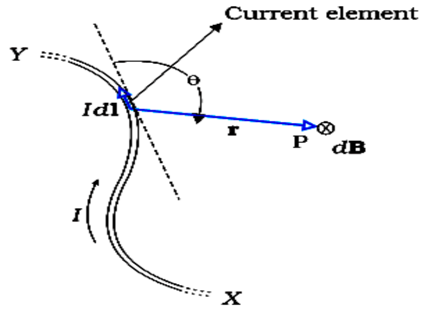
NCERT-XII / Unit- 4 – Moving charge and magnetic field

MAGNETIC FIELD DUE TO A CURRENT ELEMENT

The relation between current and the magnetic field, produced by it is magnetic effect of currents. The magnetic fields that we know are due to currents or moving charges and due to intrinsic magnetic moments of particles.

BIOT -SAVART LAW



Let the magnetic field due to an infinitesimal element $\vec{dl}$ of a finite conductor XY carrying current I, a point P which is at a distance $\vec{r}$ from it be $\vec{dB}$. Let θ be the angle between $\vec{dl}$ and the displacement vector $\vec{r}$. According to Biot-Savart's law, the magnitude of the magnetic field $\vec{dB}$ is proportional to the current I, the element length $\vec{dl}$ and inversely proportional to the square of the distance $\vec{r}$.

In vector notation $d\vec{B} \propto \frac{I\,d\vec{l} \times \vec{r}}{r^3} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{l} \times \vec{r}}{r^3}$

Its direction is perpendicular to the plane containing $\vec{dl}$ & $\vec{r}$.

In terms of magnitude $|d\mathbf{B}| = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$

In SI units $\mu_0/4\pi = 10^{-7}$ T m/A , where μ_0 is the permeability of free space or vacuum.

Comparision between as Biot-Savart law and Coulomb's law

(i) Both are long range, since both depend inversely on the square of distance from the source to the point of interest. The principle of superposition applies to both fields.

(ii) The electrostatic field is produced by a scalar source, namely, the electric charge. The magnetic field is produced by a vector source $I\,\vec{dl}$

(iii) The electrostatic field is along the displacement vector joining the source and the field point. The magnetic field is perpendicular to the plane containing the displacement vector r and the current element $I\,\vec{dl}$

(iv) There is an angle dependence in the Biot-Savart law which is not present in the electrostatic case.

There is an interesting relation between ε_0, the permittivity of free space; μ_0, the permeability of free space; and c, the speed of light in vacuum:

$$\varepsilon_0\mu_0 = (4\pi\varepsilon_0)\left(\frac{\mu_0}{4\pi}\right) = \left(\frac{1}{9\times10^9}\right)(10^{-7}) = \frac{1}{(3\times10^8)^2} = \frac{1}{c^2}$$

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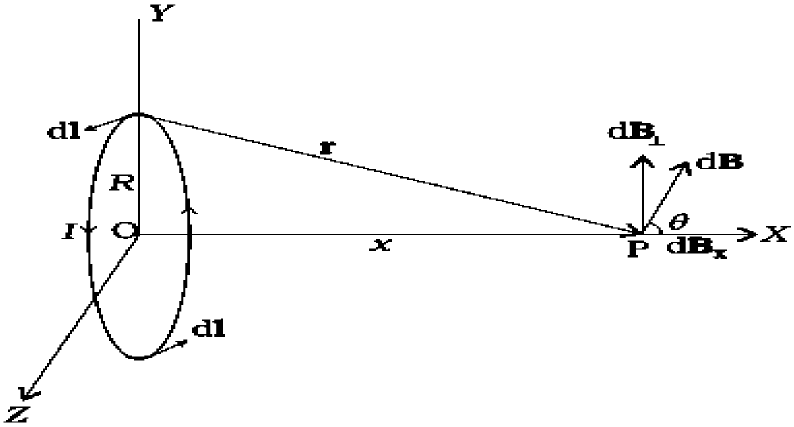
MAGNETIC FIELD ON THE AXIS OF A CIRCULAR CURRENT LOOP

Let us consider a circular loop of radius R carrying a steady current I ,be placed in the y-z plane with its centre at the origin O and the x-axis as the axis of the loop. We have to calculate the magnetic field at P on this axis , at a distance of x from O .

Considering a conducting element $\vec{dl}$ of the loop , the magnitude $\vec{dB}$ at P according to Biot-Savart law as $\vec{dB} = \frac{\mu_0}{4\pi}\frac{|I\,\vec{dl}\times\vec{r}|}{r^3}$ ………….(1)**Where , $r^2 = x^2 + R^2$**



Since any element of the loop is perpendicular to the displacement vector from the element to the axial point , so eq (1) in terms of magnitude

$$dB = \frac{\mu_0}{4\pi}\frac{I dl}{(x^2+R^2)}$$ ………………..(2)

Since $\vec{dB}$ has an x -component $\vec{dB}_x$ and a component perpendicular to x-axis, $\vec{dB}_\perp$ which when summed over, they cancel out , as $\vec{dB}_\perp$ component due to dl is cancelled by the contribution due to the diametrically opposite $\vec{dl}$ element . Thus, only the x-component survives.

The net contribution along x-direction can be obtained by integrating $|\vec{dB}_x| = dB\cos\theta$ over the loop

$$|B| = \int_0^B dB\cos\theta = \frac{\mu_0}{4\pi}\frac{I}{(x^2+R^2)}\cdot\frac{R}{(x^2+R^2)^{1/2}}\int_0^{2\pi R} dl$$

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

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

Thus, the magnetic field at P due to entire circular loop is $\mathbf{B} = B_x\hat{\mathbf{i}} = \frac{\mu_0 I R^2}{2(x^2+R^2)^{3/2}}\hat{\mathbf{i}}$ ………(3)

At the centre of the circular coil

Then P will come to the centre of the loop O and then x = 0, and we obtain, $\mathbf{B}_0 = \frac{\mu_0 I}{2R}\hat{\mathbf{i}}$ ……..(4)

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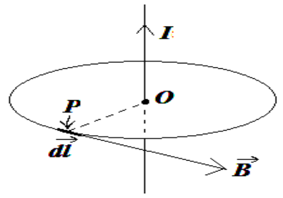
State and prove ampere circuital law

Ans :- **Ampere-circuital law** :- It states that "**the line integral of a magnetic field around a closed path is μ_0 times of total current through the area bounded by the closed path** ."

Mathematically $\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 I$



Proof: Let us Consider a straight conductor of infinite extent carrying current I in a direction as shown as the diagram. Let us consider a circular path of radius 'r' such that the conductor is passing through its centre and perpendicular to its plane. Let us consider a point P on it , where magnetic field due to the conductor is $B = \frac{\mu_o}{4\pi}\frac{2I}{r}$ 1

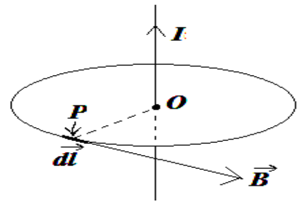
Let $d\vec{\mathbf{l}}$ be a small line element around P. The line integral of the magnetic field around the close path is $\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mathbf{B}\, d\mathbf{l} \cos 0^o$ [$\vec{\mathbf{B}}$ & $d\vec{\mathbf{l}}$ are in same direction]

$= B \oint dl$ [B is uniform along the path]

$= \frac{\mu_o}{4\pi}\frac{2I}{r} \times 2\pi r = \mu_o I$ So, $\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 I$ 2

Application Ampere Circuital law

1] Magnetic field due to a current carrying straight conductor of infinite extent



Let us consider a point P , at a perpendicular distance of r from a straight conductor of infinite extent carrying current I in a direction as shown in the diagram , where we have to calculate the magnetic field

Let us consider an amperian loop of radius 'r' such that the conductor is passing through its centre and perpendicular to its plane. Let $d\vec{\mathbf{l}}$ be a small line element around P. Using Ampere Circuital law

$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 I$

$\Rightarrow \oint \mathbf{B}\, d\mathbf{l} \cos 0^o = \mu_0 I$ [$\vec{\mathbf{B}}$ & $d\vec{\mathbf{l}}$ **are in same direction**]

$\Rightarrow \mathbf{B} \oint d\mathbf{l} = \mu_0 I$

$\Rightarrow \mathbf{B} \cdot 2\pi \mathbf{r} = \mu_0 I$

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

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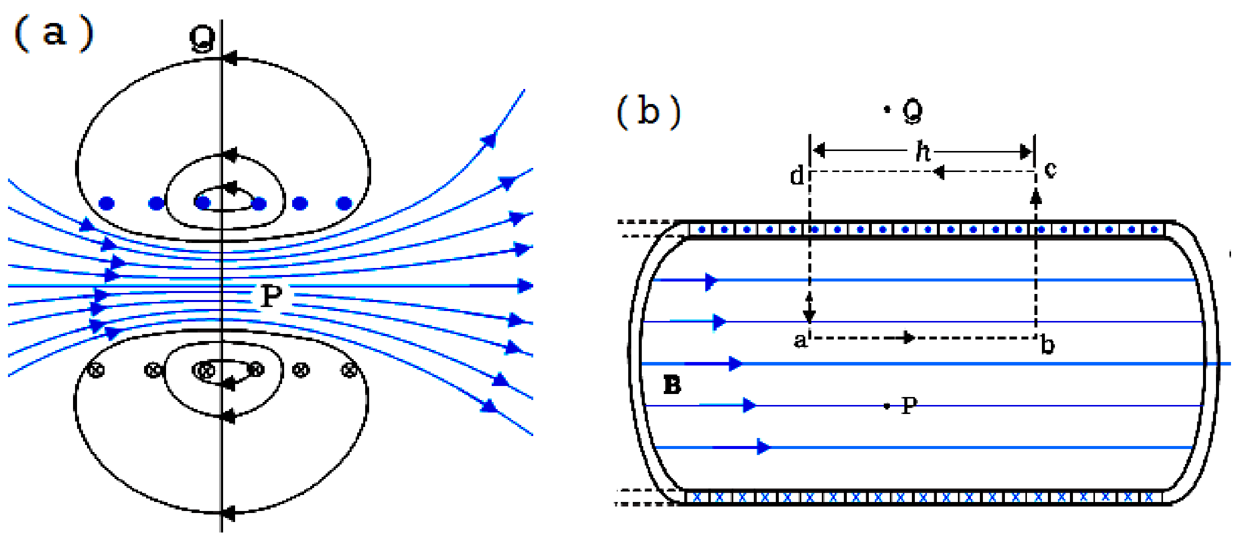
What is a solenoid A solenoid consists of a long enamelled wire wound in the form of a helix where the turns are closely spaced and are insulated from each other and the net magnetic field is the vector sum of the fields due to all the turns.

2] Magnetic field due to a solenoid

Fig (a) shows the magnetic field lines for a finite solenoid . It is seen that the field at the interior mid-point P is uniform, strong and along the axis of the solenoid. As the solenoid is made longer it appears like a long cylindrical metal sheet , the field outside the solenoid , at Q approaches zero. The field inside becomes everywhere parallel to the axis.



Consider a rectangular Amperian loop abcd. Along cd the field is zero . Along transverse sections bc and ad, the field component is zero. Thus, these two sections make no contribution.

Let the field along ab be B. Thus, the relevant length of the Amperian loop is, L = h.

Let n be the number of turns per unit length, then the total number of turns is nh.

The enclosed current is, $I_e = I\,(n\,h)$, where I is the current in the solenoid.

From Ampere's circuital law , $BL = \mu_0 I_e \Rightarrow B\,h = \mu_0 I\,(n\,h) \Rightarrow B = \mu_0\, n\, I$,

where n is the number of turns per unit length The direction of the field is given by the right-hand rule.

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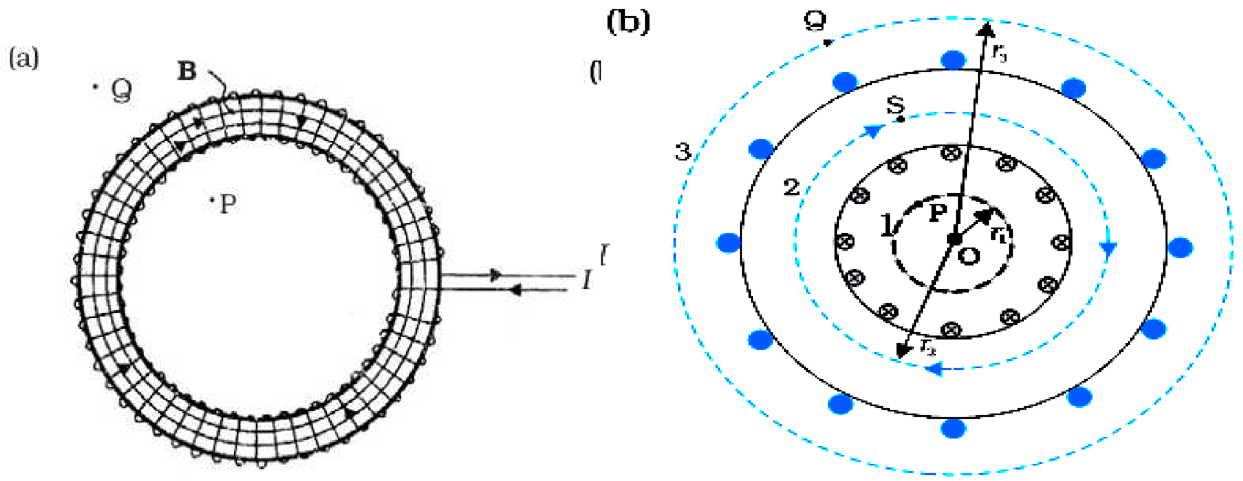
2] Magnetic field due to a Toroid The toroid is a hollow circular ring on which a large number of turns of a wire are closely wound.

Let us consider three circular Amperian loops 1, 2 and 3 as shown by dashed lines..

Let the magnetic field along loop 1 be B_1 in magnitude. Then in Ampere's circuital law , $B_1 (2 \pi r_1) = \mu_0 I_e$

However, the loop encloses no current, so $I_e = 0$. Thus, $B_1 = 0$.



Thus, the magnetic field at any point P in the open space inside the toroid is zero.

Let the magnetic field along loop 3 be B_3. However, from the sectional cut, we see that the current coming out of the plane of the paper is cancelled exactly by the current going into it , so $I_e = 0$.

Thus, $B_3 (2 \pi r_3) = \mu_0 (0) \Rightarrow B_3 = 0$.

Thus, the magnetic field at any point Q in the open space outside the toroid is zero.

Let the magnetic field inside the solenoid be B. We shall now consider the magnetic field at S.

Applying Ampere's law , $B (2 \pi r_2) = \mu_0 I_e = \mu_0 N I$, N is the total turn in the toroid .

$$\Rightarrow \quad B = \frac{\mu_0 N I}{2\pi r_1} = \mu_0 \frac{N}{2\pi r_1} I = \mu_0 n I$$

, where n is the number of turns per unit length

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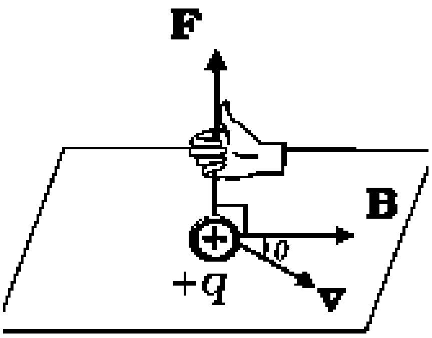
Lorentz Force

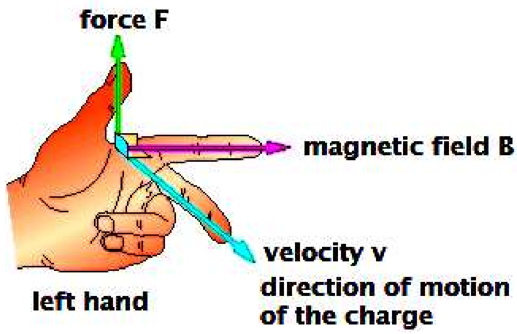
Let a point charge q , moving with a velocity v and, located at r at a given time t , in presence of both the electric field E (r) and the magnetic field B (r).

The force on an electric charge q due to both of (r) and the magnetic field B (r) is called the **Lorentz force**.

It is
$$\vec{F} \equiv \vec{F}_{electric} + \vec{F}_{magnetic} = q\,[\,\vec{E}(r) + \vec{v} \times \vec{B}(r)]$$

Magnetic force





Let a point charge q , moving in XY plane with a velocity $\vec{v}$, entering into a magnetic field $\vec{B}$, being in the same plane . According to Flemming Left hand thumb rule , the magnetic force acting on the charge is given as $\vec{F} \propto \vec{v} \times \vec{B}$ ....(1)

Or , $\vec{F} = q\,[\,\vec{v} \times \vec{B}\,]$ ....(2)

In terms of magnitude , **F = B q v sin θ**..........(3)

We find the following features about the magnetic force

(i) It depends on charge of the particle **q** , the velocity **v** and the magnetic field **B**. Force on a negative charge is opposite to that on a positive charge.

(ii) The magnetic force is zero, I f charge is not moving (as then |v|= 0) and if velocity and magnetic field are parallel or anti-parallel.

(iii) The force acts in a (sideways) direction perpendicular to both the velocity and the magnetic field.

Unit of the magnetic field

(i) In CGS unit , it is **Gauss** or **Oersted**

$B = \dfrac{F}{q\,v\sin\theta}$, if **F = 1 dyne , q = 1 emu or abCoulomb , v = 1cm/s , θ = 90^0 , then B = 1Gauss**

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The magnitude of magnetic field B is said to be 1Gauss , when the force acting on a charge of 1 emu , moving perpendicular to the magnetic field with a speed 1 cm/s, is 1 dyne .

(ii) In SI unit , it is **Tesla**

$B = \frac{F}{q\,v\sin\theta}$, if **F = 1 newton , q = 1 Coulomb , v = 1m/s , θ = 90⁰ , then B = 1Tesla**

The magnitude of magnetic field B is said to be 1 Tesla , when the force acting on a charge of 1 Coulomb , moving perpendicular to the magnetic field with a speed 1 m/s, is 1 newton .

Relation between Tesla and Gauss

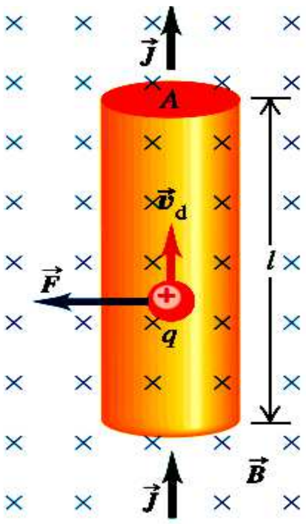
$$1\,Tesla = \frac{1\,newton}{1\,Coulomb \times 1\,m/s \times \sin 90^0} = \frac{10^5\,dyne}{\frac{1}{10}\,emu \times 100\,cm/s \times \sin 90^0} = 10^4\,Gauss$$

Dimensional formula of magnetic field **$[B] = [M^1 L^0 T^{-2} A^{-1}]$**

Dimensional formula of absolute permeability of free space **$[\mu_0] = [M^1 L^1 T^{-2} A^{-2}]$**

Magnetic force on a current-carrying conductor

Let us consider a conductor of a uniform cross-sectional area A and length L , with n as the number density of the mobile charge carriers in it , in which every charge carrier of charge q , is moving with drift velocity $\vec{v}_d$.



Let a steady current I be flowing in the conductor , constituted by nAL number of mobile charge carriers in it In the presence of an external magnetic field $\vec{B}$,The force on these carriers is Let a steady current I be flowing in the conductor , constituted by nAL number of mobile charge carriers in it In the presence of an external magnetic field $\vec{\mathbf{B}}$,The force on these carriers is

$\vec{\mathbf{F}} = (nAL)q\,\vec{\mathbf{v}}_d \times \vec{\mathbf{B}}$ 1

Now current density is $\vec{\mathbf{j}} = nq\,\vec{\mathbf{v}}_d$ and $|\mathbf{j}| = \mathbf{I}/\mathbf{A}$

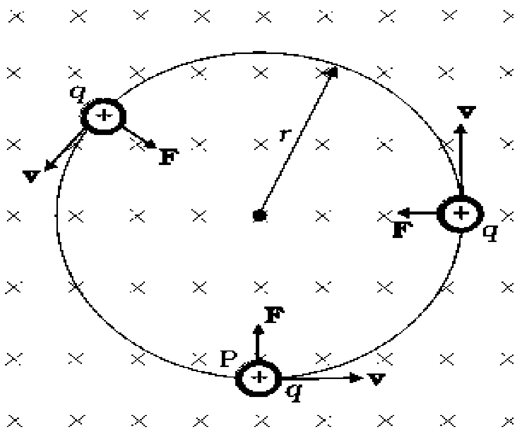
Thus , $\vec{\mathbf{F}} = [(nq\,\vec{\mathbf{v}}_d)AL] \times \vec{\mathbf{B}} = [\,\vec{\mathbf{j}}AL] \times \vec{\mathbf{B}} = I\vec{\mathbf{L}} \times \vec{\mathbf{B}}$ ……2

This is the magnetic force on a current-carrying conductor .

In terms of magnitude $|\mathbf{F}| = \mathbf{B\,I\,L}\sin\theta$ **…………..3**

MOTION IN A MAGNETIC FIELD

(i) **A charged particle entering a uniform magnetic field perpendicularly**



In case of a charge q entering into a magnetic field $\vec{\mathbf{B}}$ perpendicularly , then magnetic force on the charge is perpendicular to its velocity $\vec{\mathbf{v}}$. So no work is done and no change in the magnitude of the velocity is produced , although the direction of momentum may be changed .

The perpendicular force, $\mathbf{q}(\vec{\mathbf{v}} \times \vec{\mathbf{B}})$, acting on the charge will acts as a centripetal force and produces a circular motion perpendicular to the magnetic field. The particle will describe a circle .

Radius of the circular path followed by a charged particle in a magnetic field

Since the required centripetal force is provided by the magnetic force on the charged particle

$\mathbf{m\,v^2/r = q\,v\,B}$, which gives $\mathbf{r = m\,v / q\,B}$ ……..(1)

The larger the momentum ,the larger is the radius and bigger the circle described.

If ω is the angular frequency of revolution of the chaeged particle , then $\mathbf{v = \omega\, r}$.

So, $\boldsymbol{\omega} = \mathbf{2\pi\nu = q\,B/\,m}$ …………….(2)

Angular frequency or frequency of rotation is independent of the velocity or energy .

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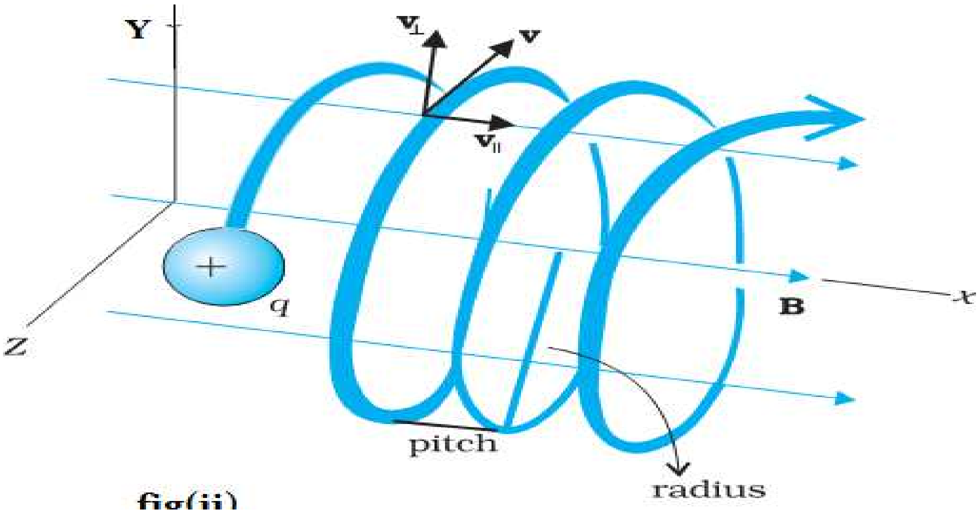
(ii) **A charged particle entering a uniform magnetic field at an angle θ ($0^0 < \theta < 90^0$)**



fig(ii)

If the charge will have two components of velocity, while entering the magnetic field ,

(i) a component perpendicular to B , on which magnetic force will act perpendicularly ,resulting a circular path .

(ii) a component along B , which remains unchanged as the motion along the magnetic field will not be affected by the magnetic field.

Thus circular path in the plane perpendicular to B will move in the direction of magnetic field resulting a helical path

Pitch of the HELIX

The distance moved along the magnetic field during the helical motion of a charged particle in a magnetic field , in one rotation is called pitch (p) .

we have $p = v_{||}T = 2\pi m v_{||} / qB$

Cyclotron

The cyclotron , invented by E.O. Lawrence and M.S. Livingston in 1934 , is a machine to accelerate charged particles or ions to high energies.

Principle - Cyclotron uses the fact that the frequency of revolution of the charged particle in a magnetic field is independent of its energy , i.e. independent of its speed or radius of its orbit . Cyclotron uses crossed electric and magnetic fields in combination to increase the energy of charged particles. The particles move most of the time inside two semicircular disc-like metal containers, D_1 and D_2, which are called dees , inside which , the magnetic field makes it go round in a circular path .

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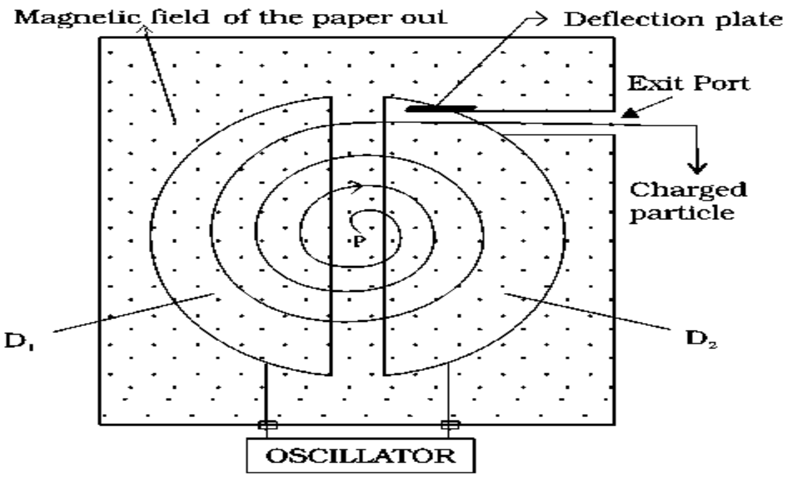
Every time the particle moves from one dee to another it is acted upon by the electric field. The particle is always accelerated in the gap between the dees , by an electric field , whose sign is changed alternately in tune with the circular motion of the particle. Each time the acceleration increases the energy of the particle. As energy increases, the radius of the circular path increases. So the path is a spiral one.



As shown in figure above , a positively charged particles (e.g., protons) are released at the centre P. They move in a semi-circular path in one of the dees and arrive in the gap between the dees in a time interval T/2; where T, the period of revolution, is given by $T = \frac{1}{\nu_c} = \frac{2\pi m}{qB}$ or $\nu_c = \frac{qB}{2\pi m}$

This frequency is called the cyclotron frequency .

The frequency ν_a of the applied voltage is adjusted so that the polarity of the dees is reversed in the same time that it takes the ions to complete one half of the revolution. The requirement $\nu_a = \nu_c$ is called the resonance condition.

It is clear that the radius of their path goes on increasing each time their kinetic energy increases.

The ions are repeatedly accelerated across the dees until they have the required energy to have a radius approximately that of the dees. They are then deflected by a magnetic field and leave the system via an exit slit. Hence, the kinetic energy of the ions is,

$$\frac{1}{2}mv^2 = \frac{q^2B^2R^2}{2m} \quad \text{as} \quad v = \frac{qBR}{m}$$

where R is the radius of the trajectory at exit, and equals the radius of a dee.

Uses – (i)The cyclotron is used to bombard nuclei with energetic particles, so accelerated by it, and study the resulting nuclear reactions.

(ii)It is also used to implant ions into solids and modify their properties or even synthesise new materials. It is used in hospitals to produce radioactive substances which can be used in diagnosis and treatment.

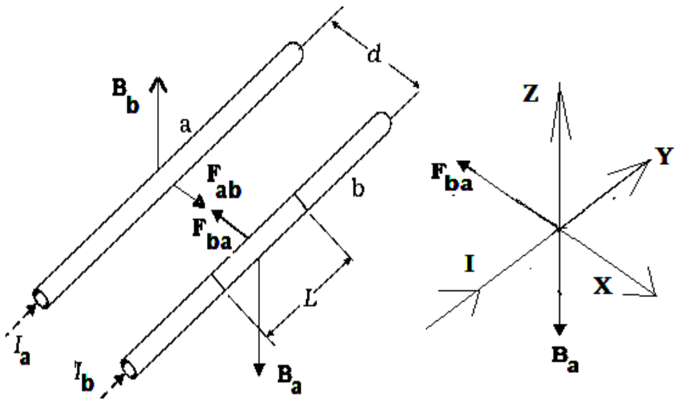
Q: Prove that Biot-Savart law and the Lorentz force yield results in accordance with Newton's third Law.

Or Prove that , Parallel currents attract, and antiparallel currents repel , flowing through two infinite conductors .

Or Find the expression for force existing per unit length between two current carrying infinite conductors .

Define 1 Ampere from it .

FORCE BETWEEN TWO PARALLEL CURRENTS ,DEFINETION OF AMPERE



Let us consider two long parallel conductors a and b separated by a distance d and carrying (parallel)currents I_a and I_b, respectively. The conductor 'a' produces the magnetic field B_a at all points along the conductor 'b', which is in downward direction (along – ve Z axis).

$$B_a = \frac{\mu_0 I_a}{2\pi d} \quad \ldots\ldots \quad \ldots\ldots\ldots..1$$

The force , F_{ba} acting on a segment L of 'b' due to 'a' is given as $F_{ba} = I_b L B_a = \frac{\mu_0 I_a I_b}{2\pi d} L$ …………2

Similarly, the conductor 'b' produces the magnetic field B_b at all points along the conductor 'a', which is in upward direction (along positive Z axis).

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$B_b = \frac{\mu_0 I_b}{2\pi d}$ ……………………….3

The force ,F_{ab} acting on a segment L of 'a' due to 'b' is given as $F_{ab} = I_a L B_b = \frac{\mu_0 I_a I_b}{2\pi d} L$ ………..4

$\vec{F}_{ba}$ and $\vec{F}_{ab}$ are equal in magnitude and acting towards

each other , so $\vec{F}_{ba} = -\vec{F}_{ab}$ ………..5

Since it is consistent with Newton's third Law , so the Biot-Savart law and the Lorentz force are in accordance with Newton's third Law.

So we can conclude from eq (5) that parallel currents attract each other. Similarly the oppositely directed currents repel each other. **Thus, Parallel currents attract, & antiparallel currents repel**.

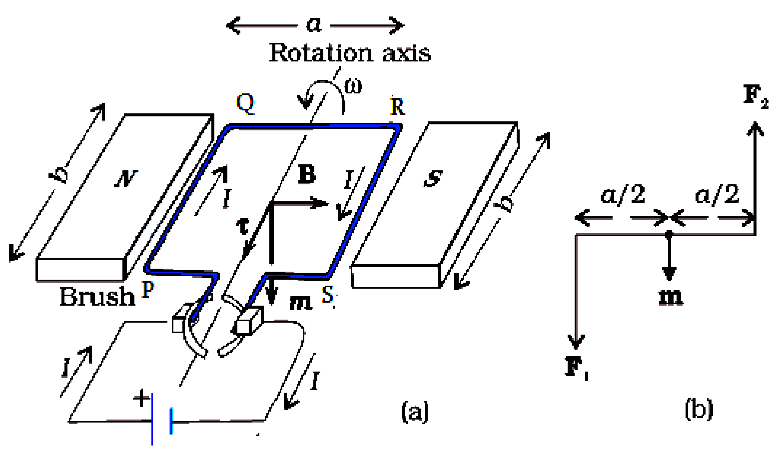
Let f_{ba} represent the magnitude of the force F_{ba} per unit length. Then, from Eq. (4) $f_{ba} = \frac{\mu_0 I_a I_b}{2\pi d}$

The ampere is the value of that steady current which, when maintained in each of the two very long, straight, parallel conductors of negligible cross-section, and placed one metre apart in vacuum, would produce on each of these conductors a force equal to 2×10^{-7} newtons per metre of length.

An instrument called the current balance is used to measure this mechanical force.

Torque on a rectangular current loop in a uniform magnetic field

(i) when the plane of the loop ,is along the magnetic field



Let us consider a uniform magnetic field $\vec{B}$, placed in the plane of a rectangular loop PQRS ,as shown in Fig(a). The field exerts no force on the two arms PS and QR of the loop. It is perpendicular to the arm PQ and exerts a force F_1 , which is directed into the plane of the loop.

Its magnitude is, $\mathbf{F_1 = \mathit{I}\, b\, B}$…………………1

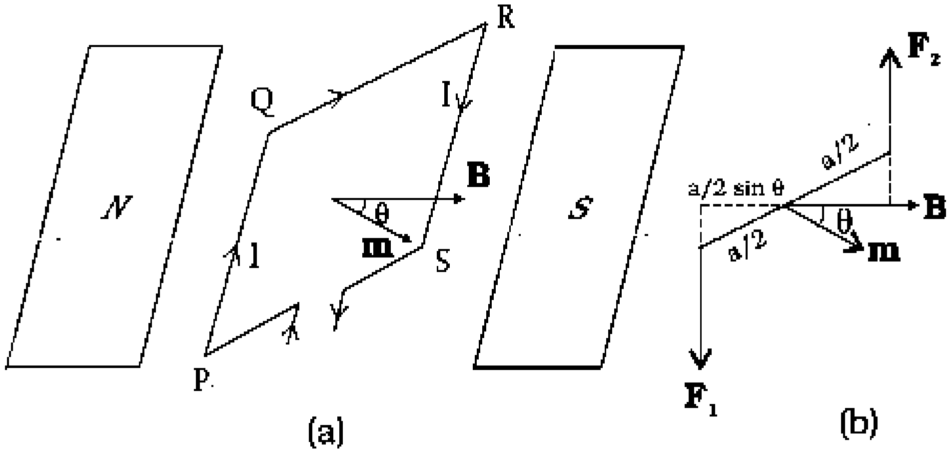
Similarly it exerts a force F_2 on the arm RS, directed out of the plane of the paper ,

$\mathbf{F_2 = I\, b\, B = F_1}$ 2

Thus, the net force on the loop is zero , & a torque is created on the loop due to the pair of F_1 and F_2. Figure(b) shows a view of the loop from the PS end , showing a torque on it , tending to rotate it anti-clockwise. This torque is (in magnitude),

$$\tau = F_1\frac{a}{2} + F_2\frac{a}{2} = IbB\frac{a}{2} + IbB\frac{a}{2} = I(ab)B = IAB$$ [where A = ab is the area of the rectangle] ………..3

(ii) when the plane of the loop ,is not along the magnetic field, but makes an angle with it.



Let the angle between the magnetic field $\vec{B}$ and the normal to the coil PQRS of area A be θ , The forces on the arms QR and SP are equal, opposite, and act along the axis of the coil, so , they cancel each other, resulting in no net force or torque.

The forces on arms PQ and RS are F_1 and F_2. They are equal and opposite ,but having different line of action and with magnitude, $\mathbf{F_1 = F_2 = I\, b\, B}$ **.**

So $\mathbf{F_1}$ and $\mathbf{F_2}$ will constitute a couple on the loop, whose magnitude is,

$$\tau = F_1\frac{a}{2}\sin\theta + F_2\frac{a}{2}\sin\theta = I\,ab\,B\sin\theta = IAB\sin\theta$$

The torque can be expressed as vector product of the magnetic moment of the coil and the magnetic field.

$\vec{\tau} = \vec{m} \times \vec{B}$, where magnetic moment of the current loop is $\vec{m} = I\vec{A}$, directed ⊥ to the plane of coil

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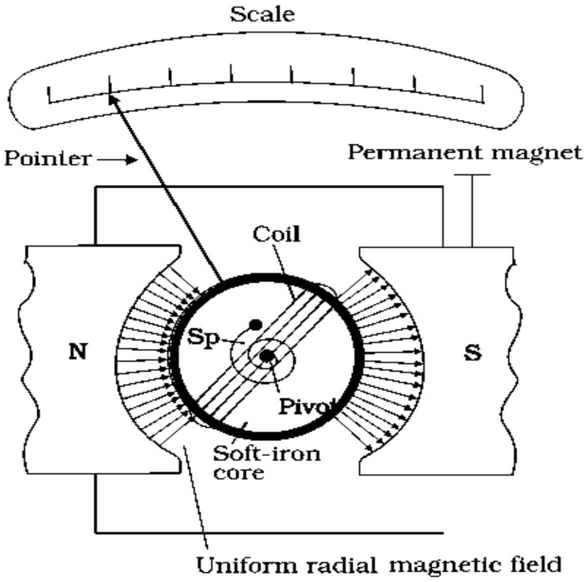
THE MOVING COIL GALVANOMETER



The galvanometer consists of a coil, with many turns, free to rotate about a fixed axis , in a uniform radial magnetic field. There is a cylindrical soft iron core which not only makes the field radial but also increases the strength of the magnetic field. When a current flows through the coil, a torque acts on it. This torque is given by

$$\tau = NI\,AB\sin\theta \quad .....1$$

where the symbols have their usual meaning. Since the field is radial by design, we have taken $\sin\theta = 1$ in (1) ,the magnetic torque NIAB tends to rotate the coil. A spring $\mathbf{S_p}$ provides a counter torque $k\varphi$ that balances the magnetic torque NIAB; resulting in a steady angular deflection φ. In equilibrium

$$k\varphi = NI\,AB \quad ....2$$

where k is the torsional constant of the spring; i.e. the restoring torque per unit twist.

The deflection φ is indicated on the scale by a pointer attached to the spring.

We have $\phi = \left(\frac{NAB}{k}\right)I$ 3

This is the working principle of the moving coil galvanometer .

Since N,B,A and k are constants $\phi \propto I$,

The deflection produced in the coil , placed in a uniform magnetic field is directly proportional to the current flowing through the coil .

Current sensitivity of the galvanometer:

Current sensitivity of the galvanometer is defined as the deflection per unit current.

The current sensitivity is, $\frac{\phi}{I} = \frac{NAB}{k}$

A convenient way for the manufacturer to increase the sensitivity is to increase the number of turns N.

Voltage sensitivity of the galvanometer;

Voltage sensitivity is defined as the deflection per unit voltage.

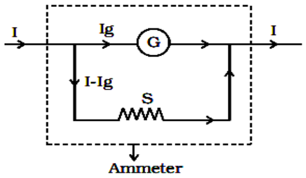
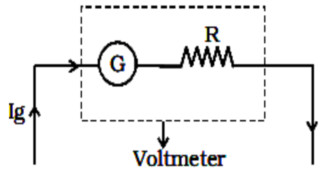
$$\frac{\phi}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V} = \left(\frac{NAB}{k}\right)\frac{1}{R}$$

Why increasing the current sensitivity does not necessarily, increase the voltage sensitivity ?

When the number of turns (n) of the coil is doubled, current sensitivity is also doubled. But increasing the number of turns also increases the resistance of the coil. Hence voltage sensitivity remains unchanged.

Why resistance of a voltmeter should be very large ?

R_v is very large, and hence a voltmeter is **connected in parallel** in a circuit as it **draws the least current** from the circuit. In other words, the resistance of the **voltmeter should be very large** compared to the resistance across which the voltmeter is connected to measure the potential difference. Otherwise, the voltmeter will draw a large current from the circuit and hence the current through the remaining part of the circuit decreases. In such a case the potential difference measured by the voltmeter is very much less than the actual potential difference. The error is eliminated only when the voltmeter has a high resistance.

Conversion of galvanometer into an ammeter :-	**Conversion of galvanometer into a voltmeter**
	
A ammeter is a device used to measure the current flowing in a circuit which is a low resistance instrument	A voltmeter is a device used to measure the potential difference between two points in a circuit. It is having a high resistance
A galvanometer can be converted into ammeter by connecting a low resistance called shunt (s) which allows only that much of current flowing through the galvanometer which is sufficient for full scale deflection (I_g) and the remaining ($I - I_g$) can flow through the shunt From ohm's law **,** **p.d across G = p.d across S** => $I_gG = (I - I_g)S$ => $S = I_gG / (I - I_g)$ …..1 This is the value of shunt to be connected in parallel with the galvanometer	A galvanometer can be converted into a voltmeter by connecting high resistance R in series with the galvanometer which will allow only that much of current through the galvanometer which is just sufficient for full scale deflection and the remaining can flow through the points to measure the potential difference. If V be the p.d to be measured , By ohm's law , $I_gR + I_gG = V$ => $I_gR = V - I_gG$ => $R = \frac{V}{I_g} - G$ …….1 From the equation the resistance to be connected in series with the galvanometer is calculated
An ideal ammeter is one which has zero resistance.	**An ideal voltmeter is one which has infinite resistance**
Effective resistance of the ammeter R_a is **($G \parallel S$)** $\frac{1}{R_a} = \frac{1}{G} + \frac{1}{S}$ => $R_a = \frac{GS}{G+S}$	**Effective resistance of voltmeter** $R_V = R + G$