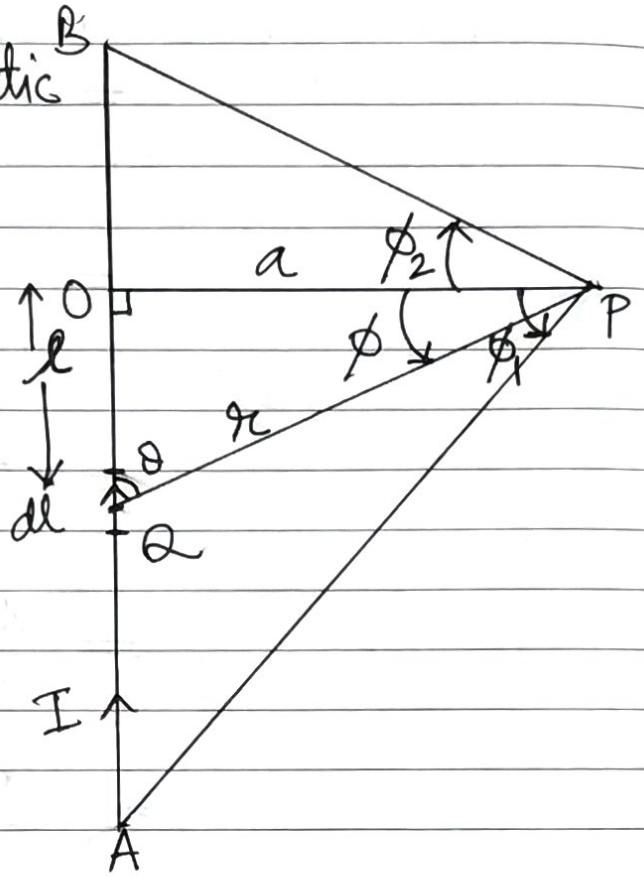
Note: ⟶

① $B_\theta = B_{AB} = \frac{\theta}{2\pi} \times \frac{\mu_0}{2} \times \frac{I}{r}$

② CHINTO ⇒ Clockwise hai
तो INTO



(B) Magnetic field due to a long current carrying conductor:



According to B.S.L. magnetic field at point P due to current element at Q can be given by

$$dB = \frac{\mu_0}{4\pi} \frac{I dl \sin\theta}{r^2} \quad \text{—①}$$

In ΔOPQ,

$$\theta + \phi = 90° \quad \text{—②}$$

$$\Rightarrow \theta = (90 - \phi)$$

$$\tan\phi = \frac{l}{a}$$

$$\Rightarrow l = a\tan\phi$$

$$\Rightarrow \frac{dl}{d\phi} = a\sec^2\phi$$

$$\Rightarrow \boxed{dl = a\sec^2\phi \, d\phi} \quad \text{—③}$$

$$\cos\phi = \frac{a}{r}$$

$$\Rightarrow \boxed{r = \frac{a}{\cos\phi}} \quad \text{—④}$$

By ①, ②, ③ & ④ we get

$$dB = \frac{\mu_0}{4\pi} \times \frac{I \times a \sec^2\phi \, d\phi \, \sin(90° - \phi)}{\frac{a^2}{\cos^2\phi}}$$

$$\Rightarrow dB = \frac{\mu_0}{4\pi} \frac{I \cancel{a} \cancel{\sec^2\phi} \cancel{\cos^2\phi} \, d\phi \, \cos\phi}{a^{\cancel{2}}}$$

$$\Rightarrow dB = \frac{\mu_0}{4\pi} \times \frac{I}{a} \cos\phi \, d\phi$$

Now, net magnetic field at point P can be given by

$$B = \int_{-\phi_1}^{\phi_2} dB$$

$$= \int_{-\phi_1}^{\phi_2} \frac{\mu_0}{4\pi} \times \frac{I}{a} \cos\phi \, d\phi$$

$$= \frac{\mu_0}{4\pi} \times \frac{I}{a} \int_{-\phi_1}^{\phi_2} \cos\phi \, d\phi$$

$$= \frac{\mu_0}{4\pi} \times \frac{I}{a} \Big[\sin\phi \Big]_{-\phi_1}^{\phi_2}$$

$$= \frac{\mu_0}{4\pi} \times \frac{I}{a} \left[\sin\phi_2 - \sin(-\phi_1) \right]$$

$$= \frac{\mu_0}{4\pi} \times \frac{I}{a} \left[\sin\phi_2 + \sin\phi_1 \right]$$

$$\Rightarrow \boxed{B = \frac{\mu_0}{4\pi} \times \frac{I}{a} \left[\sin\phi_1 + \sin\phi_2 \right]}$$

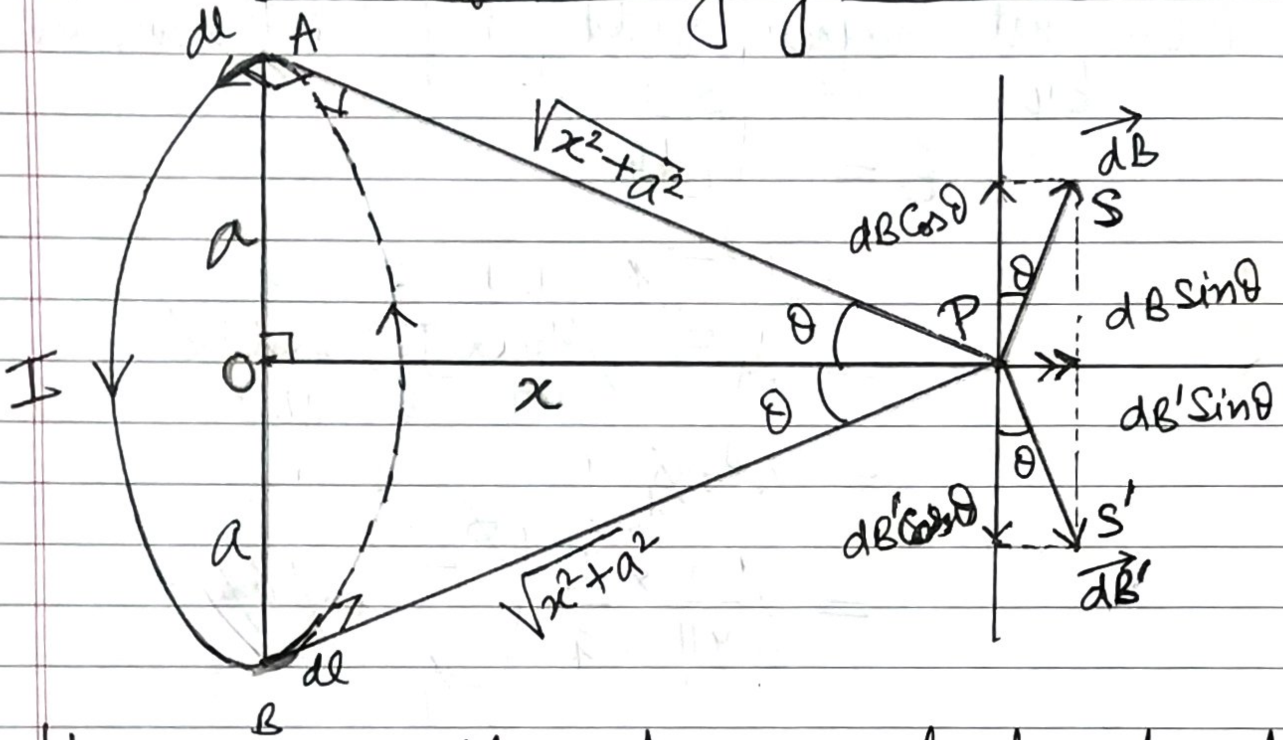
For infinitely long wire

$$\phi_1 \longrightarrow \pi/2, \quad \phi_2 \longrightarrow \pi/2$$

$$\therefore B = \frac{\mu_0}{4\pi} \times \frac{I}{a} \left[\sin\pi/2 + \sin\pi/2 \right]$$

$$\boxed{B = \frac{\mu_0}{4\pi} \times \frac{2I}{a}}$$

(c) Magnetic field on the axis of the current carrying circular coil :→



We can consider two current elements at points A and B on this coil which are diametrically opposite to each other. According to B.S.L. magnetic field at point P due to current elements at A and B can be given by

$$dB = |\vec{dB}| = \frac{\mu_0}{4\pi}\frac{I\,dl\,\sin 90^\circ}{(x^2+a^2)} = \frac{\mu_0\, I\,dl}{4\pi\,(x^2+a^2)}$$

along PS

$$dB' = |\vec{dB'}| = \frac{\mu_0}{4\pi}\frac{I\,dl\,\sin 90^\circ}{(x^2+a^2)} = \frac{\mu_0\, I\,dl}{4\pi\,(x^2+a^2)}$$

along PS'

$dB = dB'$

Now, we can resolve $\vec{dB}$ and $\vec{dB'}$ along the axis of coil and ⊥ to it.

$dB\cos\theta$ and $dB'\cos\theta$ being equal in magnitude but opposite in direction will cancel each other

$\Sigma dB\cos\theta = 0$ (Pairwise)

Net magnetic field at point P can be given by

$$B = \int_{l=0}^{l=2\pi a} dB\sin\theta$$

$$= \int_0^{2\pi a} \frac{\mu_0}{4\pi} \frac{I\,dl}{(x^2+a^2)} \times \frac{a}{\sqrt{x^2+a^2}}$$

$$= \frac{\mu_0}{4\pi} \times \frac{Ia}{(x^2+a^2)^{3/2}} \int_0^{2\pi a} dl$$

$$= \frac{\mu_0}{4\pi} \times \frac{Ia \times 2\pi a}{(x^2+a^2)^{3/2}}$$

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

$$= \frac{\mu_0}{4\pi} \times \frac{2IA}{(x^2+a^2)^{3/2}} \quad [\pi a^2 = A = \text{Area of the coil}]$$

For N turns,

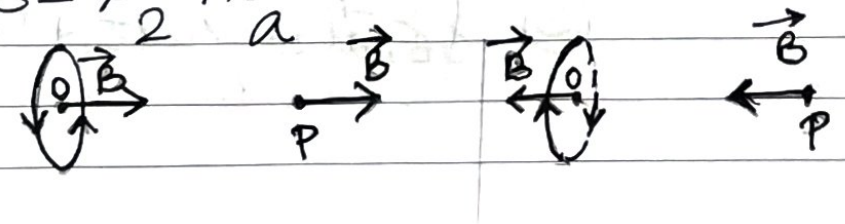
$$B = \frac{\mu_0}{4\pi} \times \frac{2NIA}{[x^2+a^2]^{3/2}} \quad \text{——— (1)}$$

Here, $NIA = M =$ Magnetic moment of the coil

$$\boxed{B = \frac{\mu_0}{4\pi} \times \frac{2M}{(x^2+a^2)^{3/2}}}$$

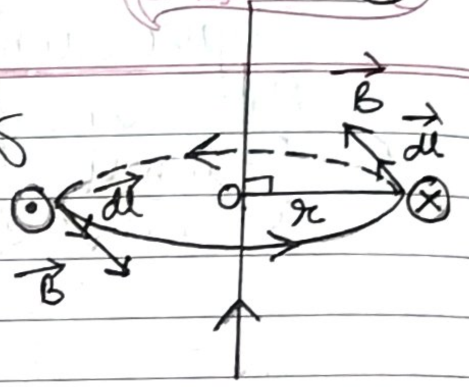
Note:— (1) For $N=1$, $x=0$ (i.e at the centre of coil)

$$B = \frac{\mu_0}{2} \times \frac{I}{a}$$

(2) 

Ampere's circuital law:-

It states that line integral of magnetic field over a closed loop in is equal to μ_0 times the current threading through the loop.



i.e. $\oint \vec{B}.\vec{dl} = \mu_0 I$

Proof:- $LHS = \oint \vec{B}.\vec{dl}$

$= \oint B\,dl \cos 0^\circ$

$= \oint \frac{\mu_0}{4\pi} \times \frac{2I}{r} dl$

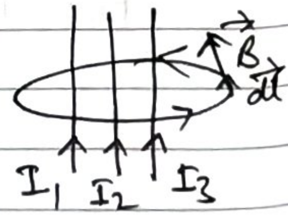
$= \frac{\mu_0}{4\pi} \times \frac{2I}{r} \oint dl$

$= \frac{\mu_0}{4\pi} \times \frac{2I}{r} \times 2\pi r$

$= \mu_0 I$

$= RHS$

A Note:- ① $\oint \vec{B}.\vec{dl} = \mu_0(I_1 + I_2 + I_3)$



② If $I_1 = I_2 = I_3 = I$

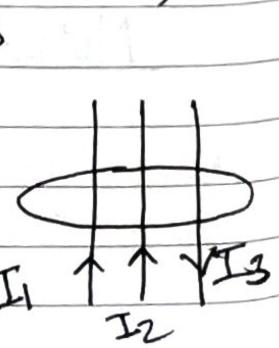
$\oint \vec{B}.\vec{dl} = \mu_0(3I)$

For N wires

$\oint \vec{B}.\vec{dl} = \mu_0(\underbrace{I + I + \ldots\ldots + I}_{N \text{ times}})$

$= \mu_0(NI)$

③ $\oint \vec{B}.\vec{dl} = \mu_0(I_1 + I_2 - I_3)$



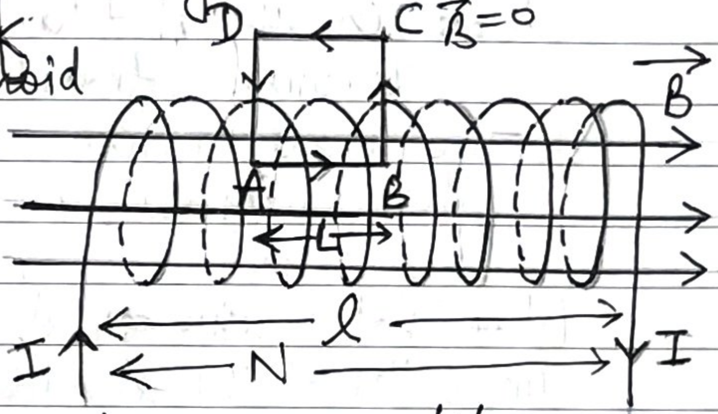
Applications of Ampere's Circuital Law:—

(A) Magnetic field inside a long solenoid:⟶

Let N = Total number of turns of the solenoid

l = length of the solenoid

$n = \frac{N}{l}$ = number of turns per unit length



We can consider a small square loop ABCD having side 'L'

Applying Ampere's circuital law over this loop,

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 (NI)$$

Total number of Ampere turns

$$\Rightarrow \int_A^B \vec{B}\cdot\vec{dl} + \int_B^C \vec{B}\cdot\vec{dl} + \int_C^D \vec{B}\cdot\vec{dl} + \int_D^A \vec{B}\cdot\vec{dl} = \mu_0 (NI) \quad \text{—— (1)}$$

Here $\int_A^B \vec{B}\cdot\vec{dl} = \int_A^B B\,dl\cos 0^\circ = B\int_A^B dl = BL$ —— (2)

$$\int_B^C \vec{B}\cdot\vec{dl} = 0 \quad \text{—— (3)} \quad [\because \vec{B} \perp \vec{dl}]$$

$$\int_C^D \vec{B}\cdot\vec{dl} = 0 \quad \text{—— (4)} \quad [\because \vec{B} = 0]$$

$$\int_D^A \vec{B}\cdot\vec{dl} = 0 \quad \text{—— (5)} \quad [\vec{B} \perp \vec{dl}]$$

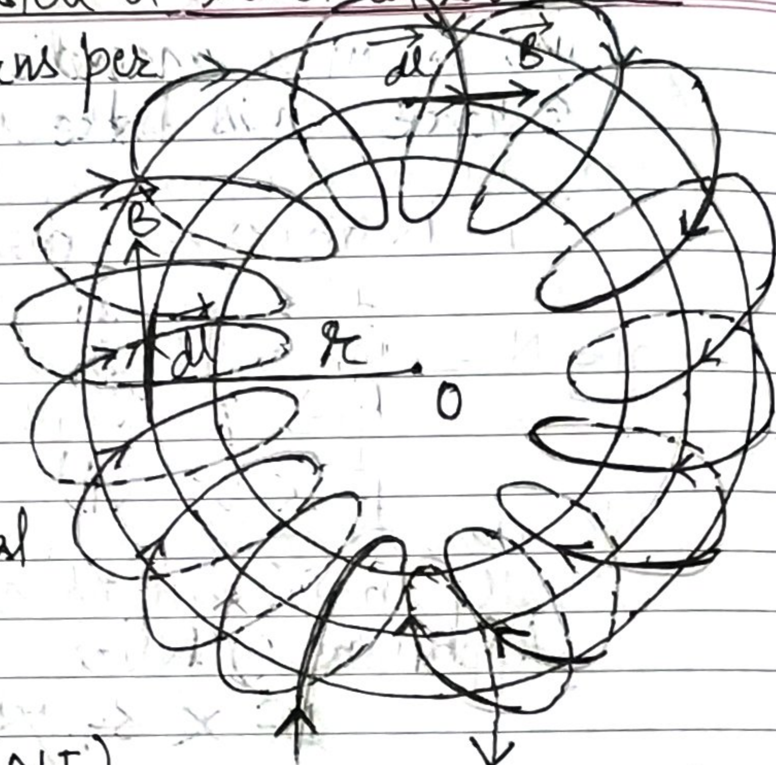
By (1), (2), (3), (4) & (5), we get

$$BL + 0 + 0 + 0 = \mu_0 (NI)$$

$$\Rightarrow BL = \mu_0 (nL) I$$

$$\Rightarrow \boxed{B = \mu_0 n I}$$

(B) Magnetic field inside a toroidal solenoid:—



let n = number of turns per unit length

r = radius of the toroidal solenoid

I = Current inside the toroidal solenoid

N = Total number of turns ~~the~~ of the toroidal solenoid

Applying Ampere's circuital law

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 (NI)$$

Number of Ampere turns

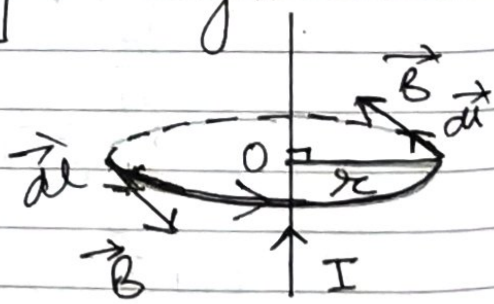
$$\Rightarrow \oint B\,dl\cos 0^\circ = \mu_0 (n\times 2\pi r) I$$

$$\Rightarrow B\oint dl = \mu_0 \times n \times 2\pi r I$$

$$\Rightarrow B\times \cancel{2\pi r} = \mu_0 \times n \times \cancel{2\pi r} I$$

$$\Rightarrow \boxed{B = \mu_0 n I}$$

(C) Magnetic field due to a long straight wire:—



According to A.C.L.

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I$$

$$\Rightarrow \oint B\,dl\cos 0^\circ = \mu_0 I$$

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

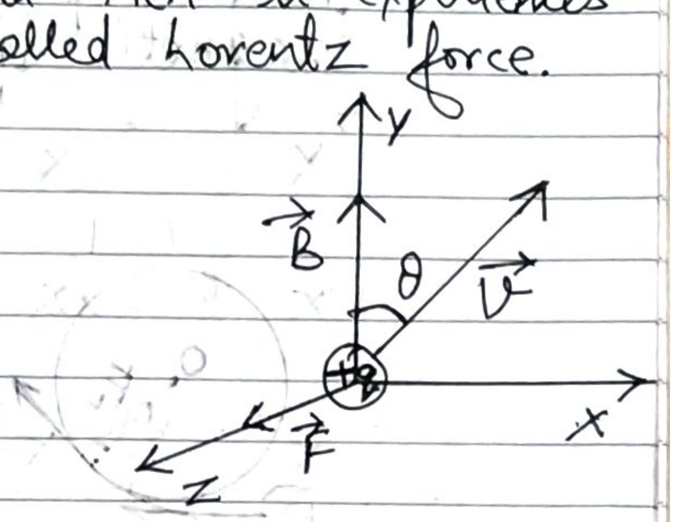
$$\Rightarrow B\times 2\pi r = \mu_0 I$$

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

$$\Rightarrow \boxed{B = \frac{\mu_0}{4\pi}\times\frac{2I}{r}}$$

Lorentz Force :—

When a charged particle moves in a magnetic field then it experiences a force, this force is called Lorentz force.



It is observed that

$F \propto B$ —(i)

$F \propto q$ —(ii)

$F \propto v$ —(iii)

$F \propto \sin\theta$ —(iv)

Combining (i) to (iv) we get

$$F \propto Bqv \sin\theta$$

$$F = KBqv \sin\theta$$

In SI system, the value of K is found to be 1

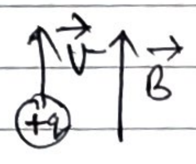
$$\therefore F = Bqv \sin\theta$$

In vector form,

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

Note ① If electric field $\vec{E}$ is also present in the space, so total Lorentz force can be given by $\vec{F} = q(\vec{v} \times \vec{B}) + q\vec{E}$

② If θ is zero or 180°

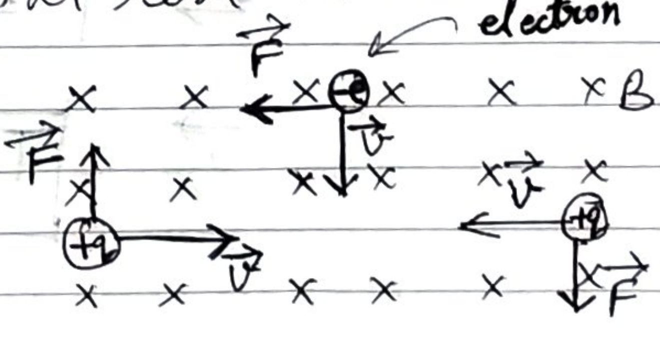


$$F = Bqv \sin 0^\circ = 0$$

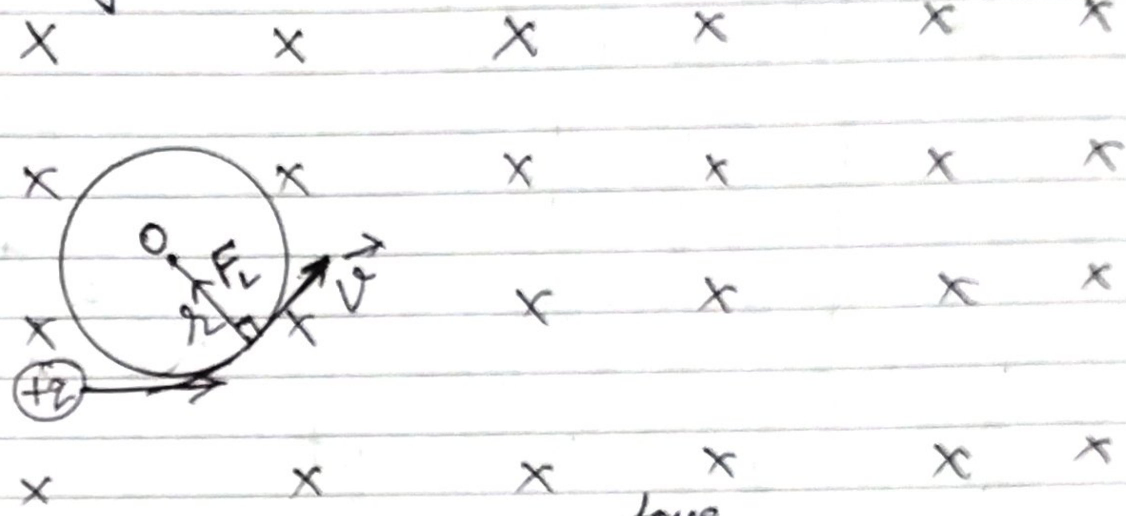
③ If particle is at rest i.e. $v = 0$

$$F = 0$$

④



Radius of the circular path attained by a charged particle entering in a uniform magnetic field perpendicularly:—



The necessary centripetal force is provided by the Lorentz force

$\therefore F_C$ (centripetal force) $= F_L$ (Lorentz force)

$$\Rightarrow \frac{mv^2}{r} = Bqv \sin 90^\circ$$

$$\Rightarrow \boxed{r = \frac{mv}{Bq}}$$

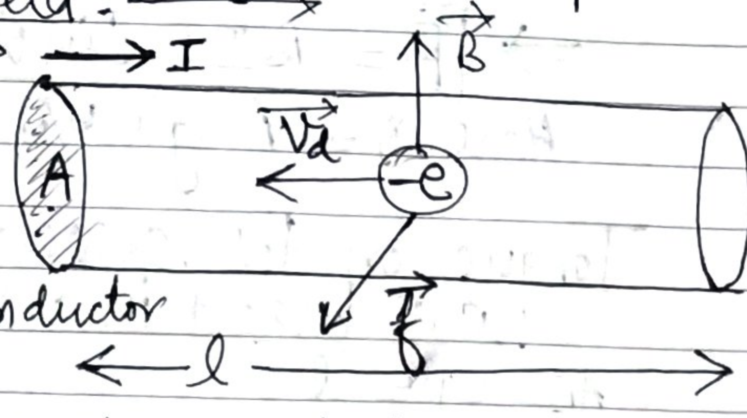
Time Period, T = $\frac{\text{Total distance covered}}{}$

$$T = \frac{2\pi r}{v}$$

$$\Rightarrow T = \frac{2\pi}{\cancel{v}} \times \frac{m\cancel{v}}{Bq}$$

$$\Rightarrow \boxed{T = \frac{2\pi m}{Bq}}$$

Force on a current carrying conductor placed in a magnetic field:



Let A = Area of cross-section of the conductor
l = length of the conductor
v_d = Drift velocity
I = Current through the conductor
n = no. of free electrons per unit volume
B = Magnetic field

Total volume of the conductor $= Al$

Total no. of free electrons in this volume can be given by $N = n(Al)$

Lorentz force on an electron can be given by

$$\vec{f} = -e(\vec{v_d} \times \vec{B})$$

∴ Net force on the conductor = Net force on 'N' electrons

$$\Rightarrow \vec{F} = N\vec{f}$$

$$\Rightarrow \vec{F} = (nAl) \times -e(\vec{v_d} \times \vec{B})$$

$$\Rightarrow \vec{F} = -neAl\vec{v_d} \times \vec{B} \quad -(1)$$

The relation b/w I and v_d can be given by

$$I = neAv_d$$

$$\Rightarrow Il = neAlv_d$$

In vector form,

$$\Rightarrow I\vec{l} = -neAl\vec{v_d} \quad -(2)$$

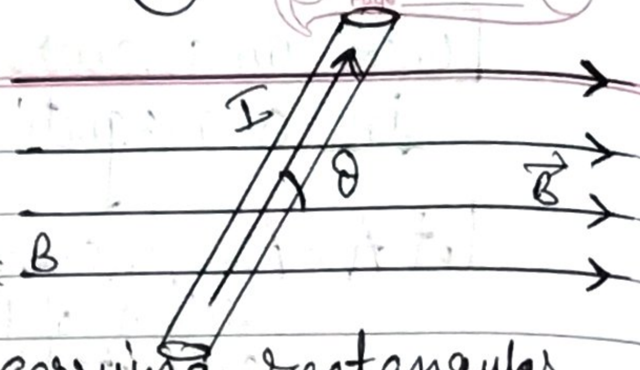
By (1) & (2) $\vec{F} = I\vec{l} \times \vec{B}$

$$\Rightarrow \vec{F} = I(\vec{l} \times \vec{B})$$

$F = I l B \sin\theta$

$\Rightarrow \boxed{F = BIl \sin\theta}$

Here θ = Angle b/w I & B



Torque on the current carrying rectangular coil placed in a uniform magnetic field:

$AB = CD = l$

$AD = BC = b$

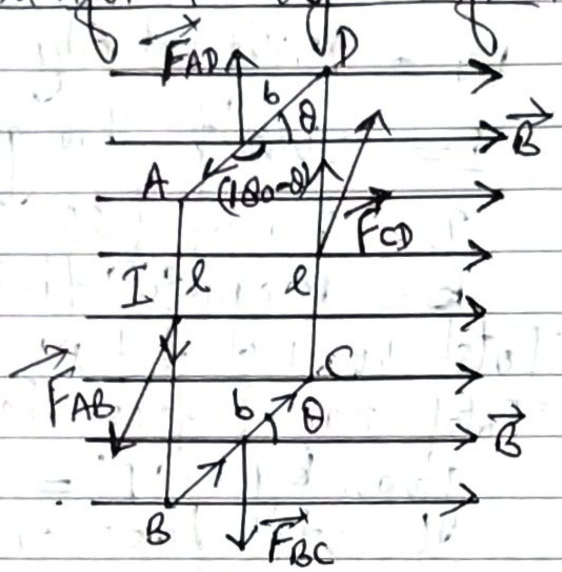
$F_{AD} = BIb \sin(180° - \theta)$

$F_{AD} = BIb \sin\theta$

$F_{BC} = BIb \sin\theta$

$F_{AB} = BIl \sin 90°$
$= BIl$

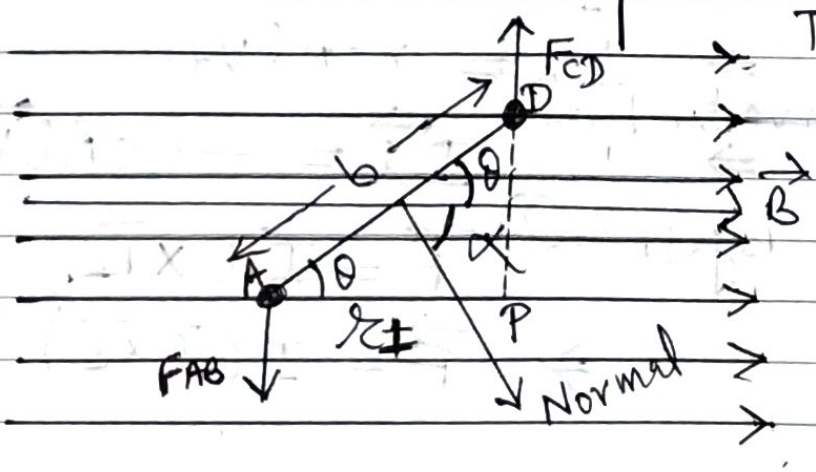
$F_{CD} = BIl \sin 90° = BIl$



Forces $\vec{F}_{AD}$ and $\vec{F}_{BC}$ are equal in magnitude opposite in direction and also they are acting along the same line of action, so these forces will cancel each other

While forces $\vec{F}_{AB}$ and $\vec{F}_{CD}$ are equal in magnitude opposite in direction ~~and also~~ but acting along the different lines of action, so these forces will create a couple.

Top view



$\theta + \alpha = 90°$

$\cos\theta = \frac{AP}{AD}$

$\Rightarrow \cos\theta = \frac{AP}{b}$

$\Rightarrow AP = b\cos\theta$

Torque due to this couple can be given by

$\tau = r_{\perp} \times$ magnitude of either force

$\Rightarrow \tau = AP \times BIl$

$\tau = b\cos\theta \times BIl$

Here $lb = A =$ Area of the rectangular coil

$\therefore \tau = IAB\cos\theta$

For N turns, $\tau = NIAB\cos\theta$

$\Rightarrow \tau = NIAB\cos(90^\circ - \alpha)$

$\Rightarrow \boxed{\tau = NIAB\sin\alpha}$

Here, $NIA = M =$ Magnetic moment of the coil

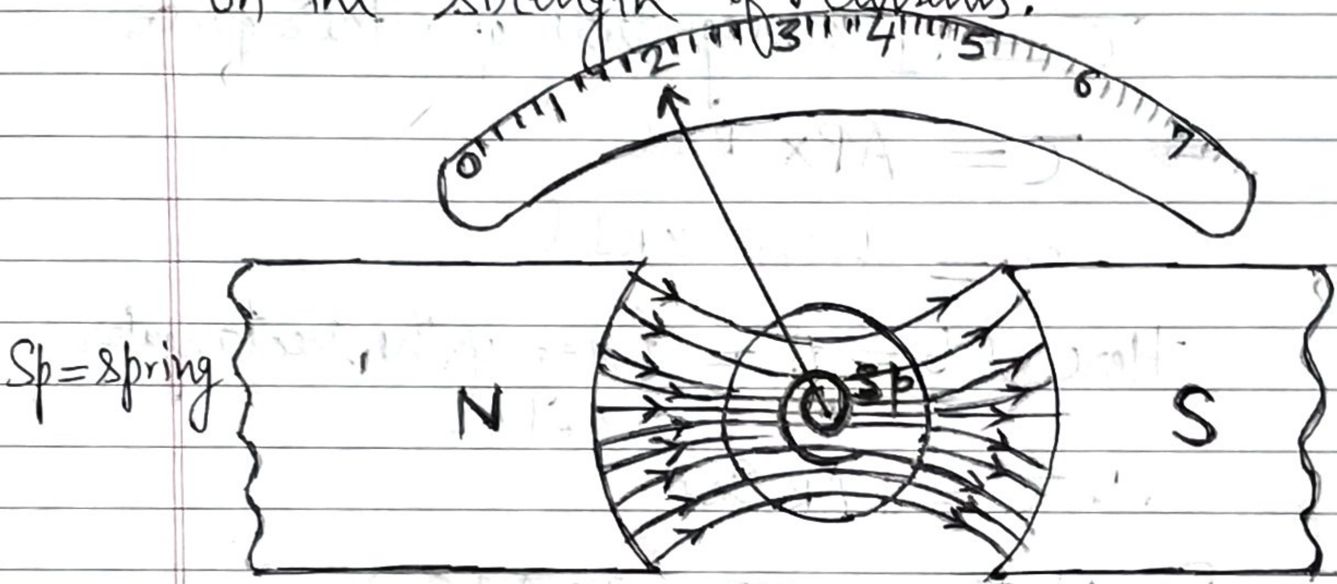
$\therefore \tau = MB\sin\alpha$

In vector form, $\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$

Q. With the help of a neat and labelled diagrams, explain the underlying principle, construction and working of a moving ~~coil~~ coil galvanometer. What is the function of (i) uniform radial field (ii) Soft iron core in such a device?

Ans:- It is a device which is used to detect the current in a circuit.

Principle:→ Its principle is based on the fact that when a current carrying coil is kept in a magnetic field then it experiences a torque, the magnitude of which depends on the strength of currents.



Construction:⟶ It consists of a rectangular coil of fine insulated copper wire wound on a light non-magnetic metallic (aluminium) frame. The two ends of the axle of this frame are pivoted b/w two jewelled bearings. The motion of the coil is controlled by a pair of hair springs of phosphor bronze. The springs provide the restoring torque and serve as current leads. A light aluminium pointer attached to the coil measures its deflection on a suitable scale.

The coil is symmetrically placed b/w the cylindrical pole pieces of a strong permanent horse-shoe magnet.

A cylindrical soft iron core is mounted symmetrically b/w the concave poles of the horse-shoe magnet. This makes the lines of force pointing along the radii of a circle. Such a field is called a radial field. The plane of a coil rotating in such a field remains parallel to the field in all positions, as shown in figure. Also, the soft iron cylinder, due to its high permeability, intensifies the magnetic field and hence increases the sensitivity of the galvanometer.

Theory & Working :→ As the field is radial, the plane of the coil always remains parallel to the magnetic field B ($\alpha \approx 90^\circ$). When a current flows through the coil, a torque acts on it. It is given by

$$\tau_{def} = NIAB \sin 90^\circ = NIAB \quad \text{--- (1)}$$

The torque τ_{def} deflects the coil through an angle θ. A restoring torque is set up in the coil due to the elasticity of the springs such that

$$\tau_{res} \propto \theta$$

$$\Rightarrow \tau_{res} = K\theta \quad \text{--- (2)}$$

where 'K' is the ~~torsional~~ torsion constant of the spring i.e. torque required to produce unit angular twist.

In equilibrium position,

Deflecting torque = Restoring torque

$$\Rightarrow \tau_{def} = \tau_{res}$$

$$\Rightarrow NIAB = K\theta$$

$$\Rightarrow I = \left(\frac{K}{NAB}\right)\theta$$

Here $\frac{K}{NAB} = G =$ galvanometer constant

$$I \propto \theta$$

Thus, the deflection produced in the galvanometer coil is proportional to the current flowing through it.

→ A uniform magnetic field provides a linear scale.

→ A soft iron core makes the field radial. It also increases the strength of the ~~galvanometer~~ magnetic field & hence increases the sensitivity of the galvanometer.

Figure of merit of galvanometer :→ It is defined as the current which produces a deflection of one scale division in the galvanometer and is given by

$$\text{Figure of merit} = \frac{\theta}{I}$$

$$= \frac{\theta}{K\theta/NAB}$$

$$= \frac{NAB}{K}$$

Sensitivity of a galvanometer :→ A galvanometer is said to be sensitive if it shows large ~~de~~ scale deflection even when a small current is passed through it or a small voltage is applied across it.

Current Sensitivity (I_s) :→

$$I_s = \frac{\theta}{I}$$

$$\Rightarrow I_s = \frac{\theta}{K\theta/NAB}$$

$$I_s = \frac{\cancel{\theta} \times NAB}{K\cancel{\theta}}$$

$$\Rightarrow I_s = \frac{NAB}{K}$$

It is defined as the deflection produced in the galvanometer when a unit current flows through it.

Voltage sensitivity (V_s) :→ It is defined as the deflection produced in the galvanometer when a unit potential difference is applied across its ends.

Voltage sensitivity,

$$V_s = \frac{\theta}{V} = \frac{\theta}{IR}$$

$$\Rightarrow V_s = \frac{\theta}{\frac{K\theta}{NAB} \times R}$$

$$\Rightarrow \boxed{V_s = \frac{NAB}{KR}}$$

$$\Rightarrow \text{Voltage sensitivity} = \frac{\text{Current sensitivity}}{R}$$

Factors on which the sensitivity of a moving coil galvanometer depends :→

1. Number of turns N in its coil.
2. Magnetic field B.

3. Area A of the coil.
4. Torsion constant k of the spring and suspension wire.

Factors by which the sensitivity of a moving coil galvanometer can be increased:-

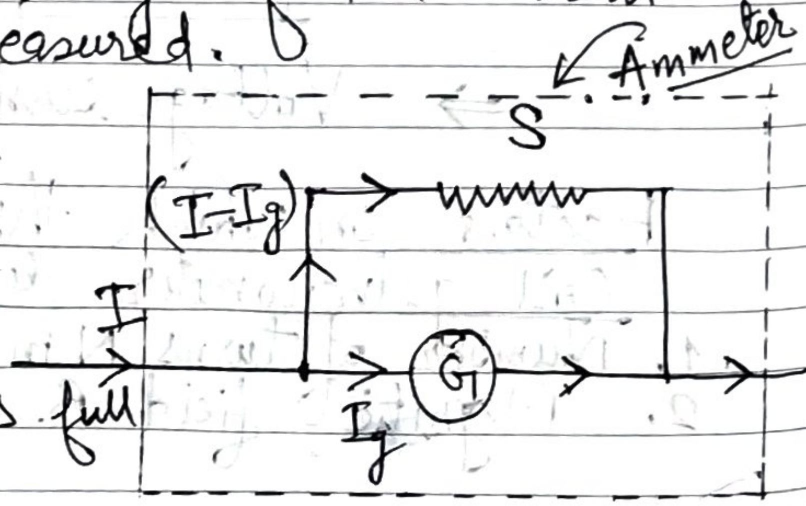
1. By increasing the number of turns N of the coil.
2. By increasing the magnetic field B.
3. By increasing the area A of the coil.
4. By decreasing the value of torsion constant k.

Conversion of a galvanometer into a voltmeter: → ammeter

To measure large currents with it, a small resistance is connected in parallel with the galvanometer coil. The resistance connected in this way is called a shunt. Only a small part of the total current passes through the galvanometer and remaining current passes through the shunt. The value of shunt resistance depends on the range of the current required to be measured.

G = resistance of the galvanometer

I_g = the current with which galvanometer gives full scale deflection.



$0 \rightarrow I$ = the required current range of the ammeter

S = Shunt resistance

$(I-I_g)$ = Current through the shunt

$$(I-I_g)S = I_g G.$$

$$\Rightarrow \boxed{S = \frac{I_g G}{(I-I_g)}}$$

Let R_A = total resistance of the ammeter

$$\frac{1}{R_A} = \frac{1}{G} + \frac{1}{S}$$

$$\Rightarrow \frac{1}{R_A} = \frac{(S+G)}{GS}.$$

$$\Rightarrow \boxed{R_A = \frac{GS}{(G+S)}}$$

As $S << G$

$$\therefore R_A \simeq \frac{\cancel{G}S}{\cancel{G}}$$

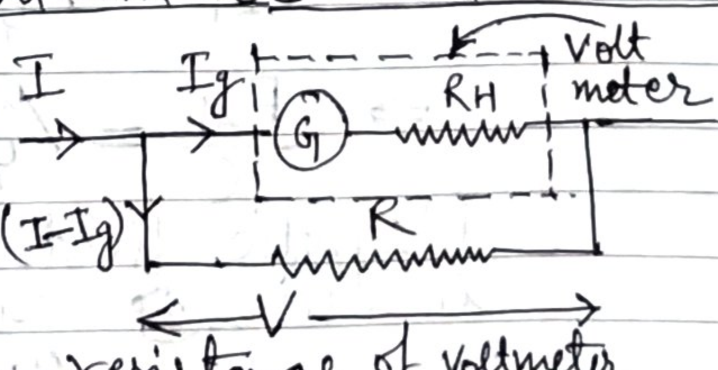
$$\Rightarrow \boxed{R_A \simeq S}$$

Conversion of a galvanometer into a voltmeter:→

$$I_g(G+R_H) = V$$

$$\Rightarrow G+R_H = \frac{V}{I_g}$$

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



Let R_V = resistance of voltmeter

$$R_V = (G+R_H)$$

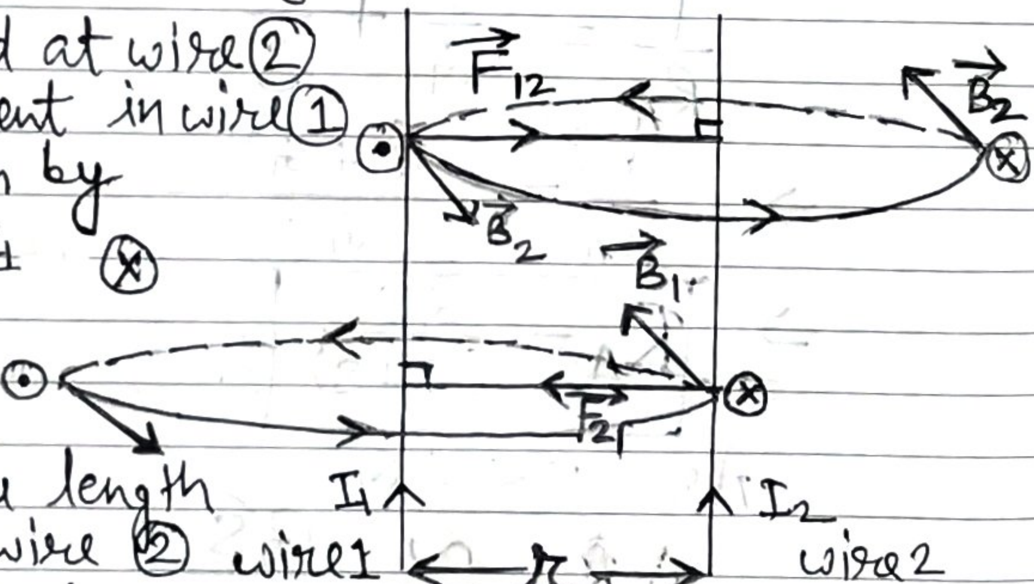
A galvanometer can be converted into a voltmeter by connecting a high resistance in series with it. The value of this resistance is so adjusted that only current I_g which produces full scale deflection in the galvanometer, passes through the galvanometer.

Force b/w two current carrying parallel wires:→

(A) When current flows in the same direction:→

Magnetic field at wire 2 due to current in wire 1 can be given by

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{2I_1}{r} \quad \otimes$$



Force on the length 'l' of the wire 2 can be given by

$$F_{21} = B_1 I_2 l \sin 90^\circ$$

$$F_{21} = \frac{\mu_0}{4\pi} \times \frac{2I_1}{r} \times I_2 l$$

$$\Rightarrow \frac{F_{21}}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1 I_2}{r} \ (N/m) \text{ towards wire 1} \quad \text{—(1)}$$

Magnetic field at wire 1 due to current in wire 2 can be given by

$$B_2 = \frac{\mu_0}{4\pi} \times \frac{2I_2}{r} \quad \odot$$

Force on the length 'l' of the wire ① can be given by

$$F_{12} = B_2 I_1 l \sin 90^\circ$$

$$F_{12} = \frac{\mu_0}{4\pi} \times \frac{2I_2}{r} I_1 l$$

$$\Rightarrow \boxed{\frac{F_{12}}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1I_2}{r}} \text{ (N/m) towards wire ②}$$

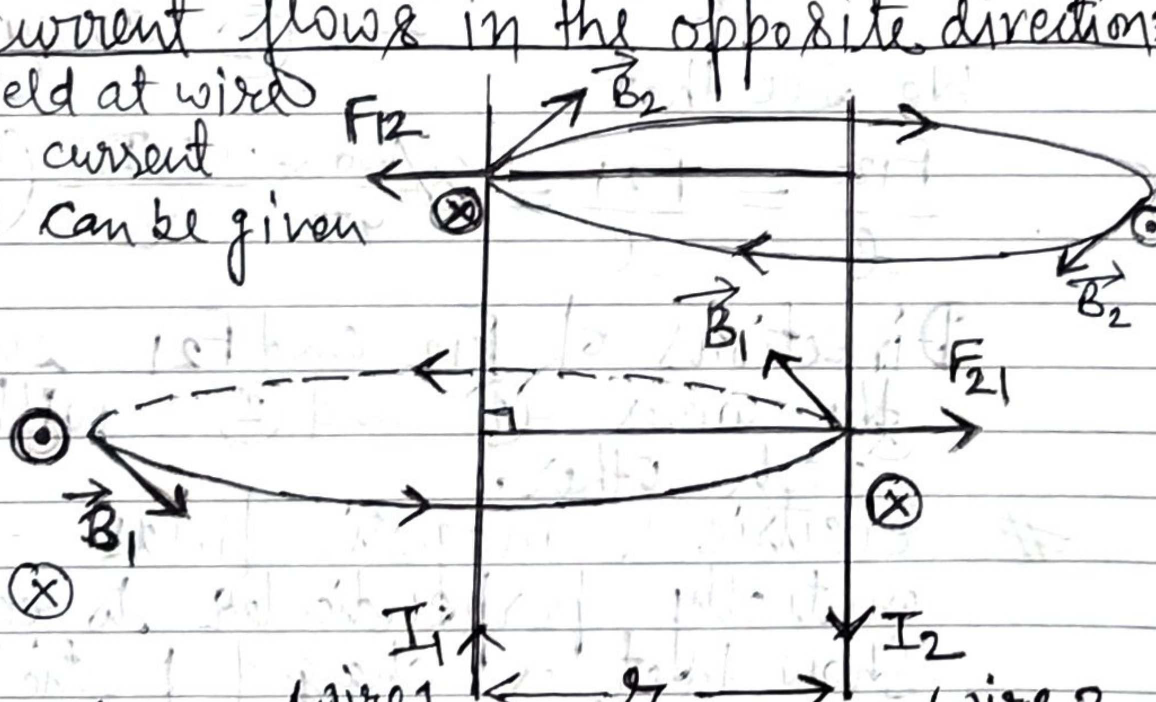
We ~~see~~ that

$$\frac{F_{21}}{l} = \frac{F_{12}}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1I_2}{r} \text{ (N/m)}$$

Directions of F_{12} and F_{21} suggest that the wires ① and ② will attract each other.

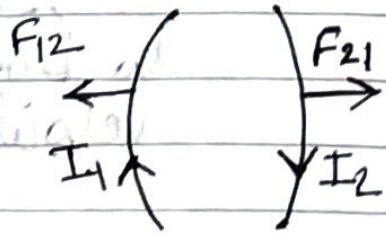
(B) When current flows in the opposite direction:-

Magnetic field at wire ② due to current in wire ① can be given by



$$B_1 = \frac{\mu_0}{4\pi} \times \frac{2I_1}{r} \otimes$$

Force on the length 'l' of the wire ② can be given by



$$F_{21} = B_1 I_2 l \sin 90^\circ$$

$$\Rightarrow F_{21} = \frac{\mu_0}{4\pi} \times \frac{2I_1}{r} I_2 l$$

$$\Rightarrow \frac{F_{21}}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1I_2}{r} \text{ (N/m)} \quad ~~towards wire~~ \text{ away from wire (1)} \quad \text{— (1)}$$

Magnetic field at wire (1) due to current in wire (2) can be given by

$$B_2 = \frac{\mu_0}{4\pi} \times \frac{2I_2}{r} \otimes$$

Force on the length l of the wire (1) can be given by

$$F_{12} = B_2 I_1 l \sin 90^\circ$$

$$\Rightarrow F_{12} = \frac{\mu_0}{4\pi} \times \frac{2I_2}{r} I_1 l$$

$$\Rightarrow \frac{F_{12}}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1I_2}{r} \text{ (N/m)} \quad \text{— (2)}$$

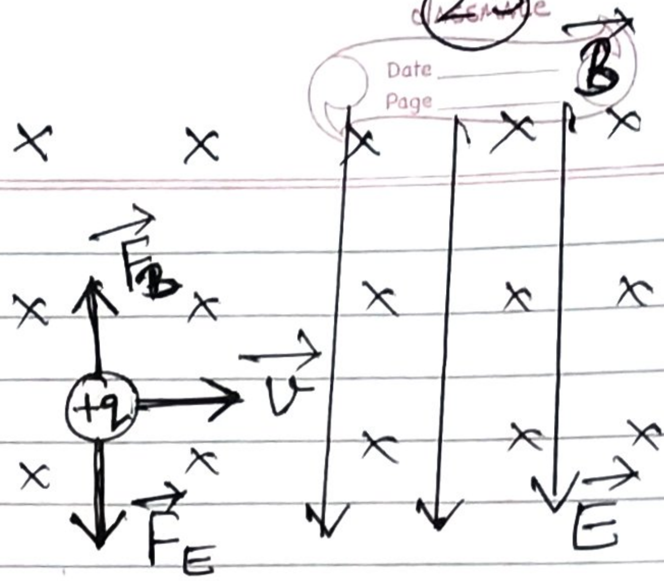
away from wire (2)

We see that

$$\frac{F_{12}}{l} = \frac{F_{21}}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1I_2}{r} \text{ (N/m)}$$

Directions of F_{12} and F_{21} suggest that the wires (1) and (2) will repel each other.

\# Electric & magnetic fields are applied mutually perpendicular to each other. Show that a charged particle will follow a straight line path perpendicular to both of these fields, if its velocity is E/B in magnitude.



Answer:— $\vec{E} \perp \vec{B}$

Charged particle will follow a straight line

if $\vec{F}_{net} = \vec{0}$

$\Rightarrow \vec{F_B} + \vec{F_E} = \vec{0}$

$\Rightarrow q(\vec{v} \times \vec{B}) + q\vec{E} = \vec{0}$

$\Rightarrow \cancel{q}(\vec{v} \times \vec{B}) = -\cancel{q}\vec{E}$

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

$\Rightarrow |\vec{v} \times \vec{B}| = |-\vec{E}|$

$\Rightarrow vB \sin 90^\circ = E$

$\Rightarrow vB = E$

$\Rightarrow \boxed{v = \frac{E}{B}}$

Note:— Direction of magnetic moment $\vec{M}$ of a coil can be taken along the direction of its own magnetic field