MAGNETISM

A magnetic field is defined as the space surrounding a magnet where a moving charge experiences a force.

Strength of the magnetic field is called the intensity of magnetic field or magnetic induction or magnetic flux density

Intensity of magnetic field at a point is defined as the force experienced by a unit north pole placed at that point, denoted by B.

S.I unit of Intensity of magnetic field is $NA^{-1}m^{-1}$

The number of lines of force passing normally through a given area is called the magnetic flux. Its S.I unit is weber. The magnetic flux per unit area is called magnetic flux density B.

$$\text{Magnetic flux density} = \frac{\text{Magnetic flux}}{\text{Area}}$$

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

S.I unit of B is Weber/m^2

Definition of B based on the force acting on a Charged particle in a Magnetic field.

Consider a charge q entering a uniform magnetic field $\vec{B}$ with an arbitrary velocity $\vec{v}$. It experiences a force $\vec{F}$. The direction of force is given by Fleming's left hand rule.

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The magnitude of the force is directly proportional to the charge q and the velocity v.

$$F \propto qv \quad \text{or} \quad F = Bqv$$

B is the uniform magnetic field called the magnetic induction.

$$\text{Thus} \quad B = \frac{F}{qv}$$

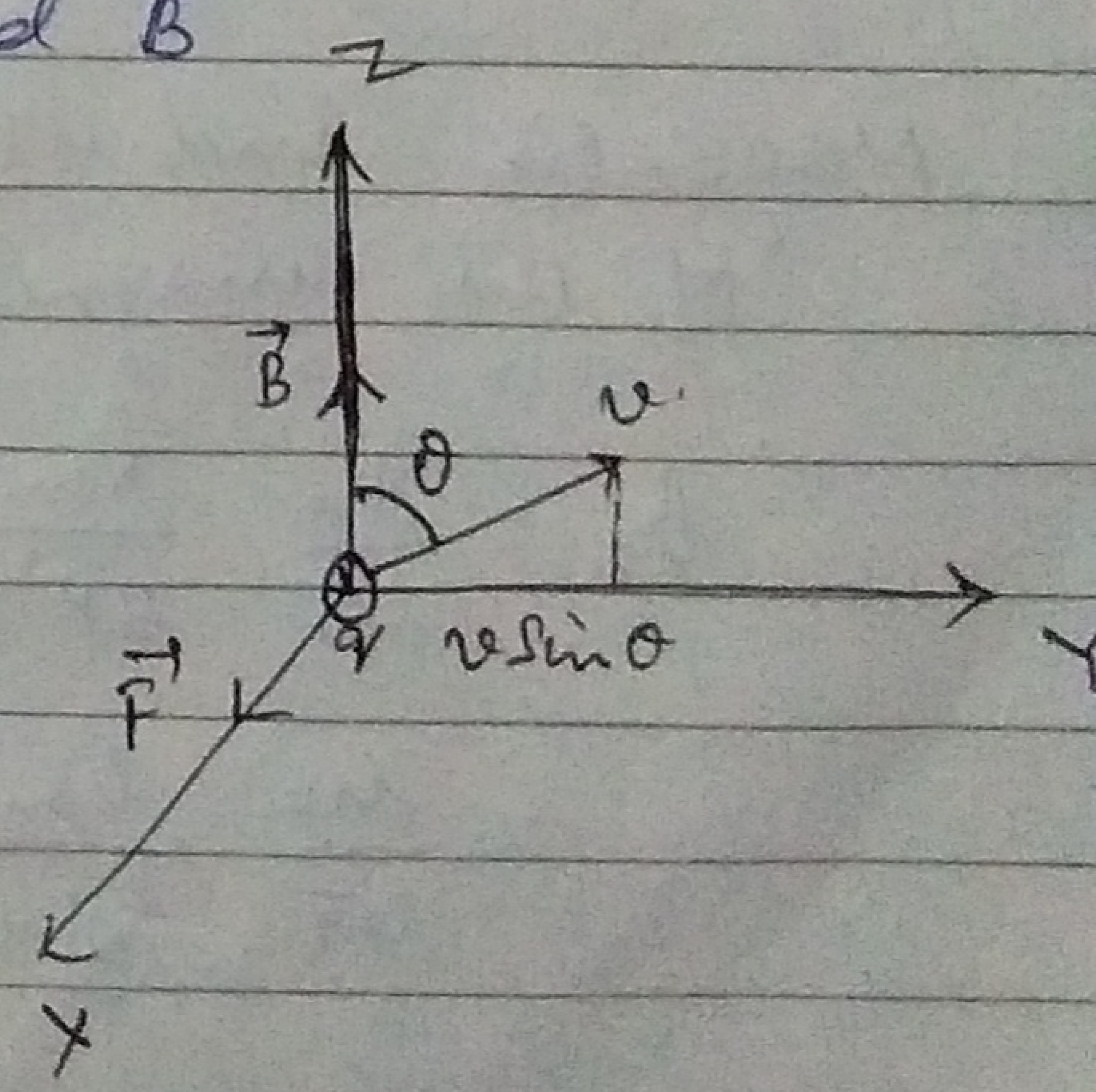
S.I unit of B is $NA^{-1}m^{-1}$ = Tesla.

The magnetic induction is numerically equal to force experienced by one coulomb of charge moving with a velocity of one metre per second at right angles to the direction of the field.

1 Tesla is the magnetic induction in a uniform magnetic field if a charge of one coulomb moving at right angles to the field experiences a force of one newton.

* Expression of Force acting on a charged particle in a magnetic field :

Force $\vec{F}$ acting on a charged particle q entering a uniform magnetic field $\vec{B}$ with velocity $\vec{v}$ is



$$\vec{F} = q\vec{v} \times \vec{B}$$

magnitude of F = $qvB \sin\theta$

($\theta \rightarrow$ is the angle between the direction of the velocity $\vec{v}$ and the direction of the magnetic field $\vec{B}$.)

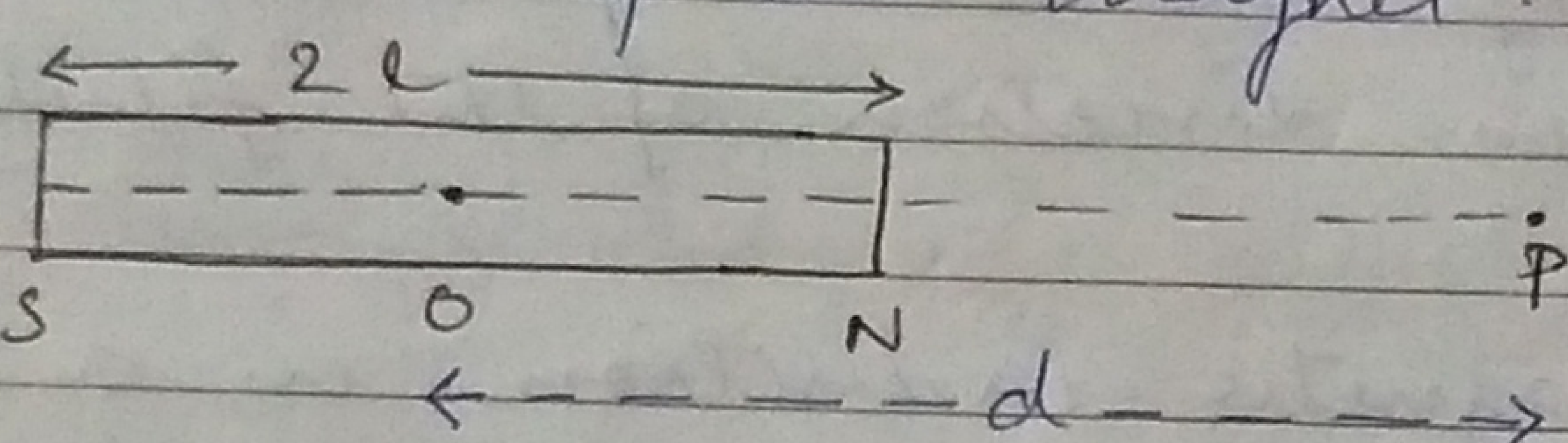
direction of F is given by Fleming's left hand rule.

* Magnetic field due to a dipole.

A north pole and a south pole separated by a small distance constitute a magnetic dipole. The distance between the magnetic poles is called magnetic length.

field due to a Magnetic Dipole at a point on the Axial Line (End on position).

Consider a bar magnet of length $2l$ and pole strength Q_m, with a magnetic moment $p_m = 2l\,Q_m$. Let P be a point at a distance d from the centre O of the magnet.



Magnetic induction B_1 at P due to north pole of the magnet

$$B_1 = \frac{\mu_0}{4\pi}\,\frac{Q_m}{NP^2} \quad \text{along } NP \quad \left[\text{By inverse square law}\right].$$

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

Magnetic induction B_2 at P due to south pole of the magnet.

$$B_2 = \frac{\mu_0}{4\pi}\,\frac{Q_m}{SP^2} \quad \text{along } PS. \qquad \left[\frac{\mu_0}{4\pi} \to \text{constant}\right].$$

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

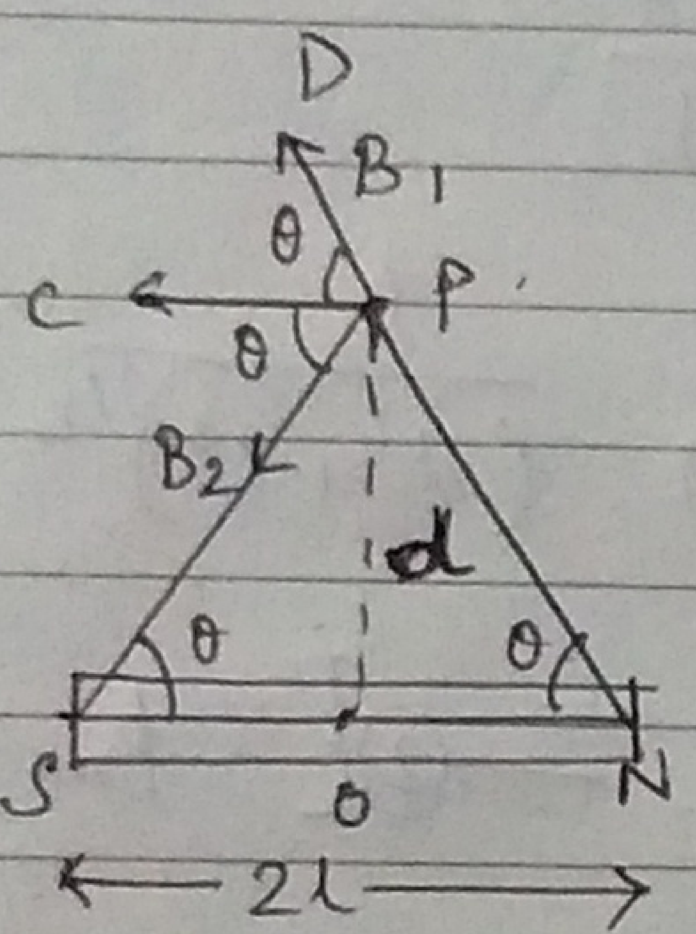
Magnetic induction at P due to the bar magnet

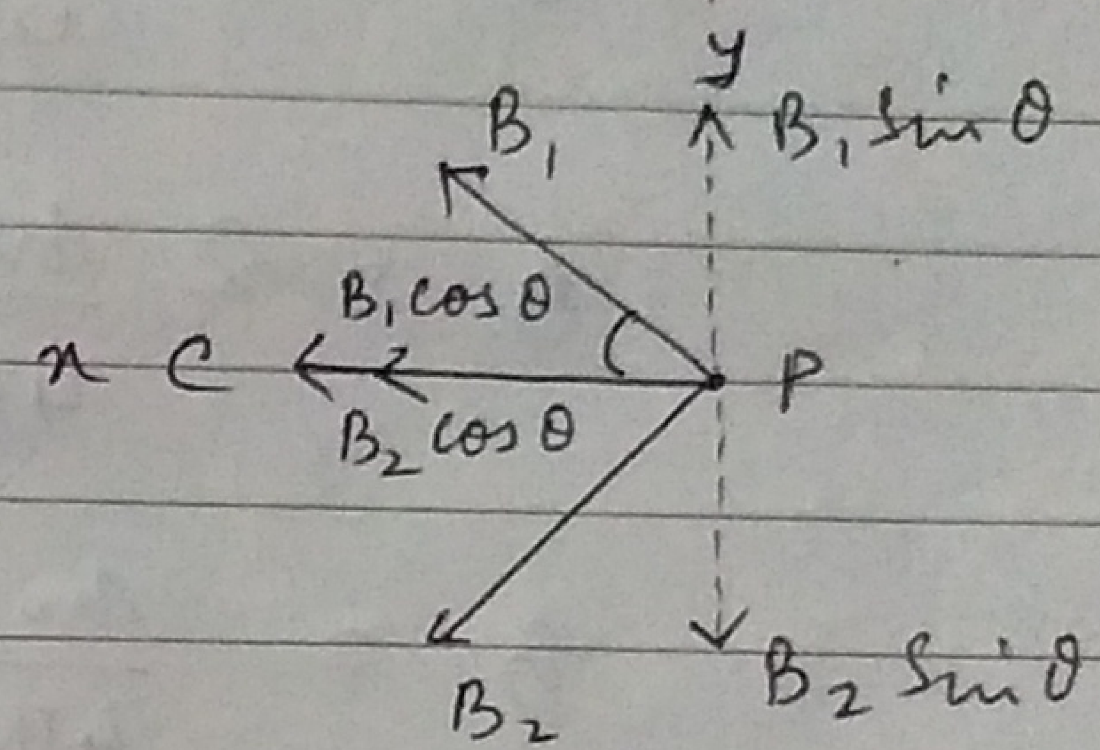
$$B = B_1 - B_2$$

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

$$= \frac{\mu_0}{4\pi} \cdot \frac{2 \cdot p_m d}{(d^2 - l^2)^2} \quad \text{—} ① \quad [p_m = 2l Q_m]$$

* field due to a magnetic dipole at a point on the equatorial line [broad-side on position]





Let P be a point at a distance d from the centre O of the magnet as shown.

Magnetic induction B_1 at P due to north pole of the magnet

$$B_1 = \frac{\mu_0}{4\pi} \frac{Q_m}{NP^2} \quad (\text{along } PD)$$

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

Magnetic induction B_2 at P due to south pole of the magnet

$$B_2 = \frac{\mu_0}{4\pi} \frac{Q_m}{SP^2} \quad (\text{along } PS)$$

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

Now B_1 and B_2 can be resolved into two components as shown. The y-components of the fields cancel each other as $B_1 \sin\theta = B_2 \sin\theta$. and they are oppositely directed. The x components add up to give the resultant.

$\therefore$ Magnitude of $\vec{B}$ is $|B| = B_1 \cos\theta + B_2 \cos\theta$

$$\therefore B = \frac{\mu_0}{4\pi} \frac{Q_m}{(d^2+l^2)} \cos\theta + \frac{\mu_0}{4\pi} \frac{Q_m}{(d^2+l^2)} \cos\theta$$

$$B = 2 \frac{\mu_0}{4\pi} \frac{Q_m \cos\theta}{(d^2+l^2)}$$

$$B = 2 \frac{\mu_0}{4\pi} \frac{Q_m}{(d^2+l^2)} \frac{l}{(d^2+l^2)^{1/2}}$$

$$B = \frac{\mu_0}{4\pi} \frac{p_m}{(d^2+l^2)^{3/2}} \quad \text{--- (2)} \quad \left[\because p_m = 2Q_m l\right]$$

* If $d >> l$.

from (1)

$$B_{axis} = \frac{\mu_0}{4\pi} \frac{2p_m}{d^3}$$

from (2)

$$B_{equatorial} = \frac{\mu_0}{4\pi} \frac{p_m}{d^3}$$

—x—