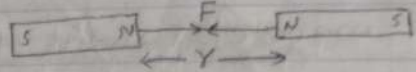
Magnetism

Fundamentals of magnetism

Coulomb's law :→

It states that the force between two poles is directly proportional to the product of the pole strengths and inversly proportional to the square of distance between them.

Let, m_1 and m_2 be the pole strengths of two poles separated by a distance r then



$$F \propto \frac{m_1 m_2}{r^2}$$

$$\therefore F = K \frac{m_1 m_2}{r^2} \quad ; \text{where, } K = \text{proportionality constant}$$

In C.G.S system, $K = 1$

$$\therefore \boxed{F = \frac{m_1 m_2}{r^2}} \quad \text{—— (1)}$$

In SI system, $K = \frac{\mu_0}{4\pi}$; ~~where~~,

$$\therefore \boxed{F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}} \quad \text{—— (2)}$$

where, μ_0 is called permeability of free space and its value is $4\pi \times 10^{-7} \, N/A^2$.

Some important terms :→

1) **Axis of magnet :→** The line joining two poles of a magnet is called axis of magnet. This is also called the axial line outside the magnet.
2) **Equatorial line :→** A line perpendicular to the axis of magnet which passes through the center of its two poles is called equatorial line.
3) **Geometric length and Effective length :→** The distance between two ends of a bar magnet is called real or geometric length

The distance between two poles of the magnet is called effective length.

Effective length $(2l)$ = 85% of geometric length.

4) <u>Magnetic dipole moment (M)</u> :→ The magnetic dipole moment of a magnet is the product of pole strength of its one pole and effective length.

i.e. Magnetic moment (M) = pole strength × effective length.

$$\therefore M = m \times 2l$$

∴ SI unit of M = Am.m
= Am^2

<u>Magnetic field</u> :→ The region around a bar magnet where it can exert a force on other magnets or magnetic materials is called magnetic field.

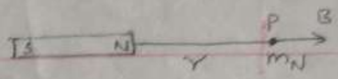
A magnetic field can be represented by magnetic lines of force.

Imp <u>Magnetic lines of force</u> :→ It is a line starting from N-pole and end to S-pole of a magnet and a tangent drawn at a point on it, gives the direction of magnetic field at that point.

Imp <u>properties of magnetic lines of force</u> :→

1) They start from N-pole and end to S-pole externally and S-pole to N-pole internally.
2) They are continuous curves.
3) They never intersect each other.
4) A tangent drawn at any point on it, gives the direction of magnetic field at that point.

Imp <u>Magnetic field intensity</u> :→ Magnetic field intensity at a point is defined as the force experienced by unit north pole placed at that point.



If F is the force between unit north pole and north pole of a magnet then

Magnetic field intensity $(B) = \frac{F}{m_N}$

But, force between the poles is,

$$F = \frac{\mu_0}{4\pi} \frac{m m_N}{r^2}$$

$$\therefore \boxed{B = \frac{\mu_0}{4\pi} \frac{m}{r^2}}$$

SI unit of B = Tesla

C.G.S unit of B = Oersted

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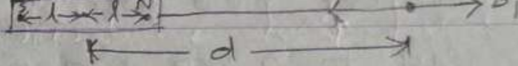
Magnetic field intensity at a point on the axis of magnet due to a bar magnet :→ (Side-on-position) :-



suppose, a bar magnet of length 2l and pole strength m as shown in fig. Let, a point P on the axis of magnet at distance d from the center of magnet. The distance of point P from N-pole is (d−l) and from S-pole is (d+l).

Now, Magnetic field intensity at P due to N-pole $(B_1) = \frac{\mu_0}{4\pi} \frac{m}{(d-l)^2}$; directed away from N-pole

Again,

Magnetic field intensity at P due to S-pole $(B_2) = \frac{\mu_0}{4\pi} \frac{m}{(d+l)^2}$; directed towards S-pole.

$\therefore$ Resultant magnetic field $(B) = B_1 + (-B_2)$

$$= \frac{\mu_0}{4\pi} \frac{m}{(d-l)^2} - \frac{\mu_0}{4\pi} \frac{m}{(d+l)^2}$$

$$= \frac{\mu_0 m}{4\pi} \left[\frac{1}{(d-l)^2} - \frac{1}{(d+l)^2}\right]$$

$$= \frac{\mu_0 m}{4\pi} \left[\frac{(d+l)^2 - (d-l)^2}{(d-l)^2 (d+l)^2}\right]$$

$$= \frac{\mu_0 m}{4\pi}\left[\frac{d^2+2dl+l^2-d^2+2dl-l^2}{(d^2-l^2)^2}\right]$$

$$= \frac{\mu_0 m}{4\pi}\left[\frac{4dl}{(d^2-l^2)^2}\right]$$

$$B = \frac{\mu_0}{4\pi}\left[\frac{m\times 2l\times 2d}{(d^2-l^2)^2}\right]$$

$$\therefore \boxed{B = \frac{\mu_0}{4\pi}\times\frac{2Md}{(d^2-l^2)^2}}$$

where, $M = m\times 2l$ is the magnetic moment.

If $d >> l$ then,

$$\therefore \boxed{B = \frac{\mu_0}{4\pi}\frac{2M}{d^3}}$$

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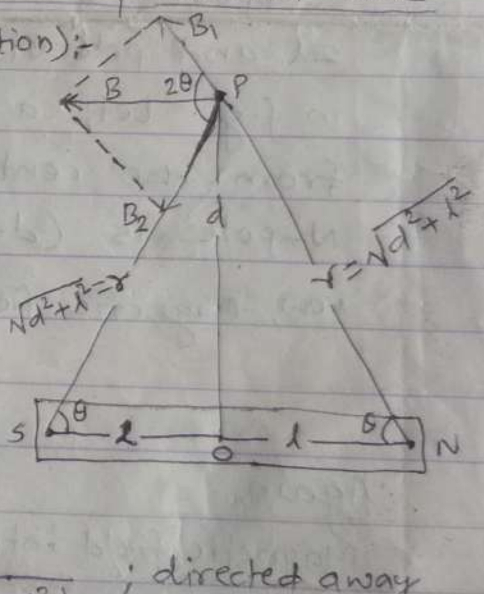
Magnetic field intensity at a point on the equatorial line due to a bar magnet :→ (Broadside position):-



Suppose, a point p is on the equatorial line of the bar magnet. Let, d is the distance of point p from the center of the magnet and p is at a distance r from each pole where $r = \sqrt{d^2+l^2}$.

Now,

Magnetic field intensity at p due to N-pole,

$$B_1 = \frac{\mu_0}{4\pi}\frac{m}{(d^2+l^2)}$$; directed away from N-pole

Again,

Magnetic field intensity at p due to S-pole,

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{(d^2+l^2)}$$; directed towards S-pole.

Let, $\angle PSO = \theta$ and $\angle PNO = \theta$, then the angle between B_1 and B_2 is 2θ.

Now, using parallelogram law of vectors,

$$B = \sqrt{B_1^2 + B_2^2 + 2B_1B_2\cos 2\theta}$$

since, $B_1 = B_2$

$$\therefore B = \sqrt{B_1^2 + B_1^2 + 2B_1B_1\cos 2\theta}$$

$$= \sqrt{2B_1^2 + 2B_1^2\cos 2\theta}$$

$$= \sqrt{2B_1^2(1+\cos 2\theta)}$$

$$= \sqrt{2B_1^2 \times 2\cos^2\theta}$$

$$= \sqrt{4B_1^2\cos^2\theta}$$

$$\therefore B = 2B_1\cos\theta \quad \text{--- (1)}$$

From figure,

$$\cos\theta = \frac{l}{\sqrt{d^2+l^2}}$$

So, eq^n (1) becomes,

$$B = 2 \times \frac{\mu_0}{4\pi}\frac{m}{(d^2+l^2)} \times \frac{l}{\sqrt{d^2+l^2}}$$

$$\therefore B = \frac{\mu_0}{4\pi}\frac{m \times 2l}{(d^2+l^2)^{3/2}}$$

$$\therefore \boxed{B = \frac{\mu_0}{4\pi}\frac{M}{(d^2+l^2)^{3/2}}} \quad \text{--- (2)}$$

where, $M = m \times 2l$ is the magnetic moment.

If $d >> l$ then,

$$\boxed{B = \frac{\mu_0}{4\pi}\frac{M}{d^3}} \quad \text{--- (3)}$$

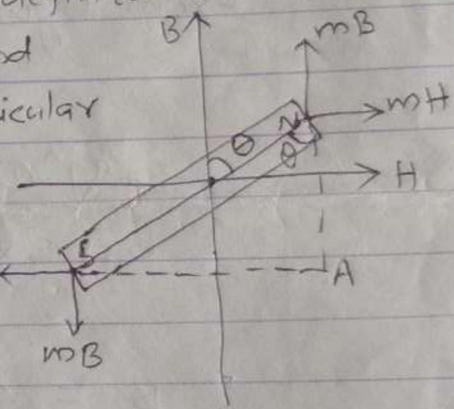
Neutral point :→ A point in the magnetic field of a bar magnet at which the resultant magnetic field intensity is zero is called neutral point.

At neutral point, the field due to a bar magnet is completely neutralized by the horizontal component of the earth's magnetic field.

Tangent law :→

When a bar magnet is kept in a region where two uniform magnetic fields perpendicular to each other then the bar magnet comes in equilibrium under the action of two couples and remains in rest in a definite direction.

Suppose, a magnet of length $2l$ and pole strength m is placed in two perpendicular magnetic fields B and H. On each pole, two forces mB and mH act in perpendicular to each other.



Now, Torque due to field $B = mB \times NA$

Torque due to field $H = mH \times SA$

At equilibrium,

$$mB \times NA = mH \times SA$$

$$\therefore \quad B = H \frac{SA}{NA}$$

From figure,

$$\tan\theta = \frac{SA}{NA}$$

$$\therefore \boxed{B = H\tan\theta}$$

This is tangent law.

Imp
Angle of dip :→ The angle of dip at a place is defined as the angle made by earth's magnetic field with its horizontal component.

Its value varries from place to place and its value is 0° at equator and increases to 90° at poles.

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Q) The horizontal and vertical components of the earth's magnetic field at a place are equal. What is the value of angle of dip at that place?

⇒ Given,
Horizontal component (H) = vertical component (V)

we have,

$$\tan\delta = \frac{V}{H}$$

$$\tan\delta = \frac{H}{H}$$

$$\therefore \tan\delta = 1$$

$$\therefore \tan\delta = \tan 45°$$

$$\therefore \boxed{\delta = 45°}$$

Classification of magnetic material :→

Magnetic materials are classified into three categories:

1) **Diamagnetic materials :→**
They are feebly magnetized in the direction opposite to the applied field.

Ex:- bismuth, copper, water, alcohol etc.

Imp
Properties:-

1) They are repelled by magnets.
2) They move from a stronger to a weaker field.
3) They are independent of temperature.

2) paramagnetic material :→

They are weakly magnetized in the same direction of applied magnetic field.

Ex:- Aluminium, oxygen, chromium etc.

imp properties :→

1) They are feebly attracted by magnets
11) They found in solid, liquid and gas.
111) They depend on temperature.

3) Ferromagnetic material:→

They are highly magnetized in magnetic field.

Ex:- Iron, Nickel & cobalt.

imp properties :-

1) They are highly attracted by magnet.
11) They move from weaker to stronger field.
111) They strongly depend on temperature.

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