

Chapter - 4

Moving charges & Magnetism

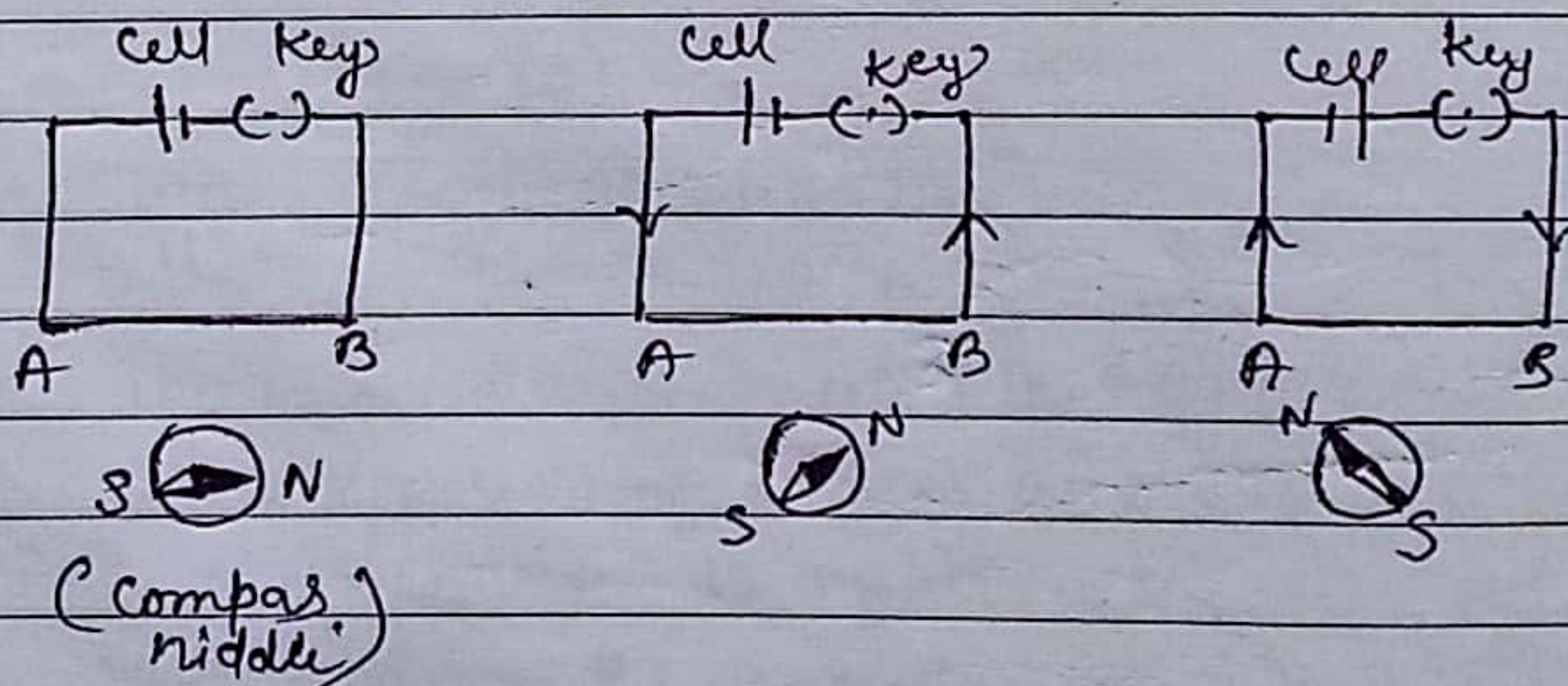
Magnetic field - The space in the surrounding of a magnet or current carrying conductor in which its magnetic influence can be experienced is called magnetic field.

SI unit of magnetic field is - Tesla, or weber/m^2 or N/(amp-m) .

In C.G.S system the unit of magnetic field is Gauss.

$$1 \text{ Tesla} = 10^4 \text{ Gauss}$$

✓ Oersted's Experiment



Oersted by his experiment concluded that a current carrying conductor deflected magnetic compass needle placed near it.
Therefore -

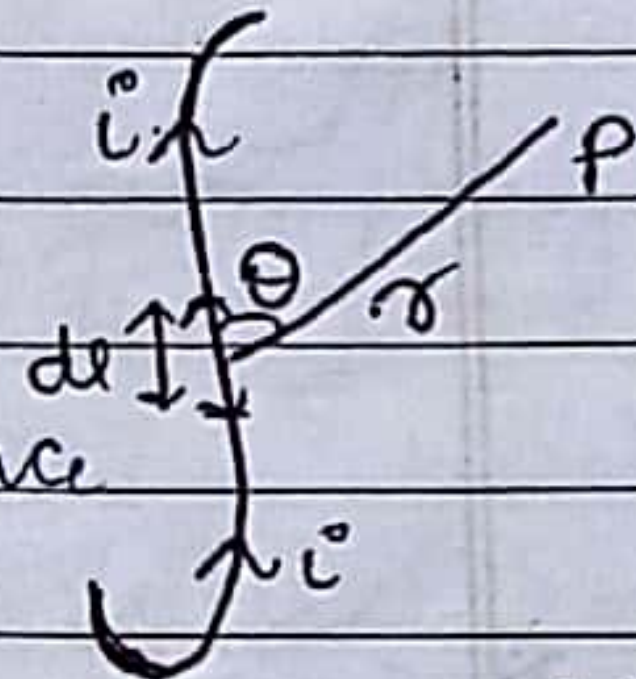


• A moving charge or current flowing through a conductor produces a magnetic field.

Magnetic field due to a current element.

(Biot Savart's law)

Let there is a current carrying conductor in which i current is flow dl is a small element of the conductor there is a point P at distance r from the element.



According to Biot Savart's law the magnetic field dB due to a current element at P depends upon following factors

- ① It is directly proportional to current i
i.e. $dB \propto i$
- ② It is directly proportional to the length of element
i.e. $dB \propto dl$
- ③ It is directly proportional to the sine of angle b/w element and the line joining the element to the point
i.e. $dB \propto \sin \theta$
- ④ It is inversely proportional to the square of distance b/w element & the point P .
i.e. $dB \propto \frac{1}{r^2}$

Therefore —

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

$$\left[dB = \frac{\mu_0}{4\pi} \frac{idl \sin \theta}{r^2} \right]$$

where μ_0 is a constant
it is called Permeability of space

$$\left[\mu_0 = \frac{4\pi \times 10^{-7} \text{ W/amp-m}}{} \right]$$

★ The magnetic field at point P due to entire current carrying conductor

$$\left[B = \int dB = \int \frac{\mu_0}{4\pi} \frac{idl \sin \theta}{r^2} \right]$$

★ The Vector representation of Biot Savart's law is

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

Direction of magnetic field

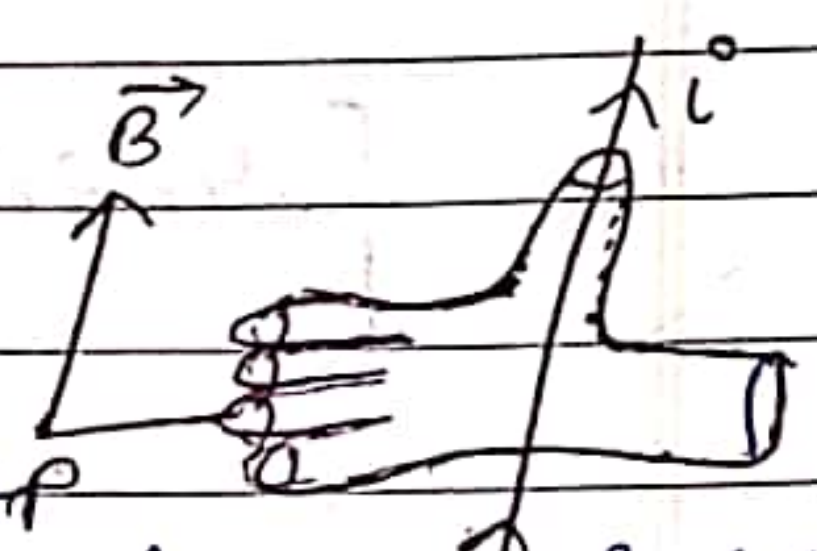
The direction of magnetic field due to a straight current carrying conductor can be found either of the following rules —



(1) Right hand thumb rule $\rightarrow$ If we hold the straight conductor in the grip of our right hand in such a way that the extended thumb points in the direction of the current then the direction of curve of fingers will give the direction of magnetic field.

(2) Right hand palm rule $\rightarrow$

If we expand our right hand palm such that in the direction of current and fingers ~~low~~ indicates towards that point at which the direction of magnetic field has been form.



The direction of magnetic field will be $\perp$ in the direction of pushing of the palm at out-ward.

(3) Maxwell screw law $\rightarrow$

If the right handed screw will rotated along the wire so that it advances in the direction of current, the direction in which the thumb rotates gives the direction of magnetic field.

Relation b/w ϵ_0 & μ_0

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N-m}^2/\text{C}^2$$

$$\epsilon_0 = \frac{1}{4\pi \times 9 \times 10^9} = 8.85 \times 10^{-12} \text{ C}^2/\text{N-m}^2$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ Tm/amp.}$$

$$\mu_0 \epsilon_0 = \frac{1}{4\pi \times 9 \times 10^9} \times 4\pi \times 10^{-7}$$

$$\mu_0 \epsilon_0 = \frac{1}{9 \times 10^{16}} = \frac{1}{(3 \times 10^8 \text{ m/sec})^2}$$

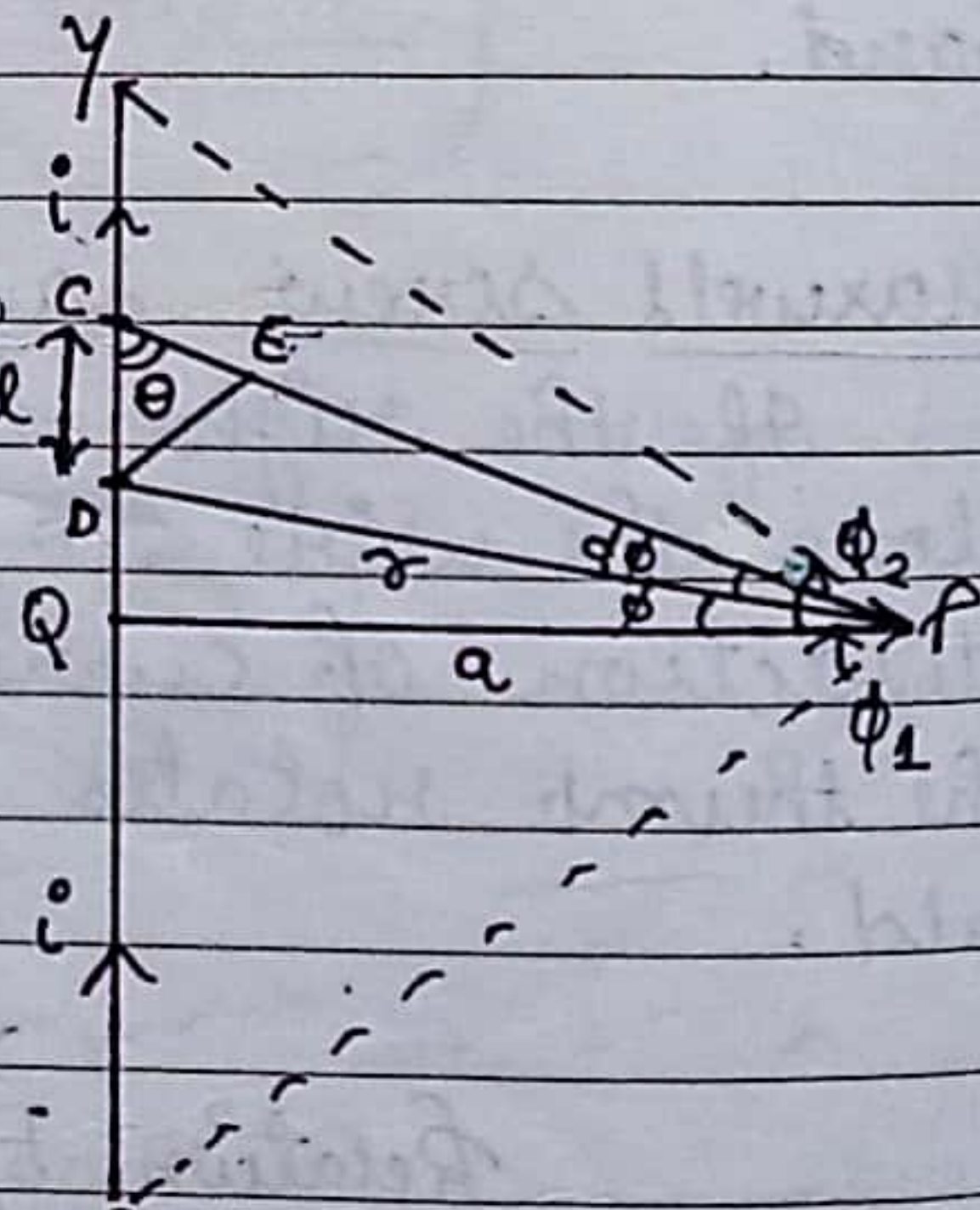
$$\left[\mu_0 \epsilon_0 = \frac{1}{c^2} \right]$$

where c is the velocity of light in vacuum.

✓ * imp

Magnetic field due to a long straight current carrying conductor

Let us consider a straight current carrying conductor xy , in which i current dl 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 this element by Biot Savart's law -

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

In $\triangle CDE$

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

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

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

$$DE = r d\phi \quad \text{--- (3)}$$

from eq (2) & (3)

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

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 $\triangle PQD$

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

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

from eqn (4)

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

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

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

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

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

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

$$\star \quad B = \frac{\mu_0}{4\pi} \frac{i}{a} [\sin \phi_1 + \sin \phi_2]$$

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 —

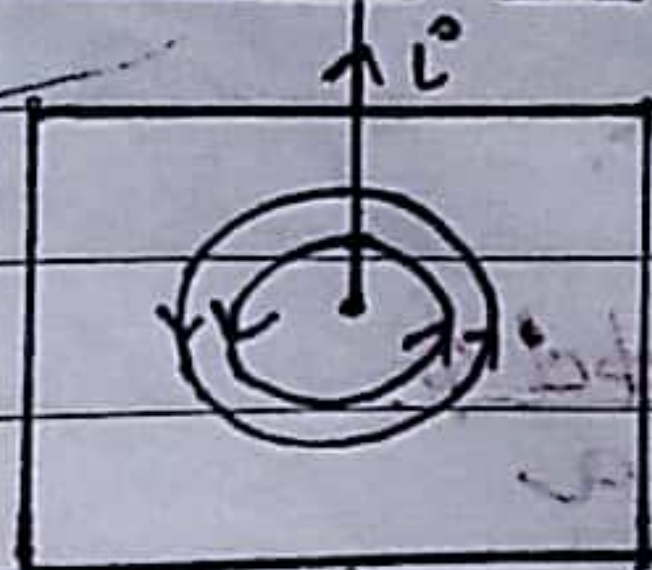
$$\phi_1 = \phi_2 = 90^\circ$$

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

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

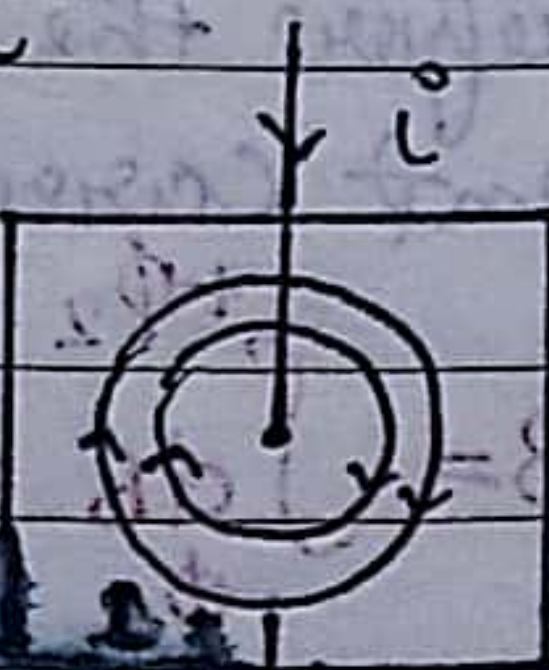
$$\star \quad B = \frac{\mu_0}{2\pi} \frac{i}{a}$$

Direction of magnetic field



↑ i

anti clockwise



↓ i

clockwise

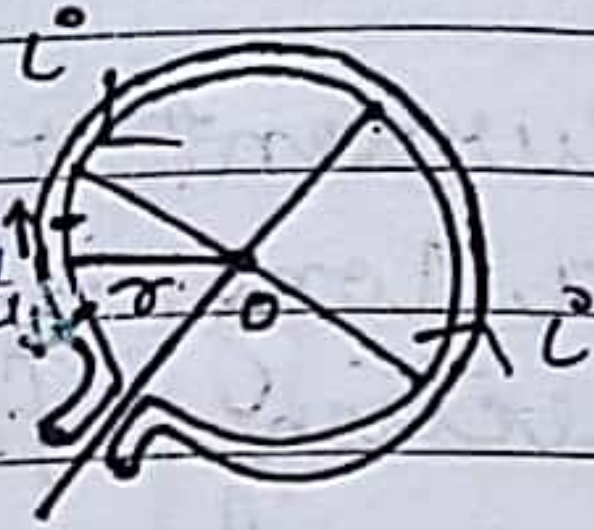
magnetic force line of a straight current conductor are concentric circle with the wire centre and in a plane $\perp$ to the wire.



✓ gmk

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 dl .



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

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

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

$$\therefore dB = \frac{\mu_0}{4\pi} \frac{idl}{r^2}$$

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

$$\checkmark B = \int dB = \int \frac{\mu_0}{4\pi} \frac{idl}{r^2}$$

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

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

$$\left[B = \frac{\mu_0 i}{2r} \right]$$

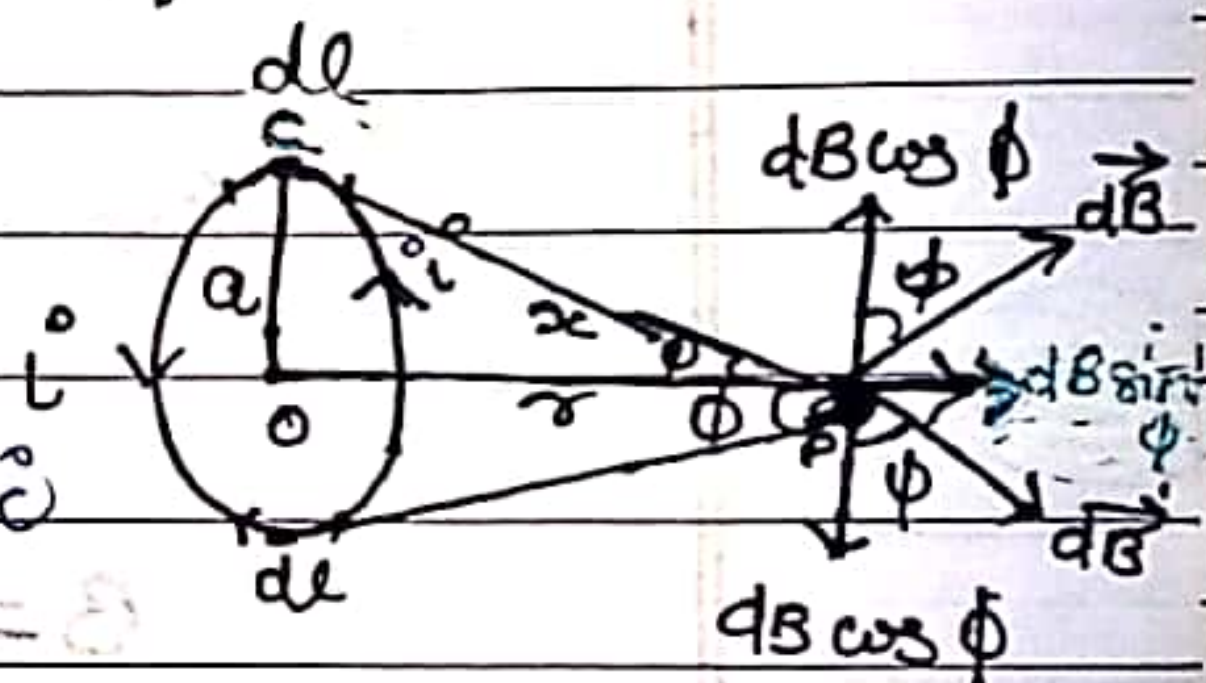
If there are N turns then

$$[B = \frac{\mu_0 N i}{2a}]$$

✓ If the current is flowing anticlockwise in the loop then the direction of magnetic field will be $\perp$ outward and if current is flowing clockwise then the direction of magnetic field will be $\perp$ 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 x from the centre O .



Consider a current element dl at the top of the loop and also at the bottom of the loop the magnetic field at P due to the current element dl according to Bio Savart's law-

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

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

Let $\angle$ b/w OP & CP is ϕ then $\vec{dB}$ can be resolved in two components

① $dB \sin \phi$ in direction of axis

② $dB \cos \phi$ $\perp$ to the axis

The Component dB w^o ϕ neutralise each other
therefore, total magnetic field will be due to
Component dB $\sin \phi$

Therefore the magnetic field at P.

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

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

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

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

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

$$B = \frac{\mu_0}{4\pi} \frac{i a}{(a^2 + r^2)^{3/2}} \int dl \quad \therefore \int dl = 2\pi a$$

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

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

at Centre—

$$r = 0$$

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

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

★ imp

Ampere's Circuital law -

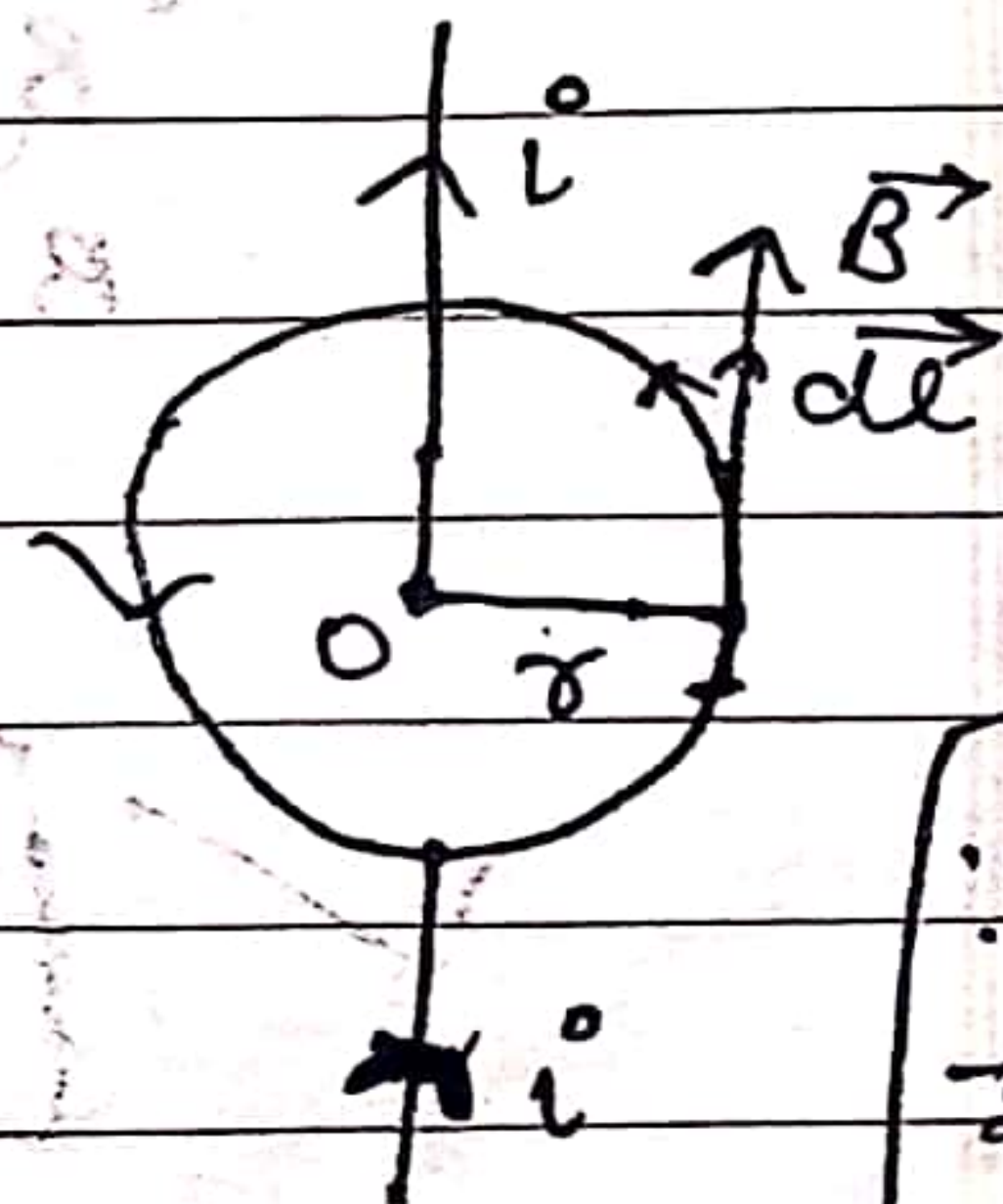
According to this law the line integral of magnetic field $\vec{B}$ around any close path in vacuum is equal to μ_0 times the net current i enclosed by the path.

$$\left[\oint \vec{B} \cdot d\vec{l} = \mu_0 i \right]$$

$$\begin{aligned} \oint \vec{B} \cdot d\vec{s} &= \oint B dl \cos 0^\circ \\ &= \oint B dl \end{aligned}$$

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

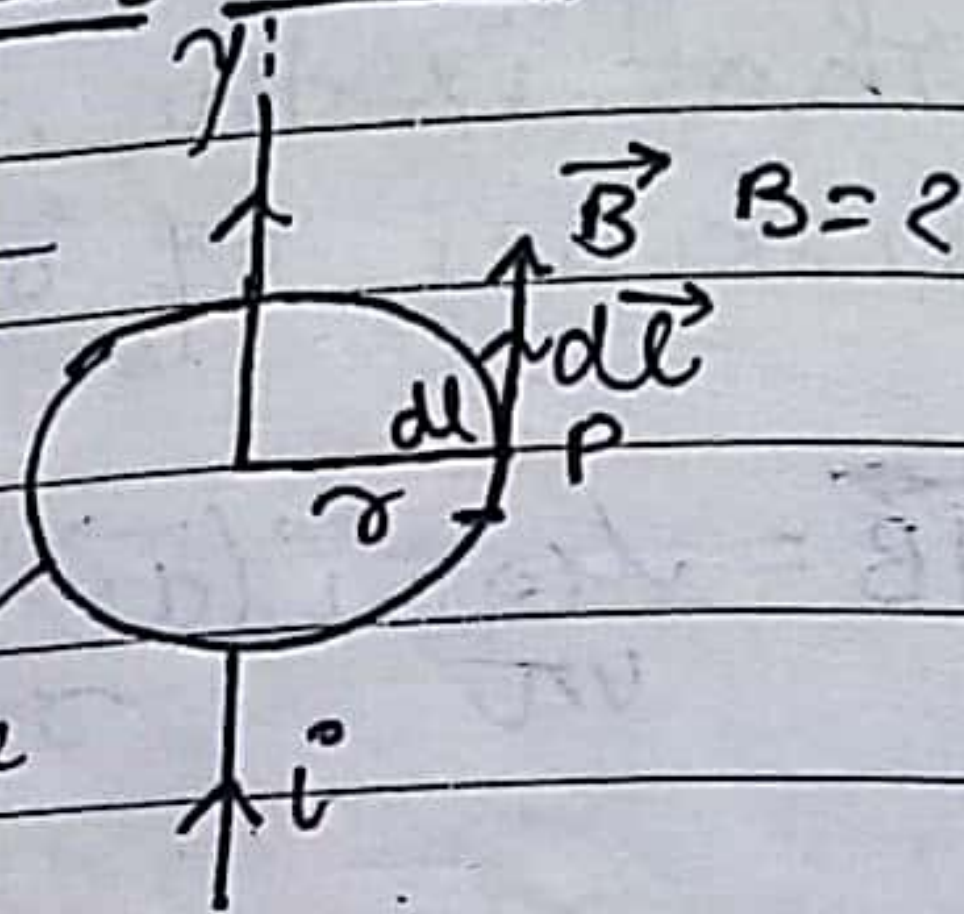
$$\left[\oint \vec{B} \cdot d\vec{l} = \mu_0 i \right] \text{ Ampere's Circuital law}$$



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

Magnetic field of a straight current carrying conductor wire

Let there is a straight current carrying wire in which i current is flowing. There is a point P at distance r at which we have to find magnitude of magnetic field.



Let us consider a circle of radius r which is taken as closed path for amperian loop.
Angle b/w $\vec{B}$ & $d\vec{l}$ is 0.

From Ampere's Circuital Law -

✓ According to amperian Circuital Law.

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i$$

$$\oint B dl \cos 0 = \mu_0 i$$

$$\oint B dl = \mu_0 i$$

$$\because \oint dl = 2\pi r$$

$$\oint B dl$$

$$B \oint dl = \mu_0 i$$

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

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

$$B = \frac{\mu_0}{2\pi} \frac{C}{r}$$

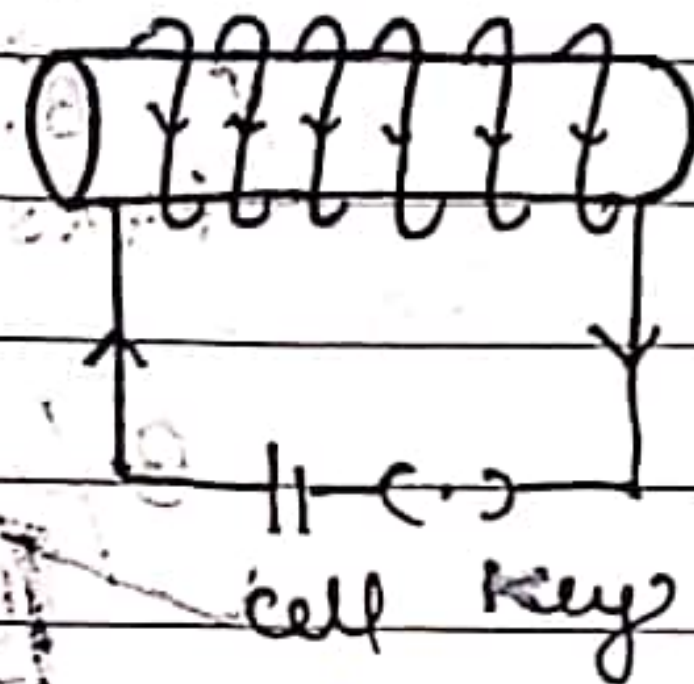
- ① The magnetic field at every point will be concentric circle whose centre will be same.
- ② The direction of magnetic field at any point will be tangential on this circle. These circular lines are called magnetic field lines.

Solenoid

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

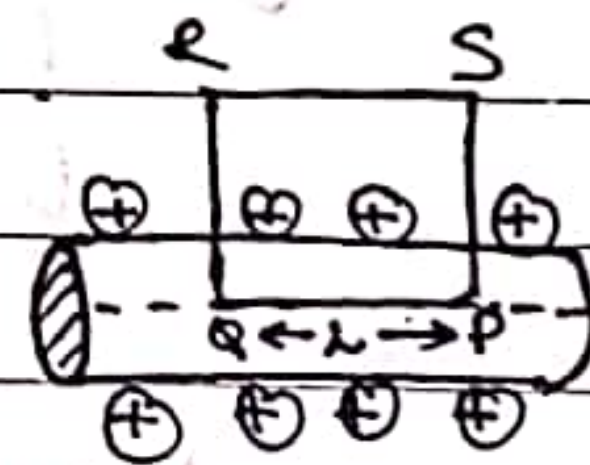
Its length is very long as compared to its diameter.

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 amperian closed path PQRS where $PQ = l$.

According to Ampere's Circuital Law

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

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

and $\oint_R \vec{B} \cdot d\vec{l} = 0 \therefore B=0$

Therefore

$\int_{PQRS} \vec{B} \cdot d\vec{l} = \oint_P^Q \vec{B} \cdot d\vec{l} = \int_P^Q B dl \cos 0 = B \int_P^Q dl = BL = 0$

The no. of turns on PQ = nL

Net current in PQ = nLi — (11)

By Ampere's Circuital law

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

$B \times L = \mu_0 \times nLi$

$[B = \mu_0 ni]$

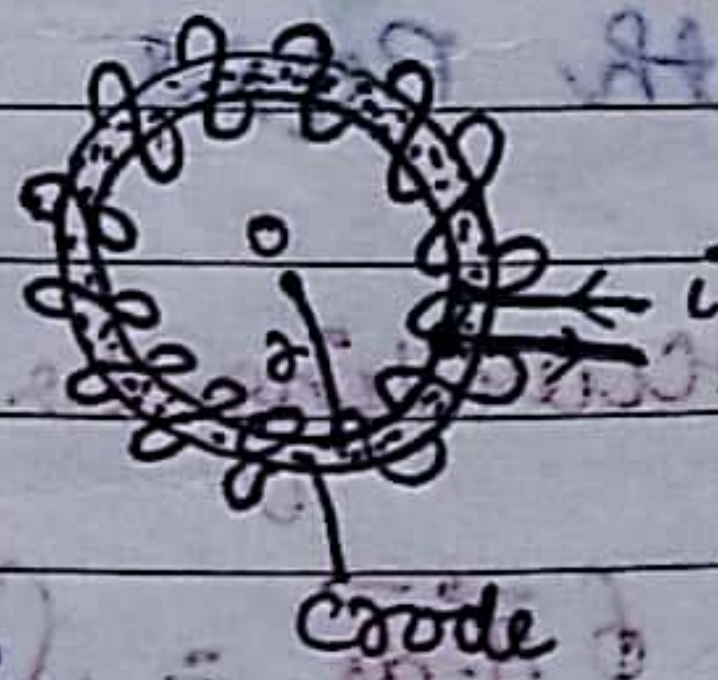
The magnetic field near any end of solenoid

$B = \frac{1}{2} \mu_0 ni$

Magnetic field of a Toroid

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

Let 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

$$i_{\text{net}} = 2\pi r \times ni$$

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

$$\therefore \theta = 0$$

So,

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i_{\text{net}}$$

$$\oint B dl \cos 0 = \mu_0 \times 2\pi r \times ni$$

$$B \oint dl = \mu_0 \times 2\pi r \times ni \quad \therefore \oint dl = 2\pi r$$

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

$$\star [B = \mu_0 ni]$$

★

NOTE → There will be no magnetic field outside the toroid and also in the empty space surrounded by the toroid.

★ Imp

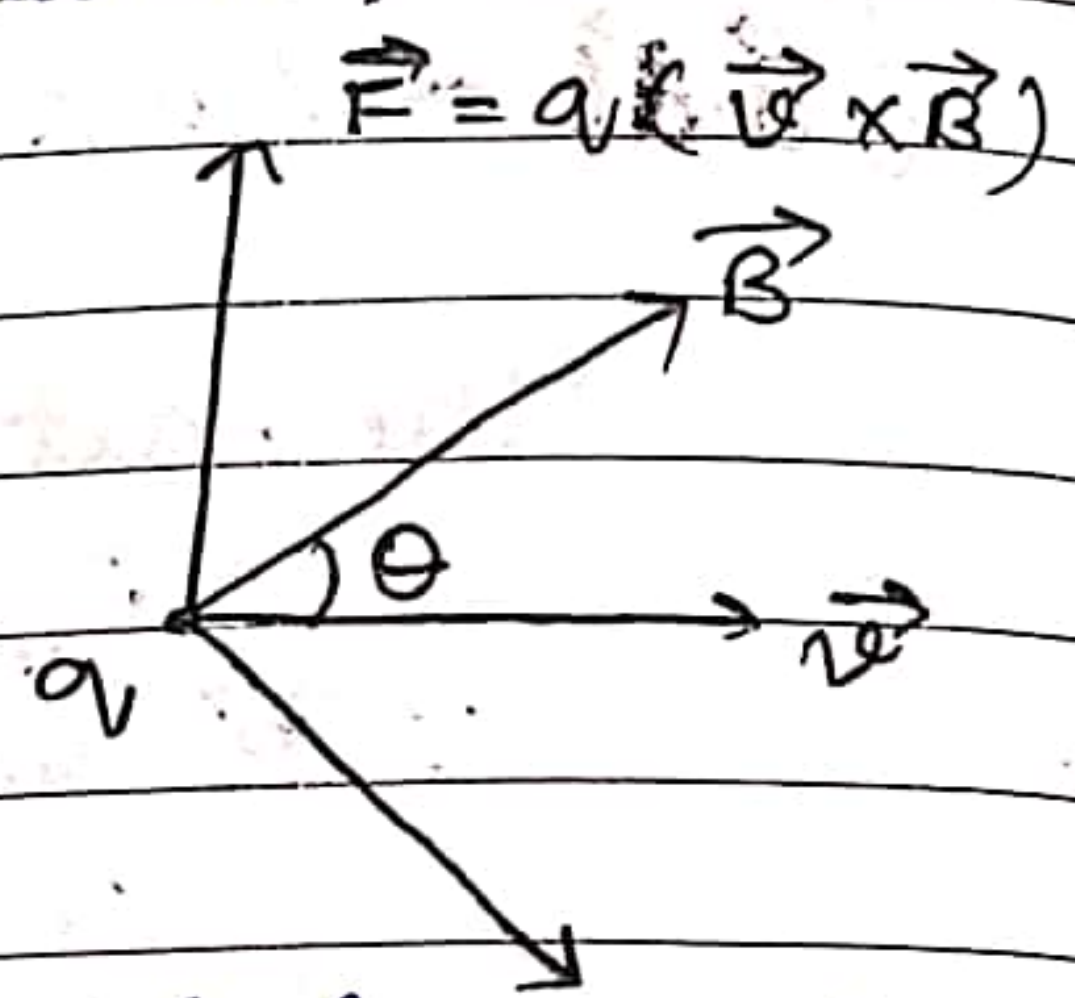
Force on a moving charge in a uniform magnetic field

When a charge particle q moves with velocity $\vec{v}$ inside the uniform magnetic field $\vec{B}$ then the force acting on it will be

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

$$[F = qvB \sin \theta]$$

The direction of force will be perpendicular to velocity $\vec{v}$ and magnetic field $\vec{B}$



- (1) If the charge is at rest in magnetic field i.e. $v=0$
 $[F=0]$

Therefore if any charge is at rest in a uniform magnetic field there will be no magnetic force on the charge.

- (2) If charge is moving perpendicular to the direction of magnetic field i.e. $\theta = 90^\circ$
then the force on the charge will be maximum

$\theta = 90^\circ$
 $[F = qvB]$

- (3) If the charge is moving in the direction of magnetic field i.e. $\theta = 0$
then $[F=0]$

it means if any charge is moving in direction of magnetic field there will be no force acting on the charge.

Force on a Moving charge in a uniform magnetic & electric field (Lorentz Force)

Suppose a point charge q is moving with velocity $\vec{v}$ in presence of electric field $\vec{E}$ & magnetic field $\vec{B}$ both. Then the total force acting on charge —

$$\vec{F}_{\text{net}} = \vec{F}_{\text{electric}} + \vec{F}_{\text{magnetic}}$$

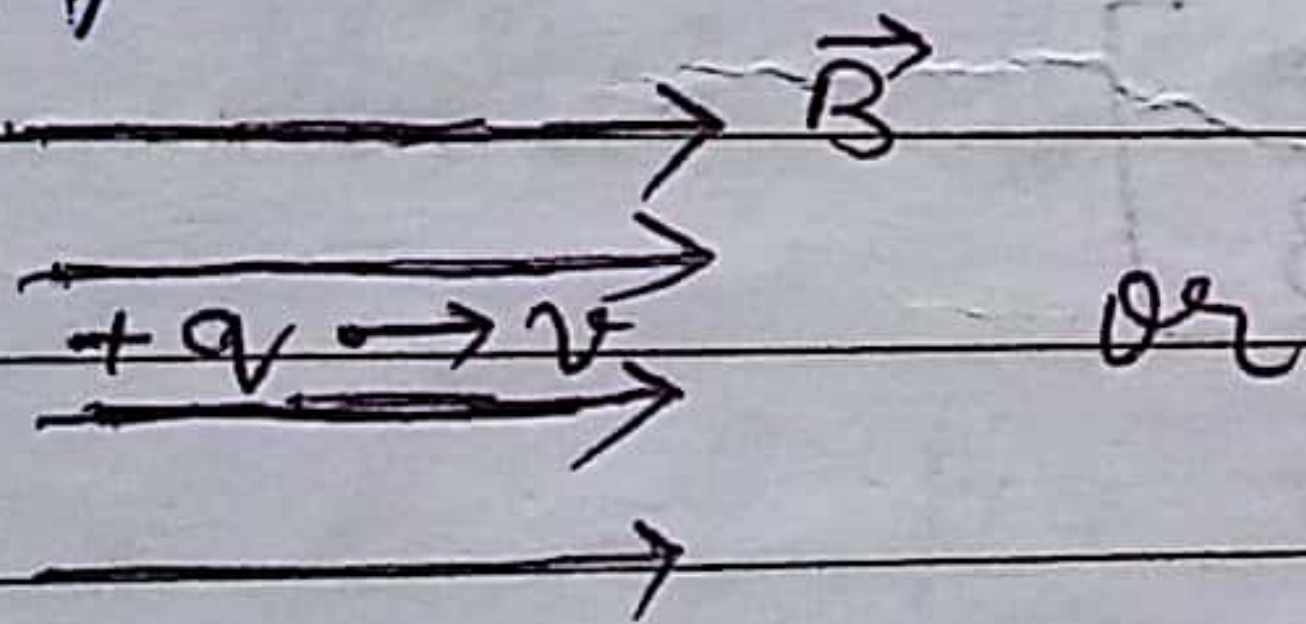
$$\vec{F}_{\text{net}} = q\vec{E} + q(\vec{v} \times \vec{B})$$

This net force is called Lorentz Force



Path of a charge particles moving in uniform magnetic field.

the charge particles move in direction of $\vec{B}$ or in opposite direction of magnetic field.

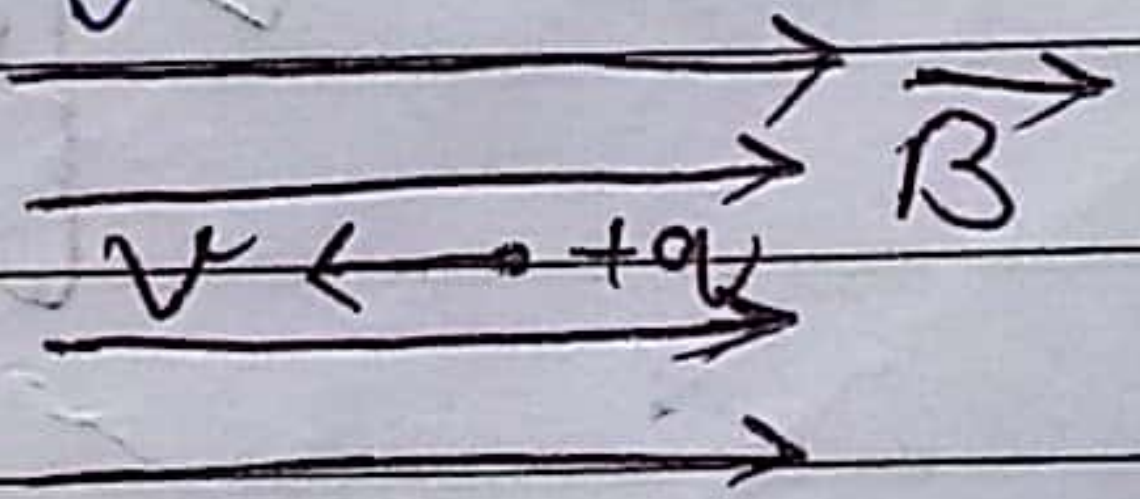


$$\theta = 0$$

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

$$F = 0$$

or



$$\theta = 180^\circ$$

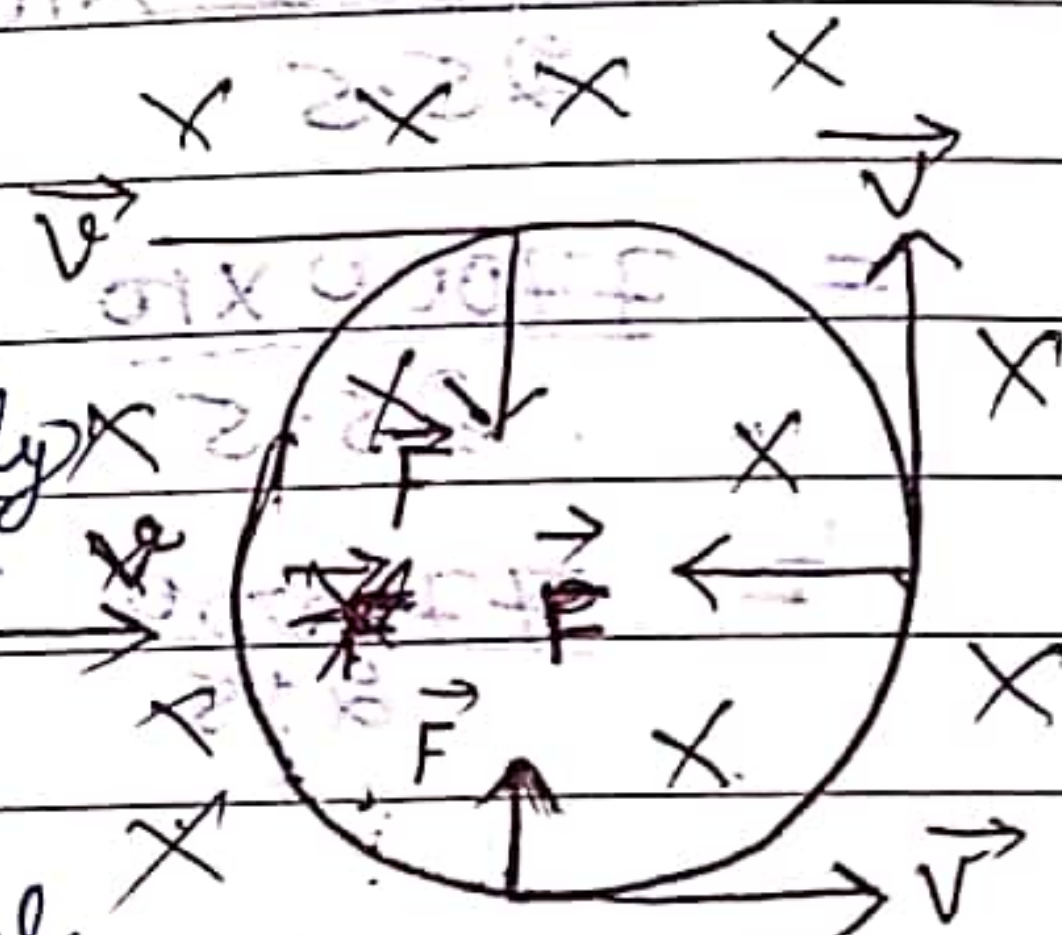
$$F = qvB \sin 180^\circ$$

$$F = 0$$

In both case there will act no force on moving charge particle therefore its moving path will be same as its original path.

(2) when charge particles entered perpendicular in uniform magnetic field.

If a charge particle entered in a uniform magnetic field perpendicularly its moving path will be circular.



Let a charge particle of mass (m) and having charge (q) enter in uniform magnetic field B perpendicularly with velocity (v) let the radius of circular path is (r) then

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

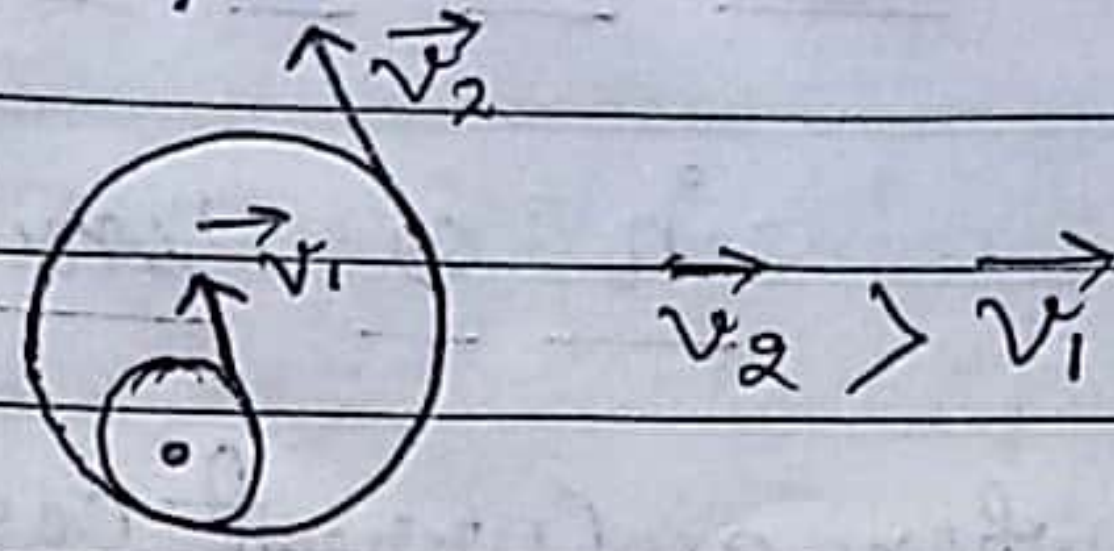
$$qB = \frac{mv}{r}$$

$$\checkmark \left[r = \frac{mv}{qB} \right]$$

The time period,

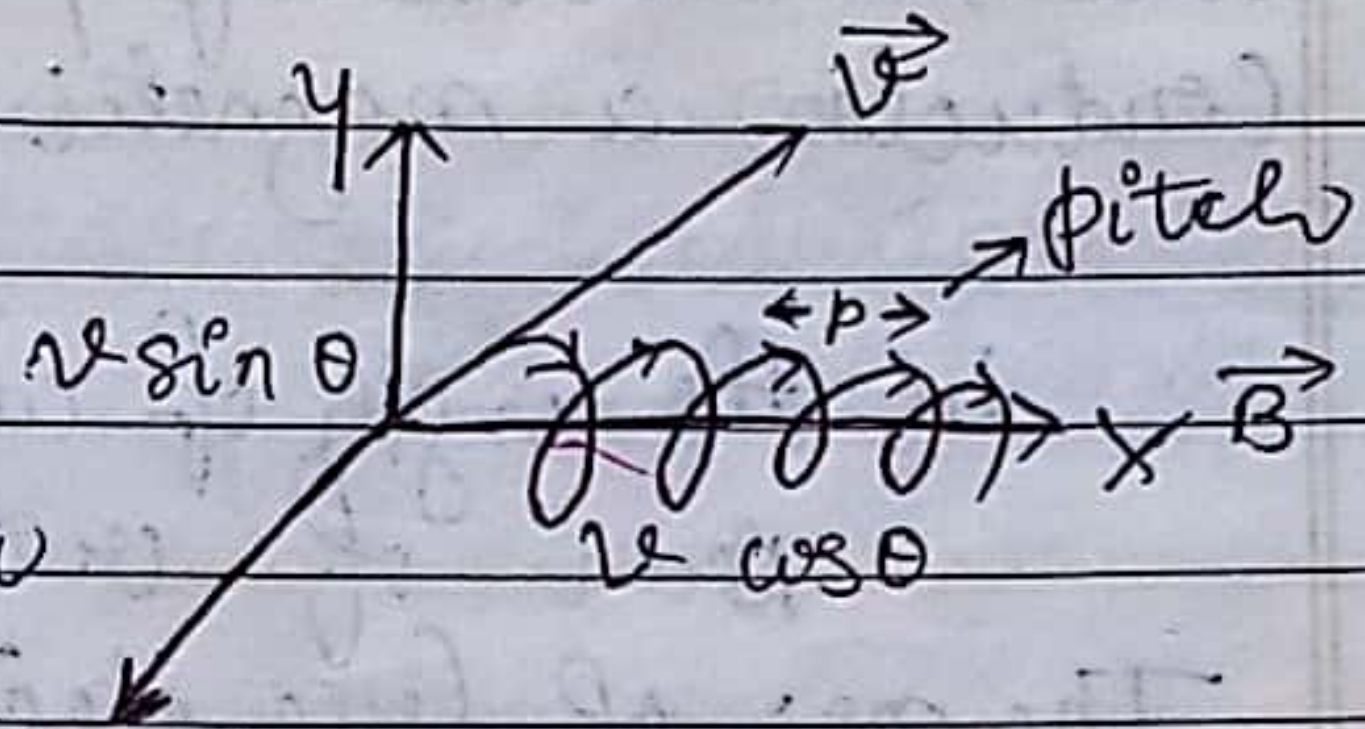
$$T = \frac{2\pi r}{v} \Rightarrow \frac{2\pi \times m \cancel{v}}{\cancel{v} \times qB} = \frac{2\pi m}{qB}$$

The time period does not depend on the velocity of particles.



(3) If the charge particle entered in magnetic field at direction θ .

In this condition the moving path of charge particle will be like a helix.



Let the radius of helix is (r)

$$\frac{mv^2}{r} = qv \sin \theta B$$

$$\frac{mv \sin \theta}{r} = qB \rightarrow \left[r = \frac{mv \sin \theta}{qB} \right]$$

For helical path the distance moved along the magnetic field in one rotation is called Pitch of helix path.

Pitch of the path

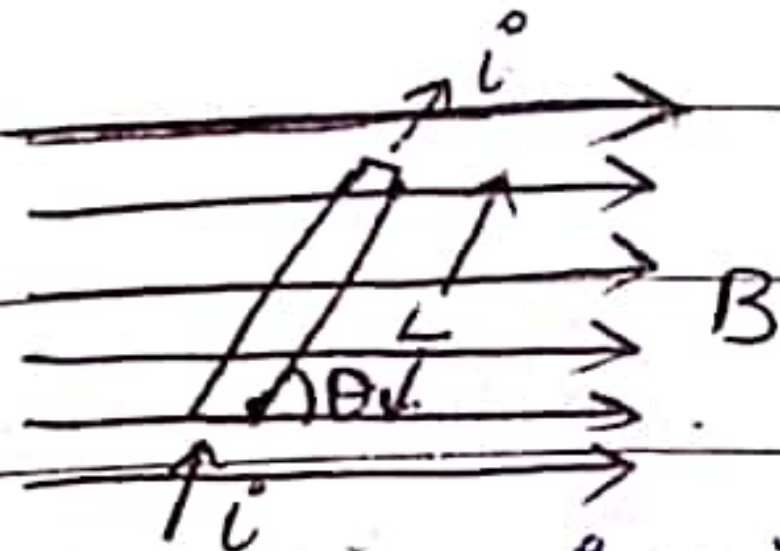
$$p = v_{||} \times T$$

$$p = v_{||} \times \frac{2\pi m}{qB}$$

$$p = \frac{2\pi m}{qB} \times v \cos \theta$$

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 force 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.

$$F' = e v_d B \sin \theta$$

Total no. of free e^- in current carrying conductor.

$$N = n A L$$

The net force on current carrying conductor.

$$F = N \times F'$$

$$F = n A L e v_d B \sin \theta$$

$$F = (n e A v_d) B L \sin \theta \quad \therefore i = n e A v_d$$

$$\boxed{F = i B L \sin \theta}$$

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 $\theta = 90^\circ$
 $[F_{\max} = iBL]$

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

Direction of Force

The direction of force acting on a current carrying conductor in a magnetic field can be found by any of the following two rules.

1. Fleming left hand Rule

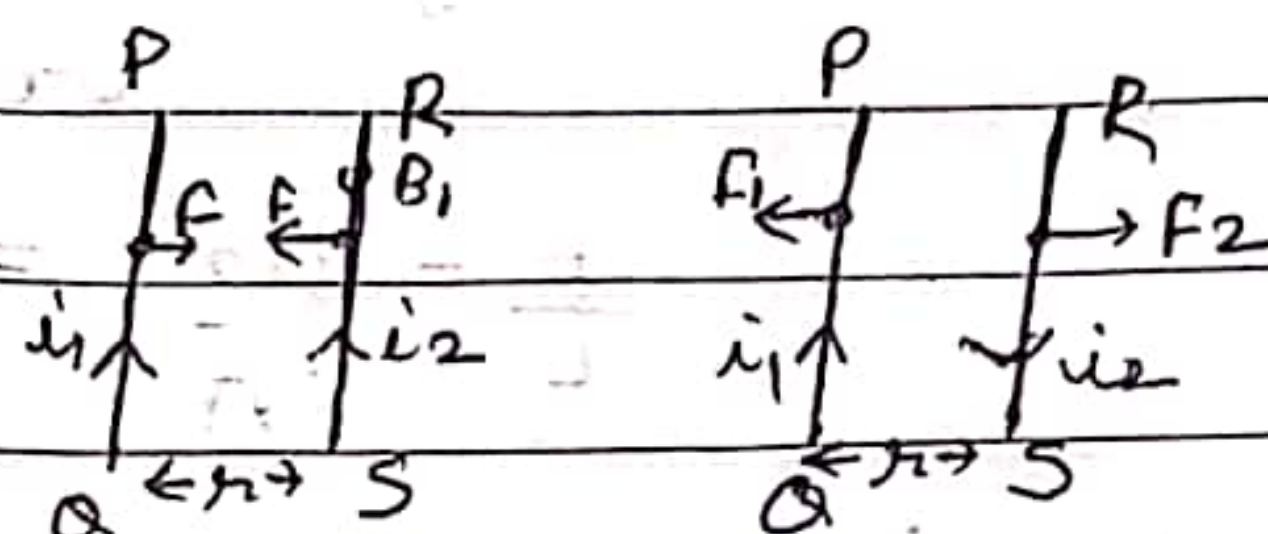
If the forefinger, middle finger & thumb of left hand are ~~stretch~~ stretch mutually $\perp$ to one another such that the forefinger points in the direction of magnetic field & the middle finger in the direction of current then thumb will point in the direction of force (F).

2. Right hand palm Rule

Stretch our right hand palm such
thumb point in the direction of current
clched fingers in the direction of
then force on the conductor will be
palm in the direction of pushing by it

emp
* 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 & R.S 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 .

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

$$F = i_2 B_1 L$$

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

$$\left[\frac{F}{L} = \frac{\mu_0}{2\pi} \frac{i_1 i_2}{r} \right]$$

Definition of ampere:-

if $i_1 = i_2 = 1 \text{ amp}$

$r = 1 \text{ m}$

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

ampere is the current which flows through the two parallel uniform long conductors which are placed at unit distance in space and which exert $2 \times 10^{-7} \text{ N/m}$ magnetic force on each other.

Cyclotron -

It is a type of machine that provides energetic charge particle.

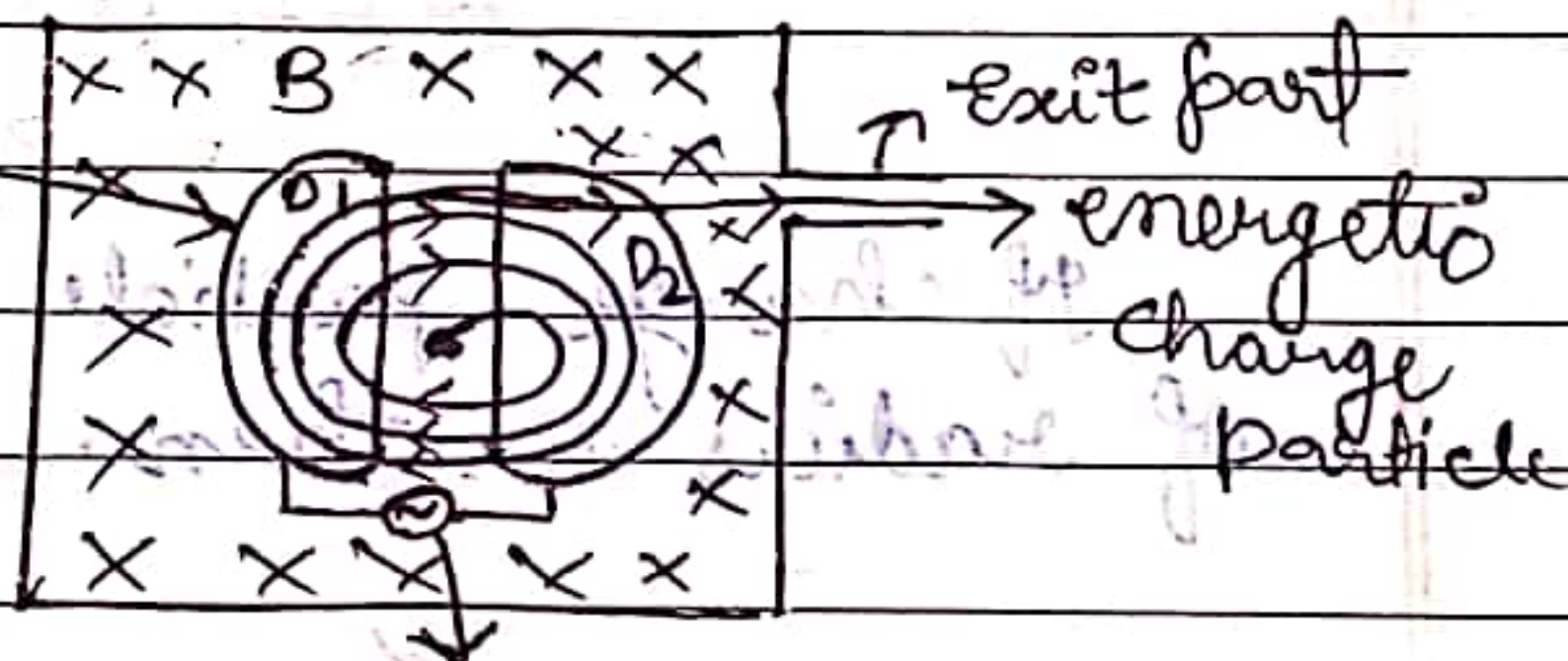
It is used to study the structure of nucleus and atom.

Principle -

When a charge particle ready to pass through a small electric field again and again with the help of strong magnetic field then it acquires high energy.

Structure -

The Cyclotron Dees is uses both electric field and magnetic field in combination to increase high tension oscillator. The energy of charge particle.



The charge particle move most of time inside two semi circular ~~dees~~ like metal container D₁ and D₂ ~~Dees~~ which are called dees.

Inside the metal boxes the particle is shielded and is not acted on by the electric field. The magnetic field however ~~is~~ acts on the particle and makes it ~~whole~~ ^{go} round in a circular inside the dees.

everytime the particle moves from one dees to another it is acted upon by the electric field this insure that the particle is always accelerated by electric field.

Each time the acceleration increases the energy of the particle. Therefore, we get an energetic charge particle.

Formula - If any charge q moving with velocity v in any magnetic field $\vec{B}$ then magnetic force on the charge particle.

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

$$\Rightarrow \vec{F}_m = qvB \sin \theta$$

$$\text{if } \theta = 90^\circ$$

$$\Rightarrow F_m = qvB \quad \text{--- (1)}$$

If charge particle move in circular path of radius R then.

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

$$\left[v = \frac{qBR}{m} \right]$$

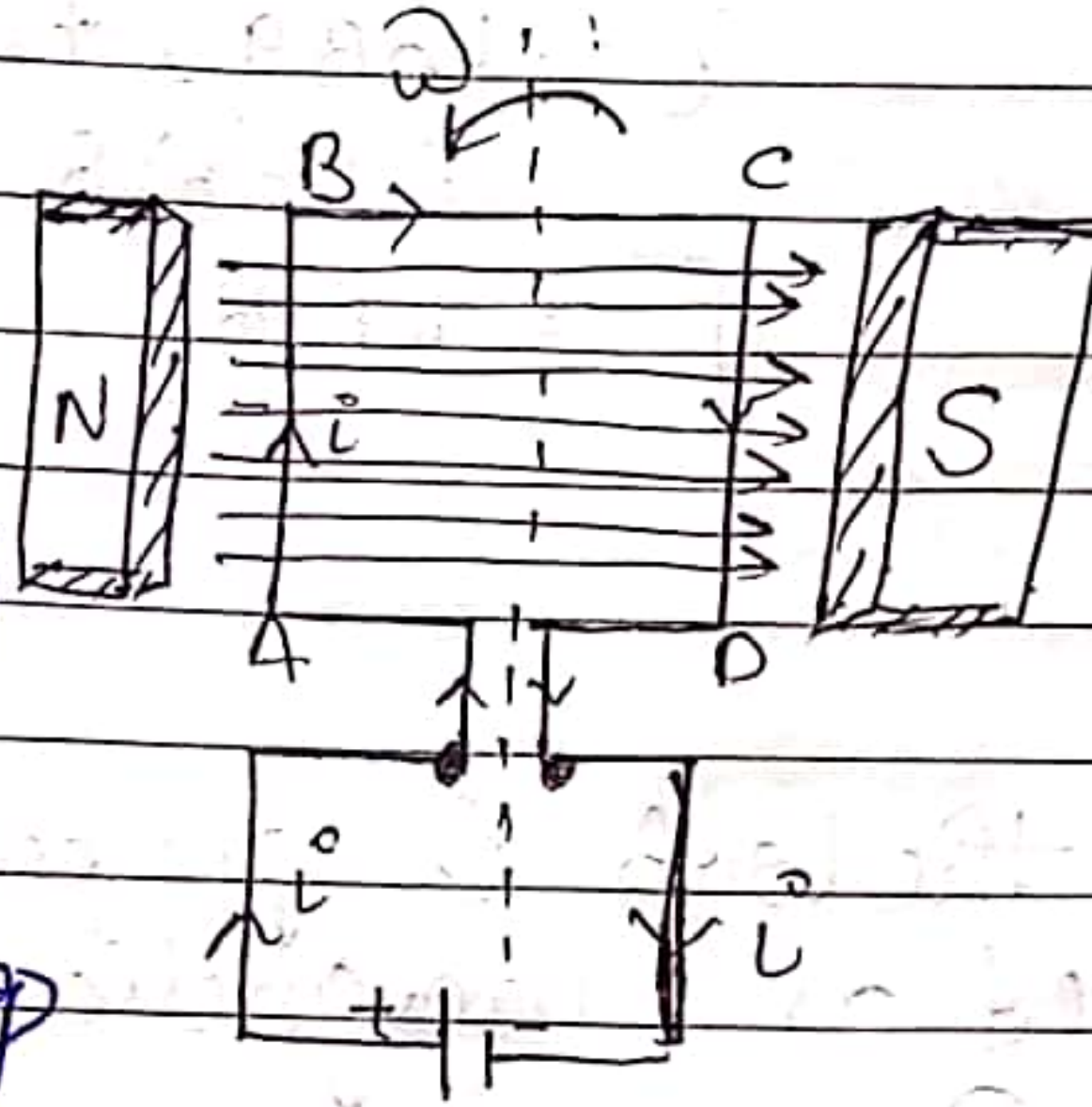
The energy of charge particle

$$\frac{1}{2}mv^2 = \frac{1}{2}m \times \frac{q^2 B^2 R^2}{m^2}$$

$$\left[\frac{1}{2}mv^2 = \frac{q^2 B^2 R^2}{2m} \right]$$

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 is in the plane of loop.

The field exerts no force on arms AB and CD of the loop because for this θ is zero

$$F = iBL \sin \theta$$

$$F = 0$$

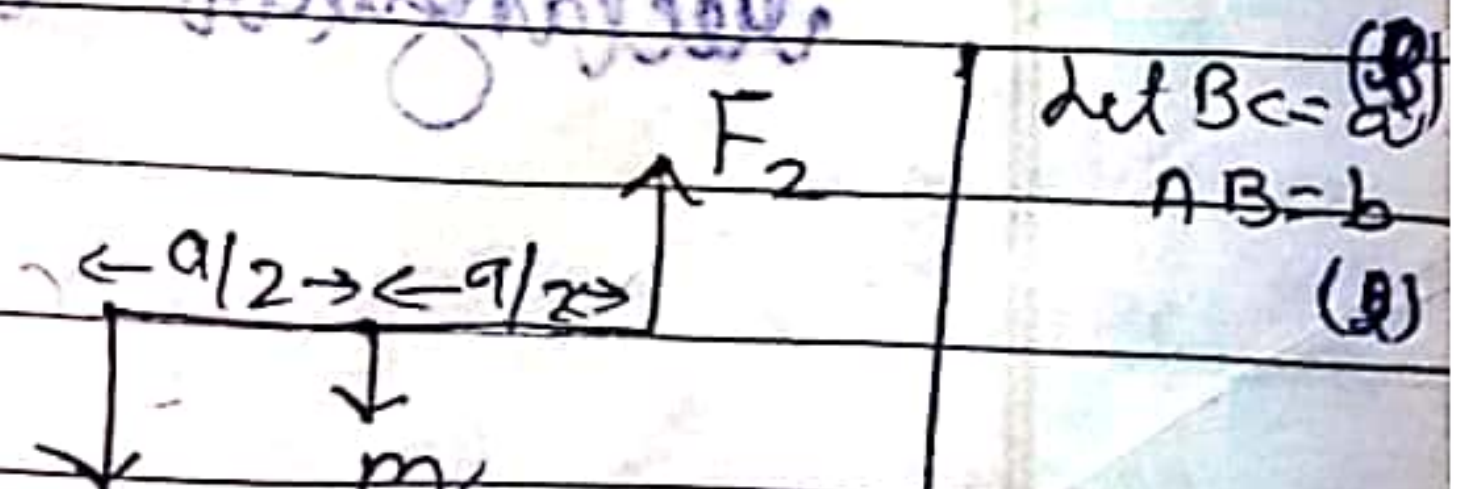
The magnetic forces on arms AB and CD F_1 & F_2

$$F_1 = F_2 = i b B \sin 90^\circ$$

$$[= i b B]$$

* 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.



$$\tau = \tau_1 + \tau_2$$

$$\tau = F_1 \times a/2 + F_2 \times a/2$$

$$\tau = i b B a/2 + i b B a/2$$

$$\tau = i (ab) B$$

$$[\tau = i A B]$$

② If the loop is placed such that the magnetic field and magnetic moment $\vec{m}$ is acts on $\angle \theta$.

$$PR = RQ = \frac{a}{2} \sin \theta$$

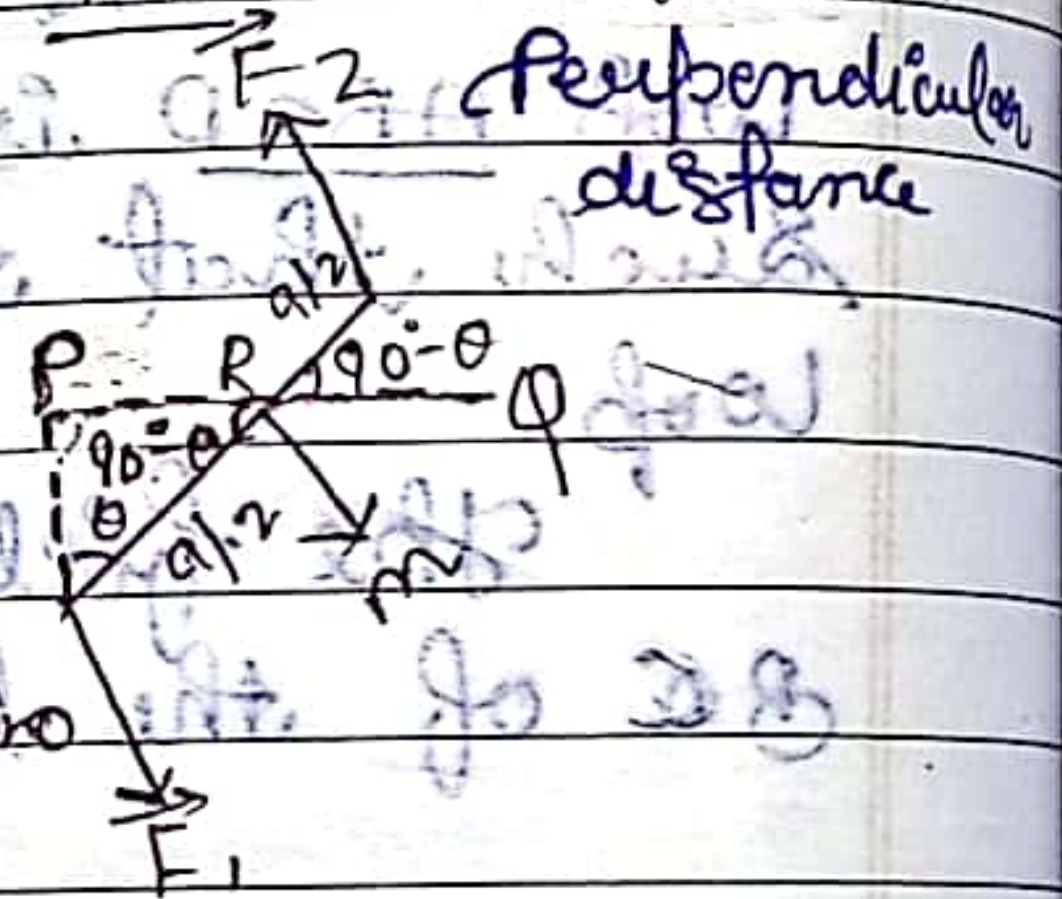
$$\tau = \tau_1 + \tau_2$$

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

$$\tau = i b B a \sin \theta$$

$$\tau = i (ab) B \sin \theta$$

$$[\tau = i A B \sin \theta]$$



$$m = i A$$

$m =$ magnetic dipole moment

$$[\tau = m B \sin \theta]$$

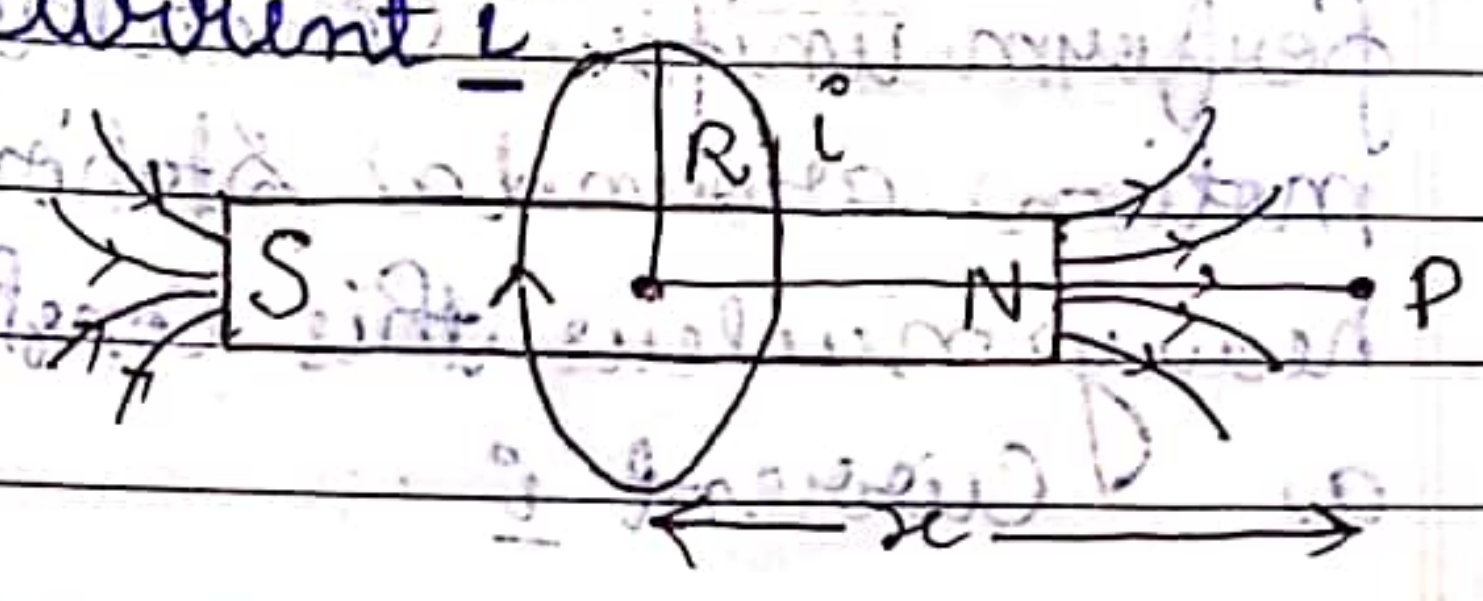
If there are N number of turns in rectangular coil then magnetic moment will be-

$$[m = N i A]$$

The S.I unit of magnetic moment is amp-m²

Circular Current Loop as a Magnetic Dipole

Let us Consider a Circular loop of radius R carrying a Steady Current i . The magnetic field at distance x on the axis of loop from its centre —



$$B = \frac{\mu_0 i R^2}{2 (R^2 + x^2)^{3/2}}$$

$$\because x \gg R$$

$\therefore R^2$ Negligible (in denominator)

$$B = \frac{\mu_0 i R^2}{2 x^3}$$

Multiplying divide by π in numerator & denominator

$$B = \frac{\mu_0 i \pi R^2}{2 \pi x^3} \quad \because \pi R^2 = A$$

$$\underline{A i} = B = \frac{\mu_0 i A}{2 \pi x^3} \quad \because i A = m$$

$$B = \frac{\mu_0 m}{2 \pi x^3}$$

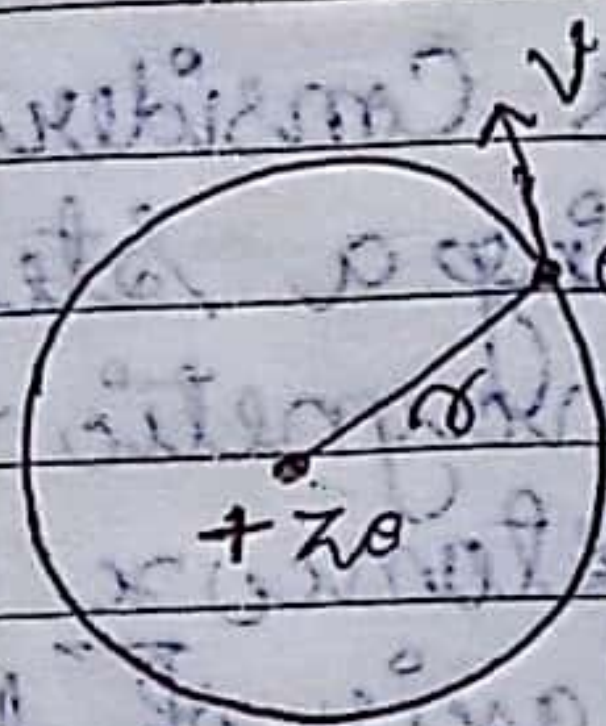
Multiplying by 2 in numerator & denominator

$$B = \frac{\mu_0 2m}{4 \pi x^3}$$

Result $\rightarrow$ The result obtained above can be shown to apply any planar rule. A planar current loop is equivalent to a magnetic dipole having magnetic dipole moment m .

✓ The Magnetic dipole moment of a revolving electron

The electron of charge e , perform uniform circular motion around a stationary heavy nucleus this constitute a current i .



⊗ μ_l
orbital dipole moment

$$i = \frac{e}{T}$$

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

$$i = \frac{e}{\frac{2\pi r}{v}}$$

$$i = \frac{ev}{2\pi r}$$

magnetic

orbital dipole moment $\mu_l = iA$

$$\mu_l = \frac{ev}{2\pi r} \times \pi r^2$$

$$\mu_l = \frac{evr}{2}$$

multiply by m in numerator & denominator

$$\mu_l = \frac{e(mvr)}{2m}$$

$$\left[\mu_l = \frac{e\hbar}{2m} \right] \text{ where } l \text{ is angular momentum}$$

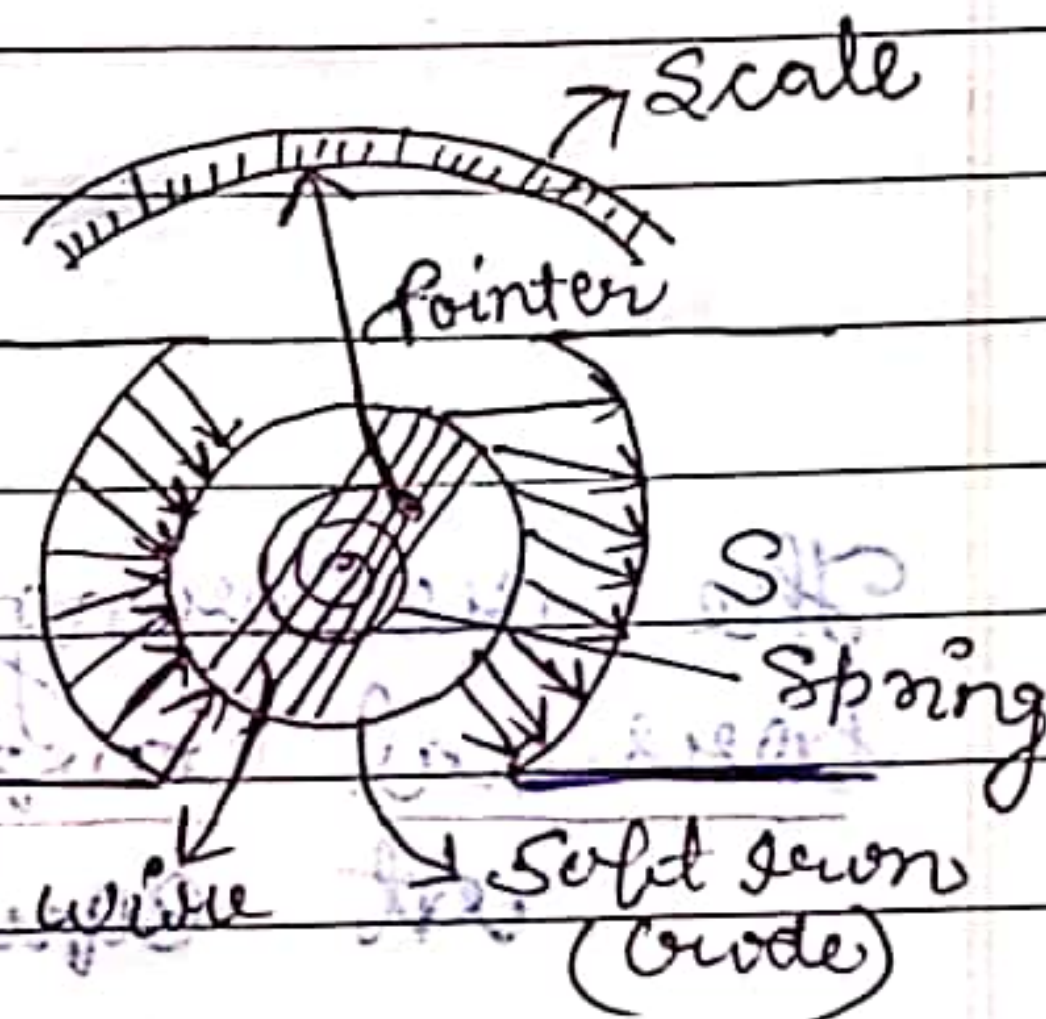
$$\left[\frac{\mu_l}{l} = \frac{e\hbar}{2m} \right]$$

is called Gyromagnetic Ratio

$$\star \left[\frac{\mu_B}{\hbar} = \frac{1.6 \times 10^{-19}}{2 \times 9.1 \times 10^{-31}} = 8.8 \times 10^{10} \text{ C/kg} \right]$$

Moving Coil Galvanometer

The instrument which measures the current in a circuit or for the voltage drop across a resistor is called moving coil galvanometer



Construction

The Galvanometer consists of a coil with many turns free to rotate about the fixed axis in a uniform radial magnetic field. There is a cylindrical soft iron (core) which makes the field radial and also increases the strength of magnetic field.

Principle

When a current flows through the coil, a torque acts on it.

$$T = N i A B \sin \theta$$

$$\text{But } \theta = 90^\circ$$

$$\therefore T = N i A B \quad \text{--- (1)}$$

The magnetic torque tends to rotate 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 torsional constant of spring.

★ The restoring torque per unit twist is called torsional constant

At equilibrium from eqn (1) & (2)

$$N I A B = K \phi$$

$$\left[\frac{\phi}{I} = \frac{N A B}{K} \right]$$

↳ Current Sensitivity $\left(\frac{\phi}{I} \right)$

If we increase number of turns then Current Sensitivity increase

$$\therefore I = \frac{V}{R}$$

$$\frac{\phi}{V/R} = \frac{N A B}{K}$$

$$\left[\frac{\phi}{V} = \left(\frac{N A B}{K} \right) \cdot \frac{1}{R} \right]$$

$\frac{\phi}{V}$ is called voltage sensitivity

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

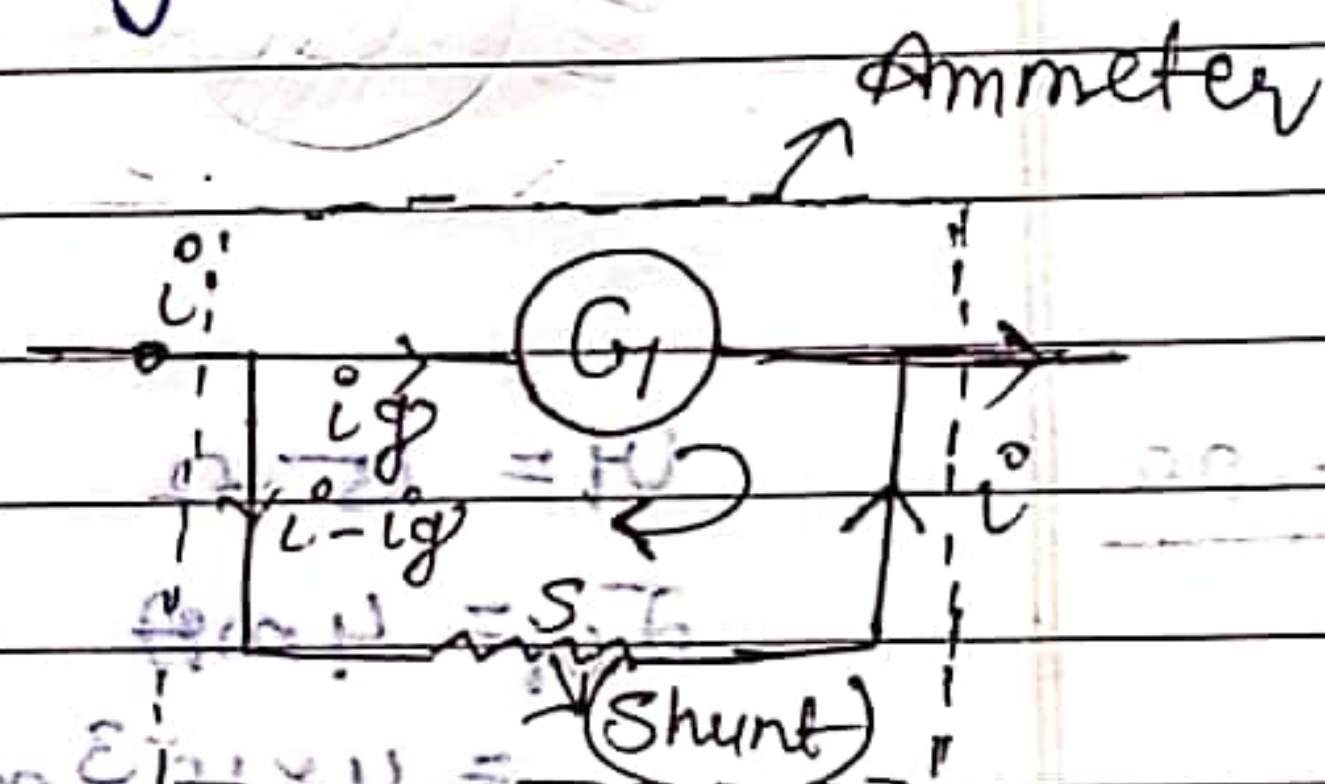
Conversion of Galvanometer into Ammeter

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

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

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

$$S = \frac{I G}{I - i_g}$$



$$\left[S = \left(\frac{I G}{I - i_g} \right) \right]$$

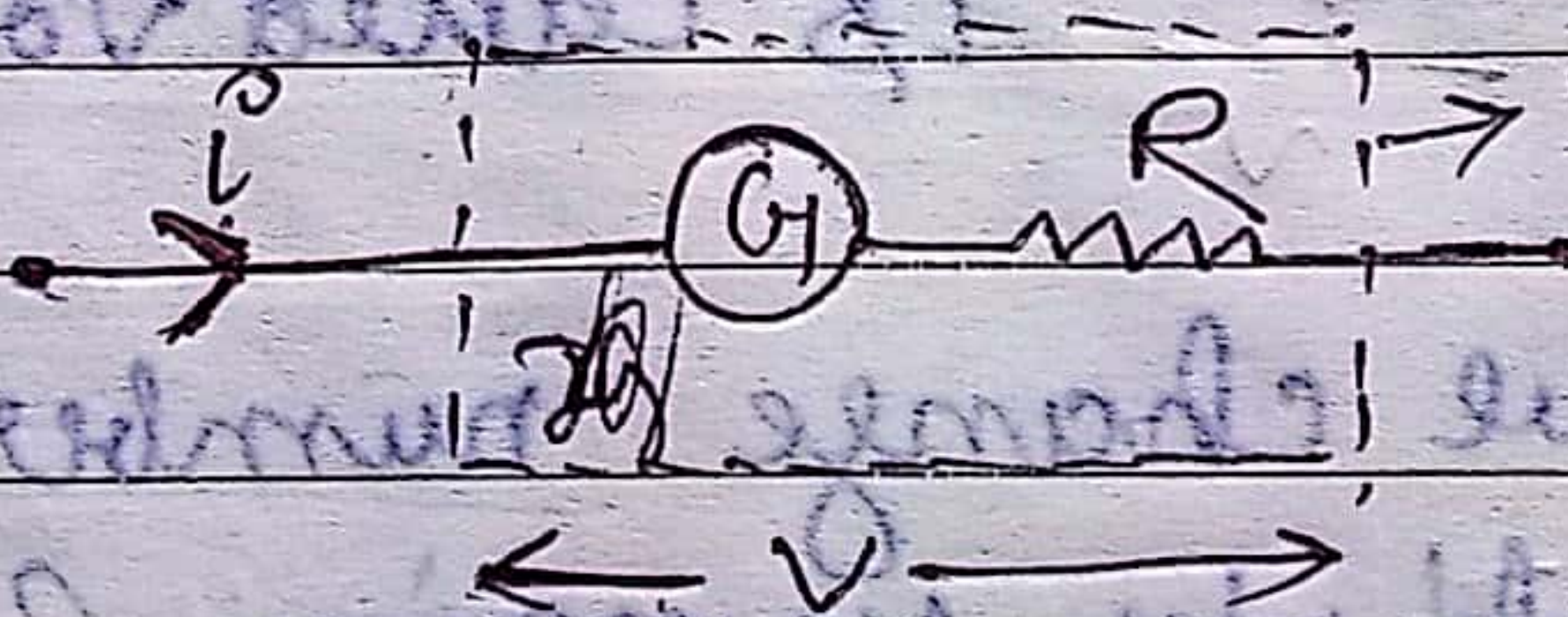
Conversion of Galvanometer into Voltmeter

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

$$I_G + I_R$$

$$= V - I_G$$

$$= \frac{V}{1} - G_V$$


 A circuit diagram on lined paper. It shows a horizontal wire with a current source labeled I_G (a circle with a dot) and a resistor labeled R (a zigzag line) connected in parallel. To the left of the current source, there is a vertical dashed line and a downward arrow labeled I_G . To the right of the resistor, there is a vertical dashed line and a rightward arrow labeled V .