Magnetic Effect of Electric Current

- **Magnetic flux:-**

  Magnetic flux lined with the surface is defined as the product of area and component of *B* perpendicular that area.

  $$\phi_B = \vec{B} \cdot \vec{A} = BA\cos\theta$$

  and

  $?_B = \mu nAH$

  Here, μ is the permeability of the medium, *n* is the number of turns, *A* is the area and *H* is the magnetic field intensity.

  (a) When ϑ = 90º, cosϑ = 0. So, $?_B$ = 0

  This signifies, no magnetic flux is linked with surface when the field is parallel to the surface.

  (b) When ϑ = 0º, cosϑ = 1. So,($?_B)_{max}$ = 1

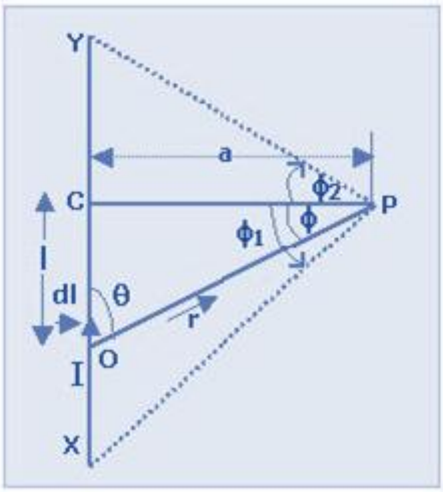
  This signifies, magnetic flux linked with a surface is maximum when area is held perpendicular to the direction of field.

- **Biot-Savart Law or Ampere's Theorem:-**

  $$d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l} \times \vec{r}}{r^3} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l} \times \hat{r}}{r^2}$$

  Or, $dB = (\mu_0/4\pi)(I\ dl \sin\vartheta/r^2)$

- **Field due to straight current carrying conductor of finite length at a point *P*, perpendicular distance *a* from the linear conductor *XY*:-**



$B = (\mu_0 I/4\pi a) \times (\sin ?_1 + \sin ?_2)$

Direction:-

(a) For current in the conductor from X to Y, the direction of B is normal to the plane of conductor downwards.

(b) For current in the conductor from Y to X, the direction of B is normal to the plane of conductor downwards.

- **Field due to straight carrying conductor of infinite length at a point *P*, perpendicular distance R from the linear conductor *XY*:-**

  $B = (\mu_0 I/2\pi a)$ (Direction is same as given above)

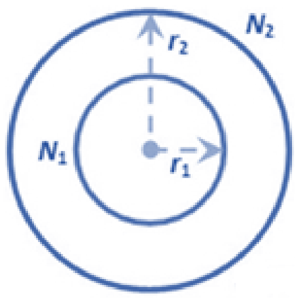
- **Field due to two concentric coils of radii r_1 and r_2 having turns N_1 and N_2 in which same current *I* is flowing in anticlockwise direction at their common center *O*:-**

  $B = \mu_0 I/2\ [N_1/r_1 + N_2/r_2]$

  If the number of turns in them is same, $B = \mu_0 NI/2\ [1/r_1 + 1/r_2]$

  Direction:- Direction of B will be normal to the plane of paper upwards.

- **Field due to two concentric coils of radii r_1 and r_2 having turns N_1 and N_2 in which same current *I* is flowing in mutually opposite direction at their common center *O*:-**



  $B = \mu_0 I/2\ [N_1/r_1 - N_2/r_2]$

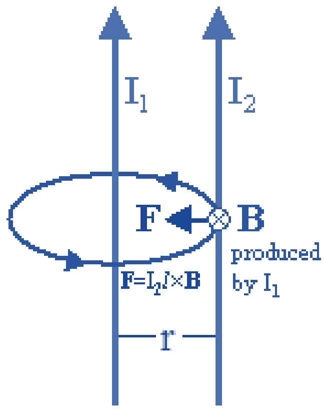
  If the number of turns in them is same, $B = \mu_0 NI/2\ [1/r_1 - 1/r_2]$

  Direction:- Direction of B will be normal to the plane of paper upwards.

- **Field due to circular coil at the center *O* :-**

  $B = \mu_0 I/2R$

- **Field due to two parallel very long linear conductors carrying current in same direction:-**



  (a) At point P i.e. at a distance $r/2$ from both conductors, $\boldsymbol{B=0}$

  (b) At a point Q i.e. at a distance x from first and $r+x$ from second conductor, $\mathbf{B = \mu_0 2I/4\pi\ [(1/x) + (1/r+x)]}$

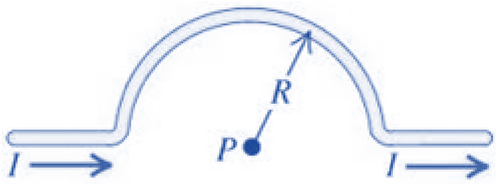
  Direction:- B is normal to the plane of paper downwards.

  (c) At a point P i.e. at a distance x from first and $r-x$ from second conductor, $B = \mu_0 2I/4\pi\ [(1/x) - (1/r-x)]$

  If B is positive, then its direction will be normal to the plane of paper upwards.

  If B is negative, then its direction will be normal to the plane of paper downwards.

- **Field due to two parallel very long linear conductors carrying current in opposite direction (refer above figure):-**
  (a) At point *P* distance *x* from first conductor,
  $B = \mu_0 2I/4\pi\ [(1/x) + (1/r\text{-}x)]$
  Direction:- of *B* will be normal to the plane of paper downwards.

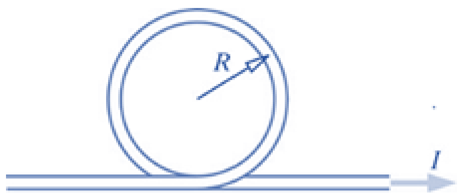


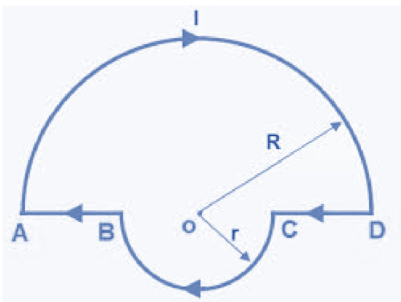
  (b) At point *Q* distance *x* from first conductor, $B = \mu_0 2I/4\pi\ [(1/x) - (1/r\text{-}x)]$
  Direction:- of *B* will be normal to the plane of paper upwards.

- **Field due to semicircular arc of wire at the center *O* of the arc:- B = $(\mu_0/4\pi)\ (\pi I/R)$**
  Direction:- Direction of *B* will be at right angle to the plane of circular arc downwards. If the direction current is in anticlockwise, then the direction of field B will be a right angle to the plane of circular arc upwards.

- **Field due to straight wire and loop at the center *O* of the loop (If the current in the looop in anticlockwise direction):-** $B = (\mu_0/4\pi)\ [2\pi I/R + 2I/R]$
  Direction:- Normal to the plane of paper upwards.

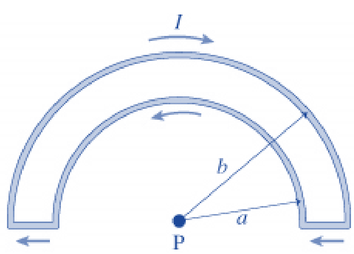
- **Field due to straight wire and loop at the center *O* of the loop(If the current in the loop in clockwise direction)**:- $B = (\mu_0/4\pi)\ [2\pi I/R - 2I/R]$
  Direction:- Normal to the plane of paper downwards





- **Field due to two semicircular arc of wire:-**
  ?B = $\mu_0 I/4\ [1/a - 1/b]$
  B = $\mu_0 I/4\ [1/R + 1/r]$
  Direction:- Normal to the plane of paper downward.

- **Field due to two concentric circular arcs at *O*:-**
  $B = (\mu_0/4\pi)\ I\vartheta\ [1/r_1 - 1/r_2]$
  Here r_1 is the radius of inner circle and r_2 is the radius of outer circle.
  Direction:- Normal to the plane of paper upwards

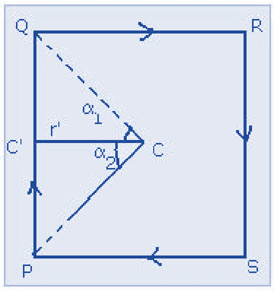


- **Field due to semicircular arc and straight conductor at point *P*:-**
  $B = (\mu_0 I/4\pi r)\ [\pi+2]$
  Direction:- Normal to the plane upward.

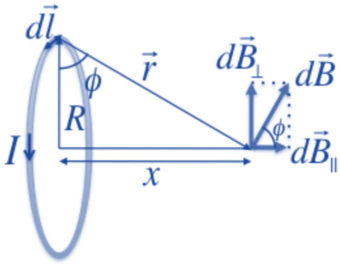
- **Field due to semicircular arc and straight conductor at point *O*:- $B = (\mu_0 I/4\pi r)\ [\pi+1]$**

  Direction: Normal to the plane upward.

- **Field due to square loop having length of side *a* at center *C*:-**
  $B = 2\sqrt{2}(\mu_0 I/\ \pi a)$
  Direction:- Normal to the plane of paper downwards.



- **Magnetic field at any point on the axis of a circular coil carrying current *I*:-**
  $B = (\mu_0/2)\ [NIa^2/(a^2 + x^2)^{3/2}]$
  (a) Magnetic field at the center of the coil:-
  $B = (\mu_0/2)\ [NI/a]$
  (b) Magnetic field at a point situated large distance away on the axis:-
  $B = (\mu_0/2\pi)\ [NIA/x^3]$
  (c) Current loop as a magnetic dipole:- $B = (\mu_0/4\pi)\ [2M/x^3]$
  Here, M (=IA) is the magnetic moment of the magnetic dipole.



- **Magnetic field at any point on the axis of a solenoid carrying current:-**
  $B = (\mu_0 NI/2l)$ [cos$?_1$-cos $?_2$]
  For an infinitely long solenoid, $?_1 = 0$ and $?_2 = \pi$. So, $B=\mu_0 NI$
  At one end, $B = \mu_0 NI/2$

- **Field due to a current in cylindrical rod:-**
  ? (a) Outside:- $B = \mu_0 I/2\pi R$
  (b) Surface:- $B = \mu_0 I/2\pi R$
  (c) Inside:- $B = \mu_0 IR/2\pi R^2$

- **Field due to a toroid:-**
  (a) Inside:- $B = \mu_0 NI - \mu_0 NI/2\pi R$
  (b) Outside:- $B = 0$

- **Force on electric current:-** $\vec{F} = \vec{H} \times \vec{B}$

- **Force on a moving charge in a magnetic field:-**

$$\vec{F} = q\left(\vec{v} \times \vec{B}\right)$$
$$= qvB\sin\theta\,\hat{n}$$

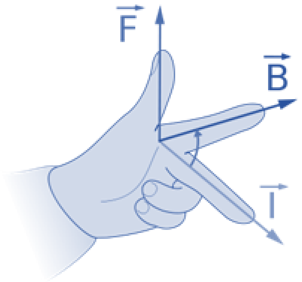
- **Lorentz Force:-**

$$\vec{F} = q\left[\vec{E} + \left(\vec{v} \times \vec{B}\right)\right]$$

- **Motion of a charged particle at right angles to a magnetic field:-**
  Radius, r = mv/Qb

- **Force on a conductor carrying current and placed in a magnetic field:-**
  $$\vec{F} = I\left(\vec{l} \times \vec{B}\right)$$
  $$= IlB\sin\theta\,\hat{n}$$

- **Fleming's left hand rule:-**



- **Force between two parallel conductors carrying currents:-**
  $F = \mu_0 I_1 I_2 / 2\pi d$

- **Torque on a current loop:-** $\tau = NIBA \cos\vartheta = NMB \cos\vartheta$ **(Since, $M = IA$)**

- **Moving Coil Galvanometer:- I = $(C/nBA)\vartheta = K\vartheta$**
  Here $K = C/nBA$ is known as the reduction factor of the moving coil galvanometer.

- **Sensitivity of a Galvanometer:-**
  (a) Current Sensitivity:- $S_i = C/nAH$
  Smaller the value of S_i, more sensitive is the galvanometer.
  (b) Voltage Sensitivity:- $S_v = V/G = CG/nAH$
  Smaller the value of S_v, more sensitive is the galvanometer

- **Conversion of a galvanometer into an ammeter:-**
  (a) $I_s/I_g = G/S$
  (b) $S = GI_g/I_g = GI_g/I - I_g$

- **Conversion of a galvanometer into a voltmeter:-** $R = (V/I_g) - G$

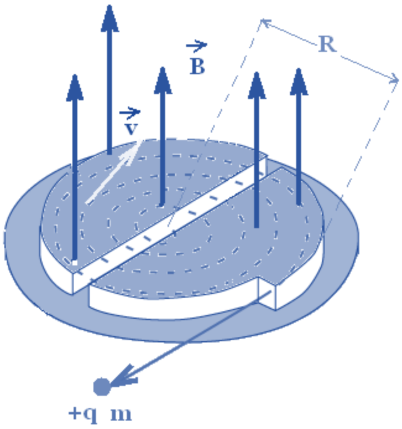
- **Ampere's current law:-**

$$\oint \vec{B}.d\vec{l} = \mu_0 I$$

Or

$$\oint \vec{H}.d\vec{l} = I$$

- **Cyclotron:-**
  - (a) $T = 2\pi m/qB$
  - (b) $v = qB/2\pi m$
  - (c) $\omega = \vartheta B/m$
  - (d) radius of particle acquiring energy E, $r = (\sqrt{2mE})/qB$
  - (e) velocity of particle at radius r, $v = qBr/m$
  - (f) the maximum kinetic energy (with upper limit of radius = R) $K_{max} = ½ [q^2B^2R^2/m]$



- **Magnetic field produced by a moving charge:-**

  (a) $\vec{B} = \frac{\mu_0}{4\pi}\frac{q(\vec{v}\times\vec{r})}{r^3}$

  (b) $B = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$