Magnetic Effects Of Electric Current - 4

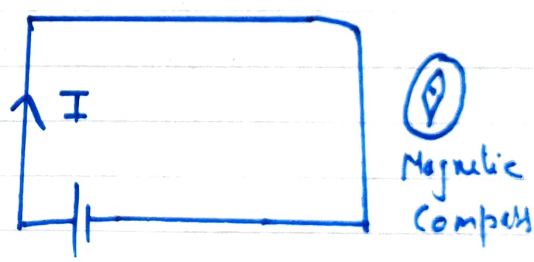
Electromagnetism ⇒ Magnetism due to flow of electric charge i.e electric current in a conductor is called electromagnetism.

Oersted's Experiment ⇒ He performed a simple experiment to establish relationship b/w electricity and magnetism.

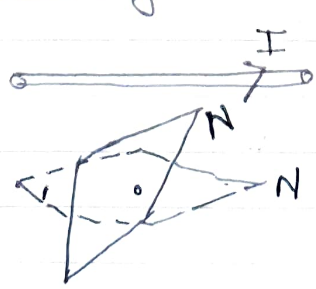
• Oersted placed a magnetic needle near a current carrying conductor. He observed that needle got deflected.

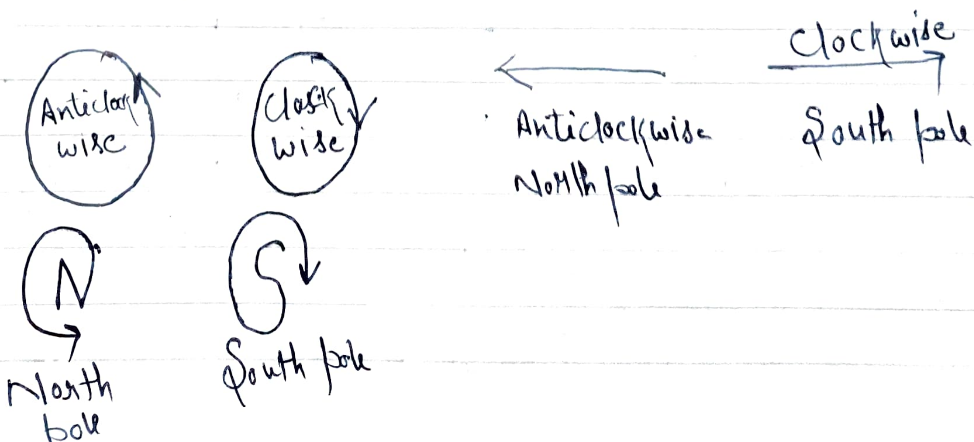
He found that the direction of deflection of needle got reversed when the direction of current was reversed.

All these observations led Oersted to interpret that that there must be some magnetic effect around the wire carrying current.



Direction of deflection of needle can be found by using Ampere's Swimming Rule.





Magnetic field ($\vec{B}$) $\Rightarrow$ The space or region around the current carrying conductor within which its influence can be experienced by the magnetic needle is called the magnetic field.

SI unit of Magnetic field is Wm^{-2} or T [tesla]
C.g.s unit of magnetic field is Gauss

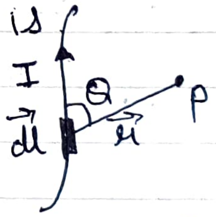
$$\boxed{1G = 10^{-4}T}$$

* **Dimension of Magnetic field is $[MA^{-1}T^{-2}]$** * It is a vector quantity.

Biot-Savart's law

Biot-Savart's law is used to determine the strength of magnetic field at any point due to current carrying conductor.

According to this law magnitude of magnetic field is



(I) $dB \propto I$ (current through conductor)
(ii) $dB \propto dl$ (Length of the current element)
(iii) $dB \propto \frac{1}{r^2}$ (r = distance of the point P from the current element)
(iv) $dB \propto \sin\theta$ (θ = Angle b/w $\vec{dl}$ and $\vec{r}$)

Combining all the above equation

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

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

{K = proportionality constant and depends upon medium}

$$K = \frac{\mu_0}{4\pi} = 10^{-7}\,TmA^{-1}$$

μ_0 = Permeability of free space.

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

Case ⇒ (I) When $\theta = 0^\circ$ $\sin\theta = 0^\circ \Rightarrow dB = 0$

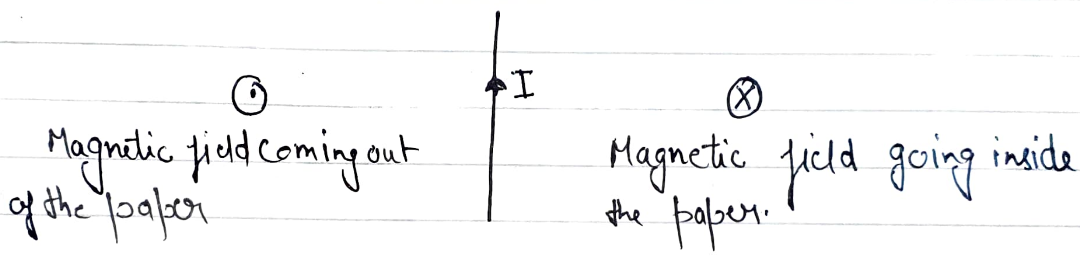
i.e magnetic field intensity at axial line of a current carrying element is always zero.

(II) If $\theta = 90$ $\sin 90^\circ = 1$ $dB =$ Maximum

Biot-Savart's law In Vector form

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I\vec{dl} \times \hat{r}}{r^2} = \frac{\mu_0}{4\pi} \frac{I\vec{dl} \times \vec{r}}{r^3} \quad \left\{ \hat{r} = \frac{\vec{r}}{r} \right.$$

The direction of $\vec{dB}$ is same as that of vector $\vec{dl} \times \vec{r}$ i.e $\vec{dB}$ is perpendicular to the plane of the paper and is directed inwards.



Permeability ⇒ It indicates the degree or extent to which magnetic field can enter a substance. It is denoted by μ. Permeability $\mu = \mu_0 \mu_r$ where μ_0 is absolute permeability of free space and μ_r = relative permeability.

Comparison between Biot-Savart's law and Coulomb's law

(i) Both Coulomb's law and Biot-Savart's law follow inverse square square law.

(ii) Coulomb's law deals with charge at rest and Biot-Savart's law deal with moving charge.

(iii) Angle matters in Biot-Savart's law But not in Coulomb's law.

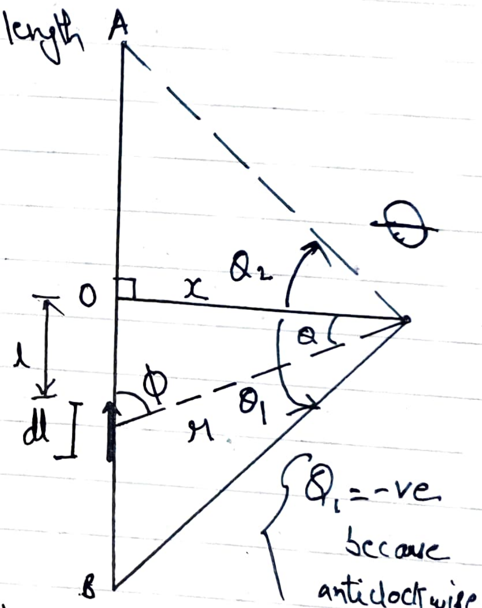
(iv) Coulomb's law takes into account permitivity whereas Biot Savart law takes into account permeability.

Application of Biot-Savart law ⇒

I) Magnetic field due to Infinitely long straight wire carrying current using Biot-Savart law →

Let us consider a long straight wire AB carrying current I. Let P be the point at a distance x from the wire where magnetic field is to be calculated.

Consider a small current element of length dl at distance r from point P.



According to Biot-Savart law magnetic field at Point P due to small element of the wire is given by

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

In right angle triangle POC

$$\boxed{\sin\phi = \frac{x}{r} = \cos\theta} \quad \text{— (2)}$$

$$\boxed{r = \frac{x}{\cos\theta}} \quad \text{— (3)}$$

also $\tan\theta = \frac{l}{x}$

OR

$$l = x\tan\theta$$

$$\frac{dl}{d\theta} = x\sec^2\theta$$

$$\boxed{dl = x\sec^2\theta \, d\theta} \quad \text{— (4)}$$

Substituting the value of (2), (3) and (4) in equation (1)

$$dB = \frac{\mu_0}{4\pi} \frac{I(x\sec^2 d\theta)\cos\theta}{\left(\frac{x^2}{\cos^2\theta}\right)}$$

$$dB = \frac{\mu_0 I \cos\theta \, d\theta}{4\pi \, x}$$

integrating both side

$$\int_0^B dB = \frac{\mu_0 I}{4\pi x}\int_{-\theta_1}^{\theta_2} \cos\theta \, d\theta$$

$$B = \frac{\mu_0 I}{4\pi x}\Big[\sin\theta\Big]_{-\theta_1}^{\theta_2} = \frac{\mu_0 I}{4\pi x}\left[\sin\theta_2 - \sin(-\theta_1)\right]$$

$$\boxed{B = \frac{\mu_0 I}{4\pi x}\left[\sin\theta_1 + \sin\theta_2\right]}$$

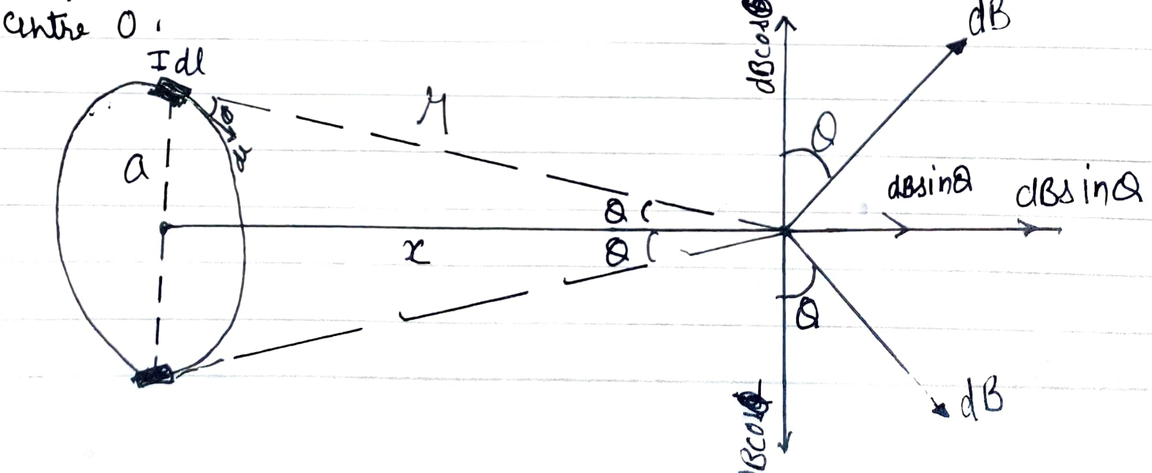
If the straight wire is infinitely long then θ_1 and θ_2 are taken as $\frac{\pi}{2}$. Then the equation will become as

$$B = \frac{\mu_0}{4\pi}\left[\sin\frac{\pi}{2} + \sin\frac{\pi}{2}\right] = \frac{\mu_0 2I}{4\pi x}$$

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

(2) Magnetic field on the axis of a circular loop carrying Current

Consider a circular coil of radius a carrying Current I. Let P is a point on the axis of a circular coil at a distance x from its centre O.



The magnetic field at point P due to dl is

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

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

Element dl is $\perp$ to r, so the direction of $d\vec{B}$ is $\perp$ to r.

from the figure $d\vec{B}$ can be resolved into two component
(i) $dB\sin\theta$ along the axis
(ii) $dB\cos\theta$ $\perp$ to the axis

Component $dB\cos\phi$ cancel each other, there for net magnetic field at P is along the axis of the ring

$$B = \int dB\sin\theta = \int \frac{\mu_0}{4\pi} \frac{I dl}{r^2} \sin\theta \qquad \left\{ \sin\theta = \frac{a}{r} \right.$$

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

$$= \frac{\mu_0 I a}{4\pi r^3} [2\pi a] = \frac{\mu_0 I a^2}{2 r^3}$$

$$\Rightarrow \boxed{B = \frac{\mu_0 I a^2}{2(a^2+x^2)^{3/2}}} \qquad \left\{ \begin{array}{l} r^2 = a^2 + x^2 \\ r = (a^2+x^2)^{1/2} \\ r^3 = (a^2+x^2)^{3/2} \end{array} \right.$$

Cases $\Rightarrow$

(i) When point lies at the centre of a coil $\boxed{x = 0}$

$$\boxed{B_0 = \frac{\mu_0 I}{2a}}$$

(ii) When $\boxed{x = a}$

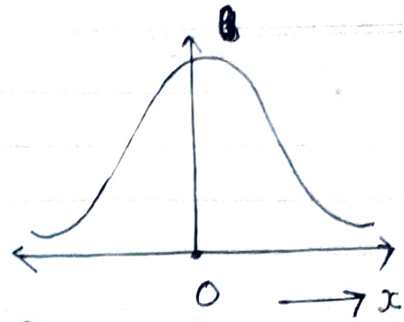
$$B = \frac{\mu_0 I a^2}{2[a^2+a^2]^{3/2}} =$$

$$B = \frac{\mu_0 I}{2^{5/2} a}$$

$$\boxed{B = \frac{1}{2\sqrt{2}} B_0}$$

(iii) When $x >> a$ then

$$\boxed{B \simeq \frac{\mu_0 I a^3}{2x^3}} \Rightarrow \boxed{B \propto \frac{1}{x^3}}$$



{Magnetic field is decreasing on both side}

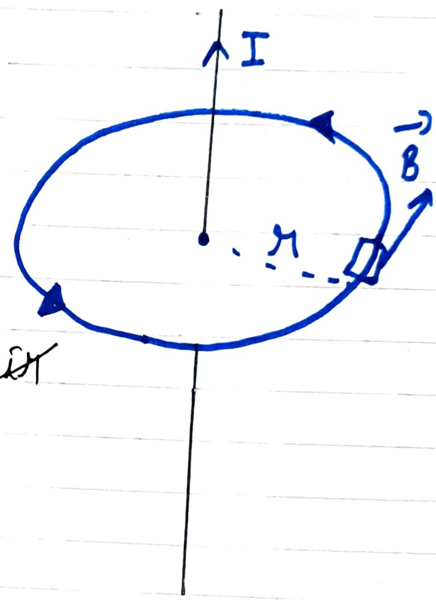
Ampere's Circuital law ⇒ The line integral of the resultant magnetic field B along a close plane curve is equal to the μ_0 times the algebric sum of the currents crossing the area bounded by the close curve.

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

~~proof~~ ⇒ Consider a infinite long straight wire carrying current I. The magnetic field lines produced are Concentric circles. The magnetic field due to this long Conductor at a distance r is

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

from Ampere Circuital law



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

$$= \oint B\,dl \qquad \{\theta = 0$$

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

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

~~Draw back of Ampere Circuital law~~ ⇒

(i) It can not be used to find out the magnetic field at the centre of a current carrying loop.

(ii) Ampere Circuital law deals with steady current.

Application of Ampere's Circuital law ⇒

(i) **Magnetic field due to Current Carrying circular Wire of infinite length**

Consider a portion of a circular wire of infinite length. Let a be the radius of wire and I current is flowing through it.

Case-1 Magnetic field Intensity at point outside the wire

According to Ampere's Circuital law

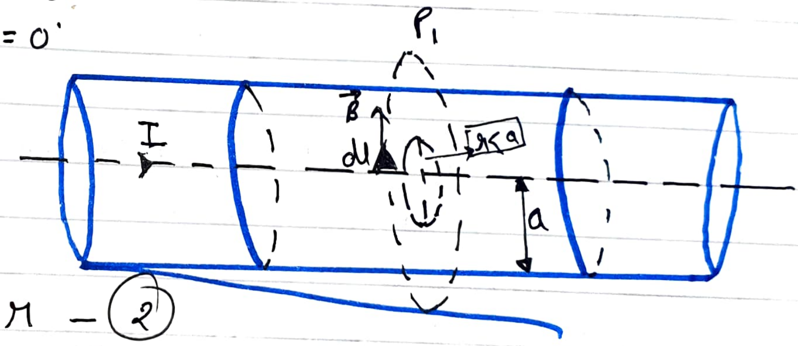
$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I \quad -(1)$$

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

$\theta = 0^\circ$

$$= \oint B\,dl$$

$$= B\int dl$$



$$\oint \vec{B}\cdot\vec{dl} = B\times 2\pi r \quad -(2)$$

from (1) and (2)

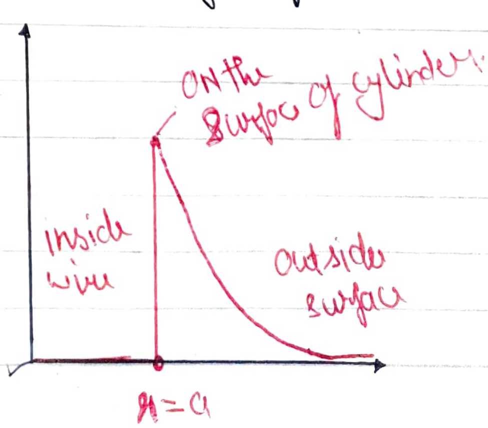
$$B\times 2\pi r = \mu_0 I$$

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

Case II Magnetic field intensity on the surface of the wire

$r = a$

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



Case III Magnetic field Intensity at a point inside the wire.

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

$I = 0$ { since current flow along the surface of the wire.

$$\boxed{B = 0}$$

Case-IV If the current is uniformly distributed throughout the cross-section of the wire then magnetic field ~~due to~~ at $\boxed{r < a}$

πa^2 — I

1 — $\dfrac{I}{\pi a^2}$

πr^2 — $\dfrac{I \times \cancel{\pi} r^2}{\cancel{\pi} a^2}$

If I' is the current flowing through the loop of radius r then its value will be

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

According to Ampere Circuital law

$$\oint \vec{B}\cdot\vec{dl} = \mu_o I'$$

$$\oint \vec{B}\cdot\vec{dl} = \frac{\mu_o I r^2}{a^2} \quad (1)$$

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl \cos\theta \quad \{ \theta = 0.$$

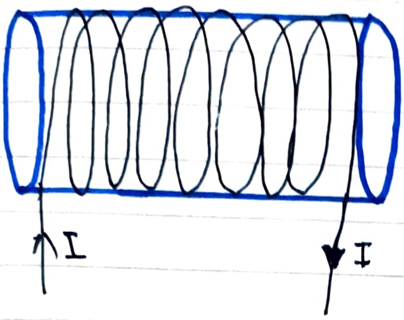
$$= B \oint dl$$

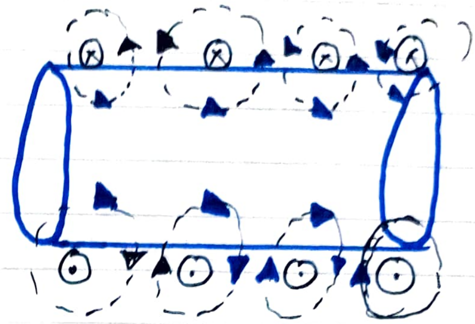
$$\oint \vec{B}\cdot\vec{dl} = B \times 2\pi r \quad — (2)$$

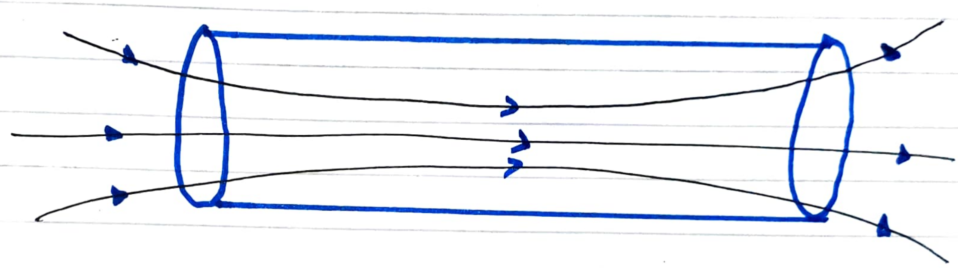
from (1) and (2)

$$B \times 2\pi r = \frac{\mu_o I r^2}{a^2} \Rightarrow \boxed{B = \frac{\mu_o}{2\pi}\frac{I r}{a^2}}$$

Solenoid → A cylindrical coil of many tightly wound turns of insulated wire with generally diameter of coil smaller than its length is called solenoid.



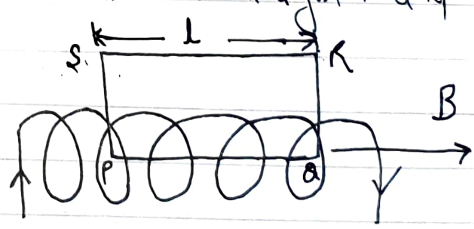




Magnetic field due to a solenoid carrying current →

Consider a long solenoid having 'n' turns per unit length carrying current I. Magnetic field inside the core is uniform and out side the solenoid is zero.

Consider a rectangular loop PQRS a shown in the fig.



$$\oint \vec{B}\cdot\vec{dl} = \int_P^Q \vec{B}\cdot\vec{dl} + \int_Q^R \vec{B}\cdot\vec{dl} + \int_R^S \vec{B}\cdot\vec{dl} + \int_S^P \vec{B}\cdot\vec{dl}$$

$$\oint \vec{B}\cdot\vec{dl} = \int_P^Q B\,dl\cos 0^\circ + \int_Q^R B\,dl\cos 90^\circ + \underbrace{0}_{\text{out side solenoid Magnetic field is zero}} + \int_S^R B\,dl\cos 90^\circ$$

$$\oint \vec{B}\cdot\vec{dl} = B\int_P^Q dl = Bl$$

$$\oint \vec{B}\cdot\vec{dl} = Bl \quad \text{—} \quad (1)$$

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 n l I \quad -② \qquad \{\text{total current} = I \times n \times l$$

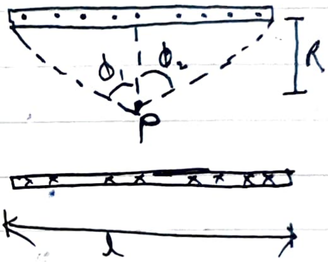
from ① and ②

$$\mu_0 n I \cancel{l} = B \cancel{l}$$

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

Note: Magnetic field at any axial point of a solenoid is given

$$B = \frac{\mu_0 n I}{2}\left[\sin\phi_1 + \sin\phi_2\right]$$



i) When the point P lies well inside the solenoid

$$\phi_1 = \phi_2 = \frac{\pi}{2}$$

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

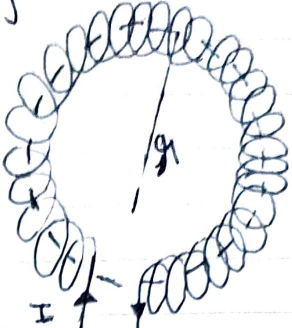
ii) If length is infinite and point P lies near to an end then $\phi_1 = 0$, $\phi_2 = \frac{\pi}{2}$

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

Toroid ⇒ A solenoid bent into the form of a closed ring is called ~~solenoi~~ toroid.

Consider a toroid having 'n' turns per unit length carrying current I. Let a point P inside the ~~solenoid~~ toroid at a distance r from the centre of the toroid.

Now from Ampere's Circuital law = $\oint B \cdot dl = \mu_0 I'$



$$\oint \vec{B} \cdot \vec{dl} = \oint B\,dl \cos 0$$

$$= B \oint dl$$

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

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

I' = total current

$I' = I \times (2\pi r) n$

from (1) and (2)

$$B \times 2\pi r = \mu_0 n (2\pi r) I$$

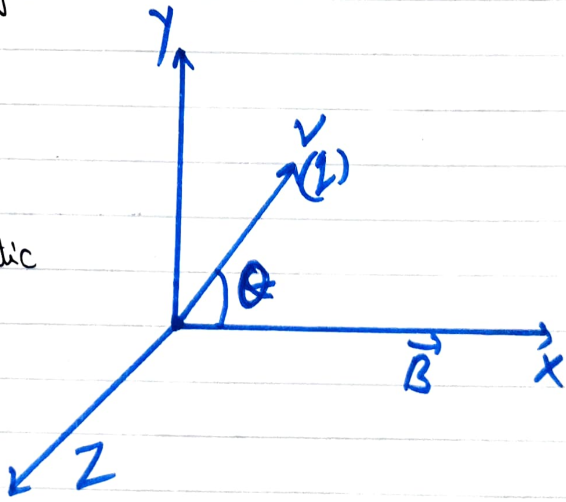
$$\boxed{B = \mu_0 n I}$$

Note

(i) Net magnetic field inside the empty space of solenoid is zero because the net current is zero

Magnetic force on a charge moving in a magnetic field.

Consider a (+q) charge moving with velocity $\vec{v}$ making an angle θ with the direction of magnetic field.



Then it is found that the force experienced by charge is

(i) Directly proportional to ~~mag~~ magnetic field

$F \propto B$ — (1)

(ii) Directly proportional to magnitude of charge

$F \propto q$ — (2)

(iii) Directly proportional to sine component of velocity

$F \propto v \sin\theta$ — (3)

Combining equation (1), (2) and (3)

$F \propto Bqv\sin\theta$

$F = KBqv\sin\theta$

$K = 1$ (In SI unit = K = 1)

$$\boxed{F = Bqv\sin\theta}$$

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

Lorentz force ⇒ When a charge particle moves in a region where both electric field and magnetic field exist, if it experiences a net force called Lorentz force.

$$\vec{F} = \vec{F_e} + \vec{F_m}$$

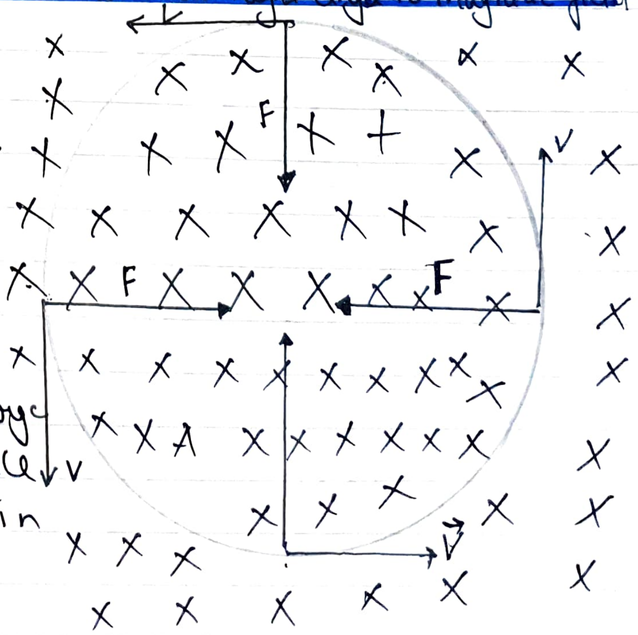
$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$$

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

★★ Charge Particle Moving in a uniform Magnetic field :

Case-1 When charged particle moves at right angle to magnetic field.

When the charge particle move inside the magnetic field at right angle then it will experience force which is always at right angle to the motion of charge particle. Due to this force the charge particle move in a circular path.



When the charge particle moves in a circular path then it will experience centripetal and centrifugal force

$F_{centrifugal}$ ~~$F_{centripetal}$~~ $=$ $F_{centripetal}$ ~~$F_{centrifugal}$~~

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

$$\frac{mv^{\cancel{2}}}{r} = Bq\cancel{v}$$

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

Radius of circular path.

Time period of Charge Particle $\quad T = \frac{\text{Distance}}{\text{Speed}} = \frac{2\pi r}{v}$

$$T = \frac{2\pi m\cancel{v}}{Bq\cancel{v}} \qquad \boxed{T = \frac{2\pi m}{Bq}}$$

$$\boxed{\nu = \frac{1}{T} = \frac{Bq}{2\pi m}} \rightarrow \text{Frequency}$$

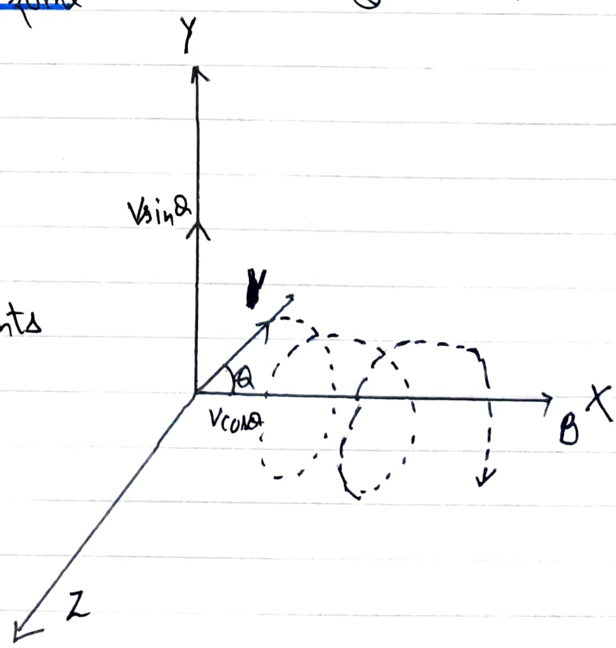
{ We can see that the frequency and time period does not depend upon velocity of particle }

Case - II. When charge particle enters the magnetic field at some angle θ

When the charge particle enters the magnetic field at some angle θ then its velocity has two components

$V_r = v\sin\theta$

$V_H = v\cos\theta$



* The component $V\sin\theta$ is normal to the direction of magnetic field so due to this it will move ~~in~~ charge in circular path.

* The component $V\cos\theta$ is in the direction of magnetic field so it will not experience any force. But will help the particle to move along the direction of magnetic field.

Due to these combined effect charge particle will move in a helical path.

Radius of circular Path

Centrifugal force = centripetal force

$$\frac{m(v\sin\theta)^2}{r} = Bq\cancel{v\sin\theta}$$

$$\boxed{r = \frac{mv\sin\theta}{Bq}}$$

Time period

$$T = \frac{2\pi r}{v\sin\theta} = \frac{2\pi mv\cancel{\sin\theta}}{\cancel{v\sin\theta}\,Bq}$$

$$\boxed{T = \frac{2\pi m}{Bq}} \qquad \boxed{\nu = \frac{1}{T} = \frac{Bq}{2\pi m}}$$

Pitch ⇒ The linear distance travelled by charge particle in the direction of magnetic field.

$$P = (v\cos\theta)T = v\cos\theta \times \frac{2\pi m}{Bq}$$

$$\boxed{P = \frac{2\pi m v\cos\theta}{Bq}}$$

⊗ Inside the plane of the paper

⊙ Outside the plane of the paper.

Velocity Selector ⇒ It is a setup to select charge particles of a particular velocity from a beam passed through a space having crossed electric and magnetic field.

~~(i)~~ When only magnetic field is present then the charge particle will move in upward

~~(ii)~~ When only electric field is present then it will move downward.

~~(iii)~~ But when ~~b~~ the field is adjusted such that $F_E = F_B$ then charge particle move in a straight path.

$$F_B = F_E \Rightarrow B\cancel{q}V\sin\theta = \cancel{q}E$$

$$\theta = 90^\circ$$

$$BV = E$$

$$\boxed{V = \frac{E}{B}}$$

Cyclotron

It is a device used to accelerate positively charge particles (like, proton, α-particles, and deutron) to acquire enough energy to carry out nuclear disintegration.

Principle ⇒ When a positively charged particle is made to move time ~~again~~ and again ~~θ~~ in a high frequency electric field and magnetic field crossed each other it get get accelerated and acquire sufficiently large amount of energy.

Construction ⇒

~~(i)~~ Strong electromagnet (N & S) ($B = 1.2T$)

~~(ii)~~ Two Dees. D_1 and D_2 · (D-shaped hollow-semi circular copper chambers called Dees, placed horizontally with a small gap in b/w D_1 and D_2.

~~(iii)~~ Source of high voltage ($V = 10^4$ to $10^5 V$) Coupled with a adjustable high frequency oscillator ($f = 10^6$ to 10^7 Hz)

~~(iv)~~ Source of charge particle at the centre of the dees.

Working ⇒

~~(i)~~ Suppose a +ve charge ion is generated at the centre of the gap when D_1 is at (+) potential at D_2 at (-ve) potential.

~~(ii)~~ The positive ion will accelerate towards the D_2 and due to ⊥ magnetic field ~~it~~ will move in a circular path inside D_2.

~~(iii)~~ Once the charge particle reaches the gap b/w D_1 and D_2 the polarity of two Dees get reversed. D_1 becomes (-Ve) and D_2 becomes (+Ve)

~~(iv)~~ Now ~~D_1~~ the charge particle accelerate again and gains energy.

~~(v)~~ This process Continues till the required energy is attained.

~~(vi)~~ Once the required energy is attained the magnetic field is made zero. The charged particle shoots out through the window, and hit the target.

Theory ⇒ The charge particle move in a circular path and the necessary centripetal force is provided by the magnetic field

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

$$Bq\cancel{v} = \frac{mv^{\cancel{2}}}{r}$$

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

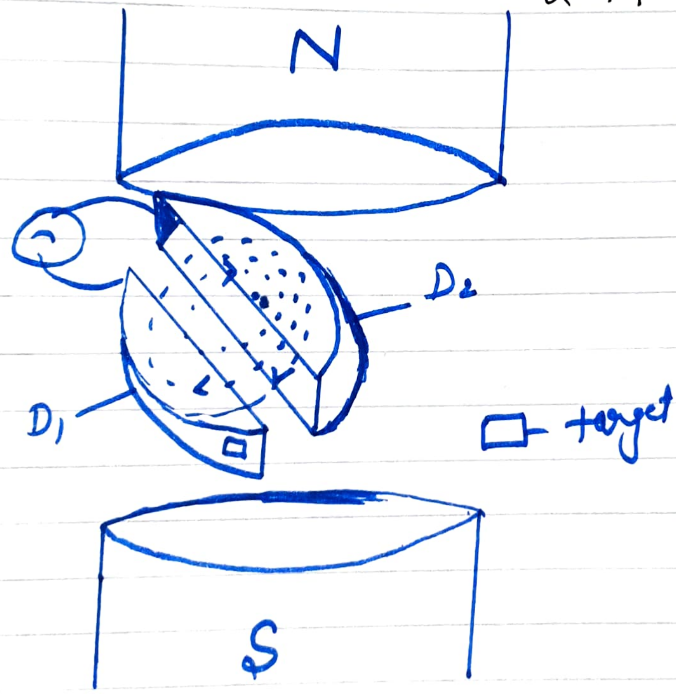
Time period ⇒ $T = \frac{2\pi r}{v} = \frac{2\pi m}{Bq}$

$$\boxed{\nu = \frac{Bq}{2\pi m}}$$

Total Energy Gained = $E = \frac{1}{2}mv^2 = \frac{1}{2}m\left[\frac{qBr}{m}\right]^2$

$$E_{max} = \frac{1}{2}\frac{B^2q^2}{m}\left[r^2_{max}\right]$$

(energy is max when $r = r_{max}$)



Limitations of cyclotron ⇒

(i) It can not accelerate neutral particle

(ii) It can not accelerate electrons [BETATRON is used to acc e^{-1}]

Reason: Due to small mass electrons starts moving at a very high speed when they gain small energy in the cyclotron. Oscillating electric field makes them to go quickly out of step because of their high speed.

(iii) It can not accelerate possitively charge particle having high mass. Because when their speed becomes comparable to speed of light their mass changes due to which it takes longer time to reach the gap and it gets out of step the oscillator.

$$\boxed{m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}}$$

Force On a Current Carrying Conductor

Let us Consider a conductor of length l having cross-sectional area A.

Let

n = No. of electrons per unit Volume of the wire

N = Total No of electrons in the Conductor

Q = Total charge in the conductor

Force on a single Charge = $Bqv\sin\theta$

Total force on the Conductor = $BQv\sin\theta$ —(1)

$Q = Ne$

$N = nAl$

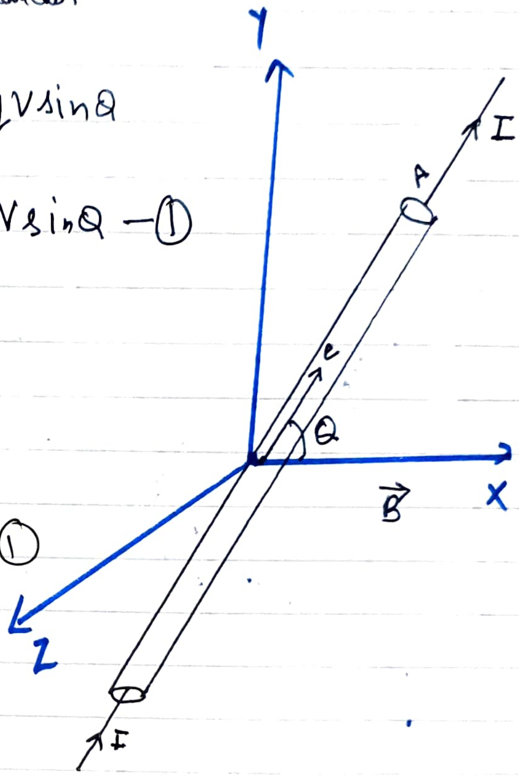
$Q = nAle$ —(2)

Put the value of (2) in equation (1)

$F = BnAlev\sin\theta$

$F = BIl\sin\theta$

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



Direction of force is determined by Fleming's left hand rule.

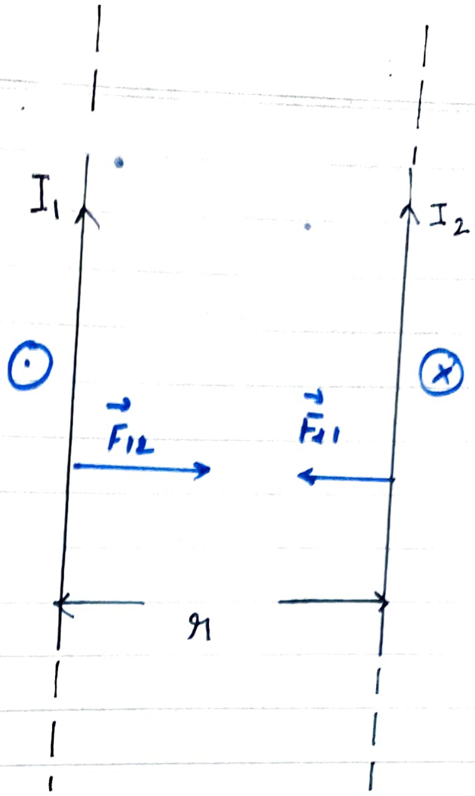
Force b/w two infinitely Long straight Parallel Conductor

Consider two long parallel conductors I and II Carrying current I_1 and I_2 in same direction. Let r be the seperation b/w them

Magnetic field produced by I_1 at any point on wire II is

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

Force on wire II due to I



$F_{21} = B_1 I_2 l_2 \sin\theta$

$\theta = 90°$

$F_{21} = B_1 I_2 l_2$

~~$F_2 = \frac{\mu_0 I_1 I_2 l_2}{}$~~ $F_2 = \frac{\mu_0 I_1 I_2 l_2}{2\pi r}$

force per unit length

$$f_{21} = \frac{F_2}{l_2} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

$$\boxed{f_{21} = \frac{\mu_0 I_1 I_2}{2\pi r}} \quad \text{Similiarly} \quad \boxed{\vec{f}_{12} = \frac{\mu_0 I_1 I_2}{2\pi r}}$$

According to Fleming's left hand Rule both the wires attract each other.

$$\boxed{\vec{f}_{12} = -\vec{f}_{21}}$$

Defination of 1 Ampere ⇒ when $I_1 = I_2 = 1A$ and $r = 1m$

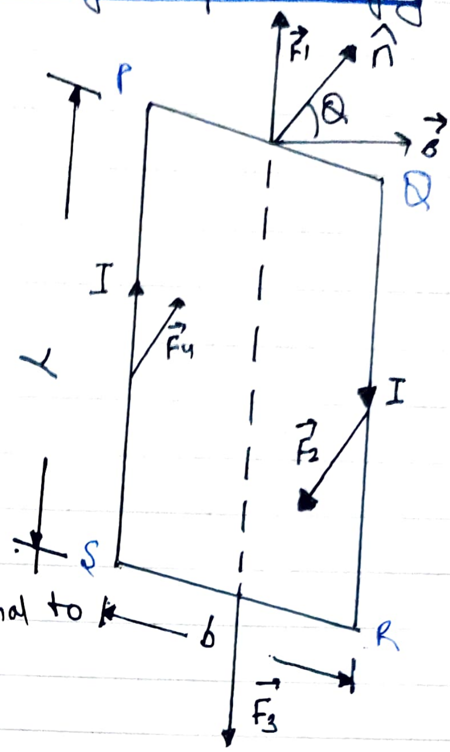
$$f = \frac{\mu_0 \times 1 \times 1}{2\pi \times 1} = 2 \times 10^{-7} \, Nm^{-1}$$

$$\boxed{f = 2 \times 10^{-7} \, Nm^{-1}}$$

One ampere is that value of steady current which on flowing in each of the two ‖ infinitely long conductors of negligible cross-sectional area placed in vaccum at a distance of 1m from each other produces b/w them a force of $2 \times 10^{-7} \, Nm^{-1}$ of their length.

Torque On a loop placed in a magnetic field carrying current

Consider a rectangular loop PQRS suspended in a uniform magnetic field $\vec{B}$. Let



I = Current flowing in the loop

l, b = Sides of the coil

A = $l \times b$

Q = Angle b/w the direction of $\vec{B}$ and that of vector $\hat{n}$ drawn Normal to the plane of the coil

Force on side PQ and RS are equal in magnitude but opposite in direction Hence they will cancel each other.

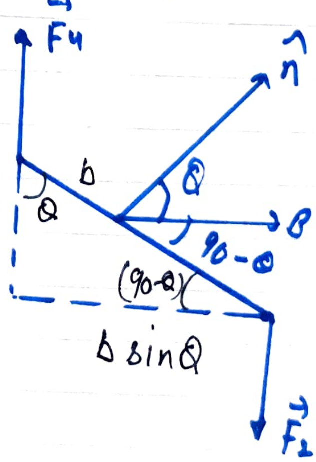
Force on side QR

$F_2 = BIl \sin 90^\circ = BIl$

Force on side SP

$F_4 = BIl$

Forces F_2 and F_4 are not Collinear and they equal and opposite so they will form a Couple



τ = force x ⊥ distance b/w them

$\tau = IBl \times b \sin Q$

$\tau = IBA \sin Q$ $\{A = l \times b\}$

If the loop Contains N turns

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

$\tau = MB \sin Q$ M = magnetic moment = IA

$\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$

* The net magnetic force on the loop is zero but torque acting on the loop is not zero.

* Torque is independent of the ~~loop's~~ shape of the loop.

Moving Coil Galvanometer

A galvanometer is a device used to detect small current in a circuit.

Principle ⇒ It is based on the fact that a current carrying coil placed in a magnetic field experiences torque.

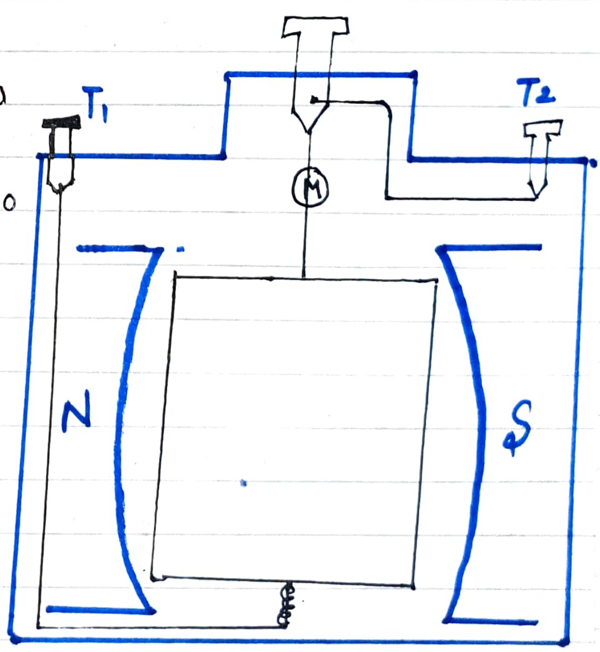
Construction ⇒

(i) It consist of a coil wound on a non metallic frame.

ii) The coil is suspended b/w two cylindrical poles of a permanent magnet with the help of a phosphor-Bronze strip.

iii) A plane circular mirror M is attached to the strip.

(iv) One end of the strip is connected ~~to~~ terminal T_1 and other end is connected to terminal T_2



Theory ⇒ Let $\vec{B}$ = Intensity of Magnetic field

$\vec{A} = l \times b$ = Area of coil

N = No. of turns in the coil.

If θ = Angle b/w normal to plane and $\vec{B}$ then torque experienced by the coil is

$$\tau = NIAB\sin\theta$$

$$\theta = 90 \Rightarrow \sin 90 = 1$$

$$\tau = NIAB$$

The torque deflects the coil through angle α. A restoring torque is set up in the coil due to elasticity of spring such that

$$\tau_{restoring} = K\alpha$$

In equillibrium

Restoring torque = Deflecting torque

$$K\alpha = NIAB$$

$$\alpha = \left(\frac{NBA}{K}\right) I$$

$$\boxed{\alpha \propto I}$$

Here

$$I = \left(\frac{K}{NBA}\right)\alpha$$

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

G = Galvanometer Constant

Figure Of Merit ⇒ It is defined as the current which produces a deflection of one scale division.

Senstivity ⇒ A galvanometer is said to be senstive if it can detect very small value of current.

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

Ideal ammeter has zero resistance

Ideal volt meter has infinite resistance

$$I_s = \frac{\alpha}{I} = \frac{NBA}{K} =$$ unit = rad A^{-1}

2 **Voltage Sensitivity (Vs)** ⇒ It is defined as the deflection produced in the galvanometer when unit potential difference is applied across its end.

$$V_s = \frac{\alpha}{V} = \frac{\alpha}{IR} = \frac{NBA}{KR} \Rightarrow \boxed{V_s = \frac{I_s}{R}}$$

Factors On which sensitivity of MCG depends

1. Depends on Number of turns
2. " " Magnetic field B
3. " " Area of Coil
4. " " $\frac{1}{K}$

Disadvantage

(i) The sensitivity can not be changed at will

(ii) It can be damaged easily by overloading.

Conversion Of MCG into Ammeter

Ammeter ⇒ It is an instrument used to measure electric current in an electric circuit.

A ~~gla~~ galvanometer Can be Converted into ammeter by connecting a low resistance called shunt in parallel to the galvanometer.

Shunt ⇒ A small resistance connected in parallel with any component of electric circuit.

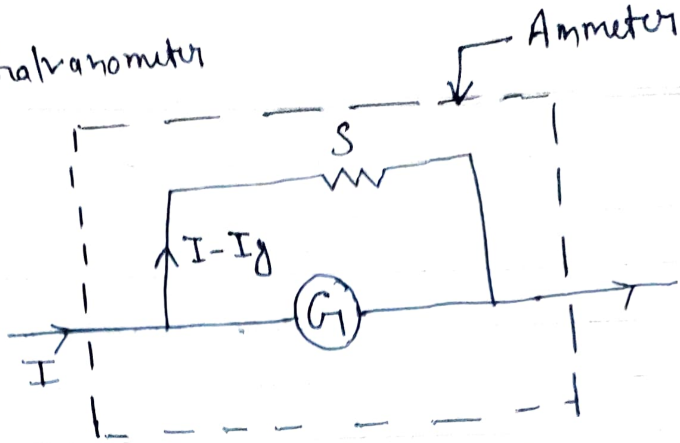
Uses (i) To increase the range of ammeter.

(ii) To prevent the galvanometer from damage.

Let G = Resistance of Galvanometer

I_g = Current through the galvanometer

S = Shunt resistance



Potential difference across shunt = Potential difference across galvanometer

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

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

We cannot decrease range of ammeter

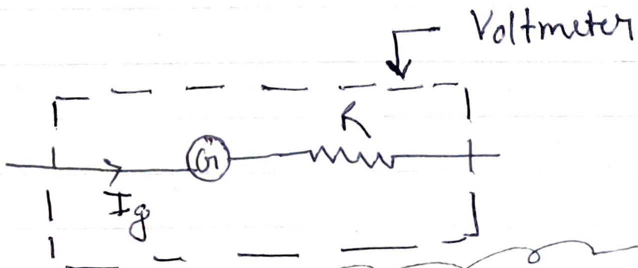
We can increase the range of ammeter by decreasing resistance of shunt.

Conversion of MCG into Voltmeter

Voltmeter ⇒ It is a device used for measuring potential difference across any two points in a circuit.

A galvanometer can be converted into a voltmeter by connecting a high resistance in series with it.

By ohm's law



$$V = I_g G + I_g R$$

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

We can increase the range of voltmeter by increasing the resistance in series.