Magnetic field of current.

Magnetic field:-

It is the region around which an influence of magnet can be experienced.

Magnetic field intensity:-

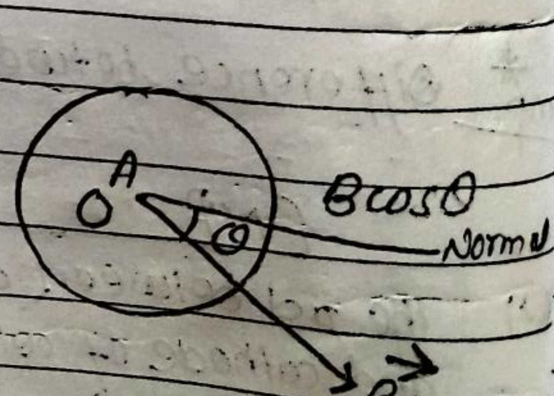
The magnetic field intensity at a point is defined as force experienced by the unit north pole at that point.

Magnetic flux (ϕ):-

Magnetic flux is defined as the total no of magnetic lines of force falling through the surface area. If B be the strength of magnetic field in which an area (A) such that the (ϕ) no of magnetic field ~~on which~~ lines of force falling through the surface area then magnetic flux is given by,

$\phi = BA$.

If normal to the surface makes an angle (θ) with the direction of magnetic field then effective component of magnetic field is $B\cos\theta$ then magnetic flux is given by,

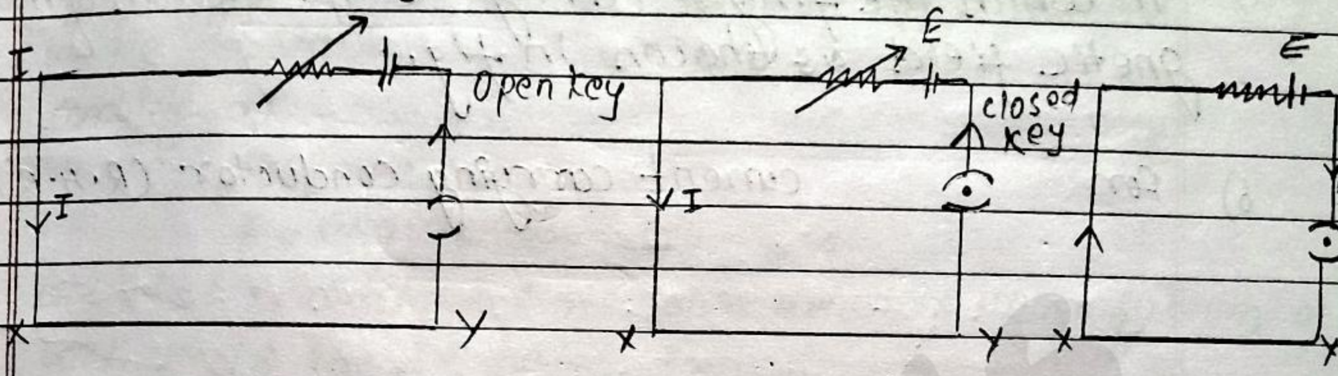


$\phi = BA\cos\theta$, It's unit is Tm^2 or weber (wb)

$1Tm^2 = 1wb$.

Oersted's experiment (Discovery)

The phenomenon of production of magnetic field around the conductor or by having current through it is called Oersted's experiment or discovery. This experiment is explained by the fig. given below:-



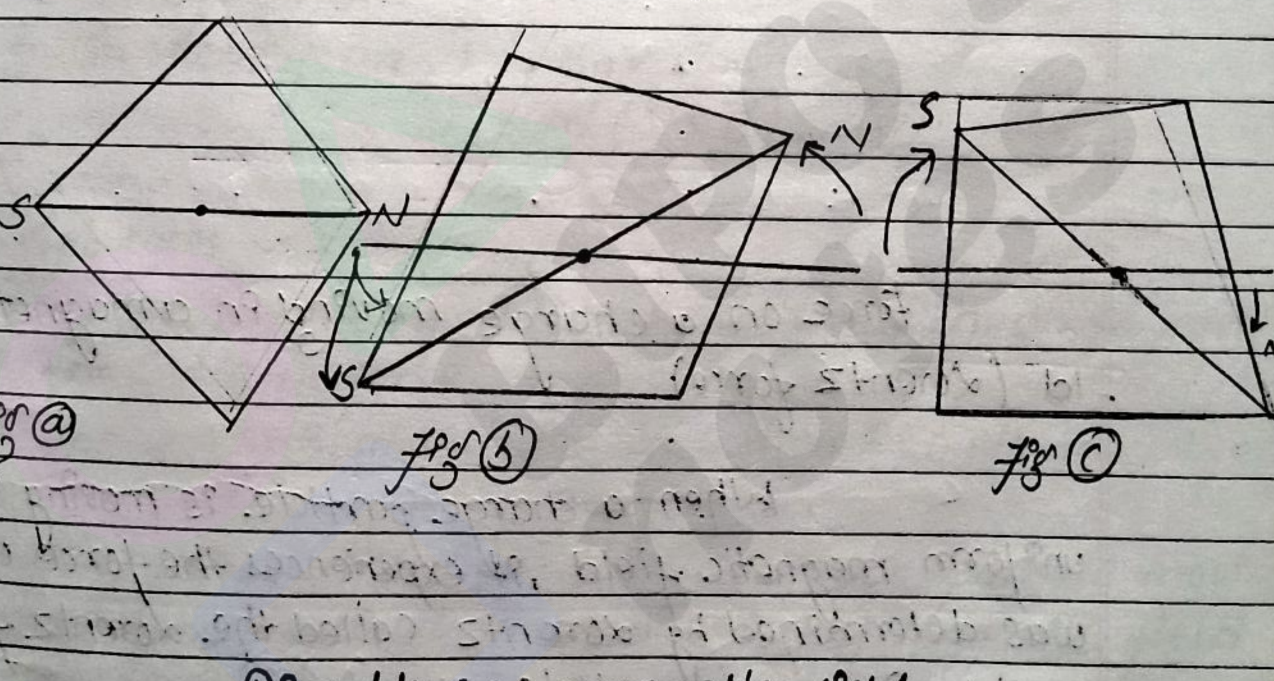
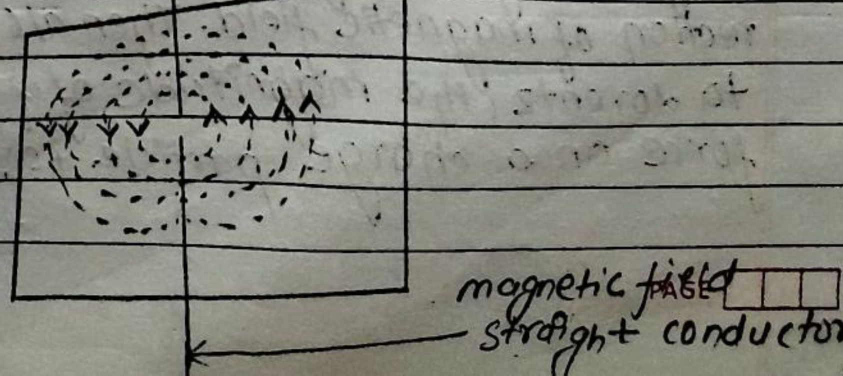


fig (a) fig (b) fig (c)

Direction of magnetic field.

a. For straight current carrying conductor (Right hand rule)



Unit & Dimensions of $\vec{B}$

we have,

$F = Bqv\sin\theta$.

If $F = 1N$, $q = 1C$, $v = 1ms^{-1}$ & $\theta = 90°$

then, $B = \frac{F}{qv\sin\theta} = \frac{1}{1 \times 1 \times 1} = 1$ Tesla.

Hence, unit of magnetic field strength is Tesla.

Dimension $= \frac{MLT^{-2}}{[AT][LT^{-1}]}$

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

Strength of magnetic field is said to be one Tesla if 1 coulomb of charge moving with velocity 1 m/s perpendicularly to the direction of magnetic field experience the force of 1N.

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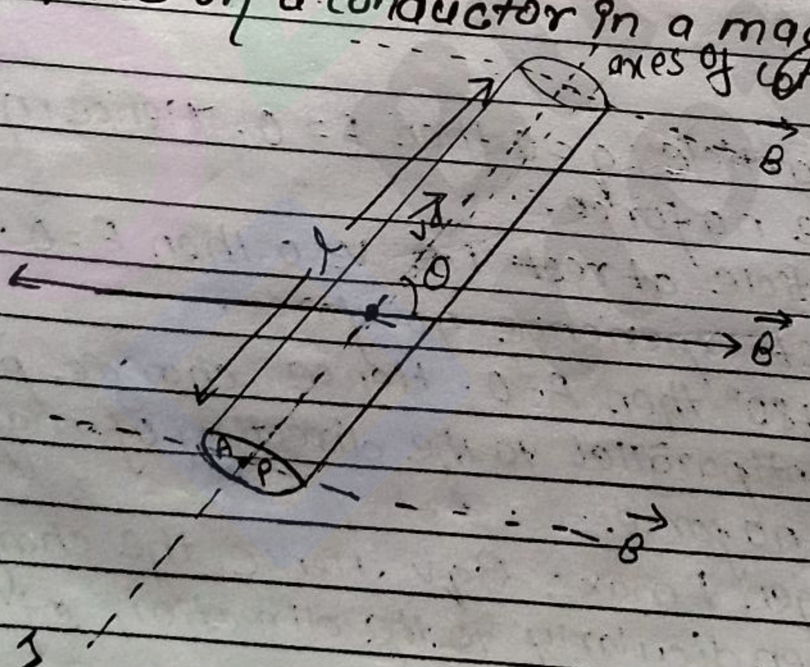
Force on a conductor in a magnetic field.



A conductor consist of large no of electrons & they are moving randomly in all direction in the absence of external field. when the external electric field

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is applied, the electrons move in the direction opposite to the direction of applied field with average velocity called drift velocity ($\vec{vd}$).

When the conductor is placed in a uniform magnetic field, each electron experiences the Lorentz force of the force experience by all the electrons present in the conductor equal to force experienced by the conductor.

Consider a conductor of length 'l', area 'A' carrying current 'I' having 'n' no of electron per unit volume. Let θ be the angle betn axis of conductor & direction of magnetic field & $\vec{vd}$ be the drift velocity of each electron. Then,

Magnetic force experienced by each electron is;

$$\vec{fe} = e(\vec{vd} \times \vec{B}) \ldots (i)$$

If 'n' be the no of electron per unit volume of a conductor then total no. of electron in the conductor is;

$$N = nV$$

But volume, $V = Al$

$$N = nAl - (ii)$$

Hence, total magnetic forced experienced by conductor is,

$$\vec{Fc} = N\vec{fe}$$

$$\Rightarrow \vec{Fc} = Alne\,(\vec{vd} \times \vec{B})$$

$$\Rightarrow \vec{Fc} = VdenA\,(lB\sin\theta\,\hat{n})$$

$$\Rightarrow \vec{Fc} = I(\vec{l} \times \vec{B}) \ldots (iii)$$

This gives the expression for force on a conductor in a magnetic field

In magnitude, $f = BIl\sin\theta$

(a) If $\theta = 90^0$

$f_{max} = BIl$

(b) If $\theta = 0^0$ or 180^0

$f_{min} = 0$.

Force & torque on a rectangular coil

consider a rectangular coil PQRS carrying current I, length 'l' and breadth 'b' placed in a uniform magnetic $\vec{B}$ such that the plane of coil makes an angle 'θ' with direction of magnetic field. Here the four arms of the coil act as conductor and hence various forces are acting on different arms which are given

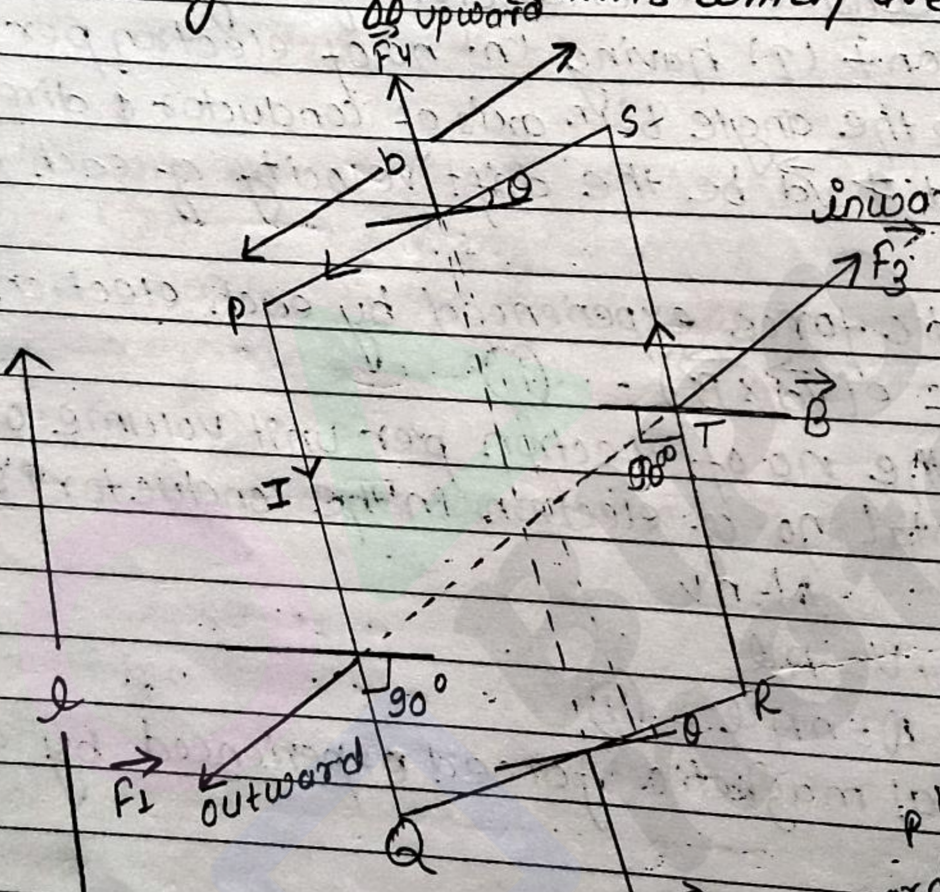


Fig (a)

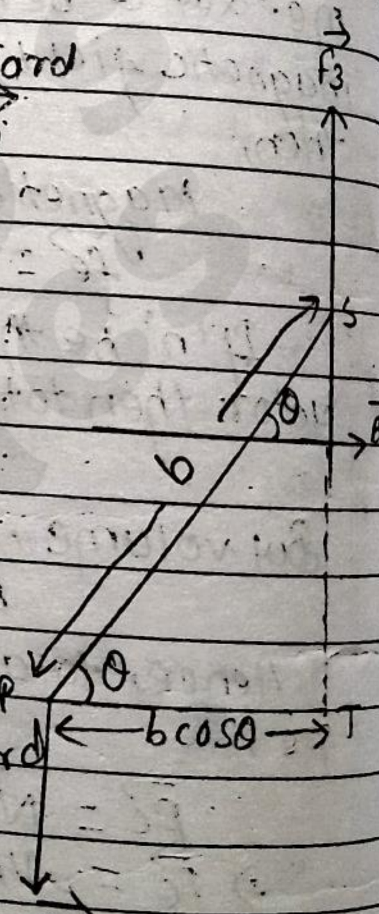


Fig (b)

1. Force on the arm $\vec{PQ}$

$\vec{F_1} = I(\vec{PQ} \times \vec{B})$. It is directed outward

In magnitude ; $F_1 = IlB\sin\theta$ but $\theta = 90^\circ$

$F_1 = IlB$ --- (i)

2. Force on the arm $\vec{QR}$

$\vec{F_2} = I(\vec{QR} \times \vec{B})$. It is directed downward.

$\vec{F_2} = IbB \sin\theta$ — (ii)

3. Force on the arm $\vec{RS}$

$\vec{F_3} = I(\vec{RS} \times \vec{B})$ It is directed inward.

$F_3 = IlB \sin 90^\circ = IlB$ -- (iii)

4. Force in the arm $\vec{SP}$

$\vec{F_4} = I(\vec{SP} \times \vec{B})$ It is directed upward.

$F_4 = IbB \sin\theta$.

Here, $\vec{F_2}$ & $\vec{F_4}$ are equal to each other & opposite & they lie on same line of action & hence cancelled with each other. so, $\vec{F_2}$ & $\vec{F_4}$ donot produce any torque on a coil. Similarly, $\vec{F_1}$ & $\vec{F_3}$ are also equal & opposite to each other but they donot cancel coz they lie on different line of action. so, $\vec{F_1}$ or $\vec{F_3}$ produce torque on a rectangular coil & which is given by,

Torque (τ) = product of magnitude of either force F_1 or F_3 & perpendicular distance betn them

Torque (τ) = $IlB \times b \cos\theta$

$= BI(lB)\cos\theta$

But area(A) = lb

$\therefore \Rightarrow \tau = BIA \cos\theta$ — (v)

If coil contains N no of turns then,

then, $\boxed{\tau_n = BINA \cos\theta}$ — (vi)

This gives required expression for the torque on the rectangular coil.

(a) If $\theta = 90^\circ$

$T_{min} = 0$

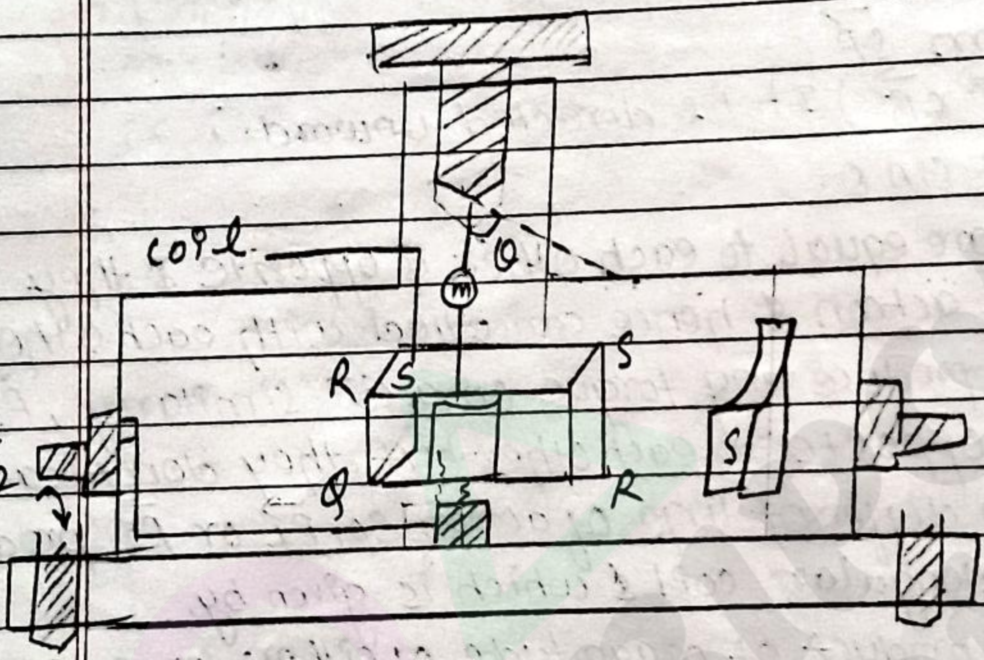
Hence, if the plane of coil is perpendicular to the direction of magnetic field then the coil experience no torque.

b. If $\theta = 0^\circ$

$T_{max} = BINA$

Hence, if the plane of coil is parallel to the direction of magnetic field, then the coil experience maximum torque.

Moving coil galvonometer.



Imp: Principle:-

Moving coil galvanometer operation is based on the principle that when a coil is placed in a uniform magnetic field, it experiences the torque.

Construction:

It consists of a rectangular coil having large no. of turns wound on a non metallic frame. The coil is suspended bet^n two poles of a permanent magnet which are cylindrical in shape. The coil is suspended by a phosphor bronze trip which acts as path for the current to the coil. The strip is finally connected to the terminal T_2 of the galvonometer : The other end of the coil is connected to a light spring which is finally connected to terminal T_2. The spring exerts a very small restoring couple on the coil. A piece of soft iron is placed within the frame of the coil. A plane circular mirror M is attached to the to note the deflection of the coil using lamp and scale management

working:-

when a ~~pre~~ current is passed through the coil, it experiences the torque under the influence of this deflecting torque, the coil begins to rotate. As the coil rotates, the phosphorus bronze wire gets twisted. As a result, the restoring torque is developed in the wire. The coil rotates until the restoring torque is balanced by the deflecting torque. It is found that restoring torque is directly proportional to the twisting angle (θ).

Theory:-

Let 'N' be the no. of turns of coil, 'I' be the current through the coil. 'A' be the area of coil & 'B' be the strength of magnetic field then deflecting torque is given by,

$$\tau_d = BINA \cos\theta'$$

But the concave pole of magnet provide uniform radial magnetic field & the plane of coil is parallel to the direction of magnetic is,

$$\theta' = 0$$

$$\tau_d = BINA \quad \text{--- (i)}$$

If θ be the twisting angle of the wire then ~~st~~ restoring torque is,

$$\tau_R \propto \theta$$

$$\tau_R = C\theta \quad \text{--- (ii)}$$ where C is proportionality constant called torsion constant & its value depends upon nature of material of coil.

Imp* Hall effect:

Edwin Hall found that when a current carrying conductor is placed in a uniform magnetic field in the direction perpendicular to the direction of current and an emf is developed across the width of the conductor which is perpendicular to both electric and magnetic field. This phenomenon of production of emf is called <u>Hall effect</u>, and the emf so produce is called <u>Hall voltage (V_H)</u>.

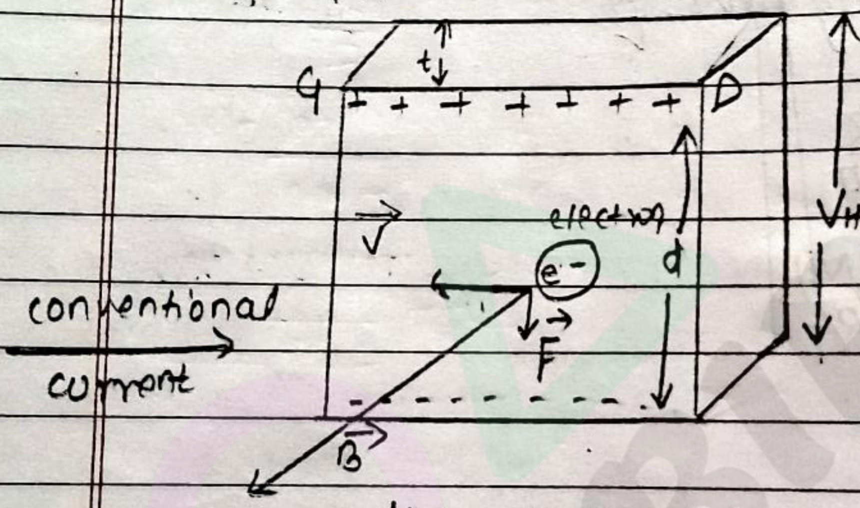


fig:- Hall effect.

To explain Hall effect consider a metal slab carrying current (I) in the direction AC. There is a drifting of current. Let the metal slab be placed in a uniform magnetic field of intencity (B). The magnetic force act on each electron from GD to AC. Due to these force, electrons move towards AC and get accumulated there. As a result, AC develop negative (lower potential). At the same time, GD develop equal but positive (higher potential). Between these two layer of charges, the emf is developed called the <u>hall voltage</u>.

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Due to this Hall voltage, electric field is setup between two layers of charges and hence each electron experience electric force. The movement of electron take place until the electric force is balanced by the magnetic force.

(A) Half voltage (V_H):-

Let 'd' be the width of the slab, 't' be the thickness of the slab, 'A' be the area of the slab, 'v' be the velocity of each electron, then electric field setup between two layer of charges is given by:

$$E = \frac{V_H}{d}$$

Then, electric force experienced by each electron is;

$$F_e = e \cdot E \quad \text{--- (i)}$$

Similarly, magnetic force experienced by each electron is;

$$F_m = Bev \quad \text{--- (ii)}$$

At equilibrium,

or $F_e = F_m$

$\Rightarrow e \cdot E = Bev$

$\Rightarrow E = BV$

$\Rightarrow \frac{V_H}{d} = BV$

$\Rightarrow \boxed{V_H = Bvd}$ --- (iii)

Also, drift current $(I) = venA$

$\Rightarrow v = \frac{I}{enA}$ --- (iv)

$\therefore \boxed{V_H = \frac{BId}{enA}}$ --- (v) [From (iv)]

Also, $A = td$

$$\Rightarrow V_H = \frac{BId}{entd}$$

$$\Rightarrow \boxed{V_H = \frac{BI}{net}} \leftarrow (vi)$$

This gives required experiences for Hall voltage

(B) Hall resistance (R).

$$R = \frac{V_H}{I}$$

$$\Rightarrow R = \frac{BI}{net \cdot I}$$

$$\Rightarrow \boxed{R = \frac{B}{net}} \leftarrow (vii)$$

(C) Hall coefficient (R_H).

We have,

$$V_H = \frac{BId}{enA}$$

$$\Rightarrow \frac{V_H}{d} = \left(\frac{1}{ne}\right)\left(\frac{I}{A}\right)B$$

$$\Rightarrow E = R_H J B \Rightarrow R_H = \frac{E}{JB} \Rightarrow \boxed{R_H = \frac{\rho_H}{B}}$$

$E = \frac{V_H}{d}$ = electric field.

$R_H = \frac{1}{ne}$ = Hall coefficent

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$J = \frac{I}{A}$ = current density

$$\therefore \boxed{R_H = \frac{1}{ne} = \frac{E}{JB} = \frac{\rho_H}{B}}$$ where; $\rho_H = \frac{E}{J}$ = Hall resistivity

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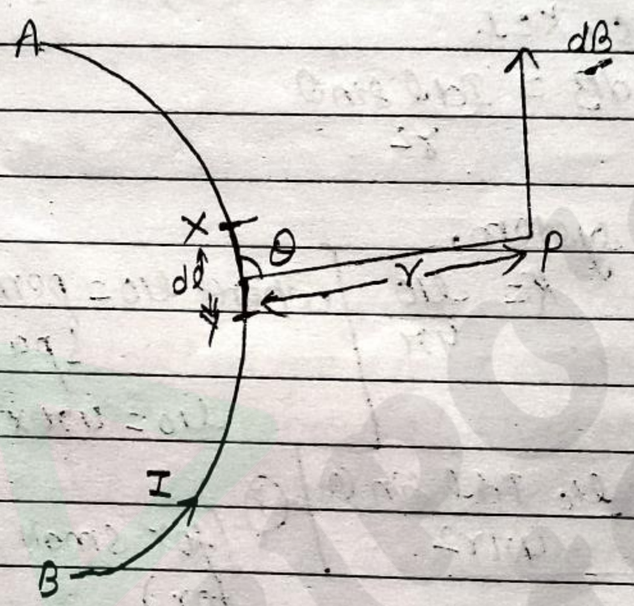
* Biot & Savart's Law :-



Biot and savart's law gives the quantitative measurement of magnetic field due to current carrying conductor. Consider a current carrying conductor AB carrying current 'I'. Let 'p' be any point at distance 'r' from conductor where magnetic field is to be determined.

To determined the magnetic field, consider a small segment of the conductor having length 'dl' carrying same current 'I' at the same ~~dire~~ distance 'r' from point 'p'. Let 'θ' be the angle between 'dl' & 'r'.

Then, according to Biot and savart's law;

(i) $dB \propto I$.

(ii) $dB \propto dl$.

(iii) $dB \propto \sin\theta$.

(iv) $dB \propto \frac{1}{r^2}$

P.T.O.

Combining all,

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

$$dB = \frac{k I dl \sin\theta}{r^2}$$ [where 'k' is porportionality constant and its value depends upon system of unit used.]

In CGS, $k = 1$.

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

In SI system,

$$k = \frac{\mu_0}{4\pi}$$ [where μ_0 = permeability of free space. $\mu_0 = 4\pi \times 10^{-7}$]

$$\Rightarrow \boxed{dB = \frac{\mu_0 I dl \sin\theta}{4\pi r^2}} \quad \text{(i)}$$ (for small segment of conductor)

Now,

Total magnetic field due to whole conductor can be obtained by integrating eqn (i) with appropriate limit as;

$$B = \int dB$$

$$\Rightarrow \boxed{B = \frac{\mu_0}{4\pi} \int \frac{I dl \sin\theta}{r^2}} \quad \text{— (ii)}$$

In vector form,

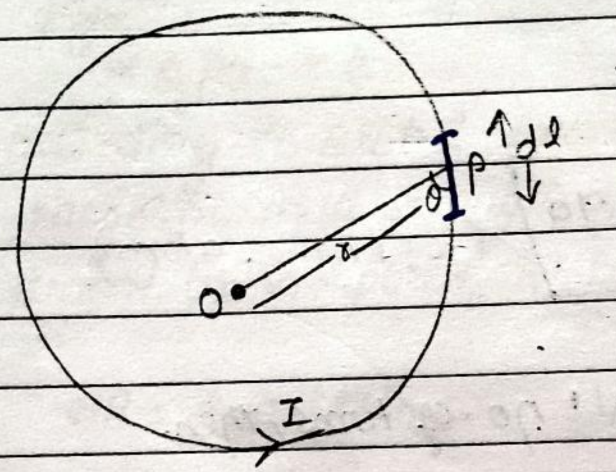
$$B = \frac{\mu_0}{4\pi} \frac{I dl \sin\theta}{r^2}$$

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

$$\Rightarrow \boxed{\vec{B} = \frac{\mu_0}{4\pi} I \left(\frac{\vec{dl} \times \vec{r}}{r^3} \right)} \quad \text{— (iii)}$$

Applications of Biot & Savart's law:-

(a) Magnetic field at the centre of circular coil



Consider a circular coil carrying current (I) having centre 'O' and radius (r'. Let 'dl' be the small segment of the circular coil at point 'P' at the distance 'r' from centre carrying same current 'I'. Since, 'dl' is small, so angle between 'dl' & 'r' is 90°. Then, according to Biot and Savart's law;

Magnetic field strength at the centre due to small current carrying element 'dl' is;

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

Here, angle between $\vec{dl}$ and $\vec{r}$ is 90°

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

Then, Magnetic field due to whole circular coil can be obtained by integrating eqn (ii) from limit 0 to $2\pi r$ (circumference : $2\pi r$)

$$\therefore B = \int_0^{2\pi r} dB$$

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

$$= \frac{\mu_0 I}{4\pi r^2}\left[l\right]_0^{2\pi r}$$

$$= \frac{\mu_0 I}{4\pi r^2}\left[2\pi r - 0\right]$$

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

$$\therefore \boxed{B = \frac{\mu_0 I}{2r} \text{ Tesla}}$$ (for 1 no. of atom)

If coil contains 'N' no. of turns, then.

$$\boxed{B_N = \frac{\mu_0 N I}{2r} \text{ Tesla}}$$

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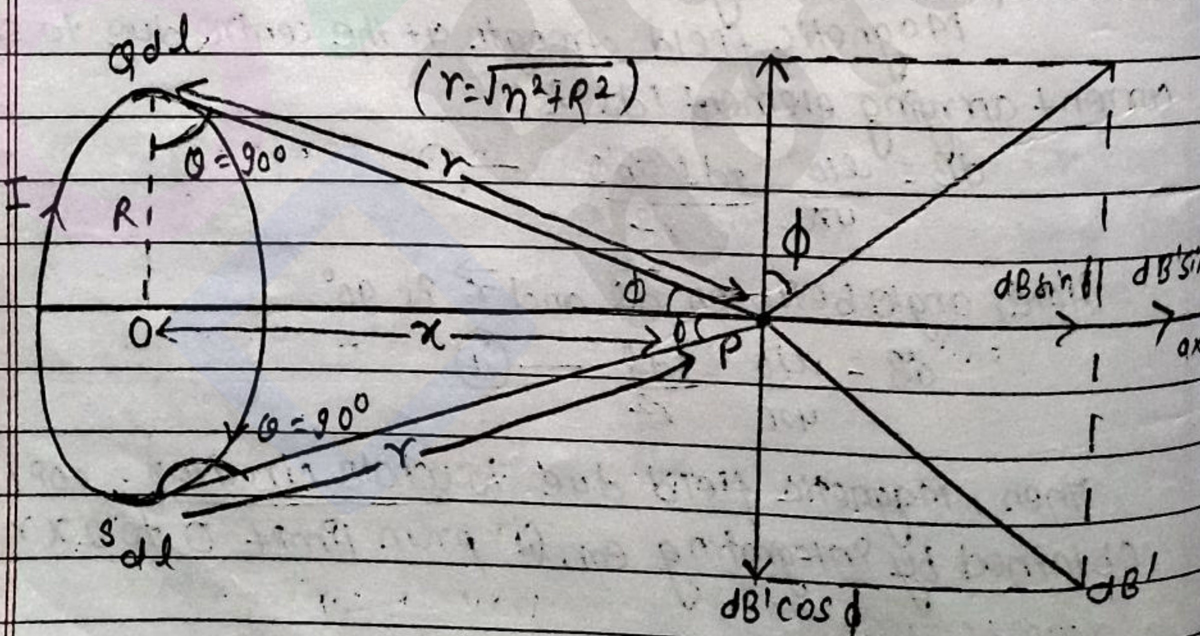
(b) Magnetic field on the axis of circular coil :-



Consider a circular coil of radius 'R' carrying current 'I'. Let 'P' be any point at distance 'x' from centre of circular coil where magnetic field strength is to be determined. To calculate the magnetic field st ength; consider a small segment 'dl' of the coil at the distance 'r' from point 'p' such that angle between 'dl' and 'r' is 90°.

From figure,

$$\angle QPO = \angle \phi$$

Then, according to Biot & Savart's law;

Magnetic field strength due to small segment 'dl' carrying current 'I' at point 'Q' is;

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

But $\theta = 90^\circ$, $\therefore dB = \dfrac{\mu_0 I dl}{4\pi r^2}$ — (i)

Similarly, let us consider another identical segment at points carrying same current 'I' & at the same distance. Then, magnetic field strength due to such segment is given by,

$$dB' = \frac{\mu_0 I dl}{4\pi r^2} \text{ — (ii)}$$

Here, dB is resolved into 2 components, one is $dB\cos\phi$ vertically upward and another is $dB\sin\phi$ along the axis of the coil.

Similarly dB' is also resolved into 2 components, one is $dB'\cos\phi$ vertically downward and another is $dB'\sin\phi$ along the axis of the coil. Here, $dB\cos\phi$ and $dB'\cos\phi$ are equal and opposite to each other and hence cancelled with each other. But $dB\sin\phi$ and $dB'\sin\phi$ are added along the axis of coil.

So, total magnetic field due to whole circular coil along the axis of coil can be obtained by integrating $dB\sin\phi$ from limit 0 to $2\pi R$ as;

$$B = \int_0^{2\pi R} dB \sin\phi$$

$$\Rightarrow B = \int_0^{2\pi R} \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2} \sin\phi$$

$$\Rightarrow B = \cancel{\int_0^{2\pi R}} \frac{\mu_0 I}{4\pi r^2} \sin\phi \int_0^{2\pi R} dl. \quad \left[\because \sin\phi = \frac{R}{r} = \frac{R}{\sqrt{x^2+R^2}}\right]$$

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

$$\Rightarrow B = \frac{\mu_0 IR}{4\pi r^3} [l]_0^{2\pi R} \quad \left[\begin{array}{l} r^2 = x^2 + R^2 \\ r = (x^2+R^2)^{1/2} \\ r^3 = (x^2+R^2)^{3/2} \end{array}\right]$$

$$\Rightarrow B = \frac{\mu_0 IR}{4\pi (x^2+R^2)^{3/2}} [2\pi R - 0]$$

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

$$\Rightarrow \boxed{B = \frac{\mu_0 IR^2}{2(x^2+R^2)^{3/2}} \text{ Tesla}} \quad \text{(iii)}$$

(for 1 no of turn)

If coil contains 'N' no of turns, then

$$\boxed{B_N = \frac{\mu_0 NIR^2}{2(x^2+R^2)^{3/2}} \text{ Tesla}} \quad \text{(iv)}$$

* Special cases:-

(1) If $x=0$, i.e at the centre of coil, then

$$B_N = \frac{\mu_0 N I R^2}{2R^3}$$

$$\Rightarrow \boxed{B_N = \frac{\mu_0 N I}{2R} \text{ Tesla}}$$

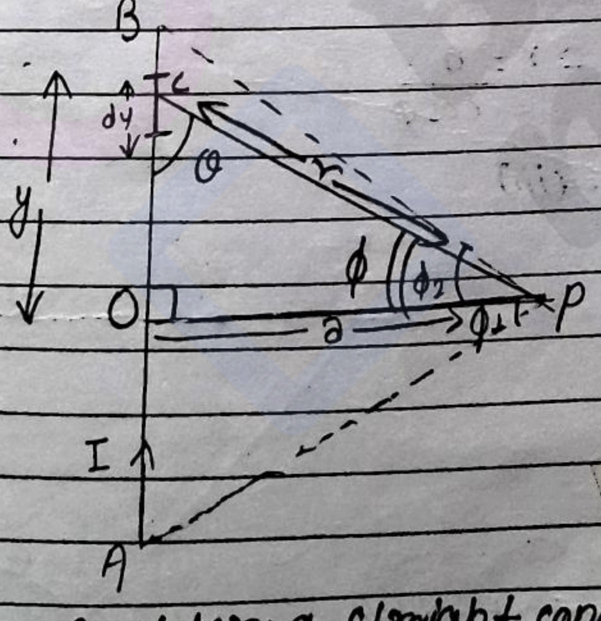
(2) If $x >>> R$. so, R can be neglected in comparing to x,

$$\boxed{B_N = \frac{\mu_0 N I R^2}{2x^2}} \text{ Tesla}$$

$$\therefore B_N \propto \frac{1}{x^3}$$

Hence, magnetic field strength is inversely proportional to cube of distance of point from centre of coil if $x >>> R$.

(C)



Consider a straight conductor AB carrying current 'I'. Let P be any point at the distance 'a' from point O. To calculate the magnetic field strength at point P, consider

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

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

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

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

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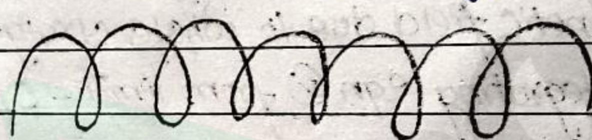
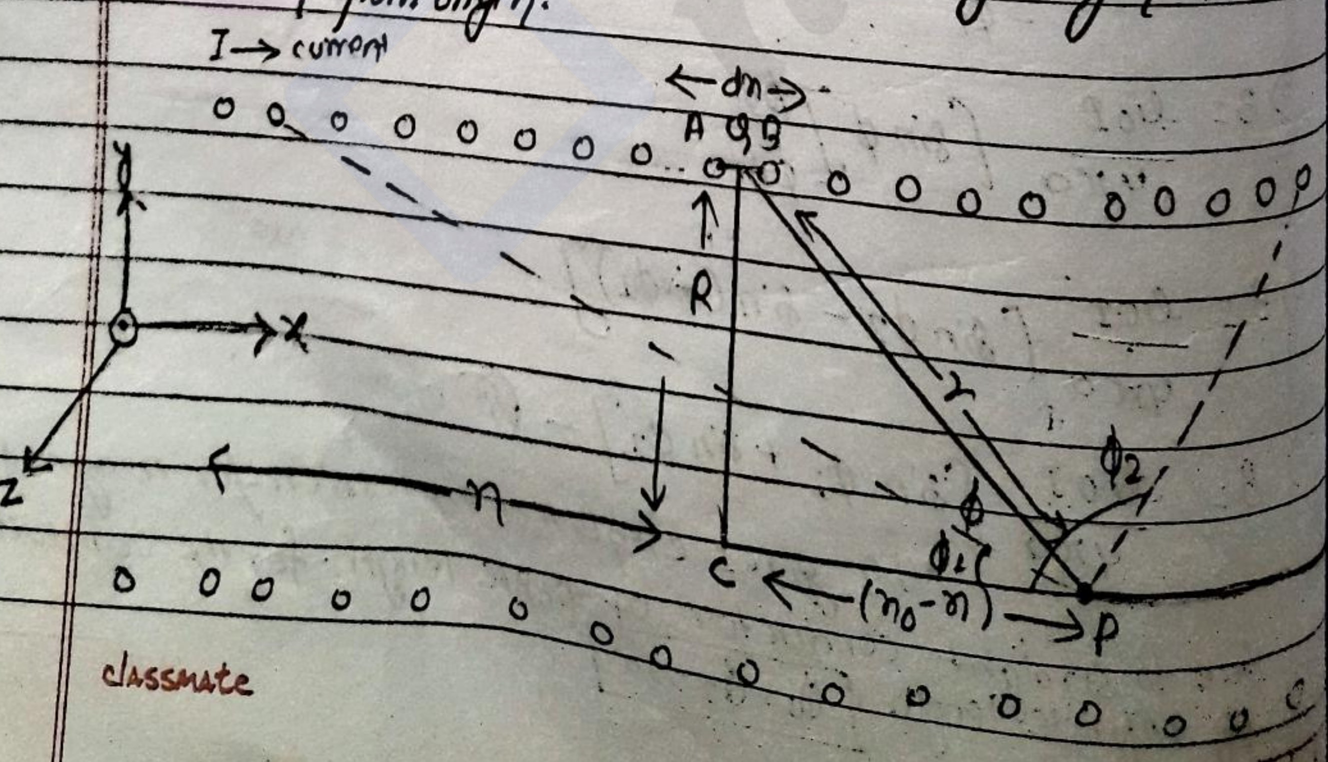
Magnetic field due to the long solenoid.



Solenoid is a long cylindrical consists a large number of circular turns in very compact form.

Consider a solenoid of radius 'R' having 'n' numbers of turns per unit length carrying current 'I'. Consider a small segment of coil AB having length 'dx' at distance 'x' from origin.



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Here each circle (o) represents the no. of turns in the solenoid. Let 'p' be any point on the axis of solenoid at the distance (x_0) from origin and ($x_0 - x$) from point 'C' where magnitude field strength is to be determined

In fig; $QC \perp^r CP$

$\angle QPC = \angle \phi$

Also, $PQ = r$, $QC = R$.

Here

total no. of turns in the section AB is;

$$\boxed{N = n\,dx} \text{ — (i) } \left(\because n = \frac{N}{dx}\right)$$

Then, magnetic field strength at point P due to 'N' no of circular turns (coil) is;

$$dB = \frac{\mu_0 I R^2 N}{2(x^2+R^2)^{3/2}} \text{ Tesla}$$

$$\Rightarrow dB = \frac{\mu_0 I R^2 n\,dx}{2r^3} \text{ — (ii) where, } \left(\begin{array}{l} r^2 = x^2+R^2 \\ r = (x^2+R^2)^{1/2} \\ \therefore r^3 = (x^2+R^2)^{3/2} \end{array}\right)$$

In ΔQCP,

$$\tan\phi = \frac{AC}{CP} = \frac{R}{(x_0 - x)}$$

$$\Rightarrow (x_0 - x) = R/\tan\phi.$$

$$\Rightarrow (x_0 - x) = R\cot\phi.$$

$$\Rightarrow \frac{d}{d\phi}(x_0 - x) = R\frac{d\cot\phi}{d\phi}.$$

$$\Rightarrow \cancel{-}\frac{dx}{d\phi} = \cancel{-}R(\operatorname{cosec}^2\phi)$$

$$\Rightarrow dx = R\operatorname{cosec}^2\phi\, d\phi \text{ — (iii)}$$

Also,

$$\sin\phi = \frac{QC}{QP} = \frac{R}{r}$$

$\Rightarrow r = R/\sin\phi$

$\Rightarrow r = R\,\mathrm{cosec}\,\phi$ — (iv)

from eqn (ii), (iii) & (iv)

$$dB = \frac{\mu_0 I R^2 n \times R\,\mathrm{cosec}^2\phi\, d\phi}{2R^3\,\mathrm{cosec}^3\phi}$$

$$\Rightarrow \boxed{dB = \frac{\mu_0 I n}{2}\sin\phi\, d\phi} \text{ — (v)}$$

Then, total magnetic field due to whole solenoid can be obtained by integrating eqn (v) from limit ϕ_1 to ϕ_2 as:-

$$B = \int_{\phi_1}^{\phi_2} dB = \frac{\mu_0 I n}{2}\int_{\phi_1}^{\phi_2} \sin\phi\, d\phi$$

$$\Rightarrow B = \frac{\mu_0 I n}{2}\left[-\cos\phi\right]_{\phi_1}^{\phi_2}$$

$$\Rightarrow B = -\frac{\mu_0 I n}{2}\left[\cos\phi_2 - \cos\phi_1\right]$$

$$\Rightarrow \boxed{B = \frac{\mu_0 I n}{2}\left[\cos\phi_1 - \cos\phi_2\right]} \text{ — (vi)}$$

This gives required expression for a solenoid of finite length.

For the solenoid of infinite length $\phi_1 = 0°$ & $\phi_2 = 180°$

$$B = \frac{\mu_0 I n}{2}\left[\cos 0° - \cos 180°\right]$$

$$\Rightarrow B = \frac{\mu_0 I n}{2}\left[1 - (-1)\right]$$

$\Rightarrow B = \frac{\mu_0 I n}{2} \times 2$

$\Rightarrow B = \mu_0 I n$ Tesla — (vii).

This gives the required expression for magnetic field strength due to solenoid of infinite length.

For the solenoid of infinite length, $\boxed{\phi_1 = 0^\circ \text{ \& } \phi_2 = 180^\circ}$

$B = \frac{\mu_0 I n}{2}\left[\cos 0^\circ - \cos 180^\circ\right]$

$\Rightarrow B = \frac{\mu_0 I n}{2}\left[1 - (-1)\right]$

$\Rightarrow B = \frac{\mu_0 I n}{2} \times 2.$

$\Rightarrow \boxed{B = \mu_0 I n \text{ Tesla}}$ — (vii)

This gives the required expression for magnetic field strength due to solenoid of infi

Magnetic field due to toroid:-

Toroid is an endless solenoid which is bent into circular form. Consider a toroid of radius 'r', centre 'O' carrying current 'I'. Let 'N' be the no. of turns of toroid and 'n' be the no. of turns per unit length of the toroid.

Then, we know

Magnetic field due to solenoid of infinite length.

$B = \mu_0 n I$

For toroid:

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

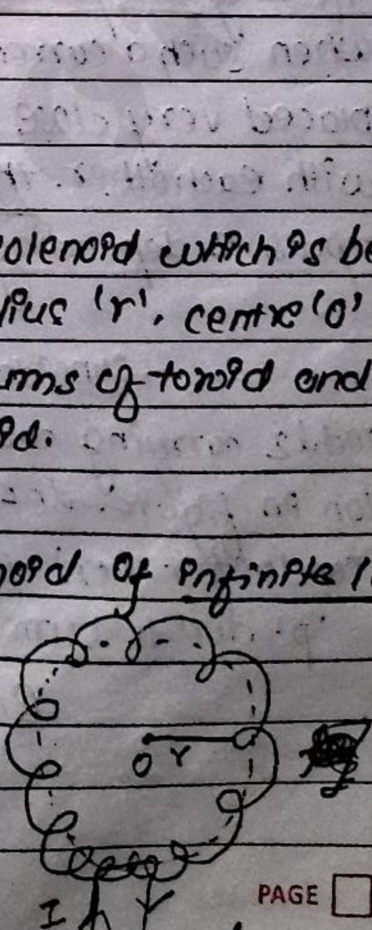
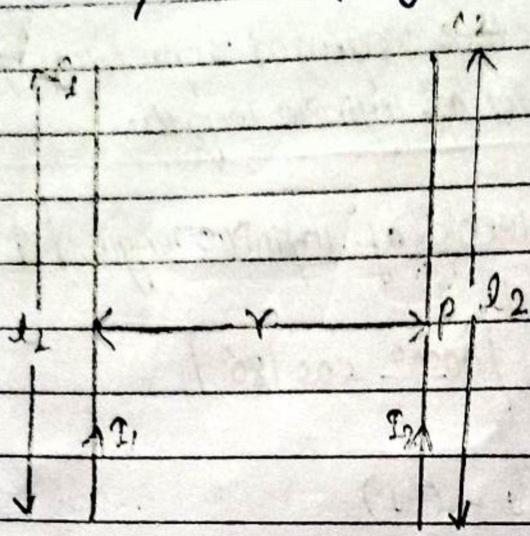


fig:- Toroid

$\therefore \boxed{B = \frac{\mu_0 N I}{2\pi r} \text{ Tesla}}$

* force between two parallel current carrying conductor

(a) when like current passes through conductor



When a current passes through conductor then magnetic field is setup around it. Similarly, when a current carrying conductor is placed in a magnetic field, it experiences the force. Hence, when two conductors carrying current are placed closed to eachother then one conductor is placed in the magnetic field, i.e produced by another conductors. Hence, when such a current carrying parallel conductor's are placed very close to eachother ~~they~~ then they exert force with eachother. The nature of force will be attractive or repulsive depending upon direction of current.

Consider two conductor c_1 & c_2 having length l_1 and l_2 carrying current I_1 & I_2 in the same direction as shown in figure. Let 'p' be any point at the distance 'r' from conductor 'c_1' then magnetic field strength at point 'p' due to current carrying conductor c_1 is;

$$B_1 = \frac{\mu_0 I}{2\pi r} \quad \text{--- (i)} \quad [\text{infinite}]$$

At point 'P', another conductor C_2 having length 'l_2' carrying current 'I_2' is placed. So, it experiences the magnetic force. The maximum value of magnetic force experienced by conductor 'C_2' when placed in a uniform magnetic field produced by conductor C_1 is;

$$F_2 = B_1 I_2 l_2 \quad \text{—(ii)}$$

from eqn (i) & (ii)

$$\boxed{F_2 = \frac{\mu_0 I_1 I_2 l_2}{2\pi r}} \quad \text{—(iii)}$$

Then, force per unit length of the conductor is given by,

$$f_2 = \frac{F_2}{l_2}$$

$$\Rightarrow \boxed{f_2 = \frac{\mu_0 I_1 I_2}{2\pi r}} \quad \text{—(iv)}$$

Similarly, magnetic field produced by C_2 at the same distance is given by,

$$B_2 = \frac{\mu_0 I_2}{2\pi r} \quad \text{—(v)}$$

In this magnetic field, the conductor C_1 is placed & hence the conductor C_1 experience the magnetic force. The maximum value of magnetic force experienced by conductor C_1 when placed in magnetic field produced by 'C_2' is given by,

$$F_1 = B_2 I_1 l_1$$

$$\therefore \boxed{F_1 = \frac{\mu_0 I_1 I_2 l_1}{2\pi r}} \quad \text{—(vi)}$$

Then, force experienced per unit length of the conductor 'C_1' is given by

$$f_1 = \frac{f_2}{l_1}$$

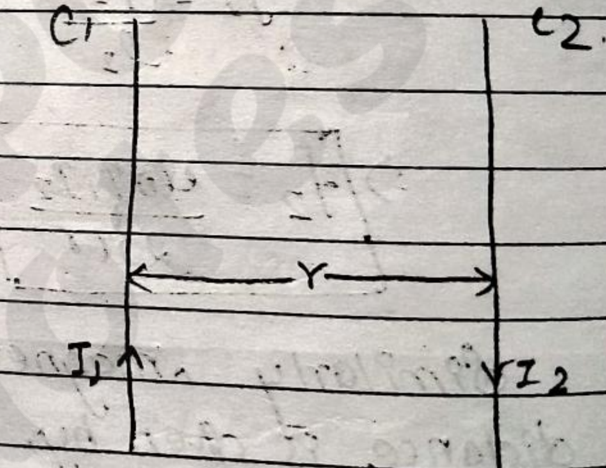
$$\boxed{f_1 = \frac{\mu_0 I_1 I_2}{2\pi r}} \quad \text{—(vii)}$$

Hence, $F_1 = F_2$

In general, $\boxed{F = \frac{\mu_0 I_1 I_2}{2\pi r}}$ —(viii)

(b) when two unlike current passes through two parallel conductors.

Then,



$f_1 = f_2$

In magnitude

$|f_1| = |f_2|$

i.e $f_1 = f_2 = \frac{\mu_0 I_1 I_2}{2\pi r}$

One Ampere current (S.Q)

we know,

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

If $I_1 = I_2 = 1A$

$r = 1m$

Then. $f = \frac{4\pi \times 10^{-7} \times 1 \times 1}{2\pi \times 1}$

$\therefore \boxed{f = 2 \times 10^{-7} N}$

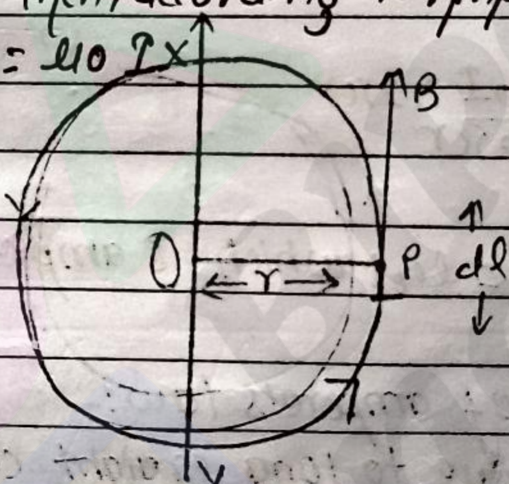
Hence, One Ampere current is the current which when pass es through the two parallel conductors separated by unit distance experience the force of ~~2×10^-7N~~ 2×10^{-7} N

Ampere's law:-
Statement:

It state that line integral of the magnetic field $\vec{B}$ around any closed path in vaccum is equal to μ_0 times the total current enclosed by that close path.

Let 'I' be the total current enclosed by the given closed path and μ_0 be the permiability of the freespace then the line integral of magnetic field around the closed path is denoted by $\oint \vec{B}\cdot\vec{dl}$. Then, according to Ampere law,

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



To prove Ampere's law. consider a infinitely long straight conductor carrying current 'I'. Let P be any point at the distance 'r' from the conductor and from point P, we draw a circle of radius 'r' and centre O such that this circle forms a close path & enclose the current flowing in the current

Let dl be the small segment of the closed path and the direction of magnetic field at any point on the closed path can be obtained by drawing tangent at any point on the circular path.

Then magnetic field strength at point P due to infinitely long straight conductor is given by,

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

Also, line integral of magnetic field $\vec{B}$ over the closed path is,

$$\oint \vec{B}\,\vec{dl} = \int_0^{2\pi r} B\,dl\cos\theta$$ but angle betn $\vec{B}$ and $\vec{dl}$ is zero.

$$\Rightarrow \oint \vec{B}\,\vec{dl} = B\int_0^{2\pi r} dl = B \times [dl]_0^{2\pi r} = B(2\pi r - 0)$$

$$\Rightarrow \oint \vec{B} \times \vec{dl} = B \times 2\pi r$$

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

$\therefore \oint \vec{B}\,\vec{dl} = \mu_0 I$ which is ampere's law.

Application of ampere's law:-

1. magnetic field due to long straight current carrying conductor.

Consider, a infinitely long straight conductor carrying current 'I'. Let 'P' be any point at the distance 'r' from the conductor and from point P, we draw a circle of radius 'r' & centre O such that this circle forms a closed path and enclosed the current flowing in the conductor. Let dl be the small segment of the closed path & the direction of magnetic field at any point on the closed path can be obtained by drawing tangent at any point on the circular path.

Then, line integral of magnetic field $\vec{B}$ over the closed path is,

$$\oint \vec{B}\,\vec{dl} = \int_0^{2\pi r} B\,dl\cos\theta$$ but angle betn $\vec{B}$ & $\vec{dl}$ is zero i.e $\theta = 0°$

$$\Rightarrow \oint \vec{B}\,\vec{dl} = B\int_0^{2\pi r} dl = B\times[dl]_0^{2\pi r} = B(2\pi r - 0)$$

$$\Rightarrow \oint \vec{B}\,\vec{dl} = B\times 2\pi r \text{ --- i}$$

Acc to ampere law

$$\oint \vec{B}\,\vec{dl} = \mu_0 I \text{ --- ii}$$

From eqn i and ii

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

$$\boxed{\Rightarrow B = \frac{\mu_0 I}{2\pi r}} \text{ --- iii}$$

DATE

(1) A positive charge of 1.5 MC is moving with speed of 2×10^{6} m/s along the positive x-axis. A magnetic field $\vec{B} = (0.2\hat{j} + 0.4\vec{k})$ T act in the space. find magnetic force, acting on a charge.

⇒ Given,

charge (q) = 1.5 MC.

velocity (v) = 2×10^{6} m/s.

magnetic field $(\vec{B}) = 0.2\vec{j} + 0.4\vec{k}$

magnetic force (F) = ?

we know,

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

$$= 1.5\times10^{-6}\left[2\times10^{6}\,i\times(0.2\vec{j} + 0.4\vec{k})\right)$$

$$= 1.5\times10^{-6}\left[2\times10^{6}\times0.2\hat{k} - 2\times10^{6}\times0.4\vec{j}\right)$$

$$= 0.6\hat{k} - 1.2\hat{j}\ \text{N}\ \text{T}.$$

(2) Copper has 8×10^{28} electron per cubic meter & cm^3. A copper wire of length 1 meter and cross sectional area $8\times10^{-6}m^2$ carrying a current and lying at right angle to the magnetic field of strength 5×10^{-3} Tesla. Experience a force of 8×10^{-2} N. calculate the drift velocity of electron in the wire.

⇒ Given,

Number of electron (n) = 8×10^{28} elc/cm^3

length (l) = 1 m

cross section Area(A) = $8\times10^{-6}\,m^2$.

$\theta = 90°$

magnetic field (B) = 5×10^{-3}

force (f) = 8×10^{-2} N.

We know,

$$f = BIl\sin\theta.$$

$$\text{or, } F = B\,V_d\,e\,n\,A\,l\,\sin 90°$$

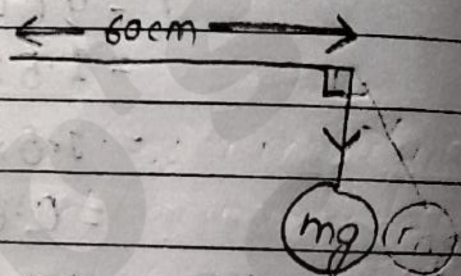
$$V_d = \frac{F}{BenAl}$$

$$= \frac{8\times10^{-2}}{5\times10^{-3}\times1.6\times10^{-19}\times8\times10^{28}\times8\times10^{-6}\times1}$$

$= 1.56\times10^{2}\times10^{-6}$

$= 1.56\times10^{-4}$.

(3) A 60 cm long wire of mass 10 gm is suspended horizontal in magnetic field of flux density 0.4 Tesla through two spring at its two end. calculate the current required to pass the wire so that there is no tension in the spring.



Given

length(l) = 60 cm = $\frac{60}{100}$ = 0.6

mass(m) = 10 gm = 10×10^{-3} kg

magnetic field (B) = 0.4 tesla.

current(I) = ?

we know

$F = mg$ ... (i)

$F = BIl\sin\theta$ — (ii)

or, $I = \frac{mg}{Bl\sin 90}$

$= \frac{10\times10^{-3}\times10}{0.4\times0.6\times1}$

$= 0.42$ A.

(4) A horizontal straight wire of mass per unit length 1.2 gm/m and length 10 cm is placed perpendicular to a uniform horizontal magnetic field of flux density 0.6 T. If the resistance per unit length of the wire 3.8 Ωm⁻¹. Calculate the p.d that has to be applied between two ends of the wire to make just self

Given,

Mass per unit length $(m/l) = 1.2\ gm/m = 1.2\times10^{-3}\ kg/m$.

length $(l) = 10\ cm = 10\times10^{-2}\ m$.

$\theta = 90^\circ$

Magnetic field $(B) = 0.6$ Tesla.

Resistance $\left(\frac{R}{l}\right) = 3.8\ \Omega m^{-1}$.

According to question.

$BIl \sin\theta = mg$.

or, $I = \frac{mg}{B\cdot l}$

or, $\frac{V}{R} = \frac{mg}{Bl}$ $\quad [V = IR]$

or, $V = \frac{mgR}{Bl}$

or, $V = ($

$= \frac{1.2\times10^{-3}\times3.8\times10\times10\times10^{-2}}{0.6}$

$= 7.6\times10^{-3}\ m/s$.

(5) A rectangular coil of sides 8 cm and 6 cm having 2000 turn sound carrying current of 200 mA is placed in a uniform of magnetic field of 0.2 T. calculate the maximum and minimum to torque in the coil.

⇒ Soln

Given

length$(l) = 8\ cm$

Breadth $(b) = 6\ cm$.

Area$(A) = l\times b = 8\times6 = 48\ cm^2 = 48\times10^{-4}\ m^2$

current$(I) = 200\ mA$.

magnetic field (B) = 0.2 T

we know

$\tau = BINA \cos\theta$.

For, τ_{max} $\theta = 0°$

$$\tau_{max} = BINA \cos 0°$$
$$= 0.2 \times 200 \times 10^{-3} \times 2000 \times 48 \times 10^{-4}.$$
$$= 0.384 \text{ Nm}.$$

For τ_{min}, $\theta = 90°$

$$\tau_{min} = BINA \cos 90°$$
$$= 0 \text{ Nm}$$

(6) A current of 200 mA deflects the coil of a moving coil galvanometer through 30°. What should be current to cause the rotation through $\pi/10$ radian? What is current sensitivity?

⇒ Soln>

current (I_1) = 200 mA

$$\theta_1 = 30° = 30 \times \frac{\pi}{180} = \frac{\pi}{6} \text{ radian.}$$

current (I_2) = ?

$$\theta_2 = \pi/10 \text{ radian}$$

we know,

$$BINA = C\theta$$

when, $I \propto \theta$

$$I_1 \propto \theta_1$$
$$I_2 \propto \theta_2$$
$$\therefore \frac{I_2}{I_1} = \frac{\theta_2}{\theta_1}$$

or, $I_2 = \frac{\theta_2}{\theta_1} \times I_1 = \frac{\pi}{10} \times \frac{6}{\pi} \times 60 = 120 \text{ mA}.$

Again,

$$S_I = \frac{\theta_1}{I_1} \text{ or, } \frac{I_2}{\theta_2}$$

$$= \frac{30}{200} = 0.15 \text{ degree } \mu A .$$

7) A galvanometer needs 50 mv for a full scale deflection of 50 division. find its voltage sensitivity. What must be its resistance if it current sensitivity is 1 div /μA.

= Given,

volt (v) = 50 mv = 50×10^{-3} V

1 division = 1°

Then, 50 division = 50°.

Current sensitivity (S_I) = 1 division / μA

$$= \frac{1}{10^{-6}} \text{ div/A.}$$

Now,

$$S_V = \frac{\theta}{V} = \frac{50}{50 \times 10^{-3}} = 10^3 \text{ degree / V.}$$

Again,

$$\frac{S_I}{S_V} = R$$

$$\text{or, } R = \frac{10^6}{10^3}$$

$$\therefore R = 100\ \Omega.$$

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8) The coil of moving coil galvanometer has 50 turns and its resistance is 10 Ω. It is replaced by a coil having 100 turns and resistance 50 Ω. find the factor by which the current and voltage sensitivities change?

$N_1 = 50$ turns $\quad N_2 = 100$ turn

$R_1 = 10\,\Omega \quad R_2 = 50\,\Omega$.

Now,

current sensitivity of first coil is;

$$(S_I)\text{ initial} = \left(\frac{\theta_1}{I_1}\right) = \frac{BN_1A}{C} \quad \text{--- (i)}$$

Also,

$$(S_I)\text{ final} = \frac{\theta_2}{I_2} = \frac{BN_2A}{C} \quad \text{--- (ii)}$$

Dividing (ii) by (i)

$$\frac{(S_I)\text{ final}}{(S_I)\text{ initial}} = \frac{\frac{BN_2A}{C}}{\frac{BN_1A}{C}} = \frac{100}{50} = 2.$$

Similarly,

$$\frac{(S_V)\text{ final}}{(S_V)\text{ initial}} = \frac{\frac{\cancel{BN_2A}}{\cancel{C}R_2}}{\frac{\cancel{BN_1A}}{\cancel{C}R_1}} \quad \cancel{= \frac{100}{50} = 2}.$$

$$= \frac{N_2}{N_1} \times \frac{R_1}{R_2}$$

$$= \frac{100}{50} \times \frac{10}{50} = \frac{2}{5}$$

$\therefore$ The current sensitivity increased by $\frac{2}{5}$ times.

(9) Two galvanometer which are otherwise identical are fixed with different coils. One has coil of 50 turns & resistance of 10 Ω. and another has no. of turns 500 and resistance of 600 Ω. What is the ratio of deflection when each is connected in turn to a cell of emf 2.5 V and internal resistance 50 Ω?

Given,

$emf(E) = 2.5\,V$

$Resistance(r) = 50\,\Omega$

$N_1 = 500 \qquad R_1 = 10\,\Omega$

$N_2 = 500 \qquad R_2 = 600\,\Omega$

$\frac{\theta_2}{\theta_1} = ?$

We know,

$BINA = C\theta$

$or,\ \theta = \frac{BINA}{C}$

where,

$I = \frac{E}{(R+r)}$

$or\ \theta = \frac{BNA}{C} \times \frac{E}{R+r}$

Then, $\theta_1 = \frac{BN_1A}{C} \times \frac{E}{R_1+r}$ --- (1)

$\theta_2 = \frac{BN_2A}{C} \times \frac{E}{R_2+r}$ --- (2)

$Or,\ \frac{\theta_1}{\theta_2} = \frac{N_2}{R_1+r} \times \frac{R_2+r}{N_2}$

$= \frac{500}{600+50} \times \frac{10+50}{50}$

$= \frac{500}{650} \times \frac{60}{50}$

$= 300/325$

$= 12/13$ #

(10) A copper strip 2cm wide and 1mm thick is placed in a magnetic field of 1.5 wb/m². If a current of 200 A is setup in the strip. what hall potential difference appears in the strip. (1m³ of strip contains 8.5×10^{28} electron).

= Given,

Thickness (t) = 1 mm.

width of slab (d) = 2cm = 2×10^{-2}m.

Magnetic field (B) = 1.5 wb/m².

current (I) = 200 A.

V_H = ?

weknow,

$$V_H = \frac{BI}{net} = \frac{1.5\times200}{8.5\times10^{28}\times1.6\times10^{-19}\times1\times10^{-3}}$$

$$= 2.28\times10^{-5}.$$

(11) A slab of copper, 2 mm thick and 5 cm wide is placed in uniform magnetic field of flux density 0.40 T, so that maximum flux pass through the slab. when a current of 75A flows through it, a potential difference of 0.8 MV is developed between the edges of the slab. find the concentration of the mobile electron in copper?

⇒ Given,

Thickness (t) = 2 cm = 2×10^{-3} m

wide (d) = 1.50 cm = 1.5×10^{-2} m.

Magnetic field (B) = 0.40 T.

current (I) = 75 A.

Induced voltage (V_H) = 0.81×10^{-6} V.

No of electron (n) = ?

we know,

$$V_H = \frac{BI}{net}$$

$$or,\ n = \frac{BI}{VH_{net}} = \frac{75 \times 0.40}{0.81 \times 10^{-6} \times 10^{-19} \times 2 \times 10^{-3}}$$

$$= 1.15 \times 10^{29}\ m^3.$$

(10) The radius of orbit of hydrogen atom is $0.5 A^0$. The electron moves in an orbit with uniform speed of 2.2×10^6 m/s. What is the magnetic field produced at the centre of nucleus due to motion of electron.

⇒ Given,

Radius $(r) = 0.5 A^0 = 0.5 \times 10^{-10} m$

velocity $(v) = 2.2 \times 10^6$ m/s

Magnetic field $(B) = ?$

Now,

$$B = \frac{\mu_0 I}{2r} \text{ --- (i)}$$

Also

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

$$or,\ T = \frac{2\pi \times 0.5 \times 10^{-10}}{2.2 \times 10^{-6}}$$

$$= 1.42 \times 10^{-16}$$

$$But,\ I = \frac{q}{T} = \frac{ne}{T} = \frac{e}{T} = \frac{1.6 \times 10^{-19}}{1.42 \times 10^{-6}} = 1.12 \times 10^{-3}.$$

from (i)

$$B = \frac{\mu_0 I}{2} = \frac{4\pi \times 10^{-7} \times 1.12 \times 10^{-3}}{2 \times 0.5 \times 10^{-5}} = 14.07 \text{ Tesla.}$$

(13) A closely would circular coil of radius 2.4cm has 800 turns.

(a) What must be current in the coil if the magnetic field at the centre of the coil is 0.058 T?

(b) At what distance from the centre of coil, on the axis of coil is the magnetic field $\frac{1}{2}$ it volume at centre.

⇒ Given,

Radius (R) = 24 cm = 24×10^{-2} m.

No of turns (N) = 800 turns.

Magnetic field (B) = 0.058 T.

we know,

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

$$\text{or, } I = \frac{B 2 R}{\mu_0 N}$$

$$= \frac{2\times 0.058 \times 24\times10^{-2}}{4\pi\times10^{-7}\times800} = 2.77\ A.$$

(b) Acc to question,

$$B_x = \frac{1}{2} B_c$$

$$\text{or, } \frac{\cancel{\mu_0 NI} R^2}{\cancel{2}(x^2+R^2)^{3/2}} = \frac{1}{\cancel{2}} \frac{\cancel{\mu_0 NI}}{2R}$$

$$\text{or, } 2R^3 = (x^2+R^2)^{3/2}$$

squaring on both sides,

$$(x^2+R^2)^{3/2\times2} = 2^2\times R^{3/2}$$

$$\text{or, } (x^2+R^2)^3 = 2^2\times R^{3/2}$$

$$\text{or, } (x^2+R^2) = 2^{2/3} R^{\cancel{3}\times2/\cancel{3}}$$

$$\text{or, } x^2 = 2^{2/3}R^2 - R^2$$

$$\text{or, } x^2 = R^2(2^{2/3}-1).$$

or, $x = R^{2\times\frac{1}{2}}\left[2^{2/3}-1\right]^{1/2}$

$x = 24\times10^{-2}\sqrt{2^{2/3}-1}$

$= 1.83\times10^{-2}$ m.

(14) A coil consisting of 100 turns of circular loops with radius 0.6 m carries a current of 5A. At what distance from the centre along the axis the magnetic field of $\frac{1}{8}$ as great as it is at the centre.

⇒ Given,

No of turn = 100

Radius (R) = 0.6m

Current (I) = 5A.

$x = ?$

According to question,

$B_x = \frac{1}{8} B_c$

or, $\frac{\cancel{\mu_0 N I} R^2}{\cancel{2}(x^2+R^2)^{3/2}} = \frac{1}{8}\times\frac{\cancel{\mu_0 N I}}{\cancel{2}R}$

or, $8R^3 = (x^2+R^2)^{3/2}$

or, $(x^2+R^2)^{3/2} = 8R^3$

Squaring on both sides, we get

$(x^2+R^2)^{3/2\times2} = 8^2\times R^{3\times2}$

or, $(x^2+R^2)^3 = (2^3)^2\times R^{3\times2}$

or, $x^2+R^2 = 2^{\cancel{3}\times2/\cancel{3}}\times R^{\cancel{3}\times2/\cancel{3}}$

or, $x^2+R^2 = 4R^2$

or, $x^2 = 4R^2 - R^2$

or, $x^2 = R^2(4-1)$

or, $x = R^{2/2}\, 3^{1/2}$

$\therefore x = 0.6\times3^{1/2}$

$= 1.04$ m.

(15) A horizontal wire of length 5cm and carrying a current of 2A is placed in the middle of a long solenoid at right angle to its axis. The solenoid has 1000 turns per meter and carries a steady current I. calculate I if the force on a wire vertically and equal to 10^{-4} N.

→ Given,

length (l) = 5cm = 5×10^{-2}.

current (I) = 2A.

$\theta = 90°$

No of turns (n) = 1000

current (I_w) = ?

force (f) = 10^{-4} N.

Now,

$$f = BI_s l \sin\theta$$

$f = \mu_0 n I_w \cdot I_s l$ where $B = \mu_0 n I_w$

or, $I_s = \dfrac{f}{\mu_0 n I_w l}$

or, $I_s = \dfrac{10^{-4}}{4\pi\times10^{-7}\times1000\times5\times10^{-2}\times2}$

$\therefore I_s = 0.8$ A.

(16) Two long parallel wires are separated by a distance of 2.5cm. The force per unit length of each wire exert on the other is 4×10^{-5} N/m and the wire repeat eachother. The current on one wire is 0.6 A. what is the current in the second wire.

→ Given,

Distance (d) = 2.5cm = 2.5×10^{-2} m

$f = \left(\dfrac{F}{l}\right) = 4\times10^{-5}$ N/m

current (I) = 0.6 A.

Now, $f = \frac{\mu_0 I_1 I_2}{2\pi r}$

or, $4 \times 10^{-5} = \frac{4\pi \times 10^{-7} \times 0.6 \times I_2}{2\pi \times 2.5 \times 10^{-2}}$

$\therefore I_2 = 8.33\,A$

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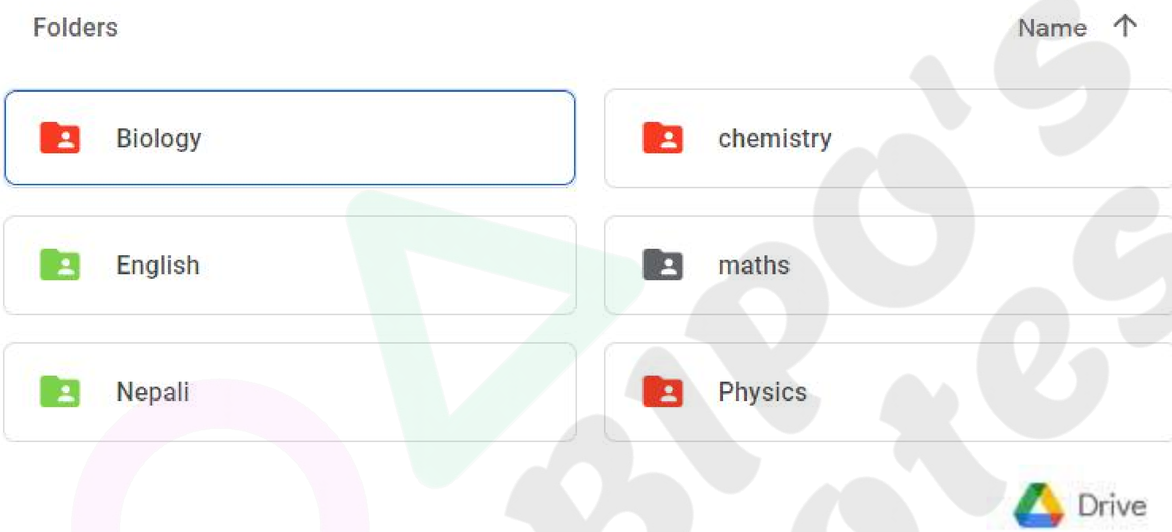
(Bipo)

Class 12 complete notes and paper collection.



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