VISUAL PHYSICS

SHORT NOTES

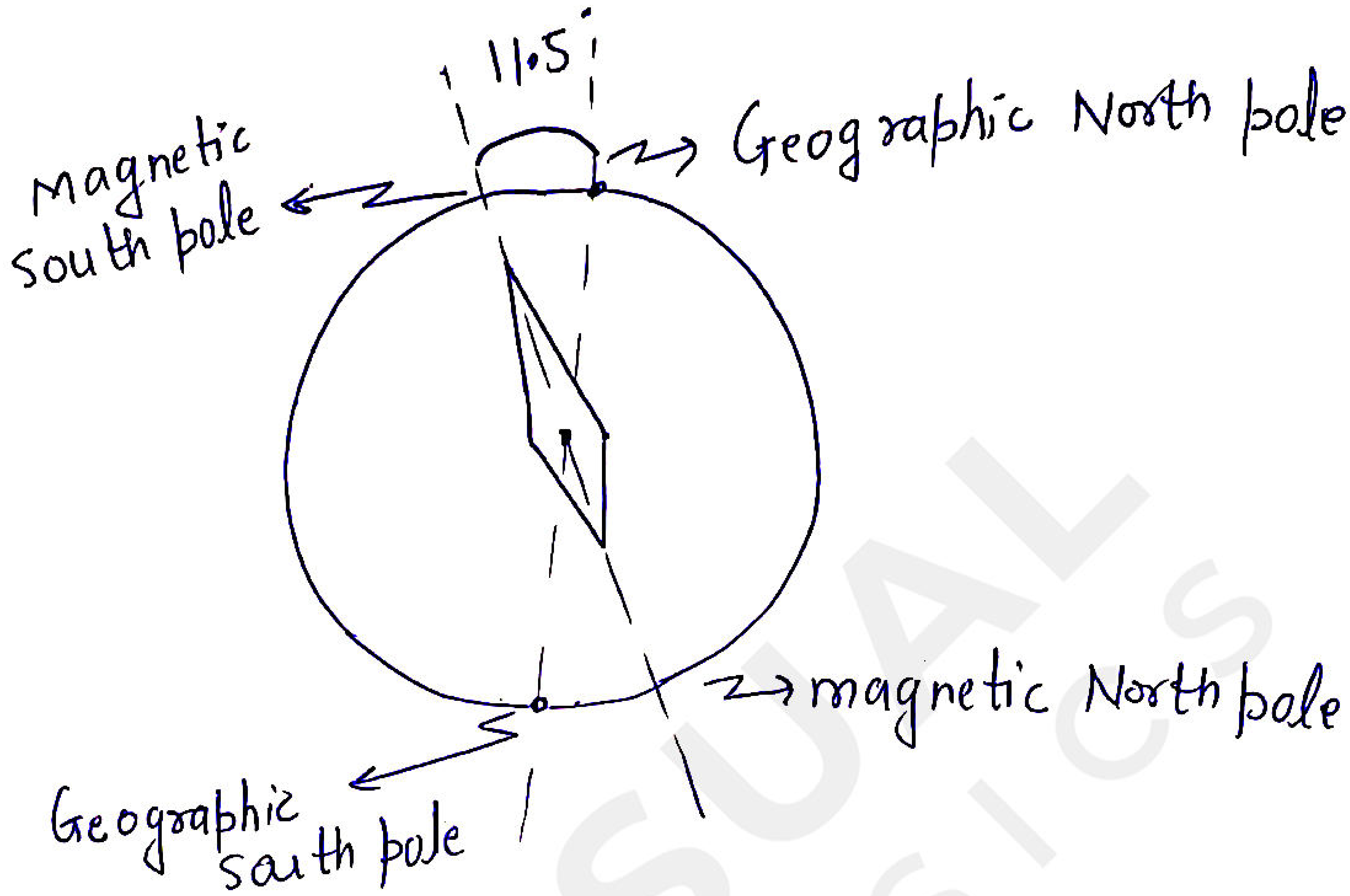
CHAPTER

Magnetic Force

+91 999021287

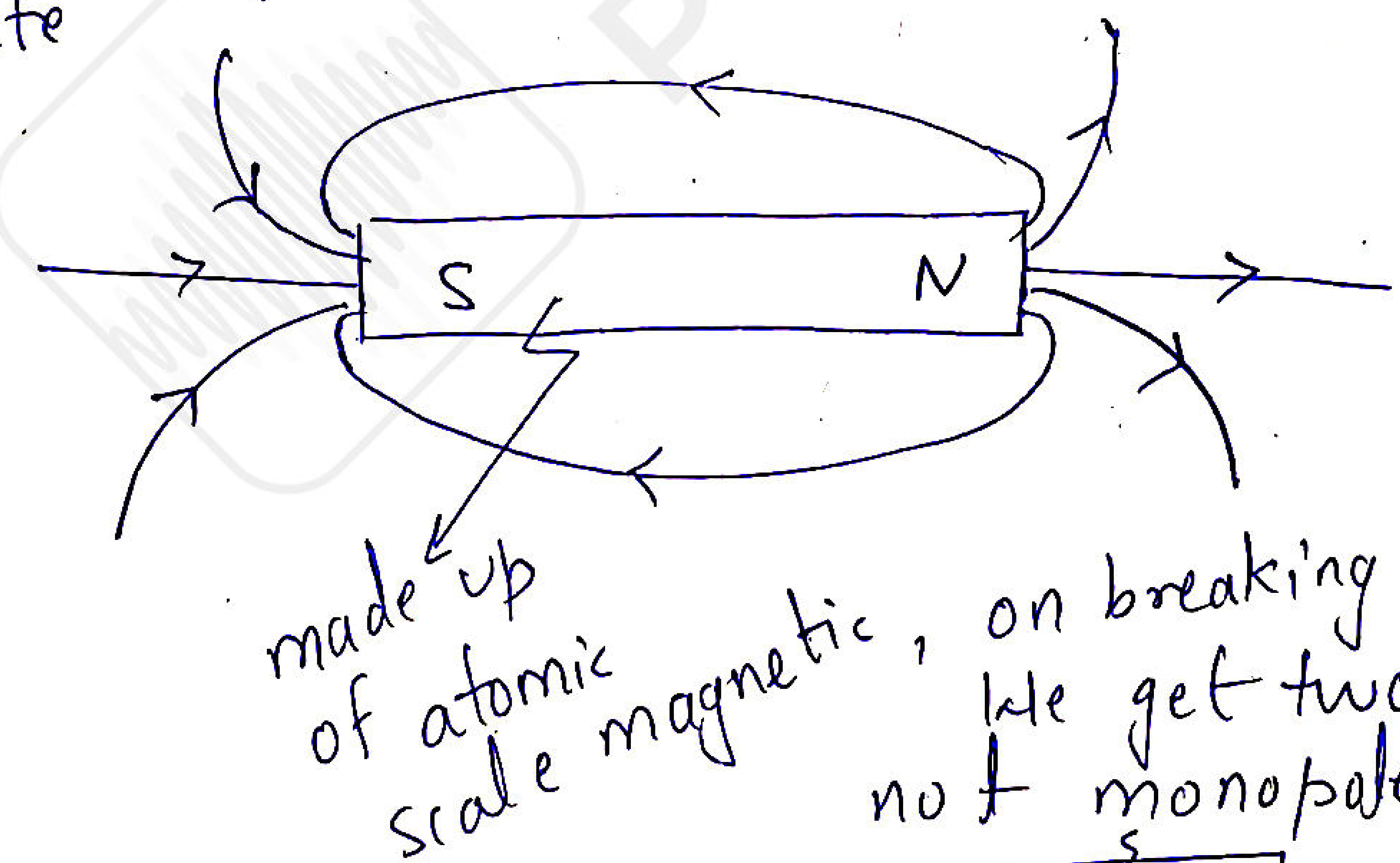
www.visualphysics.in

MAGNETIC FORCE:

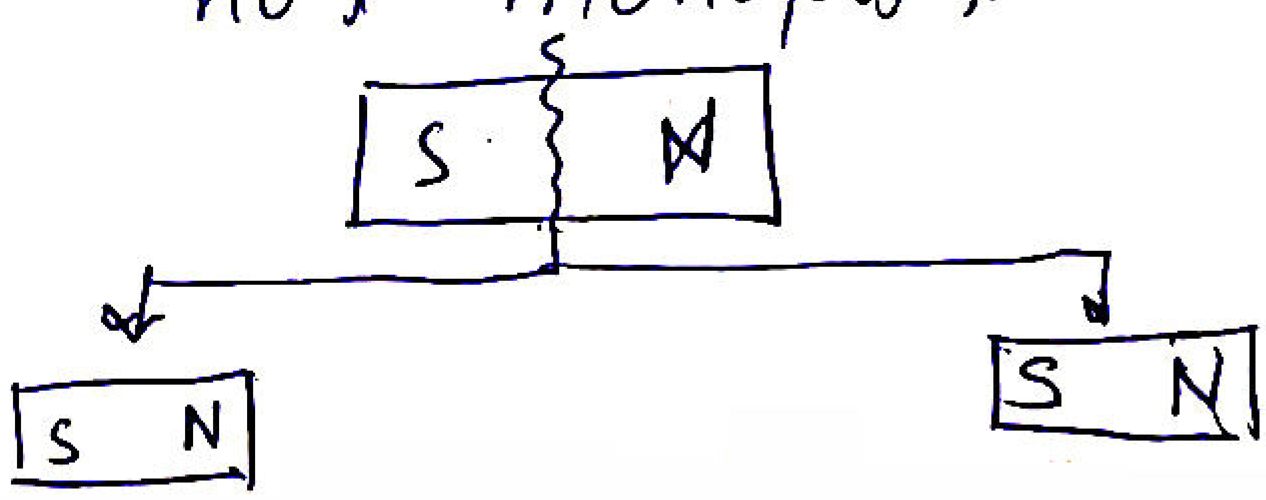


magnetic field goes from north to south.

No, magnetic monopoles have been found till date



, on breaking a magnet we get two magnet not monopoles.



electro-magnetism

electricity

magnetism

These are not independent phenomenon, they are part of single effect, electro-magnetism.

electric field have effect on magnet and magnetic field have effect of charge but under some condition.

→ charge in mag-field

on observation :

magnetic force

$$\vec{F}_B = q(\vec{v} \times \vec{B})$$

direction of force is cross product direction of $\vec{v}$ & $\vec{B}$ if q is +ve and opposite if q is -ve

$$\boxed{|F_B| = q\,vB\sin\theta}$$

force on charge in magnetic field

charge (can be +ve and -ve)

angle between V & B

$\Rightarrow \quad \vec{F_B} = +qvB\sin\theta$ [direction is $\vec{V} \times \vec{B}$ product direction]

if $q \rightarrow -ve$

$\vec{F_B} = -qvB\sin\theta$ [direction is opposite to $\vec{V} \times B$ product direction].

$$B = \frac{F_B}{|q| v \sin\theta} = \left[\frac{N}{(C/s)m}\right] \Rightarrow \text{Tesla} = T$$

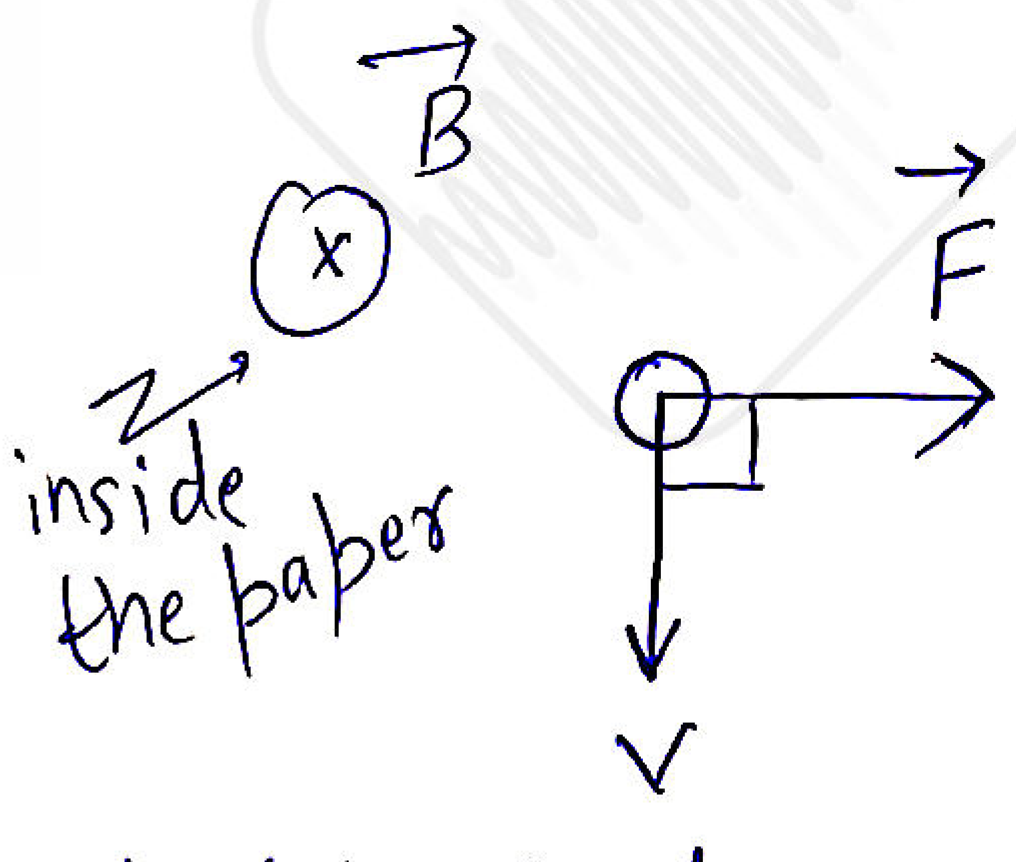
($C/s \rightarrow$ Ampere, A)

unit of B = Tesla $= \frac{N}{A\,m}$

$\Rightarrow$ as when $\theta \rightarrow 90$

$\boxed{F_B = qvB}$, (and force will be perpendicular to v & B)

direction can be found out using Fleming's left hand Rule. or right hand cross product rule

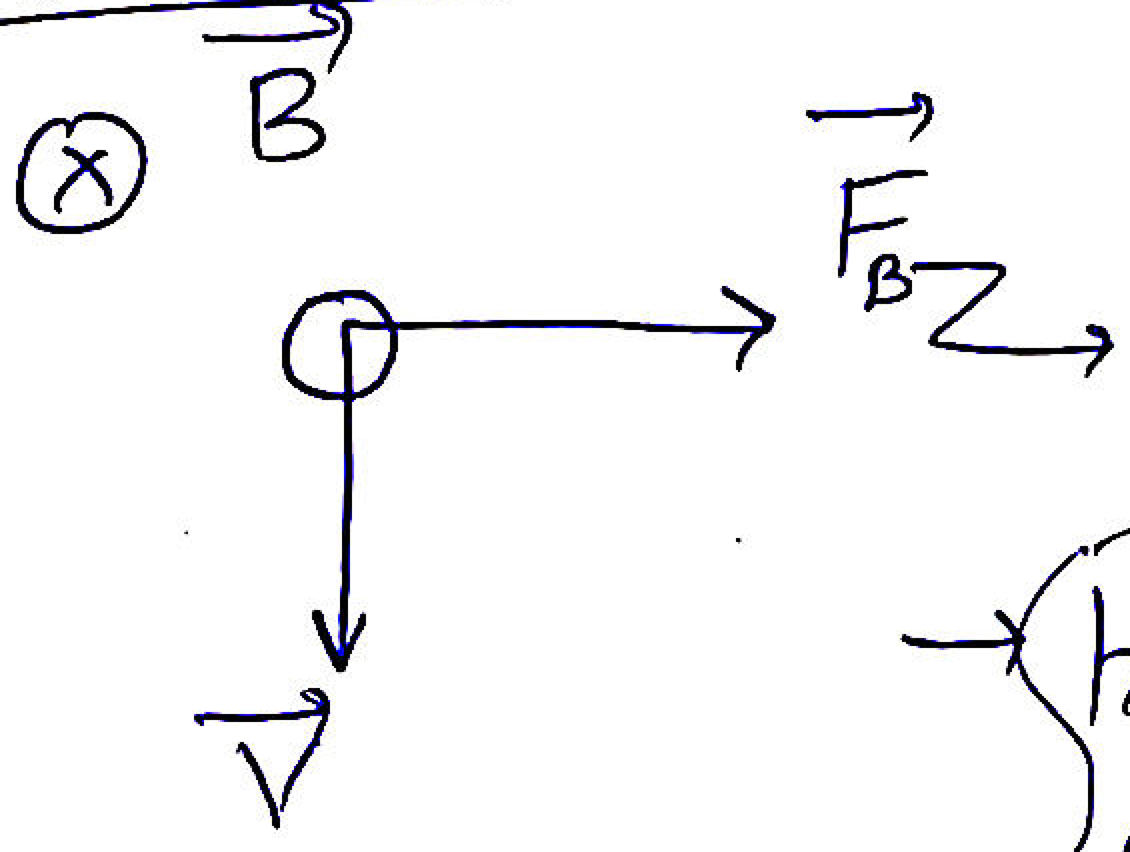


<u>left hand rule</u>: $\rightarrow$ first finger toward $\vec{B}$

$\rightarrow$ middle finger toward $\vec{V}$

$\rightarrow$ thumb gives force direction if $B \perp v$, ~~so~~ and always $F \perp B$ and v

$\boxed{F_B = qvB}$



$\vec{F_B}$ → will act as centripetal force

→ hence charge will start to move in circular motion.

★ $\boxed{\text{Work done by magnetic force on charge} = \text{zero}}$

As magnetic force is always $\perp$ to $\vec{v}$

⇒ $W = F_B \cdot d \cos 90°$ → d = displacement in v direction

⇒ $\boxed{W = 0}$ → so power is also $= 0$.

$$P = F_B \cdot v = F_B v \cos 90 = 0$$

⇒ $\boxed{\text{Magnetic force can only change direction of motion only}}$

if $v \perp B$, and as F_B is $\perp$ v & B

charge will going a circular motion

& $F_B = F_c$ ⟶ centripetal force.

$\Rightarrow \quad qvB\sin 90 = \dfrac{mv^2}{r}$

$$\Rightarrow \boxed{r = \frac{mv}{qB}}$$

if m, q, & B is fixed.

$$\Rightarrow \boxed{r \propto v}$$

$\Rightarrow$ if v increase, r increase

as Time period, $T = \dfrac{2\pi r}{v} = \dfrac{2\pi}{v}\left[\dfrac{mv}{qB}\right]$

$$\Rightarrow \boxed{T = \frac{2\pi m}{qB}} \quad \boxed{\omega = \frac{2\pi}{T}}$$

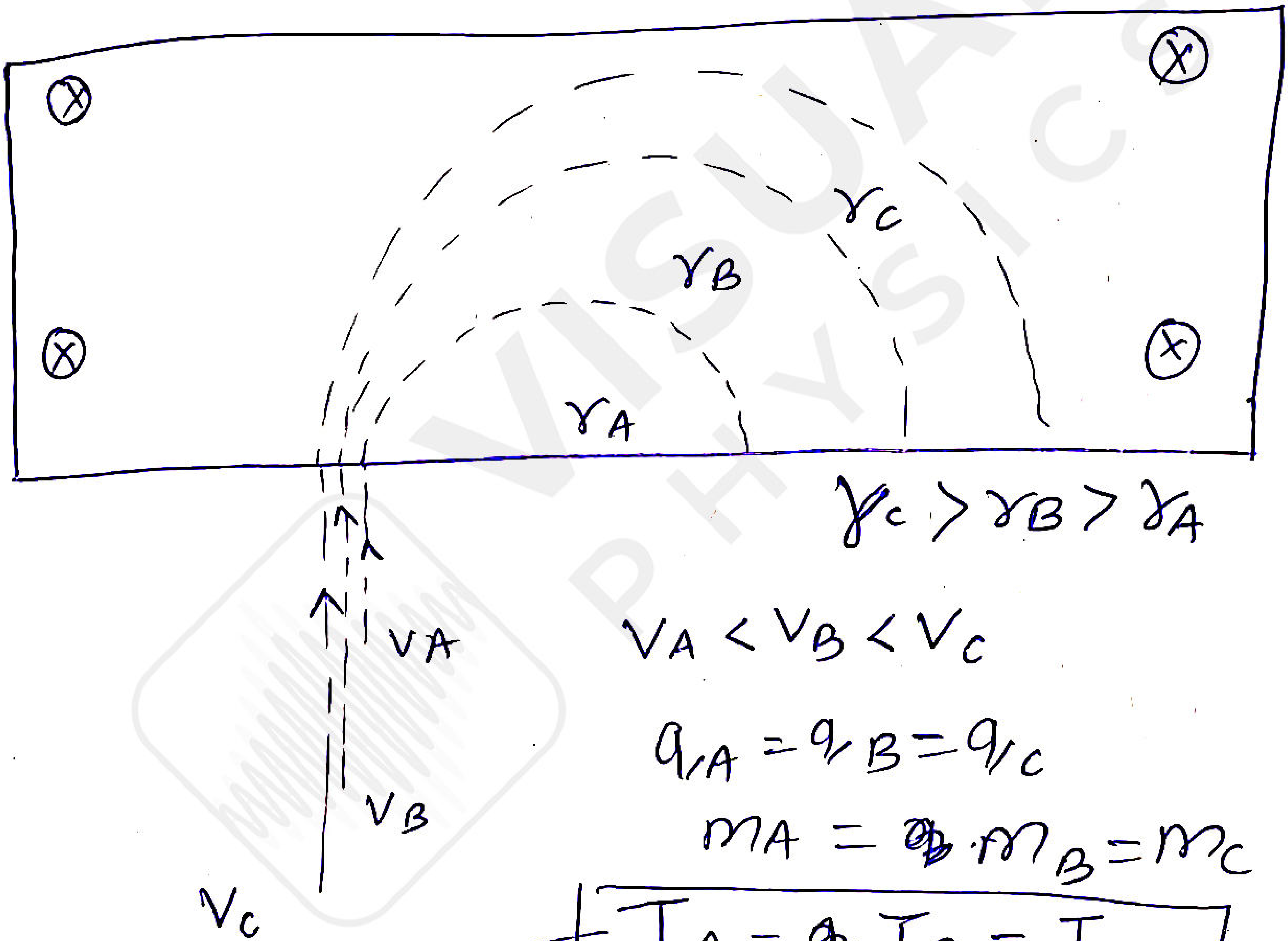
independent of speed

angular speed

So, if two charge A & B,

$$\boxed{q_A = q_B}, \quad \boxed{V_A < V_B}$$
$$\boxed{m_A = m_B} \quad \boxed{r_A < r_B}$$

But, $T_A = T_B$ as $m_A = m_B$ & $q_A = q_B$



$r_C > r_B > r_A$

$V_A < V_B < V_C$

$q_A = q_B = q_C$

$m_A = m_B = m_C$

$$\boxed{T_A = T_B = T_C}$$

Time spend in magnetic field zone are same

Cyclotron

$m_e = 9.31 \times 10^{-31}$, $m_p = 1.67 \times 10^{-27}$

mass of electron — mass of proton

to accelerate charge particle to speed 10^{12} m/s for research purpose.

$$S_e = \frac{v^2}{2a} = \frac{v^2}{2\left(\frac{qE}{m_e}\right)} \approx 1m$$

electron distance to get 10^{12} m/s

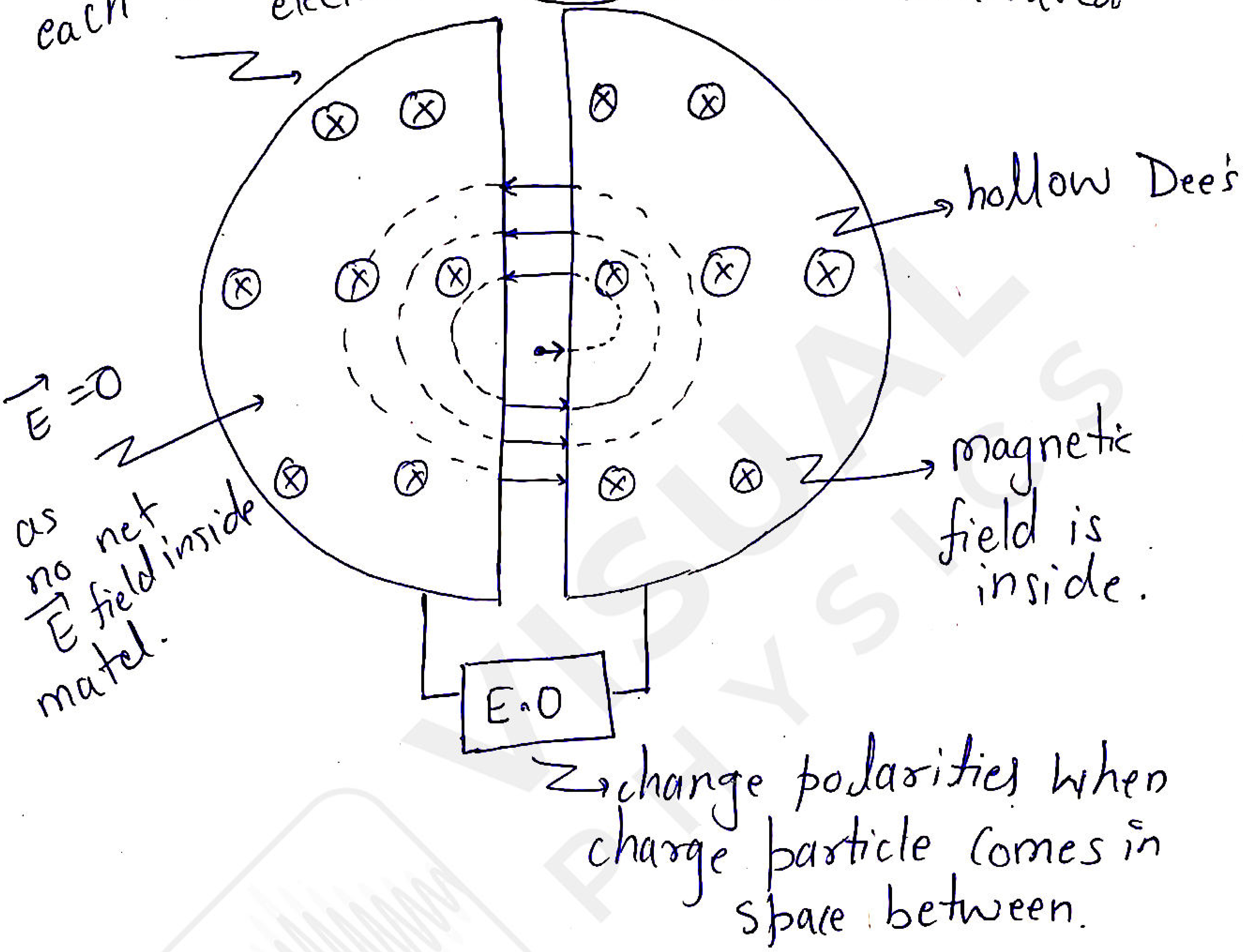
$$S_p = \frac{v^2}{2a} = \frac{v^2}{2\left(\frac{qE}{m_p}\right)} \approx 10 \text{ km}$$

distance for proton

So if we make the charge particle to accelerate in circular path we can get the required speed in small space.

large distance in small space.

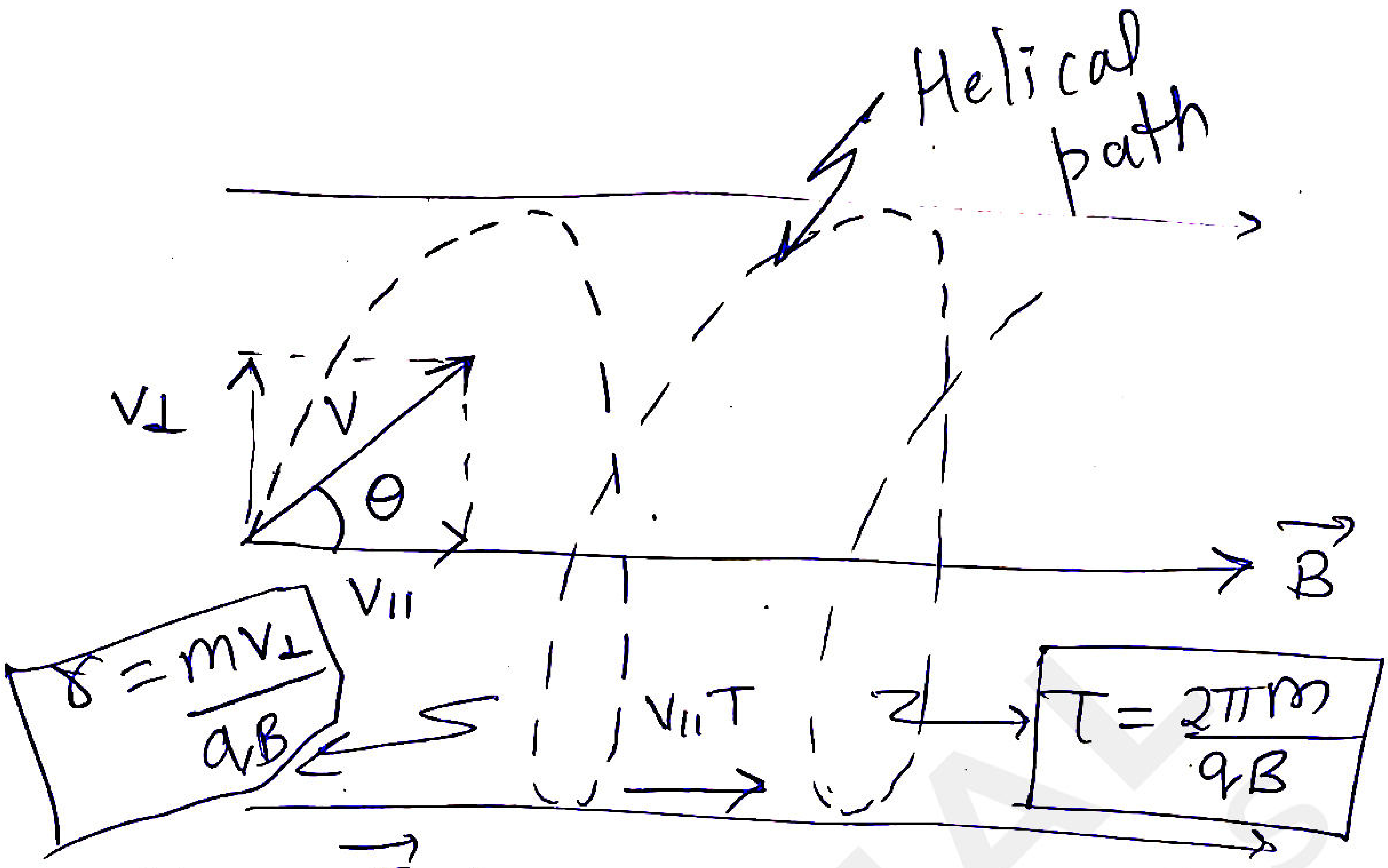
each time charge comes in space between experience electric force qE and hence accelerated



as, $T = \dfrac{2\pi m}{qB}$ → independent of speed

time spent in Dee's $t_0 = \dfrac{T}{2} = \dfrac{\pi m}{qB}$

→ $\boxed{\text{E.O time period}}$



now $\vec{F_B} = qVB\sin\theta = qV_\perp B$

as $\boxed{V\sin\theta = V_\perp}$

so, F_B provides circular motion

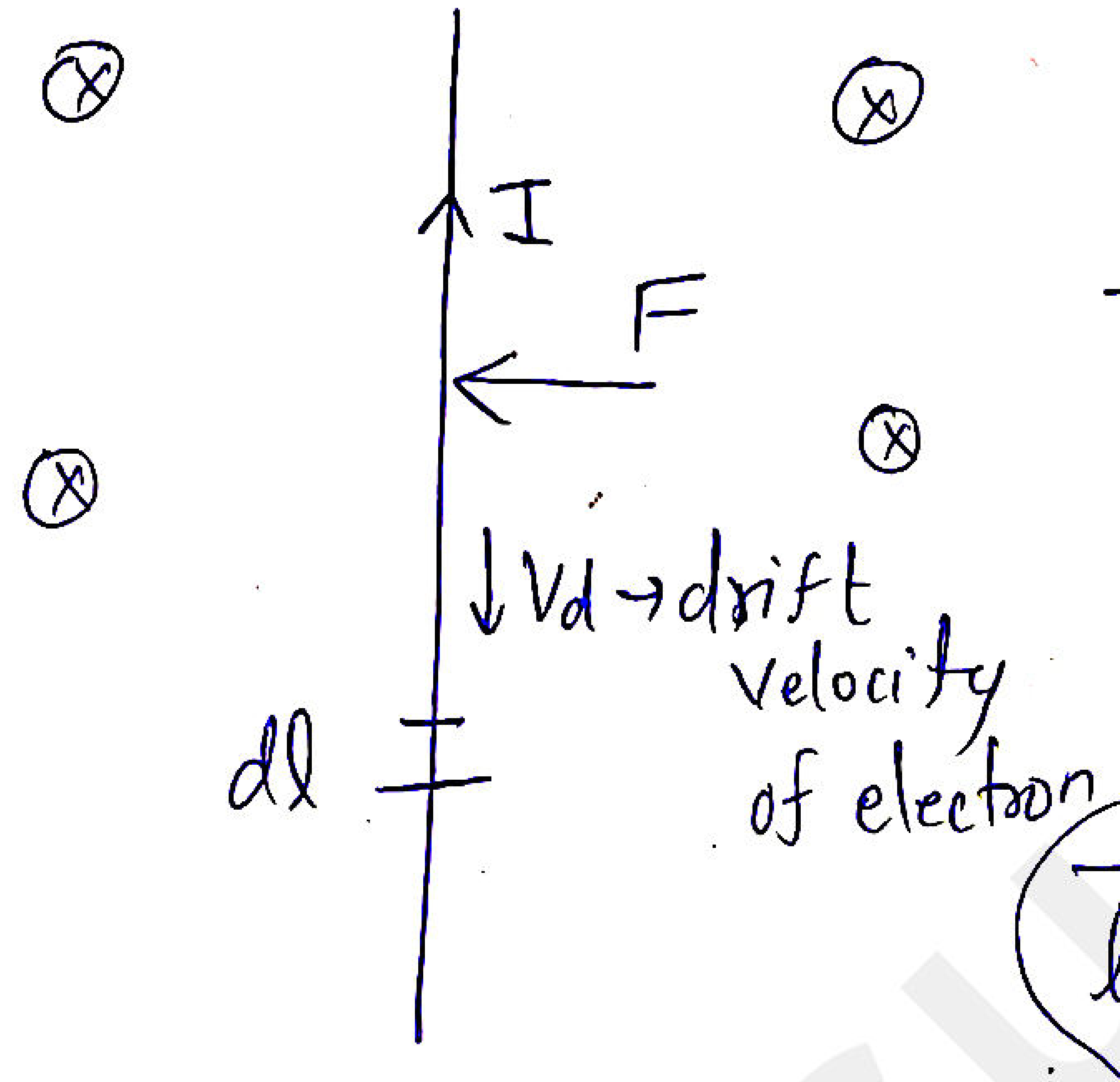
and $V_{\parallel} \Rightarrow$ parallel component of V along B, translate the charge

<u>Lorentz force</u>:

$\longrightarrow$ Total electromagnetic force on charge

$$\boxed{\vec{F} = \underbrace{q\vec{E}}_{\text{electric force}} + \underbrace{q(\vec{V} \times \vec{B})}_{\text{magnetic force}}}$$

magnetic force on wire



$\vec{l}$ → direction of length in current direction

now for dt time

$$dq = i\,dt$$

$$dF = dq\, V_d B = i(\underbrace{dt\, V_d}_{\text{length of small section} = dl})B$$

$$\Rightarrow \int dF = \int i\, dl B$$

$$\boxed{F = i l B}$$

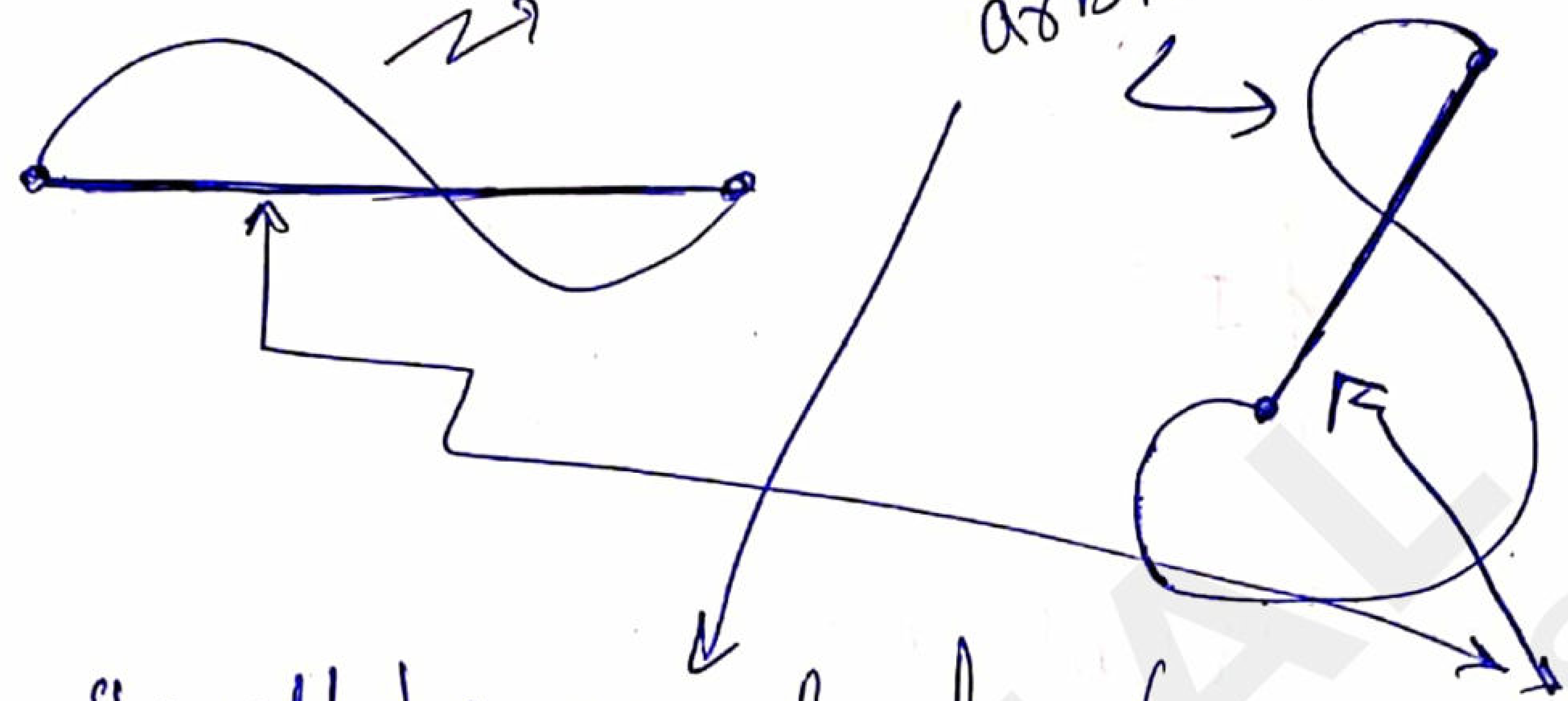
(if force on each section considered same).

if B is not ⊥ to wire

$$\Rightarrow \boxed{\vec{F} = i l B \sin\theta = i(\vec{l} \times \vec{B})}$$

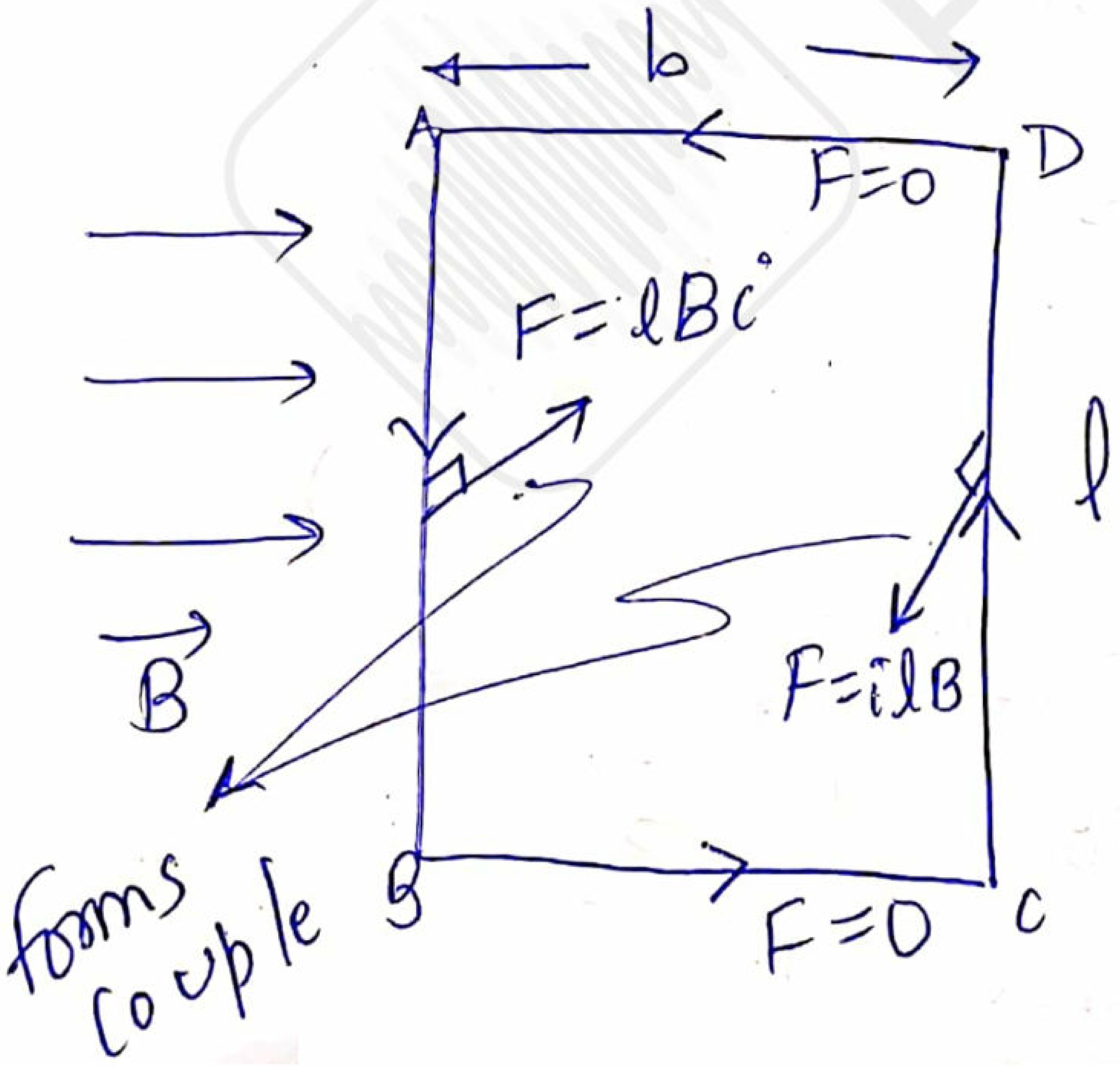
$$\boxed{d\vec{F} = i(d\vec{l} \times \vec{B})}$$

→ magnetic force on arbitary shape



"Will be equal to force on wire joining the ends of wire."

Current Loop



now force on AD and BC part

$F_{BC} = i\ell B \sin 0 = 0$

$F_{AD} = i\ell B \sin 180 = 0$

and $F_{AB} = F_{DC}$

$= i\ell B \sin 90$

$\boxed{F_{AB} = F_{DC} = ilB}$

Now Torque of Couple = $F \times b$

$\tau = i l B \times b$

$\tau = i(lb) B$

Now lb = Area of loop = A

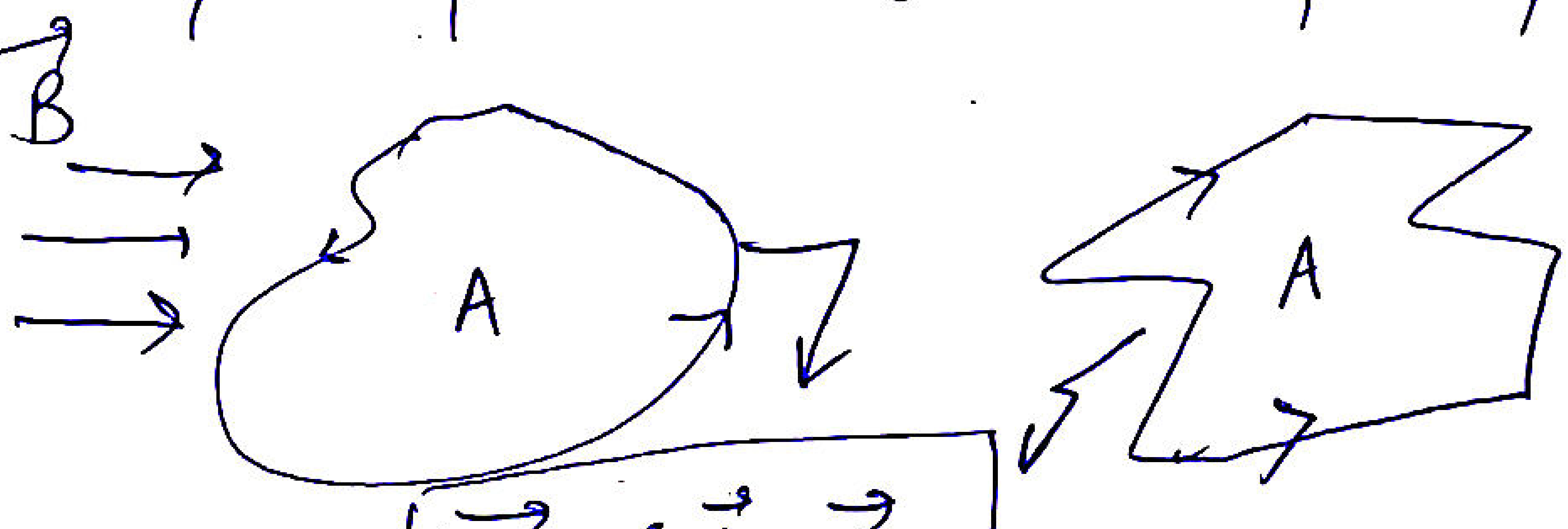
$\boxed{\tau = iAB}$ → B lies in plane of loop.

Area vector is perpendicular to plane, to know the direction, you need to curl your right hand in current direction your thumb shows the Area vector direction.

if Area Vector $\vec{A}$ makes angle θ with the magnetic field.

$\vec{\tau} = i(\vec{A} \times \vec{B}) = iAB\sin\theta$ ((direction (cross product of $\vec{A}$ & $\vec{B}$))

Though we have derived for rectangular loop but it is valid for any shape till the loop is planar.

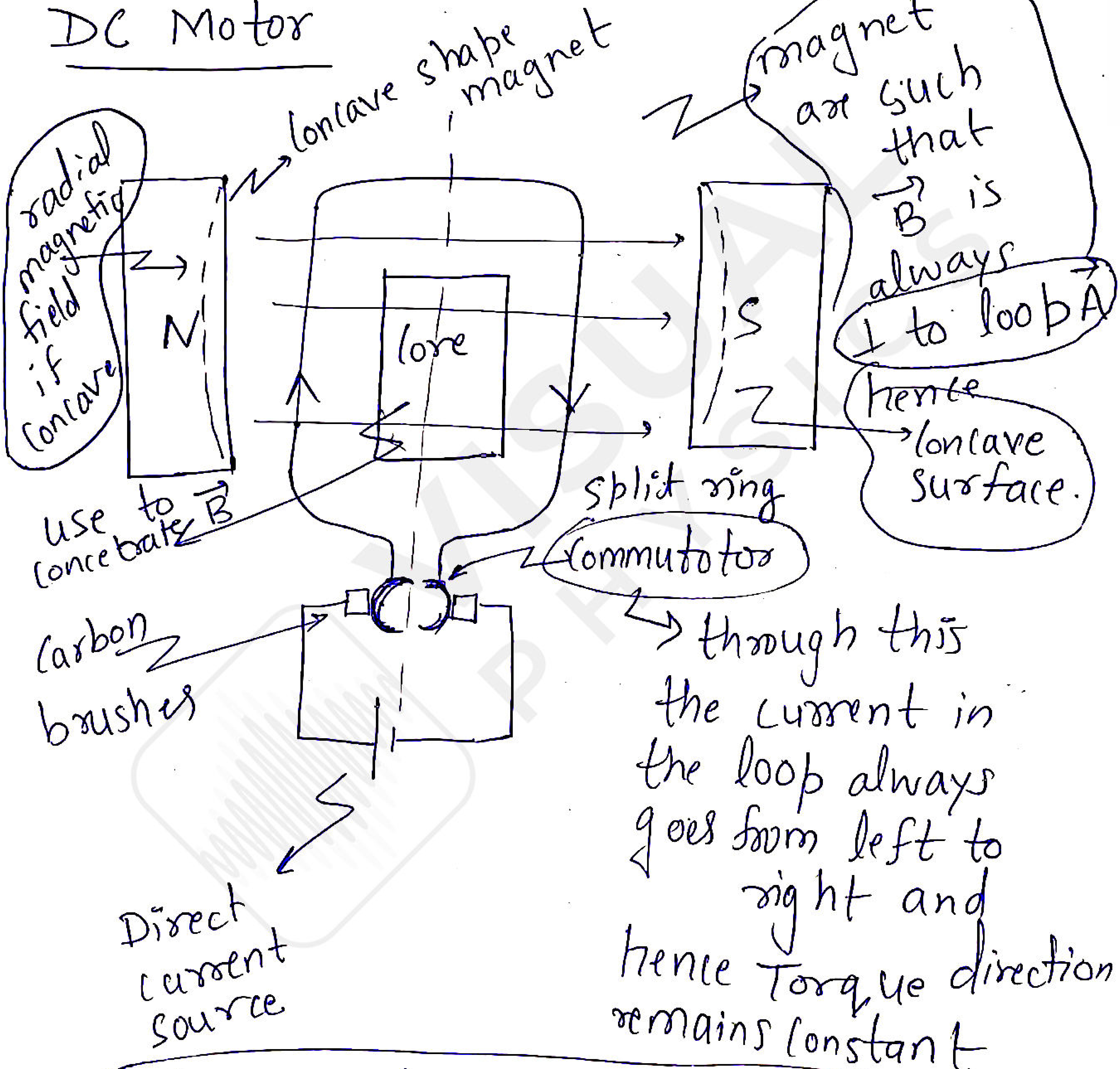


$\boxed{\vec{\tau} = i\vec{A} \times \vec{B}}$

now for N turns loop

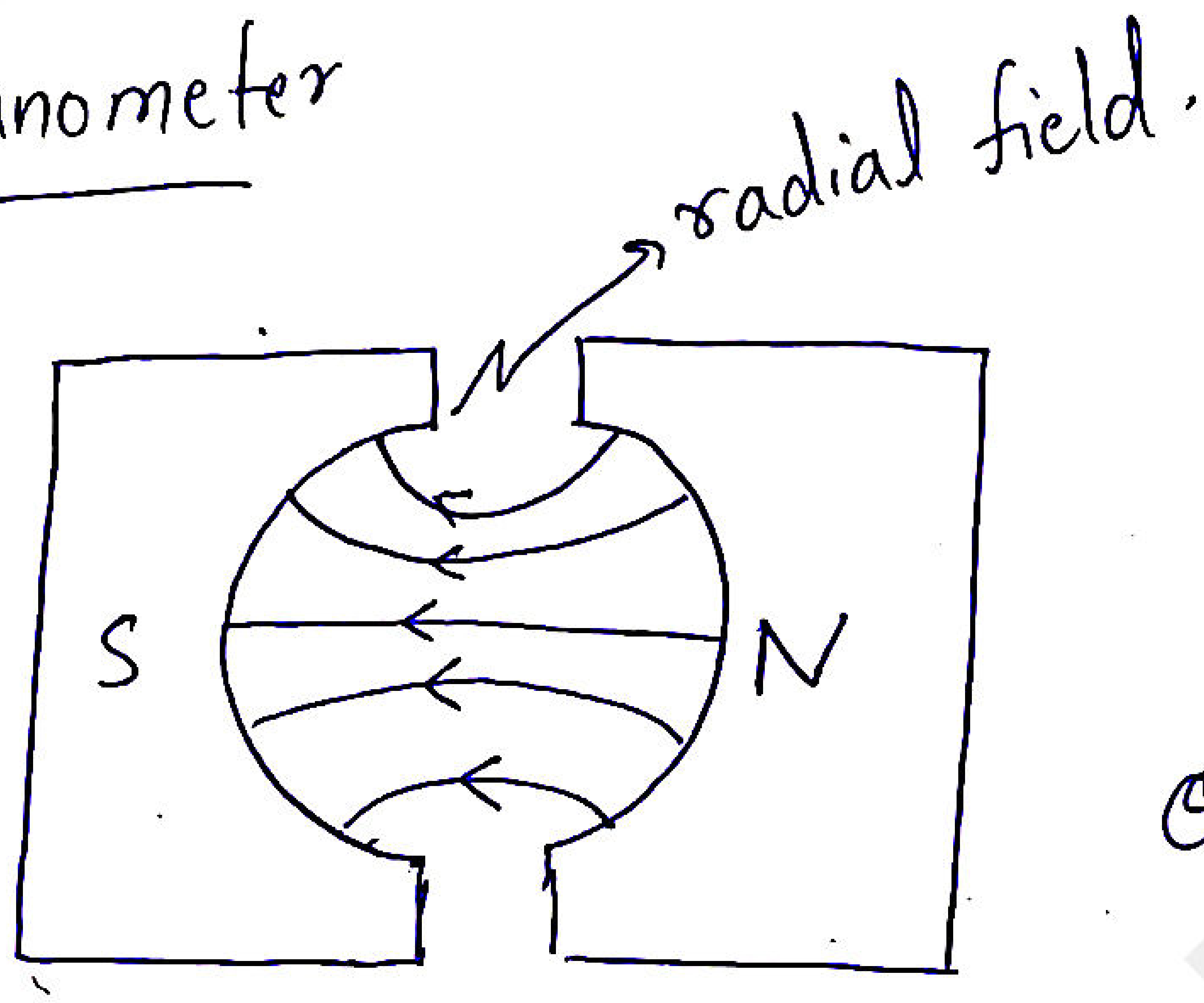
$$\boxed{\vec{\tau}_{net} = (i\vec{A} \times \vec{B}) \times N}$$ → number of loops

DC Motor



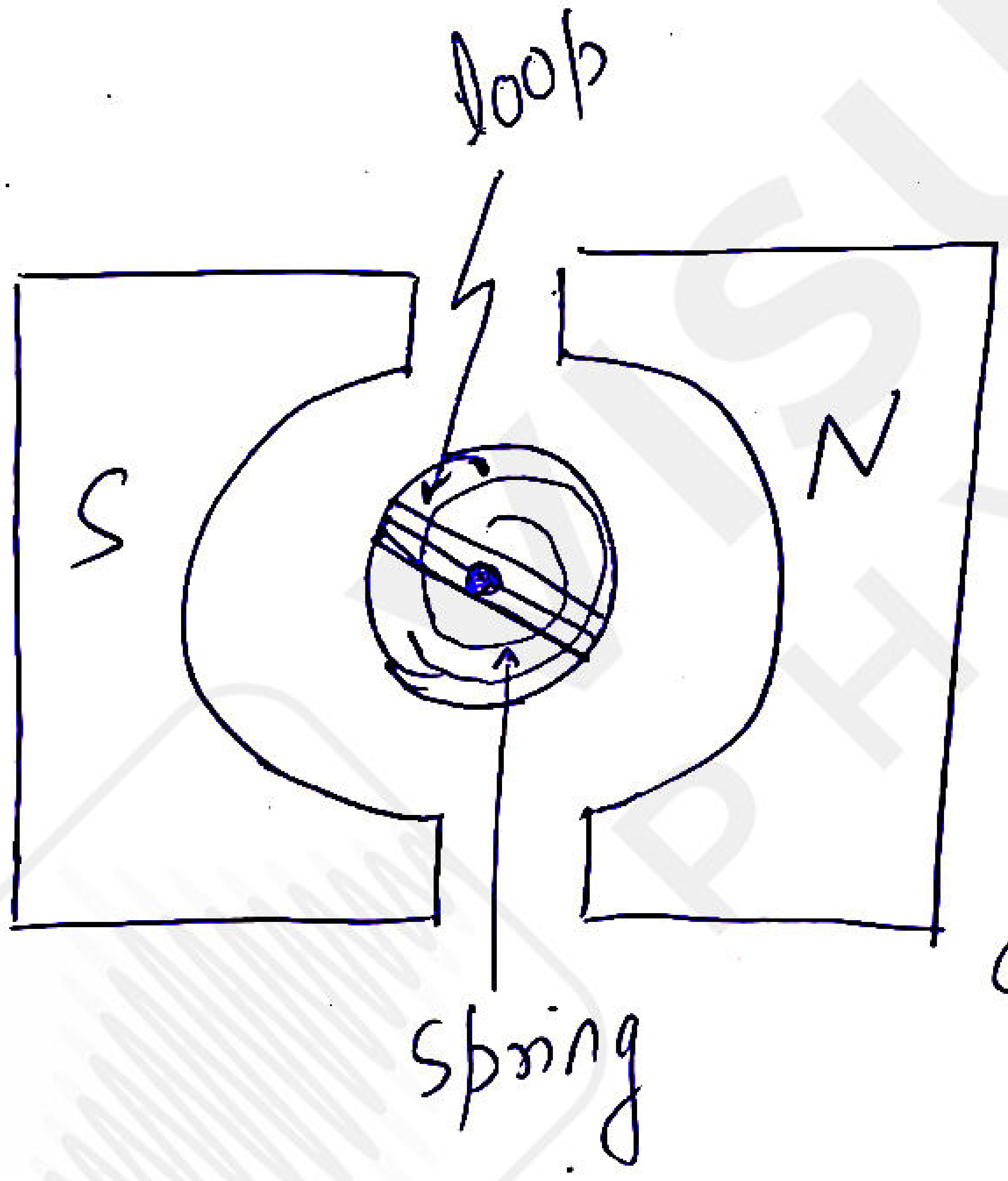
if magnet is not concave shape
B is not constant throughout rotation
so, $\boxed{\tau = iAB\sin\theta}$ ($\theta = 0$, loop vertical)

Galvanometer



$\theta = 90^\circ$

so, at any orientation, Torque remain same.



Torque due to current

$\tau_B = NiAB$

due to spring, opposite torque.

$\tau_S = C\theta$

→ spring constant

$\Rightarrow \tau_B = \tau_S$

angular deflection

$\Rightarrow \theta = \left[\frac{NAB}{C}\right] i$

$\Rightarrow \boxed{\theta \propto i}$

using this we can measure current

i_s = current sensitivity

$= \frac{\theta}{i}$

$$\boxed{i_s = \frac{NAB}{C}}$$

more sensitivity → more deflection for same current.

i_s can be increased by,

N ↑ , A ↑ or B ↓
& C↓

Galvanometer can be used to know potential difference also.

if r → internal resistance of galvanometer

$$\theta = \left(\frac{NAB}{C}\right)\frac{V}{r} \quad \left(\text{as } i = \frac{V}{r}\right)$$

$$\Rightarrow \theta = \left(\frac{NAB}{Cr}\right)V$$

$$\Rightarrow \boxed{\theta \propto V}$$

increasing voltage sensitivity

voltage sensitivity, $V_s = \frac{NAB}{Cr}$

$$\boxed{V_s \uparrow \to N\uparrow, A\uparrow, B\uparrow, C\downarrow \text{ or } r\downarrow}$$

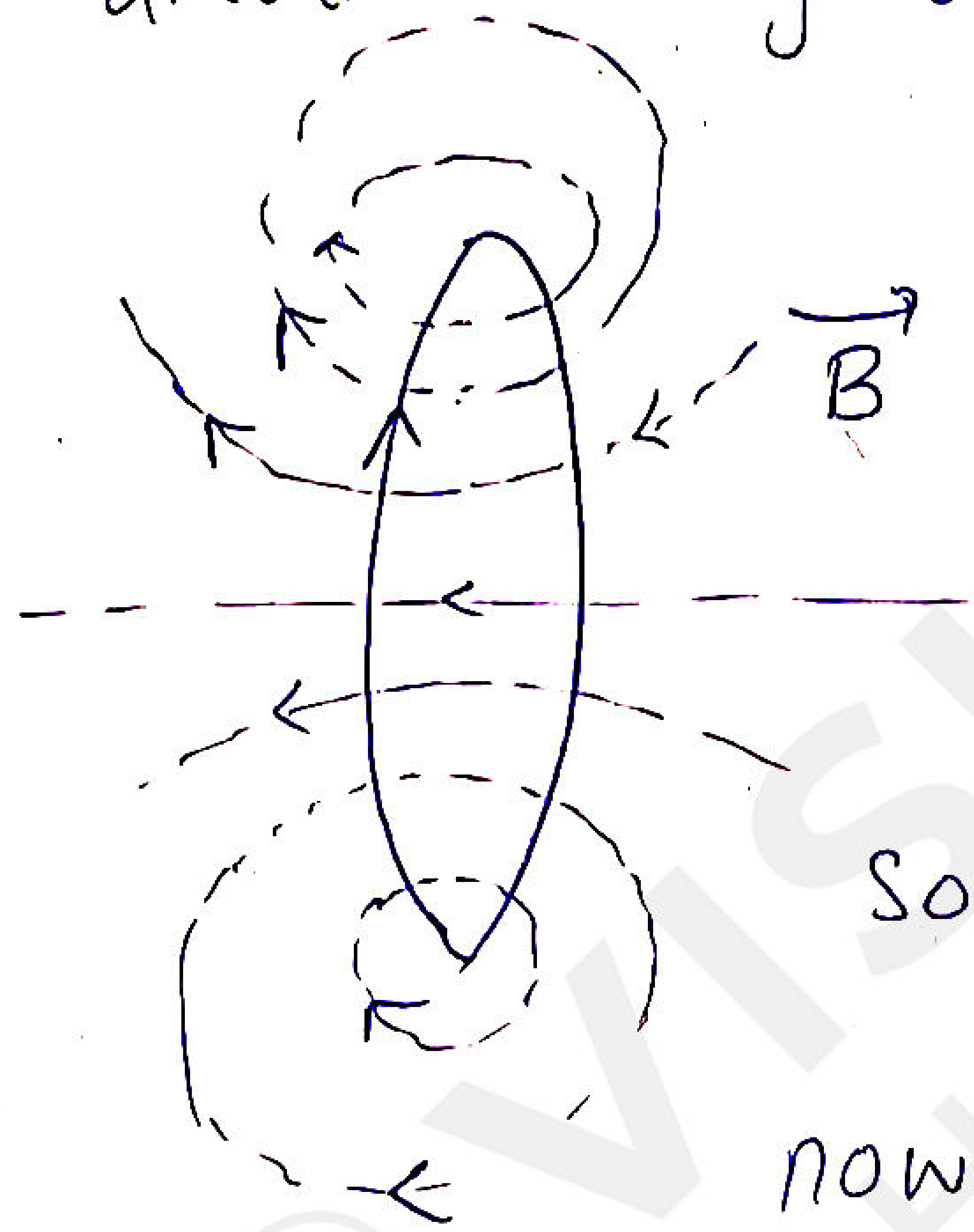
not effective

but if $N\uparrow, A\uparrow \to r\uparrow$

Current produces → magnetic field.

Current carrying loop behave as magnet

Using right hand thumb rule to know the direction magnetic field.



$$\boxed{\vec{M} = i\vec{A}}$$

magnetic moment

So, $\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$

now, τ_{max} when $\theta \to 90°$

$\tau_{min} \to 0$, when $\theta \to 0°, 180°$

it behave same as electric dipole.

$\theta \to 180°$ unstable equillibrium

$\theta \to 0°$ stable equillibrium

When displace by small amount will return to same position

will not return to same position after small disturbance.

Similar to electric dipole,
potential energy of magnetic dipole

$$\boxed{U = -\vec{M}\cdot\vec{B}}$$

$U_{min} \rightarrow \theta = 0°$, $U_{min} = -MB$

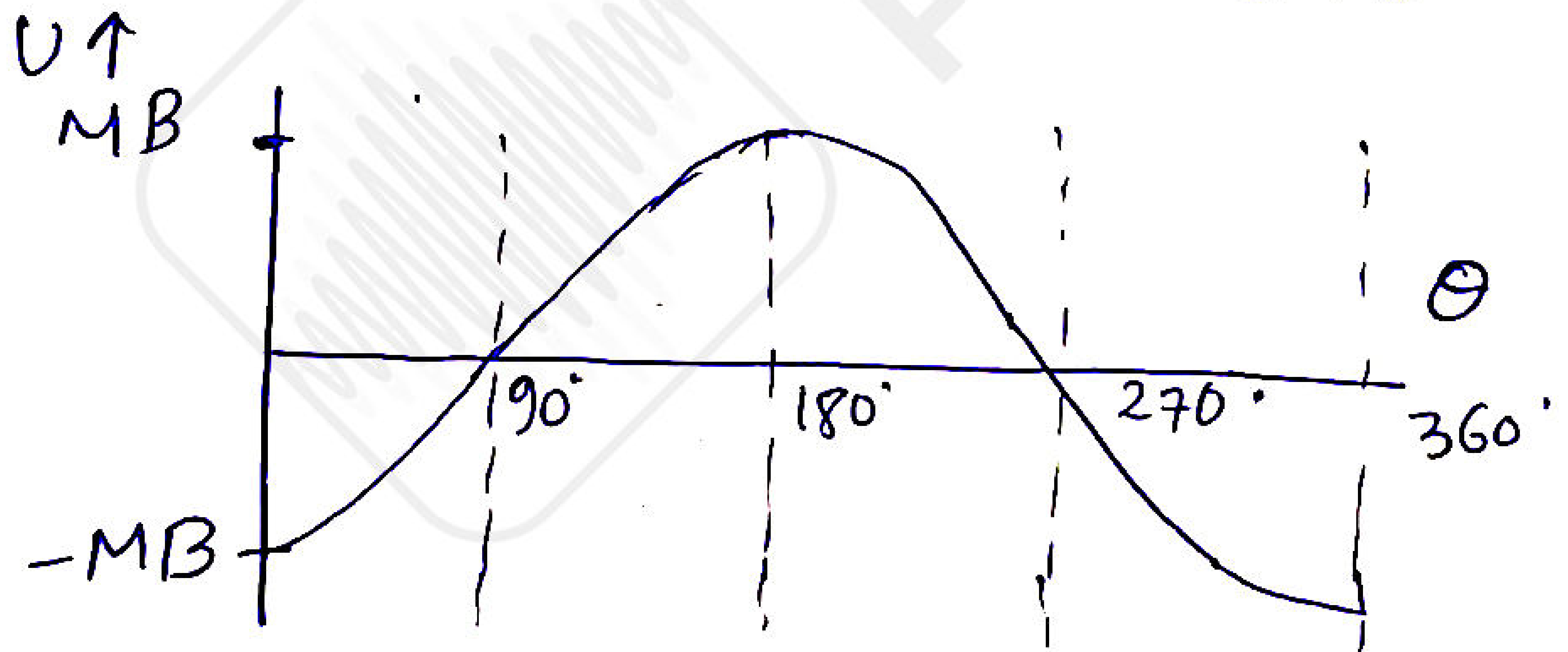
$U_{max} \rightarrow \theta = 180°$, $U_{max} = MB$

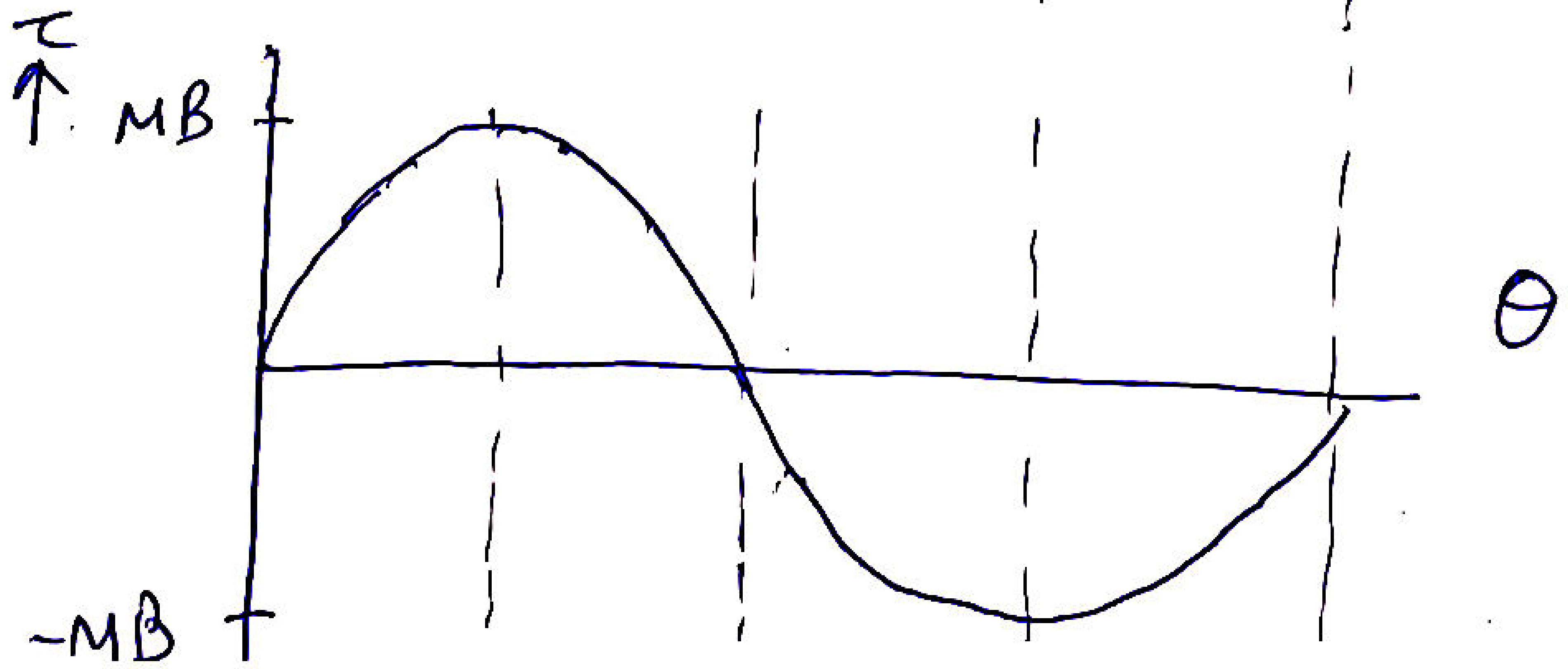
Work done $= -\Delta U$ ⟶ change of potential energy

$$\boxed{\text{Work done} = -MB\left[\cos\theta_f - \cos\theta_i\right]}$$

from formula, $U = -MB\cos\theta$

$\tau = MB\sin\theta$

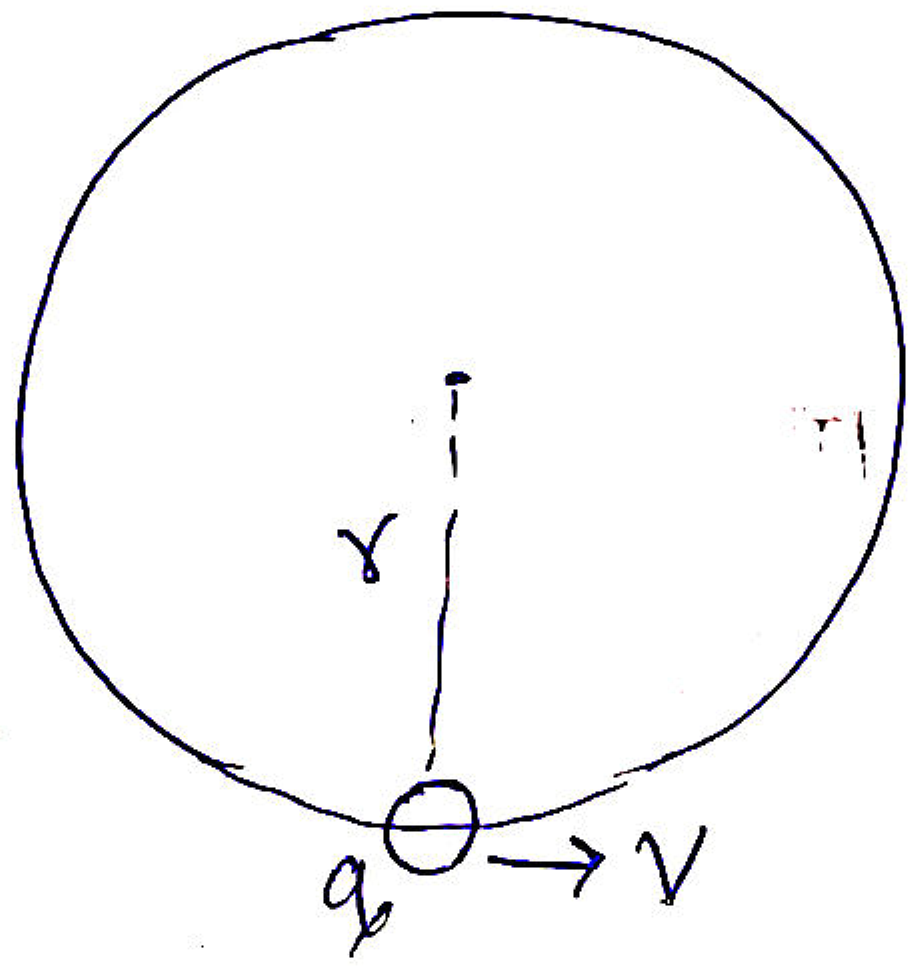




Revolving charge.

Time period

$T = \frac{2\pi r}{v}$



direction of L & M same

motion of charge produce current

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

$i = \frac{qv}{2\pi r}$

current

$\Rightarrow M = iA$ ($A = \pi r^2$)

magnetic moment

$M = \frac{qv}{2\pi r} \times \pi r^2 \Rightarrow \boxed{M = \frac{qvr}{2}}$

$\vec{L} = I\vec{\omega}$

angular momentum

$L = mr^2\left(\frac{v}{r}\right) = mvr$

$\boxed{\gamma = \frac{M}{L} = \frac{qvr/2}{mvr} = \frac{q}{2m}}$

Gyromagnetic ratio

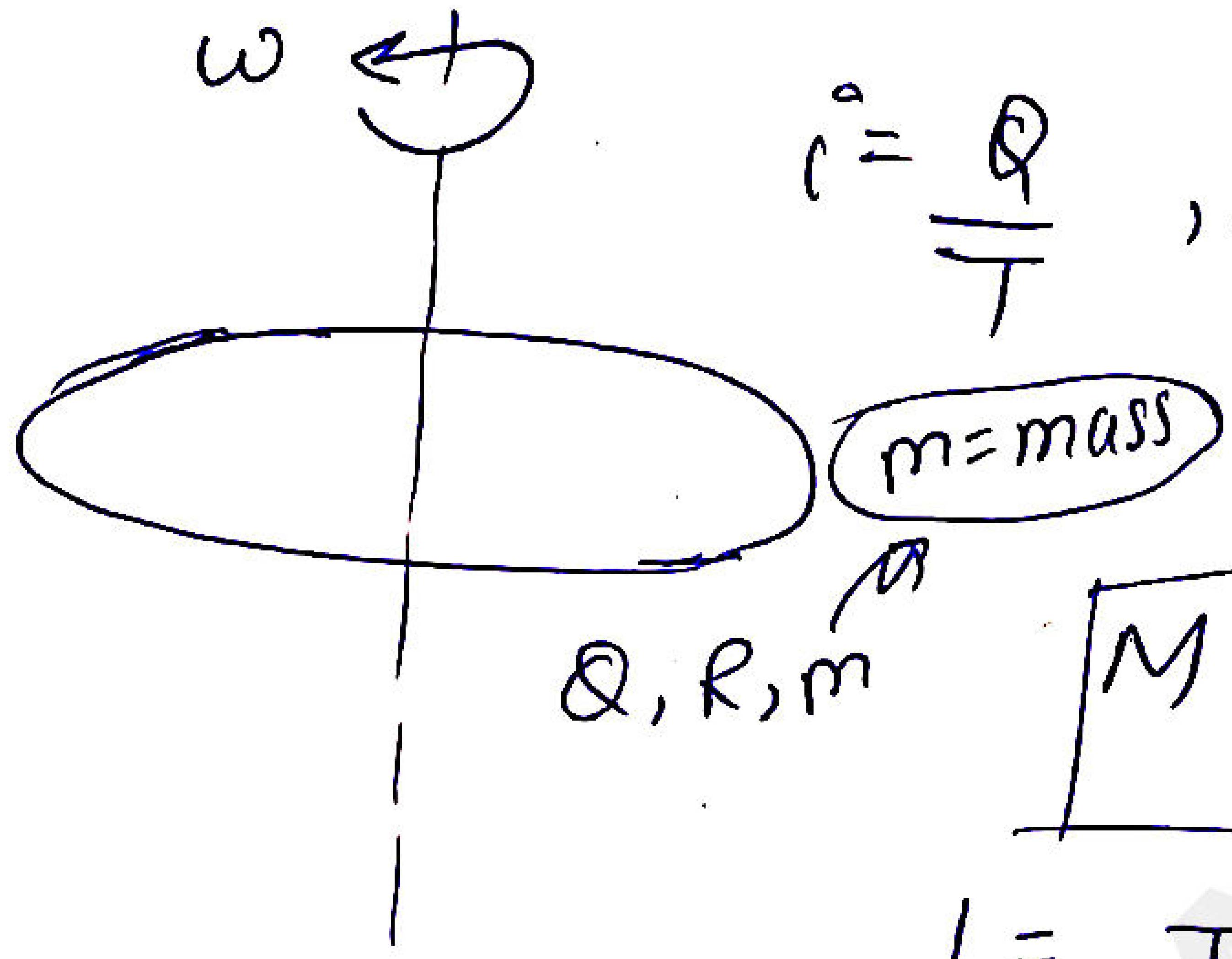
depend on mass and charge only.

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

* same for any charged body rotating about any axis if charge and mass uniform

used for rotating charge.

as :



$i = \frac{Q}{T}$, $M = iA$

$= \frac{Q}{2\pi}\omega \pi R^2$

$$\boxed{M = \frac{Q\omega R^2}{2}}$$

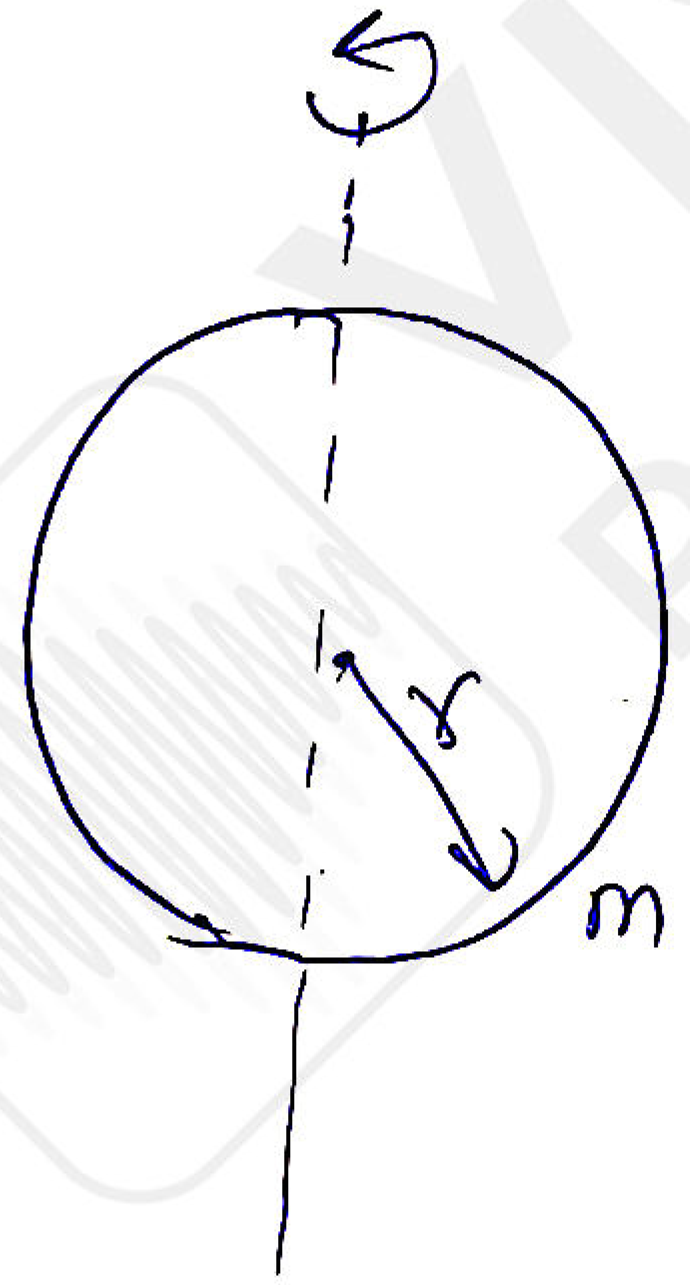
$L = I\omega = MR^2\omega$

$\Rightarrow$ $$\boxed{M = \left(\frac{Q}{2m}\right)L = \frac{Q\omega R^2}{2}}$$

as $\frac{M}{L} = \frac{Q}{2m}$

Same result

if



$M = \left(\frac{Q}{2m}\right)L$

$= \frac{Q}{2m}\left(I\omega\right)$

$M = \frac{Q}{2m}\left[\frac{mr^2}{2}\omega\right]$

easy to calculate $$\boxed{M = \frac{Q\omega R^2}{4}}$$

$$\gamma = \frac{M}{L} = \frac{q}{2m}$$ $\Rightarrow$ valid is charge and mass distribution are identical