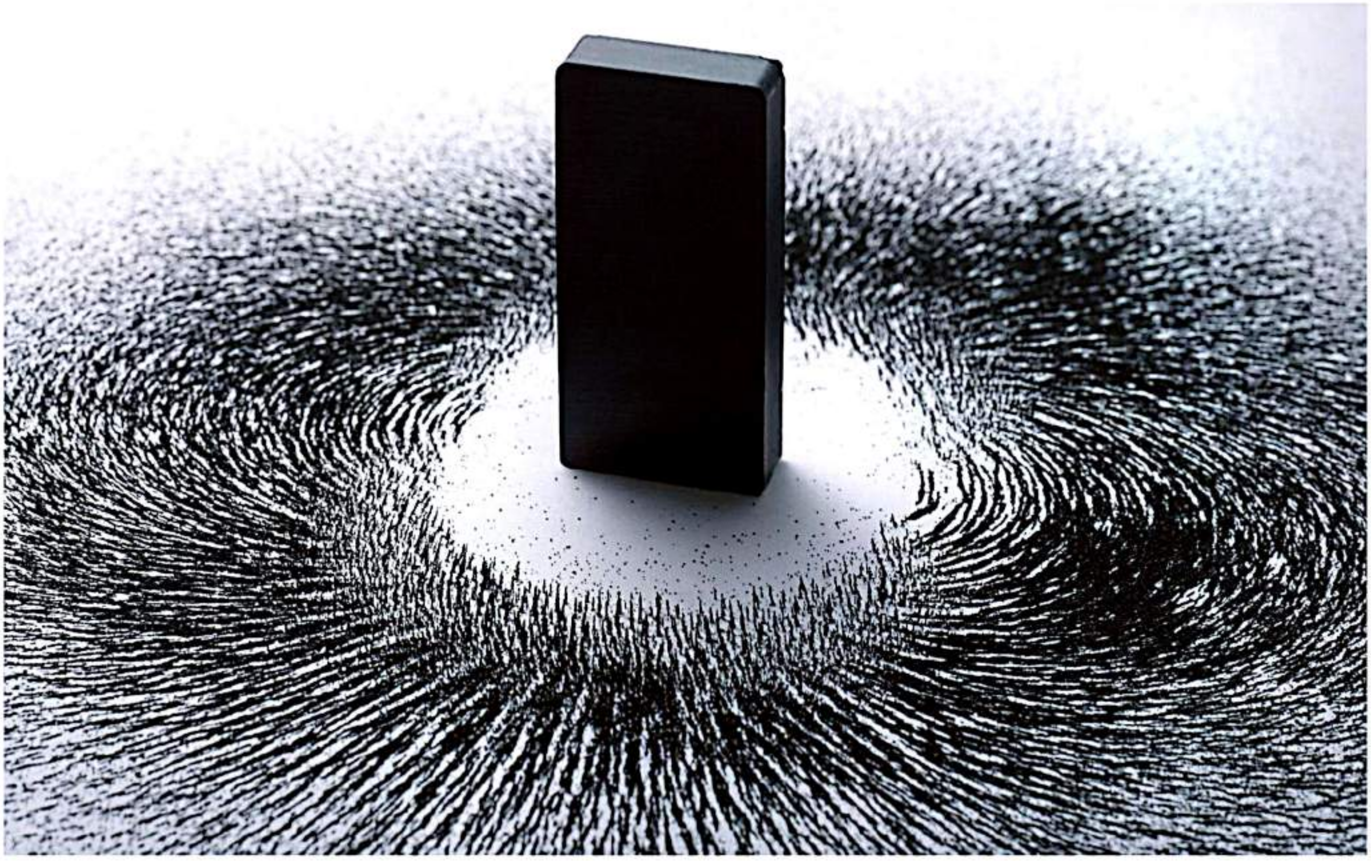
Chapter–4

# Moving Charges and Magnetism

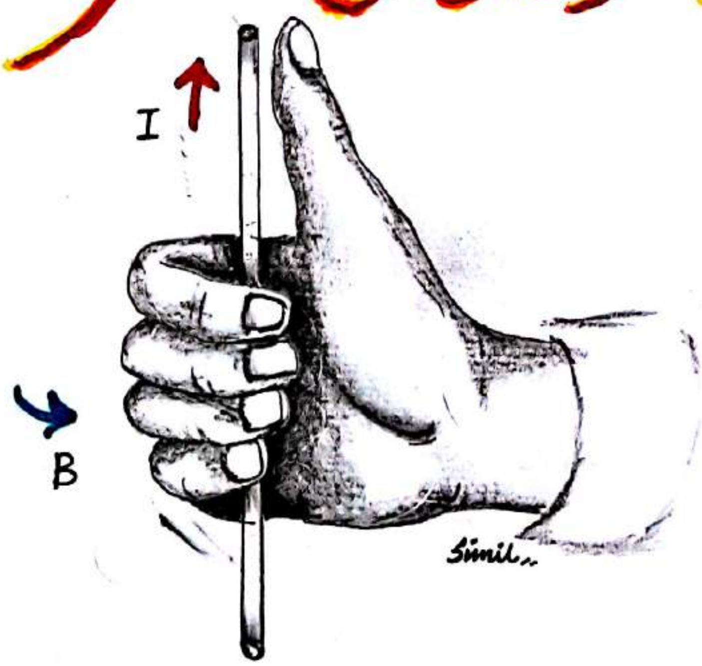


**CBSE CLASS XII NOTES**

**Dr. SIMIL RAHMAN**

Unit III

# Magnetic Effects of Current




$XII^{th}$ CBSE Notes..

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M.E.S Qatar..

# * Magnetic Effects of Current & * Magnetism..

simil...

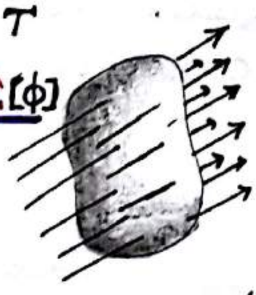
## Magnetic field

The region around a magnet or a current carrying conductor where its Influence is felt/experienced by another magnet is known as the magnetic field.

Wb → weber
T → Tesla

* denoted by $\vec{B}$.
* Direction of compass needle represents the direction of $\vec{B}$.
* SI unit $Wb/m^2$ or T

## Magnetic flux[$\phi$]



The number of magnetic field lines passing through the surface perpendicular to it is known as magnetic flux.

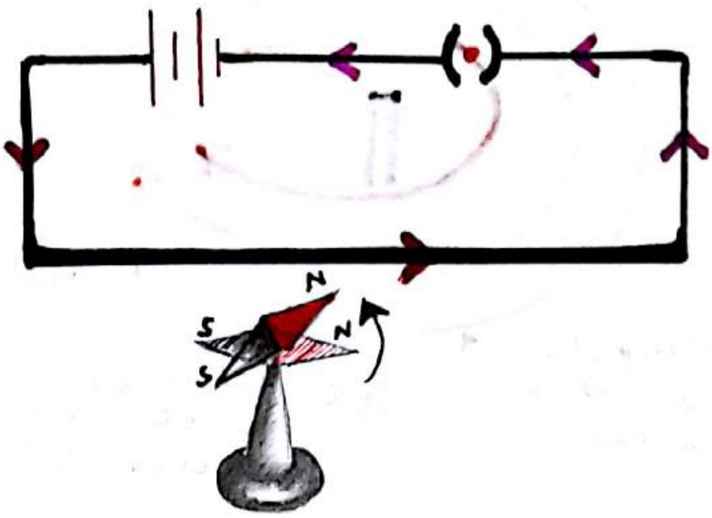
$\phi = BA$ ; A → Area

* SI unit weber (wb)

$B = \frac{\phi}{A}$

## Oersted Experiment

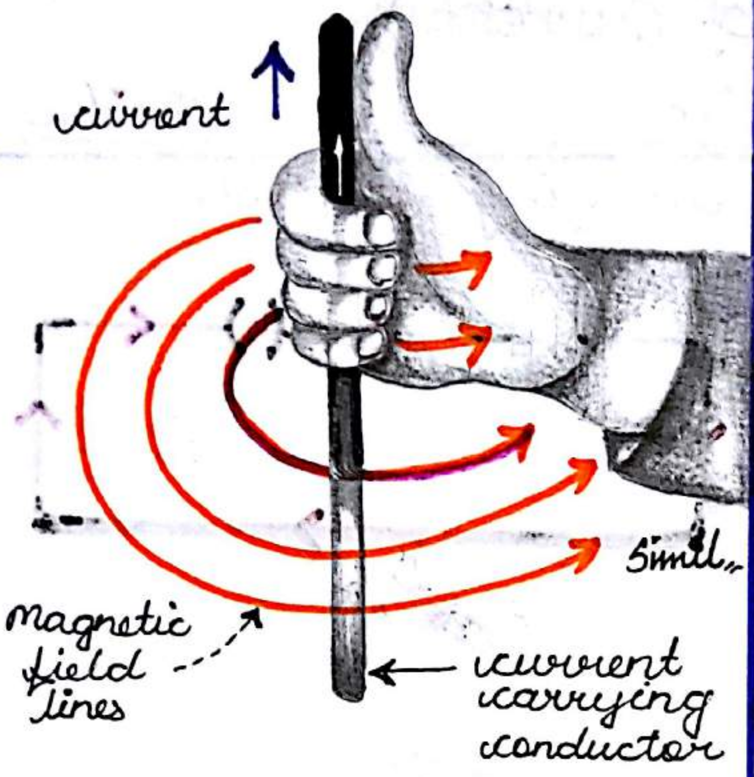
Han christian Oersted found that a magnetic needle gets deflected when it is brought near a current carrying conductor.



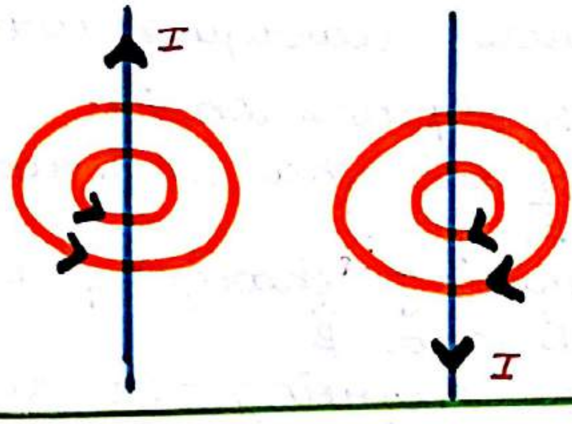

* magnetic field is always associated with a conducter carrying current.
* B depends on I.
* static charges produces $\vec{E}$.
* moving charges produce $\vec{E}$ and $\vec{B}$
* On reversing the direction of I deflection also gets reversed.

## Right hand Thumb Rule

If you hold the current carrying conductor in your right hand, if the thumb shows the direction of current, then the fingers wrapped arount it shows the direction of $\vec{B}$ produced.




* Magnetic field lines using thumb rule.




## * Magnetic lorentz force.

When a charge 'q' is moving with velocity V in B, then the force on charge is called magnetic lorentz force.

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

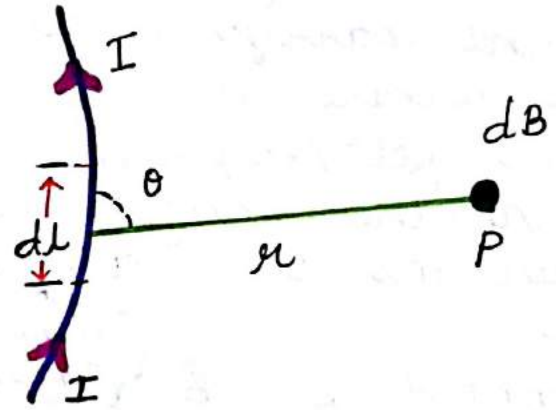
$F = BqV \sin\theta$.

$\vec{F} \perp \vec{V}$, $\vec{F} \perp \vec{B}$

'F' is maximum when $\theta = 90°$

'F' is minimum when $\theta = 0°$.

## Biot-Savat Law




According to this law. the magnetic field at P due to a current element 'dl'

$dB \propto I$

$dB \propto dl$

$dB \propto \sin\theta$.

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

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

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

where '$\mu_0$' is magnetic permiability of free space

$\mu_0 = 4\pi \times 10^{-7}\ T\,m\,A^{-1}$ or $H/m$

vector form

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

Direction of $\vec{dB}$

$\vec{dB}$ ⊥r to plane containing $\vec{dl}$ and $\vec{r}$

## Relationship b/w $\mu_0$, $\varepsilon_0$ and c

$$\mu_0 \varepsilon_0 = 4\pi \times 10^{-7} \times \frac{1}{4\pi \times 9 \times 10^{9}}$$

$$\mu_0 \varepsilon_0 = \frac{1}{9 \times 10^{16}} = \frac{1}{(3\times 10^{8})^2}.$$

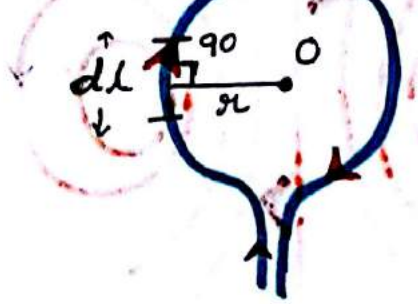
$$\sqrt{\mu_0 \varepsilon_0} = \frac{1}{c}$$

$$\therefore \boxed{c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}}$$

## Applications of Biot-Savart law

** Expression for $\vec{B}$ due to current carrying coil at centre using Biot-savart's law.

consider a circular loop of radius r carrying current I.




dl - current Element

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

since $\theta = 90°$

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

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

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

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

* If there are 'N' - no of turns

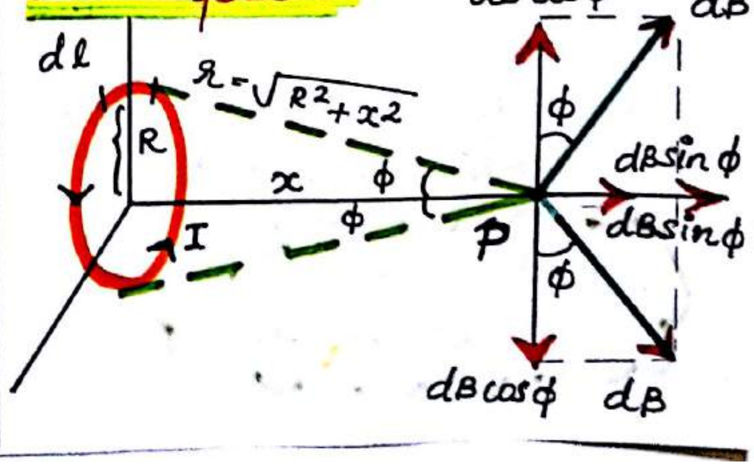
$$\boxed{B = \frac{\mu_0 N I}{2r}}$$

* SI unit of magnetic field is Tesla

* For clock wise current the direction of magnetic field will be inwards

* For anticlock wise current the direction of field will be outward.

** magnetic field due to circular loop at axial point.



let us find B at P on axial line of current carrying coil.

* according to Biot-Savarts law.

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

Resolve dB into two components $dB\cos\phi$ and $dB\sin\phi$.

* The component $dB\cos\phi$ get cancelled due to $dB\cos\phi$ of opposite current element dl

* Net field is $dB\sin\phi$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl}{(R^2+x^2)} \cdot \frac{R}{\sqrt{R^2+x^2}}$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl}{(R^2+x^2)} \cdot \frac{R}{(R^2+x^2)^{1/2}}$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \cdot R}{(R^2+x^2)^{3/2}}$$

Integrate to find B

$$\int dB = \frac{\mu_0}{4\pi} \frac{IR}{(R^2+x^2)^{3/2}} \int dl$$

$$B = \frac{\mu_0}{4\pi} \frac{IR}{(R^2+x^2)^{3/2}} \cdot 2\pi R$$

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

If there are N-turns

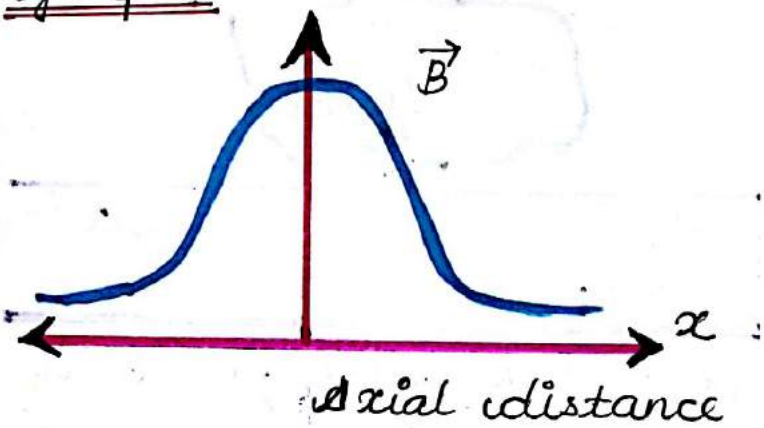
$$\boxed{B = \frac{\mu_0 NIR^2}{2(R^2+x^2)^{3/2}}}$$

If the point is at the centre

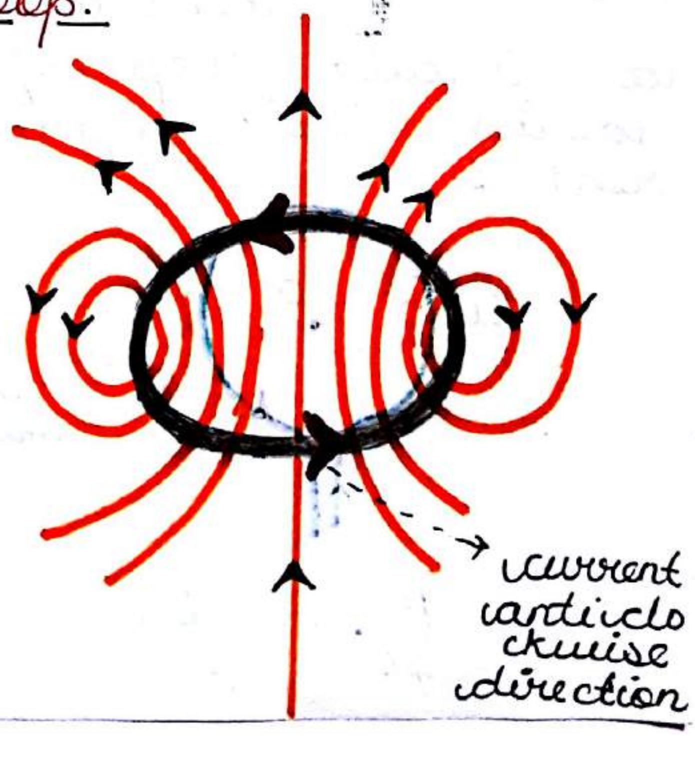
then $x=0$.

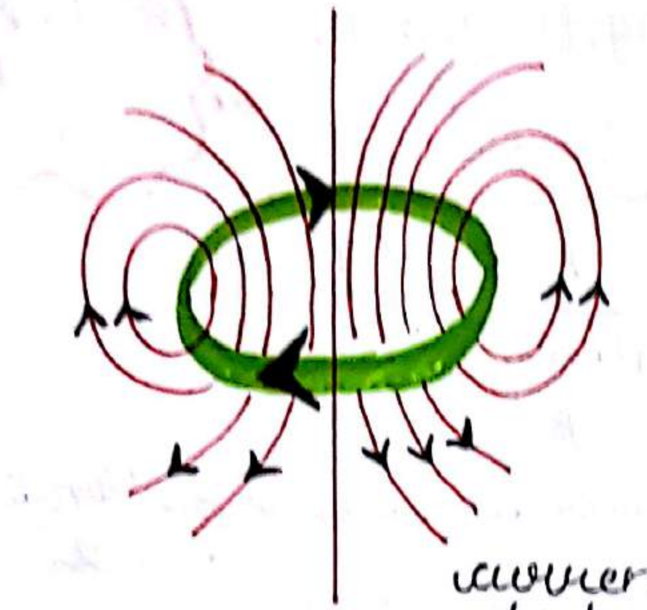
$$\boxed{B = \frac{\mu_0 NI}{2R}}$$

graph




magnetic field lines due to a current carrying loop.





current clockwise direction.

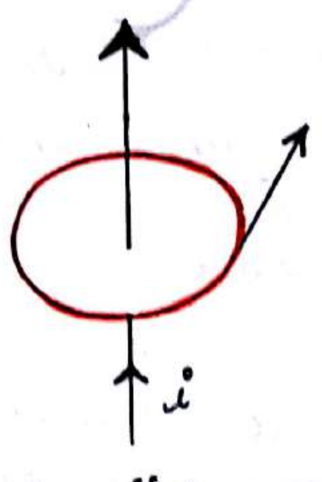
## condition for charge 'q' to move without deflecting in B

$F = BqV \sin\theta$.

(i) $B = 0$.

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

## ** Amperes Circuital Theorem. imp



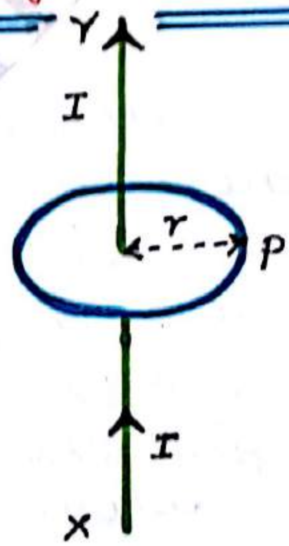

"It states that the line Integral of magnetic field around any closed path in free space is equal to '$\mu_0$' times the total current"

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

$$\oint B\,dl\cos\theta = \mu_0 \Sigma i$$

## Applications of Amperes circuital theorem.

## * magnetic field due to a long straight conductor.




consider a long straight conductor carrying current as shown in figure. Inorder to find magnetic field at a point P. draw an amperian loop of radius 'r'.

$$\oint B\,dl\cos\theta = \mu_0 I$$

$$\theta = 0^\circ = 1$$

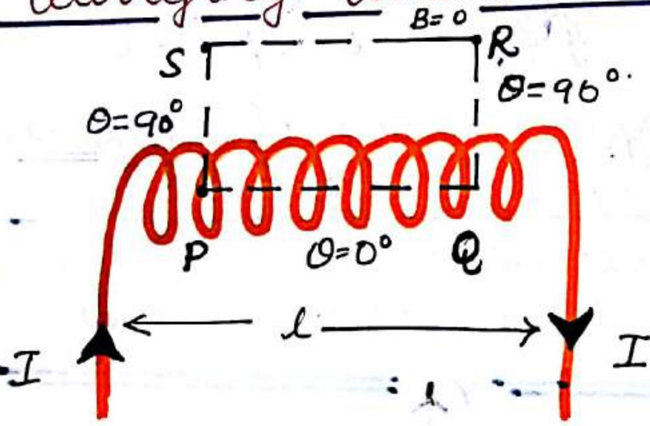
$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I$$

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

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

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

## * B due to a current carrying solenoid.




consider a long solenoid of length l and number of turns per unit length n carrying current I. In order to find the magnetic field along the axis of the solenoid, imagine an amperian loop PQRS as shown in the figure.

$$\Rightarrow \oint_{PQRS} \vec{B}\cdot\vec{dl} = \oint_P^Q \vec{B}\cdot\vec{dl} + \oint_Q^R \vec{B}\cdot\vec{dl} + \oint_R^S \vec{B}\cdot\vec{dl} + \oint_S^P \vec{B}\cdot\vec{dl} = \mu_0 \Sigma i$$

$$\Rightarrow \oint_{PQRS} \vec{B}\cdot\vec{dl} = \oint_P^Q \vec{B}\cdot\vec{dl} + 0 + 0 + 0 = \mu_0 n l I$$

$$B \oint dl = \mu_0 n l I$$

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

$$\therefore N = nl$$

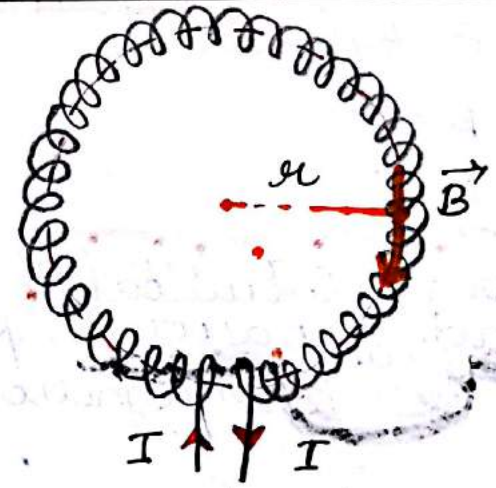
$$B\, l = \mu_0 n l I$$

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

* Along the axis $B = \mu_0 n I$
* Near the ends $B = \frac{\mu_0 n I}{2}$
* outside $B = 0$.

## magnetic field due to a current carrying toroid using Amperes circutal theorem

imp →




let $n = \frac{\text{No of turns}}{\text{unit length}}$

$$n = \frac{N}{2\pi r}$$

consider a toroid of radius 'r' as shown in figure let 'I' be the current flowing through the toroid.

according to Amperes circuital theorem.

$$\oint B\cdot dl = \mu_0 N I$$

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

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

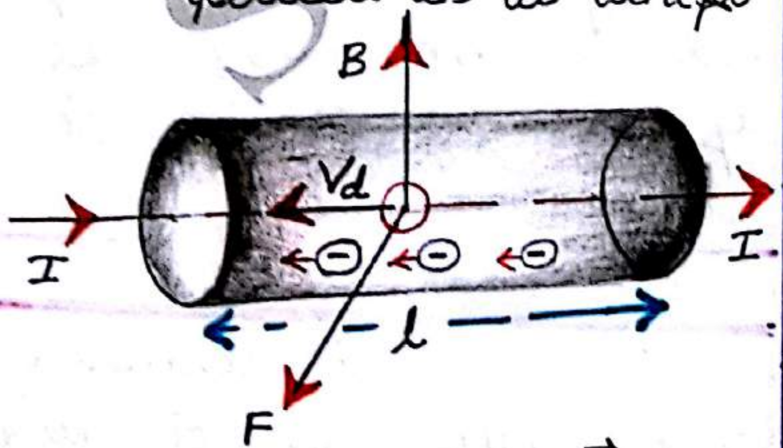
$$B = \mu_0 \frac{N}{2\pi r} I \qquad \frac{N}{2\pi r} = n$$

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

* outside the toroid $B = 0$
* B will be there only along the axis of toroid.

## Force on a current carrying conductor placed in B.

consider a conductor of length 'l' and cross-sectional area A carrying a current 'i'. It is placed in a uniform magnetic field $\vec{B}$.




let $n = \dfrac{\text{No of } \bar{e}}{\text{unit volume}}$

$$n = \frac{N}{Al} \quad \therefore N = nAl$$

according to magnetic lorentz force

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

Force on one $\bar{e}$

$$\vec{F} = e(\vec{V_d}\times\vec{B})$$

Force on N no of $\bar{e}$

$$\vec{F} = N e(\vec{V_d}\times\vec{B})$$

$$\vec{F} = nAle(\vec{V_d}\times\vec{B})$$

$$I = nAeV_d$$

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

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

Note:-

(i) $\vec{F} \perp r\ I\vec{l}$

$\vec{F} \perp r\ B$

(ii) $F_{max}$ when $\theta = 90^\circ$

$F_{min}$ when $\theta = 0^\circ$

(iii) Direction of '$\vec{F}$' can be found by Flemings Left hand rule.

## magnetic lorentz force and lorentz force.

magnetic lorentz force

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

Lorentz force.

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

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

## Motion of charged particle in B

let a charge 'q' enters B ⊥r (at 90°). It follows a circular due to magnetic lorentz force.

(i) centripetal force = magnetic lorentz force

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

$$\theta = 90^\circ$$

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

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

Time period (T)

$$T = \frac{\text{distance}}{\text{velocity}} = \frac{2\pi r}{v}$$

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

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

Frequency (f)

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


## CYCLOTRON

★★ V.IMP (5 Marks)

CBSE [2005-2013]

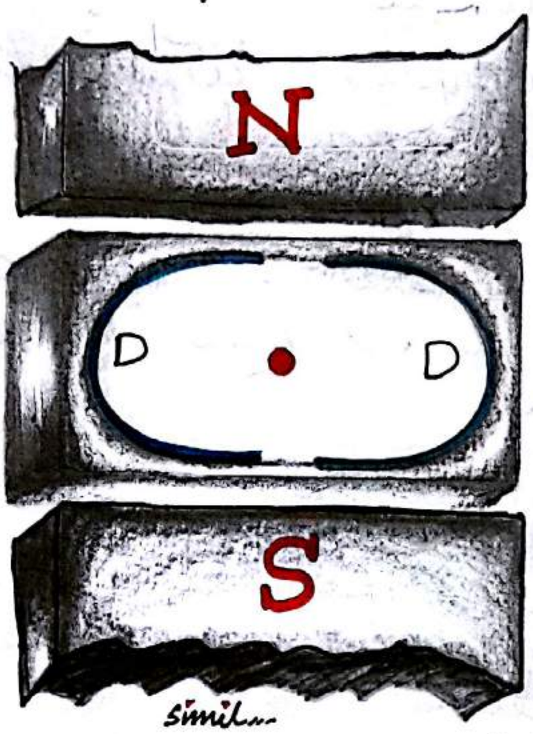
It is a particle accelerator used for accelerating charged particles (+vely charged particles like proton, deutron etc)

### Principle

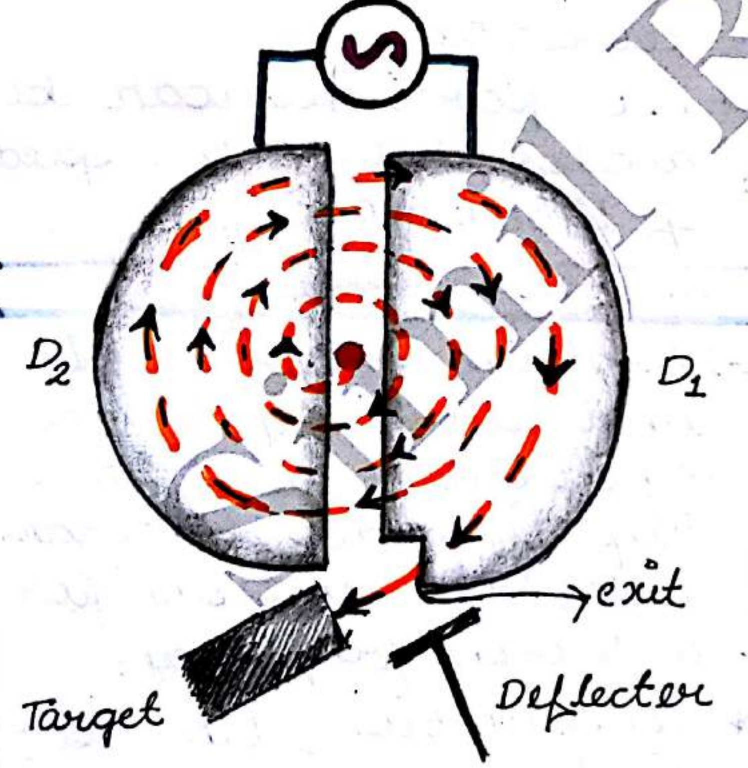
A positive ion acquires sufficiently large energy by accelerating it in electric field by making use of strong magnetic field.

### construction

It consists of two hollow semicircular metallic Dees $D_1$ and $D_2$. The dees are connected to a high frequency oscillator. A strong magnetic field $\vec{B}$ acts perpendicullar to the plane of dees.




cyclotron




* A source of ions is located near the midpoint of gap between the dees.
* An exit pole is provided with a deflection plate for the energetic particle to come out.



## WORKING & THEORY.

At an instant of time let $D_1$ be -ve and $D_2$ be positive.

* The positive ion enters $D_1$ and traverse a semicircular path due to strong magnetic field.
* when it reaches the gap between two dees the polarity changes
* As a result, the +ve ion enters into $D_2$ and traverse a semicircular path of bigger radius.
* The process is repeated and high energetic particles comes out of the dees through exit

$\therefore$ centripetal force = magnetic lorentz force

$$\boxed{\frac{mv^2}{r} = Bqv\sin\theta} \quad [\theta = 90^\circ]$$

$$\therefore \frac{mv^2}{r} = Bqv.$$

$$\therefore r = \frac{mv^2}{Bqv}, \quad \boxed{r = \frac{mv}{Bq}} \quad \ldots (1)$$

$$\boxed{v = \frac{Bqr}{m}} \quad \ldots (2)$$

## Time period (T)

$$T = \frac{\text{distance}}{\text{velocity}} = \frac{2\pi r}{v}$$

$$T = \frac{2\pi}{v} \cdot \frac{mv}{Bq}$$

$$\boxed{T = \frac{2\pi m}{Bq}} \quad \ldots (3)$$

## Frequency (f)

$$f = \frac{1}{T} = \frac{Bq}{2\pi m}$$

$$\therefore \boxed{f = \frac{Bq}{2\pi m}} \quad \ldots (4)$$

This is called cyclotron frequency.

$$(4) \Rightarrow 2\pi f = \frac{Bq}{m}$$

$2\pi f = \omega$

$$\therefore \boxed{\omega = \frac{Bq}{m}}$$

## Kinetic Energy ($K.E_{max}$)

$$K.E_{max} = \frac{1}{2} m v_{max}^2$$

$$K.E_{max} = \frac{1}{2} m \left(\frac{Bqr}{m}\right)^2 \quad \because V = \frac{Bqr}{m}$$

$$K.E_{max} = \frac{1}{2} m \frac{B^2 q^2 r^2}{m^2}$$

$$\boxed{K.E_{max} = \frac{B^2 q^2 r^2}{2m}}$$

## Uses

* To accelerate charged particles
* To implant ions into solids and modify their properties.
* To produce radio active substances in hospitals.

## Limitations

* Neutral particles (neutron) cannot be accelerated.
* Electrons cannot be accelerated.
* No particles can be accelerated to the speed of light

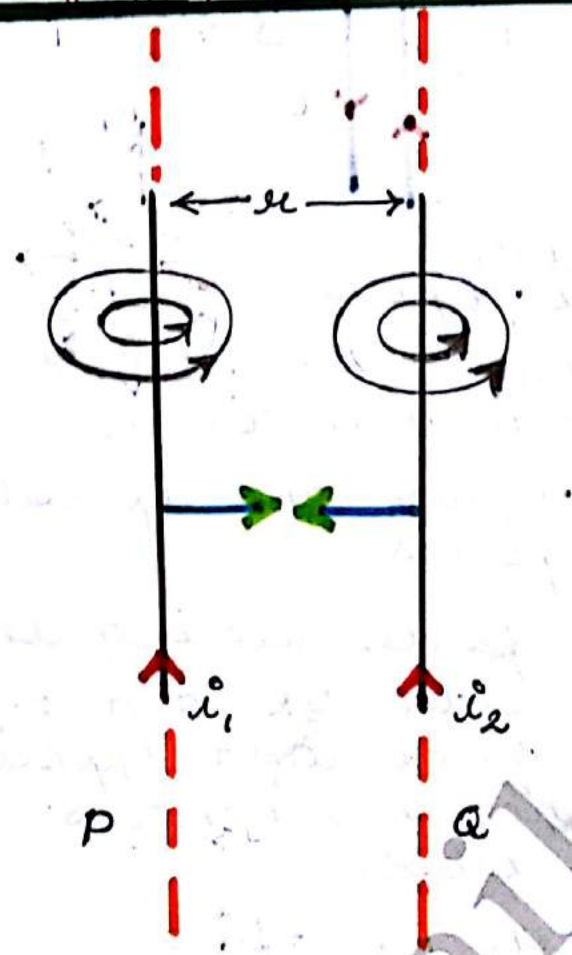
## CBSE QUESTIONS.

(1) Explain the principle and working of a cyclotron with the help of neat diagram. Write the expression for cyclotron frequency?

* construction, time period, cyclotron frequency
* Resonance condition
* f – independent of speed
* K.E

[D-2009, AI, F, 2008, 2007, 06, 2005 2011, AI-2013]

* Force between two straight parallel current carrying conductors.
* - force per unit length due to current carrying parallel conductors.




P, Q parallel conductors
$i_1, i_2$ - currents
F → force.
B → magnetic field.

P and Q are two parallel conductors seperated by a distance 'r' apart. let $i_1$ and $i_2$ be the currents through these conductors in the same direction.

magnetic field at 'Q' due to $i_1$

$$B = \frac{\mu_0 i_1}{2\pi r} \quad \ldots \rightarrow (1)$$

Force experienced by 'Q' due to B.

$$F = B i_2 l \sin\theta$$
$$\theta = 90^\circ$$
$$F = B i_2 l \quad \ldots \; (2)$$

(1) in (2)

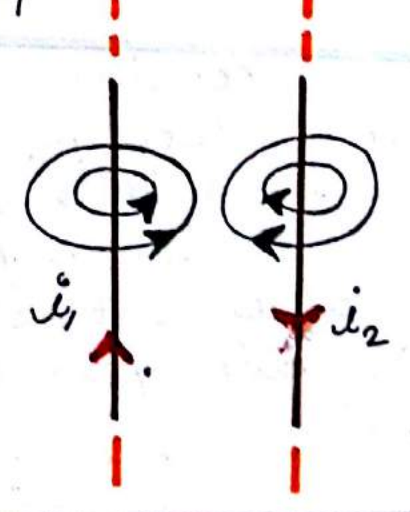
$$F = \frac{\mu_0 i_1 i_2 l}{2\pi r}$$

$$\therefore \frac{F}{l} = \frac{\mu_0 i_1 i_2}{2\pi r}.$$

similarly conductor P also experiences same force towards Q.

$$\frac{F}{l} = \frac{\mu_0 i_1 i_2}{2\pi r}.$$

* parallel currents attract
* Anti parallel currents. repel.



## Definition of one Ampere :

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

if $i_1 = i_2 = 1A$ ; $r = 1m$.

$\mu_0 = 4\pi \times 10^{-7}$

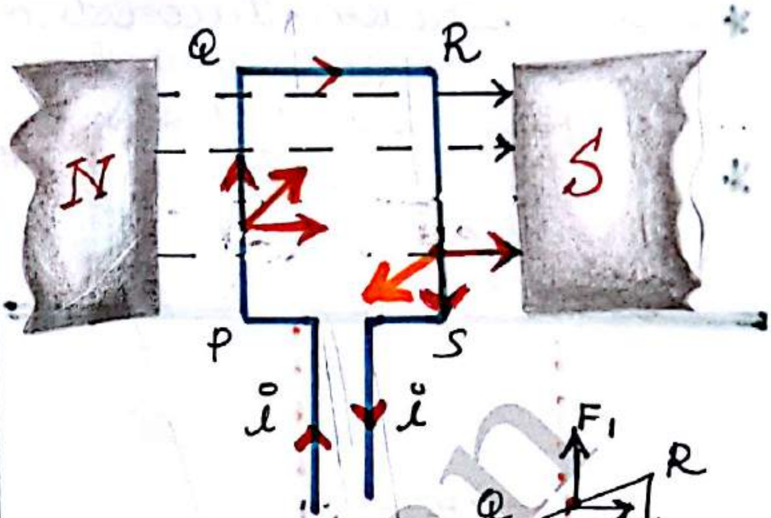
$$\frac{F}{l} = \frac{4\pi \times 10^{-7} \times 1 \times 1}{2\pi \times 1}$$

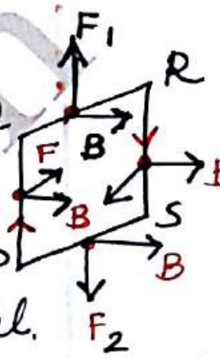
$$\frac{F}{l} = 2 \times 10^{-7} \text{ N/m}$$

Defintion :- one ampere is that current which if maintained in two straight parallel conductors of infinite length and of negligible cross-section, placed 1m apart in vaccum will produce between them a force of $2 \times 10^{-7}$ newtons/ metre length.

## Torque on a current loop in a B

. consider a rectangular loop pqrs of sides 'l' and 'b' placed in a uniform magnetic field of Intensity B with its plane parallel to the field.




NS → north south poles

l, b → length and breadth of coil.

$F_1$, $F_2$ – equal and opposite forces.

* The forces acting on the sides QR and PS are equal and opposite hence they cancels each other.

Force on PQ = Bil
[into the plane]

Force on RS = Bil
[out of the plane]

These two equal and opposite forces constitue a couple which deflects the loop.

Torque $\tau = Bil \times b$.

$\tau = BiA$ ∵ $l \times b = A$ □gle

If it makes an angle θ,

$\tau = BiA \sin\theta$

In vector form

$$\tau = i(\vec{A} \times \vec{B})$$

If there are 'N' no of turns.

$$\tau = NBiA\sin\theta$$

$$\tau = mB\sin\theta$$

$$\tau = m \times B$$

$m = NiA$ Magnetic Moment

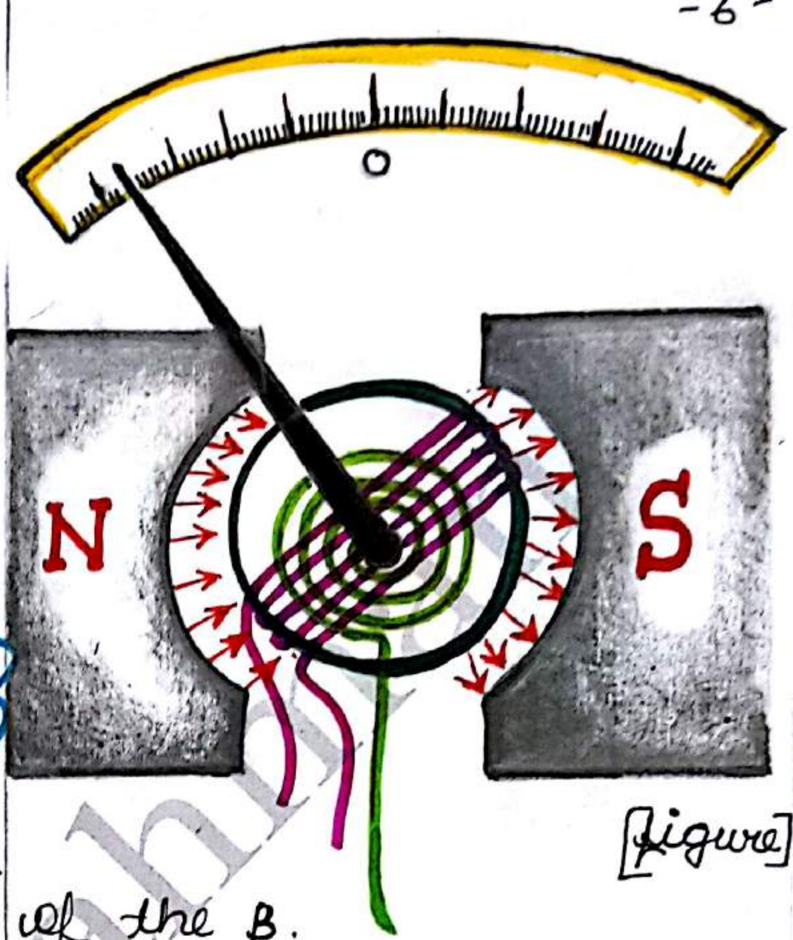
# Moving Coil Galvanometer

Galvanometer is a device used to detect small value of current.

construction

* The galvanometer consists of a coil with large no of turns, free to rotate about a fixed axis in a uniform radial magnetic field

* There is a cylindrical soft iron core which not only make the field radial but also increases the strength of the B.




[figure]

* The pointer is connected to the soft iron core with a scale arrangement as shown in figure.

Principle :-

when current I is passed through a coil kept in magnetic field, coil experiences a torque.

Theory

Deflection Torque

$$\tau = NBiA\sin\theta$$

$$\tau = BANi\sin\theta$$

$$\theta = 90^\circ$$

$$\therefore \tau = BANi$$

## Restoring Torque

$\tau = k\theta$

i.e, Deflection Torque = Restoring Torque.

$\therefore BANI = k\theta$

$I = \left(\frac{k}{BAN}\right)\theta$

$I = \left(\frac{k}{BAN}\right)\theta$ ; i.e, $I \propto \theta$

$I = G\theta$ where G-galvanometer const

$\boxed{G = \frac{k}{BAN}}$

* Hence the deflection of the galvanometer is directly proportional to the current passing through it.

* Functions of radial field

(1) keeps the coil parallel to magnetic field always

(2) $\tau = BANi$ as $\theta = 90^\circ$

(3) $\tau \rightarrow$ Maximum

* Functions of soft iron core.

(1) Gives radial Magnetic field

(2) makes B very strong.

## Sensitivity of Galvanometer

A galvanometer is said to be sensitive if it gives large deflection on passing small current through the coil

$\frac{1}{G} = \frac{BAN}{k} \rightarrow$ measure of sensitivity of galvanometer.

## current sensitivity

It is the deflection produced per unit current.

$\boxed{I = \frac{k}{BAN}\theta}$

$\boxed{\frac{\theta}{I} = \frac{BAN}{K}}$

* It depends upon B, N & k
* can be increased by Increasing B, N and k ↓ (decreasing k)

## voltage Sensitivity

It is defined as the deflection produced per unit voltage

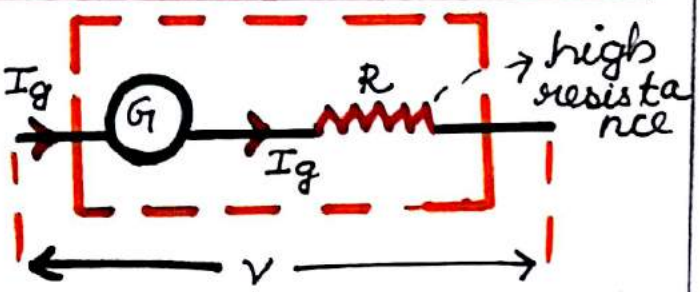
ie, $\frac{\theta}{V} = \frac{\theta}{IR} = \frac{BAN}{KR}$

$\boxed{\frac{\theta}{V} = \frac{BAN}{KR}}$ $\boxed{I = \left(\frac{k}{BAN}\right)\theta}$

It can be Increased by B ↑ and k ↓

$\frac{N}{R}$ — const, when N ↑ R will also ↑.

## * conversion of a galvanometer into voltmeter




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

$$\therefore V = I_g(G+R)$$

$$\frac{V}{I_g} = G+R$$

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

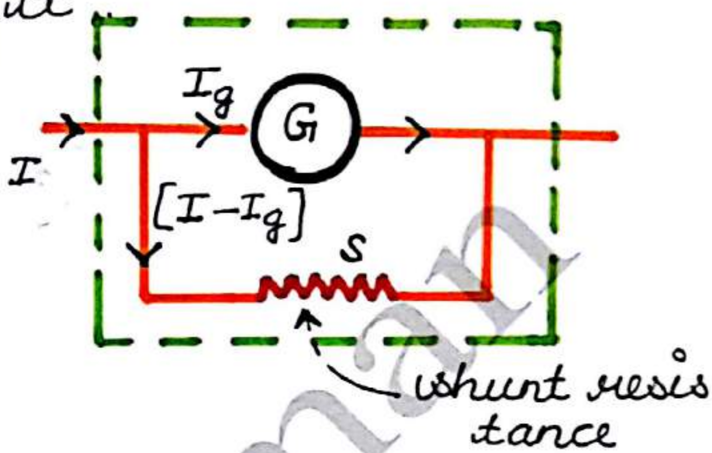
$I_g \rightarrow$ current flowing through galvanometer

$G \rightarrow$ Resistance of Galvanometer

$$R_{eff} = R + G$$

## * conversion of Galvanometer into ammeter.

A galvanometer can be converted into an ammeter for measuring large currents by connecting a shunt to it




$$V_G = V_S$$

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

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

equivalent resistance

$$\frac{1}{R_{eff}} = \frac{1}{G} + \frac{1}{S}$$

$$\frac{1}{R_{eff}} = \frac{G+S}{GS}$$

$$\therefore R_{eff} = \frac{GS}{G+S}$$