# II PUC - CHAPTER 04
# MOVING CHARGES AND MAGNETISM

**Direction of magnetic field produced by a current carrying conductor**

**Right hand clasp rule:** If a straight conductor carrying current is clasped in the right hand with thumb pointing in the direction of the current, then the direction in which the remaining fingers encircling the conductor gives the direction of the magnetic field.

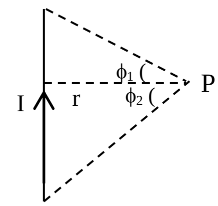
**Biot-Savart's law or Laplace's law**

1) The magnetic field dB due to a current carrying element $d\ell$ at a point P distant 'r' from it is given by

$dB = \frac{\mu_o}{4\pi}\frac{Idl\sin\theta}{r^2}$ where I is the current; θ = angle between direction of $\vec{dl}$ and $\vec{r}$

2) The vector form of above equation $\vec{dB} = \frac{\mu_o}{4\pi} I \frac{\vec{dl}\times\vec{r}}{r^3}$

**Magnetic field due to a straight conductor carrying current**




1) $B = \frac{\mu_o I}{4\pi r}(\sin\phi_1 + \sin\phi_2)$

I = current through the conductor

r = perpendicular distance of the point from the conductor

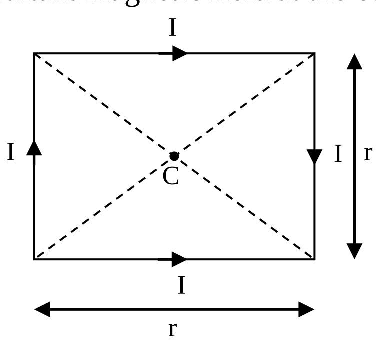
$\mu_o$ = absolute permeability of free space

2) The magnetic field at a perpendicular distance 'r' from the mid-point of the conductor is $B_C = \frac{\mu_o I}{2\pi r}$

3) The magnetic field at perpendicular distance 'r' from end of the conductor is $B_E = \frac{\mu_o I}{4\pi r}$

4) For a long straight conductor carrying current $B_C : B_E = 2:1$

5) a) Resultant magnetic field at the centre of square




$B_C = \frac{\mu_0}{4\pi}\frac{I}{(r/2)}[\sin 45^o + \sin 45^o][4] = \frac{\mu_0}{4\pi}\frac{2I}{r}\left[2 \times \frac{1}{\sqrt{2}}\right]4 = 2\sqrt{2}\left(\frac{\mu_o I}{\pi r}\right)$

b) Resultant magnetic field at the centroid of an equilateral triangle of side r

$B_C = \frac{9}{2}\left(\frac{\mu_o I}{\pi r}\right)$

c) Resultant magnetic field at the centre of an regular hexagon of side r

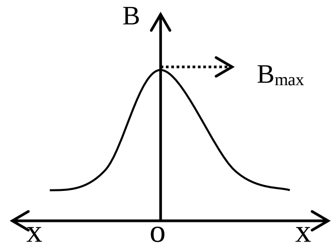
$B_C = \sqrt{3}\left(\frac{\mu_o I}{\pi r}\right)$

**Magnetic field at a point on the axis of a circular coil carrying current**

1) $B = \frac{\mu_o}{4\pi}\frac{2\pi N I r^2}{(x^2 + r^2)^{3/2}}$

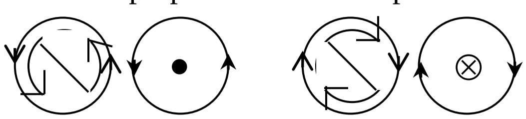
N = number of turns in the coil; I = current in the coil; r = mean radius of the coil
x = distance of the point on the axis from the centre of the coil.

2) Variation of magnetic field at any point on the axis with the distance from the centre of the coil is as shown.




3) $B_c = \frac{\mu_o}{4\pi}\frac{2\pi N I}{r} = \frac{\mu_o N I}{2r}$

4) The direction of B is perpendicular to the plane of the coil.



5) Magnetic field due to one turn $B_C = \frac{\mu_o I}{2r}$

Magnetic field due to semi circular coil $B_C = \frac{1}{2}\left(\frac{\mu_o I}{2r}\right) = \frac{\mu_o I}{4\,r}$

Magnetic field due to ¼th of circular coil $B_C = \frac{1}{4}\left(\frac{\mu_o I}{2r}\right) = \frac{\mu_o I}{8\;r}$

6) Ratio of magnetic field at the centre to that at a point on the axis of a circular coil carrying current is $\frac{B_C}{B_A} = \frac{(r^2 + x^2)^{3/2}}{r^3}$ x – distance of the point from the centre

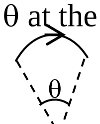
When x = r, then $B = \frac{B_C}{2\sqrt{2}}$

$x = \sqrt{3}r$ then $B = \frac{B_C}{8}$

x = 2r, then $B = \frac{B_C}{5\sqrt{5}}$

7) Magnetic field due to a current carrying arc subtending angle θ at the centre,

$B = \frac{\mu_o}{4\pi}\frac{2\pi I}{r}\left(\frac{\theta}{2\pi}\right) = \frac{\mu_o I}{2r}\left(\frac{\theta}{2\pi}\right)$ where θ is in radians




8) If B is the magnetic field produced at the centre of a circular coil of one turn carrying current, then magnetic field at its centre when the same coil is rewound into N turns is $B' = N^2 B$

9) If B is the magnetic field produced at the centre of a circular coil of one turn of radius r carrying current, then magnetic field at its centre when the same coil is rewound to decrease the radius 'N' times is $B' = N^2 B$

**Magnetic field due to a current carrying solenoid and toroid**

1) If the solenoid is of infinite length, then the magnetic field at the centre of the solenoid $B_C = \mu_o nI$

2) Magnetic field at the ends of the solenoid $B_E = \frac{\mu_o nI}{2}$

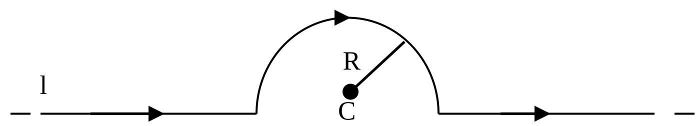
3) For a long solenoid, $B_C = 2B_E$
i.e. Magnetic field at the centre of a long solenoid is double that at its ends.

4) Magnetic field inside a toroid is $B = \frac{\mu_o NI}{2\pi r} = \mu_o nI$
N = number of turns; I = current; r = mean radius
n = number of turns per circumference = $N/2\pi r$

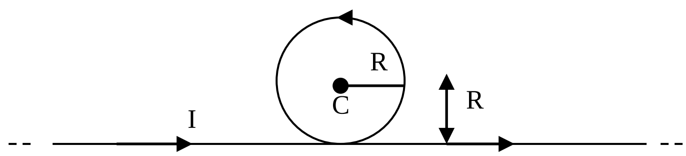
**Some special current configurations:**

**(a)** $B_C = \frac{\mu_0}{4\pi}\frac{2\pi I}{R}\left(\frac{\pi}{2\pi}\right) = \frac{\mu_0 I}{4R}$

Here, the straight wire behaves as if it is infinite conductor passing through C, hence it produces no magnetic field at C.

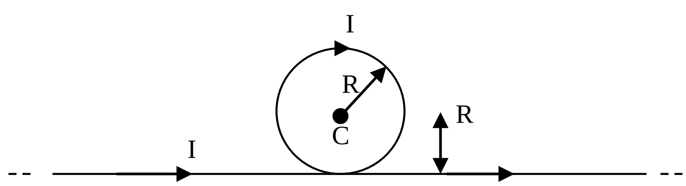



**(b)**



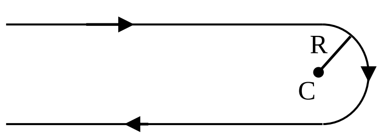

$$B_C = \frac{\mu_0}{4\pi}\frac{2\pi I}{R} + \frac{\mu_0}{4\pi}\frac{2I}{R} = \frac{\mu_0}{4\pi}\frac{2I}{R}(\pi + 1)$$

**(c)**



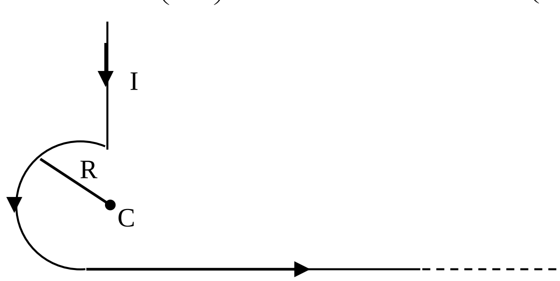

$$B_C = \frac{\mu_0}{4\pi}\frac{2\pi I}{R} - \frac{\mu_0}{4\pi}\frac{2I}{R} = \frac{\mu_0}{4\pi}\frac{2I}{R}(\pi - 1)$$

**(d)**



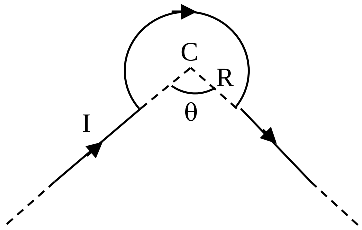

$$B_C = \frac{\mu_0}{4\pi}\frac{2\pi I}{R}\left(\frac{\pi}{2\pi}\right) + \frac{\mu_0}{4\pi}\frac{2I}{R} = \frac{\mu_0}{4\pi}\frac{2I}{R}\left(\frac{\pi}{2} + 1\right)$$

**(e)**




$$B_C = \frac{\mu_0}{4\pi}\frac{2\pi I}{R}\left(\frac{\pi}{2\pi}\right) + \frac{\mu_0}{4\pi}\frac{2I}{R}\left(\frac{1}{2}\right) = \frac{\mu_0}{4\pi}\frac{2I}{R}\left(\frac{\pi}{2} + \frac{1}{2}\right)$$

**(f)**

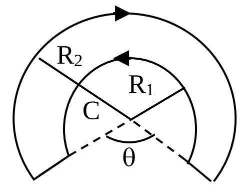



$$B_C = \frac{\mu_0}{4\pi}\,\frac{2\pi I}{R}\left(\frac{2\pi-\theta}{2\pi}\right)$$

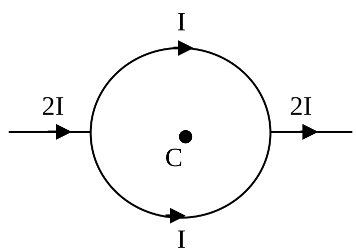
**(g)**

$$B_C = \frac{\mu_0}{4\pi}\,\frac{2\pi I}{R_1}\left(\frac{2\pi-\theta}{2\pi}\right) - \frac{\mu_0}{4\pi}\,\frac{2\pi I}{R_2}\left(\frac{2\pi-\theta}{2\pi}\right)$$

$$= \frac{\mu_0}{4\pi}\,2\pi I\left(\frac{2\pi-\theta}{2\pi}\right)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

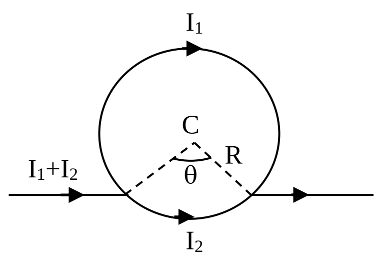



**(h)**




$B_C = 0$ (∵ magnetic field due to upper part cancelled by lower part)

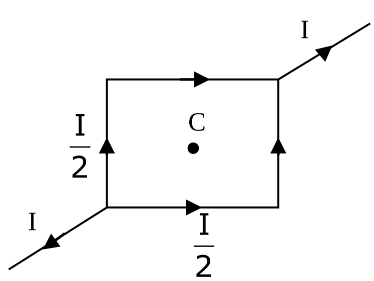
**(i)**



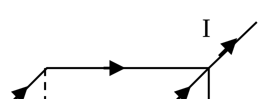

Here $I_1(2\pi - \theta) = I_2\theta$ (∵ the resistances of the two parts are proportional to $(2\pi - \theta)$ and $\theta$ respectively).
Also:

$$B_C = \frac{\mu_0}{4\pi}\,\frac{2\pi I_1}{R}\left(\frac{2\pi-\theta}{2\pi}\right) - \frac{\mu_0}{4\pi}\,\frac{2\pi I_2}{R}\left(\frac{\theta}{2\pi}\right) = 0$$

**(j)**



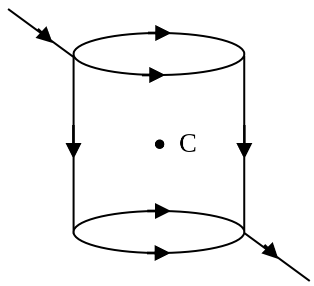

$B_C = 0$



**(k)**

$B_C = 0$

**($\ell$)**




$B_C = 0$

**Magnetic moment due to current loop:**

1) Magnetic dipole moment of a current loop is defined as the product of current and the area of the loop i.e., $\vec{M} = I\vec{A}$.

2) Torque acting on a current loop suspended in a uniform magnetic field B of magnetic moment M is $\vec{\tau} = \vec{M} \times \vec{B}$

$\tau = MB \sin\theta$ where $\theta$ is the angle between M and B

3) If the loop has N turns then $\tau = MB \sin\theta = NIAB\sin\theta$

4) When $\theta = 0^o$, $\tau_{min} = 0$

Torque on a current loop in a magnetic field is minimum when the plane of the loop is perpendicular to the direction of the magnetic field.

5) When $\theta = 90^o$, $\tau_{max} = MB$

Torque on a current loop in a magnetic field is maximum when the plane of the loop is parallel to the direction of the magnetic field.

**Magnetic moment due to revolving electrons:**

1) Orbital magnetic moment of the electron $\mu_\ell = \frac{evr}{2} = \frac{eL}{2m}$

L = Angular momentum of the electron

2) In the n^th orbit of H-atom orbital angular momentum is $\mu_\ell = \frac{nhe}{4\pi m}$

where n = 1, 2, 3,…. h = Planck's constant

**Force on a charged particle moving in a magnetic field**

1) The magnetic force experienced by a charge of 'q' coulomb moving with a velocity 'v' in a magnetic field of strength B is given by $F = Bqv\sin\theta$

where $\theta$ is the angle between the velocity vector and magnetic field vector.

2) The rule states that, if the first three fingers of the left hand are stretched in three mutually perpendicular directions with the fore finger pointing the direction of magnetic field, middle finger pointing the direction of the velocity, then thumb gives the direction of magnetic force on the charged particle.

3) The direction of the force on a –ve charge is opposite that of the force experienced by positive charge.

**Force on a charged particle moving perpendicular to a magnetic field (Circular path)**

1) Acceleration $a = \frac{qvB}{m}$

2) Radius of the circular path is also given by $r = \frac{p}{Bq} = \frac{mv}{qB} = \frac{2E}{Bqv} = \frac{\sqrt{2mE}}{Bq}$

where p is momentum and E is kinetic energy of the particle.

3) Period of revolution of the charged particle $T = \frac{2\pi m}{qB}$

4) Frequency of revolution of charged particle is $f = \frac{Bq}{2\pi m}$

5) Angular frequency of revolution of the charged particle, $\omega = \frac{Bq}{m}$

6) Period and frequency of revolution of the charged particle is independent of radius and velocity of the charged particle.

7) When a charged particle revolves in a circular path velocity and momentum changes whereas speed and the kinetic energy does not change. Hence work done by the magnetic force is zero.

8) Kinetic energy of the charged particle is independent of the magnetic field.

9) Change in magnetic field, changes only the radius of the path.

**Cyclotron**

1) Cyclotron frequency $\nu_c = \frac{Bq}{2\pi m}$

2) Maximum kinetic energy gained by the ion is $K = \frac{q^2B^2R^2}{2m} = 2m\pi^2\nu_c^2R^2$

q = charge, B = magnetic field, R = radius of the orbit, m = mass

**Motion of a charged particle in a combined electric and magnetic fields:**

1) If a charged particle of charge 'q' moves through a region of both electric field E and magnetic field B then the net force on the charge is $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$. This force is called **Lorentz force.**

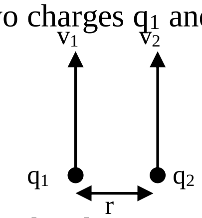
2) If the two fields are mutually perpendicular (E along y-axis and B along z-axis) then Lorentz force acting on the charged particle moving along x-axis is $\vec{F} = q(E - vB)\hat{j}$

3) When $\vec{v}$, $\vec{E}$ and $\vec{B}$ are mutually perpendicular to each other and if $F_B = F_E$ then the particle moves with a velocity v = E/B

**Force between two moving charges**

1) Two charged particles in motion experiences magnetic force in addition to electrostatic force.

2) Magnetic force between the two charges $q_1$ and $q_2$ moving with velocities $v_1$ and $v_2$ parallel to each other is $F_m = \left(\frac{\mu_o}{4\pi}\right)\frac{q_1 q_2 v_1 v_2}{r^2}$




Here r is the separation between the charges.

3) The ratio of the electric force $F_e$ and the magnetic force $F_m$ between two moving charges is as follows:

$$\frac{F_e}{F_m} = \frac{c^2}{v_1 v_2}$$

4) The electrostatic force continues to be repulsive between similar charges and attractive between dissimilar charges. Also $F_e >> F_m$.

5)

| Cases | Magnetic force | Electric force |
|---|---|---|
| When charges are of same nature and moving | Attractive | Repulsive |

| | | |
|---|---|---|
| in the same direction | | |
| When charges are of same nature and moving in the opposite direction | Repulsive | Repulsive |
| When charges are of opposite nature and moving in the same direction | Repulsive | Attractive |
| When charges are of opposite nature and moving in the opposite direction | Attractive | Attractive |

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

1) The magnitude of mechanical force is given by F = BIL sin$\theta$
where B is the uniform magnetic field, I is the current, L is the length of the conductor and $\theta$ is the angle between the direction of the current and the magnetic field.

2) **Fleming's left hand rule:** The rule states that, if the first three fingers of the left hand are stretched in three mutually perpendicular directions with the fore finger pointing the direction of magnetic field, middle finger pointing the direction of the current, then thumb gives the direction of mechanical force on the conductor.

3) When a current carrying conductor is placed parallel to the magnetic field, force on it is minimum (or zero). i.e. $F_{min} = 0$
When a current carrying conductor is placed perpendicular to the magnetic field the force on it is maximum. i.e. $F_{max} = BIL$

4) Unit of magnetic induction is tesla = $Wbm^{-2} = NA^{-1}m^{-1}$

5) Vector form of mechanical force is $\vec{F} = I(\vec{\ell} \times \vec{B})$

**Force between two long straight parallel current carrying conductors:**

1) Magnitude of the force $F = \frac{\mu_o}{2\pi}\frac{I_1 I_2}{r}$
$I_1$ and $I_2$ are currents in two conductors placed parallel to each other separated by a distance 'r' in free space.

2) Two straight parallel conductors carrying current in the same direction attract each other if the currents are in the opposite direction they repel each other.

**Moving coil galvanometer**

1) The current I in a moving coil galvanometer $I = \left(\frac{K}{NBA}\right)\phi$
K = torsional constant; $\phi$ = deflection of the coil.
N = number of turns in the coil, A = area of the coil, B = magnetic field.

2) $\frac{I}{\phi} = \frac{K}{NBA}$ is called galvanometer constant

3) Current sensitivity of a galvanometer is $\frac{\phi}{I} = \frac{NBA}{K}$

4) Voltage sensitivity $\frac{\phi}{V} = \left(\frac{NAB}{K}\right)\frac{I}{V} = \frac{NAB}{RK}$

**Conversion of a galvanometer into an ammeter**

1) A galvanometer of resistance 'G' can be converted into an ammeter by connecting a low resistance S in parallel with its coil (Shunt resistance).

2) Shunt resistance $S = \frac{I_g G}{I - I_g}$ where $I_g$ is the current in the galvanometer required to produce full-scale deflection. I is the maximum current to be measured.

3) Current required for full-scale deflection is $I_g = \frac{IS}{S + G}$

4) Effective resistance of the ammeter, $R_{eff} = \frac{SG}{S + G}$

5) To increase the range of an ammeter, shunt resistance required, $S = \frac{G}{n - 1}$

where $n = \frac{\text{new range}}{\text{initial range}}$ and G is the initial resistance of the ammeter.

**Conversion of a galvanometer into a voltmeter**

1) A galvanometer of resistance 'G' can be converted into a voltmeter by connecting a high resistance 'R' in series with it.

2) High resistance to be connected in series with galvanometer is $R = \frac{V}{I_g} - G$

Where $I_g$ is the current in the galvanometer, which produces full-scale deflection.
V is the maximum voltage to be measured.

3) Maximum p.d to be measured is $V = I_g(R + G)$

4) Effective resistance of the voltmeter, $R_{eff} = R + G$

5) To increase the range of a voltmeter, resistance to be connected in series with it,
$R = (n - 1)G$

where $n = \frac{\text{new range}}{\text{initial range}}$ and G is the resistance of the voltmeter.