MAGNETIC EFFECTS OF CURRENT

Magnetic Moment [M] :

i) The product of the length of the magnet (2l) and pole strength is called magnetic moment.

ii) It is a vector quantity. $\left(\overrightarrow{SN}\right)$.

Magnetic movement $\left(\vec{M}\right) = 2lm$

Unit: $A - m^2$. **D.F**: IL^2

iii) If a bar magnet is cut into 2 equal parts perpendicular to its length.

a) Length becomes half

b) Pole strength doesn't change.

c) Moment becomes half $M^1 = \frac{M}{2}$

iv) If a bar magnet is cut into n equal parts perpendicular to its length $M' = \frac{M}{n}$

v) If a bar magnet is cut into 2 equal parts along its length

a) Length does not change

b) Pole strength becomes half

c) Magnetic moment becomes half

vi) If bar magnet is cut into n equal parts along its length $M' = \frac{M}{n}$

vii) If a bar magnet is cut into n equal parts first along the length and then perpendicular to its length, its pole strength becomes m/n are moment becomes M/n^2.

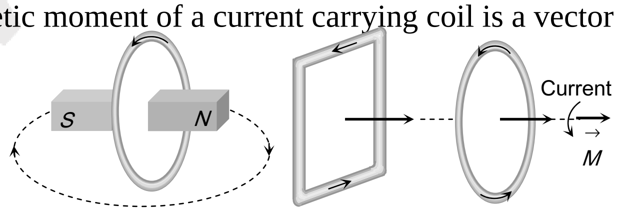
viii) If two bar magnets are making an angle θ with each other the resultant movement is given by $M^2 = M_1^2 + M_2^2 + 2M_1M_2\cos\theta$

Current Loop as a Magnetic Dipole

i) A current carrying circular coil behaves as a bar magnet whose magnetic moment is

M = NiA Where N = Number of turns in the coil, i = Current through the coil and A = Area of the coil

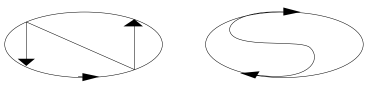
Magnetic moment of a current carrying coil is a vector and it's direction is given by right hand thumb rule



ii) For a given perimeter, circular shape has maximum area. Hence magnetic moment is maximum

iii) For any loop or coil $\vec{B}$ at centre due to current in loop, and $\vec{M}$ are always parallel.

Hence the current carrying coil behaves like a magnetic dipole with the poles on either side of its faces.



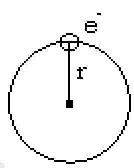
North Pole can be imagined to have formed on the face carrying anti clockwise current.

South Pole can be imagined on the face carrying clockwise current.

Magnetic dipole moment of a revolving electron:

i) Consider an electron is revolving in a circular orbit of radius ‘r’ with a speed v and frequency ‘n’. Consider a point ‘p’ on the circle then the electron crosses this point once after every revolution. Then, due to the motion of the electron, an electric current is associated with the coil so that it creates a magnetic field then the magnetic dipole moment is given by:

$$M = iA \Rightarrow M = \frac{e}{t}A$$



$$\Rightarrow M = \frac{ev}{2\pi r} \times \pi r^2$$

$$\Rightarrow M = \frac{evr}{2} \quad \Rightarrow M = \frac{er^2\omega}{2}$$

the angular momentum of the revolving electron is L = mvr

$$vr = \frac{L}{m} \qquad \Rightarrow M = \frac{eL}{2m}$$

$$\Rightarrow M = \frac{L}{2} \times specific\ charge$$

ii) A wire of length ‘l’ is bent in the form of a circular loop with ‘n’ turns and carries a current ‘i’, then its magnetic moment is,

$$l = n(2\pi r) \quad \Rightarrow r = \frac{l}{2\pi n} \Rightarrow M = ni(\pi r^2)$$

$$\Rightarrow M = ni\pi \times \frac{l^2}{2\pi^2 n^2} \qquad \Rightarrow M = \frac{iL^2}{4\pi n}$$

$$\Rightarrow M = \frac{L}{2} \times specific\ charge$$

Coulomb's Law :

i) The force of attraction (or)repulsion between two magnetic poles is directly proportional to the product of their

Pole strengths and inversely proportional to the square of the distance between them and acts along the line joining the poles.

$F = \frac{\mu}{4\pi}\frac{m_1 m_2}{d^2}$ Where μ is called the

Permeability of the medium and $\mu = \mu_0 \mu_v$

Where μ_0 is the permeability of free space and μ_r is the relative permeability of the medium.

$\therefore F_{medi} = \frac{\mu_0 \mu_r}{4\pi}\frac{m_1 m_2}{d^2}$

But, for air (or vacuum $\mu_r = 1$

$\therefore F_{air} = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{d^2}$ Here $\mu_0 = 4\pi \times 10^{-7}$ Newton/amp^2 (or) Henry / meter

ii) .Coulomb's law in the vectorial form can be written as $\overline{F} = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}.\hat{r}$

$\overline{F} = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}.\left(\frac{\overline{r}}{|\overline{r}|}\right)$ Or $\overline{F} = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^3}.\overline{r}$

iii) Ferro Magnetic $\mu_r >>> 1$

Para Magnetic $\mu_r > 1$

Diamagnetic $\mu_r < 1$(Negative)

- **Magnetic lines of force :**

A line of force in a magnetic field is the path or the curve along which a free unit north pole travels.

- **Characteristics of magnetic lines of force :**

i. Magnetic lines of force start from North – Pole and ends on the South – Pole outside the magnet.

ii. Inside the magnet magnetic lines of force run from South Pole to North Pole.

iii. They are closed loops.

iv. No two magnetic lines of force intersect each other.

v. They have a tendency to repel each other laterally (They have lateral elongation).

vi. They contract longitudinally.

vii. The tangent drawn to the magnetic line of force at any point gives the direction of magnetic field at that point.

viii. In uniform magnetic field lines of force will be straight and parallel lines.

ix. The number of lines of force at a region represents the intensity of magnetic field at that region. i.e., if field is strong, the lines of force are crowded, where as in weak fields they are spaced apart.

- **Lines of force in case of isolated poles :**

i) For an isolated North–pole, the lines of force are radial, pointing away.

ii) For an isolated South–pole, the lines of force are radial, pointing inwards.

- **Magnetic flux density (or) magnetic induction (B) :**

i) The magnetic lines of force per unit area through a normal plane in a magnetic field is called flux density (or) magnetic induction. It is a vector quantity. Its unit is weber / m^2 (or) Tesla.

$$B = \frac{\phi}{A}$$

Magnetic induction can also be defined as the force acting on a unit North Pole placed in a magnetic field. $B = \frac{\mu_0}{4\pi}\frac{m}{d^2}$

The force acting on a pole of pole strength m placed in a magnetic field is given by

$F = mB$

If the pole is north, F and B and parallel

If the pole is south, F and B are anti - parallel.

Units of B: wb/m^2 (or) Tesla (or) N/A-m.

DF of B: $\left[M^1L^1T^{-2}A^{-1}\right]$

- **Intensity of magnetic field (H) :**

i) It is the force acting on a unit pole placed in a magnetic field. $H = \frac{1}{4\pi}\frac{m}{d^2}$

Unit of H: A/m DF: $\left(AL^{-1}\right)$

$$B = \mu H = \mu_0\mu_r H$$

For air (or) vacuum $B = \mu_0 H$

- **Intensity of magnetization (I) :**

The magnetic moment per unit volume (or) pole strength per unit area is called the intensity of magnetization.

$$I = \frac{M}{vol.} = \frac{m}{area}\ amp/m$$

This is a vector quantity.

➢ **Susceptibility (ψ) :**

The magnetic susceptibility of a magnetic substance is the ratio of the intensity of magnetization to the magnetic intensity. $\chi = \frac{I}{H}$

$\chi >>> 1$ for Ferro

$\chi > 1$ for Para

$\chi < 1$ for dia

➢ **Magnetic permeability (μ) :**

Permeability of a substance as the ratio of magnetic induction and the magnetic intensity $\mu = \frac{B}{H}$

It gives the degree of concentration of magnetic lines of force through a specimen.

Unit of μ : Tesla–meter / amp.(or) henry/meter.

➢ **Couple acting and bar magnet in a uniform magnetic field :**

i) $\tau = MB\sin\theta$ (Or) $\tau = \mu_0 MH\sin\theta$

Where M(=2lm) is called the moment of the magnet

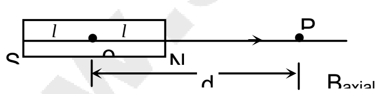
In the vector form, $\bar{\tau} = \bar{M} \times \bar{B}$

Where the direction of the torque is perpendicular to the plane containing $\bar{M}$ and $\bar{B}$.

ii) The work done to rotate the bar magnet from a position θ_1 to a position θ_2 with in this field is given by.

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

➢ **Magnetic induction at a point on the axial line of a bar magnet :**



Let 'P' is a point which is at a distance'd' from the centre of a bar magnet on its axial line.

The magnetic induction field at point 'P' is given by

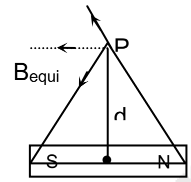
$$B_{axial} = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2 - \ell^2)^2}$$

i) For a short bar magnet $\ell^2 << d^2$ Hence ℓ^2 can be neglected. $B_{axial} = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$

ii) The direction of B is from south to north along the axial line.

- **Magnetic induction at a point of the equatorial line of a bar magnet :**

Let 'P' is a point on the equatorial line of a bar magnet which is at a distance'd' from the centre of the bar magnet.



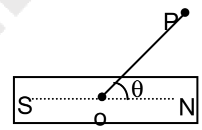
The magnetic induction field at point 'P' is given by

$$B_{eqi} = \frac{\mu_0}{4\pi}\frac{M}{\left(d^2 + \ell^2\right)^{3/2}}$$

i) For a short bar magnet, $B_{eqi} = \frac{\mu_0}{4\pi}\frac{M}{d^3}$

- **Magnetic induction at a point due to a dipole :**

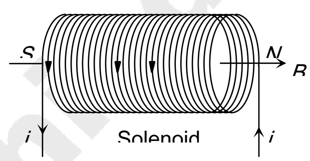
Let 'P' is a point which is at a distance 'd' from the centre of a short bar magnet and the line joining the point (P) to the centre of the magnet makes an angle 'θ' with the axis of the bar magnet, then magnetic induction at point P is given by,



$$B = \frac{\mu_0}{4\pi}\frac{M}{d^3}\sqrt{1+3\cos^2\theta}$$

- **Solenoid :**

i) Cylindrical coil of many tightly wound turns of insulated wire with generally diameter of the coil smaller than its length are called a solenoid.

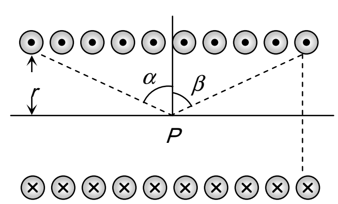


A magnetic field is produced around and within the solenoid. The magnetic field within the solenoid is uniform and parallel to the axis of solenoid.

(1) **Finite length solenoid:**

If N = total number of turns, l = length of the solenoid,

n = number of turns per unit length $= \frac{N}{l}$



(i) Magnetic field inside the solenoid at point P is given by

$$B = \frac{\mu_0}{4\pi}(2\pi ni)[\sin\alpha + \sin\beta]$$

(ii) **Infinite length solenoid:** If the solenoid is of infinite length and the point is well inside the solenoid i.e. $\alpha = \beta = (\pi/2)$.

$$\boldsymbol{B_{in} = \mu_0 ni}$$

(iii) If the solenoid is of infinite length and the point is near one end i.e. $\alpha = 0$ and $\beta = (\pi/2)$

$$\boldsymbol{B_{end} = \frac{1}{2}(\mu_0 ni)} \qquad \left(B_{end} = \frac{1}{2}B_{in}\right)$$

- **Earth's Magnetic Field (Terrestrial Magnetism):**

(i) A vertical plane passing through the geographical axis is called geographical meridian.

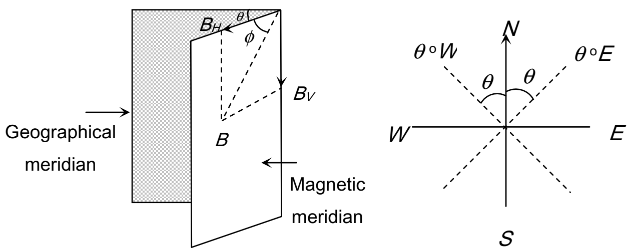
(ii) Magnetic axis and Geographical axis don't coincide but they make an angle of 17.5° with each other.

(iii) Direction of earth's magnetic field is from *S* (geographical south) to *N* (geographical north).

- **Magnetic Elements:**

The magnitude and direction of the magnetic field of the earth at a place are completely given by certain quantities known as magnetic elements.

(i) **Magnetic Declination (θ):** It is the angle between geographic and the magnetic meridian planes.



(A) **(B)**

(ii) **Angle of inclination or Dip (ϕ):** It is the angle between the direction of intensity of total magnetic field of earth and a horizontal line in the magnetic meridian.

(iii) **Horizontal component of earth's magnetic field (B_H):** Earth's magnetic field is horizontal only at the magnetic equator. At any other place, the total intensity can be resolved into horizontal component (B_H) and vertical component (B_V).

Also $B_H = B\cos\phi$ and $B_V = B\sin\phi$

$$B = \sqrt{B_H^2 + B_V^2}$$

And $\tan\phi = \dfrac{B_V}{B_H}$

- **Magnetic Maps and Neutral Points**

(i) **Magnetic maps:** Magnetic maps (*i.e*. Declination, dip and horizontal component) over the earth vary in magnitude from place to place. It is found that many places have the same value of magnetic elements. The lines are drawn joining all places on the earth having same value of a magnetic element. These lines form magnetic map.

(ii) Isogonic lines: These are the lines on the magnetic map joining the places of equal declination.

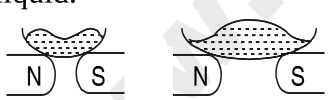
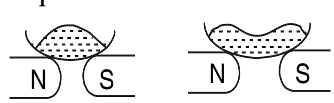
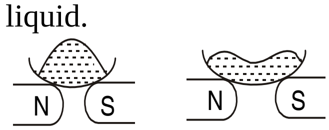
(iii) Agonic line: The line which passes through places of zero declination is called agonic line.

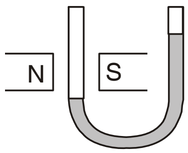
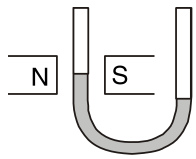
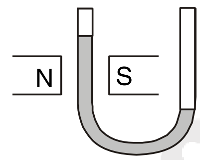
(vi) Isoclinic lines: These are the lines joining the points of equal dip or inclination.

(v) Aclinic line: The line joining places of zero dip is called aclinic line (or magnetic equator)

(vi) Isodynamic lines: The lines joining the points or places of the same value of horizontal component of earth's magnetic field are called isodynamic lines.

- **Magnetic Materials:**

DIAMAGNETIC SUBSTANCES	PARAMAGNETIC SUBSTANCES	FERROMAGNETIC SUBSTANCES
1. This is a universal property of all materials.	1. Properties are specifically possessed by some materials only.	1. Properties are specifically possessed by some materials only. (In general ferromagnetic substances show all the properties of paramagnetic substances with greater intensity).
2. When placed in a magnetic field, they get magnetised in a direction opposite to the applied field.	2. They get magnetised in the direction of the applied field.	2. They get magnetised in the direction of the applied field.
3. When placed in a magnetic field, they move from stronger to weaker parts of the field.	3. They move from weaker to stronger parts of the field.	3. They move from weaker to stronger parts of the field.
4. When a rod of a diamagnetic substance is freely suspended in a magnetic field, it orients itself perpendicular to the field.	4. When a rod of paramagnetic substance is freely suspended in a magnetic field, it orients itself in the direction of the field.	4. When a rod of paramagnetic substance is freely suspended in a magnetic field, it orients itself in the direction of the field.
5. Behaviour of a diamagnetic liquid.  when poles are very close	5. Behaviour of a paramagnetic liquid.  when poles are very close	5. Behaviour of a ferromagnetic liquid.  when poles are very close
6. When a diamagnetic substance is placed in a magnetic field, the concentration of magnetic lines of force is more	6. When a paramagnetic substance is placed in a magnetic field, the concentration of lines of force is slightly more inside	6. When a ferromagnetic substance is placed in a magnetic field, the concentration of lines of force inside is much more than outside the

outside than inside the substance.	than outside the substance.	substance.
7. Behaviour of corresponding substance in a U-tube. 		
8. Permeability (μ): less than 1 and positive.	8. Slightly greater than 1.	8. Much greater than 1.
9. Susceptibility (χ): low &negative.	9. Small and positive.	9. Large and positive.
10. Do not obey Curie's law.	10. Obey Curie's law. $\chi = \frac{C}{T}$	10. Obey Curie's law. At Curie temperature ferromagnetic substances changes to paramagnetic substances. $\chi = \frac{C}{T - T_C}$
11. e.g: inert gases : He, Ar etc. Metals: Au, Zn, Cu, Hg, Bi, Sb, Pb, Sn, Others Like: P, H_2O, Glass, Marble, Alkyl halides and many organic compounds.	11. e.g.: gases: O_2, N_2 Metals: Al, Pt, Mn, Cr, Pd Alkali & alkaline earth metals and rare earths.	11. e.g.: Fe, Co, Ni, Gadolinium (Gd),Dysprosium (Dy) alloys like Alnico.