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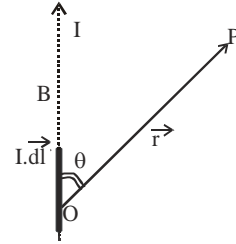
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Magnetic Effect of Current & Magnetism

- (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.

Biot-Savart's law : 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 :

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

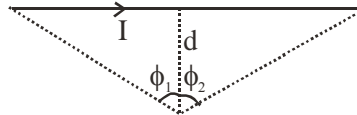


For $\theta = 0$ or $\theta = \pi$, $\sin \theta = 0$ thus field at a point on the line of the wire is zero.

- (ii) The magnetic induction B due to a straight wire of finite length carrying current I at a perpendicular distance

d is given by

$$B = \frac{\mu_0}{4\pi} \times \frac{I}{d} (\sin \phi_1 + \sin \phi_2)$$



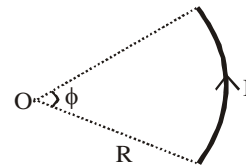
where ϕ_1 and ϕ_2 are the angles made by upper and lower ends of the wire with the perpendicular distance d at the point of observation.

- (iii) If the wire is infinitely long, from both sides then $\phi_1 = \phi_2 = 90^\circ$. 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 :

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



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 \vec{v} then it experience a sideways deflecting force F , given by $\vec{F} = q(\vec{v} \times \vec{B})$

Thus, the force \vec{F} is always perpendicular to \vec{v} 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. $\vec{V} \perp \vec{B}$

- (i) Since the force is perpendicular to velocity vector \vec{v} , it provides the required centripetal force for circular motion.
- (ii) (a) The force equation towards centre is $\frac{mv^2}{r} = qvB$
- (b) The radius of circular path is $r = \frac{mv}{qB}$
 where $mv = p = \sqrt{2mK}$ = momentum of the particle .
- (c) Time period of revolution is $T = \frac{2\pi r}{v} = \frac{2\pi m}{qB}$
- (d) The frequency is $f = \frac{1}{T} = \frac{qB}{2\pi m}$
- (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{v} is not perpendicular to \vec{B}).

- (i) In this case, the path is helical.
- (ii) It is a superposition of vertical drift and horizontal circular motion.
- (iii) Due to component of v perpendicular to \vec{B} i.e. $v_{\perp} = v \sin \theta$, the particle describes a circular path of radius r , such that

$$\frac{mv_{\perp}^2}{r} = qv_{\perp}B \quad \text{or} \quad r = \frac{mv_{\perp}}{qB} = \frac{mv \sin \theta}{qB}$$

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

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

- (v) The pitch of the helical path is

$$p = v_{\parallel} \times T = v \cos \theta \times T = \frac{2\pi m v}{qB} \cos \theta = \frac{2\pi r}{\tan \theta}$$

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. $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$
- (ii) For a long solid metal rod of radius R carrying a current I

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

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

- (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 :

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

- (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

$$I_1 \text{ and } I_2 \text{ is given by } \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Magnetic field produced by a moving charge :

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

