CHAPTER 4
MOVING CHARGES AND MAGNETISM

- **Christian Oersted** discovered magnetic field surrounding a current carrying wire.
- The direction of the magnetic field depends on the direction of current.
- The laws of electricity and magnetism were unified and formulated by James Maxwell who then realized that light was electromagnetic waves.
- **Radio waves** were discovered by **Hertz** and produced by **J C Bose** and **G Marconi**

Magnetic Lorentz force

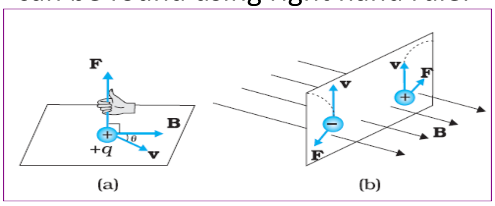
- Force on charge moving in a magnetic field.
  $F = qvB\sin\theta$, q –charge, v- velocity, B – magnetic field, θ- angle between v and B.
- Or $F = q(v\times B)$

Special Cases:

- **If the charge is at rest**, i.e. v = 0, then F = 0.
- Thus, a stationary charge in a magnetic field does not experience any force.
- **If θ = 0° or 180°** i.e. if the charge moves parallel or anti-parallel to the direction of the magnetic field, then F = 0.
- **If θ = 90°** i.e. if the charge moves perpendicular to the magnetic field, then the force is maximum.
  $$F_{\max} = qvB$$

Right Hand Thumb Rule

- The direction of magnetic Lorentz force can be found using right hand rule.



Work done by magnetic Lorentz force

- The magnetic Lorentz force is given by $F = q(v\times B)$
- Thus F, is perpendicular to v and hence perpendicular to the displacement.
- Therefore the work done $W = Fd\cos 90 = 0$
- Thus **work done by the magnetic force** on a moving charge is **zero.**
- The change in kinetic energy of a charged particle, when it is moving through a magnetic field is zero.
- The magnetic field can change the direction of velocity of a charged particle, but not its magnitude.

Lorentz force

- Force on charge moving in combined electric and magnetic field.
- $F = qE + q(v\times B) = q\left[E + (v\times B)\right]$

Units of magnetic field (magnetic induction or magnetic flux density)

- SI unit is **tesla (T)**
- Other unit is **gauss(G)**
- **1 gauss =10^{-4} tesla**
- **The earth's magnetic field is about 3.6×10^{-5} T**

Definition of Tesla

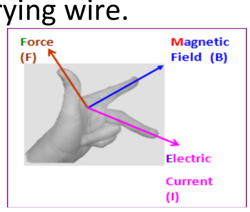
- The magnetic induction (B) in a region is said to be one tesla if the force acting on a unit charge (1C) moving perpendicular to the magnetic field (B) with a speed of 1m/s is one Newton.

Force on a current carrying wire in a magnetic field

- The total number of charge carriers in the conductor = n Al
- Where, n-number of charges per unit volume, A-area of cross section, l-length of the conductor.
- If e is the charge of each carrier , the total charge is $Q = enAl$
- The magnetic force is $F = Q(v\times B)$
- Where v – drift velocity
- Thus $F = enAl(v\times B) = nAve(l\times B)$
- Thus
  $$F = IlB\sin\theta$$
- Since $I = nAve$
- When θ=0 , F=0
- When θ=90^0, F = IlB

Fleming's left hand rule

- A rule to find the direction of the force n a current carrying wire.

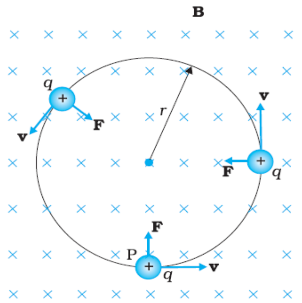


- Fore finger – direction of magnetic field
- Middle finger –direction of current
- Thumb – direction of force.

Motion of a charged particle in a Magnetic field

Velocity perpendicular to B

- Charged particle **entering perpendicular** to a magnetic field undergoes **circular motion.**
- The perpendicular force qvB acts as a centripetal force.



Frequency of circular motion

- We have centripetal force **$mv^2/r = qvB$**
- The radius of the circle described by the particle.

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

- The time period of rotation is

$$T = \frac{2\pi r}{v} = \frac{2\pi mv}{qBv} = \frac{2\pi m}{qB}$$

- Thus the frequency

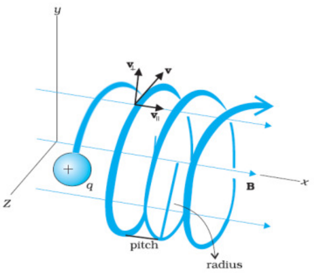
$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

- This frequency is called **cyclotron frequency.**
- The angular frequency is given by

$$\omega = 2\pi f = \frac{2\pi qB}{2\pi m} = \frac{qB}{m}$$

When the initial velocity makes an arbitrary angle with the field direction

- Charged particle **entering at an angle** to a magnetic field undergoes **helical path**.



- The component of velocity along B remains unchanged.
- The motion in the plane perpendicular to B is circular.
- The charged particle continues to move along the field with a constant velocity.
- Therefore the resultant path of the particle is helix.
- The linear distance travelled by the charged particle in the direction of the magnetic field during its period of revolution is called ***pitch*** of the helical path.

$$p = Tv\cos\theta = \frac{2\pi mv\cos\theta}{qB}$$

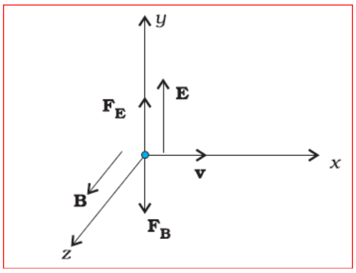
- The radius of the circular component of motion is called ***radius of the helix.***
- A natural phenomenon due to the helical motion of charged particles is ***Aurora Boriolis.***

Motion in combined Electric and Magnetic Fields

Velocity Selector

- The Lorentz force acting on a charged particle is

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) = \mathbf{F}_E + \mathbf{F}_B$$



- When B is perpendicular to E

$$\mathbf{E} = E\,\hat{\mathbf{j}},\ \mathbf{B} = B\,\hat{\mathbf{k}},\ \mathbf{v} = v\,\hat{\mathbf{i}}$$

$$\mathbf{F}_E = q\mathbf{E} = qE\,\hat{\mathbf{j}},\ \mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$$

$$= q\left(v\,\hat{\mathbf{i}} \times B\hat{\mathbf{k}}\right) = -qB\,\hat{\mathbf{j}}$$

$$\text{Therefore, } \mathbf{F} = q(E - vB)\,\hat{\mathbf{j}}$$

- The total force on the charge is zero, when $qE = qvB$
- Thus $v = \dfrac{E}{B}$
- The crossed E and B fields serve as a velocity selector.
- Only particles with speed E/B pass undeflected through the region of crossed fields.
- This method was employed by J J Thomson to measure ***e/m*** ratio of an electron.

- This principle is also employed in Mass Spectrometer-a device that separates charged particles, usually ions, according to their charge to mass ratio.

Cyclotron

- Device to accelerate charged particles.
- Designed by E O Lawrence and M S Livingston.

Principle / Theory

- A charged particle can be accelerated to very high energies by passing through a moderate electric field number of times.
- This can be done with the help of a perpendicular magnetic field which throws the charged particle into a circular motion.

Cyclotron frequency

- We have centripetal force **$mv^2/r = qvB$**
- The radius of the circle described by the particle.

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

- The time period of rotation is

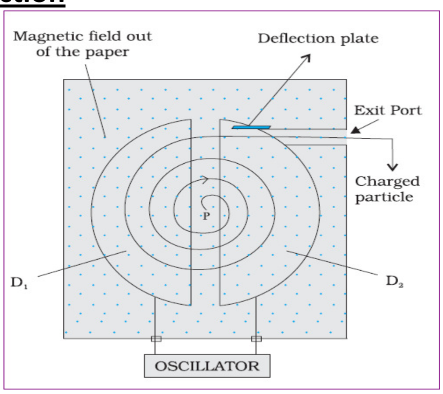
$$T = \frac{2\pi r}{v} = \frac{2\pi mv}{qBv} = \frac{2\pi m}{qB}$$

- Thus the frequency

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

- Cyclotron frequency is, $f = \frac{qB}{2\pi m}$

Construction



- The whole device is in high vacuum so that air molecules do not collide with charged particles.

Working

- The positive ion entering the gap between two dees gets accelerated towards D_1 if it is negative.
- The perpendicular magnetic field throws it into a circular path.
- If D_1 becomes positive and D_2 negative it accelerates towards D_2 and moves faster describing a larger semicircle than before.
- If the frequency of the applied voltage is is same as the frequency of revolution of charged particle then every time the particle reaches the gap between the dees the electric field is reversed and particle receives a push and finally it acquires very high energy.
- In a cyclotron the charged particle follows **a spiral path**.

Cyclotron's Resonance Condition

- The condition in which the frequency of the applied voltage is equal to the frequency of revolution of charged particle.

Maximum Kinetic Energy

- We have $mv^2/R = qvB$
  Therefore $v = qBR/m$
- Thus the kinetic energy

$$K = \frac{1}{2}mv^2 = \frac{q^2B^2R^2}{2m}$$

- Where , q- charge, B- magnetic field, R – radius, m- mass.

Limitations of cyclotron

- According to special theory of relativity

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

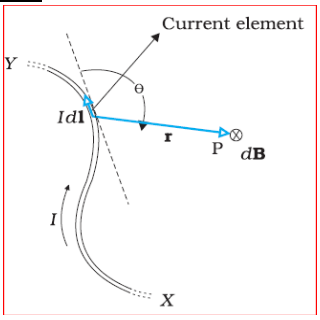
- At high velocities the cyclotron frequency will decrease due to increase in mass and the particle will become out of resonance.
- This can be overcome by
  - **Increasing magnetic field –** Synchrotron
  - **Decreasing the frequency of ac –** Synchro-Cyclotron
- Electrons cannot be accelerated
- Neutrons being electrically neutral cannot be accelerated in a cyclotron.

Uses

- To study nuclear structure – high energy particles from cyclotron are used to bombard nuclei.
- To generate high energy particles
- To implant ions in to solids.

- To produce radioactive isotopes used in hospitals.

Biot-Savart Law



- The magnetic field at a point due to the small element of a current carrying conductor is
- directly proportional to the current flowing through the conductor (I)
- The length of the element dl
- Sine of the angle between r and dl
- And inversely proportional to the square of the distance of the point from dl.
- Thus the magnetic field due to a current element is

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

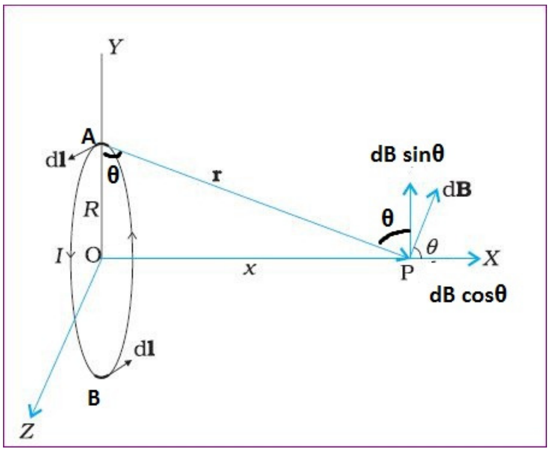
- μ_0-permeability of free space, I – current, r- distance
- or $dB = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\vec{r}}{r^3}$
- where , $\frac{\mu_0}{4\pi} = 10^{-7}Tm/A$
- The direction of magnetic field is given by right hand rule.

Comparison between Coulomb's law and Biot-Savart's law

Coulomb's law	Biot – Savart's law
$F = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{r^2}$	$\boxed{dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}}$
Electric field is due to scalar source	Magnetic field is due to vector source
Electric field is present everywhere	Along the direction of current magnetic field is zero

Applications of Biot-Savart Law

Magnetic Field on the Axis of a Circular Current Loop



- The magnetic field at P due to the current element dl , at A is

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin 90^0}{r^2} = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}$$

- The component dB cos**θ** is cancelled by the diametrically opposite component.
- Thus magnetic field at P ,due to the current element is the x- component of dB.
- Therefore $dB_x = dB\cos\theta$

$$dB_x = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}\cos\theta$$

- But we have $r = \left(x^2+R^2\right)^{1/2}$ and

$$\cos\theta = \frac{R}{\left(x^2+R^2\right)^{1/2}}$$

- Therefore

$$dB_x = \frac{\mu_0}{4\pi}\frac{Idl}{(x^2+R^2)}\frac{R}{(x^2+R^2)^{1/2}}$$

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

- The summation of the current elements dl over the loop gives , the circumference 2πR.
- Thus the total magnetic field at P due to the circular coil is

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

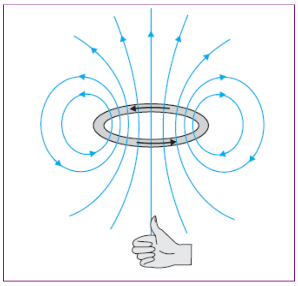
- Therefore

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

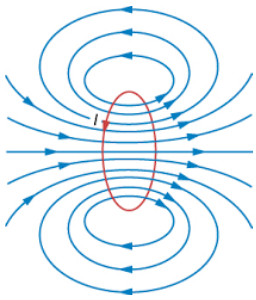
- **At the centre of the loop** x=0, thus,

$$B_0 = \frac{\mu_0 I}{2R}$$

- The direction of the magnetic field due to a circular coil is given by ***right-hand thumb rule***.
- Curl the palm of your right hand around the circular wire with the fingers pointing in the direction of current. Then the right hand thumb gives the direction of magnetic field.



Magnetic field lines due to a circular current loop



Relation Connecting Velocity of Light , Permittivity and Permeability

- We have

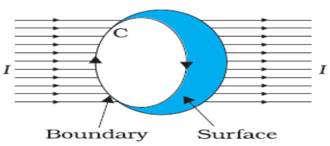
$$\varepsilon_0\mu_0 = \frac{4\pi\varepsilon_0}{1}\left(\frac{\mu_0}{4\pi}\right) = \frac{10^{-7}}{9\times10^{9}} = \frac{1}{9\times10^{16}}$$

- Thus $\varepsilon_0\mu_0 = \dfrac{1}{\left(3\times10^{8}\right)^2} = \dfrac{1}{c^2}$
- Where c – speed of light in vacuum.
- Therefore the speed of light is given by

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

- In general , $v = \dfrac{1}{\sqrt{\varepsilon\mu}}$

Ampere's Circuital Law



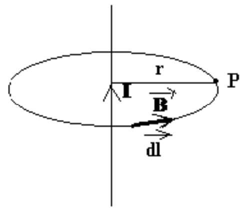
- The closed line integral of magnetic field is equal to μ_0 times the total current.

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

- The closed loop is called ***Amperian Loop.***

Applications Of Ampere's Circuital Law

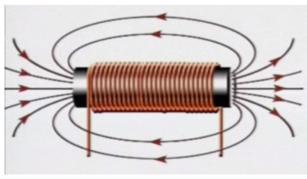
1. **Magnetic field due to a straight wire**



- Over the Amperian loop B and dl are along the same direction.
- Thus $\oint_l B.dl = \oint_l Bdl\cos 0 = B\oint_l dl$
- That is $\oint_l B.dl = B(2\pi r)$
- From ampere's circuital law , $B\times 2\pi r = \mu_0 I$
- Thus $B = \dfrac{\mu_0 I}{2\pi r}$

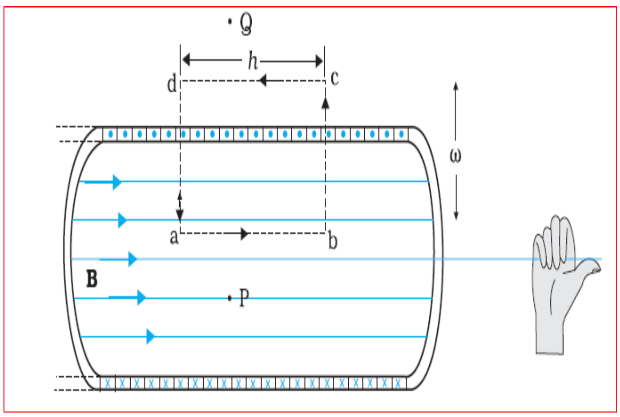
2. **Magnetic field due to a solenoid**

Solenoid



- A solenoid is an insulated copper wire closely wound in the form of a helix
- When current flows through the solenoid, it behaves as a bar magnet.
- For a long solenoid, the field outside is nearly zero.
- A solenoid is usually used to obtain a uniform magnetic field.
- If the current at one end of the solenoid is in the anticlockwise direction it will be the North Pole and if the current is in the clockwise direction it will be the South Pole.

Expression for magnetic field inside a solenoid



- Consider an amperian loop **abcda**
- The magnetic field is zero along cd,bc and da.
- The total number of turns of the solenoid is $N = nh$, where n – number of turns per unit length, h –length of the amperian loop.
- Therefore the total current enclosed by the loop is $I_e = nhI$,
- where, I –current in the solenoid
- Using Ampere's circuital law

$$\oint_l B.dl = Bh = \mu_0 I_e$$

$$Bh = \mu_0 nhI$$

- Therefore , the magnetic field inside the solenoid is

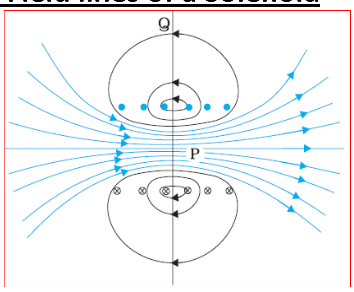
$$B = \mu_0 nI$$

- The direction of the field is given by ***Right Hand Rule.***

The magnetic field due to a solenoid can be increased by

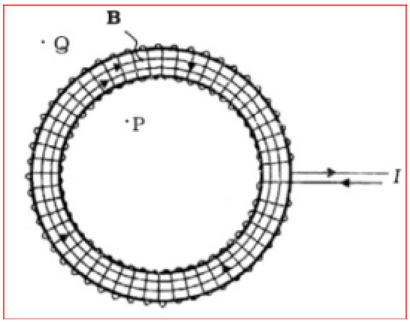
i) Increasing the no. of turns per unit length (n)
ii) Increasing the current (I)
iii) Inserting a soft iron core into the solenoid.

Magnetic Field lines of a Solenoid



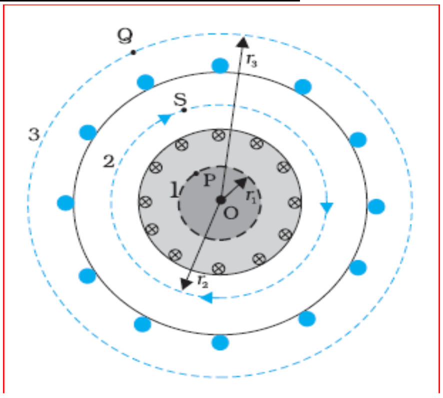
3. Magnetic Field due to a Toroid

Toroid



- Toroid is a hollow circular ring on which a large number of turns of a wire are closely wound.
- The magnetic field in the open space inside (point P) and exterior to the Toroid (point Q) is zero.
- The field B is constant inside the Toroid.

Magnetic Field due to a Toroid



For points interior (P)

- Length of the loop 1 , $L_1 = 2\pi r_1$
- The current enclosed by the loop = 0.
- Therefore

$$\boxed{B_1 (2\pi r_1) = \mu_0(0), \quad B_1 = 0}$$

- Magnetic field at any point in the interior of a toroid is **zero**.

For points inside (S)

- Length of the loop , $L_2 = 2\pi r_2$
- The total current enclosed $= N I$, where N is the total number of turns and I the current.
- Applying Ampere's Circuital Law and taking $r_2 = r$

$$B(2\pi r) = \mu_0 NI$$

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

- Or

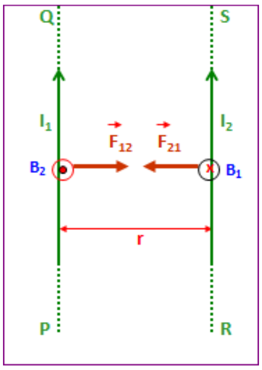
$$B = \mu_0 nI$$

- Where $n = \dfrac{N}{2\pi r}$

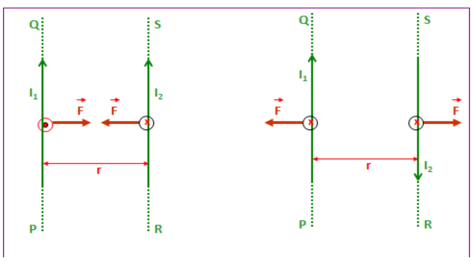
For points Exterior(Q)

- Each turn of the Toroid passes twice through the area enclosed by the Amperian Loop 3.
- For each turn current coming out of the plane of the paper is cancelled by the current going into the plane of paper.
- Therefore ***I = 0, B = 0***.

Force between two parallel wires



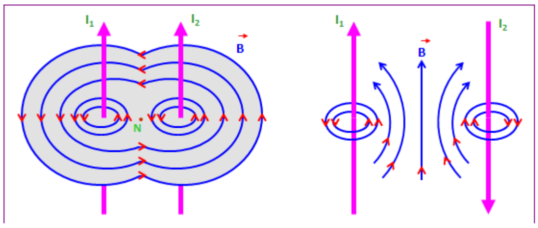
- Magnetic Field on RS due to current in PQ is
  $B_1 = \frac{\mu_0 I_1}{2\pi r}$ (Acts into the plane of diagram)
- B_1 acts perpendicular and into the plane of the diagram by Right Hand Thumb Rule
- Magnetic Field on PQ due to current in RS is
  $B_2 = \frac{\mu_0 I_2}{2\pi r}$ (Acts out to the plane of diagram)
- Force acting on PQ due to current I_1 through it is
  $$F_{12} = \frac{\mu_0 I_2}{2\pi r} I_1 l \sin 90^0 = \frac{\mu_0 I_2 I_1 l}{2\pi r}$$
  $$F_{12} = \frac{\mu_0 I_2 I_1 l}{2\pi r}$$
- Force acting on RS due to current I_2 through it is
  $$F_{21} = \frac{\mu_0 I_1}{2\pi r} I_2 l \sin 90^0 = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$
  $$F_{21} = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$
- Thus $F_{12} = F_{21} = F = \frac{\mu_0 I_1 I_2 l}{2\pi r}$
- Force per unit length of the conductor is
  $$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$
- **<u>Parallel currents attracts</u>** and **<u>anti-parallel currents repels.</u>**



Definition of Ampere

- Force per unit length of the conductor is
  $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$ N/m
- When $I_1 = I_2 = 1$ Ampere and r = 1 m, then F = 2 x 10^{-7} N/m.
- **One ampere is that current which, if passed in each of two parallel conductors of infinite length and placed 1 m apart in vacuum causes each conductor to experience a force of 2 x 10^{-7} Newton per metre of length of the conductor.**

Magnetic field lines of parallel wires

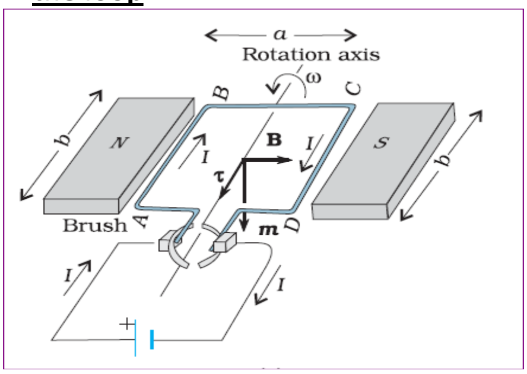


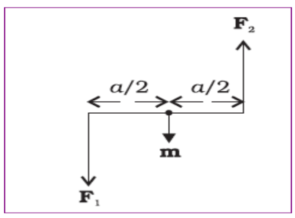
Magenetic dipole moment due to a current

- It is the product of current and area
- Magnetic dipole moment, $m = IA$
- For a coil of N turns, $m = NIA$
- The dimensions of the magnetic moment are [A][L^2] and its unit is Am^2.

Torque on a rectangular current loop in a uniform magnetic field

❖ **<u>When magnetic field is in the plane of the loop</u>**





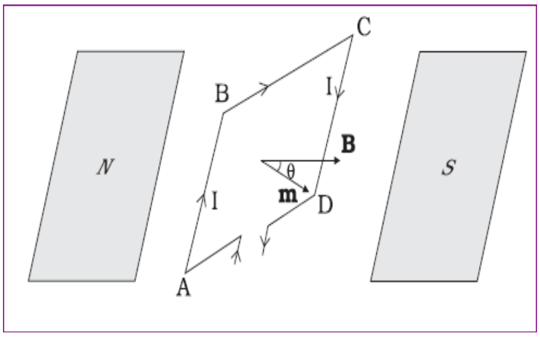
- We have, the force acting on a conductor kept in a magnetic field
  $$F = IlB \sin\theta$$

- The field exerts no force on the two arms AD and BC of the loop.
- The force on the arm AB is
  $F_1 = IbB$ (into the plane of loop)
- The force on the arm CD is
  $F_2 = IbB$ (out of the plane of loop)
- Thus the net force on the loop is zero.
- The torque on the loop is

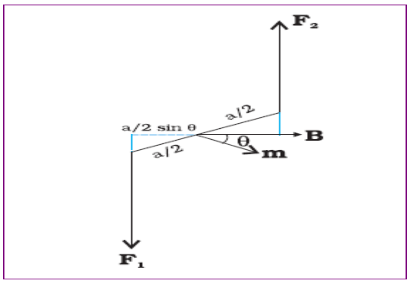
$$\boxed{\tau = F_1 \frac{a}{2} + F_2 \frac{a}{2}}$$

$$\tau = IbB\frac{a}{2} + IbB\frac{a}{2} = I(ab)B$$

- Or $\tau = IAB$, where A = ab – area
- Also $\tau = mB$, where $m = IA$, magnetic moment.
- **When magnetic field makes an angle with the plane of the loop**



- The forces on the arms BC and DA are equal, opposite, and act along the axis of the coil, and hence cancel each other.
- The forces on AB and CD are
  $F_1 = F_2 = IbB$



- Thus the torque is

$$\boxed{\tau = F_1 \frac{a}{2}\sin\theta + F_2 \frac{a}{2}\sin\theta}$$

- $\tau = IbB\frac{a}{2}\sin\theta + IbB\frac{a}{2}\sin\theta = I(ab)B\sin\theta$

  or $\tau = IAB\sin\theta$

  $\tau = mB\sin\theta$, m- magnetic moment
- Thus $\tau = m \times B$

Circular current loop as a magnetic dipole

- We have the magnetic field on the axis of a circular loop

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

- For x>>R,

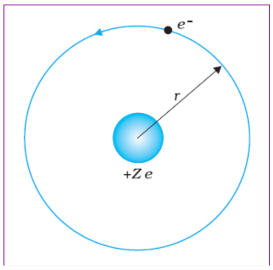
$$B = \frac{\mu_0 IR^2}{2x^3}$$

- Thus $B = \frac{\mu_0 I\left(\pi R^2\right)}{2\pi x^3} = \frac{\mu_0 IA}{2\pi x^3}$, where A – Area of the loop.
- Or $B = \frac{\mu_0 m}{2\pi x^3} = \frac{\mu_0}{4\pi}\frac{2m}{x^3}$
- This expression is similar to the electric field due to a dipole in the axial point.
- Similarly the magnetic field at a point on the plane of the loop is

$$B = \frac{\mu_0}{4\pi}\frac{m}{x^3}$$

- Thus a current loop produces magnetic field and behaves like a magnetic dipole at large distances.

Magnetic dipole moment of a revolving electron



- The current due to the revolution of electron is $I = \frac{e}{T}$, where e – electronic charge, T – time period of revolution.
- We have $T = \frac{2\pi r}{v}$, r – radius of orbit, v – orbital velocity.
- Thus $I = \frac{ev}{2\pi r}$
- The magnetic moment associated with this circulating current is

$$\mu_l = I\left(\pi r^2\right) = \frac{ev}{2\pi r}\left(\pi r^2\right)$$

$$\mu_l = \frac{evr}{2}$$

- The direction of the magnetic moment is into the plane of the paper.
- Multiplying and dividing RHS of the above equation with mass of electron m_e, we get

$$\mu_l = \frac{em_e vr}{2m_e}$$

Or $\mu_l = \frac{el}{2m_e}$, where *l*- orbital angular momentum of the electron.

- Vectorially

$$\boxed{\mu_l = -\frac{e}{2m_e}\mathbf{l}}$$

- The negative sign indicates that the angular momentum of the electron is opposite in direction to the magnetic moment.

Gyromagnetic ratio

$$\boxed{\frac{\mu_l}{l} = \frac{e}{2m_e}}$$

- Its value is 8.8×10^{10} C /kg for an electron

Bohr magneton

- According to Bohr quantization condition , the angular momentum of an electron is given by

$$\boxed{l = \frac{nh}{2\pi}}$$

Where h – Planck's constant, n =1, 2,3..

- Thus , $\mu_l = \frac{enh}{4\pi m_e}$
- The value of magnetic dipole moment of an electron for n=1 is called **Bohr magneton.**
- Thus for n= 1

$$\mu_l = \frac{eh}{4\pi m_e}$$

- Substituting the values we get

$$\mu_l = \frac{eh}{4\pi m_e} = \frac{1.6\times10^{-19}\times6.63\times10^{-34}}{4\times3.14\times9.11\times10^{-31}} = 9.27\times10^{-24}\,Am^2$$

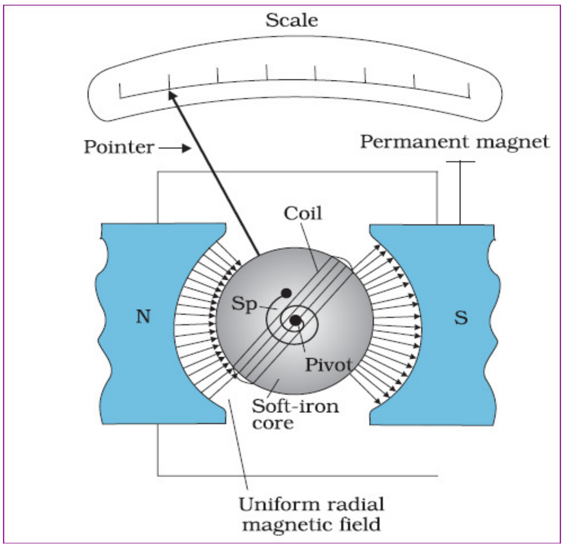
- Any charge in uniform circular motion would have an orbital magnetic moment.
- Besides the orbital moment an electron has an **intrinsic magnetic moment** called **spin magnetic moment**.

Moving coil galvanometer (MCG)

- Device to know presence of current.
- With simple modifications, it can be used to measure current and voltage.

Construction

- 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.



Principle /Theory

- Works on the torque acting on a rectangular loop in a magnetic field.
- The torque on a coil of N turns is given by $\tau = NIAB\sin\theta$
- As the magnetic field is radial , $\theta=90^0$
- Therefore $\tau = NIAB$
- This magnetic torque tends to rotate the coil.
- A spring Sp provides a counter torque $k\phi$.
- Thus in equilibrium

$$k\phi = NIAB$$

- where *k* is the torsional constant of the spring (the restoring torque per unit twist)
- The deflection ϕ is indicated on the scale by a pointer attached to the spring.
- Thus $\phi = \left(\frac{NAB}{k}\right)I$
- The current, $\phi = GI$, where $G = \frac{NAB}{k}$,the galvanometer constant.
- The galvanometer cannot as such be used as an ammeter to measure the value of the current in a given circuit.

This is for two reasons:

- Galvanometer is a very sensitive device, it gives a full-scale deflection for a current of the order of µA.
- For measuring currents, the galvanometer has to be connected in series, and as it has a large resistance, this will change the value of the current in the circuit.

Current sensitivity of the galvanometer

- Ratio of deflection to the current

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

- Current sensitivity can be increased by
  - Increasing the number of turns
  - Increasing the area of the loop
  - Increasing the strength of the field
  - Decreasing the torque per unit twist.

Voltage sensitivity of the galvanometer

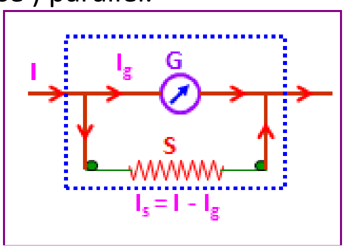
- Deflection produced per unit voltage

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

- Voltage sensitivity increases when
  - Number of turns increases
  - Area of the loop increases
  - Strength of the field increases
  - Torque per unit twist decreases
  - Resistance decreases

Conversion of galvanometer to ammeter

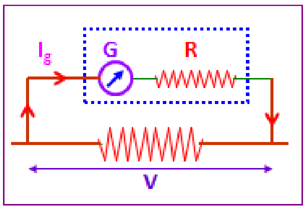
- By connecting small resistance (shunt resistance) parallel.



- Potential difference across the galvanometer and shunt resistance are equal.
- Thus $(I-I_g)S=I_gG$
- Shunt resistance $S=\dfrac{I_gG}{(I-I_g)}$

Conversion of galvanometer to voltmeter

- By connecting high resistance in series.



- Potential difference across the given load resistance is the sum of p.d across galvanometer and p.d. across the high resistance.
- Thus $V=I_g(G+R)$
- Therefore , $R=\dfrac{V}{I_g}-G$

Difference between Ammeter and Voltmeter

S.No.	Ammeter	Voltmeter
1	It is a low resistance instrument.	It is a high resistance instrument.
2	Resistance is GS / (G + S)	Resistance is G + R
3	Shunt Resistance is $(GI_g) / (I - I_g)$ and is very small.	Series Resistance is $(V / I_g) - G$ and is very high.
4	It is always connected in series.	It is always connected in parallel.
5	Resistance of an ideal ammeter is zero.	Resistance of an ideal voltmeter is infinity.
6	Its resistance is less than that of the galvanometer.	Its resistance is greater than that of the voltmeter.
7	It is not possible to decrease the range of the given ammeter.	It is possible to decrease the range of the given voltmeter.

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