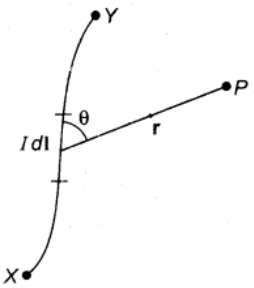
S2 Unit – 4.1 Magnetic effect of Electric Current

Scope of Syllabus

4.1 MAGNETIC EFFECT OF ELECTRIC CURRENT: Bio- Savart's law. Magnetic field: (i) for infinitely long straight current conductor, (ii) at the centre of a current carrying circular coil, (iii) for infinitely long current solenoid (no deduction, only concept and mathematical expression in S.I. units). Force on a current carrying conductor placed in a magnetic field (formula only), Fleming's left hand rule. Application of Magnetic effect of current – Galvanometer (concept only).

Biot – Savart Law :

Biot - Savart law states that the magnetic field (dB) at any point **P** due to a small current carrying element (dl) carrying current (I), at a distance r from it is :



(i) directly proportional to the current. ($dB \propto I$)

(ii) directly proportional to the length of the current element. ($dB \propto dl$)

(iii) directly proportional to the sine of angle between dl and r. ($dB \propto sin\theta$)

(iv) inversely proportional to the square of the distance r. ($dB \propto \frac{1}{r^2}$)

Combining them we have

$$dB \propto \frac{Idlsin\theta}{r^2}$$

$$or\ \boldsymbol{dB} = \frac{\boldsymbol{\mu_0}}{\boldsymbol{4\pi}} \frac{\boldsymbol{Idlsin\theta}}{\boldsymbol{r^2}}$$

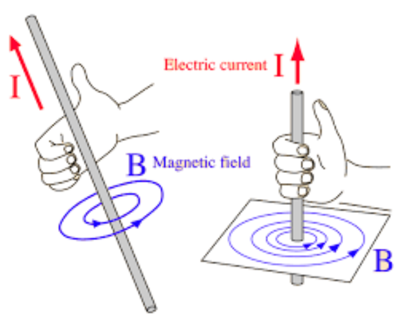
$(where\ \frac{\mu_0}{4\pi}\ is\ the\ constant\ of\ proportionality\ and\ \mu_0\ is\ a\ constant\ called\ \boldsymbol{premeability}\ of\ free\ space.$
$The\ value\ of\ \mu_0\ in\ S.I.\ is\ 4\pi \times 10^{-7}\ Wb/Am\ )$

SI Unit of Magnetic Field (B) : Weber / m² (Wb / m²) or Tesla.

Note : In vector notation the magnetic field is expressed as :

$$\overrightarrow{\boldsymbol{dB}} = \frac{\mu_0}{4\pi} \frac{I(\overrightarrow{\boldsymbol{dl}} \times \vec{\boldsymbol{r}})}{r^3}\ and\ is\ directed\ \perp r\ to\ the\ plane\ containing\ \boldsymbol{dl}\ and\ \boldsymbol{r}$$

$The\ direction\ of\ the\ magnetic\ field\ (B)\ is\ conveniently\ given\ by\ the\ \boldsymbol{Right\ Hand\ Thumb\ rule}$



Magnetic Field :

1. Due to an Infinitely long straight conductor carrying current I at a distance r from it.

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

2. At the centre of a circular coil of radius r carrying current I

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

$$or\ \boldsymbol{B} = \frac{\boldsymbol{\mu_0}}{\boldsymbol{4\pi}}\frac{\boldsymbol{2\pi NI}}{\boldsymbol{r}}\ where\ N\ is\ the\ number\ of\ turns\ of\ the\ coil$$

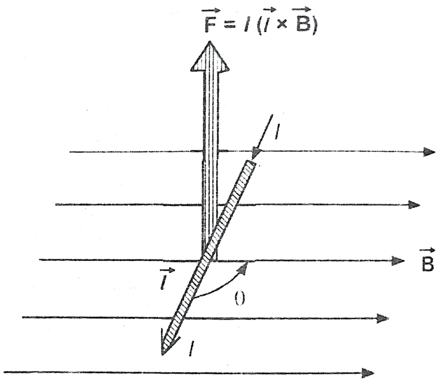
3. At the centre of a long solenoid having N number of turns and length l and carrying current I

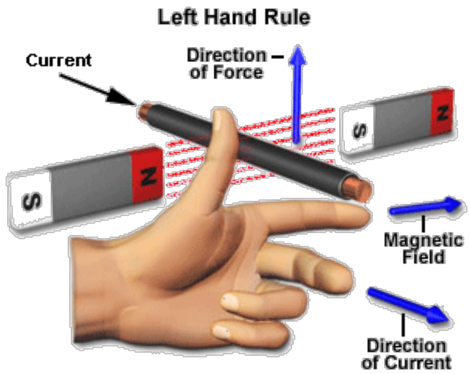
$$\boldsymbol{B} = \boldsymbol{\mu_0 nI}$$

$$where\ n\ is\ the\ number\ of\ turns\ per\ unit\ length\ of\ the\ solenoid, given\ by\ n = \frac{N}{l}$$

Force on a current carrying conductor placed in a magnetic field :

When a current carrying conductor is placed in a magnetic field, it experiences a force acting on it, the direction of which is given by Fleming's Left Hand rule.





$$\boldsymbol{Force\ (F) = IBl sin\theta}$$

$$in\ vector\ form, \vec{F} = I(\vec{l} \times \vec{B})$$

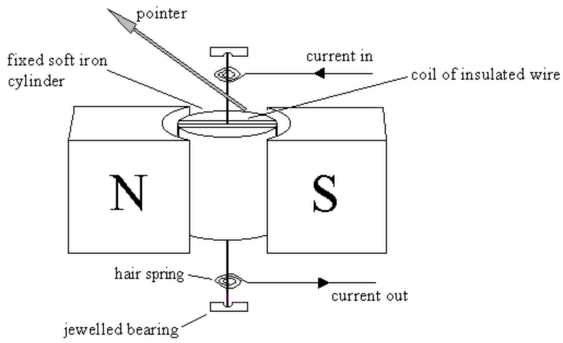
$(where\ \boldsymbol{I}\ is\ the\ current\ flowing\ in\ the\ conductor, \boldsymbol{B}\ is\ the\ magetic\ field\ and\ \boldsymbol{l}\ the\ length\ of\ conductor.$
$\boldsymbol{\theta}\ is\ the\ angle\ between\ B\ and\ l. The\ direction\ of\ the\ force\ is\ given\ by\ \boldsymbol{Fleminng's\ Left\ Hand\ rule})$

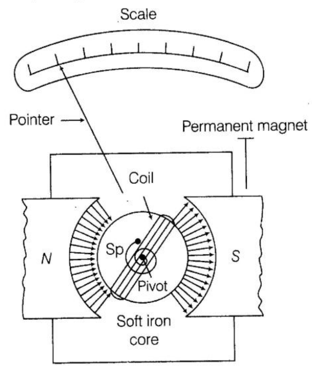
Fleming's Left hand Rule : If the thumb, index and middle fingers of the left hand are held mutually perpendicular to eachother such that the index finger points in direction of magnetic field, middle finger the direction of current, then the thumb will point in the direction of the force.

Special Cases :

1. When the conductor is placed perpendicular to the magnetic field i.e. when θ = 90˚, the force acting on the conductor is maximum and is given by $F = IBl$.
2. When the conductor is placed parallel to the magnetic field i.e. when θ = 0˚ or 180˚, the force acting on the conductor is zero i.e. $F = 0$.

Moving Coil Galvanometer





Working Principle : When a current-carrying coil is suspended in a uniform magnetic field it is acted upon by a torque. Under the action of this torque, the coil rotates and the deflection in the coil in a moving coil galvanometer is directly proportional to the current flowing through the coil.

Theory : The deflection torque acting in the galvanometer coil due to the couple formed by the equal and opposite force acting on it is given by

$$Torque\ (\tau) = \ Force\ (iBl) \times \ Perpendicular\ distance\ (b)$$

$$or\ \boldsymbol{\tau} = \boldsymbol{AIB}\ where\ A\ is\ the\ area\ of\ the\ coil\ (A = lb), B\ is\ the\ magnetic\ field\ and\ I\ is\ the\ current$$

$$for\ N\ turns\ of\ the\ coil\ we\ have\ \boldsymbol{\tau} = \boldsymbol{NAIB}$$

The rotation of the coil produces a twist in the fibre which produces a restoring torque which is directly proportional to the angle of deflection θ. Hence we have

$$\tau \propto \theta$$

$$\tau = k\theta$$

$$where\ \boldsymbol{k}\ is\ a\ constant\ called\ the\ \boldsymbol{torsional\ constant}\ or\ the\ \boldsymbol{torque\ per\ unit\ twist}.$$

In the equilibrium position (when the coil comes to rest) the restoring torque will balance the deflecting torque. So in equilibrium position of the coil, we have

$$deflecting\ torque = restoring\ torque$$

$$NAIB = k\theta$$

$$or\ \boldsymbol{I} = \left(\frac{\boldsymbol{k}}{\boldsymbol{NAB}}\right)\boldsymbol{\theta},$$

$$here\ \left(\frac{k}{NAB}\right)\ is\ a\ constant\ for\ a\ galvannometer, also\ called\ the\ \boldsymbol{galvanometer\ constant}.$$

$$or\ \boldsymbol{I} \propto \boldsymbol{\theta}$$

Thus in a moving coil galvanometer, current in the coil is directly proportional to the angle of deflection of the coil (more current flowing in the coil more is the deflection).

Sensitivity of a Galvanometer : The sensitivity of moving coil galvanometer is defined as the ratio of the change in deflection of the galvanometer to the change in the current. $Sensitivity = \frac{d\theta}{di}$. A galvanometer is said to be more sensitive if it gives larger deflection for a small current.

Sensitivity of moving coil galvanometer can be increased by (i) Increasing the number turns (N) of the coil, (ii) Increasing the area (A) of the coil (iii) increasing the magnetic induction (B) and (iv) decreasing the torsional constant (k) of the suspension fibre.

Some Previous Years Questions with Answers :

1. The magnetic field at any point due to an infinitely long straight current carrying wire is directly proportional to - (*a*) distance of the point from the wire, (*b*) diameter of the wire (*c*) resistance of the wire, (*d*) the magnitude of the current in the wire. *Answer (d)*
2. Magnetic field due to a long straight current carrying conductor is - (*a*) $(\mu_0/4\pi)2I/r$ (*b*) $(\mu_0/4\pi)I/r$ (*c*) $(\mu_0/2\pi)2I/r$ (*d*) None of these. *Answer (a)*
3. A straight conductor of length 50 cm is placed in a uniform magnetic field of 1.5 T with its length parallel to the direction of the field. If the current through the conductor be 1.0 A, the force on the conductor is - (*a*) 0.75 N, (*b*) 7.5 N, (*c*) 75.0 N, (*d*) zero. *Answer (d)*
4. An very long air-filled solenoid of length L and total number of turns N is carrying a current I. The magnetic field inside the solenoid is (μ_0= permeability of air) - (*a*) $B = \mu_0 NI$ (*b*) $B = \mu_0 NIL$ (*c*) $B = \frac{(\mu_0 NI)}{L}$ (*d*) $B = \frac{\mu_0 IL}{N}$. *Answer (c)*
5. What is the magnitude of force on a current carrying conductor placed in a magnetic field? *See Notes*
6. State Fleming's left hand rule. *See Notes*
7. State Biot Savart's law related to production of magnetic field due to a small current element. *See Notes*
8. Write down the expression for the magnetic field developed inside a long solenoid carrying a current. *See Notes*
9. Which rule gives the direction of the force on a current carrying conductor when placed in a magnetic field? State it. *See Notes (same as question 6)*
10. Two long parallel conductors carrying currents in the same direction (like currents) attract each other explain.

    A wire carrying current produces a magnetic field around it. If a second wire carrying current is brought near it, the magnetic field due to the first wire causes the second wire to experience a force acting towards the first wire. The magnetic field due to the second wire also causes the first wire to experience a force towards the second wire. Hence the wires are attracted towards eachother.

11. Why magnetic field does not apply force on a static charge?

    The force on an electric charge moving in a magnetic field is given by Lorentz force F = q (v × B), where q is the charge, v is the velocity of the charge and B is the magnetic induction field. As the velocity is zero (v = 0) in case of a static charge, the force acting on it is zero.

12. What is the work done by the magnetic field on moving charge?

    The work done by a uniform magnetic field on a moving charge is equal to zero. This is because the magnetic force is always perpendicular to velocity of the moving charge.