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Ch-4

Moving charges and magnetism

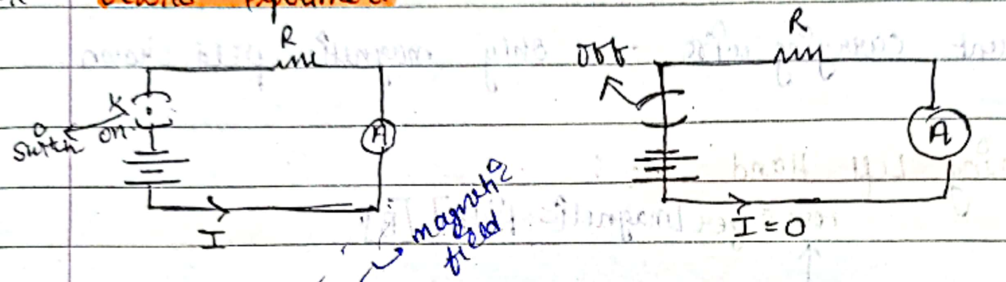
↓ Electrodynamics [charge is in motion]

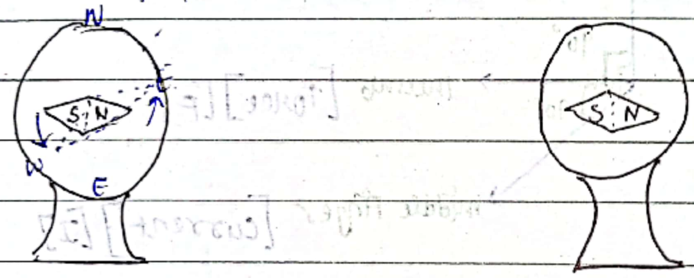
↳ Phenomenon of attraction b/w ferrous material & magnet.

✱ **Compass Niddle :**

⇒ It is also called as bar magnet.

✱ **Oersted experiment.**





No deflection of compass needle because there is no flow of current.

Movement of compass needle

⇒ N-pole → Towards west

S-pole → Towards east

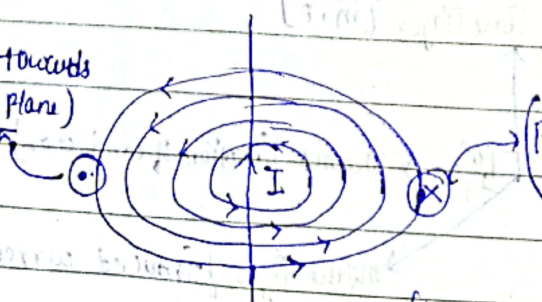
⇒ Anti-clockwise.

• Current carrying wire : contain magnetic field around conductor.

✱ **Right hand thumb rule** ; observer

⊙ → Anti clockwise

(Field line towards outside the plane)



(Field line ~~___~~ towards inside the plane)

⊗ → clockwise

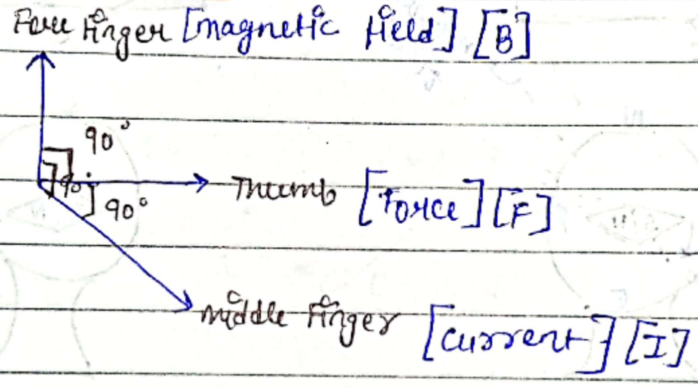
• current carrying wire form ...etic field

✱ Thumb : Dirⁿ of current
... magnetic field.

⇒ A current or a field [electric or magnetic] emerging out of the plane of the paper is depicted by a dot [⊙]. A current or a field going into the plane of the paper is depicted by a cross [⊗].

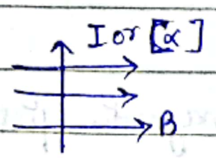
- Due to charge → electric field is shown
- Due to moving charge → electric as well as magnetic field is shown
- Current carrying wire → only magnetic field shown.

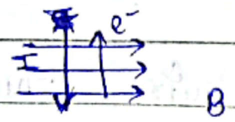
* **Fleming Left Hand Rule :**



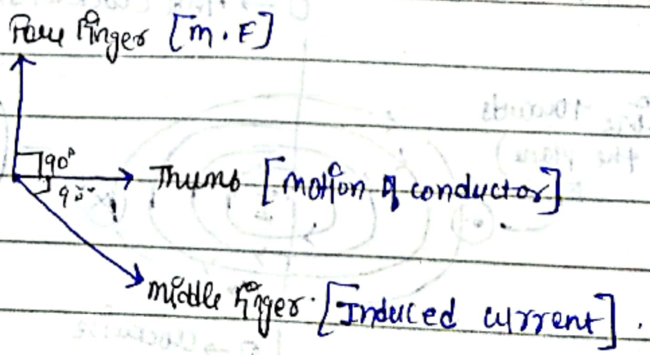
⇒ **Application :**
- Electric motor
- washing machine
- Fan.

⇒ **Note :**





* **Fleming Right Hand Rule :**



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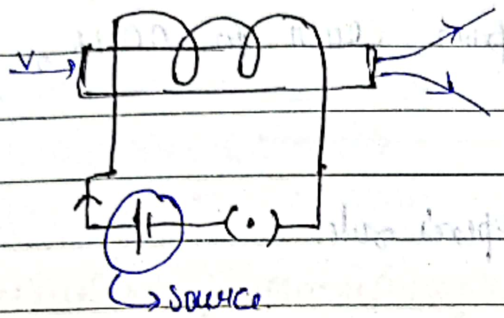
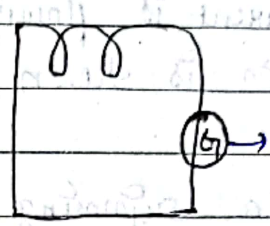
⇒ Application.

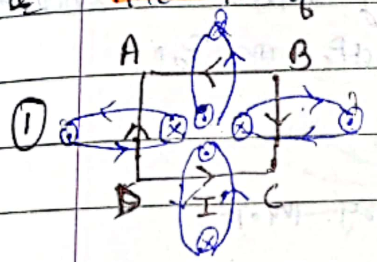
- Electric Generator
- Transformer
- Mutual Induction.

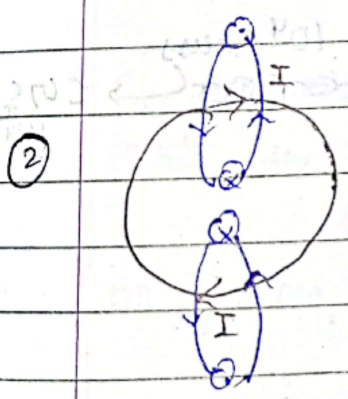


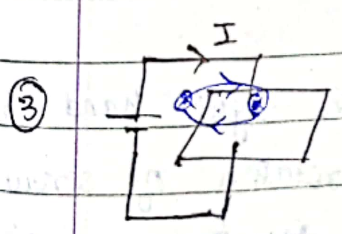


- Primary coil
- Secondary coil.

Q Find Dirⁿ of magnetic field.

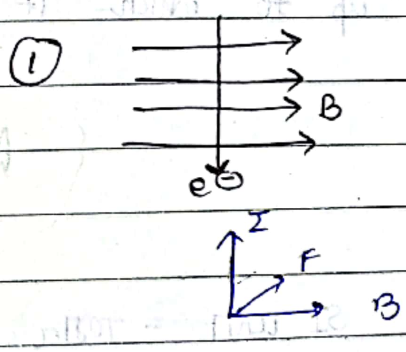


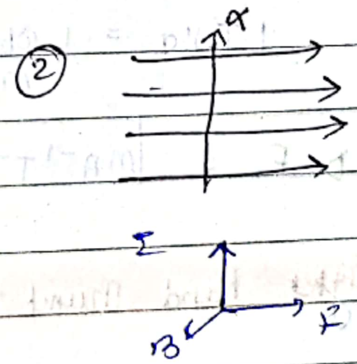




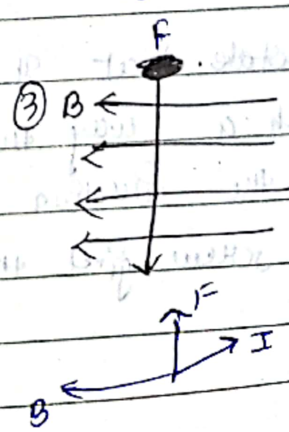
Q Find Dirⁿ of Force

= inside the plane





Direction of M.F
= outward the plane



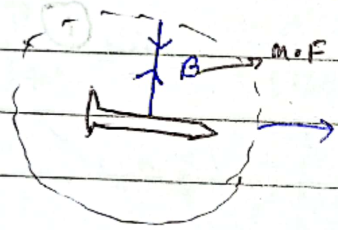
Dirⁿ of current
⇒ inside the plane.

~~Second~~ Oested Experiment

- Oerasted experiment : Oested observed that if magnetic needle is placed near a current carrying wire the needle shows deflection for a moment.
- If current is flowing from south to north, the west deflection is shown
- Also s/a swimming Ampere's rule.

Magnetic field :

- The space around the current carrying wire or conductor up to which it can attract magnetic material.



- SI unit = Tesla
  1 Tesla = $1 \frac{wb}{m^2}$ → MKS unit.
- 1 T = 10^4 Gauss → CGS unit
- D.F = $\boxed{MA^{-1}T^{-2}}$

Right hand Thumb rule / Maxwell Rule

- It state that if we hold the screw in right hand in such a way that the direction of rotation of screw is in the direction of current then the direction of motion of screw gives the direction of magnetic field.

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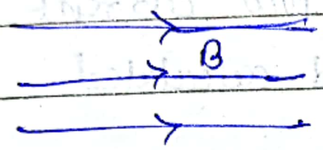
- $\otimes$ ↳ Indicates M.F inside

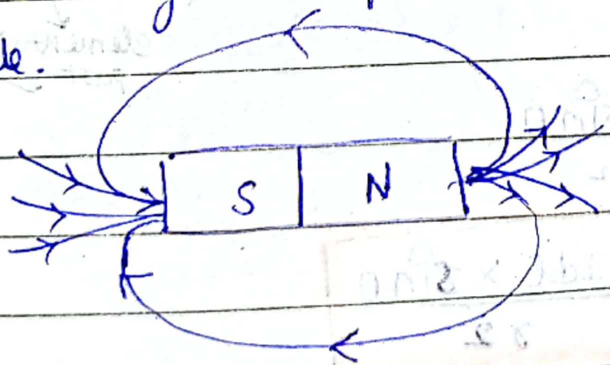
$\odot$ ↳ Indicates M.F outside.

- If M.F lines are straight & parallel it is kla uniform M.F lines.



* **Properties of magnetic field lines.**

- magnetic field lines are imaginary & close loop.
- M.F lines originate from north pole & merge into south pole.



- Two magnetic lines never intersect each other.
- ~~Inside~~ the dirⁿ of magnetic field lines inside the magnet is south to north.
- no. of magnetic field lines $\propto$ magnetic strength.

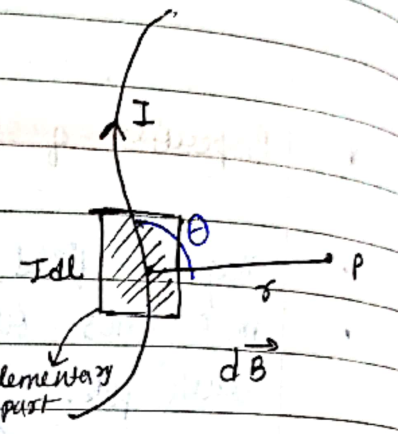
* Biot - Savart law.

- According this law, the magnetic field, magnitude at any point due to current element depends directly upon current element [Idl], sin of angle θ, inversely proportional to square of distance b/w current & point where the magnitude of magnetic field calculated.

⇒ $dB \propto Idl$ —①

⇒ $dB \propto \sin\theta$ —②

⇒ $dB \propto \frac{1}{r^2}$ —③



considering eqn ①, ②, & ③

$$dB \propto \frac{Idl \sin\theta}{r^2}$$

$$\boxed{dB = \frac{\mu_0}{4\pi} \frac{Idl \times \sin\theta}{r^2}}$$

→ Permittivity in free space [vaccum].

$$\boxed{\int dB = \frac{\mu_0 I \sin\theta}{4\pi r^2} \int_0^l dl}$$

- $\frac{\mu_0}{4\pi} = 10^{-7}\ Tm/A$

- In vector form

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{Idl \sin\theta\ \hat{r}}{r^2}$$

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{Idl \sin\theta\ \vec{r}}{r^3} \qquad \left[\hat{r} = \frac{\vec{r}}{|r|}\right]$$

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$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{[d\vec{l} \cdot \vec{r} \sin\theta]}{r^3}$$

$$\boxed{d\vec{B} = \frac{\mu_0 I \, [d\vec{l} \times \vec{r}]}{4\pi r^3}}$$

case I

$\theta = 0°$

$\boxed{d\vec{B} = 0}$

↳ $d\vec{l}$ is parallel to $\vec{r}$

case II

$\theta = 90°$

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

Imp * ~~Dimensional formula of permeability~~ $[\mu_0]$

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I dl \sin\theta}{r^2}$$

$$\mu_0 = \frac{dB \times r^2}{(I)(dl)}$$

$$= \frac{T \cdot l^2}{A \times l}$$

$$= T L A^{-1}$$

$$= [M A^{-1} T^{-2} A^{-1} L]$$

$$= [M L T^{-2} A^{-2}]$$

Eg 4.4 $I = 10A$ $\quad \Delta x = 1cm$ $\quad r = 0.5 m$ $\quad \Delta l = \Delta x \hat{i}$

0.01

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

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

$$= 4 \times 10^{-8} \ T$$

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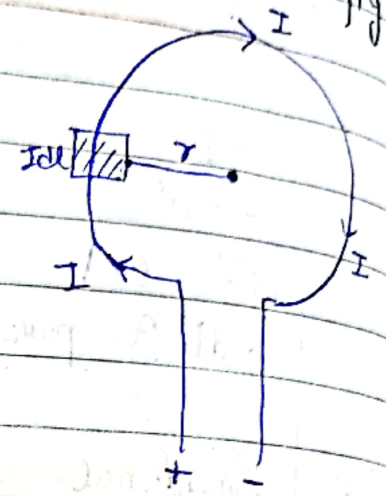
✱ Application of Biot - Savart law

• **Expression of magnetic field for circular current carrying wire**



We know,

$$dB = \frac{\mu_0}{4\pi} \frac{Idl \sin\theta}{r^2}$$ [Biot-Savart's law]

$\theta = 90°$

$$\int_0^B dB = \frac{\mu_0}{4\pi} \frac{I}{r^2} \int_0^L dl$$

$$B = \frac{\mu_0}{4\pi} \times \frac{I}{r^2} \left[L \right]_0^L$$

$$B = \frac{\mu_0 I}{4\pi r^2} \times L$$ [$L = 2\pi r$ [circumference]]

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

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

→ For semi-circular loop.

$$l = \frac{\cancel{2}\pi r}{\cancel{2}} = \pi r$$

→ For quadrant-circular loop.

$$l = \frac{\cancel{2}\pi r}{\cancel{4}2} = \frac{\pi r}{2}$$

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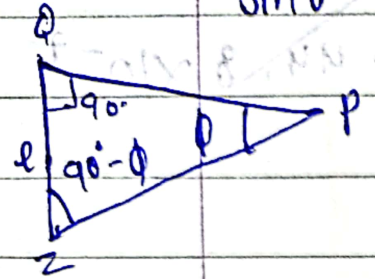
* **Magnetic field due to a long straight current carrying conductor.**

$+\phi_2 = CW$

$-\phi_1 = ACW$

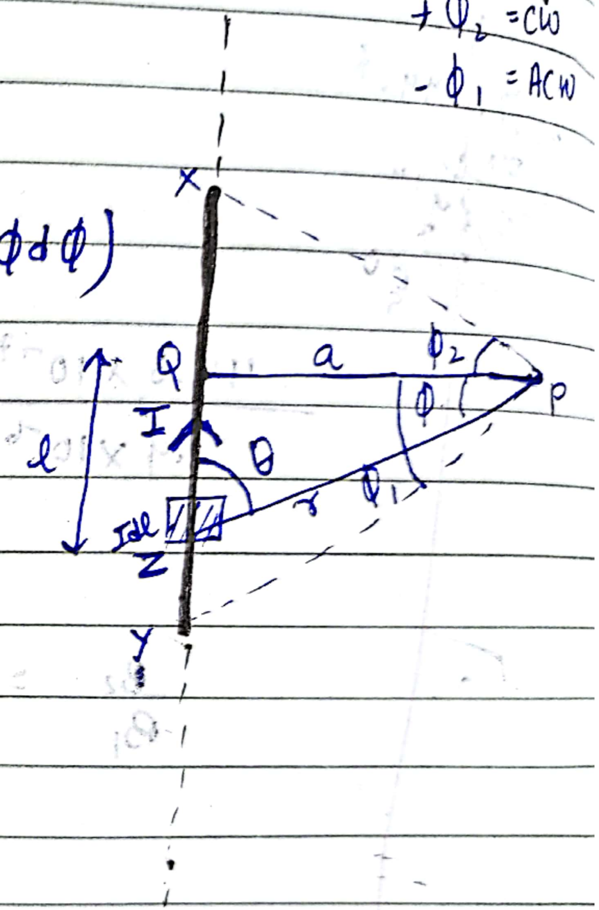


$$\sin\theta = \sin[90-\phi] = \cos\phi$$

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

$$l = a\tan\phi$$

$$(dl = a\sec^2\phi\, d\phi)$$



we know,

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

$$dB = \frac{\mu_0 I}{4\pi}\frac{a\sec^2\phi\, d\phi \times \cos\phi}{\left(\frac{a}{\cos\phi}\right)^2}$$

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

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

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Integrating both side.

$$\int_0^B dB = \frac{\mu_0 I}{4\pi a}\int_{-\phi_1}^{+\phi_2} \cos\phi \, d\phi$$

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

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

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

Case I.

$\phi_1 = \phi_2 = \phi$ [symmetrical wire] [axis bisect the conducting wire].

$$B = \frac{\mu_0 I}{4\pi a}\left[\sin\phi + \sin\phi\right]$$

$$B = \frac{\cancel{2}\mu_0 I}{\cancel{4}_2\pi a}\sin\phi$$

$$\boxed{B = \frac{\mu_0 I}{2\pi a}\sin\phi}$$

Case II

$\phi_1 = \phi_2 = 45^\circ$

$$B = \frac{\mu_0 I}{2\pi a} \times \sin 45^\circ$$

$$B = \frac{\mu_0 I}{2\pi a} \times \frac{1}{\sqrt{2}}$$

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

Case III

$\phi_1 = 0 \quad \phi_2 = 45^\circ$

$$B = \frac{\mu_0 I}{4\pi a}\left[\sin 45^\circ + 0\right]$$

$$B = \frac{\mu_0 I}{4\pi a} \times \frac{1}{\sqrt{2}}$$

$$\boxed{B = \frac{\sqrt{2}\,\mu_0 I}{8\pi a}}$$

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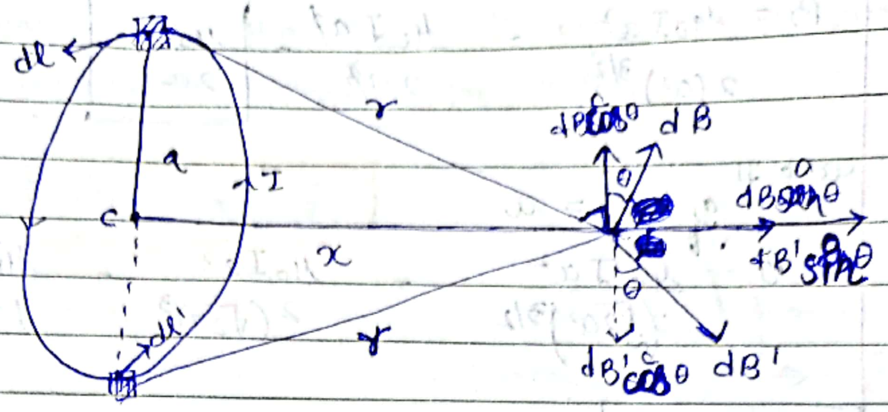
* Magnetic field on the axis of a circular current loop.



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

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{[d\vec{l} \times \vec{r}]}{r^3}$$

$$dB = dB'$$

$$\int dB = \int dB \sin\theta$$

$$\oint_0^B dB = \int dB' \sin\theta$$

$$B = \int_0^L \frac{\mu_0 I \, dl' \sin\theta}{4\pi r^2} \qquad \left[\sin\theta = \left(\frac{a}{r}\right)\right]$$

$$B = \frac{\mu_0 I a}{4\pi r^3} \int_0^l dl$$

$$B = \frac{\mu_0 I a}{\cancel{4}_2 \pi r^3} \times \cancel{2}\pi a$$

$$B = \frac{\mu_0 I a . a}{2 r^3}$$

$$r = \sqrt{x^2 + a^2}$$

$$B = \frac{\mu_0 I a^2}{2 r^3}$$

$$\boxed{B = \frac{\mu_0 I a^2}{2[x^2 + a^2]^{3/2}}}$$

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Practise ques → 1, 2, 3

case I

∴ If point lies on centre.

$x = 0$

$$B = \frac{\mu_0 I a^2}{2(a^2)^{3/2}} = \frac{\mu_0 I \cancel{a^2}}{2a\cancel{^3}} = \boxed{\frac{\mu_0 I}{2a}}$$

case II

If $x = a$

$$B = \frac{\mu_0 I a^2}{2(2a^2)^{3/2}} = \frac{\mu_0 I a^2}{2(\sqrt{2}a)^3} = \frac{\mu_0 I \cancel{a^2}}{4\sqrt{2}a\cancel{^3}}$$

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

q 4.6 $N = 100$ $r = \frac{10 cm}{100}$ $I = 1 A$

$$B = \frac{\mu_0 N I}{2R} = \frac{4\pi \times 100 \times 10^{-7} \times 1}{\cancel{2} \times 10^{-1}}$$

$= 2 \times 10^2 \times 10^{-7} \times 10$

$= 2\pi \times 10^{-4}$

$= 2 \times 3.14 \times 10^{-4}$ T

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

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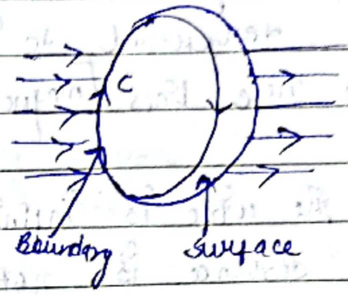
* Ampere's Circuital law

This law states that the $\oint B.dl$ is equal to μ_0 times of total current passing through the surface.

$$\boxed{\oint B.dl = \mu_0 i}$$

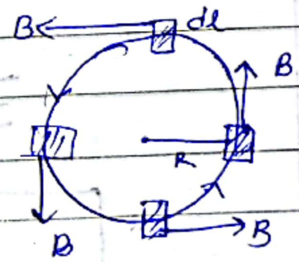


⇒ Important points of Ampere's circuital law.

- B is tengential to the surface B is non-zero
- B is normal to the loop.
- B vanishes.

⇒ Application.

- magnetic field of circular loop



we know that

$\oint \vec{B}.\vec{dL} = \mu_0 i$

$\oint B \times dl \cos\theta = \mu_0 i$ $[\theta = 0°]$

$B \oint dl = \mu_0 i$

$B \times 2\pi r = \mu_0 i$

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

$$\boxed{B = \frac{N \mu_0 I}{2\pi R}}$$ → for N no. of turns.

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*) Parts of Ampere's Circuital law

- It implies that the field at every point on a circle of radius r, [with the wire along the axis] is same in the magnitude.

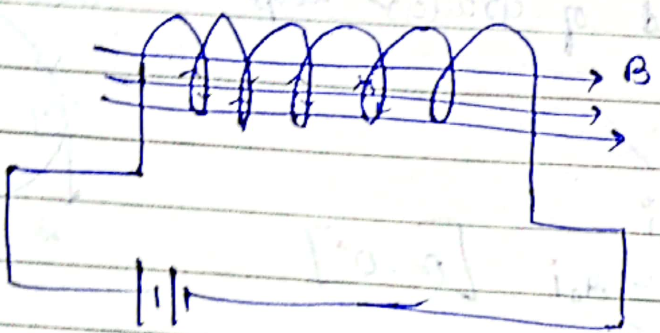
- *) The field direction at any point on the circle is tangential to it.
  *) These lines [magnetic field] forms close loop.

- The wire is infinite, the field due to it at non-zero distance is not infinite. [$R \to \infty$].

- Grasp the wire in your right hand with your extended thumb pointing in the direction of the current. Your fingers will curl around in the dirn of the magnetic field.

*) Solenoid

- It consists of a long wire wound in the form of a helix where the neighbouring turns are closely spaced.



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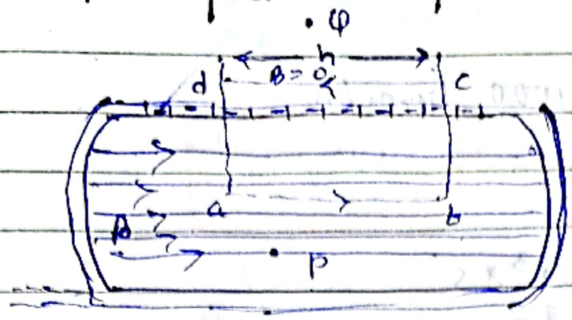
Magnetic field of solenoid for N no. of turns.



B = magnetic field.

i = current passing through

n = No. of turns per unit length

$$\boxed{n = \frac{N}{l}}$$

l = length of wire.

loop [rectangular ABCDA]

Magnetic field of side 'AB' $[B_{AB}] = \oint_A^B B \cdot dL \cos\theta = \oint_A^B B \cdot dl$

" " " " 'BC' $[B_{BC}] = \oint_B B \cdot dL \cos 90^\circ = 0$

$$B_{net} = B \cdot \int_0^h dL$$

$$\mu_0 I = B \cdot h$$

$$\boxed{\frac{\mu_0 I}{h} = B}$$

For 'N' no. of turns

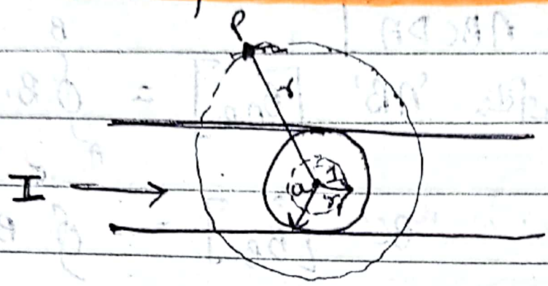
$$B = \frac{\mu_0 I N}{h}$$

$$B = \frac{\mu_0 I n \cancel{h}}{\cancel{h}}$$

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

no. of turns / m

Ex 4.8 Figure shows a long straight wire of a circular cross-section [radius a] carrying steady current I. The current I is uniformly distributed across this cross-section. Calculate the magnetic field in the region $r < a$ and $r > a$



(i) $r < a$

(ii) $r > a$

(iii) $r = a$

$\hookrightarrow B = \frac{\mu_0 I}{2\pi a}$

At point 'p'

$L = 2\pi r$

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

$B \cdot 2\pi r = \mu_0 I$

$B = \frac{\mu_0 I}{2\pi r}$ $\left[B \propto \frac{1}{r}\right]$

$I_e = \frac{I(\cancel{\pi} r^2)}{\cancel{\pi} a^2}$

$I_e = \frac{I r^2}{a^2}$

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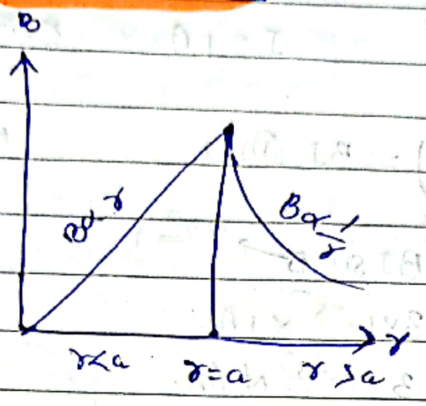
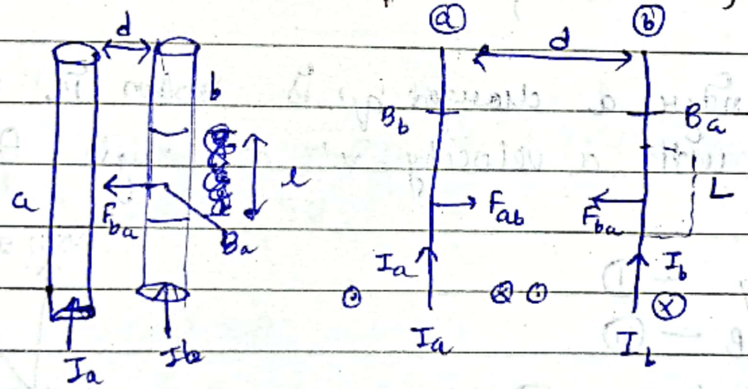
$$B = \frac{\mu_0 I_e}{2\pi r} = \frac{\mu_0 I r^{\cancel{2}}}{2\pi \cancel{r} a^2}$$

$$\boxed{B = \frac{\mu_0 I r}{2\pi a^2}} \quad (B \propto r)$$



★ Force Between Two parallel currents, the ~~Ampere~~.



Acc. to Ampere circuital law,

$$B_a = \frac{\mu_0 I_a}{2\pi d} \quad \text{— (i)}$$

Magnetic force on wire 'b'

$$F_{ba} = BIL \sin\theta \quad [\theta = 90^\circ]$$

$$F_{ba} = B_a I_b L \quad \text{— (ii)}$$

Putting value 'B_a' in eq (ii)

$$F_{ba} = \frac{\mu_0 I_a}{2\pi d} \times I_b \cdot L$$

$$F_{ba} = \boxed{\frac{\mu_0 I_a I_b \times L}{2\pi d}}$$

Force per unit length $\left(\frac{F_{ba}}{L}\right)$

$$\boxed{F = \frac{\mu_0 I_a I_b}{2\pi d}}$$

Eg 4.9 $B = 3 \times 10^{-5}\,T$ $I = 1\,A$

(a) $f = \left(\frac{F}{L}\right) = BI\sin\theta$

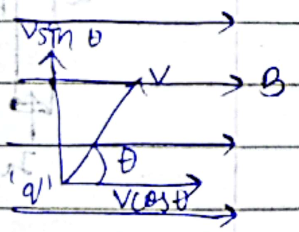
$$f = BI\sin\theta \xrightarrow{} 90^\circ = 1$$
$$= 3\times10^{-5} \times 1\,A$$
$$= 3\times10^{-5}\ N/m.$$

(b) $\theta = 0^\circ$

$f = 0$

★ **Motion in a magnetic field**

Let us consider a charged 'q' is thrown in uniform magnetic field 'B' with a velocity 'v' at angle θ



$F \propto q$ — (I)

$F \propto B$ — (II)

$F \propto v\sin\theta$ — (III)

combining eqn (I), (II) & (III)

$$F \propto q.v.B\sin\theta$$
$$F = Kq.vB\sin\theta \qquad [K = 1]$$
$$\boxed{F = q\,[vB\sin\theta]}$$

↳ Scalar form

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

↳ vector form.

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Case I

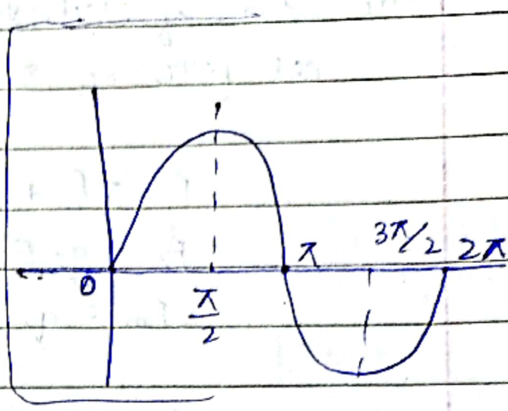
If charged particle is thrown antiparallel to uniform magnetic field.

$\theta = 180^\circ$

$F = q.v.B\sin\theta$

$F = qVB \times 0$

$\boxed{F = 0}$



Case II

$V \parallel B$

$\theta = 0^\circ$

$\boxed{F = 0}$

Case III

If a charged particle is held in stationary uniform magnetic field.

$V = 0$

$F = q.v\,B\sin\theta$

$\boxed{F = 0}$

Case IV

Max^n magnitude of force.

$\theta = 90^\circ$

$\boxed{F = q.v.B}$

$\boxed{F = \frac{E}{V} \times vB}$ $\left[V = \frac{W}{q} = \frac{E}{q} \quad q = \frac{E}{volt} \right]$

V = potential difference

E = Energy

v = velocity of charge particle

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* Lorentz force

The sum of electrostatic force and magnetic force represent the net force of moving charged particle.

$$F = F_e + F_m \quad — (A)$$

$$F_e = q E \quad — (1)$$

$$F_m = q \cdot [\vec{v} \times \vec{B}] \quad — (11)$$

Put F_e & F_m in eqn (A)

$$F = [q E + q \cdot \vec{v} \times \vec{B}]$$

$$\boxed{F = q [\vec{E} \times \vec{v} \times \vec{B}]}$$

$$\boxed{F = q [E + vB \sin\theta]}$$

Case I

$\theta = 0°$

$\boxed{F = F_e}$ $\boxed{F = q E}$

Case II $\theta = 90°$

$$\boxed{F = q E + q v B}$$

case III

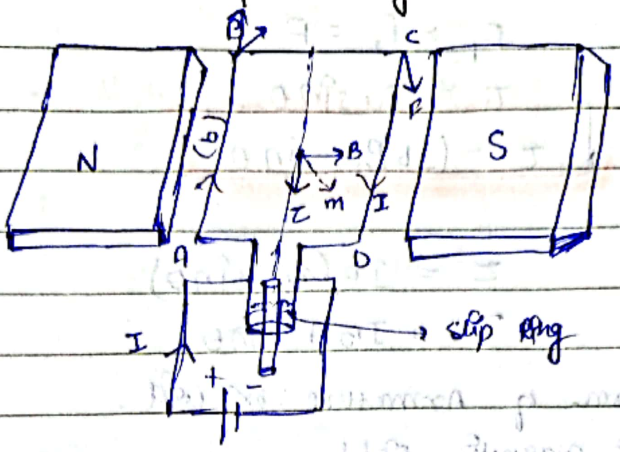
$F = 0$

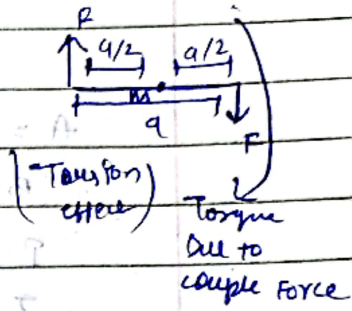
$$0 = q E + q v B$$

$$-\cancel{q} v B = \cancel{q} E$$

$$\boxed{B = \frac{|E|}{|v|}} \qquad \boxed{v = \frac{-|E|}{|B|}}$$

* Torque on a current loop, magnetic Dipole.





Boundary condition.

$F_1 = F_2 = (Ib)B$

moment About 'm' Due to F_1

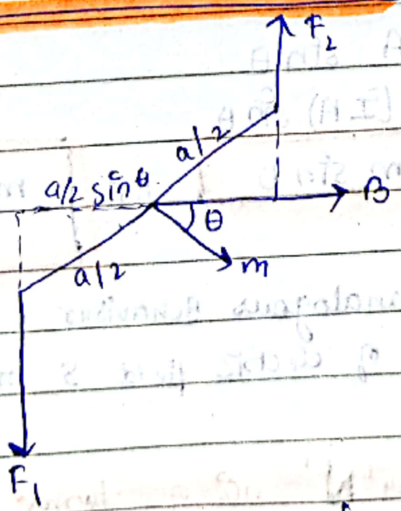
$M_m = F_1 \propto \frac{a}{2}$

Due to F_2

$M_m = F_2 \propto \frac{a}{2}$

$\tau = M_m(F_1) + M_m(F_2)$

$$\boxed{\tau = F_1 \frac{a}{2} + F_2 \frac{a}{2}}$$



$M_m(F_2) = F_2 \cdot \frac{a}{2} \sin\theta$

$M_m(F_1) = F_1 \frac{a}{2} \sin\theta$

$\tau = M_m(F_1) + M_m(F_2)$

$= F_1 \frac{a}{2}\sin\theta + \frac{F_2 a}{2} \sin\theta$

$$F = (Ib)B$$

$$F_1 = F_2 = F$$

$$\tau = Fa \sin\theta$$

$$\boxed{\tau = (Ib)Ba \sin\theta}$$

$$\tau = IB(ab) \sin\theta)$$

$$\tau = IBA \sin\theta$$

A = Area of Armature or coil.

B = magnetic field.

I = current

τ = Torque on coil.

★ **Magnetic Moment**.

1) The product of electric current and cross-sectional area of coil and armature [Area -vector].

$$\boxed{m = IA}$$

unit : $A \cdot m^2$

$$\tau = IBA \sin\theta$$

$$\tau = B(IA) \sin\theta$$

$$\boxed{\tau = B \cdot m \sin\theta} \quad \text{or} \quad \boxed{m = \frac{\tau}{B \sin\theta}}$$

$\tau = B \cdot m$
$\tau = E \cdot F$ → analogous behaviour of electric field & m.f

2) **magnetic moment for 'N' no. of turns**

$$\boxed{m = NIA}$$

$$\boxed{\tau = NIAB \sin\theta}$$

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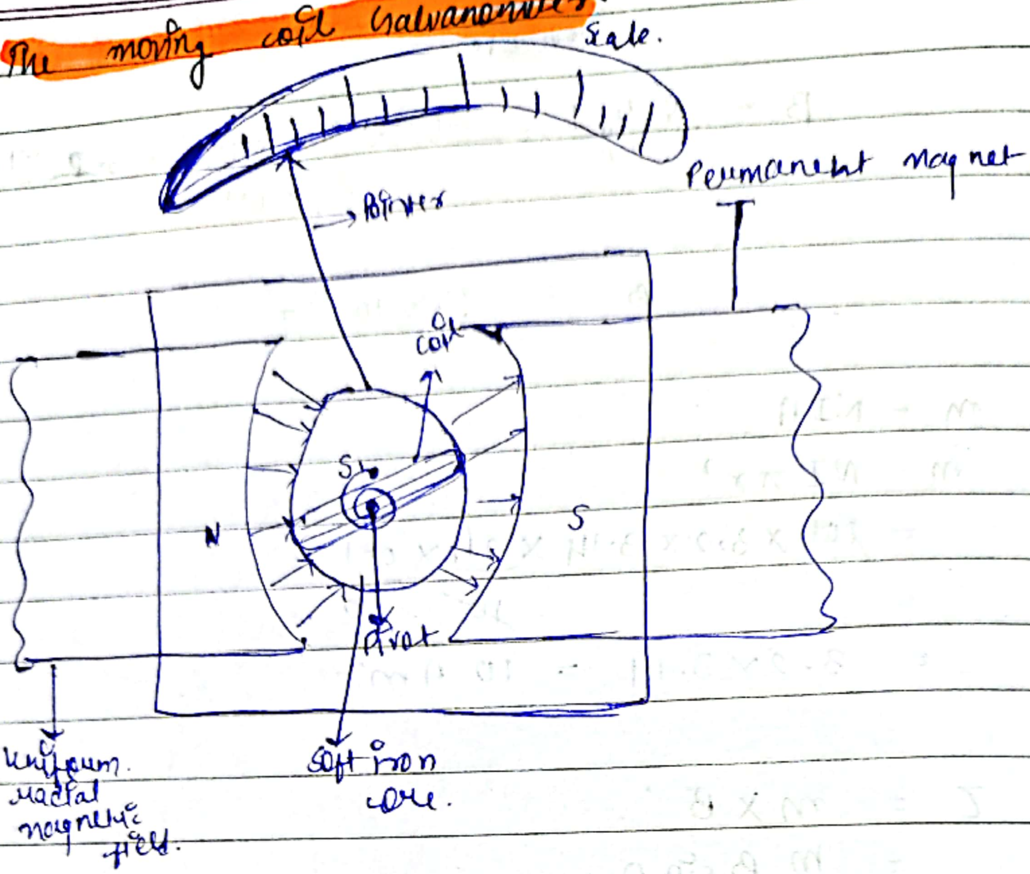
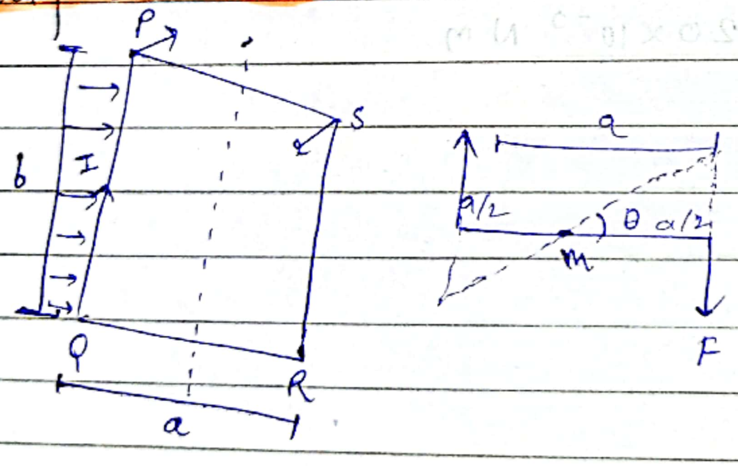
* **The moving coil Galvanometer.**



• **Torque calculation**



$$\tau = F \cdot \frac{a}{2} \sin\theta + F \frac{a}{2} \sin\theta$$

$$= \cancel{2} F \frac{a}{\cancel{2}} \sin\theta$$

$$\boxed{\tau = F \cdot a \sin\theta} \rightarrow 90^\circ = 1$$

$F = NBIL$

$F = NBIb$

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$\tau = F \cdot a \sin\theta$

$\tau = NBI(ba)\sin\theta$ [A = ba → Area of armature.]

$\boxed{\tau = NBIA \sin\theta}$

$$\boxed{I = \frac{\tau}{NBA \sin\theta}}$$

For $\theta = 90^\circ$

$$\boxed{I = \frac{\tau}{NBA}}$$

* For deflection / sensitivity

$\tau = k\alpha = NIBA$

$$\boxed{\alpha = \frac{NIBA}{k}}$$ k → Torsional constant

α = angular deflection

* Factor on which the sensitivity of moving coil galvanom depends.

1) No. of turns [N]
2) Magnetic field [B]
3) Area of coil [A]
4) Torsional constant [k]

Q A rectangular coil having each turn of length 5 cm breath 2 cm is suspended freely in a radial magnetic field of induction 2.5×10^{-2} w/m². K of suspension fibre is 1.5×10^{-8} N m / rad. The coil deflect through the angle of 1.2 radium when current flow 2 μA ↳ 2×10^{-6} A
Find the no. of Turns ?

$N = \frac{k\alpha}{IBA}$

$5\times2 = 10$ cm² $= 0.1$

Ans

$\therefore N = \frac{1.5\times10^{-8} \times 1.2 \times \cancel{10}\, 5}{2\times10^{-6} \times 2.5\times10^{-2} \times 0.1} = \frac{1.5\times1.2\times10^{-4}\times5}{2.5} = \boxed{3.6\times10^{-4}}$

3.6×10^{-4}

$\frac{R}{B} = \frac{\pi}{180}$ $R = \frac{\pi}{180} \times 18$

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Practice qust - 8, 12, 3, 4

Voltage sensitivity

$$V_s = \frac{\alpha}{V} = \frac{\alpha}{IR} = \frac{NIBA}{KIR}$$

$$\boxed{V_s = \frac{NBA}{KR}}$$ → Resistance.

Current sensitivity

$$\boxed{I_s = \frac{NBA}{K}}$$

Q To increase the current sensitivity of a moving coil galvanometer by 50%, it's resistance is increased so that the new resistance becomes twice its original resistance by what factor does it voltage sensitivity change

	Initial	Final.
I_s	100	150
V_s	"	"

$$\frac{150}{100} = \frac{3}{2}$$

Ratio = 3 : 2.

Q $A = 5 \times 10^{-4} m^2$ $N = 60$ $I = 0.20 mA$ (10^{-3}) $B = 90 G$ (gauss) $= 9 \times 10^{-4} T$

$\alpha = 18°$ $K = ?$

$R = \frac{\pi}{180} \times 18$

$R = \frac{\pi}{10} = \frac{3.14}{10}$

$= 0.314$ rad.

$$K = \frac{NIBA}{\alpha} = \frac{60 \times 0.20 \times 10^{-3} \times 9 \times 10^{-4} \times 5 \times 10^{-4}}{0.314}$$

$$= \frac{5400 \times 10^{-11}}{0.314} = 1.7 \times 10^{-7} Nm/rad$$