Magnetic Effect of Current & Magnetism

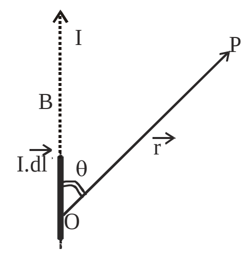
(i) Oesterd experimently discovered a magnetic field around a conductor carrying electric current.

(a) A magnet at rest or charge in motion produces a magnetic field around it while an electric charge at rest produces an electric field around it.

(b) A current carrying conductor has a magnetic field and not an electric field around it. On the other hand, a charge moving with a uniform velocity has an electric as well as a magnetic field around it.

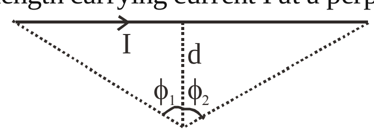
<u>Biot-Savart's law :</u> The magnetic induction $d\vec{B}$ at a point P due to an infinitesimal element of current (length dl and current I) at a distance r is given by :

$$d\vec{B} = \frac{\mu_0}{4\pi} I \frac{(d\vec{l} \times \vec{r})}{r^3}$$



For $\theta = 0$ or $\theta = \pi$, $\sin\theta = 0$ thus field at a point on the line of the wire is zero.

(ii) The magnetic induction B due to a straight wire of finite length carrying current I at a perpendicular distance d is given by $\boxed{B = \frac{\mu_0}{4\pi} \times \frac{I}{d}(\sin\phi_1 + \sin\phi_2)}$

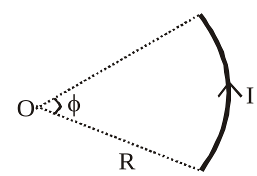


where ϕ_1 and ϕ_2 are the angles made by upper and lower ends of the wire with the perpendicular distance d at the point of observation.

(iii) If the wire is infinitely long, from both sides then $\phi_1 = \phi_2 = 90^0$. So, magnetic field at perpendicular distance d is given by $B = \frac{\mu_0}{4\pi} \times \frac{2I}{d} = \frac{\mu_0 I}{2\pi d}$

- Magnetic field due to a part of circular current carrying loop (arc) subtending angle ϕ at the centre O is :

$$\boxed{B = \frac{\mu_0 I \phi}{4\pi R}}$$; where ϕ is in radian.



So, Magnetic field at the centre of semicircular current carrying loop is : $B = \frac{\mu_0 I}{4R}$

- The magnetic induction along the axis of a long current carrying solenoid at the centre part. $B = \mu_0 nI$ where I = current flowing through solenoid, n = (N/l) = number of turns per unit length of solenoid. Magnetic induction at the ends of the solenoid. $B' = (\mu_0 nI/2)$

2. Lorentz force on a charged particle in uniform constant magnetic field :

(i) When a charge q moves in a magnetic field of induction B with a velocity υ then it experience a sideway deflecting force F, given by $\vec{F} = q(\vec{\upsilon} \times \vec{B})$

Thus, the force $\vec{F}$ is always perpendicular to $\vec{\upsilon}$ and $\vec{B}$. So, no workdone and hence no change in kinetic energy.

(ii) If charge is at rest inside the magnetic field no force will act on it, hence the particle remains at rest.

(iii) If charge is moving parallel to magnetic field $(\theta = 0)$ no force acts on it. Thus, a charged particle initially moving parallel to magnetic field will continue to move with same constant velocity.

Case A When charged particle enters the magnetic field at right angles i.e $\boxed{\vec{V} \perp \vec{B}}$

(i) Since the force is perpendicular to velocity vector $\vec{\upsilon}$, it provides the required centripital force for circular motion.

(ii) (a) The force equation towards centre is $\frac{m\upsilon^2}{r} = q\upsilon B$

(b) The radius of circular path is $\boxed{r = \frac{m\upsilon}{qB}}$

where $m\upsilon = p = \sqrt{2mK}$ = momentum of the particle .

(c) Time period of revolution is $\boxed{T = \frac{2\pi r}{\upsilon} = \frac{2\pi m}{qB}}$

(d) The frequency is $\boxed{f = \frac{1}{T} = \frac{qB}{2\pi m}}$

(e) The angular frequency is $\omega = 2\pi f = \frac{qB}{m}$. This is often called cyclotron frequency.

Case B : When the particle enters the magnetic field at an inclination (i.e. $\vec{\upsilon}$ is not perpendicular to B).

(i) In this case, the path is helical.

(ii) It is a superposition of vertical drift and horizontal circular motion.

(iii) Due toc omponent of υ perpendicular to $\vec{B}$ i.e. $\upsilon_\perp = \upsilon \sin\theta$, the particle describes a circular path of radius r, such that

$$\frac{m\upsilon_\perp^2}{r} = q\upsilon_\perp B \quad \text{or} \quad r = \frac{m\upsilon_\perp}{qB} = \frac{m\upsilon\sin\theta}{qB}$$

(iv) The time period, frequency and angular frequency are :

(a) $T = \frac{2\pi m}{qB}$ (b) $f = \frac{qB}{2\pi m}$ (c) $\omega = \frac{qB}{m}$

(v) The pitch of the helical path is

$$p = \upsilon_{\|} \times T = \upsilon\cos\theta \times T = \frac{2\pi m\upsilon}{qB}\cos\theta = \frac{2\pi r}{\tan\theta}$$

Ampere's law :

(i) The line integral of magnetic field around any closed path is equal to μ_0 times the total current passing through the closed circuit, i.e. $\oint \vec{B}.d\vec{l} = \mu_0 I$

(ii) For a long solid metal rod of radius R carrying a current I

If $r < R$, $B = \left(\frac{\mu_0 I}{2\pi R^2}\right) r$, i.e. $B \propto r$

But If $r \geq R$; $B = \frac{\mu_0 I}{2\pi r}$; for both solid and hollow metallic rod (pipe).

(iii) For a hollow metallic rod carrying a uniform current, for points inside the rod, the magnetic field is zero.

5. Force on current carrying wire in a magnetic field :

(i) Force on a current element of length dl placed in a magnetic field B is : $d\vec{F} = I(d\vec{l} \times \vec{B})$

In special case of a straight wire of length l in a uniform magnetic field $\vec{B}$, the force is :

$\boxed{\vec{F} = I(\vec{l} \times \vec{B})}$ or $F = IlB \sin\theta$ where $\theta =$ angle between of current flow and magnetic flight.

(ii) Force between two parallel current carrying conductors :

(a) Two parallel wires carrying currents in the same direction attract each other, while those carrying currents in the opposite direction repel each other.

(b) The force of attraction or repulsion per unit length between two parallel conductors carrying current I_1 and I_2 is given by $\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$

Magnetic field produced by a moving charge :

The magnetic field produced by a moving charge q, at point P is : $\vec{B} = \frac{\mu_0}{4\pi}\frac{q(\vec{\upsilon} \times \hat{r})}{r^2}$ tesla