



VISUAL
PHYSICS

SHORT NOTES

C H A P T E R

Electromagnetic Induction



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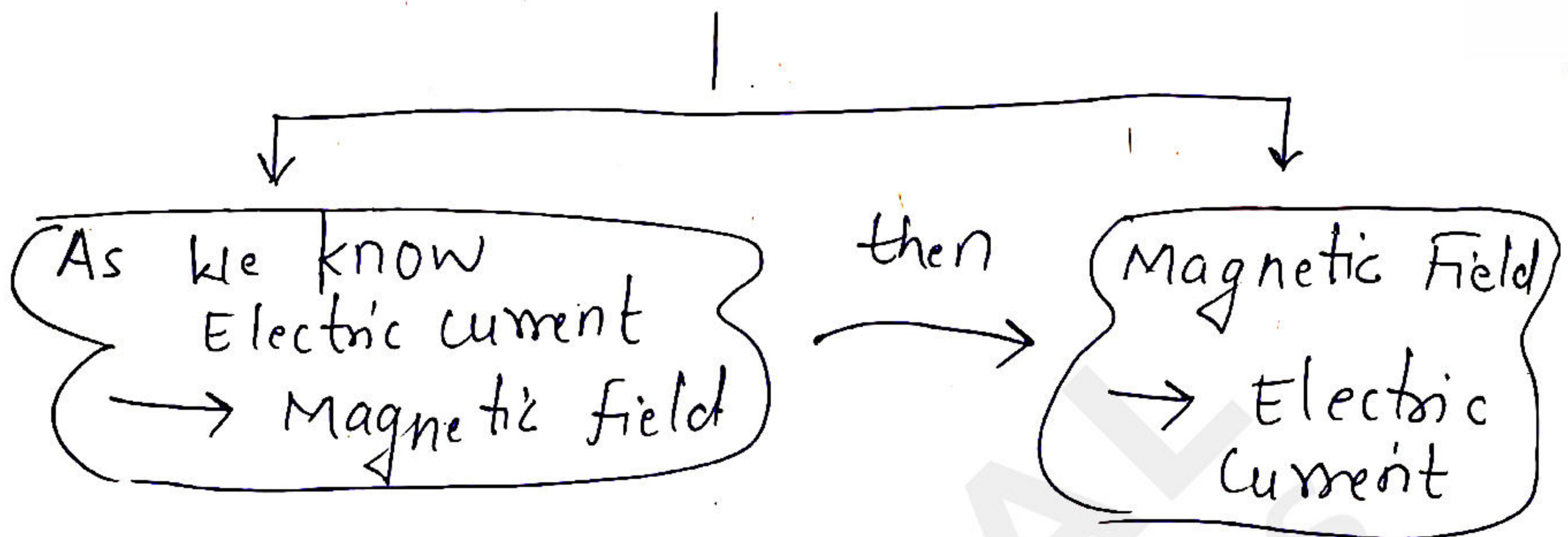


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ELECTRO MAGNETIC INDUCTION



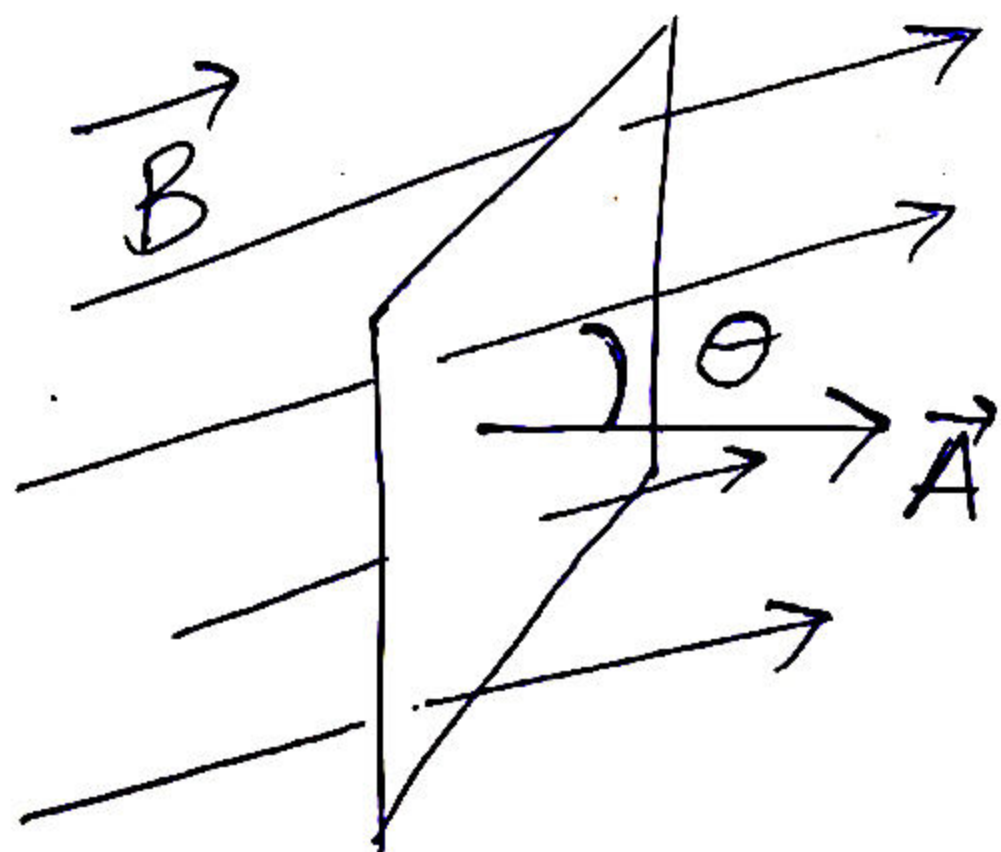
Magnetic flux:

SAME as we discussed for Electric flux.

→ The number of magnetic field lines passing per unit perpendicular Area is known as magnetic field Intensity = B

as flux, $\phi = \vec{B} \cdot \vec{A}$

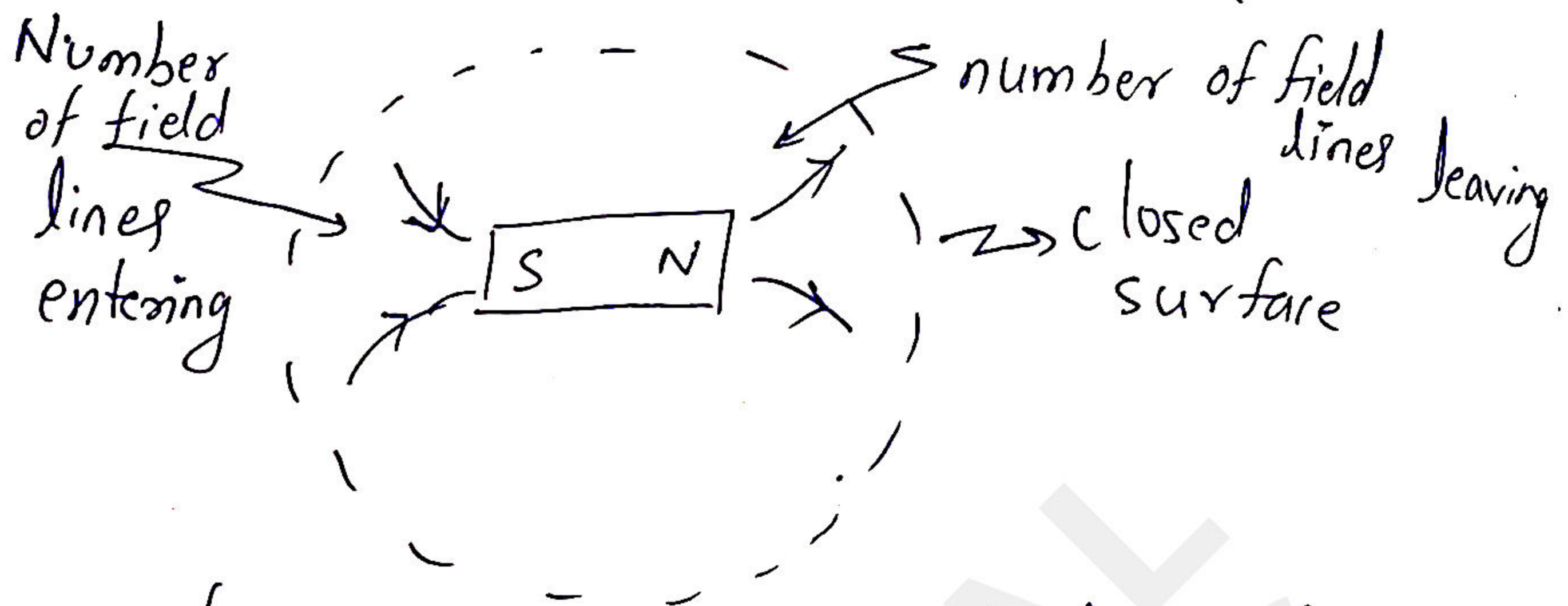
$= BA \cos\theta$



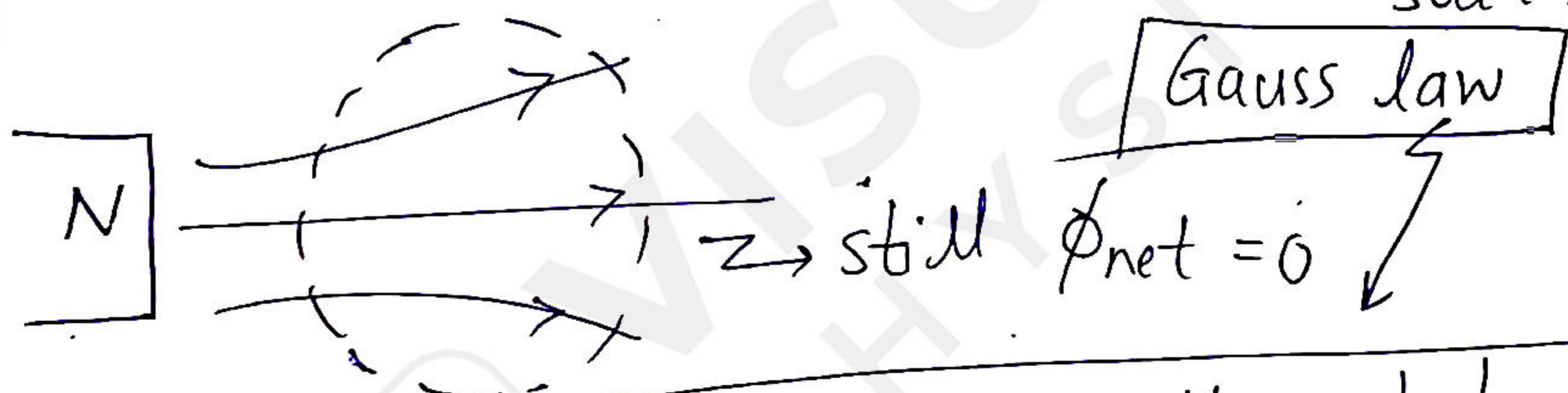
angle between $\vec{B}$ & $\vec{A}$

Area vector

Now flux for a closed surface.



$\phi_{\text{net}} = \text{Zero}$, As magnet always comes in pair (North + South)



So for magnet, no matter what the flux for closed surface = Zero

$\oint \vec{B} \cdot d\vec{A} = \mu_0 M_{\text{enc}}$ → zero as of magnetic dipole
↙ closed surface ↘ Net magnetic charge enclosed

as, $\phi_{\text{in}} = \phi_{\text{out}}$
 $\Rightarrow \boxed{\phi_{\text{net}} = 0}$

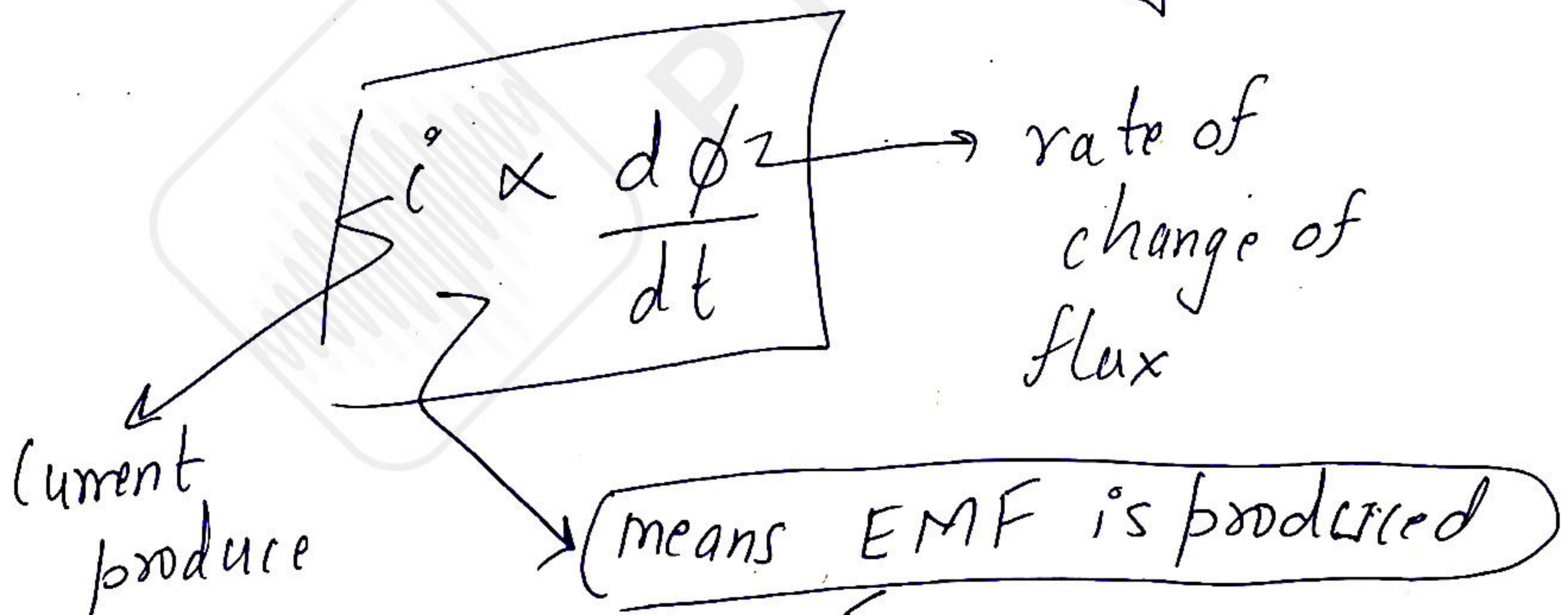
for $\phi_{\text{net}} \neq 0$, magnetic monopoles should exist

★ Hence Gauss law says that magnetic monopoles do not exist

Faraday's law:

Observe $\rightarrow$ Current in the coil is produced when flux linked with the coil changes

↓
Magnet move relative to coil Coil move relative to magnet.



Creation of Induced EMF and current Because of changing magnetic flux
 $\rightarrow$ Electro magnetic Induction

$$|\mathcal{E}| = \left| \frac{d\phi}{dt} \right| \quad \rightarrow \quad \text{rate of change of magnetic flux}$$

$\swarrow$
 emf produced
 $\nwarrow$
 Faraday's law of Induction

$\Rightarrow$ If 'N' turns

then,

$$|\mathcal{E}| = N \left| \frac{d\phi}{dt} \right|$$

Now

$$\phi = BA \cos \theta$$

so, ϕ change

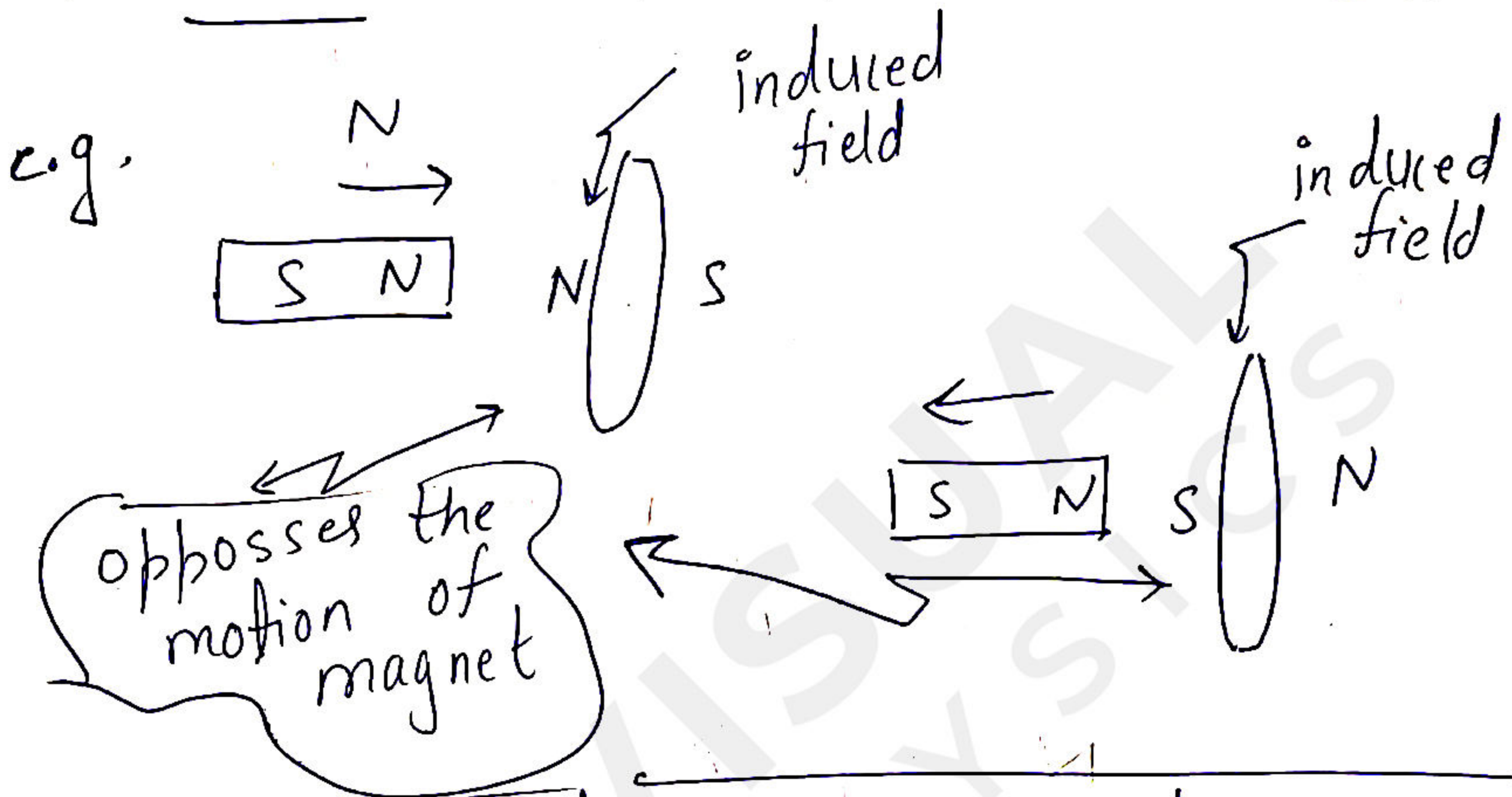
$\downarrow$
changing
Area

$\downarrow$
magnetic
field

$\downarrow$
orientation
of (oil)

Lenz's law

→ effect always opposes the cause



Induced field opposes the change in flux direction not the external field

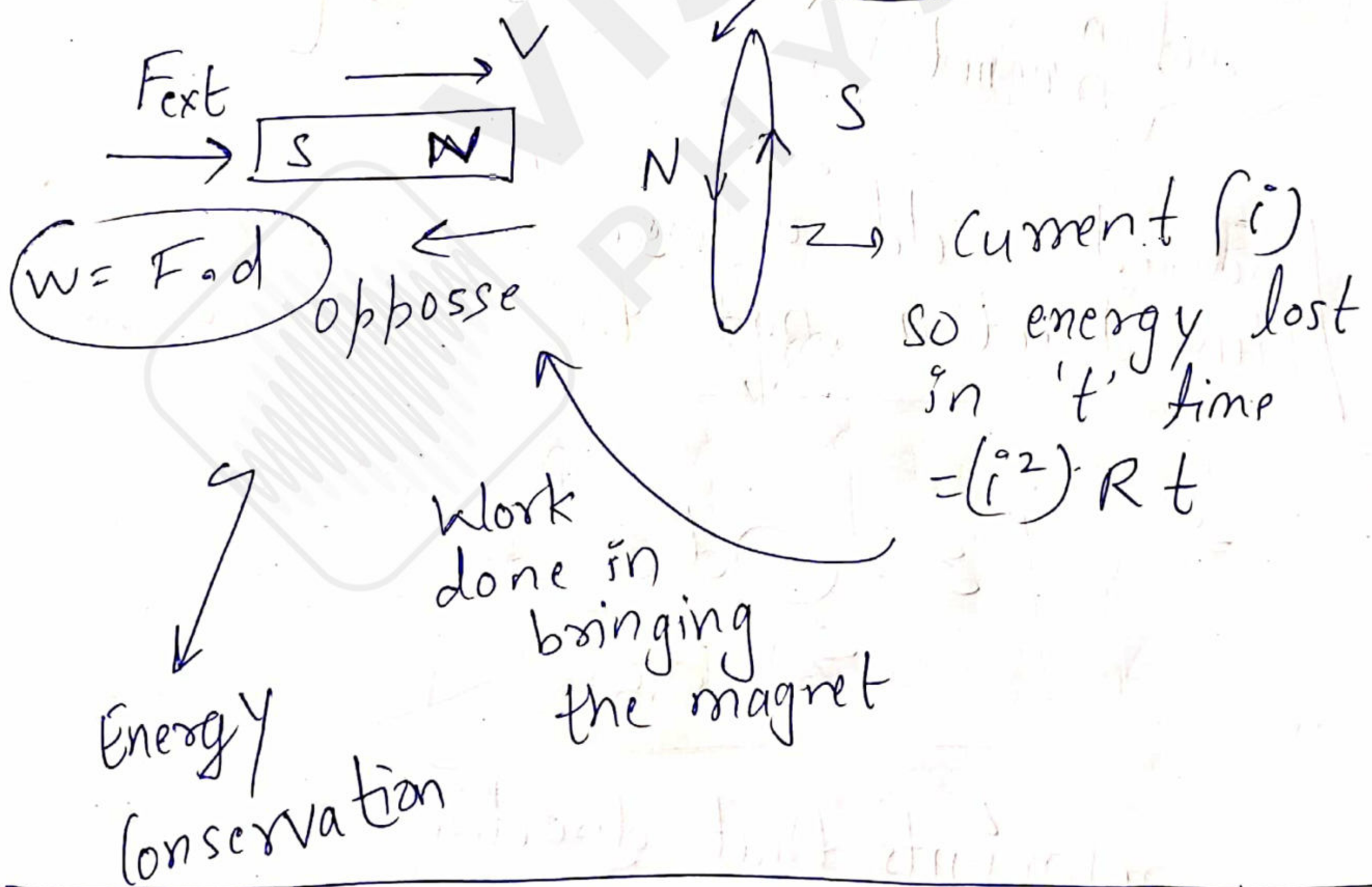
⇒

$$\mathcal{E} = - \frac{d\phi}{dt}$$

represents that direction of $|\mathcal{E}|$ is opposite to the change in flux direction

Conservation of Energy $\rightarrow$ Lenz's law

* As from Lenz's law induced emf is opposite to change in flux direction, so the restriction in motion goes in the form of field or current in coil.



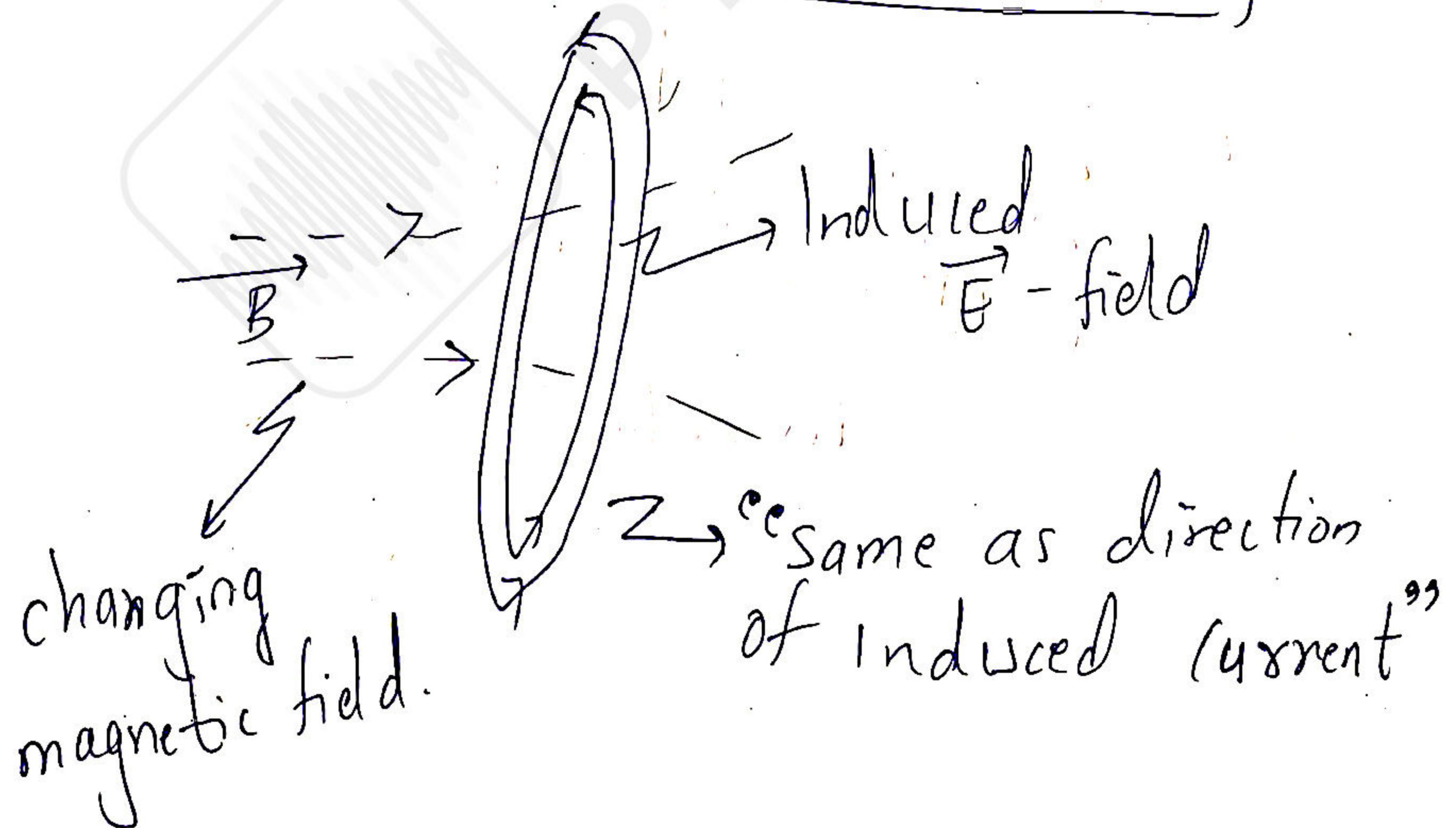
When magnetic flux changes

↓
Electric field is produced

↓
which causes the Induced current.

if coil is not there, even then Electric field in space is produced.

★ Induced electric field
↳ Closed loop



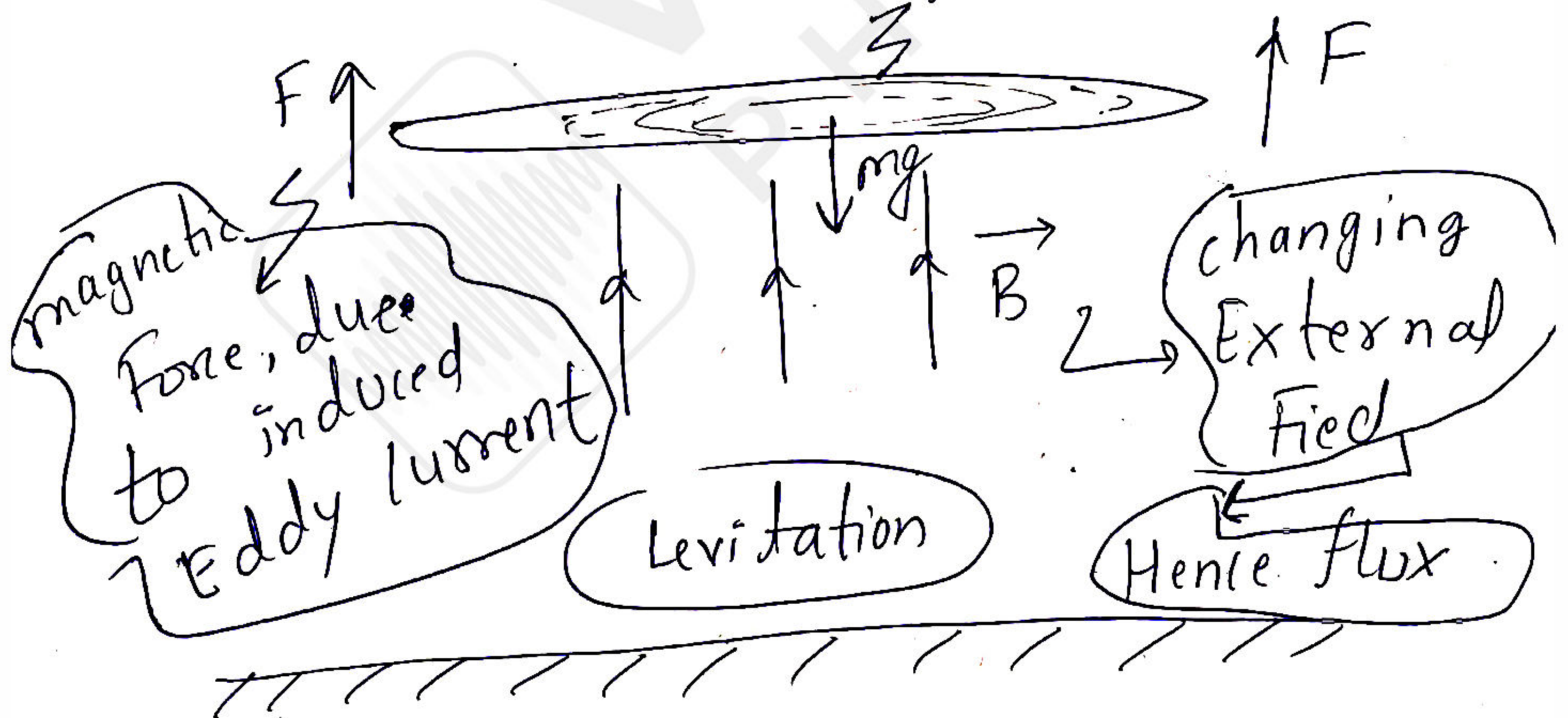
If disc is placed, in changing magnetic flux

↳ due to concentric electric field is produced

↳ concentric electron motion occurs

Hence we say Eddy current is produced,

Used in magnetic Levitation



As, work done $= \oint \vec{F} \cdot d\vec{s} = W$
 In closed loop
 of induced field $= \oint q \vec{E} \cdot d\vec{s}$

So, $\mathcal{E}_{mf} = \mathcal{E} = \frac{W}{q}$

$\Rightarrow \boxed{\mathcal{E} = \oint \vec{E} \cdot d\vec{s}}$

★ Induced $\vec{E}$ is symmetry about $\vec{B}$

$\Rightarrow \boxed{\mathcal{E} = \oint \vec{E} \cdot d\vec{s}} = \frac{d\phi}{dt}$

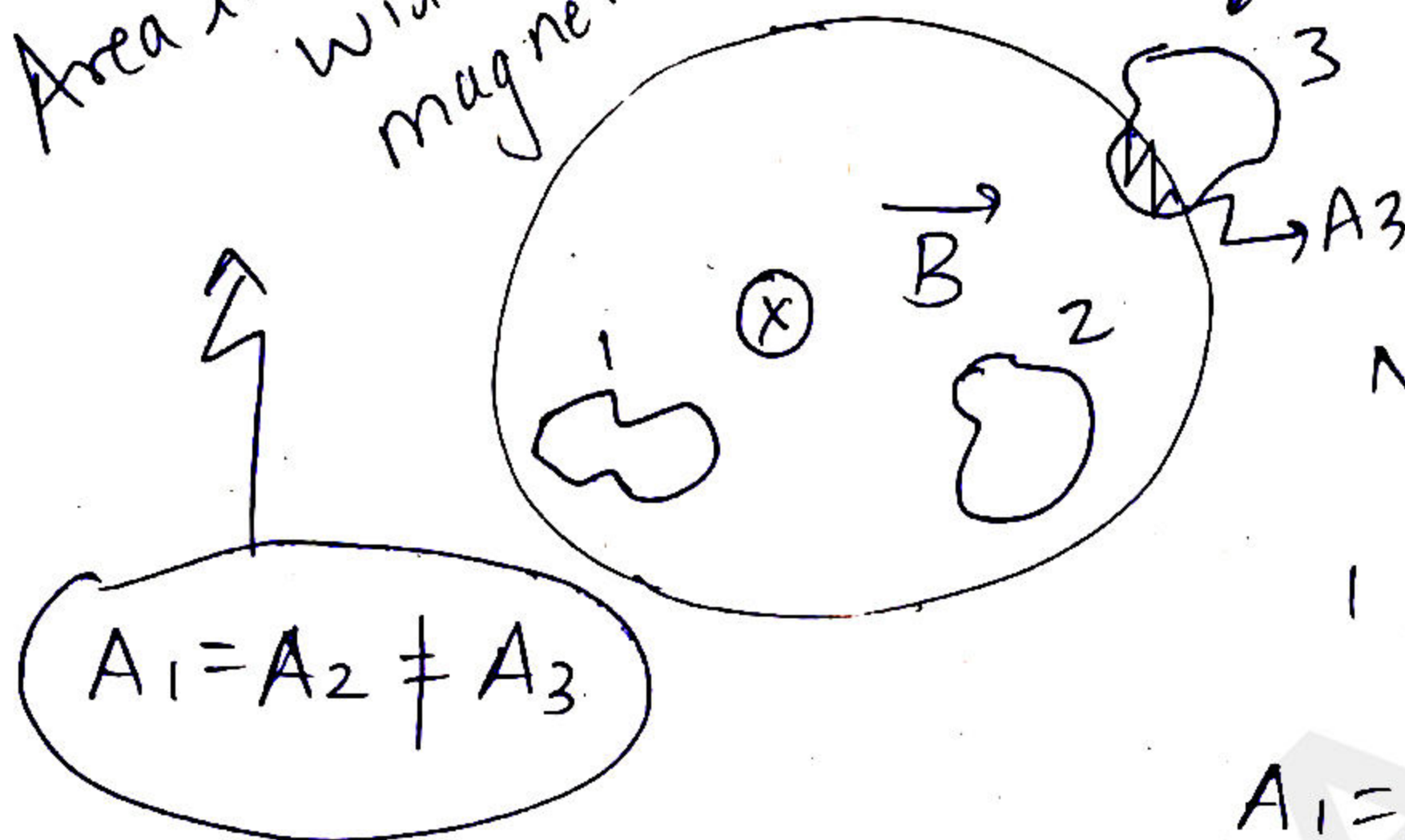
Can be any closed loop

Now, $\phi = BA$

So if Area are equal for any path

emf induced will be equal

Area linked with magnetic field $\vec{B}$ are not same
 $\hookrightarrow$ Flux linked



Net area of loop 1, 2 & 3 are equal but

$$A_1 = A_2 \neq A_3$$

$$|\vec{E}_1| = |\vec{E}_2| \neq |\vec{E}_3|$$

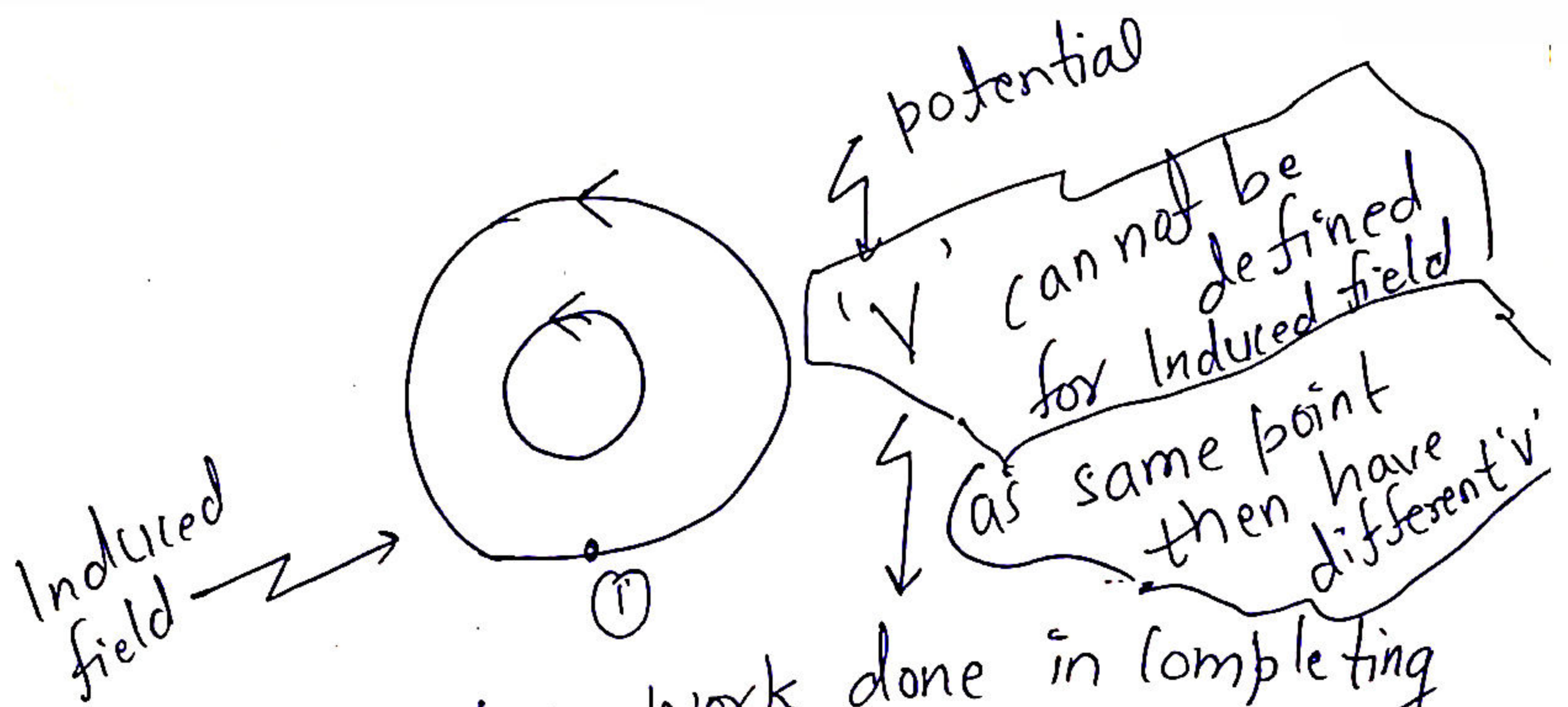
Now for Electrostatic field

$$\oint \vec{E} \cdot d\vec{l} = 0$$

Hence Conservative field

But Induced $\vec{E}$ -field is not conservative

Non-conservative $\Rightarrow \oint \vec{E} \cdot d\vec{l} \neq 0$

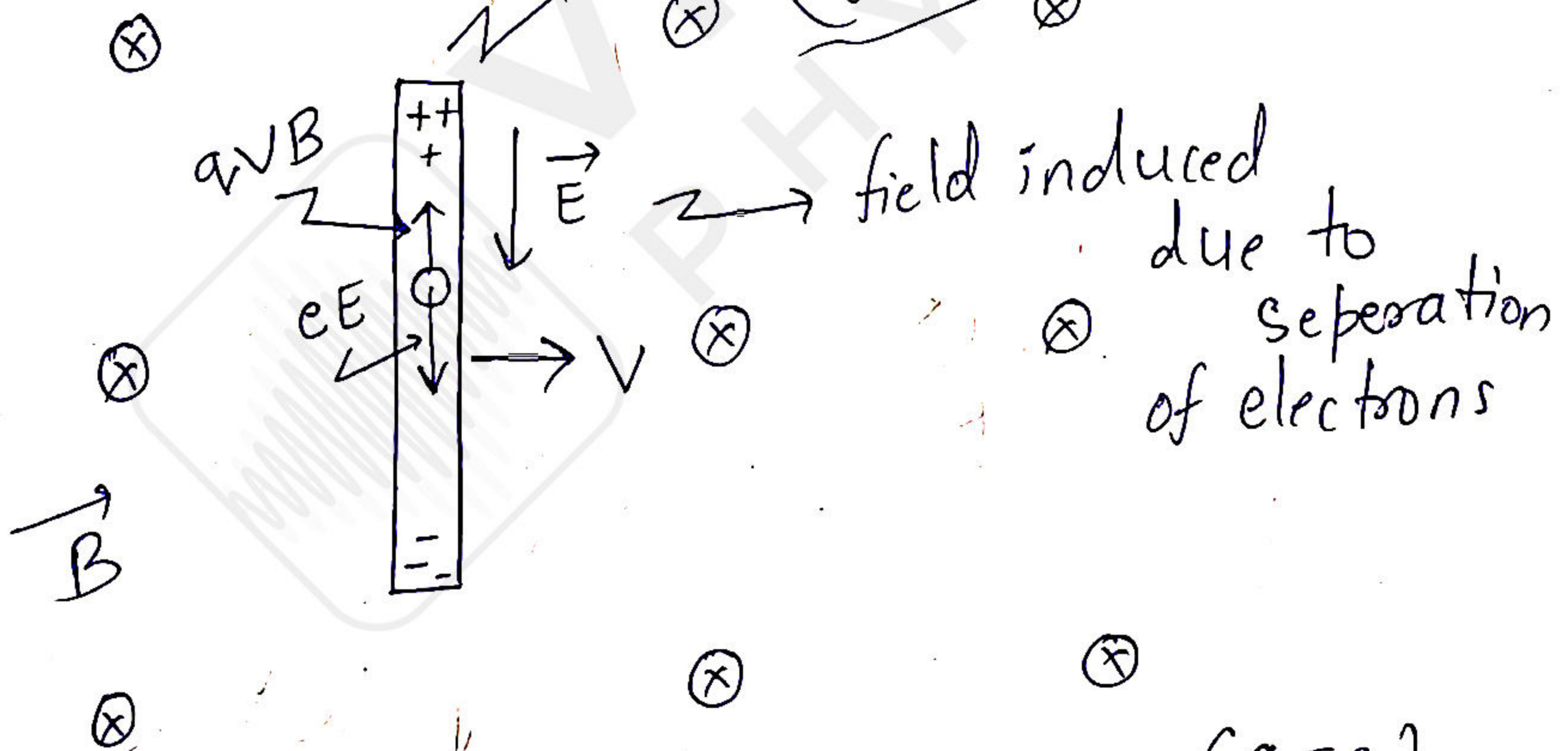


Now work done in completing one circular path $\neq 0$

$$\mathcal{E} = \oint \vec{E} \cdot d\vec{l}$$

emf induced

magnetic force drift the electrons



$$qVB = eE$$

$$(q=e)$$

Now

$$\Rightarrow E = VB$$

$$\text{or } \vec{E} = \vec{v} \times \vec{B}$$

$$\text{so, motional emf} = \mathcal{E} = \vec{E} \cdot d\vec{l} = \int (\vec{v} \times \vec{B}) \cdot d\vec{l}$$

★ direction of $\mathcal{E}$ mf can be found using right hand cross-product.

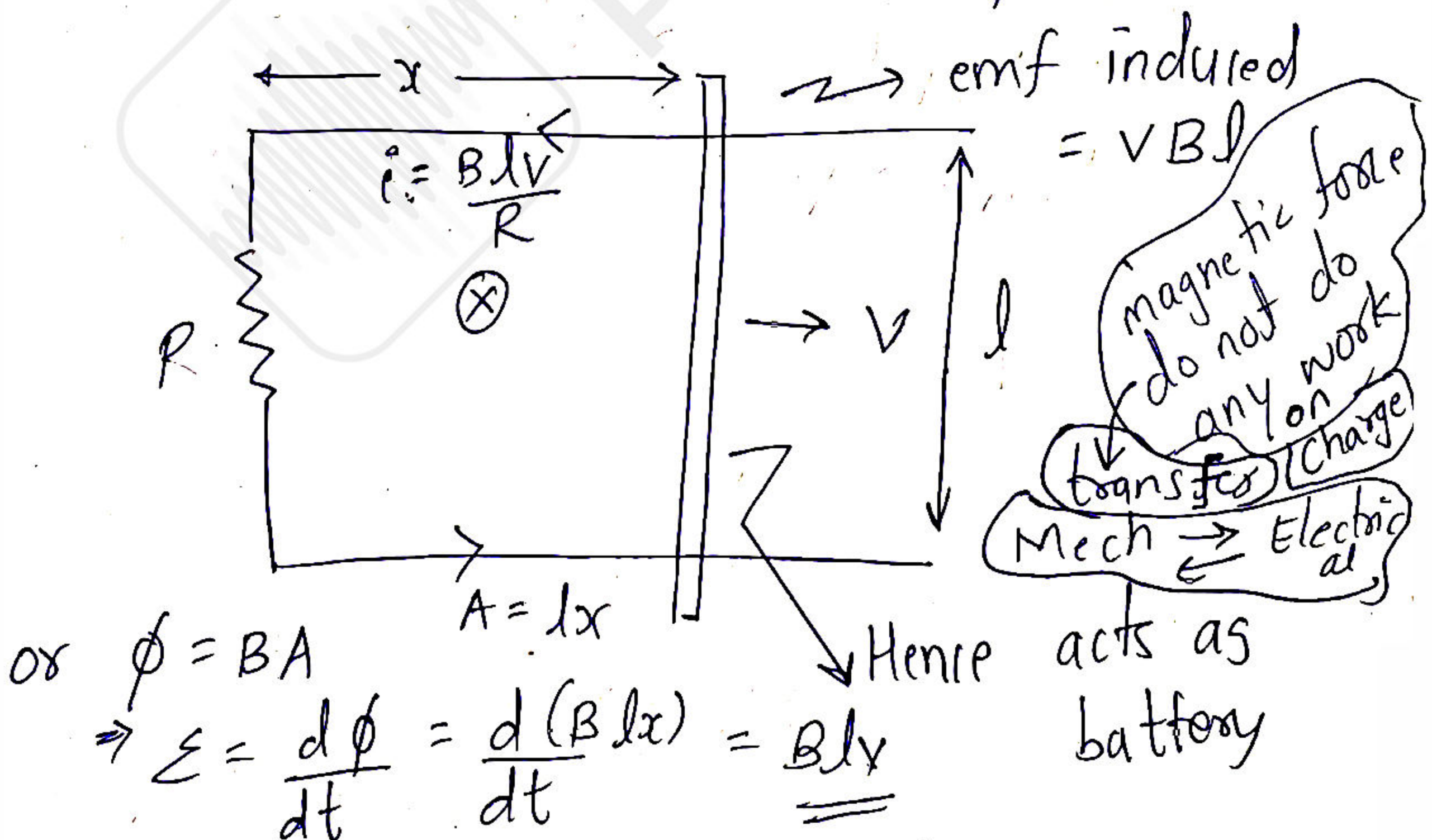
Now

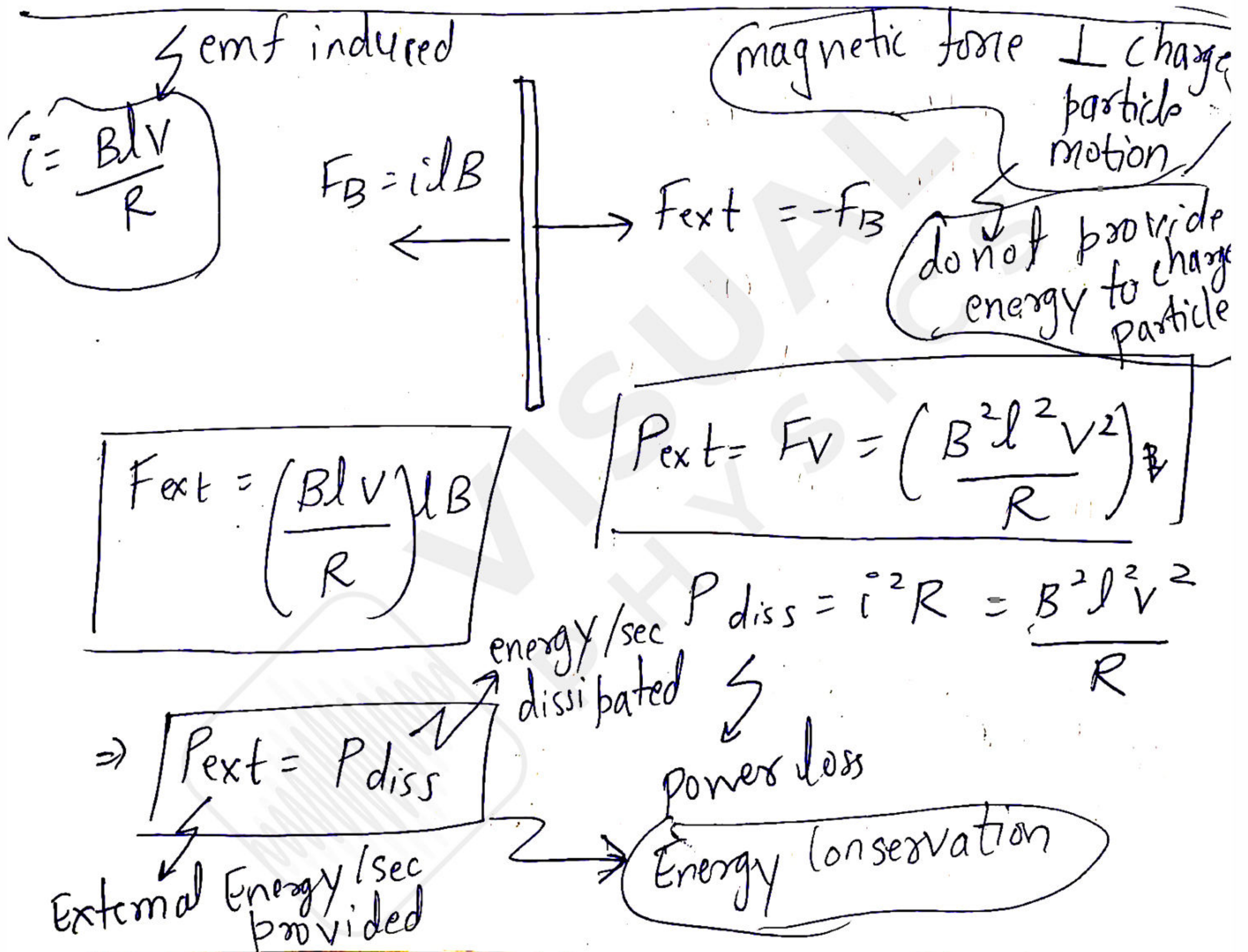
$(\vec{v} \times \vec{B}) \cdot \vec{l} \rightarrow$ Scalar Triple product of $\vec{B}$, $\vec{v}$, and $\vec{l}$

In scalar Triple product

$$(\vec{v} \times \vec{B}) \cdot \vec{l} = \vec{v}_\perp \vec{B}_\perp l_\perp$$

mutual perpendicular components





Induced Emf

If $\vec{B}$ is not changing

No Induced $\vec{E}$ -field

Emf is induced by
motion of conductor
→ motional emf

If $\vec{B}$ is changing

because of $\vec{E}$ -field
induced is emf
produced

Induced $\vec{E}$ -field

* Motional emf and Induced $\vec{E}$ -field
Are two different phenomena

But Faraday's combine it
to

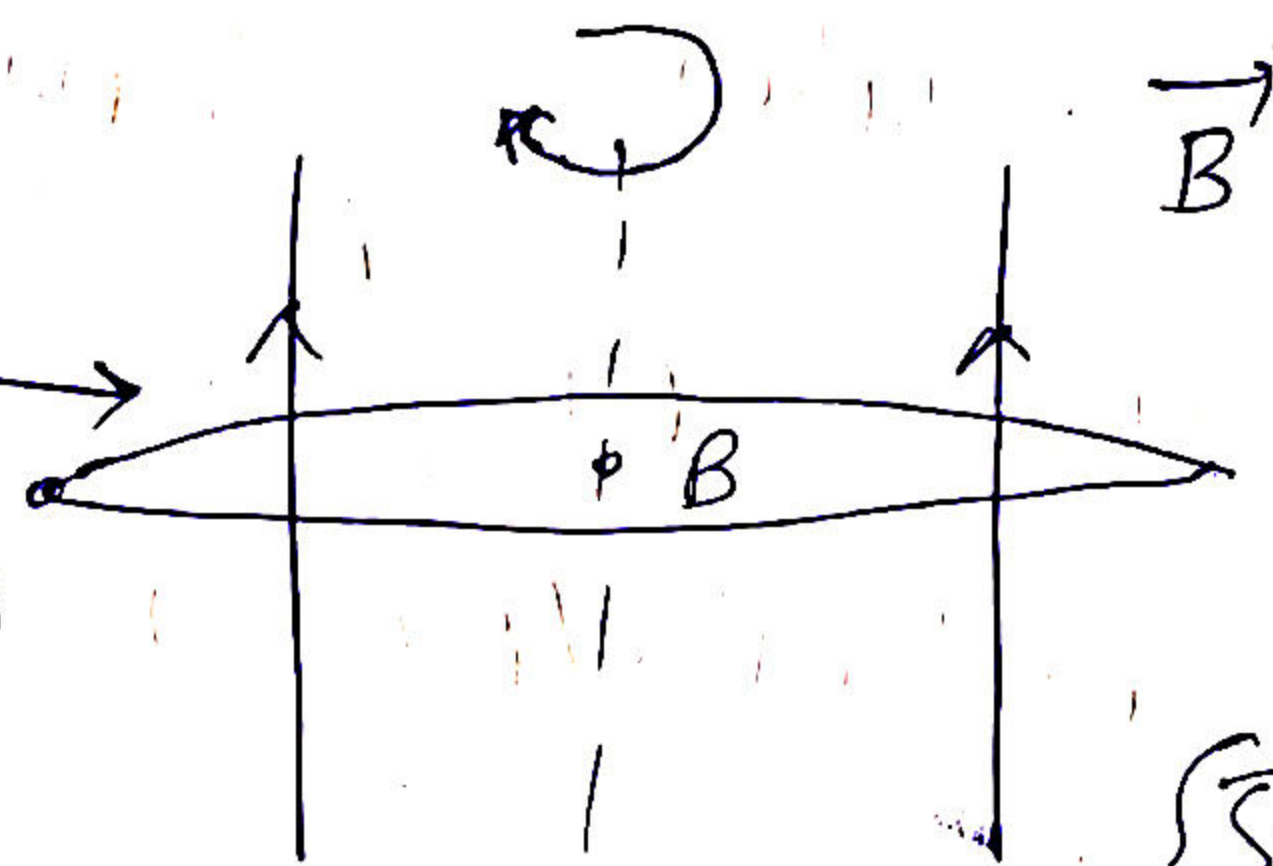
$$\text{Emf} = -\frac{d\phi}{dt}$$

valid
for most
cases

but not true for all

It's an
observation
not a law

It can be explained by motional emf

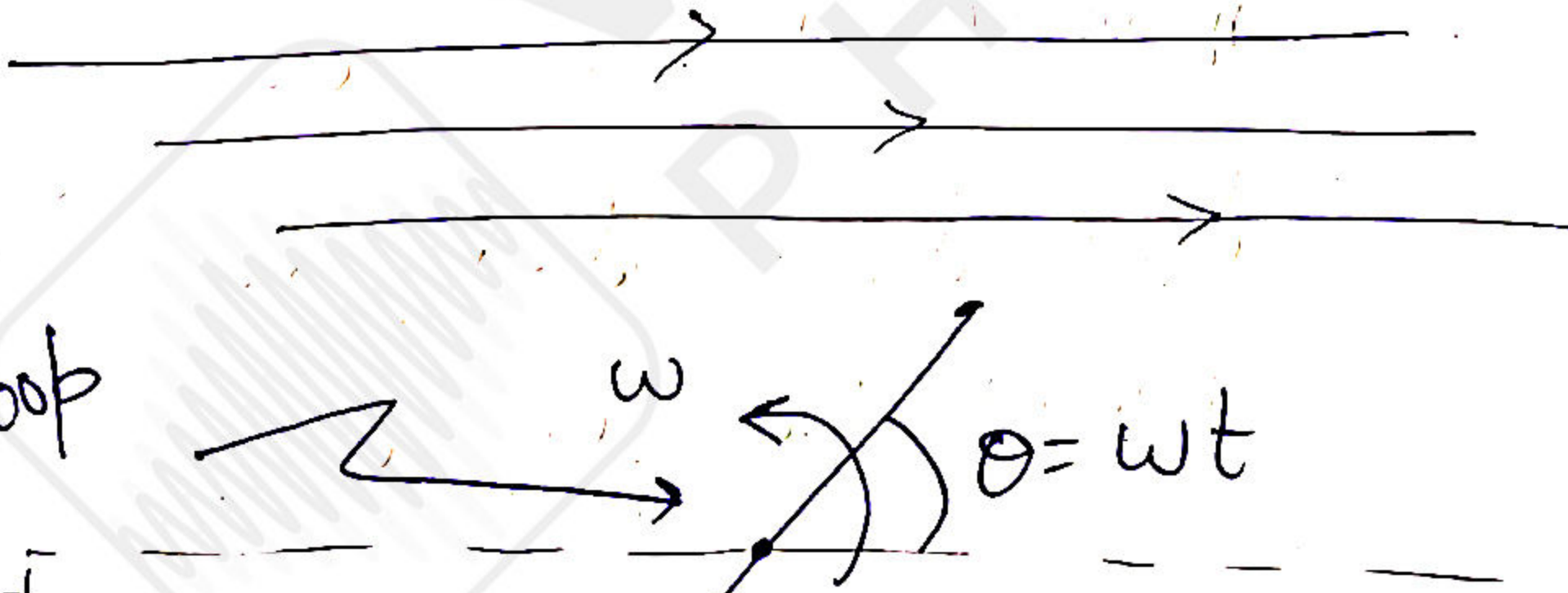


as ϕ is not changing

As $\mathcal{E} = -\frac{d\phi}{dt}$

So $\mathcal{E}$ between A & B should be zero from Faraday law

but this is not true



A conductor is moving

$$\phi = B A \sin \theta$$

$$\phi = B A \sin \omega t$$

$$|\mathcal{E}| = \frac{d\phi}{dt}$$

$$\Rightarrow \boxed{\mathcal{E} = B A \omega \cos \omega t}$$

Here motional emf is responsible for induced emf

for general situation

$$\phi = BA \sin(\theta + \phi)$$

Initial condition

$$\Rightarrow \mathcal{E} = BA\omega \cos(\theta + \phi)$$

maximum value of emf

when, $\theta + \phi = 0$

means $\vec{A}$ is $\perp$ to $\vec{B}$.