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! Physics !

Magnetic Field Due to Electric current.

The phenomena of producing magnetic field by passing electric current through a conductor is called as magnetic feild due to electric curren

Q. What is Lorentz Force?

When a charged particle moves through a region of electric field ($\vec{E}$) and magnetic field ($\vec{B}$) then the net is force experienced by charged particle is called as Lorentz force.

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

$$F_L = \vec{qE} + q(\vec{V} \times \vec{B})$$

$$F_L = q.\vec{E} + (\vec{V} \times \vec{B}).$$

Q. Define cyclotron Formula.

(i) In a magnetic field a charged particle typically undergoes circular motion.

(ii) centripetal force necessary for circular motion is the magnetic force on the particles.

$\therefore$ Centripetal Force = Magnetic Force.

$$\frac{mv^{\cancel{2}}}{R} = q\cancel{v}B$$

This is know as cyclotron formula.

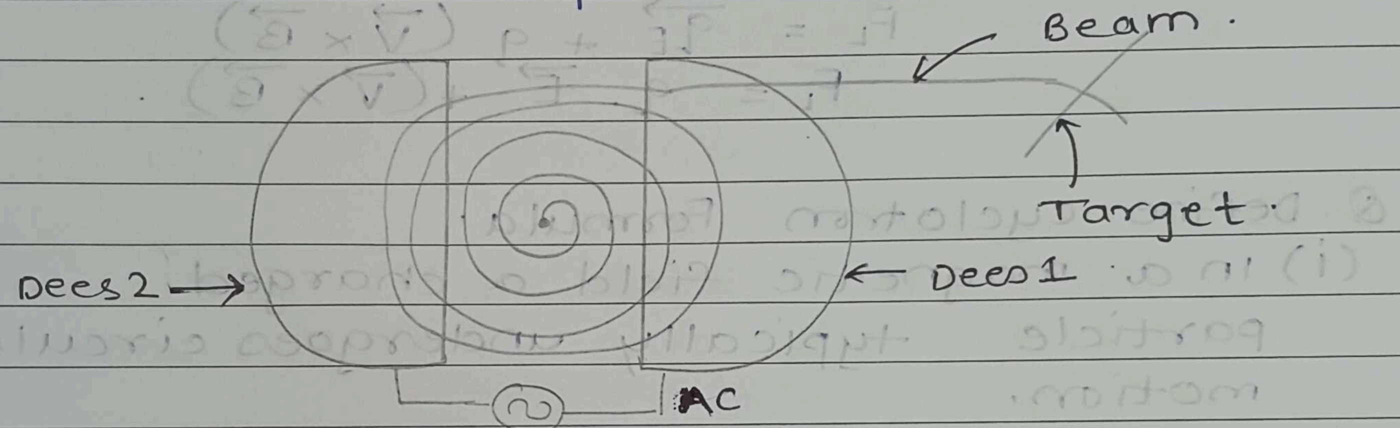
$$\frac{mv}{R} = qB$$

$$mv = qBR$$

Q. Explain working principle, Draw the construction and working of cyclotron Also derive the formula for velocity of charge, time period, frequency, kinetic energy.

→ Defination: cyclotorn is a charged particle accelerator used for accelerating charged particle to higher enegies.

→ Working principle: in cyclotron, both electric and magnetic field are used. Magnetic Field puts ions (particles) into circular path and electric field accelerates the particles.



→ Using cyclotron formula,

$$mv = qBR.$$

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

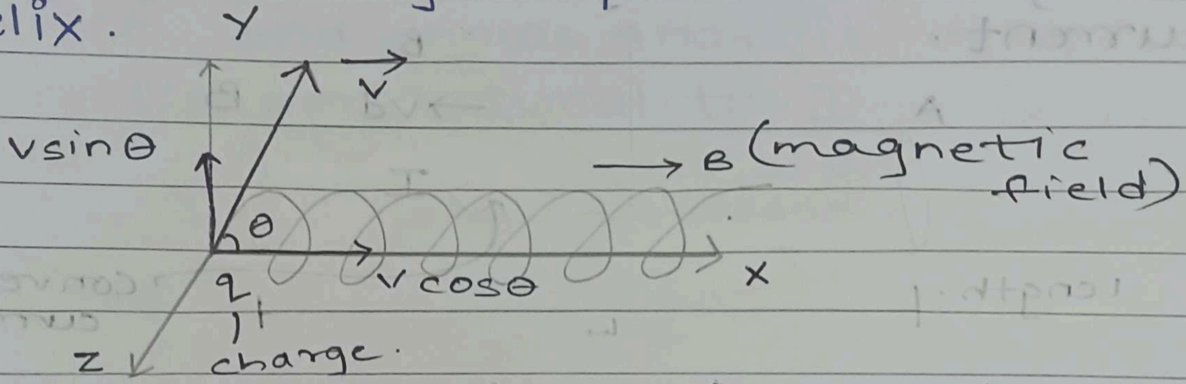
But, $T = \frac{\text{circumference}}{\text{speed}} = \frac{2\pi R}{\frac{qBR}{m}} = \frac{2\pi m}{qB}.$

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

Kinetic Energy: $\frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{qBR}{m}\right)^2 = \frac{q^2B^2R^2}{2m}.$

K.E directly proportional to square of Radius

Q. Helical Motion: Draw and explain the path of charged partical become helix.



→ The above fig. shows helical motion of charged particles when it moves with velocity $(\vec{V})$.

→ This velocity is resolved into two components.

(I) Parallel to magnetic field.

(II) Perpendicular to magnetic field.

→ Due to this, it obtains helical path,

$$F_m = \vec{V} \times \vec{B}$$

$$F_m = VB \sin\theta$$

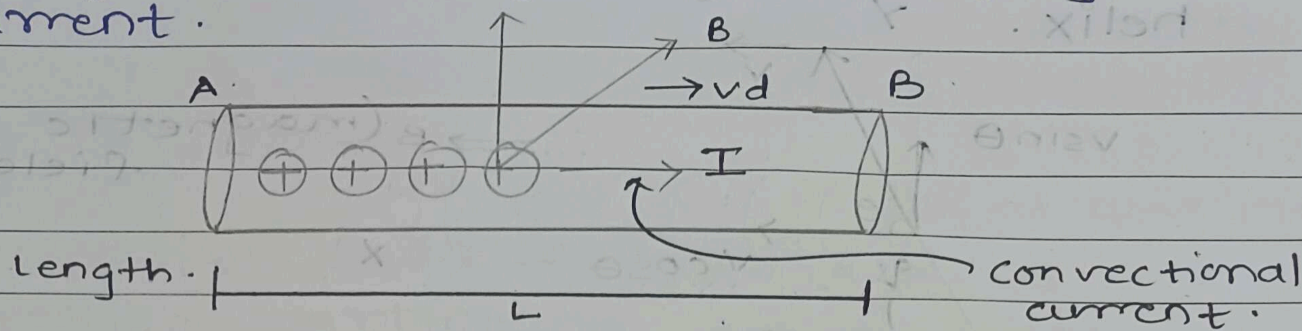
(I) V parrallel to B. $\theta = 0$ $\sin 0° = 0$.

$$\therefore F_m = 0$$

(II) V perpendicular to B. $\theta = 90$ $\sin 90° = 1$

$$\therefore F_m = VB.$$

Q. Derive the relation for magnetic force acting on a straight wire carrying current.



→ consider a straight wire of length (L). in which magnetic field is applied.
→ Let 'I' be the current flowing through it by velocity (Vd).

$$I = \frac{q}{t}$$

$$\therefore q = I \times t$$

But, $Vd = \frac{L}{t} \left[\frac{Disp}{time}\right]$

$$\therefore t = \frac{I}{Vd}$$

$$q = I \times \frac{L}{Vd}$$

The magnetic force on the charge is.

$$\vec{Fm} = q(\vec{Vd} \times \vec{B}).$$

$$\vec{Fm} = I \frac{L}{Vd} \; VdB\sin\theta$$

$$\vec{Fm} = ILB\sin\theta = BiL\sin\theta.$$

In vector form,

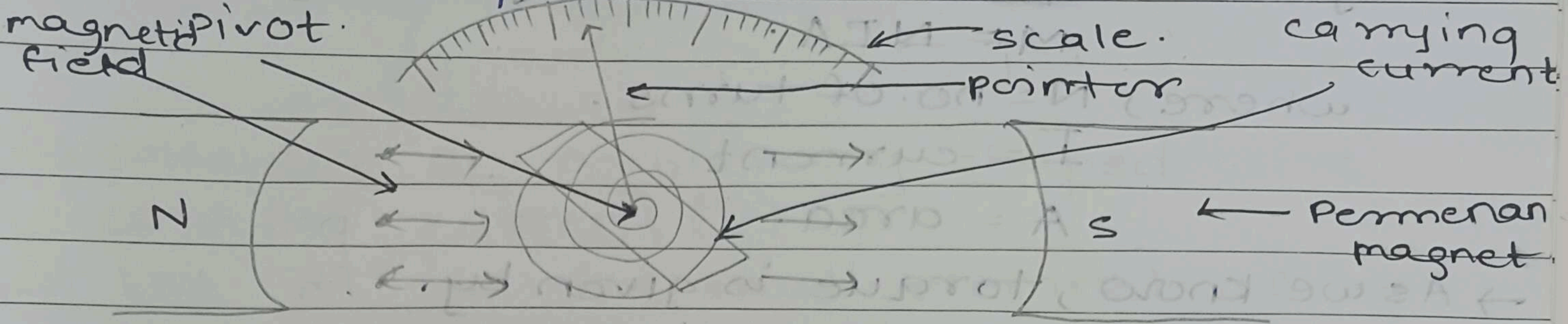
$$\vec{Fm} = I(\vec{L} \times \vec{B})$$ — For straight wire.

For an arbitary shape(we have to take small length.)

$$d\vec{Fm} = I(d\vec{L} \times \vec{B})$$

$$\int d\vec{Fm} = \int I(d\vec{L} \times \vec{B})$$

Q. Draw a neat labelled diagram of moving suspended coil galvanometer. state its principle and shows that it deflection is directly porprotional to I.



→ When a current carrying coil is suspended in a uniform magnetic field, it experience torque ~~and maximum~~ due to which coil rotates and maximum flux passes through coil.

Proof.

(1) The coil of mcg rotates due to torque acting on it which is called as deflecting torque

Formula: $\tau d = NIAB$ — (1).

(11) The rcstoring torque (τr) due to spring is given by

$$\tau_r \propto \phi$$

$$\tau r = K\phi \text{ — (11)}.$$

ϕ = deflection, K = torsinal constant.

$$\tau d = \tau r$$

$$NIAB = K\phi.$$

$$I = \frac{K\phi}{nAB}.$$

K, N, A, B are constant.

$$I = \left[\frac{K}{NAB}\right]\phi.$$

$$I \propto \phi.$$

Hence proved.

Q. what is magnetic dipole movement (M)? Derive an expression for potential energy (U) and torque (τ).

→ magnetic dipole moment is given by;

$$M = NIA.$$

where, N = no. of turns.
I = current
A = area.

→ As we know, torque is given by.

$$\tau = NIBA\sin\theta.$$

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

in vector form,

$$\vec{\tau} = \vec{m} \times \vec{B}$$

→ We know that, magnetic potential energy is given by $u = -mB\cos\theta$

→ case I: If $\theta = 0°$

then $U = -mB\sin\theta.$

$= -mB.$

This is minimum potential energy.

case II: If $\theta = 180°$ then.

$$u = -mB\cos 180°.$$

$$u = mB$$

This is maximum potential energy.

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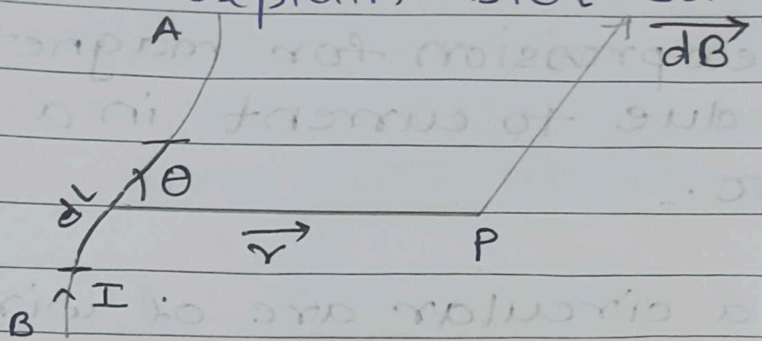
Q. state and explain Biot-savart Law.



→ consider an arbitrary shaped wire carrying current (I).

→ Let 'dl' be the small element of the wire.

→ we have to find magnetic field 'dB' at point which is

(I) Directly porportional to small element.

$$dB \propto dl \quad —(I)$$

(II) Directly proportional to 'I'.

$$dB \propto I \quad —(II)$$

(III) inversely proportional to square of distance

$$dB \propto 1/r^2 \quad —(III)$$

→ From (I) (II) and (III) and (IV) ($dB \propto \sin\theta$) dB is directly porportional to

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

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

$$dB = \frac{4_0}{4\pi}\,\frac{I\,dl\sin\theta}{r^2}$$

μ_0 = permeability of free space.

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

$\therefore {}^{4_0}/_{4\pi} \times 10-7$

$$\therefore d\theta = 10^{-7}\,\frac{I\,d\sin\theta}{r^2}$$

Application 1.

Q. Derive an expression for magnetic field at centre due to current in a circular arc of wire.

(i) consider a circular arc of wire carrying current I.

(ii) The circular arc has an angle (θ) form centre.

(iii) Let 'dl' be the small element.

Proof,

→ Using Biot - savart Law at point O,

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

$\theta = 90°$ $\sin 90° = 1$

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

Total magnetic field at point B is

$$B = \int dB$$

$$B = \int \mu_0/4\pi \; I\,dl/r^2$$

But $dl = r \times d\theta$

$$B = \int \frac{\mu_0}{4\pi} \frac{I \times r \times d\theta}{r^2}$$

$$B = \int \mu_0/4\pi \; I\,d\theta/r$$

$$B = \frac{\mu_0}{4\pi} \frac{I}{r} \int d\theta$$

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

For circular wire,

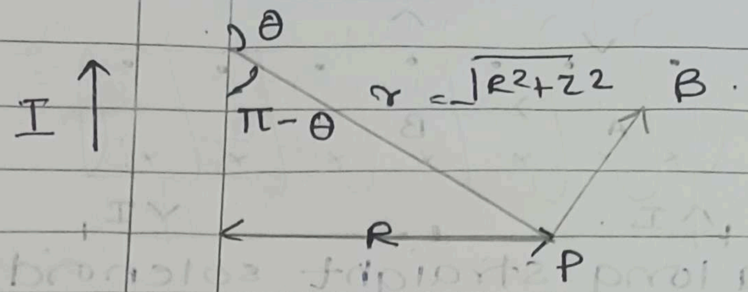
$$\theta = 2\pi$$

$$B = \mu_0/\cancel{4}_2\cancel{\pi} \; I/r \times \cancel{2}\pi$$

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

Application 2.

Q. Derive an expression for magnetic field at a point which is perpendiular distance form infinite long straight wire.



→ consider an infinite long straight wire carrying current I.

→ Let P be the point at distance R for the wire

From the figure,

$$r^2 = L^2 + R^2$$

$$r = \sqrt{L^2 + R^2}$$

But $\sin(\pi - \theta) = \dfrac{R}{\sqrt{R^2 + L^2}} = \dfrac{\text{OPP}}{\text{Hyp}}$

$$\sin\theta = \frac{R}{\sqrt{R^2 + L^2}} \qquad \sin(180 - \theta)$$

Magnetic field DB at point P is

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dL \sin\theta}{r^2}$$ (Biot-swart Law)

Q. state and explain ampere circuit law.

→ The line integral of magnetic induction ($\vec{B}$) around any closed path in the free space (μ_0) is equal to times the total current flowing through area bounded by the closed path.

Mathematically: $\oint \vec{B} \cdot \vec{ds} = \mu_0 I$.

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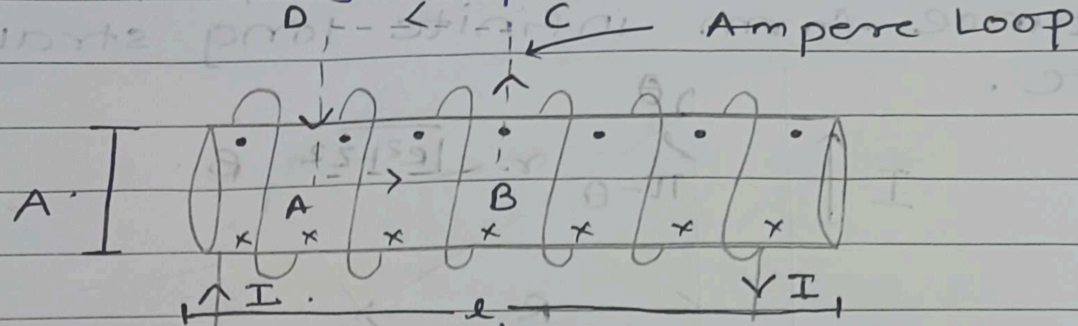
Q. Derive an expression for magnetic field along the axis due to long, straight, solenoid using ampere's Law:



→ consider a long straight solenoid of length (L) carrying current (I).
→ The (•) sign shows the current is coming out form is the plain and (x) shows current is going into the plane.
→ let 'n' be the no. of turns per unit length

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

→ Acc. to ampere circuit law,

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

But $\frac{N}{L} = n$.

$$n \times L = N.$$

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

(LHS) (RHS).

case I: LHS $= \oint \vec{B} \cdot \vec{dl}$:

For rectangular loop. ABCD.

$$\oint \vec{B}\, \vec{dl} = \oint_A^B \vec{B}\, \vec{dl} + \oint^C \vec{B}\, \vec{dl} + \oint \vec{B}\, \vec{dl} + \oint_D^A \vec{B} \cdot \vec{dl} \quad \text{--- (2)}.$$

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I) For path AB.

$$\oint_A^B \vec{B}\,\vec{dl} = \oint_A^B B\,dl\cos\theta.$$

$$\theta = 0^\circ$$

$$[\vec{B} \parallel \text{path } AB]$$

$$= \oint_A^B B\,dL$$

$$= B \oint_A^B dL$$

$$= BL. \quad \text{— (A)}.$$

II) For path BC.

$$\oint_B^C \vec{B}\,\vec{dL} = \oint_B^C B\,dL\cos\theta$$

$$\theta = 90^\circ$$

$$\cos 90^\circ = 0$$

$$\oint_B^C \vec{B}\,\vec{dl} = 0 \quad (B).$$

(III) similary path AD = 0. $\oint_D^A \vec{B}\,\vec{dL} = 0$ — (C).

(IV) outside the solenoid the mF is very weak as compared to inside
∴ It is consider to be zero.

$$\oint_C^D \vec{B}\,\vec{dL} = 0 \quad \text{— (D)}.$$

put (A) (B) (C) and (D) in eq (2).

$$\oint \vec{B}\,\vec{dL} = BL + 0 + 0 + 0.$$

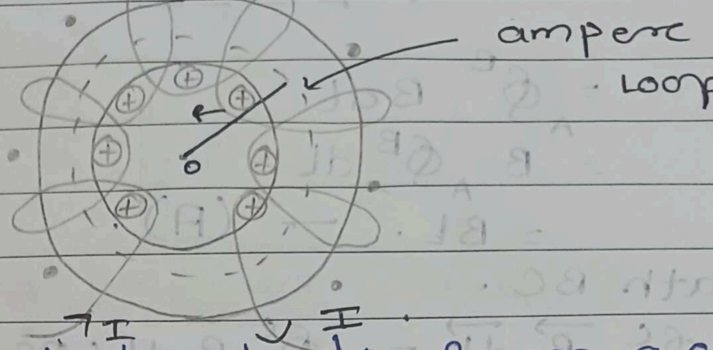
$$\oint \vec{B}\,\vec{dl} = BL \quad \text{— (3)}.$$

from eq (3) and (1).

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

$$B = \mu_0 n I$$

Q. What is Toroid? Using ampere's Law derive an expression for magnetic induction at a point along the axis of toroid.



→ When solenoid is bent to form a circular loop like structure then it is called Toroid.

→ consider an ampere loop or radius 'R'. along the axis of Toroid carrying current 'I'. with total no. of turns 'N'.

→ Acc. to ampere law.

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

$$\oint \vec{B}\, dl \cos\theta = \mu_0 N I$$

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

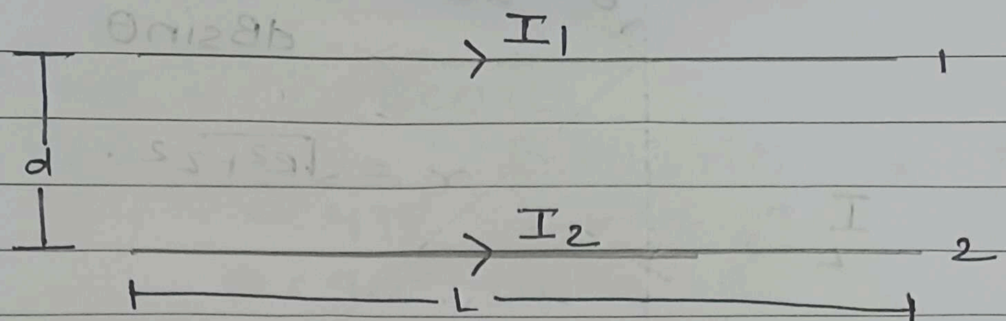
$$\oint B\, dl = \mu_0 N I$$

But $\oint dl = \cancel{\mu_0 N I}\ 2\pi R$.

$$B \times 2\pi R = \mu_0 N I$$

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

Q: Derive an expression for force between to long current carring wire separated by small distance 'd'.



→ Consider two wire carrying current I_1 and I_2 in the same direction. separated by distand 'd'.

→ The current I_1 in the first wire produces magnetic field B on 2nd wire That is $B = \frac{\mu_0 I_1}{2\pi d}$.

→ Now due to current I_2 and magnetic field $\vec{B}$ form 1st wire produces a force which acts on 2nd wire.

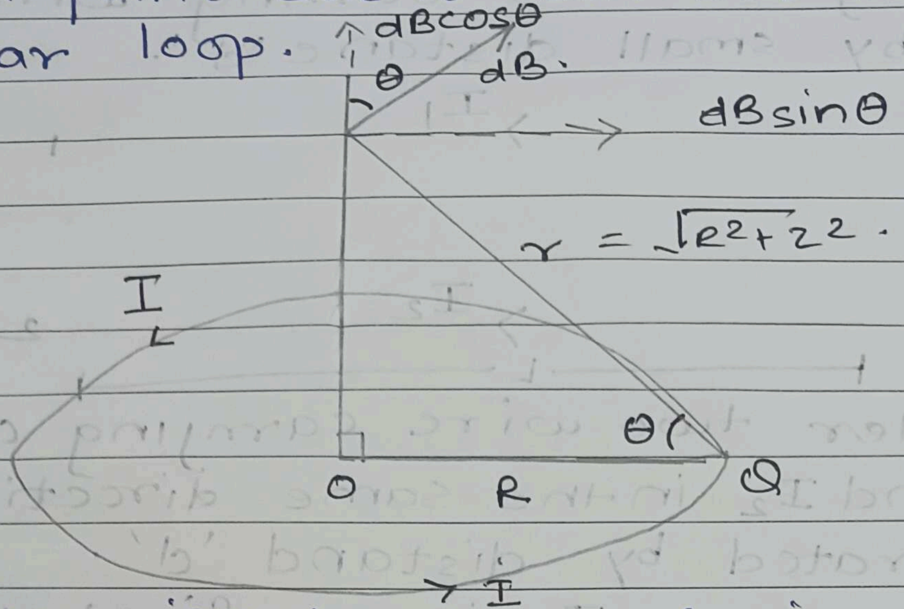
$$E = B I_2 L$$

$$F = \frac{\mu_0 I_1}{2\pi d} I_2 L$$ (It is attractive force).

Force per unit length of wire is.

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}.$$

Q. Derive an expression for magnetic field at an point due to current in the circular loop.



→ consider a circular loop of wire carrying current 'I'. Let P be the point at distance 'r'.

From the figure, . .

$$r^2 = R^2 + z^2$$

$$r = \sqrt{R^2 + z^2}$$

$$\cos\theta = \frac{R}{r} = \frac{\text{Adj}}{\text{Hyp}}$$

$$\cos\theta = \frac{R}{\sqrt{R^2+z^2}} \quad \text{—— (1)}$$

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

$$dB = \frac{\mu_0}{4\pi}\,\frac{I\,dl\,\sin\theta}{R^2+z^2} \quad \text{—— (2)}.$$

Now. dB is resolved.

$dB\sin\theta$ = Horizontal

$dB\cos\theta$ = vertical.

Q. The component $dB \sin\theta$ will cancled out due to symmetry. Therefore net magnetic field is.

$$B_{net} = \int dB\cos\theta$$

$$B_{net} = \int \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{(R^2+Z^2)} \times \frac{R}{\sqrt{R^2+Z^2}}$$

$$\theta = 90^\circ \quad \sin 90^\circ = 1$$

$$B_{net} = \int \frac{\mu_0}{4\pi} \frac{I\,dl}{(R^2+Z^2)} \times \frac{R}{\sqrt{R^2+Z^2}}$$

$$B_{net} = \frac{\mu_0}{4\pi} \frac{I}{R^2+Z^2} \times \frac{R}{\sqrt{R^2+Z^2}} \int dl$$

$$= \frac{\mu_0}{4\pi} \frac{I}{(R^2+Z^2)} + \frac{R}{(\sqrt{R^2+Z^2})^{1/2}} \int dl.$$

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

But $\int dl = 2\pi R$.

$$B_{net} = \frac{\mu_0 IR}{\cancel{4}_{2}\pi(R_2+Z^2)^{3/2}} \, 2\pi R$$

$$B_{net} = \frac{\mu_0 IR}{2(R^2+Z^2)^{3/2}}.$$