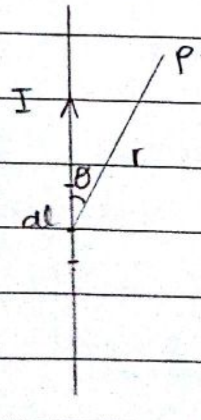
Moving Charges & Magnetism.

Oesterd's experiment - Oestered observed that a magnetic needle kept near a current carrying conductor was undergoing some deflection the direction of deflection is reversed when the direction of current is reversed.

He concluded that, there is a magnetic field around a current carrying conductor and the direction of magnetic field depends upon the direction of current.

Biot Savart's law.

According to Biot Savart's law the magnetic field at any point at a distance 'r' from the centre of a small current carrying element of length dl is directly propotional to (i) strength of the current I (ii) length of the element dl (iii) $\sin\theta$ and inversly propotional to the square of the distance b/w the point and the centre of dl



i.e. the small magnetic field at P,

$$dB \propto I$$

$$dB \propto dl$$

$$dB \propto \sin\theta$$

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

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

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

where μ_0 is a constant called the permeability of free space.

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

~~dB/A~~

If the point P is in a medium then

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

where μ_r is the relative permeability of the medium.

The total magnetic field due to the entire conductor,

$$B = \int dB.$$

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

Biot Savart's law in vector form,

we have

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

In vector form

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

where $\hat{r}$ is a unit vector.

But $\hat{r} = \frac{\vec{r}}{r}$

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

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

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

From the above expression it is clear that the direction of magnetic field is $\perp^r$ to both $d\vec{l}$ and $\vec{r}$. It can be determined by right hand thumb rule

Right hand thumb rule.

If a current carrying conductor is held in the right hand in such a way that the thumb indicate the direction of current then the closed fingers will indicate the direction of ~~current~~ magnetic field.

A power line carrying current from north to south direction. Find the direction of magnetic field passing through the head of a bird standing on a line.

- East to west.

*note

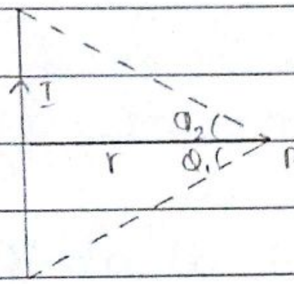
Let the point P is on the conductor then $\theta = 0$

$\therefore B = 0$. ie the magnetic field along the length of the conductor is 0.

Applications of Biot-Savart's law

(i) Magnetic field due to a straight conductor

Consider a straight conductor carrying current I. P is a point at a ⊥ʳ distance r from the conductor



the magnetic field at P

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

If it is an infinitely long conductor then
$\phi_1 = \phi_2 = 90°$.

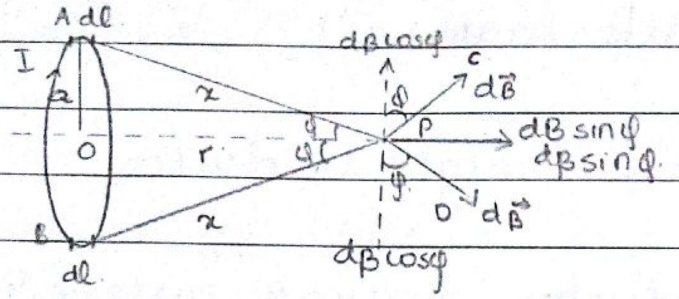
$$\therefore B = \frac{\mu_0 I}{4\pi r}[\sin 90 + \sin 90]$$

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

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

(ii) Magnetic field due to a circular coil

Consider a circular coil of radius 'a' and total no. of turns 'n' carrying current I. P is a point on its axis at a distance r from its centre.



Magnetic field at P due to a small element dl at A,

$$d\beta = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{x^2}.$$

$$= \frac{\mu_0}{4\pi} \frac{I\,dl}{x^2} \quad (\because \theta = 90^\circ)$$, directed along PC

Magnetic field at P due to the element dl at B.

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl}{x^2}$$, directed along PD.

The rectangular components of dB are shown in fig. Since the cos components are equal and opp, they will cancel each other.

∴ the resultant magnetic field at P due to the entire coil, $B = \oint dB \sin\phi$.

$$= \oint \frac{\mu_0}{4\pi} \frac{I\,dl}{x^2} \cdot \sin\phi$$

$$= \oint \frac{\mu_0}{4\pi} \frac{I\,dl}{x^2} \cdot \frac{a}{x} \quad \because \left(\sin\phi = \frac{a}{x}\right).$$

$$= \frac{\mu_0 I a}{4\pi x^3} \oint dl$$

$$= \frac{\mu_0 I a}{4\pi x^3} \times 2\pi a$$

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

$\because$ But $x = (a^2+r^2)^{1/2}$

$x^3 = (a^2+r^2)^{3/2}$

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

Since there are N turns in the coil,

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

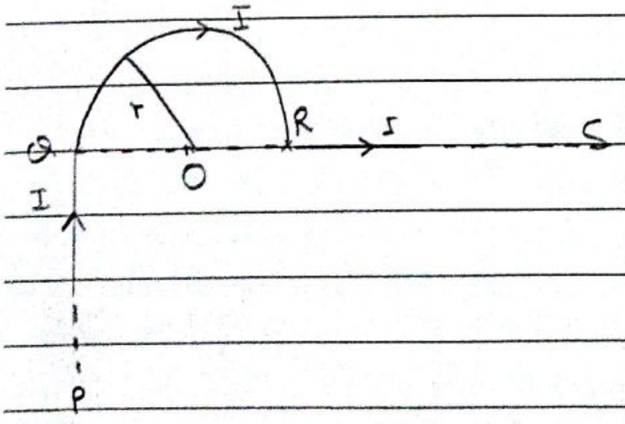
NOTE

let the point P is at the centre of the coil, then $r=0$,

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

$$B = \frac{\mu_0 N I}{2a}$$

Find the magnitude and direction of magnetic field at the point O. (i)



$B = \frac{\mu_0 I}{4\pi r}(\sin\phi_1 + \sin\phi_2)$

$= \frac{\mu_0 I}{4\pi r}(\sin 90 + \sin 0)$

$= \frac{\mu_0 I}{4\pi r}$

B due to PQ, $B_1 = \frac{\mu_0 I}{4\pi r}$

B due to QR, $B_2 = \frac{\mu_0 I}{4r}$

B due to RS $B_3 = 0$ since it is along the line

$B_{tot} = B_1 + B_2$

$= \frac{\mu_0 I}{4r}\left[\frac{1}{\pi} + 1\right]$

Direction - Into the plane of the paper

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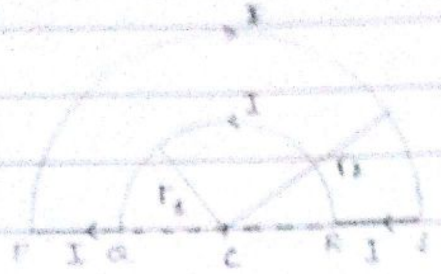
(ii)



B due to QR $= \frac{\mu_0 N I}{2a}$

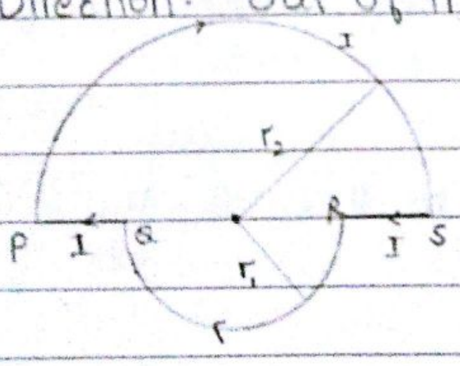
$$B_1 = \frac{\mu_0 I}{4 r_1}$$

B due to PS $= \frac{\mu_0 I}{4 r_2}$

$$B_2 = \frac{\mu_0 I}{4 r_2}$$

$$B = B_1 - B_2$$
$$= \frac{\mu_0 I}{4}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$$

Direction: out of the plane of the paper

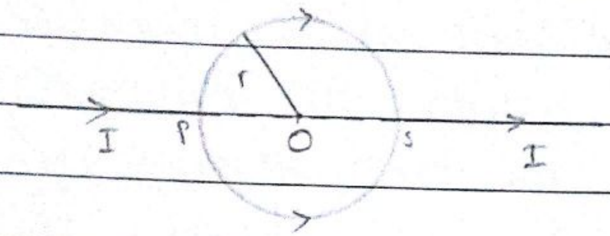


B due to PS $B_1 = \frac{\mu_0 I}{4 r_2}$

B due to QR $B_2 = \frac{\mu_0 I}{4 r_1}$

$$B = B_1 + B_2$$
$$= \frac{\mu_0 I}{4}\left[\frac{1}{r_1} + \frac{1}{r_2}\right]$$ Direction into the plane of the paper

(iv)



$$B_1 = \frac{\mu_0 I/2}{4r}$$

$$B_2 = \frac{\mu_0 I/2}{4r}$$

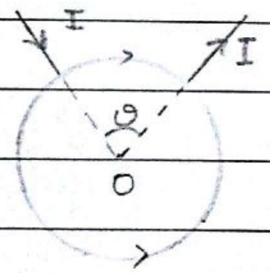
$B = \vec{B}_1 + \vec{B}_2$ But $B_1 = -B_2$

$$B = B_1 - B_2$$

$$= \frac{\mu_0 I/2}{4r} - \frac{\mu_0 I/2}{4r}$$

$$= 0$$

no direction



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

$$B_2 = \frac{\mu_0 I_2 (2\pi - \theta)}{2r \cdot 2\pi}$$

$$B = B_1 - B_2$$

$$= \frac{\mu_0}{4\pi r}\left(I_1\theta - I_2(2\pi - \theta)\right) \quad \text{—} (1)$$

$$R_1 = \frac{R\theta}{2\pi}$$

$$R_2 = \frac{R}{2\pi}(2\pi - \theta)$$

$$I_1 R_1 = I_2 R_2$$

$$\frac{I_1 \times R\theta}{2\pi} = \frac{I_2 \times R(2\pi - \theta)}{2\pi}$$

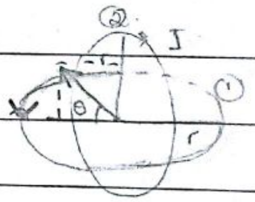
$$I_1\theta = I_2(2\pi - \theta)$$

Substituting ①

$$B = \frac{\mu_0}{4\pi r}(I_1\theta - I_1\theta)$$

$$B = 0$$

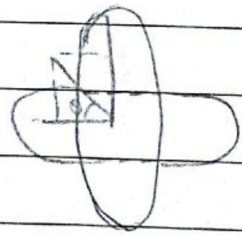
2 identical concentric circular coil of radius r and carrying current I are kept in such a way that their planes are ⊥ to each other. Find the magnitude and direction of the magnetic field at the centre of the coil.



$$B_1 = \frac{\mu_0 I}{2r} \qquad B_2 = \frac{\mu_0 I}{2r}$$

$$B = \sqrt{B_1^2 + B_2^2}$$

$$= \sqrt{\left(\frac{\mu_0 I}{2r}\right)^2 + \left(\frac{\mu_0 I}{2r}\right)^2}$$



$$= \sqrt{2}\,\frac{\mu_0 I}{2r}$$

Direction

$$\tan\theta = \frac{B_1}{B_2}$$

$$= 1 \qquad [\because B_1 = B_2]$$

$$= 45^\circ$$

Subject ______ Day ______ Date / /

Ampere's Circuit theorem

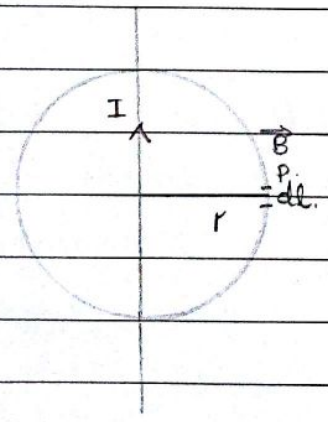
The theorem states that the line Integral of magnetic field around any closed path is equal to μ_0 times the net current enclosed by the path. i.e.

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

Proof

Consider a point P at a distance r from an Infinitely long conductor carrying current I.
the magnetic field at P is given by $B = \frac{\mu_0 I}{2\pi r}$

Figure shows a circular amperian loop of radius r. and passing through the point P.



Consider a small element dl on the loop then,

$$\oint B\cdot dl = \oint B dl \cos\theta$$
$$= \oint B dl \cos 0$$
$$= \oint B dl$$
$$= B \oint dl$$
$$= \frac{\mu_0 I}{2\pi r} \times 2\pi r$$

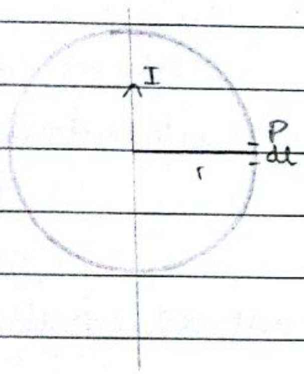
$$\oint B\cdot dl = \mu_0 I$$

Hence proved.

Applications of Amperes Circuital theorem.

(i) Magnetic field due to a straight conductor

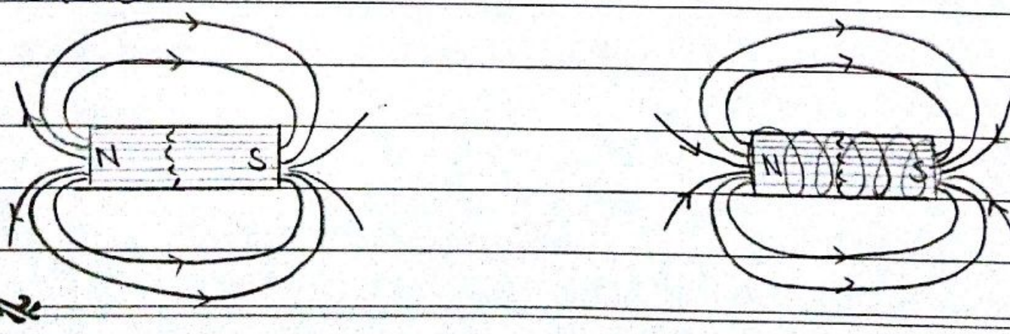
Consider a point P at a distance r from a straight conductor carrying current I.
To find the magnet field at P, consider a circular amperian loop of radius r as shown in the figure.



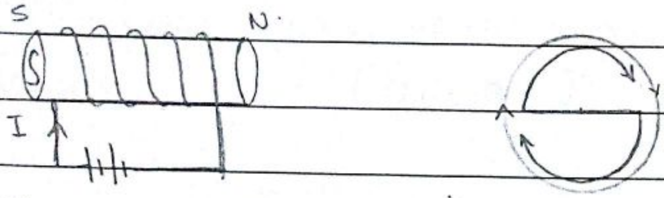
dl is a small element on the loop, according to amperes circuital theorem,

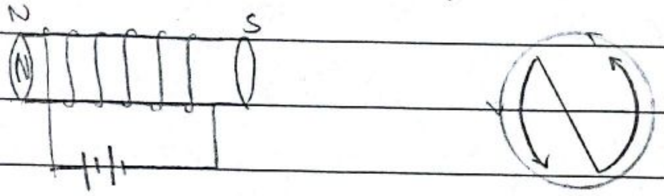
$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I$$
$$\oint B\,dl\cos\theta = \mu_0 I$$
$$\oint B\,dl\cos 0 = \mu_0 I$$
$$\oint B\,dl = \mu_0 I$$
$$B\oint dl = \mu_0 I$$
$$B \cdot 2\pi r = \mu_0 I$$
$$B = \frac{\mu_0 I}{2\pi r}$$

(ii) Magnetic field due to a solenoid.
A current carrying solenoid and a bar magnet produce similar magnetic field The magnetic field is uniform inside the solenoid and is 0 just outside.



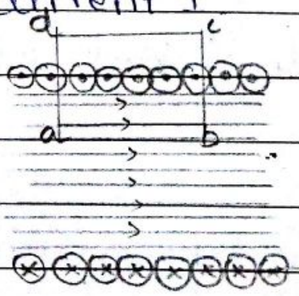
The polarity of solenoid is determined by the direction of current. If the current at one end of the solenoid is flowing in clockwise direction, that end is the south pole and if the current is flowing in anticlockwise direction that end in the north pole





Expression for magnetic field due to a solenoid.

fig shows the cross sectional pictures of a solenoid of no. of turns per unit length n and carrying a current I.



According to Amperial circuit theorem

$\oint B.dl = \mu_0 I_{net}$ ——— (1)

a, b, c, d is a rectangular amperian loop of side l

$$\oint \vec{B}.\vec{dl} = \int_a^b \vec{B}.\vec{dl} + \int_b^c \vec{B}.\vec{dl} + \int_c^d \vec{B}.\vec{dl} + \int_d^a B\,dl \text{ ——— (2)}$$

$$\int_a^b \vec{B}\cdot d\vec{l} = \int_a^b B\,dl\cos\theta = \int_a^b B\,dl\cos 0$$

$$= \int_a^b B.dl$$

$$= B\int_a^b dl$$

$$= Bl$$

$$\int_b^c \vec{B}\cdot d\vec{l} = \int_d^a \vec{B}\cdot d\vec{l} = 0 \quad (\because \theta = 90)$$

$$\int_c^d B.dl = 0 \quad (\because B = 0)$$

$\therefore$ (2) $\Rightarrow$ $\oint B.dl = Bl$

$I_{net} = nlI$

$\therefore$ (1) $\Rightarrow$

$Bl = \mu_0 nlI$

$$\boxed{B = \mu_0 nI}$$

Note

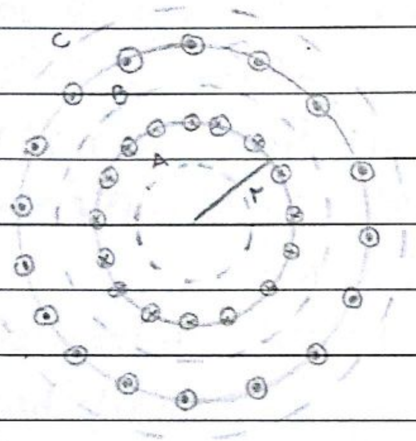
If a substance of relative permeability μ_r is kept inside a solenoid then $B = \mu_0 \mu_r nI$

The magnetic field due to a solenoid depends on
(i) strength of the current
(ii) No. of turns per unit length
(iii) Nature of the material kept inside the solenoid.

The magnetic field at the ends of the solenoid,
$B = \frac{\mu_0 nI}{2}$

Magnetic field due to a toroid

Consider a toroid of no. of turns per unit length n with mean radius 'r' and carrying current I. To find the magnetic field due to the toroid, consider 3 circular amperean loops A, B and C as shown in the figure.



loop. A.

$\oint B.dl = \mu_0 \times$ Net current enclosed by the loop. A

$= 0$

$\therefore B = 0$

loop. B

$\oint B.dl = \mu_0 \times$ Net current enclosed by the loop. B

$\oint B.dl \cos\theta = \mu_0 \times 2\pi r n I$

$\oint B.dl = \mu_0 \times 2\pi r n I \quad (\because \theta = 0)$

$B \oint dl = \mu_0 \times 2\pi r n I$

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

$B = \mu_0 n I$

loop. C

$\oint B.dl = \mu_0 \times$ net ~~charg~~ current enclosed by the loop C

$= 0 \times \mu_0 \quad (I_{net} = NI - NI$

$\therefore B = 0$

From the above result, it is clear that the field exist only inside the toroid.

Magnetic Lorentz force.

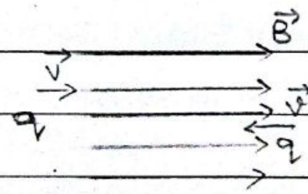
The force experienced by a charged particle when it is moving ~~a~~ through a magnetic field, ~~it~~ is called magnetic lorentz force.

Consider a charge 'q', moving through a magnetic field of Intensity B, with a velocity v. then the magnetic lorentz force $F = q(\vec{V} \times \vec{B})$.

$F = qvB\sin\theta$. where θ is the angle b/w $\vec{V}$ & $\vec{B}$.

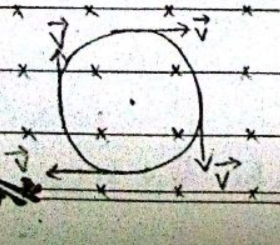
The direction of this force is ⊥' to both $\vec{V}$ & $\vec{B}$.

Special Cases.
let $\theta = 0°$ or $180°$.



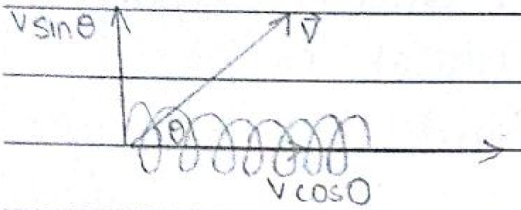
Then $F = qvB\sin 0$ or $qvB.\sin 180$
$F = 0$
i.e, the force is 0 if the charge enters parallel or antiparallel with the field.
∴ the charge moves without any deviation

Case - 2.
let $\theta = 90°$



$F = qvB\sin 90$
$= qvB$.
i.e, the force is max. when the charge enters ⊥' to the field and it follows a circular path.

Case 3 $0 < \theta < 90$



$F = qvB\sin\theta$ & the charge follows a helical path.

NOTE

when a charged particle is moving through a combined form of electric and magnetic fields, it will experience both electric lorentz force and magnetic lorentz force

i.e $\vec{F} = \vec{F}_E + \vec{F}_B$

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

CYCLOTRON

cyclotron is a device used to accelerate charged particles

principle

when a charged particle enters a magnetic field ⊥' to the field, it follows a circular path the necessary centripetal force for the circular motion is provided by the magnetic lorentz force.

i.e $\frac{mv^2}{r} = qvB$

$$v = \frac{qBr}{m}$$

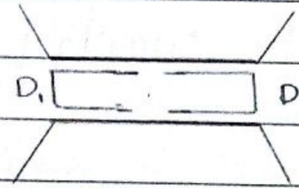
$$v \propto r$$

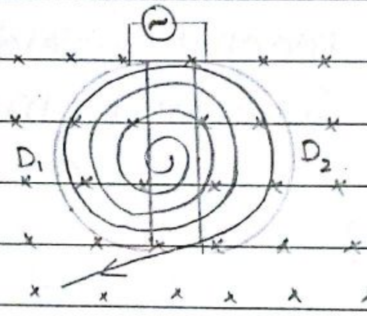
i.e, the velocity of the particle increases with the increase in radius.

working

A cyclotron consists of 2 DEE's (semicircular box) D_1 & D_2 kept in b/w the poles of a magnet i.e. there is a uniform magnetic field ⊥ to the plane of the DEE's.

The DEEs are connected to an alternating source of voltage





Consider a particle (say a proton). Of charge 'q' is kept at the centre of the DEE's. Initially let the DEE D_1 is at a +ve potential and the DEE D_2 is at a negative potential. then the particle will be attracted towards D_2 and follows a circular path. when the particle again reaches in the gap b/w D_1 & D_2., the polarities of the DEE's are interchang such that D_1 is at a -ve potential & D_2 is at a +ve potential. As a result the particle will be attracted towards D1 and ∴ its radius of ~~the~~ its path increases. this process repeats and therefore the radius increases and finally the particle comes out of the DEE's with very high velocity.

(i) Time period (T)

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

$$= \frac{2\pi r}{\frac{qBr}{m}}$$

$$T = \frac{2\pi m}{qB}$$

(ii) frequency (f)

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

(iii) kinetic energy (KE)

$$KE = \frac{1}{2} m v^2$$
$$= \frac{1}{2} \times m \times \frac{q^2 B^2 r^2}{m^2}$$

$$\boxed{KE = \frac{q^2 B^2 r^2}{2m}}$$

limitations of cyclotron.

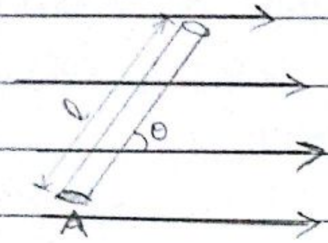
Neutrons cannot be accelerated using cyclotron since it is electrically neutral.
Electrons cannot be accelerated using cyclotron sin electron is very less, its velocity increases rapidly due to this increase in velocity, the mass of electron als increases as per the concept of relativity $m = \frac{m_0}{\sqrt{1 - v^2/c}}$

we have $T = \frac{2\pi m}{qB}$, $T \propto m$.

$\therefore$ the e^- will take more time to follow the circular path.

*force experienced by a current carrying conductor kept in a magnetic field

Consider a conductor of length 'l', and area of cross-section A kept in a uniform magnetic field of intensity B as shown in the figure



let n be the no. of free electrons per unit volume and V_d be the drift velocity.

volume of the conductor = Al
Total no. of electrons = nAl
Total charge $q = nAle$

we have the magnetic lorentz force

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

$= nAleV_dB\sin\theta$

$= neAV_d . lB\sin\theta$

$F = IlB.\sin\theta$, where $I = n_e AV_d$, the current.

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

The direction of force is ⊥' to both $\vec{l}$ & $\vec{B}$.

Special cases.

1) let $\theta = 0°$ or $180°$

$F = IlB\sin 0$ / $IlB\sin 180$

$F = 0$

∴ The force ~~the~~ is 0 when the conductor is kept ∥ or antiparallel with the field.

2) Case 2, let $\theta = 90°$

$F = IlB\sin 90$

$F = IlB$.

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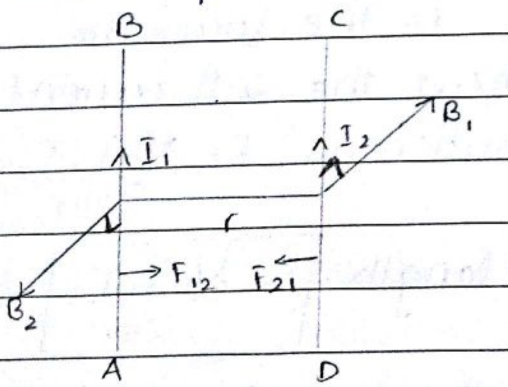
i.e, the force is max. when the conductor is kept ⊥ to the field.

Flemings Left hand rule.

Stretch the 1st three fingers of the left hand in mutually ⊥ directions. If the fore finger indicates the direction of magnetic field & ~~thumb~~ middle finger indicates the direction of current then the thumb will indicates the direction of force.

Force b/w 2 parallel current carrying conductors.

Consider 2 long ∥ conductors AB and CD, carrying currents I_1 & I_2 respectively in the same direction and seperated by a distance. r



Magnetic field on CD due to the current I_1.

$B_1 = \frac{\mu_0 I_1}{2\pi r}$ (directed inward)

∴ force on a length l of the conductor CD,

$F_{21} = I_2 l B_1 \sin 90$

$= \frac{I_2 . l \mu_0 I_1}{2\pi r}$

$F_{21} = \frac{\mu_0 I_1 I_2 . l}{2\pi r}$ —— (1),

directed towards left

Magnetic field on AB, due to the current I_2

$B_2 = \frac{\mu_0 I_2}{2\pi r}$, directed outwards

$\therefore$ force on a length l of the conductor AB,

$F_{12} = I_1 . l . B_2 \sin 90$

$= I_1 l . \frac{\mu_0 I_2}{2\pi r}$

$F_{12} = \frac{\mu_0 I_1 I_2 . l}{2\pi r}$ —— (2), directed towards right

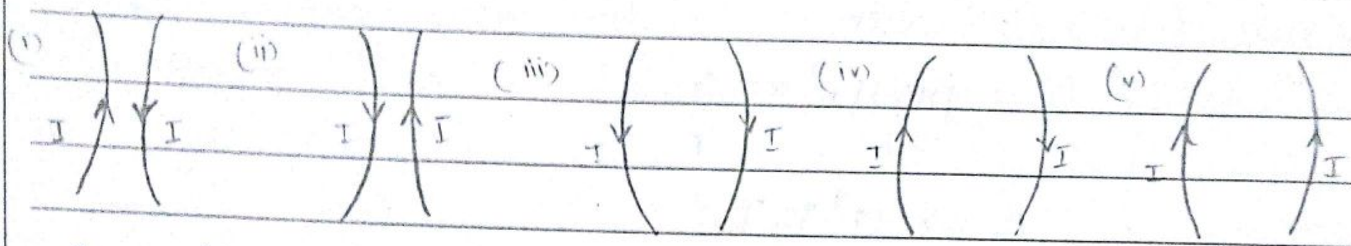
from (1) & (2).

It is clear that $\vec{F}_{12} = -\vec{F}_{21}$. i.e the forces are equal and opp. $\therefore$ the force b/w the 2 ∥ current carrying conductor can be written as $F = \frac{\mu_0 I_1 I_2 . l}{2\pi r}$

$\therefore$ the force acting per unit length, $\boxed{F = \frac{\mu_0 I_1 I_2}{2\pi r}}$

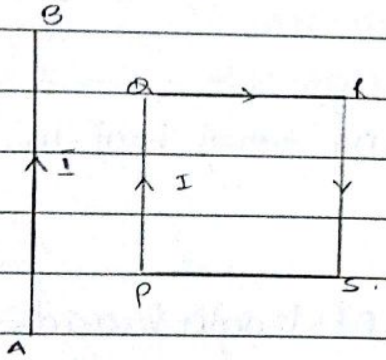
The force is attractive if the currents are in the same direction and are repulsive if they are in the opp. direction.

Q.1 Pick the correct one



ans- (iv) Since the direction of current is opp. it is repulsive.

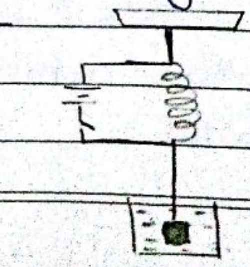
2. figure shows a rectangular current carrying loop PQRS which is free to move and a straight current carrying conductor AB which is fixed the loop will ( )



(i) move towards AB
(ii) move upwards
(iii) move away from AB
(iv) move downwards
(v) remains stationary

ans (i) move towards AB (since attractive force dominates)

Q A stone is suspended by a insulator wire from a metal spring as shown in the figure what will happen to the stone when the circuit is switched on. justify



the stone will be lifted upwards since, when the circuit is switched on the turns of the spring acts like current carrying ∥ plate so the spring contracts

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Definition of 1 Ampere

We have $F = \frac{\mu_0 I_1 I_2}{2\pi r}$

$$= \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{I_1 I_2}{r}$$

$$= 2\times 10^{-7} \frac{I_1 I_2}{r}$$

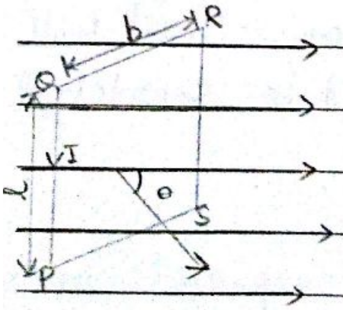
let $I_1 = I_2 = 1A$ & $r = 1m$

Then $F = 2\times10^{-7} N$

$\therefore$ 1 A is that current which when passing through 2 parallel conductors kept at a distance of 1 m in free space produces a force of 2×10^{-7} N per unit length b/w them.

Torque acting on a current carrying loop kept in a uniform magnetic field.

Consider a rectangular loop PQRS of length l and breadth 'b' carrying current I kept in a uniform magnetic field of intensity B. let the normal to the plane of the loop is making an angle θ with the direction of field as shown in figure.

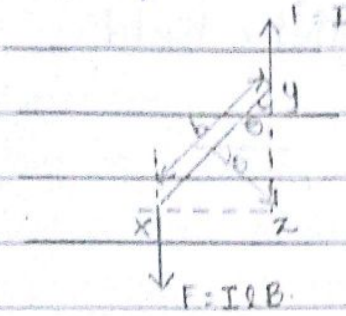


The forces experienced by the sides QR & PS are equal and opposite and cancel each other.

The force experienced by the side PQ, $F = IlB$, directed outward force experienced by the side RS,

$F = IlB$, directed inward.

these 2 forces are unlike parallel forces and constitute a couple therefore the loop experiences a torque



we have torque

$\sin\theta = \frac{xz}{xy}$

$\tau = F \times \perp'$ distance

$= IlB \times xz$

$xz = xy\sin\theta$
$= b\sin\theta$

$= IlB \times b.\sin\theta$

$\tau = IAB\sin\theta$

where $A = \cancel{lB}\ l \times b$, the area of the loop

If there are N turns in the loop, then

$\tau = NIAB\sin\theta$

$\tau = MB\sin\theta$.

$\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$ where $M = NIA$, called the magnetic dipole moment.

Special cases.

Case 1

let $\theta = 0°$

then $\tau = NIAB\sin\theta$

$= 0$ i.e the torque is minimum when the plane of the loop is $\perp'$ to the ~~plo~~ field.

Case 2

let $\theta = 90°$

then $\tau = NIAB\sin 90$

$= NIAB$ ie, the torque is max when the plane of the loop is kept $\parallel$ to the field

The torque acting on a current carrying loop depends on:
(i) no. of turns of the loop
(ii) strength of the current
(iii) Area of the loop
(iv) Orientation of the loop in the magnetic field.

NOTE
Magnetic dipole moment
$\boxed{M = NIA}$
dipole moment is a vector quantity and its direction is ⊥' to the plane of the loop.
Its unit is Am^2.

A square loop and a circular loop of same area, carrying the same current are kept in a uniform magnetic field at the same angle, which one will experience greater torque and why.

Both will experience the same torque since it is independent of the shape of the loop.

A square loop and a circular loop made from 2 wires of same length, carrying same current are kept in a magnetic field at the same angle, which one will experience greater torque and why?

The circular loop will experience greater torque since its area is more.
$\tau = NIAB \sin\theta$
$\tau \propto A$

Moving coil Galvanometer.

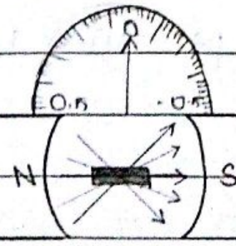
Galvanometer is a device used to detect the presence of current or to measure small current.

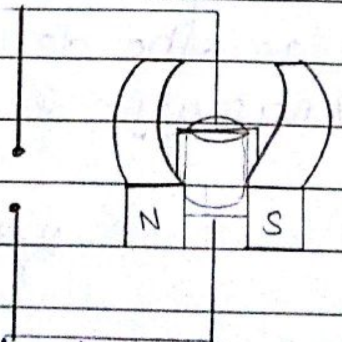
PRINCIPLE

When a current carrying loop is kept in a uniform magnetic field it will experience a torque. The torque is max. when the plane of the loop is parallel to the magnetic field.

WORKING

A moving coil Galvanometer consists of a rectangular copper coil, suspended in between the pole pieces of a cylindrical magnet by using a phosphor bronze strip. The magnets are made cylindrical to make the magnetic field radial so that the torque is maximum always. There is an Iron cylinder inside the coil to concentrate the magnetic field and for producing electro-magnetic damping.





Let N be the no. of turns of the coil, and A be the area of cross section. The ends of the coil are connected to a source of voltage. When the circuit is switched on the loop will experience a torque and is given by

$\tau = NIAB \sin\theta$

$\tau = NIAB$ ($\because \theta = 90$) where I is the current flowing through th

~~$\tau = k\phi$~~

Due to this torque let the coil rotates through an angle ϕ.

A restoring torque will set up in the loop and is given by $\tau = k\phi$ where k is a constant called the Torsion constant or τ per unit twist.

At Equilibrium, experienced torque = Restoring torque

i.e. $NIAB = k\phi$

$$\boxed{I = \frac{k}{NAB} \cdot \phi}$$

$$I = G\phi$$

where $G = \frac{k}{NAB}$ called the galvanometer constant.

Sensitivity of a Galvanometer

Current Sensitivity - Current sensitivity can be defined as ~~the defined as~~ the deflection produced per unit current

Current Sensitivity $= \frac{\phi}{I}$

$$= \frac{NAB}{k}$$

$\therefore$ current sensitivity of a Galvanometer is $\propto$

(i) no. of turns of the coil

(ii) Area of the coil

(iii) Strength of the magnetic field

and inversly $\propto$ to the ~~[illegible]~~ torsion constant

11) Voltage Sensitivity - Voltage sensitivity of a Galvanometer can be defined as the deflection per unit potential difference.

voltage sensitivity $= \frac{\phi}{V}$

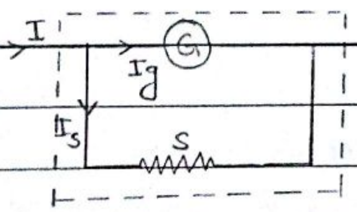
$= \frac{\phi}{IR}$

$= \frac{NAB}{K.R.}$ where R is the resistance of the coil.

$\therefore$ the voltage sensitivity can be increased by decreasing the value of R.

Conversion of Galvanometer Into an Ammeter

A Galvanometer can be converted into an ammeter by connecting a low ~~rest~~ resistance (shunt resistance) parallel to it.



let G be the resistance of the galvanometer and S that of the Shunt. I_g is the current through the Galvanometer and I_s be the current through the shunt

then $I = I_g + I_s$

$I_s = I - I_g$

Since the galvanometer and the shunt are connected in parallel.

Pd Across G = Pd Across S

$I_g G = I_s S$

$S = \frac{I_g G}{I_s}$

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

Resistance of the ammeter, $R = \frac{GS}{G+S}$

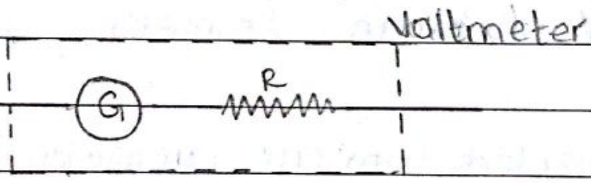
$R \approx \frac{GS}{G}$ (Since S is very small)

$\therefore R \approx S$.

ie Ammeter is a device with a very low resistance

Conversion of Galvanometer into a Voltmeter.

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



let I_g be the current through the galvanometer

$V = I_g (G+R)$.

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

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

The resistance of the voltmeter = $G+R$, it is very high
ie, voltmeter is a device with very high resistance.

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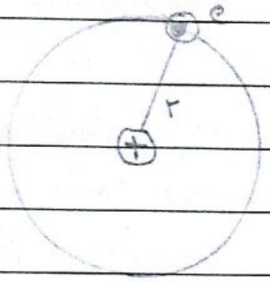
Bohr Magneton

Consider the Bohr Model of Hydrogen Atom. An electron of mass m and charge e is revolving around the nucleus in an orbit of radius 'r' with a velocity v.



let T be the time period of the electron then the current $I = \frac{e}{T}$

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

$\therefore I = \frac{ev}{2\pi r}$.

Magnetic dipole moment,

$M = IA$.

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

$= \frac{evr}{2}$

Multiply and divide the RHS of the above equation by the mass of e^-,

$M = \frac{evr}{2} \times \frac{m}{m}$

$M = \frac{e \times mvr}{2m}$

$M = \frac{eL}{2m}$ —— (1) where $L = mvr$, the angular momentum of e^-

$\frac{M}{L} = \frac{e}{2m}$

$\frac{M}{L} = 8.8 \times 10^{10}$ C/kg

Gyro magnetic ratio

but $L = \frac{nh}{2\pi}$

$\therefore$ (1) becomes

$$M = \frac{e \times nh}{2m \times 2\pi}$$

If $n = 1$ then

$$M = \frac{eh}{4m\pi}$$

$$= 9.27 \times 10^{-24} \text{ Am}^2$$

This is called the Bohr Magnetone.

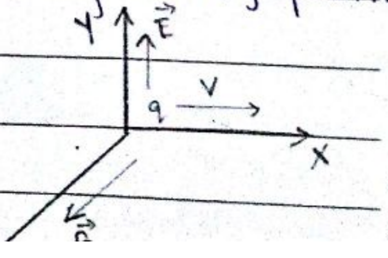
Velocity Selector

Consider an electric field of intensity E and magnetic field of intensity B, $\perp$r to each other let the electric field is directed along positive Y-axis and the magnetic field is directed along positive X-axis.

i.e, $\vec{E} = E\hat{j}$

$\vec{B} = B\hat{k}$

Consider a particle of charge q, moving along positiv X-direction with a ~~p~~ velocity v



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The electric force experienced by the charged particle.

$\vec{F}_E = qE\hat{j}$ directed along positive y-axis

Magnetic force experienced by the charged particle

$\vec{F}_B = q(V\hat{i} \times B\hat{k})$

$= -qVB\hat{j}$ $\quad (\because \hat{i} \times \hat{k} = -\hat{j})$ directed along -ve y-axis

The two forces are oppositely directed. If $F_E = F_B$, the net force is 0. that is the charge moves without any deviation.

$$qE = qVB$$

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

This result can be used to select charged particles moving with a particular velocity from a group of particles moving with diff. velocity. This is called velocity selector