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Moving Charges and Magnetism

Oersted's experiment :-

According to Oersted when electric current flows through a conducting wire then magnetic needle near it deflects and when flows of current is taken opposite then deflection of magnetic needle also becomes opposite. This Experiment is called ~~Oersted~~ Oersted's experiment.

Ampere's swimming rule

If a swimmer swims in the current direction while facing a magnetic needle, the north pole of the magnetic field deflects towards his left hand and the south pole towards his right hand, according to Ampere's swimming rule.

The word 'SNOW' can also help remember this. It indicates that if the current flows from south to north, the north pole will be deflected to the east.

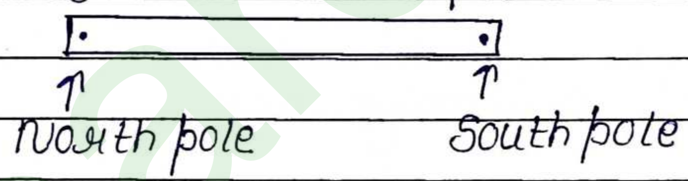
Note:- From the above discussion we conclude there are various source of magnetic field except a magnet.

→ A current carrying wire.
→ Moving e^-
→ Moving charge particles.

Magnet :-

The substance which attract iron, nickel, cobalt etc. magnetic substances is called magnet.

It contains two poles



Magnetic field :-

The field around a pole up to where magnetic force is acting is called magnetic field.

↳ It is vector quantity.
↳ It is denoted by B.
↳ Its magnitude is equal to magnetic force acting at unit pole strength.

$$B = \frac{\text{Magnetic Force}}{\text{Pole strength}}$$

$$\boxed{B = \frac{F}{m}}$$

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SI unit = Tesla (T)
CGS unit = Gauss (G)

Relation between Tesla and Gauss

$$1\,T = 10^4\,G$$

Dimension of magnetic field :

$$B = \frac{F}{m}$$

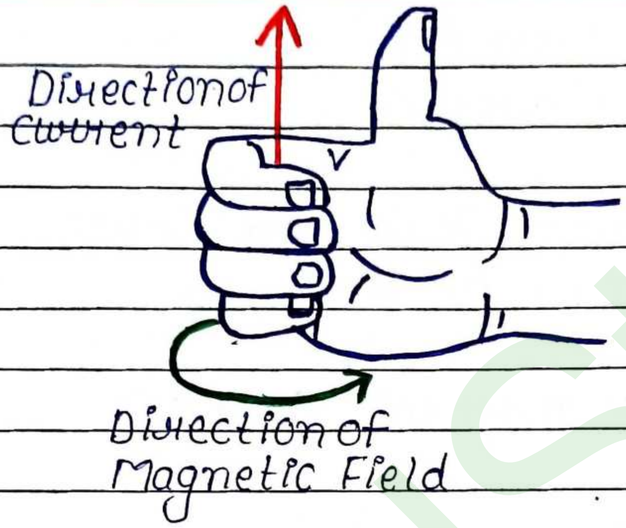
$$B = \frac{[MLT^{-2}]}{[A][L]} \quad \because m = IL$$

$$[B] = [ML^0T^{-2}A^{-1}]$$

Direction of magnetic field

(1) In straight wire carrying current -
The direction of magnetic field is given by Maxwell's Right hand thumb rule.

Maxwell right hand thum rule -
It states that if we hold a straight current carrying conductor with our right hand such that the thumb points in the direction of the current then the curled fingers indicate the direction of the magnetic field lines.



(2) In closed loop carrying current –
The direction of magnetic field is given by right hand screw rules.

Right hand screw rule –
It states that if we hold the screw in right hand in such a way that the direction of relation of screw is in the direction of current then the direction of milion of screw gives the direction of magnetic field.

→ In case of circular loop carrying current magnetic field is in the form of straight line.

→ Both current and magnetic field are perpendicular to each other.

Biot - Savart's Law :-

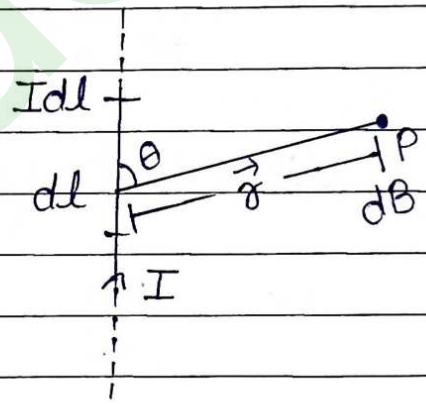
When electric current flows through a conducting wire then magnetic field due to small length of the conductor is directly proportional to flowing current, small length and $\sin\theta$ while inversely proportional to square of distance.

i.e;

$$dB \propto I\,dl$$

$$dB \propto \sin\theta$$

$$dB \propto \frac{1}{r^2}$$



Combining all fector-

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

$$dB = \frac{K\,I\,dl\,\sin\theta}{r^2} \qquad \because K = \frac{\mu_0}{4\pi} = 10^{-7}$$

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

Where K is proportionality constant and μ_0 is permeability of free space.

In vector from :-

$$d\vec{B} = \frac{\mu_0}{4\pi}\cdot\frac{I\,dl\,\sin\theta}{r^2}\,\hat{r} \qquad \because \hat{r} = \frac{\vec{r}}{|\vec{r}|}$$

$$d\vec{B} = \frac{\mu_0}{4\pi}\cdot\frac{I\,dl\,\sin\theta}{r^3}\,\vec{r}$$

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$$\boxed{d\vec{B} = \frac{\mu_0}{4\pi} \frac{I(d\vec{l} \times \vec{r})}{r^3}}$$

→ direction of $d\vec{B}$ is perpendicular to plane containing $d\vec{l}$ and $\vec{r}$.

Units and dimension of μ_0 :-

Unit :-

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

$$dB = \frac{\mu_0 I dl}{r^2}$$ [∵ 4π and θ have no dimension(Constant)].

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

$$\mu_0 = \frac{Tm^2}{Am}$$

$$\boxed{\mu_0 = TmA^{-1}}$$

dimension :-

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

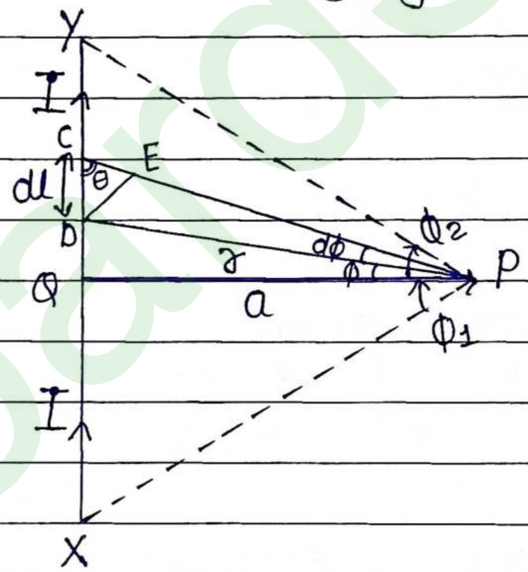
$$\mu_0 = \frac{[MT^{-2}A^{-1}][L^2]}{[A][L]}$$

$$\boxed{\mu_0 = [MLT^{-2}A^{-2}]}$$

Application of Biot - Savart's Law -

Magnetic field due to straight current carrying conductor –

Let us consider a straight current carrying ~~conductor~~ conductor XY in which i current is flowing there is a point P at distance a where we have to find magnetic field due to current carrying conductor.



Consider a small element dl the magnetic field at P due to this element by Biot Savart's law –

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

In ΔCDE

$$\sin\theta = \frac{DE}{CD} = \frac{DE}{dl}$$

$$DE = dl \sin\theta \quad \text{—— (2)}$$

$$\because d\phi = \frac{DE}{r}$$

$$DE = r\,d\phi \quad \text{—— (3)}$$

From eq (2) & (3)

$$r\,d\phi = dl \sin\phi$$

from eq (1)

$$dB = \frac{\mu_0}{4\pi} \times \frac{I \times r\, d\phi}{r^2}$$

$$dB = \frac{\mu_0}{4\pi} \times \frac{I\, d\phi}{r} \quad \text{—— (4)}$$

In Δ PQD

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

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

from eqn (4)

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

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

Therefore the magnetic field at P due to whole current carrying conductor.

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

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

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

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

If the current carrying conductor is (∞ long) infinitely long then —

$$\phi_1 = \phi_2 = 90^\circ$$

Therefore magnetic field due to this current carrying conductor at P —

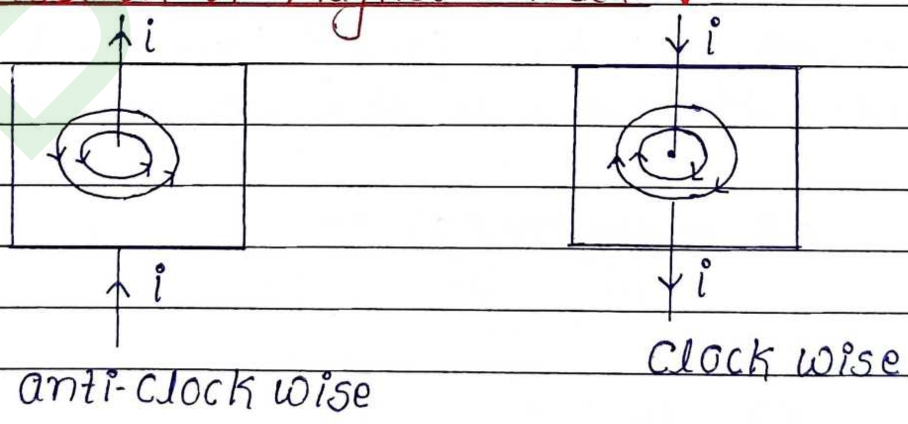
$$\phi_1 = \phi_2 = 90^\circ$$

$$B = \frac{\mu_0}{4\pi}\frac{I}{a}\left[\sin 90^\circ + \sin 90^\circ\right]$$

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

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

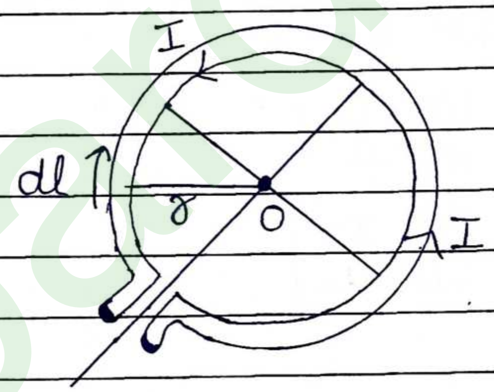
Direction of Magnetic field :-



The magnetic force line of a straight current carrying conductor are cocentric circle with the wire at the centre and in a plane ⊥ to the wire.

Magnetic field at the Centre of Current Carrying Loop—

Let us consider a circular loop of radius r carrying current I. We wish to calculate its magnetic field at the centre O. The entire loop can be divided into a large no. of small current element. Let us consider an element dl.



According to Biot Savart law the magnetic field at O due to this element dl.

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

$\because \sin 90^\circ = 1$

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

The magnetic field due to whole circular current loop at the centre O —

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

$$= \frac{\mu_0}{4\pi} \times \frac{I}{r^2} \int dl \qquad \because \int dl = 2\pi r$$

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

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

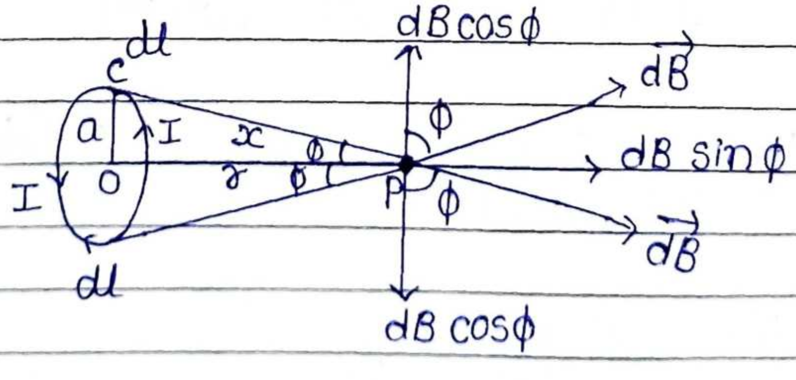
If there are N turns then

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

If the current is flowing anticlockwise in the loop then the direction of magnetic field will be ⊥ outward and if current is flowing clockwise then the direction of Magnetic field will be ⊥ inward.

Magnetic field along the axis of a current Carrying Loop —

Let us consider a circular loop of wire of radius a & carrying current I. we have to find magnetic field at an axial point P at distance r from the centre O.
Consider a current element dl at the loop of the loop and also at the bottom of the loop. the magnetic field at p due to the current element dl.



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According to Biot savart Law —

$$dB = \frac{\mu_0}{4\pi} \frac{Idl \sin 90^\circ}{x^2}$$

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

Let ∠ b/w OP & CP is ϕ then $d\vec{B}$ can be resolve in two component.

① $dB \sin\phi$ in direction of axis.

② $dB \cos\phi$ ⊥ to the axis.

The component dB us ϕ neutralise each other. therefore, total magnetic field will be due to component $dB \sin\phi$.

Therefore the magnetic field at P.

$$B = \int dB \sin\phi$$

$$B = \int \frac{\mu_0}{4\pi} \frac{Idl}{x^2} \sin\phi$$

$$\because x^2 = a^2 + r^2$$

$$\sin\phi = \frac{a}{x} = \frac{a}{(a^2+r^2)^{1/2}}$$

$$B = \int \frac{\mu_0}{4\pi} I \times \frac{a}{(a^2+r^2)^{1/2}} \times \frac{1}{(a^2+r^2)} dl$$

$$B = \frac{\mu_0}{4\pi} \frac{Ia}{(a^2+r^2)^{3/2}} \int dl \qquad \because \int dl = 2\pi a$$

$$B = \frac{\mu_0 I a \times \cancel{2}\cancel{\pi} a}{\underset{2}{\cancel{4\pi}} (a^2+r^2)^{3/2}}$$

$$\left[B = \frac{\mu_0 I a^2}{2(a^2+r^2)^{3/2}} \right]$$

At centre —

$$r = 0$$

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

$$\left[B = \frac{\mu_0 I}{2a} \right]$$

Ampere circuital Law :-

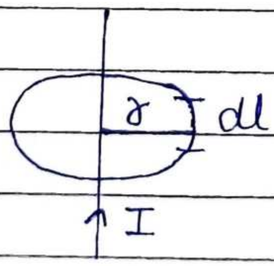
It states that the line integral of magnetic field over a closed loop is equal to 'μ_0' times current enclosed.

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

Proof :-

Let a wire carrying current I then magnetic field develop around it in the form of concentric circle s.

let r is radius of amperian loop.



Net magnetic field due to loop is given by

$$\oint \vec{B} \cdot d\vec{l}$$

$$\oint \vec{B} \cdot d\vec{l} = \oint B\,dl \cos\theta$$

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\,\cos 0^\circ$$
$$= \oint B\,dl$$
$$= B\oint_0^{2\pi r} dl$$
$$= B\,[dl]_0^{2\pi r}$$
$$= B\cdot[2\pi r - 0]$$
$$\therefore \oint \vec{B}\cdot\vec{dl} = B\,2\pi r \quad \text{--- (1)}$$

Magnetic field near centre of wire.

$$B = \frac{2\mu_0 I}{4\pi r} \quad \text{--- (2)}$$

Put eq(2) in eq^n (1)

$$\oint \vec{B}\cdot\vec{dl} = \frac{2\mu_0 I}{\cancel{r}\,4\pi} \times 2\pi \cancel{r}$$

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

Hence proved

↳ Application of Ampere's circuital law :-

i) Magnetic field due to infinite long straight wire carrying current :-

P is a point at ⊥ar distance r from current carrying straight wire having current I.

We have to find magnetic field at P.

Now,

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\,\cos\theta \qquad \theta = 0^\circ$$
$$= \oint B\cdot dl\,\cos 0^\circ$$

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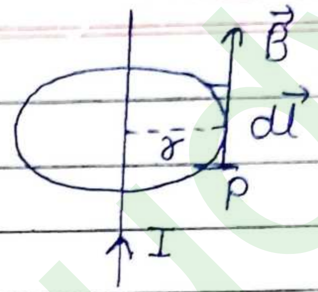
$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl$$
$$= B\oint dl$$
$$= B\,2\pi r \quad \text{—— (1)}$$



Apply Ampere circuital law.

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I \quad \text{—— (2)}$$

From (1) and (2)

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

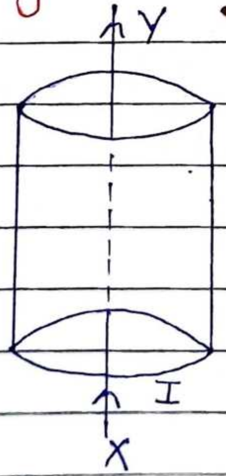
$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

2) Magnetic field due to hollow cylinder :-

A hollow cylinder is one to which any given current will distribute on the surface of cylinder i.e, there is no current inside the cylinder. consider a hollow cylinder of radius R and carrying a current 'I' as shown in fig.

case (I) Magnetic field inside the cylinder.

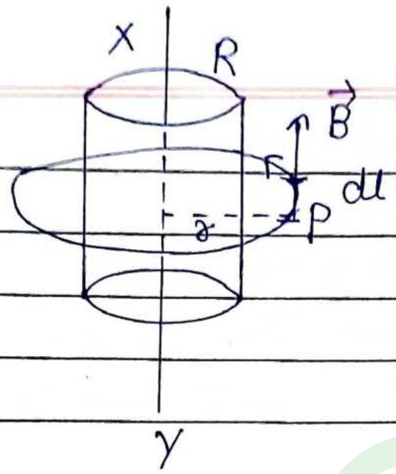
$(r < R)$



Since there is no I inside the cylinder.

$\therefore$ Magnetic field inside the cylinder is zero.

case (II) Magnetic field outside the cylinder.



Consider a point P at a distance 'r' from the centre of cylinder $(r > R)$

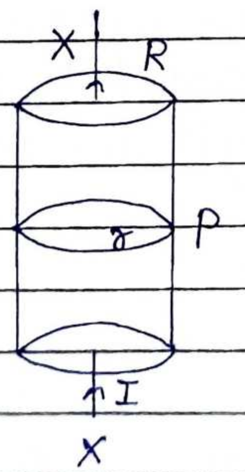
Net M.F at P
$\theta = 0°$
$\cos 0 = 1$

$$\oint \vec{B}\cdot d\vec{l} = \oint B\,dl \cos\theta$$
$$= B\oint dl$$
$$\oint \vec{B}\cdot d\vec{l} = B2\pi r \quad \text{—— (1)}$$

Applying ampere circuital law :
$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I \quad \text{—— (2)}$$

From (1) and (2)
$$B2\pi r = \mu_0 I$$
$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

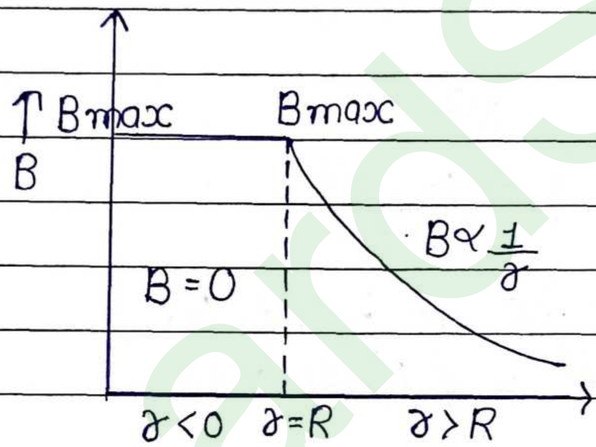
Case (III) Magnetic field on the surface of cylinder — $(r = R)$



When point P lies on surface of cylinder then,

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

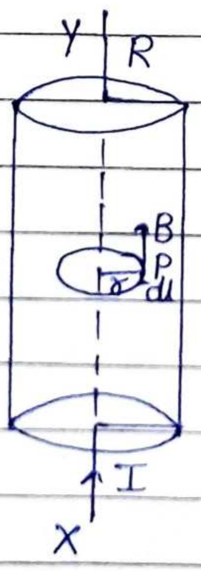
Graphical Representation :



3) Magnetic field due to solid cylinder —

A solid cylinder is one which any given current will distribute uniformly over the whale cylinder.

Consider a solid cylinar of radius 'R' and carrying current I as shown in fig:



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Case (1) Magnetic field inside the cylinder — ($r<R$)

Consider a point P inside the cylinder at a distance 'r' from centre of cylinder.

$$\pi R^2 — I$$
$$\pi r^2 — \frac{I}{\pi R^2} \times \pi r^2$$
$$\pi r^2 — \frac{I r^2}{R^2}$$
$$\because I' = \frac{I r^2}{R^2}$$

Now, Net M.F at point P.

$$\oint \vec{B}\cdot d\vec{l} = \oint B \cdot dl \cos\theta$$
$$\oint \vec{B}\cdot d\vec{l} = B \oint dl$$
$$\oint \vec{B}\cdot d\vec{l} = B\cdot 2\pi r \quad —— (1)$$

Apply Ampere's circuital law:

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I' \quad —— (2)$$

equating (1) and (2)

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

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

Case (2) On the Surface of cylinder ($r = R$).

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

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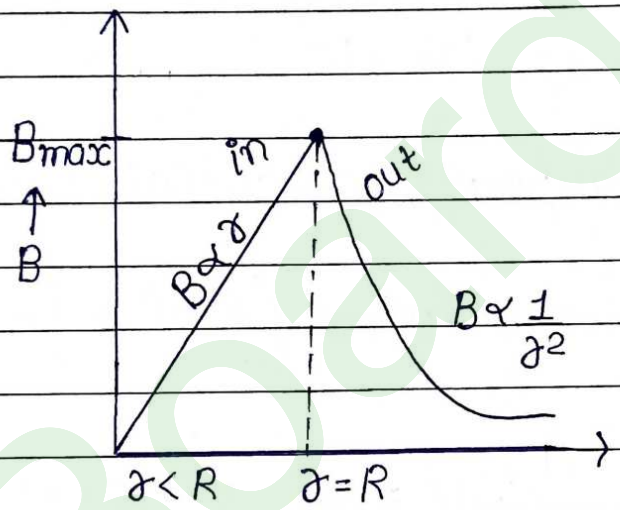
Case (III) Magnetic field outside the cylinder ($r > R$).

Now consider a point P from distance r' from the centre of cylinder such that $r > R$.

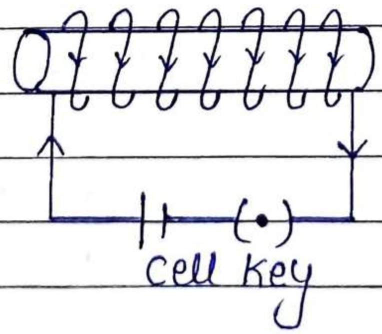
$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

Graphical Representation :-



* Solenoid

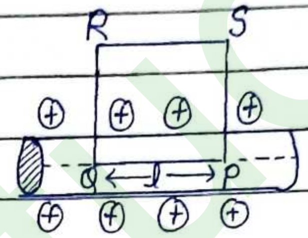
A solenoid is an insulated long wire closely found in the form of helix.



Its length is very long as compare to its diameter. We make use of solenoid to generate magnetic field.

Magnetic field of a solenoid

Let us consider a solenoid in which i current is flowing in every turn. let there is a small n turns in per unit length.



let us consider a rectangular ampere closed path PQRS where $PQ = L$.

According to Ampere's circuital Law

$$\oint_{PQRS} \vec{B}\cdot d\vec{l} = \int_P^Q \vec{B}\cdot d\vec{l} + \int_Q^R \vec{B}\cdot d\vec{l} + \int_R^S \vec{B}\cdot d\vec{l} + \int_S^P \vec{B}\cdot d\vec{l}$$

$$\because \int_Q^R \vec{B}\cdot d\vec{l} = \int_S^P \vec{B}\cdot d\vec{l} = 0 \quad \because \theta = 90^\circ$$

$$\text{and} \int_R^S \vec{B}\cdot d\vec{l} = 0 \quad \because B = 0$$

Therefore,

$$\int_{PQRS} \vec{B}\cdot d\vec{l} = \oint_P^Q \vec{B}\cdot d\vec{l} = \oint_P^Q B\,dl\cdot\cos 0 = B\oint_P^Q dl = BL \text{ — (i)}$$

The no. of turns on $PQ = nL$

Net current in $PQ = nLi$ — (ii)

By Ampere's circuital Law

$$\oint_{PQRS} \vec{B}\cdot d\vec{l} = \mu_0 i_{net}$$

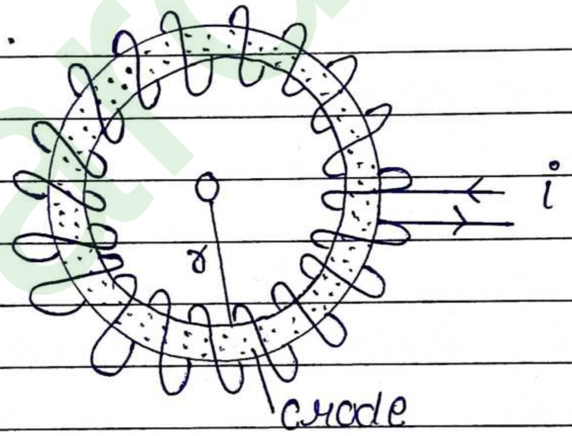
$$BL = \mu_0 \times nLi$$
$$[B = \mu_0 ni]$$

The magnetic field near any end of solenoid.

$$\left[B = \frac{1}{2}\mu_0 ni\right]$$

Magnetic field of a Toroid

An endless solenoid in the form of ring is called toroid.



Let small r is the mean radius of toroid, n is the number of turns per unit length and i is the current.

Therefore,

by Ampere circuital law

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \times \text{total current bounded by closed path.}$$

The net current bounded in closed path

$$i_{net} = 2\pi r \times n \times i$$

$\because$ $\vec{B}$ and $d\vec{l}$ are in the direction

$\because \theta = 0$

so,

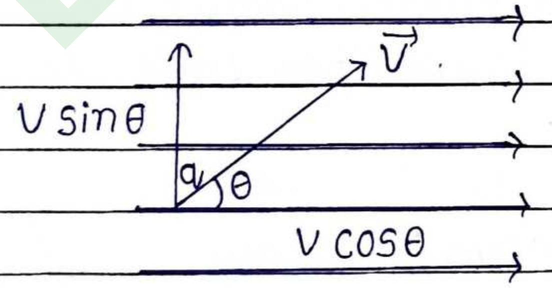
$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{net}$$
$$\oint B\,dl \cos 0 = \mu_0 \times 2\pi r \times ni$$
$$B \oint dl = \mu_0 \times 2\pi r \times ni \quad \because \oint dl = 2\pi r$$
$$B \times \cancel{2\pi r} = \mu_0 \times \cancel{2\pi r} \times ni$$

$$[B = \mu_0 ni]$$

Note :- There will be no magnetic field outside the taroid and also in the empty space surrounded by the taroid.

Force Acting on a charged particle in uniform magnetic field :-

Let a charge 'q' is thrown in uniform magnetic field 'B' with a velocity 'v' at angle θ.



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

In the presence of magnetic field, charged particle experience a force given by

$F \propto q$ — F will be ⊥ar to both V and B.

$F \propto B$ — if $\varepsilon = 0$.

$F \propto v \sin\theta$ — Magnetic Lorentz force

On combining,

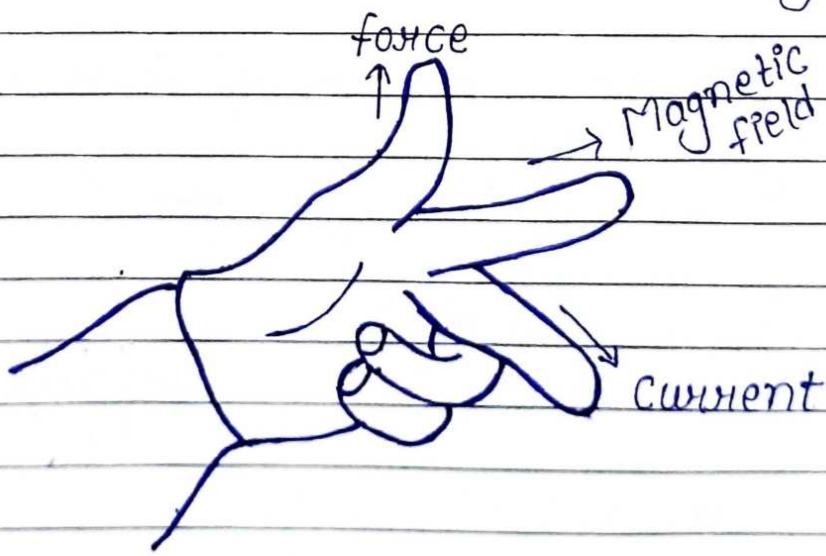
$$F \propto qBV \sin\theta$$
$$F = KqBV \sin\theta \qquad \because K = 1.$$
$$\boxed{F = qBV \sin\theta}$$

Note (i) If charged particle is thrown parallel to magnetic field then $\theta = 0°$.
and, $F = qBV \sin 0°$
$F = 0$

(ii) If a charged particle is thrown antiparallel to uniform magnetic field, then $\theta = 180°$
$F = qBV \sin 180°$
$F = 0 \qquad \sin 180° = 0$

* Fleming's left hand Rule :-

When thumb, forefinger and midfinger of left hand are kept perpendicular to each other and electric current flows along midfinger then direction of produced magnetic field will be along forefinger and magnetic force will be acts along thumb.



$$P = \sqrt{2KE \cdot m}$$
$$P = \sqrt{2(qV)m}$$

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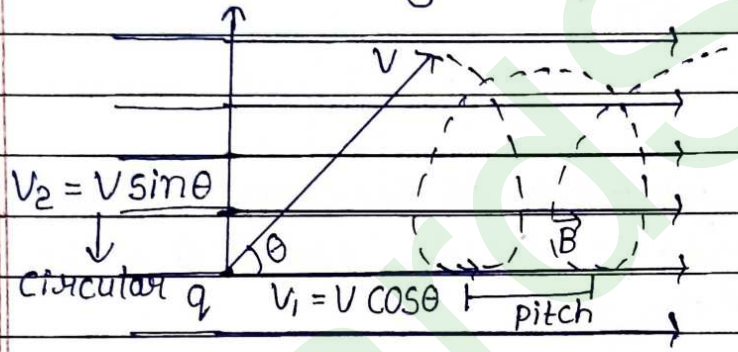
Motion of charge particles in uniform magnetic field :-

Let a charge particles having 'q' is thrown in uniform magnetic field 'B' with velocity 'V' and an angle θ with magnetic field.



helicle motion

$$\text{pitch} = V_{\parallel} \times T$$
$$= \frac{2\pi m V\cos\theta}{qB}$$

Resolving V in to two component $V\cos\theta$ and $V\sin\theta$ respectively as show in fig.

→ Radius of circular path.
→ In presence of magnectic field charged particle experience a force is given by -

$$F = qBV\sin\theta$$
$$F = qBV_2 \quad \text{—— (1)} \qquad \because [V_2 = V\sin\theta]$$

A necessary centripetal force acting on charged particle -

$$F = \frac{mV_2^2}{r} \quad \text{—— (2)}$$

from (1) and (2) :-

$$qBV_2 = \frac{mV_2^2}{r}$$

$$r = \frac{mV_2^{\cancel{2}}}{qB\cancel{V_2}} = \frac{mV_2}{qB}$$

$$r = \frac{mV}{qB}$$

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from this, $r \propto v_2 = \frac{mv\sin\theta}{qB}$ — ③

Angular momentum L, moving around the nucleus has magnetic moment $= \frac{-eL}{3m}$

Time taken to cover one complete circle is given by,

$$\text{Time} = \frac{\text{Distance}}{\text{speed}} = \frac{2\pi r}{v_2}$$

put eqⁿ – ③

$$t = \frac{2\pi m \cancel{v_2}}{\cancel{v_2} qB}$$

$$\left[t = \frac{2\pi m}{qB} \right]$$

Time taken is constant and independent of r. because $r \propto v_2$

From here, $T \propto 1/B$ i.e,

if magnectic field is increases, time taken to complete one circle decrease.

Frequency, $\nu = \frac{1}{T}$

$$\left[\nu = \frac{qB}{2\pi m} \right]$$

Angular frequency, $\omega = 2\pi\nu$

or velocity $\omega = \frac{\cancel{2\pi} qB}{\cancel{2\pi} m}$

$\because \omega = \frac{\theta}{t}$ $\left[\omega = \frac{qB}{m} \right]$

→ **From above discussion :**

- The component $v \sin\theta$ provide the circular motion where as $v \cos\theta$ provide linear, path, straight line motion.
Due to this combined effect, motion of charge particle become helical.

* Lorentz Force :-

When charge is moving in uniform electric and magnetic field then both electric and magnetic forces are act on it. Resultant of there forces is called lorentz force. So,

Lorentz Force

$$\vec{F} = \vec{F_e} + \vec{F_m} \quad — ①$$

$$\vec{F_e} = q\vec{E} \quad — ②$$

$$\vec{F_m} = q(\vec{B} \times \vec{V}) \quad — ③$$

put equation ② and ③ in equation ① —

$$\vec{F} = q\vec{E} + q(\vec{B} + \vec{V})$$

$$\vec{F} = q[\vec{E} + (\vec{B} + \vec{V})]$$

This is called Lorentz force.

$$\vec{F} = q[\vec{E} + BV \sin\theta].$$

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Special case ① — If charged particle is thrown ⊥ar to the magnetic field.
i.e, $\theta = 90°$ then
$$\vec{F} = q\,[\vec{E} + BV \sin 90°]$$
$$\vec{F} = q\,[\vec{E} + BV]$$

Note :- Lorentz force will be zero, when electric field perpendicular to magnetic field perpendicular to velocity.
i.e, $E \perp B \perp V$

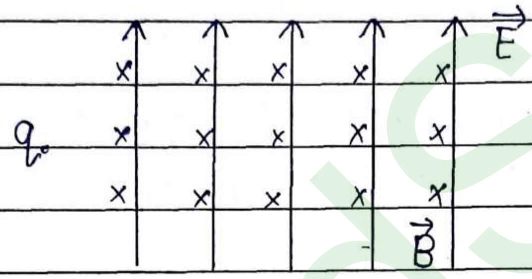
$$0 = q\,[\vec{E} + BV]$$
$$0 = E + BV$$
$$-E = BV$$
$$\because V = \frac{-E}{B}$$
$$\boxed{V = \frac{|E|}{|B|}}$$

Case ② — If charged particle is thrown parallel or antiparallel to the M.F. i.e, $\theta = 0°$ or $180°$, then,
$$\vec{F} = q\,[\vec{E} + BV \sin 0°]$$
$$\vec{F} = qE$$
$\left\{\begin{matrix} \sin 0° = 0 \\ \sin 180° = 1 \end{matrix}\right\}$

* Velocity Filter :-
A velocity filter is an arrangement of cross electric and magnetic field in a region that allows us to choose charged particles with a specific velocity

from a beam, regardless of their mass and charge.

Principle :- It is based on Lorentz force.



As shown in figure, the magnetic field is applied across z-axis denoted by ⊗. Electric field is applied along y-axis and charged particles are protected along x-axis.

Due to this, electric field and velocity all are perpendicular to each other. Therefore, net force on charged particle is zero of velocity.

$$V = \frac{|E|}{|B|}.$$

So, that charge will go straight without any deflection and rest are deviated here and there. Thus, we get charged particles of required velocity.

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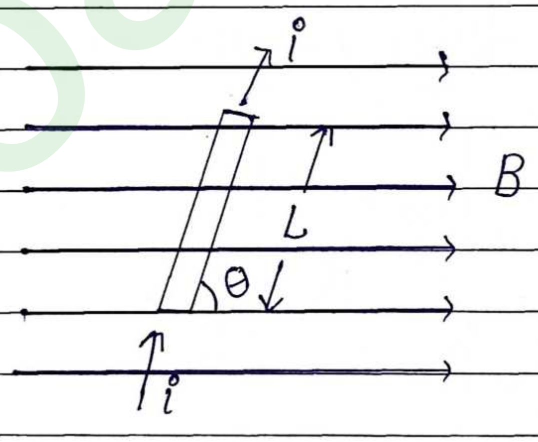
Force on a current carrying conductor in a uniform magnetic field –

When a current carrying conductor is placed in a uniform magnetic field then due to motion of free electrons inside the conductor a magnetic forces acts on it.

Let the length of current carrying conductor is (L).
Area of cross section $= (A)$
The no. of free electrons in per unit volume $= (n)$
Let the drift velocity of free electrons $= (V_d)$



The force on one free electron
$$F' = eV_d B \sin\theta$$
Total no. of free e^- in current carrying conductor
$$N = nAL$$

The net force on current carrying conductor
$$F = N \times F'$$
$$F = nAL\,eV_d\,B \sin\theta$$
$$F = (neAV_d)\,BL\sin\theta \qquad \{\because i = neAV_d\}$$
$$[F = iBL\sin\theta]$$

(i) If $\theta = 0$

$F = 0$

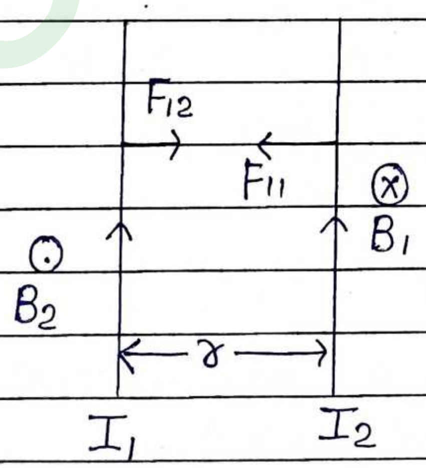
It means if a current carrying conductor is placed parallel to the direction of M.F. experiences no force.

(ii) If $\theta = 90°$

$$[F_{max} = iBL]$$

It means a current carrying Conductor is placed $\perp$ to the direction of magnetic field experienances maximum force.

↳ Force acting between two current carrying conductor field parallel to each other :-

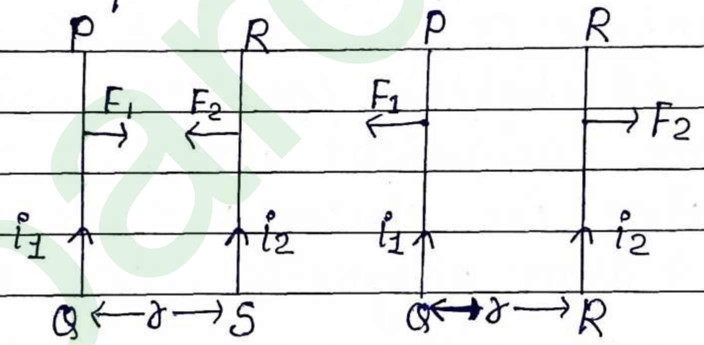


Let two conductor carrying current I_1 and I_2 in same direction which are placed distance 'r' apart.

From diagram, we conclude both conductor are in magnetic field produced by neigh-bouring conductor.

Force between two parallel current carrying Conductor —

If two parallel current carrying conductors are placed a short distance then one conductor applied magnetic force on one another. If the current are in same direction then there will be attractive force and if carrying current in opposite direction there will be repulsion.



Let P, Q & RS are two infinite long current carrying conductor i_1 & i_2 are the currents flowing through them and these are placed at distance (r).

The magnetic field on conductor RS due to current carrying conductor PQ

$$B_1 = \frac{\mu_0}{2\pi} \frac{i_1}{r}$$

The magnetic force of current carrying conductor RS on length L.

$$F = i_2 B_1 L \sin 90^\circ$$

$$F = i_2 B_1 L$$

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

$$\boxed{\frac{F}{L} = \frac{\mu_0}{2\pi}\frac{i_1 i_2}{r}}$$

Definition of Ampere :-

if $i_1 = i_2 = 1$ amp.

$r = 1m$

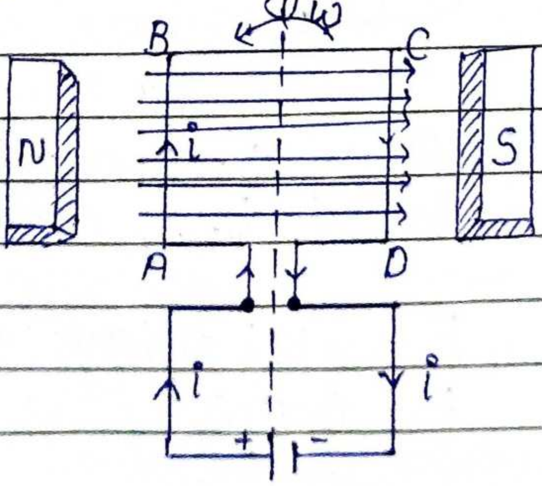
$$\frac{F}{L} = \frac{\mu_0}{2\pi} = 2 \times 10^{-7}\ N/m.$$

1 ampere is the current which flows through each of the two parallel uniform long linear conductors which are placed unit distance in space and which applied 2×10^{-7} N/m magnetic force on each other.

Torque On current Loop : Magnetic Dipole.

When a rectangular current carrying loop is placed in a uniform B (magnetic field) it experiences a torque.

Let a current carrying loop ABCD is placed such that the magnetic field in the plane of loop.



The field exerts no force on arms AD and BC of the loop because for this θ is zero.

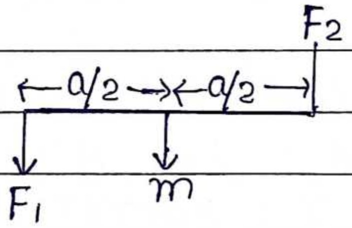
$$F = iBl \sin 0^\circ$$
$$\boxed{F = 0}$$

The magnetic forces on arms. AB and CD F_1 & F_2

$$F_1 = F_2 = ibB \sin 90^\circ$$
$$[= ibB]$$

Therefore the net force on the loop is zero. There is torque on the loop due to the force F_1 & F_2.

The resultant torque on the loop.

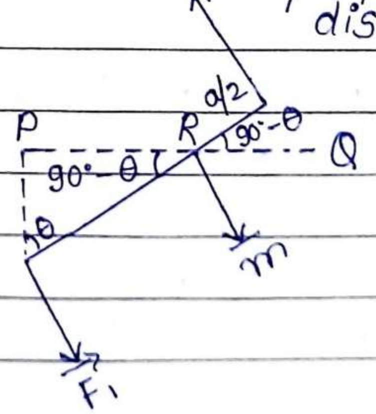


let $BC = a(l)$
$AB = b$ (l)

$$\tau = \tau_1 + \tau_2$$
$$\tau = F_1 \times a/2 + F_2 \times a/2$$
$$\tau = ibB\, a/2 + ib\, B\, a/2$$
$$\tau = i(ab)B$$
$$[\tau = iAB]$$

↳ If the loop is placed such that the magnetic field and magnetic moment m is acts on $\angle\theta$.

perpendicular distance



$$PR = RQ = \frac{a}{2} \sin\theta$$
$$\tau = \tau_1 + \tau_2$$
$$\tau = F_1 \times a/2 \sin\theta + F_2 \times a/2 \sin\theta$$
$$\tau = ibBa \sin\theta$$
$$\tau = i(ab)B \sin\theta$$
$$[\tau = iAB \sin\theta]$$

$\because m = iA$

m = magnetic dipole moment

$$[\tau = mB\sin\theta]$$

If there are N number of turns in rectangular coil then magnetic moment will be –

$$[m = NiA]$$

• The S.I unit of magnetic moment is amp-m^2.

~~Space~~

Special case :–

(i) If the coil is normal to of the magnetic field : i.e, $\theta = 0°$

$\tau = NBIA \sin 0°$

$\tau = NBIA \times 0$

$\tau_{min} = 0$

(ii) If the coil is in plane to the magnetic field i.e. $\theta = 90°$

$\tau_{max} = NIAB \sin 90° = NIAB$

* Radial Magnetic field :– If the plane of coil is parallel to magnetic field then magnetic field is said to be radical. i.e, $\theta = 0°$.

→ It is provided with the help of U-shaped magnet, horse shoe magnet, concave and semi-cylinder shaped magnet.

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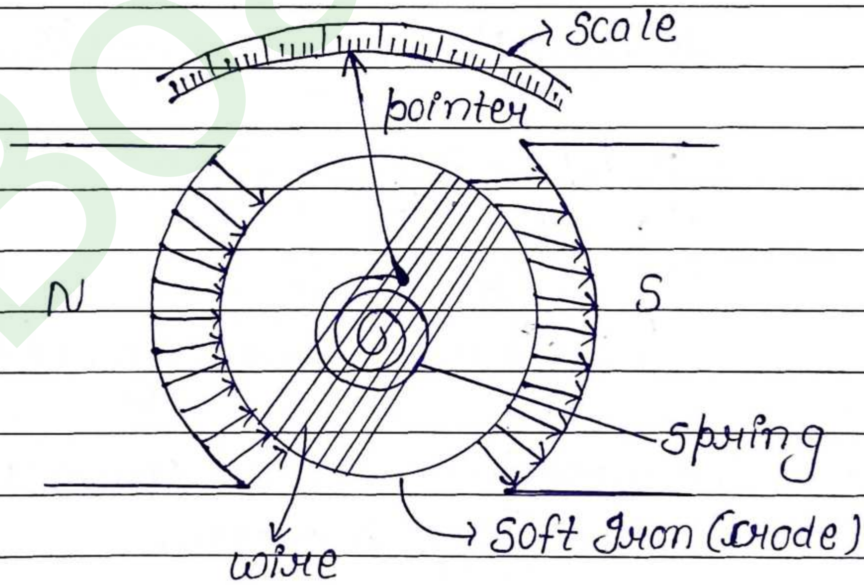
* Moving coil Galvanometer :-

The instrument which measure the current in a circuit or the voltage drop across a resister is called moving coil Galvanometer.

Construction :-

The Galvanometer consist of a coil with many turns free to rotate about the fix axis in a uniform radial magnetic field. there is a cylindrical soft iron (crode) which makes the field radical and also increases the strength of magnetic field.



Principle :-

When a current flows through the torque x on it.

$$\tau = NiAB \sin\theta$$

$$\theta = 90°$$

$$\because \tau = NiAB \quad \text{—— (1)}$$

The magnetic torque tends to arotate the coil then spring provide a counter torque which is directly proportional the deflection angle ϕ this deflection ϕ is indicated on the scale by a pointer attach to the spring.

$$\tau \propto \phi$$

$$\tau = K\phi \quad \text{—— ②}$$

↳ where K is constant which is torsinal constant of spring.

★ The restoring torque per unit twist is called torsinal constant.

At equilibrium force eqn ① & ②

$$NiAB = K\phi$$

$$\left[\frac{\phi}{i} = \frac{NAB}{K}\right]$$

↳ current senstivity. $\left(\frac{\phi}{i}\right)$

If we increase number of turns then current senstivity increase.

$$\because i = \frac{V}{R}$$

$$\frac{\phi}{V/R} = \frac{NAB}{K}$$

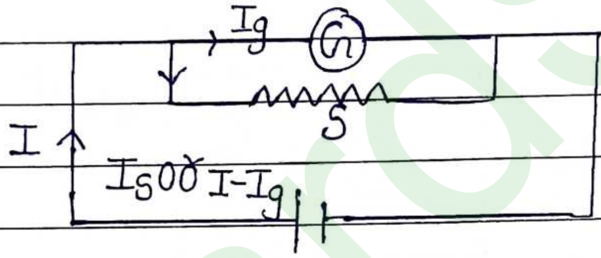
$$\left[\frac{\phi}{V} = \left(\frac{NAB}{K}\right)\frac{1}{R}\right]$$

$\frac{\phi}{V}$ is called voltage senstivity.

If we change number of turns of coil voltage sensitivity remain constant.

* Shunt :-

It is a small resistance always connected in parallel to save the electrical appliances from electrical damage.



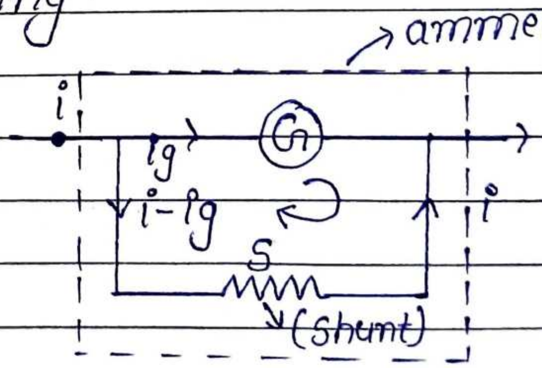
As G and S are parallel.

Potential across G = Potential across

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

Conversion of Galvanometer into Ammeter -

To Convert a galvanometer into ammeter its resistance needs to be lower so that the maximum current can pass through it & it can give exact reading.



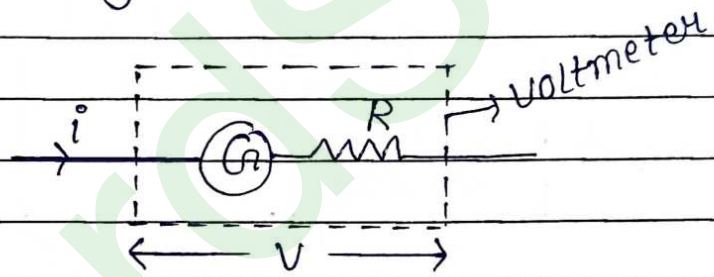
$$i_g G - (i - i_g) S = 0$$

$$i_g G = (i - i_g) S$$

$$S = \frac{i_g G}{i - i_g} \Rightarrow \boxed{S = \left(\frac{i_g}{i - i_g}\right) G}$$

Conversion of Galvanometer into voltmeter –

To convert a galvanometer into voltmeter its resistance need to be increase so that there is no potential drop across it because with high resistance no current is passes through it.



$$V = iG + iR$$

$$iR = V - iG$$

$$\left[R = \frac{V}{i} - G \right]$$