
PRAYAS
JEE 2025
ATDB.uno
Lecture -08
Physics
Magnetism
By- Saleem Ahmed Sir
Physics Wall

# Today's Goal

- magnetic moment
- Bar magnet

$\vec{P} = q\vec{l} \longrightarrow \vec{m} = i\vec{A} \cdot N$

$\vec{P} \longrightarrow \vec{m}$

$\vec{\tau} = \vec{P} \times \vec{E} \longrightarrow \vec{\tau} = \vec{m} \times \vec{B}$

$U = -\vec{P} \cdot \vec{E} \longrightarrow U = -\vec{m} \cdot \vec{B}$

$T = 2\pi\sqrt{\frac{I}{PE}} \longrightarrow T = 2\pi\sqrt{\frac{I}{mB}}$

$T = 2\pi\sqrt{\frac{I}{mB}}$

$I \longrightarrow$ MOI

$m \longrightarrow$ magnetic moment

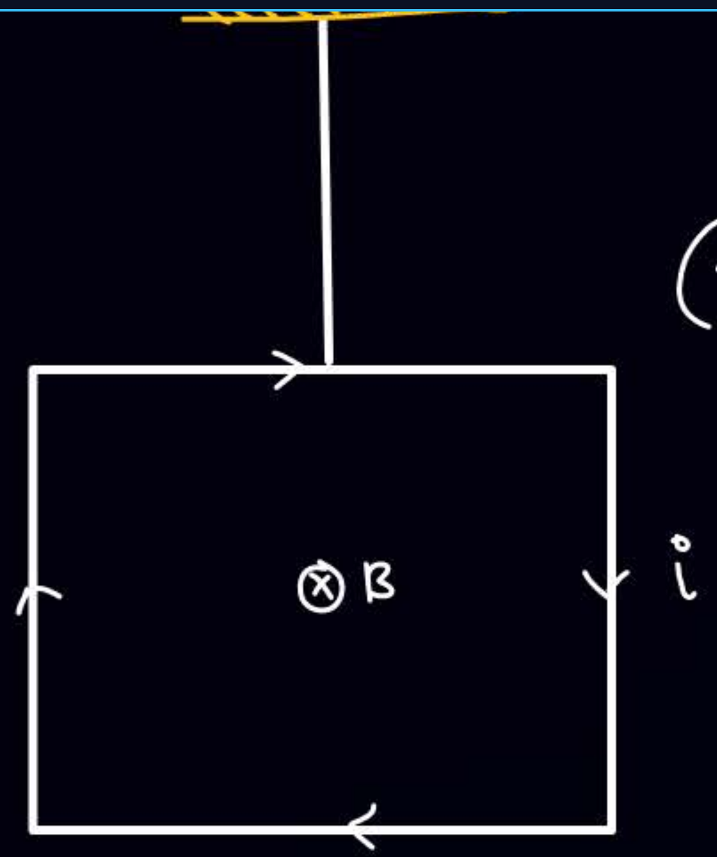
$\longrightarrow P$ | $\longrightarrow M$
$\longrightarrow E$ | $\longrightarrow B$

$\theta = 0$ | $\theta = 0$
$\tau = 0$ | $\tau = 0$
Stable | Stable

$\theta = 0$ (stable) $\longrightarrow$ $\theta = 0$ (stable)

$\theta = 180$ (Unstable) | $\theta = 180$ (Unstable)

Q



$\theta = 0$, stable

(4 rod each of mass m & L)

$\vec{B}_{ext} = -B\hat{k}$

$\tau = mB\sin\theta$

$\vec{\tau} = -mB\vec{\theta}$

$T = 2\pi\sqrt{\frac{I}{mB}}$ (Angular SHM)

If loop is rotated slightly by angle '$\theta$', find time period of oscillation.

Sol$^n$

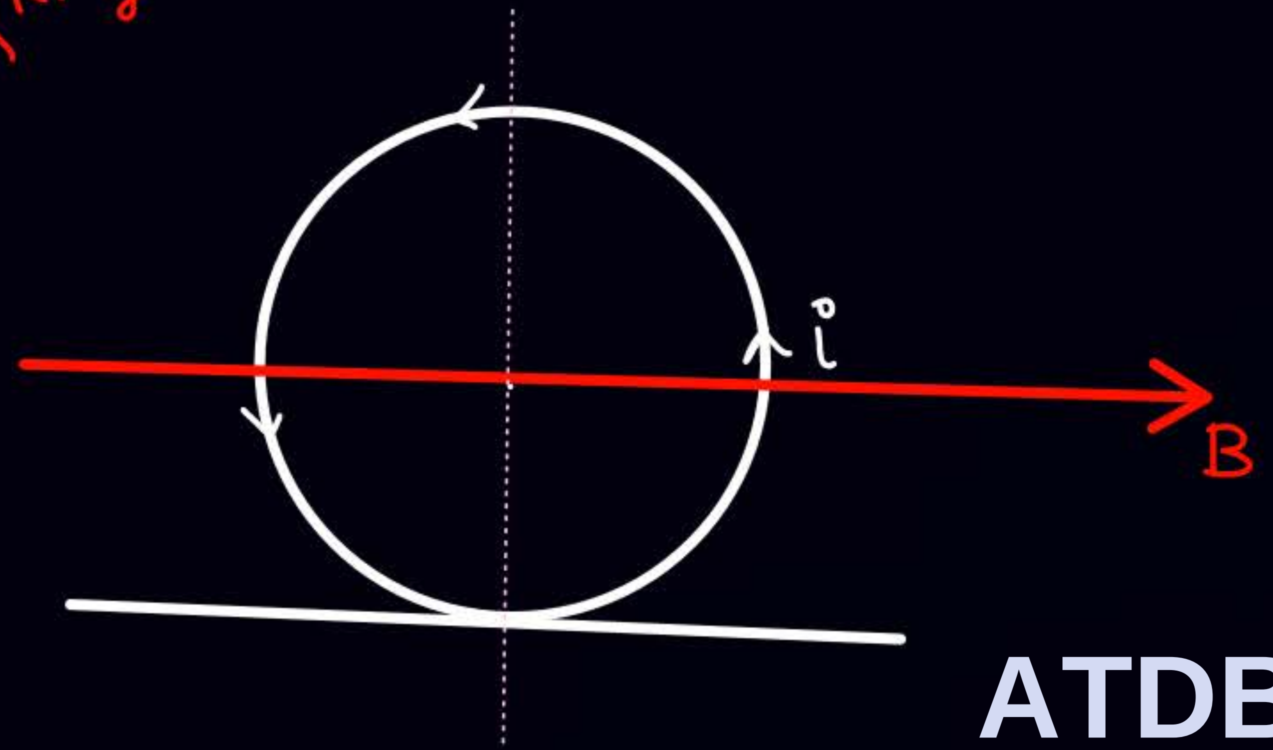
$T = 2\pi\sqrt{\frac{I}{MB}}$

$I = \left[\frac{mL^2}{12} + m\left(\frac{L}{2}\right)^2\right] \times 2 = \frac{2mL^2}{3}$

magnetic moment $= iL^2$

$$T = 2\pi\sqrt{\frac{\frac{2mL^2}{3}}{i \cdot L^2 B}}$$

Q (Ring m, R)




find '$\alpha$' of ring at given instant.

sol$^n$ $\vec{\tau} = \vec{M} \times \vec{B}$

$\vec{m} = i\pi R^2 \hat{k}$

$\vec{B} = B\hat{i}$

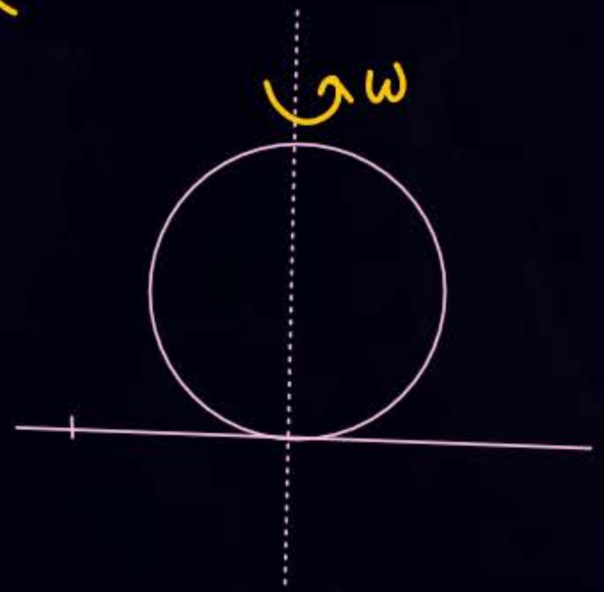
$\tau = i\pi R^2 B = I\alpha$

$\hat{\tau} \equiv \hat{k} \times \hat{i} \equiv \hat{j}$

$\tau = i\pi R^2 B = \frac{mR^2}{2}\alpha$

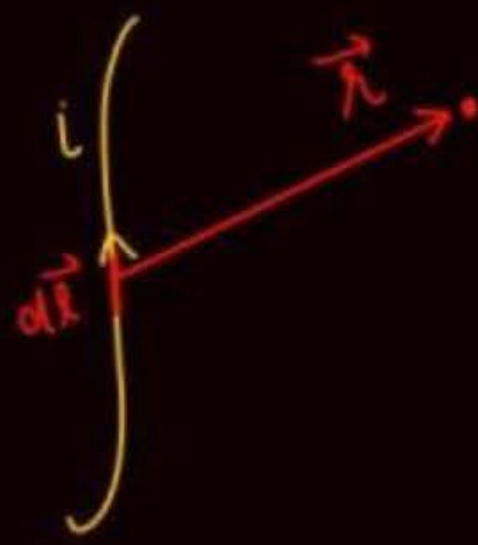


$\alpha = \frac{2i\pi B}{m}$



# Biot-Savart Law

① for wire

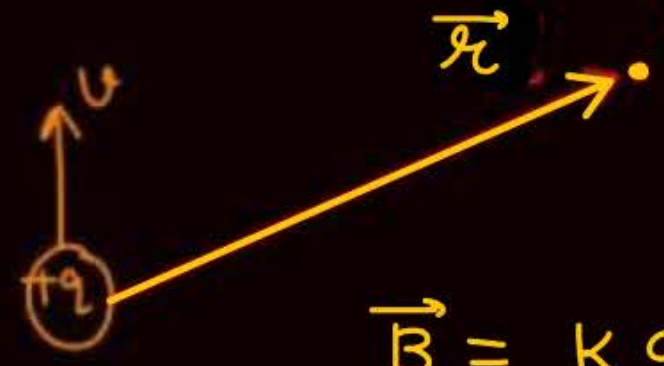



$$d\vec{B} = \frac{K\,i\,(d\vec{l}\times\vec{r})}{r^3}$$

→ due to small element $dl$.

$$K = \mu_0/4\pi$$

② For moving point charge



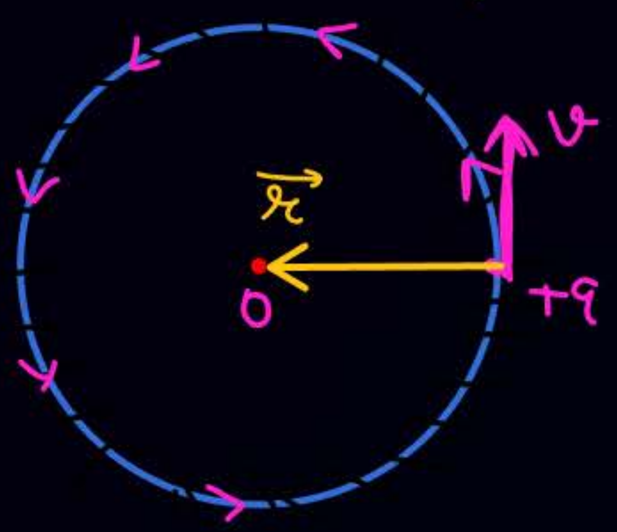

$$\vec{B} = \frac{K\,q\,(\vec{v}\times\vec{r})}{r^3}$$

with sign

$$\vec{B} = \frac{K\,q\,(\vec{v}\times\vec{r})}{r^3}$$

Q If a charge particle $(+q, m)$ is moving in a circular path with const speed $v, \omega$. find magnetic field at the center of circle.

Sol$^n$

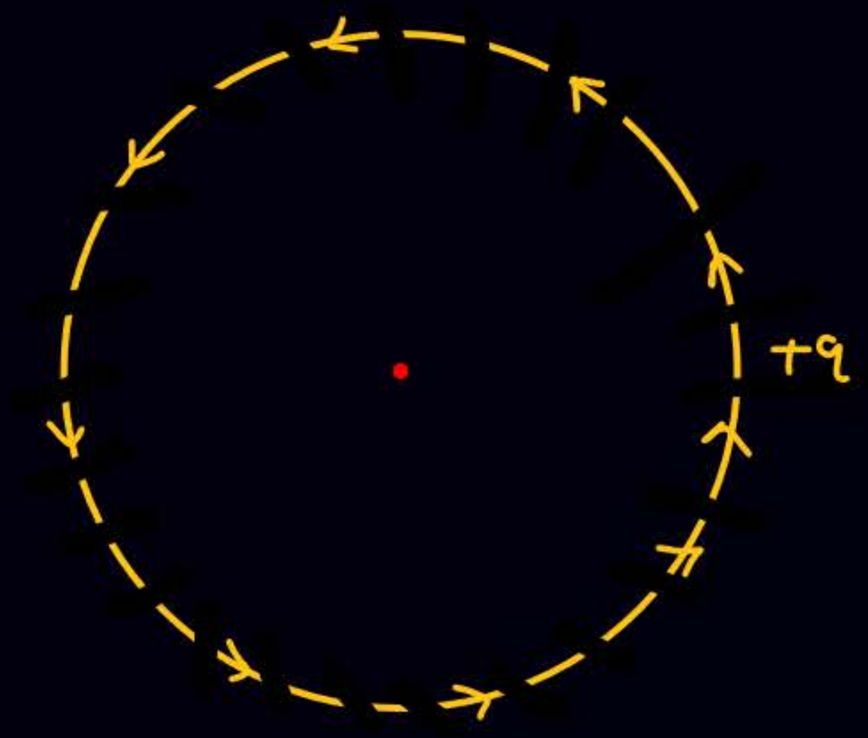



$$\vec{B} = \frac{Kq(\vec{v} \times \vec{r})}{r^3}$$

$$\vec{B} = \frac{Kq\, v\, r \sin 90}{r^3} \odot$$



$$\vec{B} = \frac{K \cdot q \cdot r\omega r}{r^3} = \frac{Kq\omega}{r}$$




$$\equiv$$

$i = \frac{q}{T}$

$T \rightarrow$ time period



$$K = \frac{Kq\omega}{R} = \frac{\mu_0}{4\pi}\cdot\frac{q}{R}\cdot\frac{2\pi}{T}$$

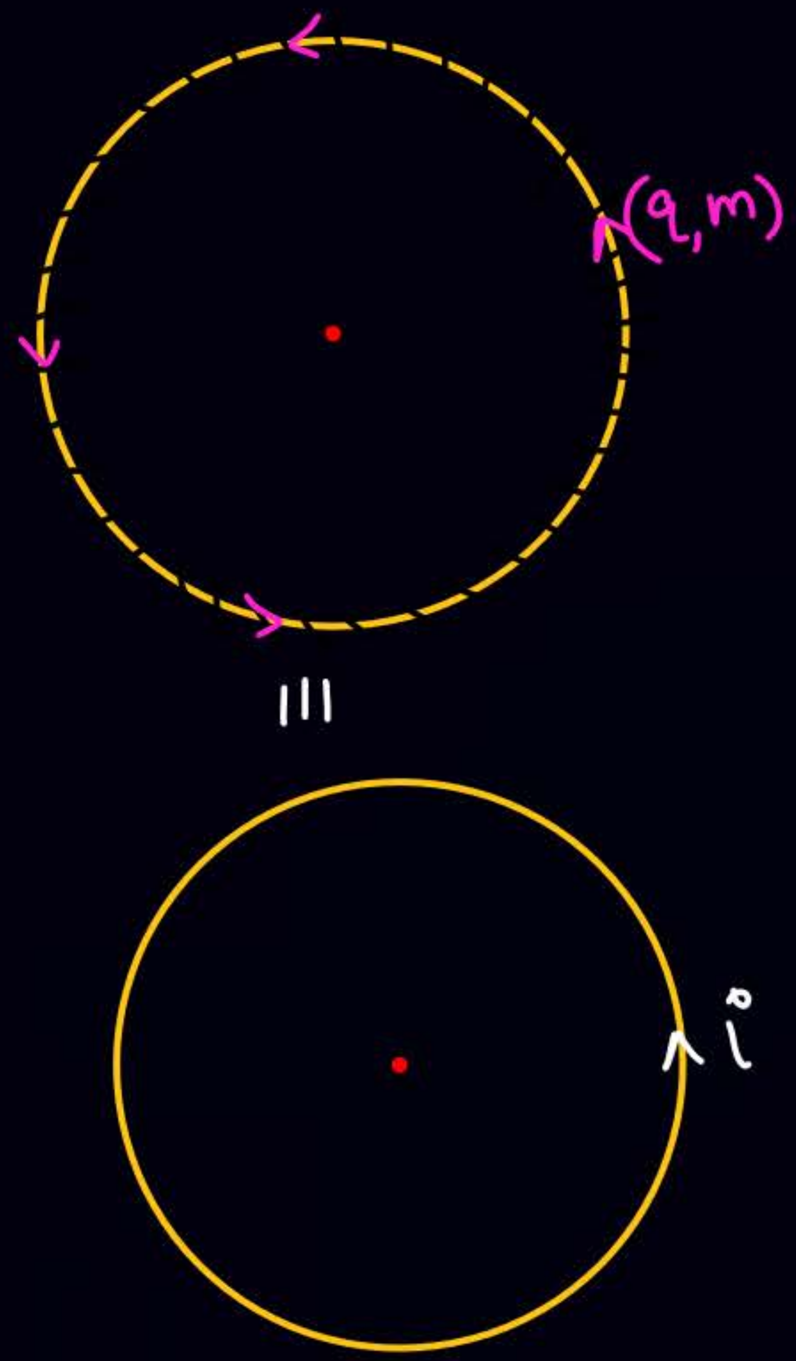
$$= \frac{\mu_0 q}{2RT}$$

$\vec{M}$ = magnetic moment = ?

$$B_{center} = \frac{\mu_0 i}{2R} = \frac{\mu_0}{2R}\frac{q}{T}$$

$\vec{M}$ = magnetic moment = $iA = \frac{q}{T} \times \pi R^2$

Q




① $B_{center} = \frac{\mu_0 i}{2R} = \frac{\mu_0 (q/T)}{2R} (\hat{k})$

② magnetic moment $= iA = \frac{q}{T} \cdot \pi R^2 (\hat{k})$

③ Angular momentum $= mvR = mR\omega R = mR^2\omega(-\hat{k})$

④ $$\frac{|\vec{m}|}{|\vec{L}|} = \frac{\frac{q}{T} \cdot \pi R^2}{mR^2\omega} = \frac{q\pi}{Tm\frac{2\pi}{T}} = \frac{q}{2m}$$



$$\boxed{\vec{m} = \frac{q}{2m}\vec{L}}$$

$$\boxed{m = \frac{q}{2m}L}$$

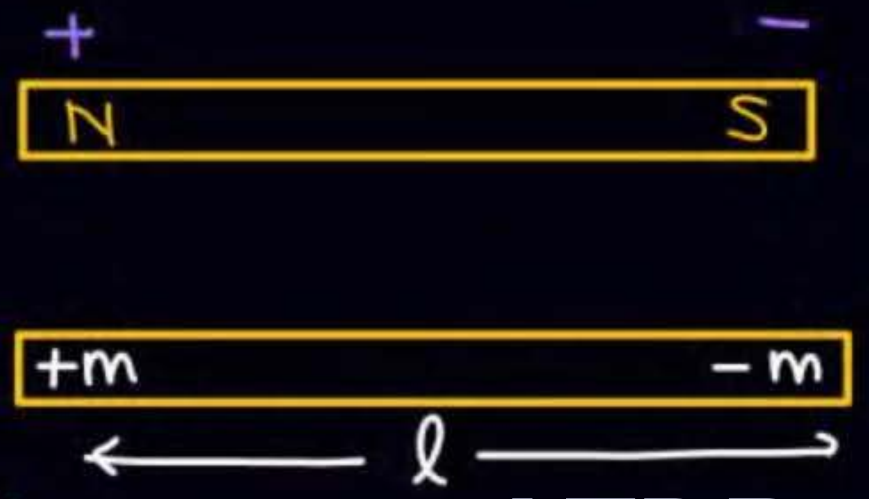
magnetic moment

mass

Angular moment

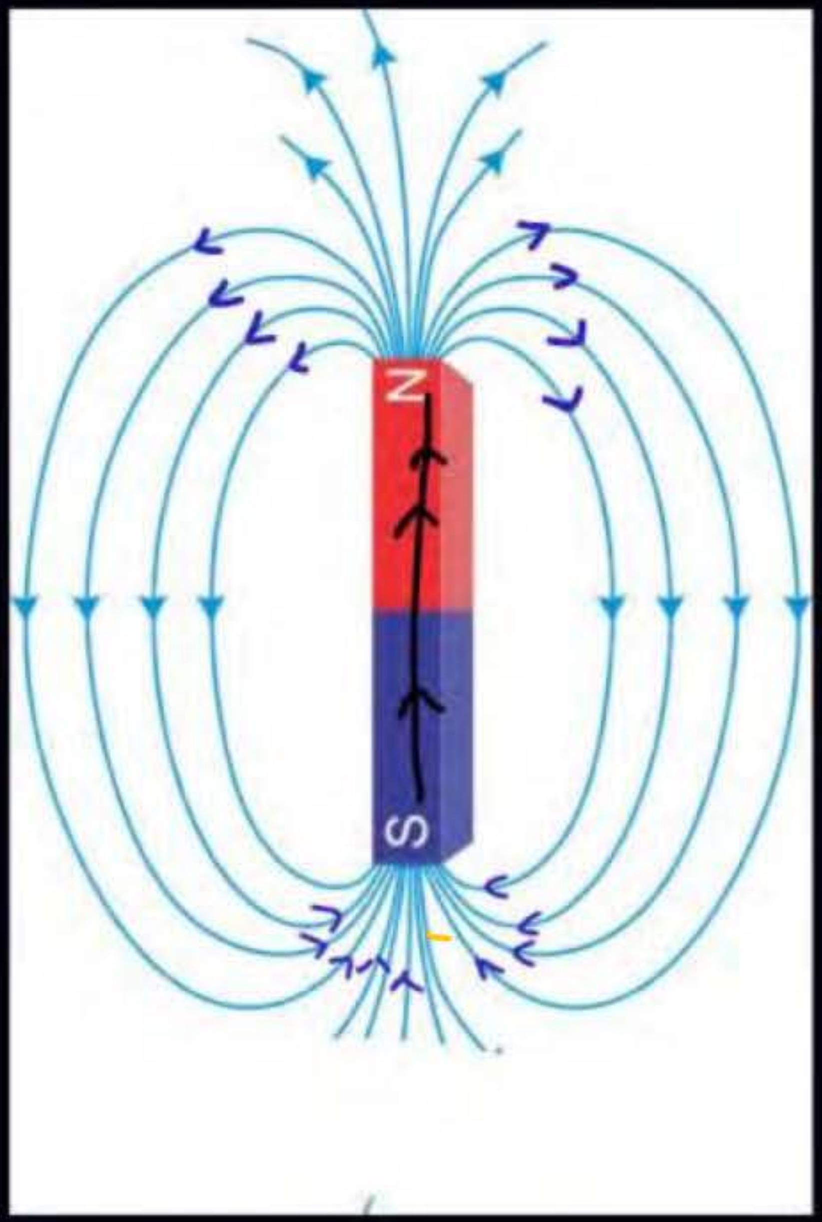
# Bar magnet

$m \longrightarrow$ pole strength




magnetic dipole moment

$\vec{M} = m\vec{l}$ (south to north)




(North pole ≡ +ve charge)

(South pole ≡ −ve charge)

* Inside magnet magnetic field is from South to north.



$$\vec{m}_{net} = m\vec{\ell}$$

magnetic dipole moment

$$\vec{p} = q\vec{\ell}$$

Electric dipole moment

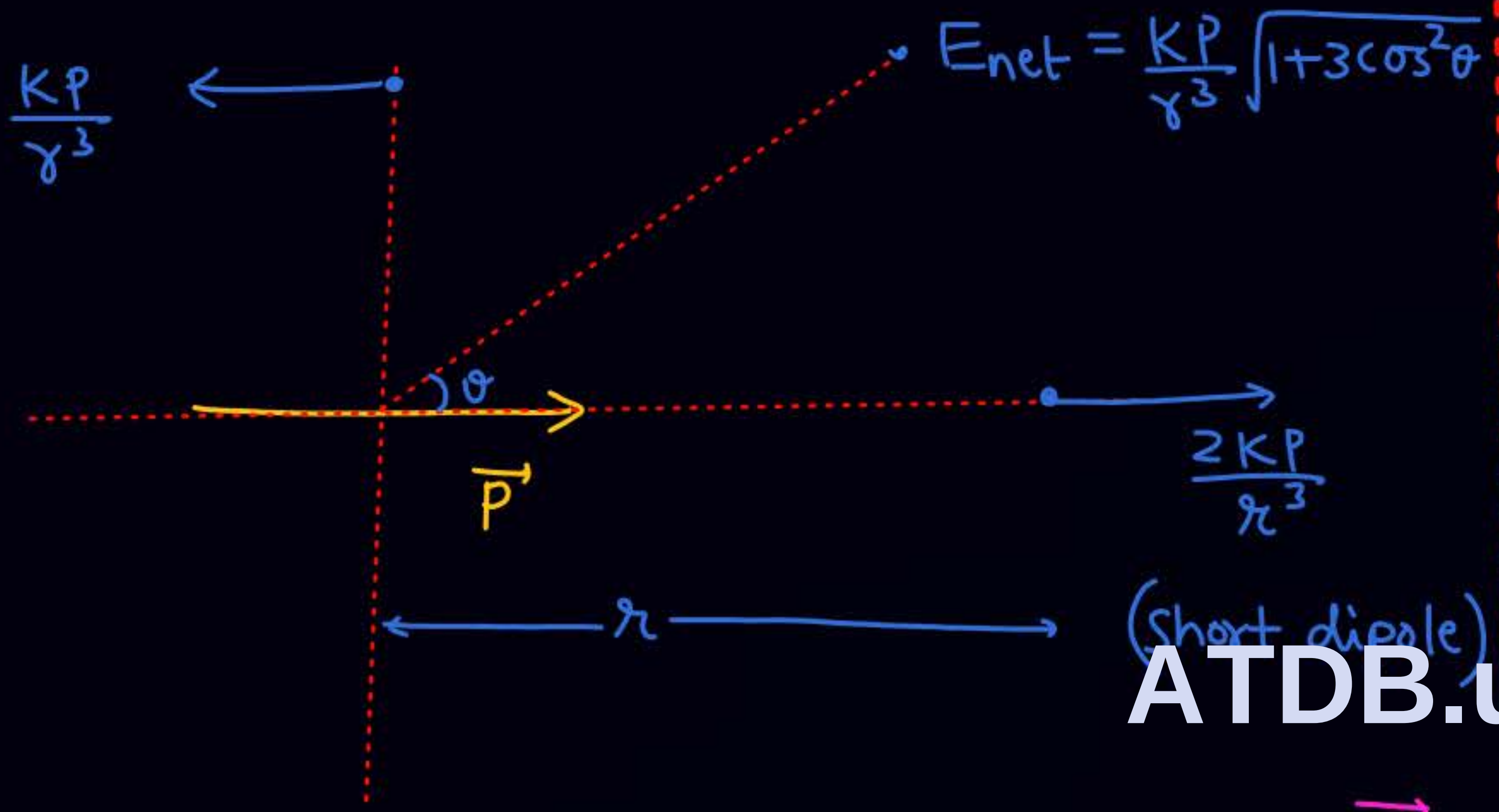
$$m \longrightarrow q$$

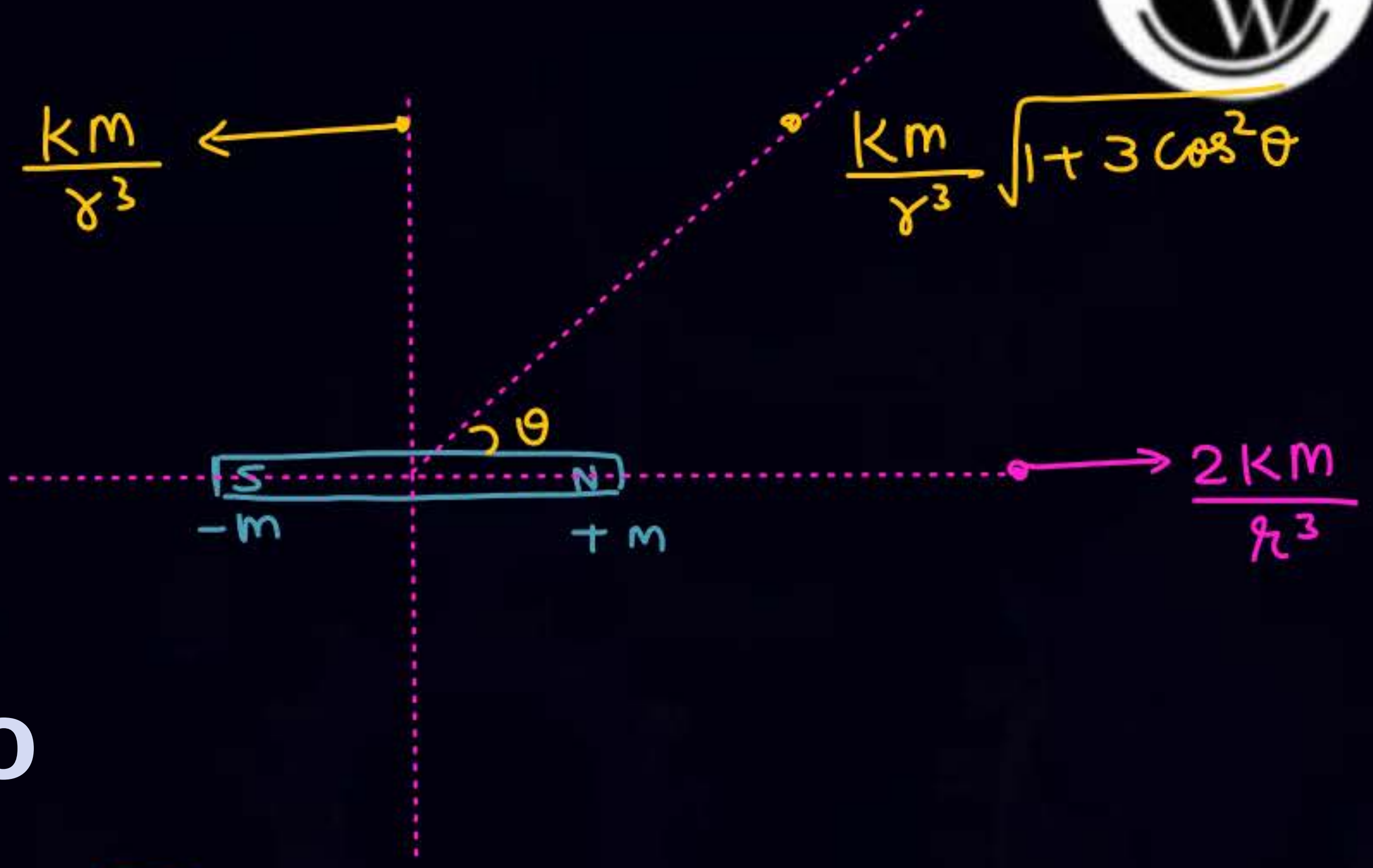
$$\vec{M} \longrightarrow \vec{P}$$

$$\vec{\tau} = \vec{m}\times\vec{B} \longrightarrow \vec{\tau} = \vec{p}\times\vec{E}$$

$$U = -\vec{m}\cdot\vec{B} \longrightarrow U = -\vec{p}\cdot\vec{E}$$

$$T = 2\pi\sqrt{\frac{I}{mB}} \longrightarrow T = 2\pi\sqrt{\frac{I}{pE}}$$



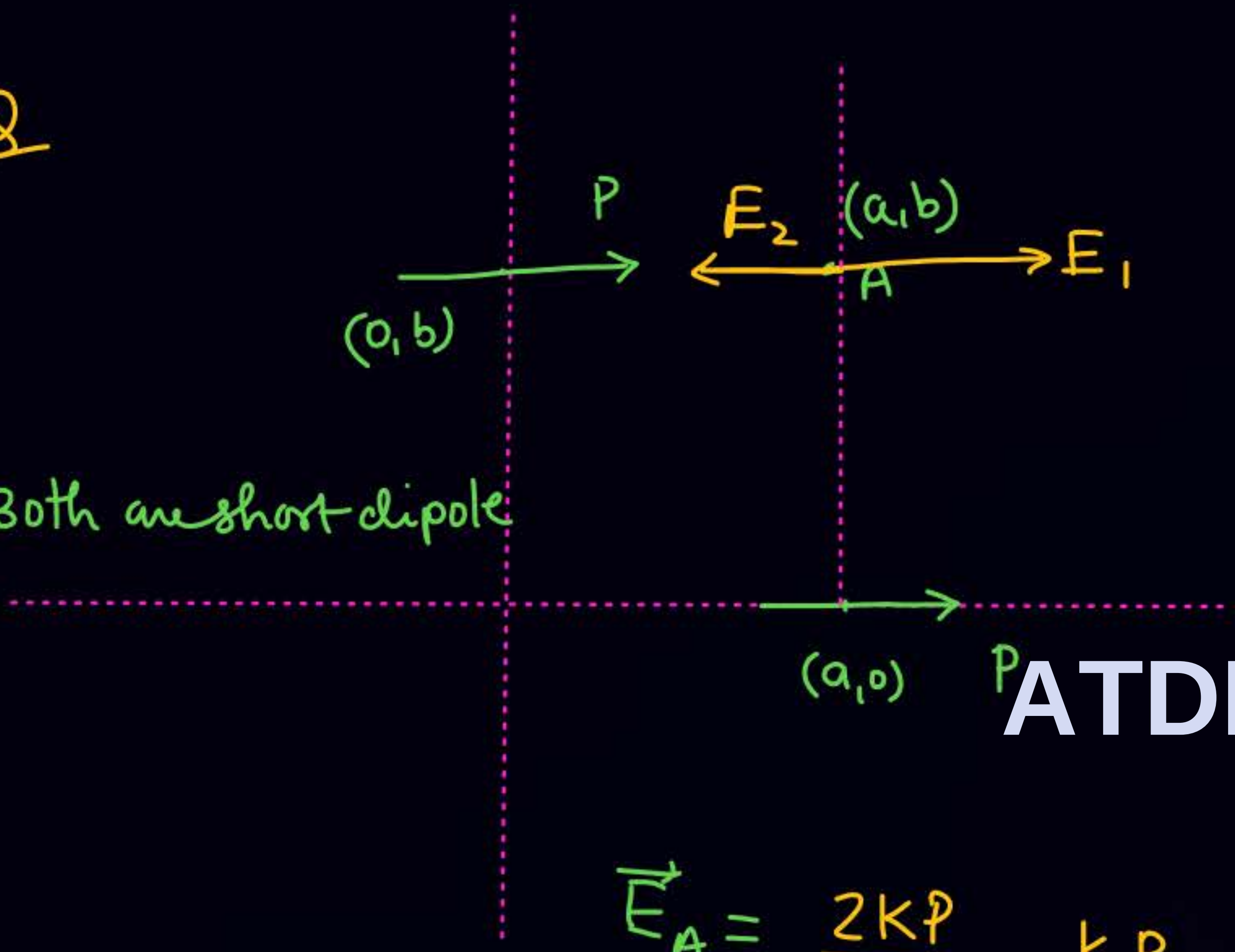



$\vec{P} \longrightarrow \vec{m}$

$q \longrightarrow m$

$K = \frac{1}{4\pi\epsilon_0} \longrightarrow k = \frac{\mu_0}{4\pi}$

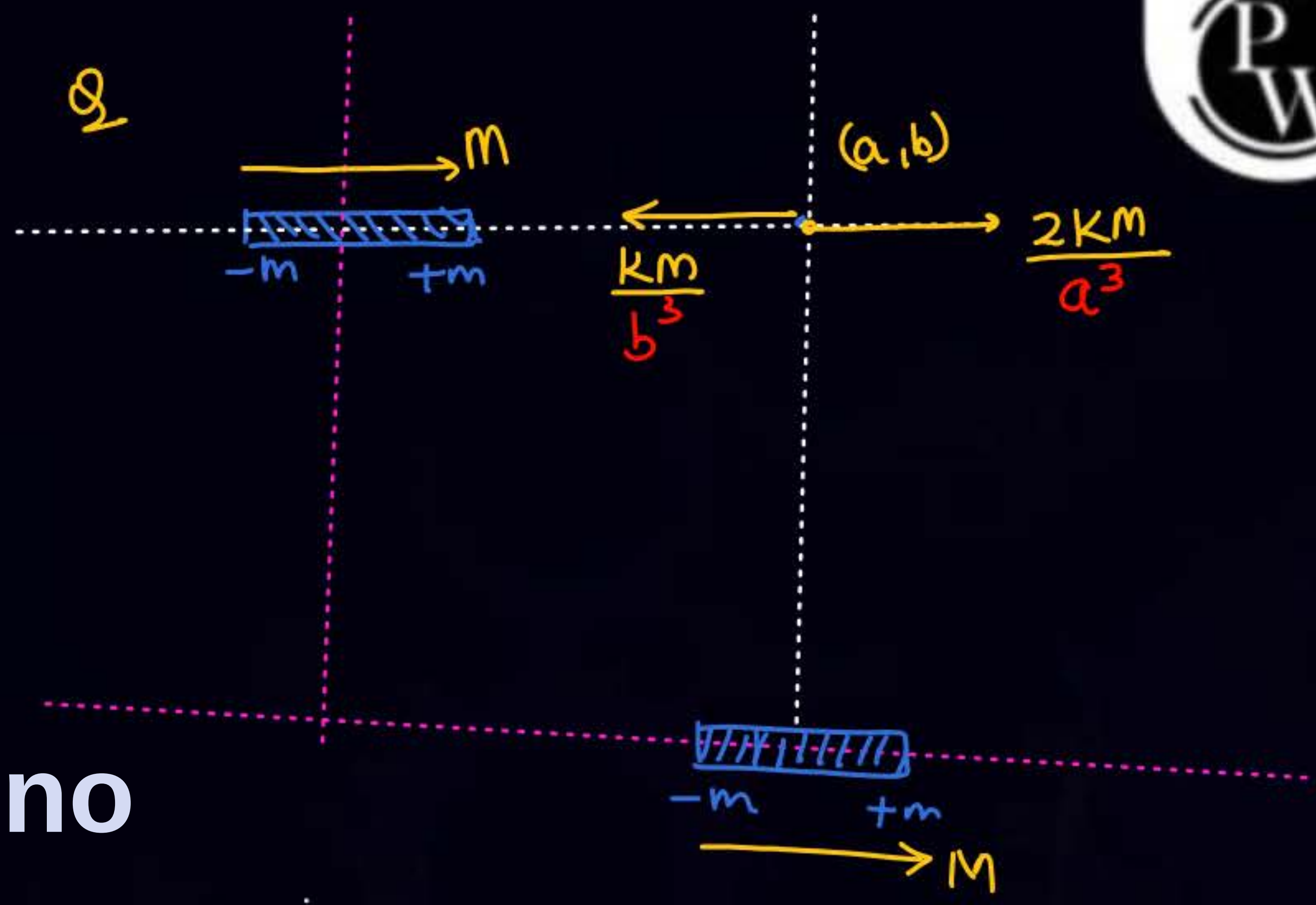
Q




Both are short dipole

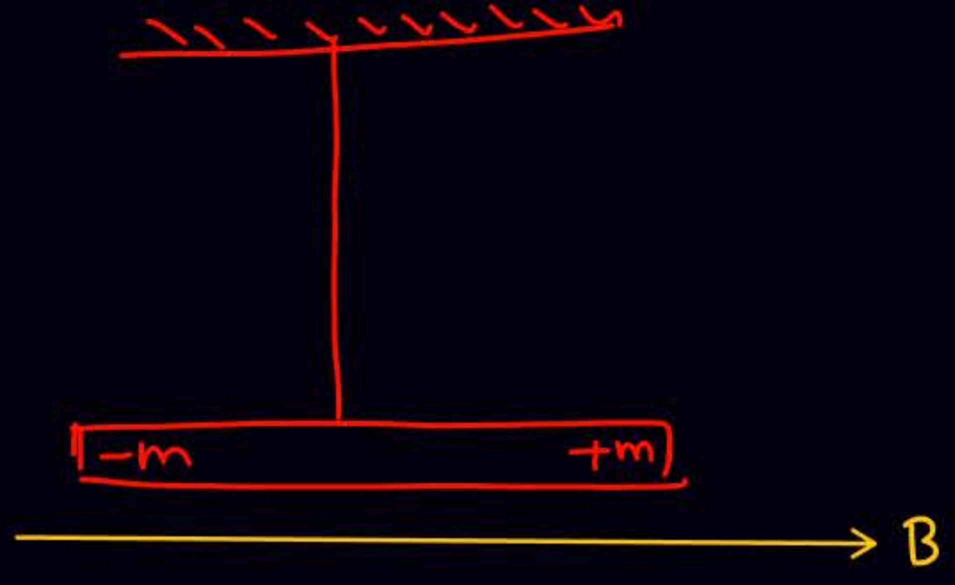
$$\vec{E}_A = \frac{2KP}{a^3} - \frac{KP}{b^3}$$

Q



Jm frst

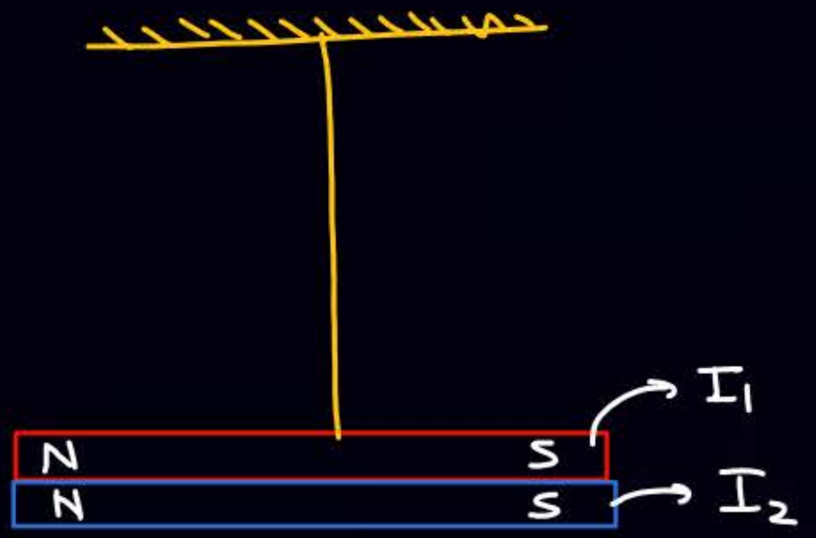
Q




$$T = 2\pi\sqrt{\frac{I}{mB}}$$

$m$ → magnetic moment

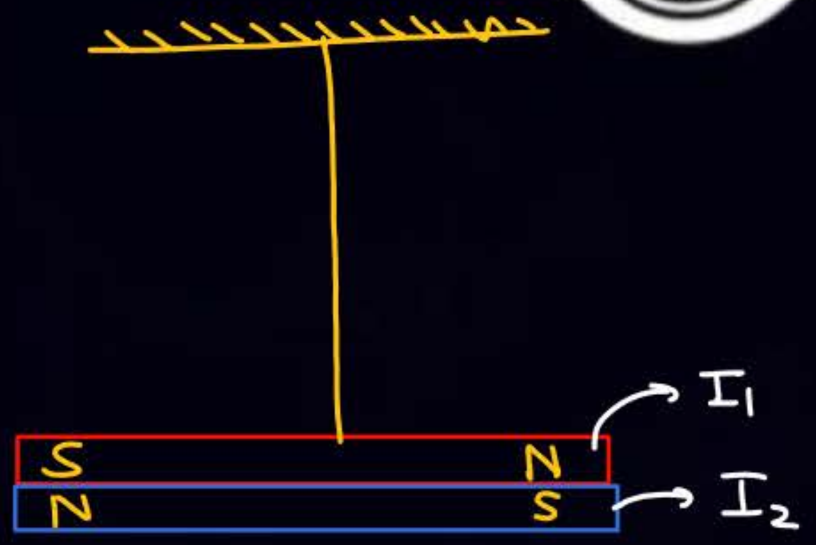
#




$$T = 2\pi\sqrt{\frac{I_1+I_2}{(m_1+m_2)B}}$$



#




$$T = 2\pi\sqrt{\frac{I_1+I_2}{|(m_1-m_2)|B}}$$


$$F = \frac{6KP_1P_2}{r^4}$$


$$F = \frac{6Km_1m_2}{r^4}$$

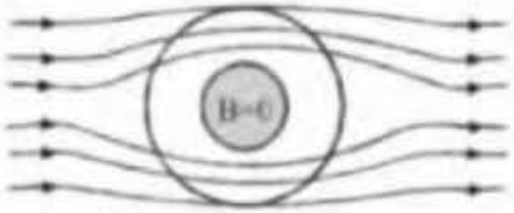
$$= \frac{}{4\pi (r^2 + \ell^2)\sqrt{(r^2 + \ell^2)}}$$

$$B_{eq} = \frac{\mu_0}{4\pi} \cdot \frac{M}{(r^2 + \ell^2)^{3/2}}, \qquad \text{where } M = m(2\ell)$$

If magnet is short $r >> \ell$, then $B_{eq} = \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3}$

**Magnetic shielding**

If a soft iron ring is placed in magnetic field, most of the lines are found to pass through the ring and no lines pass through the space inside the ring. The inside of the ring is thus protected against any external magnetic effect. This phenomenon is called magnetic screening or shielding and is used to protect costly wrist–watches and other instruments from external magnetic fields by enclosing them in a soft–iron case or box.




Iron ring in a field

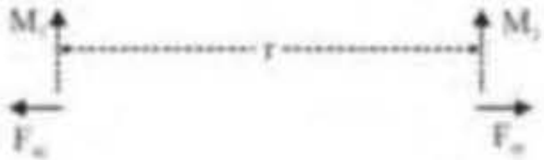


(i) Super conductors also provides perfect magnetic screening due to exclusion of lines of force. This effect is called **'Meissner effect'**

(ii) Relative magnetic premeability of super conductor is zero. So we can say that super conductors behaves like perfect dimagnetic.


Super conductor in a field

**Dipole - Dipole Interactions :**

| **S.No.** | **Relative position of dipoles** | **Magnetic force ($F_m$)** |
|---|---|---|
| (a) |   | $\frac{\mu_0}{4\pi} \cdot \frac{6M_1M_2}{r^4}$ (along r) |
| (b) |   | $\frac{\mu_0}{4\pi} \cdot \frac{3M_1M_2}{r^4}$ (along r) |
| |   | $\frac{\mu_0}{} \; 3M_1M_2$ |

$$= \frac{\quad}{4\pi (r^2 + \ell^2)\sqrt{(r^2 + \ell^2)}}$$

$$B_{eq.} = \frac{\mu_0}{4\pi} \cdot \frac{M}{(r^2 + \ell^2)^{3/2}},$$ where $M = m(2\ell)$

$K = \frac{\mu_0}{4\pi}$

If magnet is short $r >> \ell$, then $B_{eq.} = \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3}$

short

① 


$F = \frac{K\,6\,m_1 m_2}{r^4}$ (Same as electrostatic

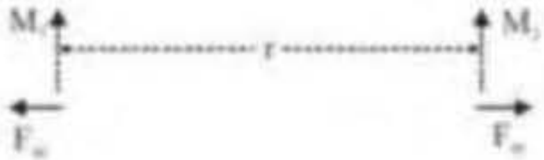
② 


$F = \frac{3k\,m_1 m_2}{r^4}$ (along $\vec{r}$)

③ 


$F = \frac{3k\,m_1 m_2}{r^4}$ ($\perp^r$ to r)

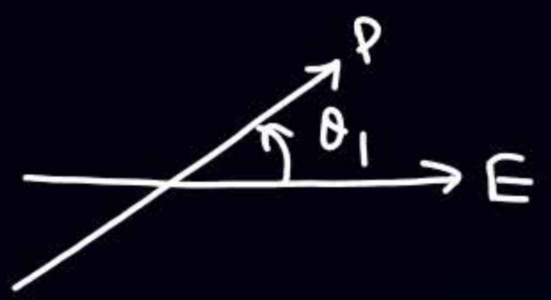
**Dipole - Dipole Interactions :**

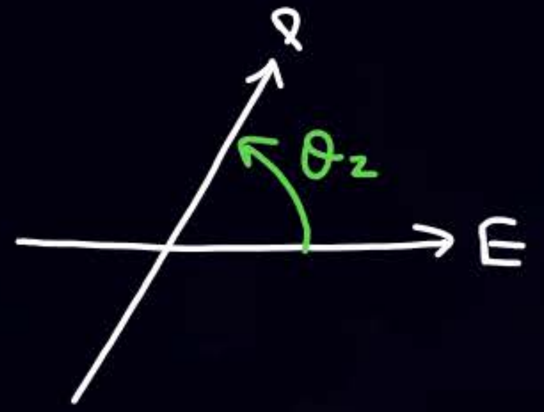
| S.No. | Relative position of dipoles | Magnetic force ($F_m$) |
|---|---|---|
| (a) |  | $\frac{\mu_0}{4\pi} \cdot \frac{6M_1M_2}{r^4}$ (along r) |
| (b) |  | $\frac{\mu_0}{4\pi} \cdot \frac{3M_1M_2}{r^4}$ (along r) |
| |  | $\frac{\mu_0}{4\pi} \cdot \frac{3M_1M_2}{}$ |

Jm

* $(WD)_{\text{by ext-agent}}$ required to rotate dipole from $\theta_1$ to $\theta_2 = -PE(\cos\theta_2 - \cos\theta_1)$

$$= PE\cos\theta_1 - PE\cos\theta_2$$






\#


$$(WD)_{ext} = -MB(\cos\theta_2 - \cos\theta_1)$$

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

Recalling that the potential energy for an electric dipole is $U = -\vec{p} \bullet \vec{E}$ [see Eq.], a similar form is expected for the magnetic case. The work done by an external agent to rotate the magnetic dipole from an angle $\theta_0$ to $\theta$ is given by

$$W_{ext} = \int_{\theta_0}^{\theta} (\mu B \sin\theta')d\theta' = \mu B(\cos\theta_0 - \cos\theta)$$

$$= \Delta U = U - U_0$$

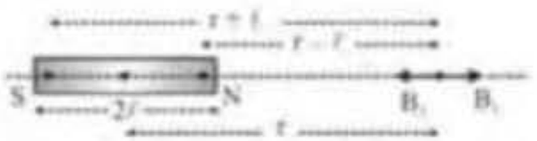
Once again, $W_{ext} = -W$, where W is the work done by the magnetic field. Choosing $U_0 = 0$ at $\theta_0 = \pi/2$, the dipole in the presence of an external field then has a potential energy os



$$U = -\mu B \cos\theta = -\vec{\mu} \bullet \vec{B}$$

The configuration is at a stable equilibrium when $\vec{\mu}$ is aligned parallel to $\vec{B}$, making U a minimum with $U_{min} = -\mu B$. On the other hand, when $\vec{\mu}$ and $\vec{B}$ are anti-parallel, $U_{max} = +\mu B$ is a maximum and the system is unstable.

Derivation



(i) **At Axial position :–**

Magnetic field at point 'P' due to north pole $B_1 = \frac{\mu_0}{4\pi}\frac{m}{(r-\ell)^2}$ (away from north pole)

Magnetic field at point 'P' due to south pole $B_2 = \frac{\mu_0}{4\pi}\frac{m}{(r+\ell)^2}$ (towards north pole)

Net magnetic field at point 'P'

$$B_{axis} = B_1 - B_2, (\because B_1 > B_2) = \frac{\mu_0 m}{4\pi}\left[\frac{1}{(r-\ell)^2} - \frac{1}{(r+\ell)^2}\right] = \frac{\mu_0 m}{4\pi}\left[\frac{4r\ell}{(r^2-\ell^2)^2}\right]$$

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2-\ell^2)^2}, \text{ where } M = m(2\ell)$$

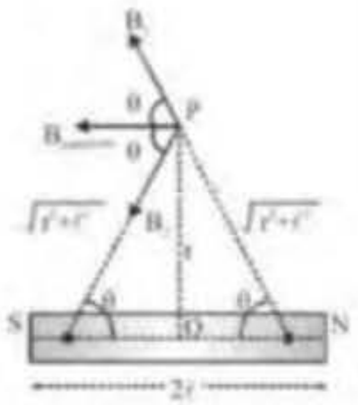


If magnet is short $r >> \ell$, then $B_{axis} = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$

(ii) **At equatorial position :–**

Magnetic field at point 'P' due to north pole :–

$$B_1 = \frac{\mu_0}{4\pi}\frac{m}{\left(\sqrt{r^2+\ell^2}\right)^2} \quad \text{..... (1)} \qquad \text{(along NP line)}$$



Magnetic field at point 'P' due to south pole :–

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{\left(\sqrt{r^2+\ell^2}\right)^2} \quad \text{..... (2)} \qquad \text{(along PS line)}$$

From equation (1) & (2) $B_1 = B_2 = \frac{\mu_0}{4\pi}\cdot\frac{m}{r^2+\ell^2} = B$ (Let)

Net magnetic field at point 'P'

$$B_{eq} = 2B\cos\theta = 2\cdot\frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\cos\theta, \qquad [\text{where } \cos\theta = \frac{\ell}{\sqrt{r^2+\ell^2}}]$$

# Home work

- PYQ attached


THANK
YOU