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Class 11
Physics

Chapter 12

Handwritten Notes

Chapter 12 Electromagnetism

Magnetic field
The region or space around a magnet in which another magnet, magnetic compass moving charge or current in a wire feels a magnetic force is called magnetic field.

Magnetic field strength (B):-
Strength of magnetic field at any point inside the magnetic field is called magnetic field strength. It is represented by $\vec{B}$.
It is a vector quantity. Its SI unit is Tesla which is represented by "T".

Cause of Magnetic field:-
Magnetic field is produced by the following four sources which are given below.

A- Permanent magnets.
B- Current ~~only~~ carry conductors/E.C.
C- Moving charges.
D- Fluctuating electric field.

Magnetic field lines:-
Imaginary lines drawn to visualise the magnetic field in a region of space are called electric field lines.

Properties of Magnetic Field lines :-

A- Direction:-
Magnetic field lines go from North to South outside the magnet and from South to North inside the magnet.

B- No crossing.
Two magnetic field lines never cross because the magnetic field has only one direction at one point.

C- Closed loops.
Magnetic field lines from closed loops, showing that single magnetic poles do not exist.

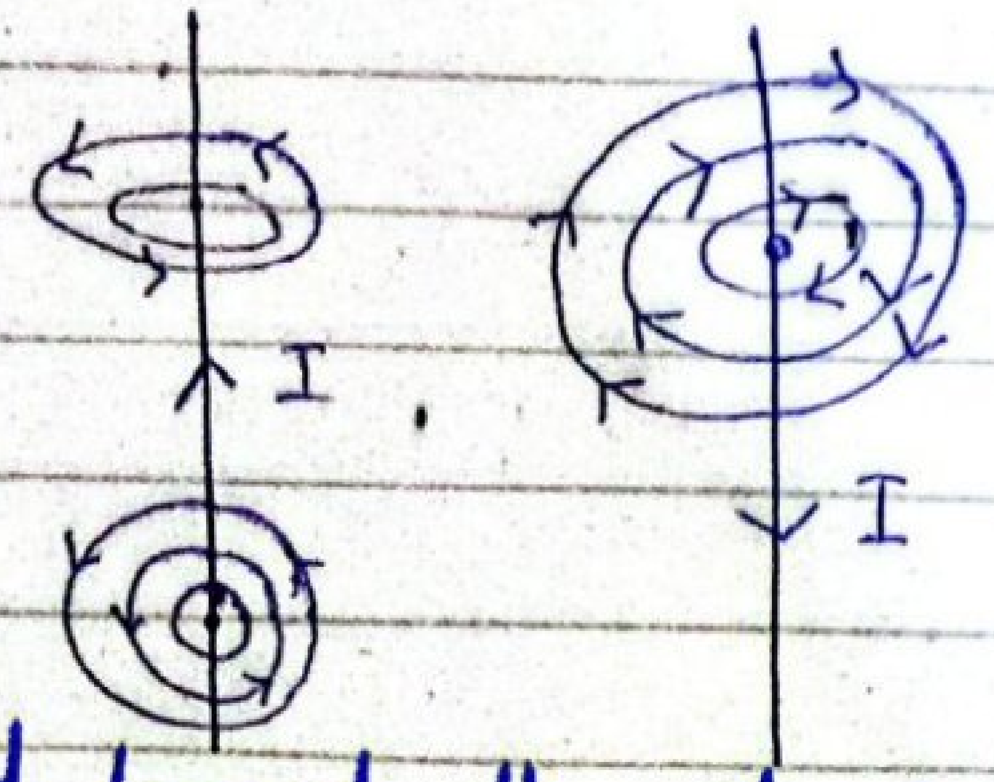
D- Field strength:-
More crowded lines have stronger magnetic field and less crowded lines has weaker field.

E. Poles behaviour:
Like poles repel each other and unlike poles attract each other.

Magnetic field due to a straight current carrying conductor:-

A current carrying straight conductor produces a magnetic field around itself. The shape of magnetic field is like a circle with the direction of circle in clockwise or Anticlockwise

direction depending upon the direction of current the conductor
Diagram



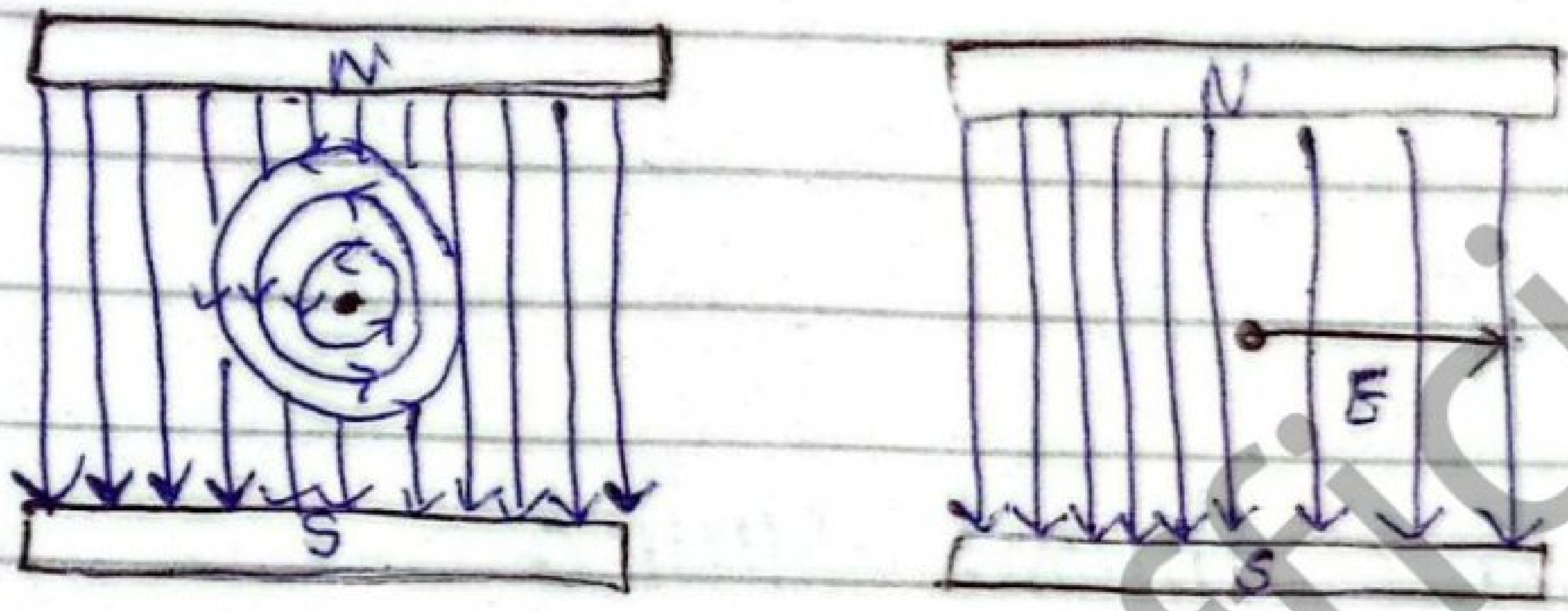
Right hand thumb rule:

Right hand thumb rule is used to predict the direction of magnetic field around a straight current carrying conductor.
According to this rule, grab/hold the conductor in your right hand such that your thumb points in direction of current then your curling fingers show direction of circular magnetic field.

Show that current carrying Conductor in an external magnetic field:-

When a current carrying conductor is placed in external magnetic field it experiences a magnetic ~~field~~ force. Force a region of of stronger magnetic field to a region of weaker magnetic field due to the interactions of external magnetic field and magnetic field of conductor.

Diagram:-



Mathematically:-

Experimentally it was observed that the magnetic force on a current carrying conductor is directly proportional to the current passing through the conductor, length of conductor inside the magnetic field "sin" of angle b/w the current.

Therefore, conductor and external magnetic field

i.e. $F \propto I$ ... ① $F \propto B$ ... ③

$F \propto l$ ... ② $F \propto \sin\theta$ ... ④

Combining all equations, we have.

$F \propto IlB \sin\theta$.

$F = \text{Constant } IlB \sin\theta$.

$F = K\, IlB \sin\theta$.

In SI, units value of "K" is unity.

$[K = 1]$

Therefore $F = KIlB \sin\theta$

$$F = IlB \sin\theta.$$

In vector form:

$$\vec{F} = I(\vec{l} \times \vec{B}).$$

Maximum Force (F_{max}):-

When angle b/w external magnetic field and length of conductor is 90°. i.e; $\theta = 90°$ then force on the conductor is maximum.

$$F = IlB \sin\theta.$$

$$F_{max} = IlB \sin 90°$$

$$F_{max} = IlB.$$

Minimum Force (F_{min}):-

When current through conductor is parallel ($\theta = 0°$) or anti parallel to external magnetic field then there is magnetic force on the conductor in magnetic field. i.e; $F_{min} = 0$.

$$F = IlB \sin\theta.$$

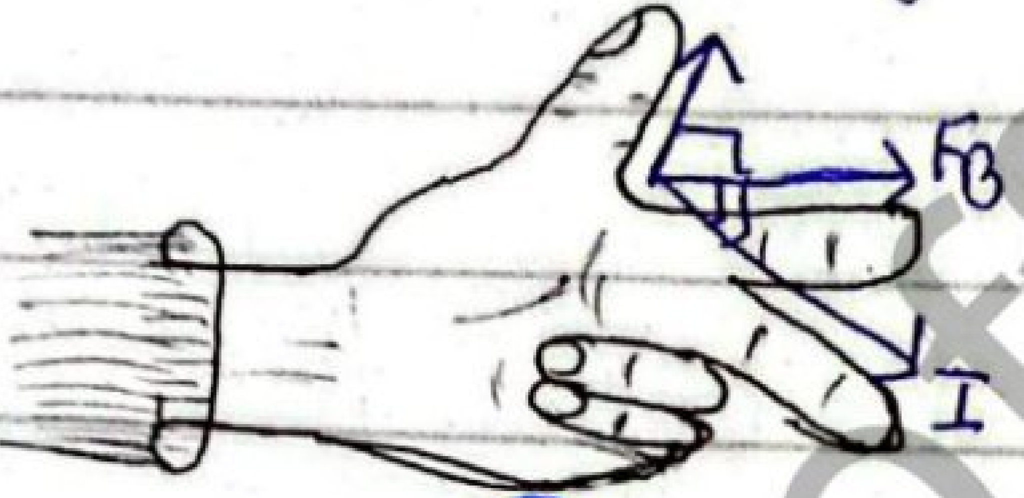
$$F_{min} = IlB \sin 0° = IlB \sin 180°$$

$$F_{min} = 0.$$

Fleming left hand rule:-

Fleming left hand rule is used to determine the direction of magnetic force on a current carrying conductor in an external magnetic field.

According to this rule, keep your thumb, forefinger of middle finger mutually perpendicular. Now, paint forefinger in direction of external B-field, middle finger in direction of current then your erect will point in direction of magnetic force on the current carrying conductor in B-field.



Magnetic Induction / flux density / field intensity (B):

Definition;

Strength of Magnetic is said to be one tesla (1T) when a conductor of length one meter (1m) carrying a current of one Ampere (1A) held perpendicular to the external magnetic field experiences a force of one Newton (1N).

Formula:-

$$B = \frac{F}{Il}$$

Unit;-

$$B = \frac{F}{Il} = \frac{N}{A \cdot m} = NA^{-1}m^{-1} = Tesla = T$$

$$B = \frac{N}{A \cdot m} = NA^{-1}m^{-1} = T.$$

Gauss:-
SI unit of B-Induction is Tesla. CGS unit of B-field in "Gauss".
where

$$1T = 10000G = 10^4 G.$$
$$G = 10^{-4} T$$

Magnetic force on a moving charge in an external magnetic field:-

Moving charged particle create its own F_B. When this moving charged particle enters into a B-field, Both magnetic fields interact and moving charged particle feels a magnetic force.

Dependance of B-Force:
Experimentally, it was observed that.

$F \propto Q$ ... ① $F \propto V$ ... ③
$F \propto B$ ... ② $F \propto \sin\theta$ ... ④

Combining ① ② ③ and ④.

$$F \propto QVB \sin\theta$$
$$F = \text{Constant } QVB \sin\theta.$$
$$F = KQVB \sin\theta.$$

where. "K" is the constant of proportionality. In SI units, its value is unity.
Therefore:

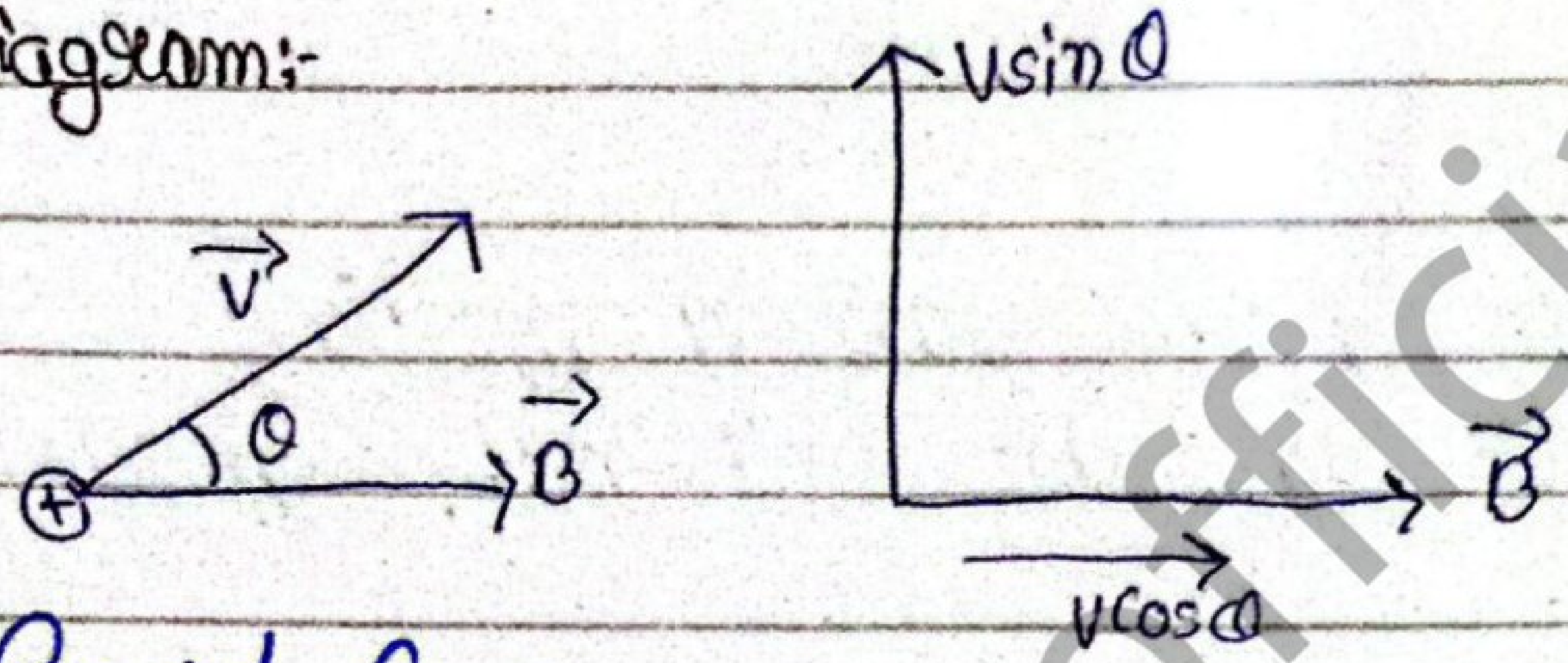
$$F = QVB \sin\theta.$$

where "θ" is the angle b/w external magnetic field vector (B) and velocity vector of moving charged particle ($\vec{V}$)

In vector, Force can be written as.

$$\vec{F} = Q(\vec{V} \times \vec{B}).$$

Diagram:-



Special Cases:-

Case #01 ($\theta = 0°$ i.e; $\vec{V}$ and $\vec{B}$ are parallel)

In the present case, charged partical moves in the direction of external B-field.

$F = QVB\sin\theta = QVB\sin 0° = QVB(0)$

$F = 0.$

No, magentic force acts on moving charge.

Case #02 ($\theta = 180$ i.e; $\vec{V}$ & $\vec{B}$ are antiparallel)

In present case, charged particle move in direction opposite to external magnetic field.

$F = QVB\sin\theta$, $QVB\sin 180° = QVB(0) = 0.$

$F = 0.$

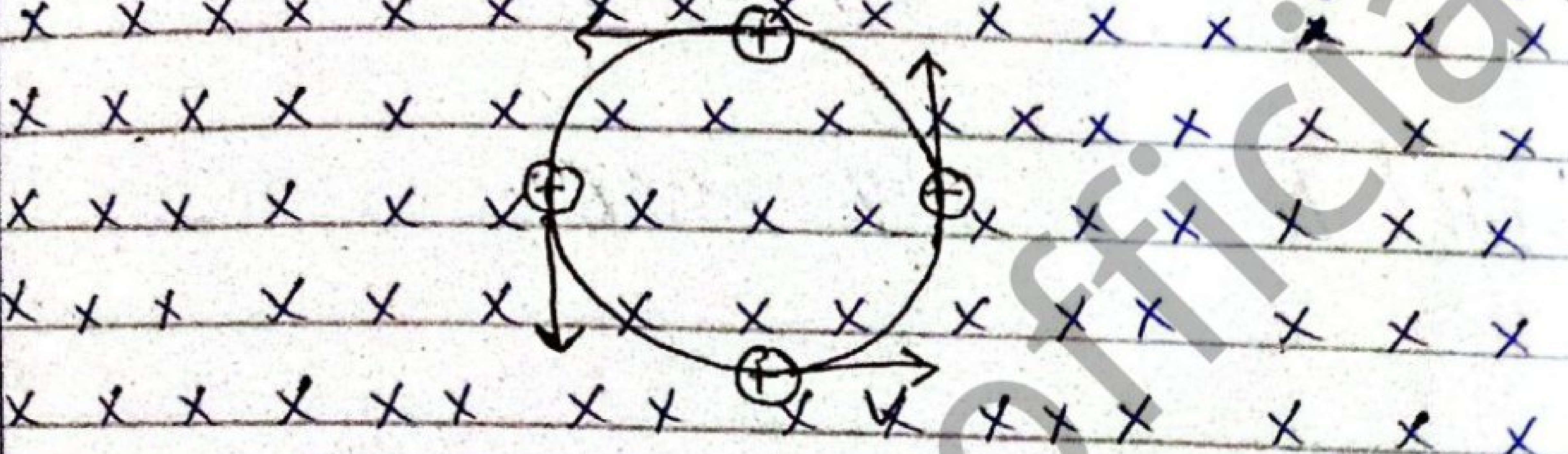
No, magnetic force acts on moving charge particle.

Case # 03 ($\theta = 90°$. $\vec{V}$ is perpendicular to $\vec{B}$).
In present case, charged particle moves perpendicular to external B-field.

$$F = QVB \sin\theta \quad , = QVB \sin 90°$$

$$F = QVB.$$

Maximum magnetic force acts on moving charge.



Case # 04 ($\theta < 90$, $\theta > 0$)
When charged particle enters into an external magnetic field with angle greater than "0" and less than "90°".
Then magnetic field charged particle is.

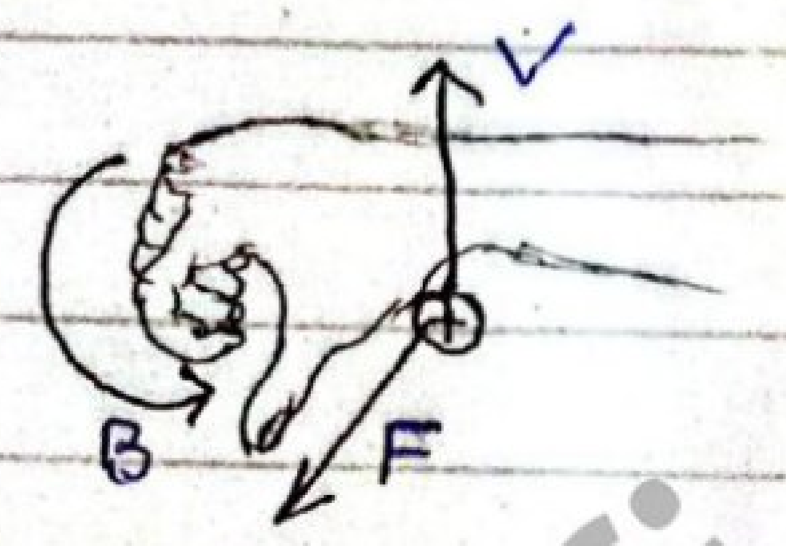
$$F = QVB \sin\theta.$$

and particle moves in a helical path.

Right hand Rule-II

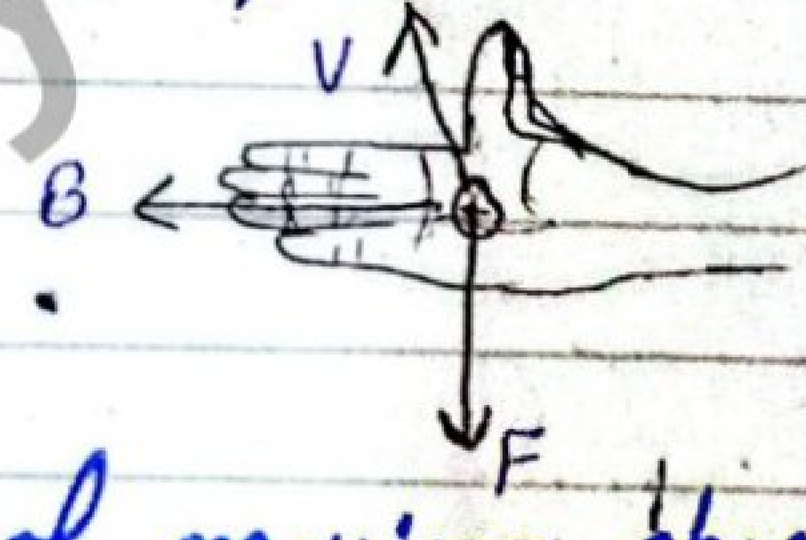
This rule is used to know the direction of magnetic force on a moving charged or Current carrying conductor in an external B-field.
According to this rule, Curl the fingers of your right hand from the direction of $\vec{V}$ or $\vec{l}$

towards external B-field then your erect thumb will point in direction of the magnetic field force on charge/wire.



Right hand palm rule:-

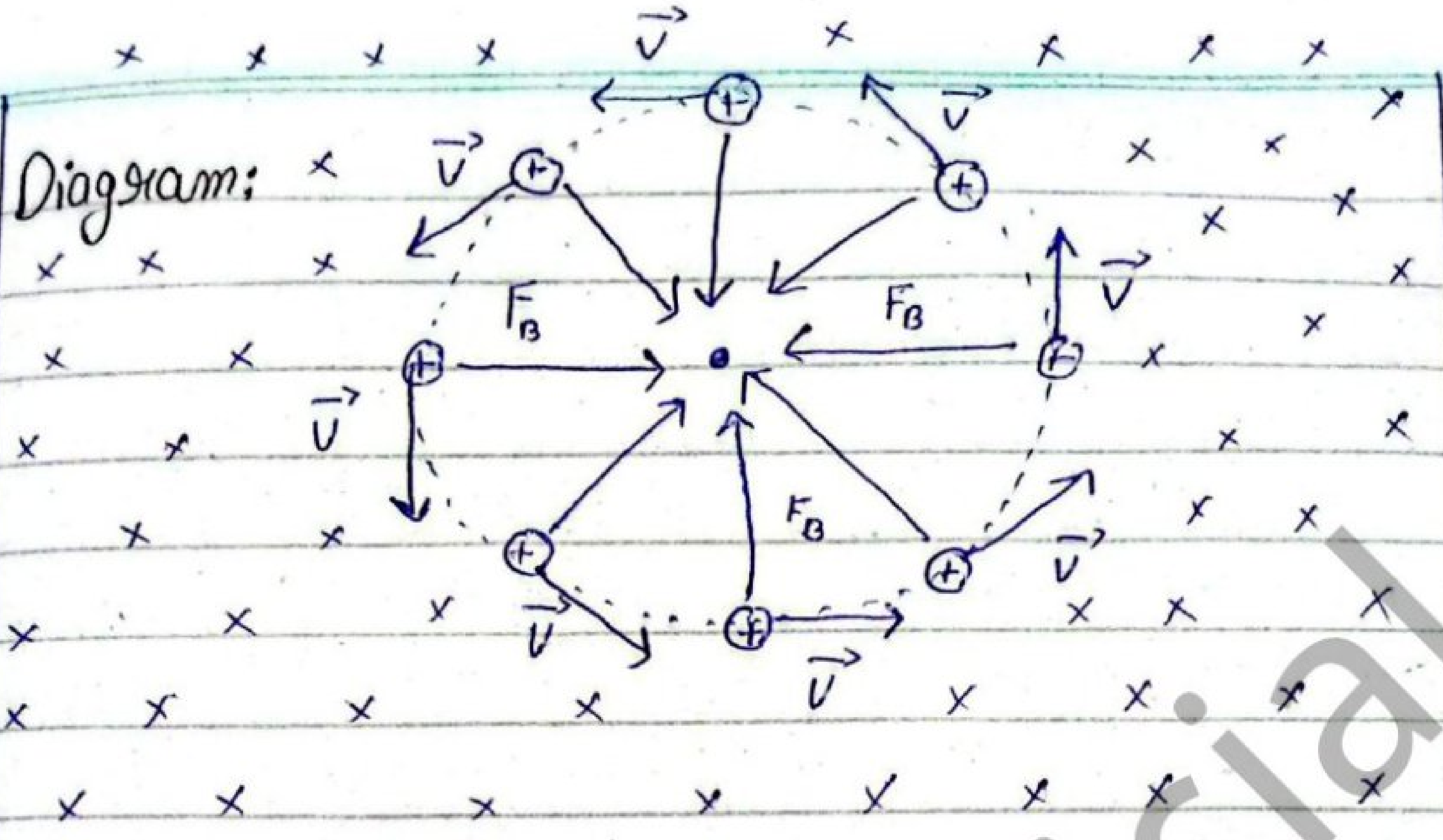
According to this rule, place the all fingers of your right hand in direction of the external magnetic field and thumb in direction of velocity of moving charge or current through the conductor.
Then, palm will point in the direction of B-Force on moving charge or current carrying wire/conductor.



Motion of moving charged particle in a uniform external B-field.

when a moving charged particle enters into a uniform external magnetic field perpendicularly, magnetic force moves the particle into a circular path. Centripetal force required by the particle is provided the magnetic force.

Diagram:



Mathematically:-
Since, charge is moving in circular path,
Therefore,

A→ $$F_C = F_B \,,\quad \frac{mv^2}{r} = QvB$$

$$\frac{mv}{r} = QB$$

$$\frac{r}{mv} = \frac{1}{QB}$$

$$r = \frac{mv}{QB}.$$

This is the radius of the circle.

B→ Angular frequency velocity (ω):-

we know that $r = \dfrac{mv}{QB}$ $\quad \therefore v = r\omega$

$$r = \frac{mr\omega}{QB},$$

$$QBr = mr\omega$$

$$\omega = \frac{QB}{m}$$

This is the angular velocity of the moving particle charge.

C → linear frequency (f) :-
we know that

$$\omega = \frac{QB}{m} \qquad \therefore \omega = 2\pi f$$

$$2\pi f = \frac{QB}{m}, \quad f = \frac{QB}{2\pi m}.$$

This is the frequency of the particle.

D → Time Period of Charge (T) :
we know that

$$f = \frac{QB}{2\pi m} \qquad \therefore f = \frac{1}{T}$$

$$\frac{1}{T} = \frac{QB}{2\pi m}, \quad \frac{T}{1} = \frac{2\pi m}{QB}.$$

$$T = \frac{2\pi m}{QB}.$$

Velocity Vector :-

Definition :-
A device which is used to separate charged particle designed velocities is called velocity Selector.

Principle :-
It allows only those particles that experience equal and opposite electric and magnetic forces.

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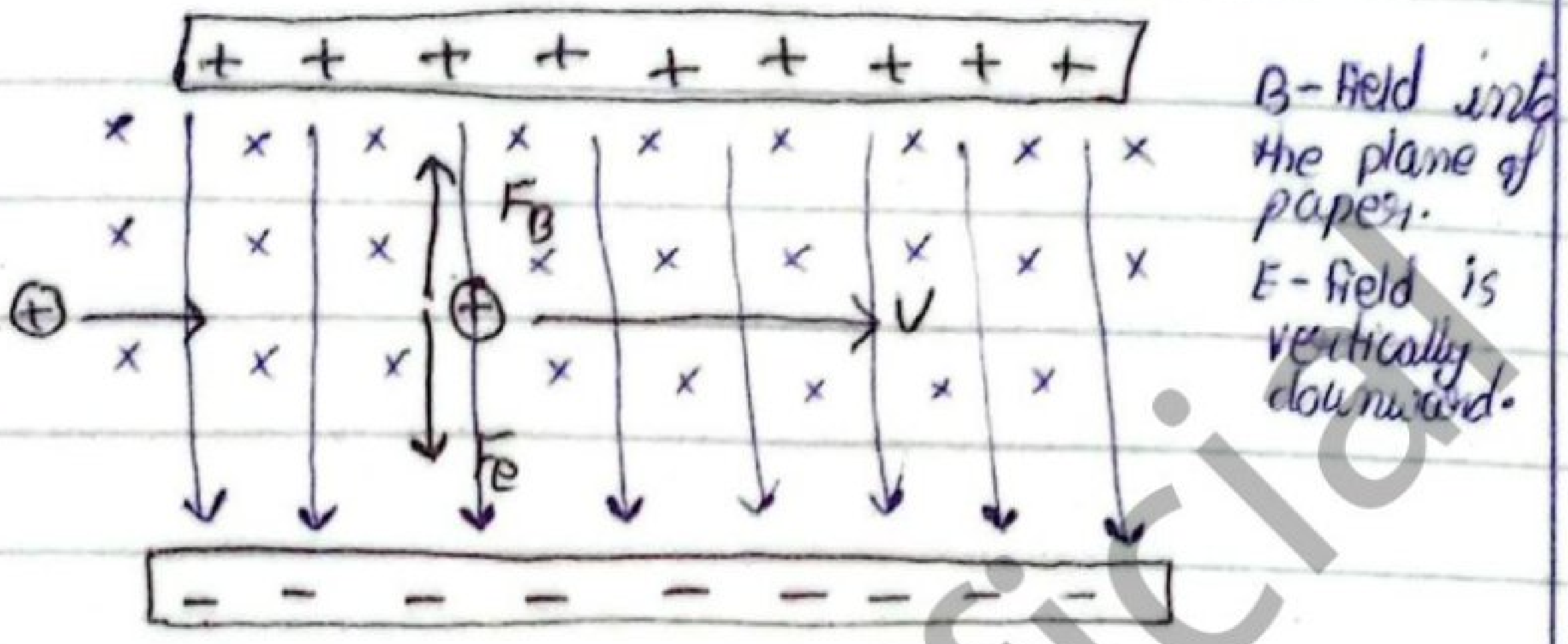
Construction:-
It consists of an electric and magnetic fields that are mutually perpendicular.

Diagram:-



Mathematically:-
For particle to pass straight,

$$|F_e| = |F_B|$$
$$QE = QVB\sin\theta$$
$$QE = QVB\sin 90^\circ$$
$$QE = QVB$$
$$E = VB \quad , \quad VB = E \, , \quad \boxed{V = \frac{E}{B}}$$

Lorentz Force:-

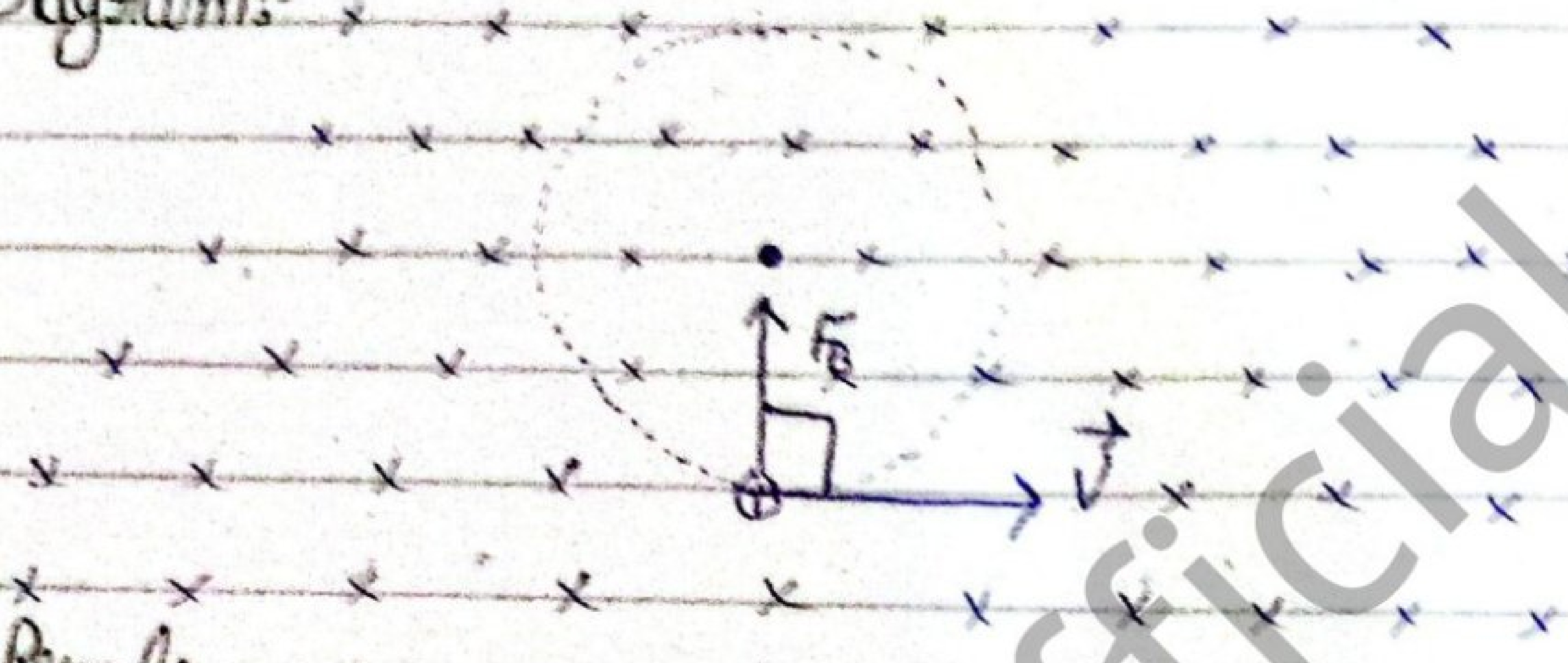
When a moving charged particle enters into an external electromagnetic field, it experiences both electric and magnetic forces simultaneously.
Net force on charged particle is the vector sum of electric and magnetic forces. This resultant force is called Lorentz force

i.e:- $\vec{F_R} = \vec{F_e} + \vec{F_m}$

$$\vec{F_R} = QE + Q(\vec{v} \times \vec{B}).$$

Show that, work done by magnetic force on a moving charged particle remains zero and its K·E remains unchanged.

Diagram:-



Proof:-

We know that, displacement of a moving charged particle is always in direction of velocity of particle is always perpendicular the magnetic force (F_B) acting on moving charged ~~circuit~~ / particle.

Therefore:-

$$W = \vec{F} \cdot \vec{S} = FS\cos\theta = FS\cos 90^\circ$$

$$W = FS\cos 90 = FS(0) = 0$$

$$W = 0$$

According to work K·E theorem,

work done on a moving particle = change in K·E of the particle.

$$W = \Delta(K \cdot E) = (K \cdot E)_f - (K \cdot E)_i$$

$$W = (K \cdot E)_f - (K \cdot E)_i$$

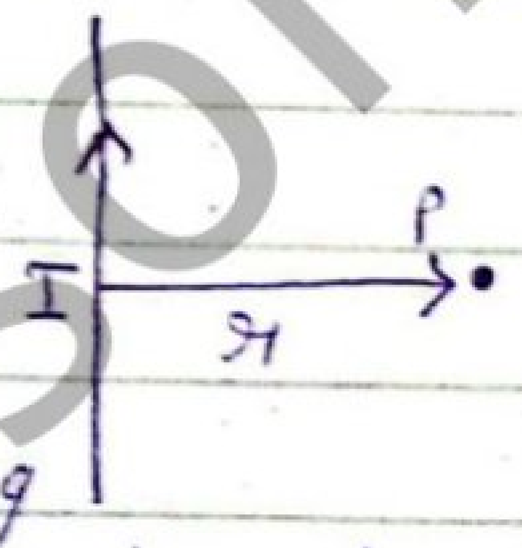
$$0 = (K \cdot E)_f - (K \cdot E)_i$$

$$(K \cdot E)_i = (K \cdot E)_f$$

Magnetic field due to a straight current carrying conductor or wire.

A straight current carrying conductor produces a magnetic field around itself in the form concentric circle. The strength of magnetic field depends upon the magnitude of current, distance of field point from wire and surrounding medium.

The magnitude of B-field due to straight wire is $B = \frac{\mu_0 i}{2\pi r}$



where "μ_0" is called permeability of surrounding medium. Its numerical value for air/vacuum is $\mu_0 = 4\pi \times 10^{-7}$ Wb.

Magnetic field due to a circular loop carrying current at its centre.

A current carrying circular loop produces a magnetic field and behaves like a tiny magnet the magnitude of B-field its centre is given by. $B = \frac{\mu_0 i}{2r}$

where "μ_0" is the permeability of the medium. with value for air/vacuum as $\mu_0 = 4\pi \times 10^{-7}$ Wb.

Magnetic field due to a ~~current carrying solenoide~~ ; circular loop carrying current at its centre:

A current carrying circular loop produces a magnetic field and behaves likes a tiny magnet. The magnitude of B-field its centre is given by.

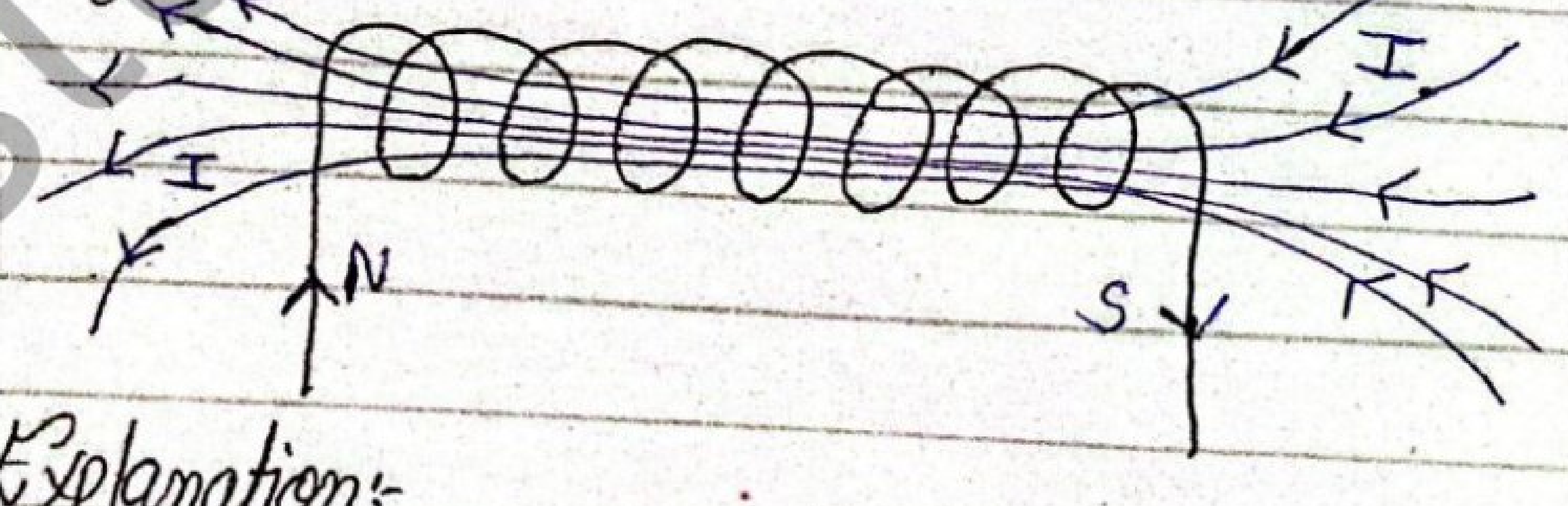
$$B = \frac{\mu_0 i}{2r}$$

where, "μ_0" is the ~~proportionality~~ permeability of the medium with value for air/vaccume as
$\mu_0 = 4\pi \times 10^{-7}$ wb.

Magnetic field due to a current carrying Solenoid.

Definition:-
A conductor wounded in the form of helix and carrying a current forms a solenoid.

Diagram:-



Explanation:-
When current passes through a solenoid, it produces a magnetic field similar to a bar magnet in its interior and behaves

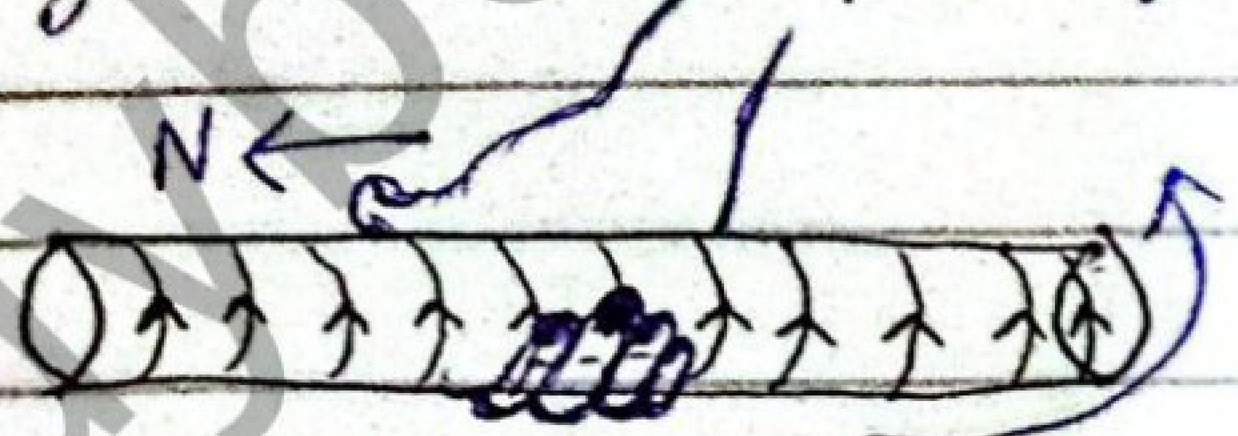
like a bar magnet with one end as North pole and other end as south pole.
~~Magnetic field~~ Magnitude of B-field in the interior of solenoid is given by

$$B = \mu_o n i = \frac{\mu_o N i}{l}$$

where "μ" is the permeability of medium present inside the solenoid. "N" total no. of turns of solenoid. "l" is the length of solenoid and "n" is the turn density.

Right hand Rule-III:

Grab Solenoid in your right hand such that your fingers curl in direction of current. Then your thumb will point in direction of the North pole of solenoid.

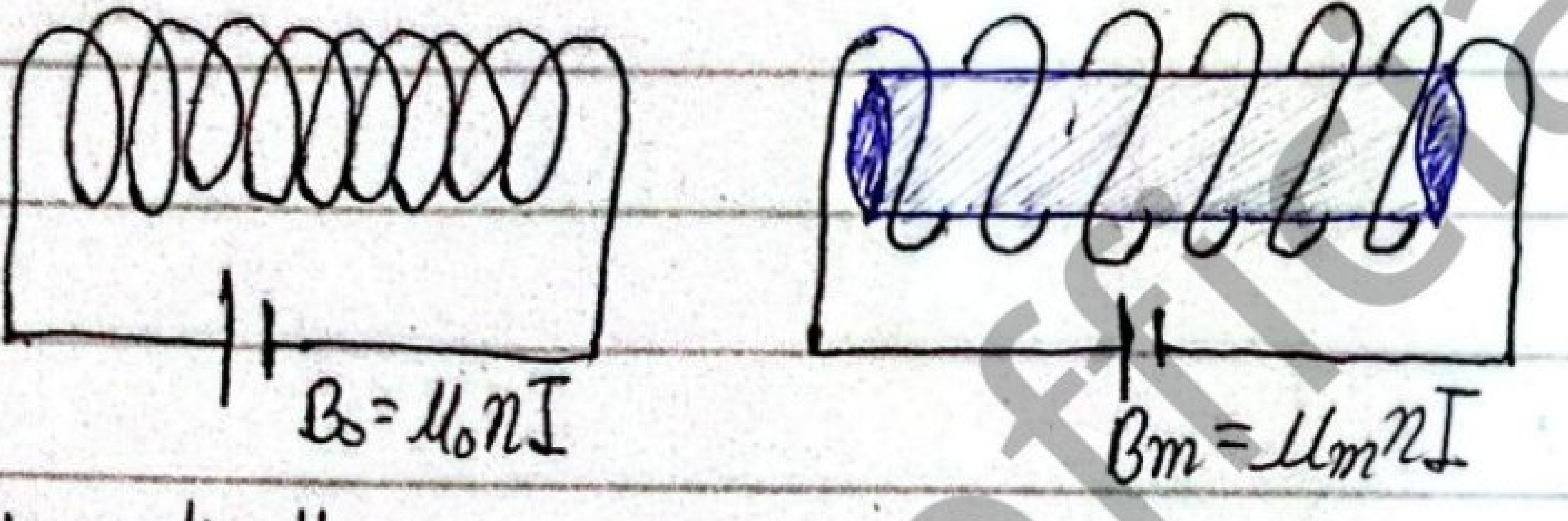


Show that, Placing a ferromagnetic core inside a solenoid increases its B-field.

when a ferromagnetic material is placed inside solenoid, it gets magnetized and produces its own magnetic field parallel of B-field of solenoid.

Both B-fields support each other & overall B-field inside the solenoid becomes uniform and strong represented by straight, parallel and equally spaced magnetic field lines.

Diagram:-



Mathematically:-

Expression for magnetic field inside the solenoid is $B = \mu n I$

For air vaccume as medium,

$$B_0 = \mu_0 n I \quad \ldots \text{①}$$

For any ferromagnetic material as medium such as iron, Carbon steel and iron oxide

$$B_m = \mu_m n I$$

$$B_m = \mu_r \mu_0 n I$$

$$B_m = \mu_r (\mu_0 n I)$$

using eq ①

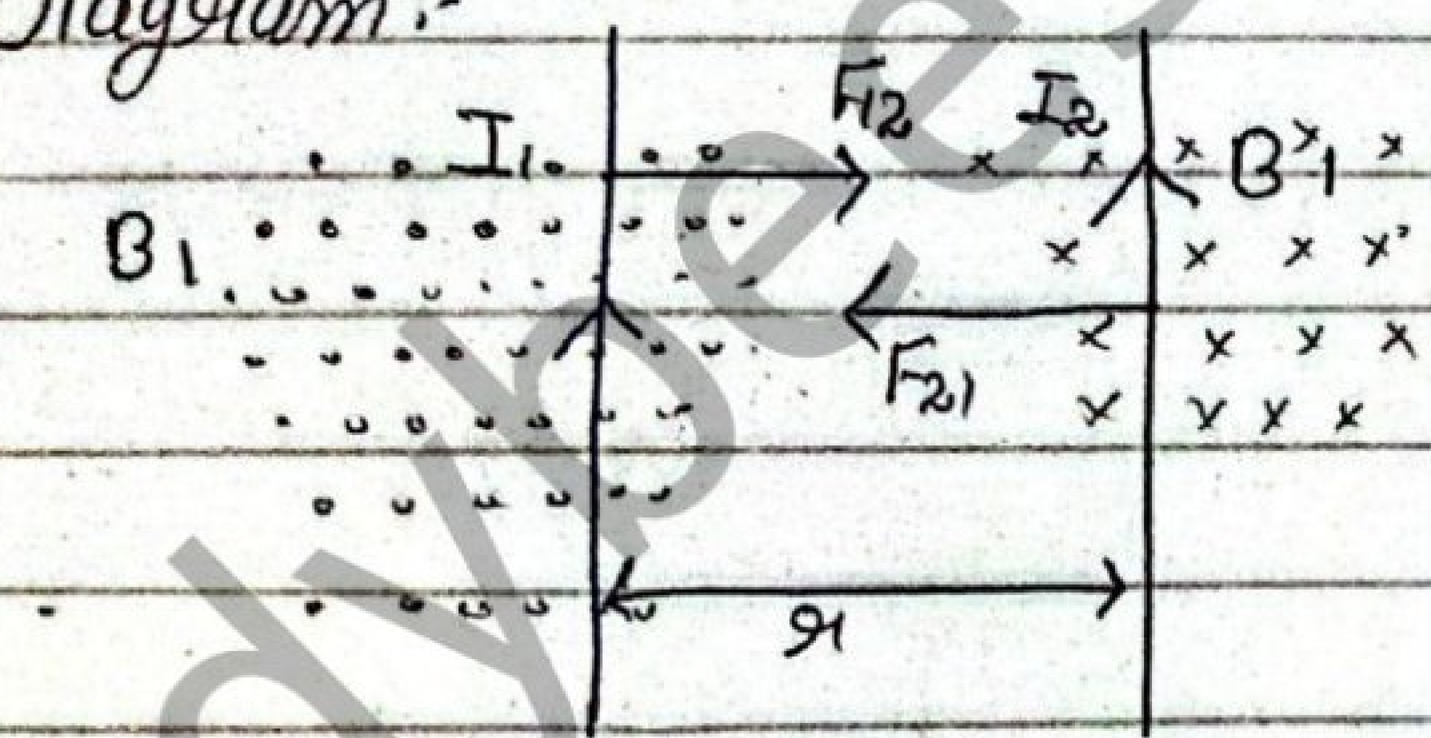
$$B_m = \mu_r B_0$$

Where "μ_r" is the permeability of the medium used as core. Relative permeability of iron ranges from "200" to "5000".

Magnetic force b/w to straight, parallel current carry wires / conductors:-

Origin of magnetic force b/w parallel wire:-
Two straight, parallel wire carrying current in same direction attract each other because net magnetic field in region b/w the wires decreases as compared to other sides.
Two straight, parallel wires carrying current in opposite direction repel each other because net magnetic field in region b/w the wires increases as compared to other sides.

Diagram:-



Mathematically:-
Wire ② is in the B-field of wire ①. F_{21} is magnetic force on wire ② due to wire ①
Therefore,

$$F = I l B \sin\theta \qquad \because \theta = 90^\circ$$

$$F_{21} = I_2 l B_1 \sin 90^\circ = I_2 l B_1 (1) = I_2 l B_1$$

$$F_{21} = I_2 l B_1 \qquad \because B_1 = \frac{\mu_0 I_1}{2\pi r}$$

$$F_{21} = I_2 l \frac{\mu_0 I_1}{2\pi r}$$

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$$F_{21} = \frac{\mu_0 i_1 i_2 l}{2\pi r}$$

$$F_{21} = \frac{\mu_0 i_1 i_2 l}{2\pi r} \quad \ldots (A)$$

Wire (1) is in the magnetic field wire (2). F_{12} is the force on wire (1) due to wire (2).

Therefore, $F = IlB\sin\theta$

$$F_{12} = I_1 l B_2 \sin\theta \qquad \because B_2 = \frac{\mu_0 i_2}{2\pi r}$$

$$F_{12} = I_1 l B_2 \sin 90$$

$$F_{12} = I_1 l B_2$$

$$F_{12} = I_1 l \left(\frac{\mu_0 i_2}{2\pi r}\right)$$

$$F_{12} = \frac{\mu_0 i_1 i_2 l}{2\pi r} \quad \ldots (B)$$

From equations (A) and (B) along with dig.

$$\vec{F_{12}} = -\vec{F_{21}}$$

So, both forces form action-reaction obeying Newton's 3rd law of motion.

Magnetic flux (ϕ_B) :-

Definition:

Total number of magnetic field lines passing through an area held perpendicular to the magnetic field lines is called magnetic flux. It is the dot / scalar product of magnetic field and vector area.

Formula:-

By definition of magnetic flux.

$$\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta.$$

Where, "θ" is the angle b/w magnetic field and area vector $(\vec{A})$.

Unit:-

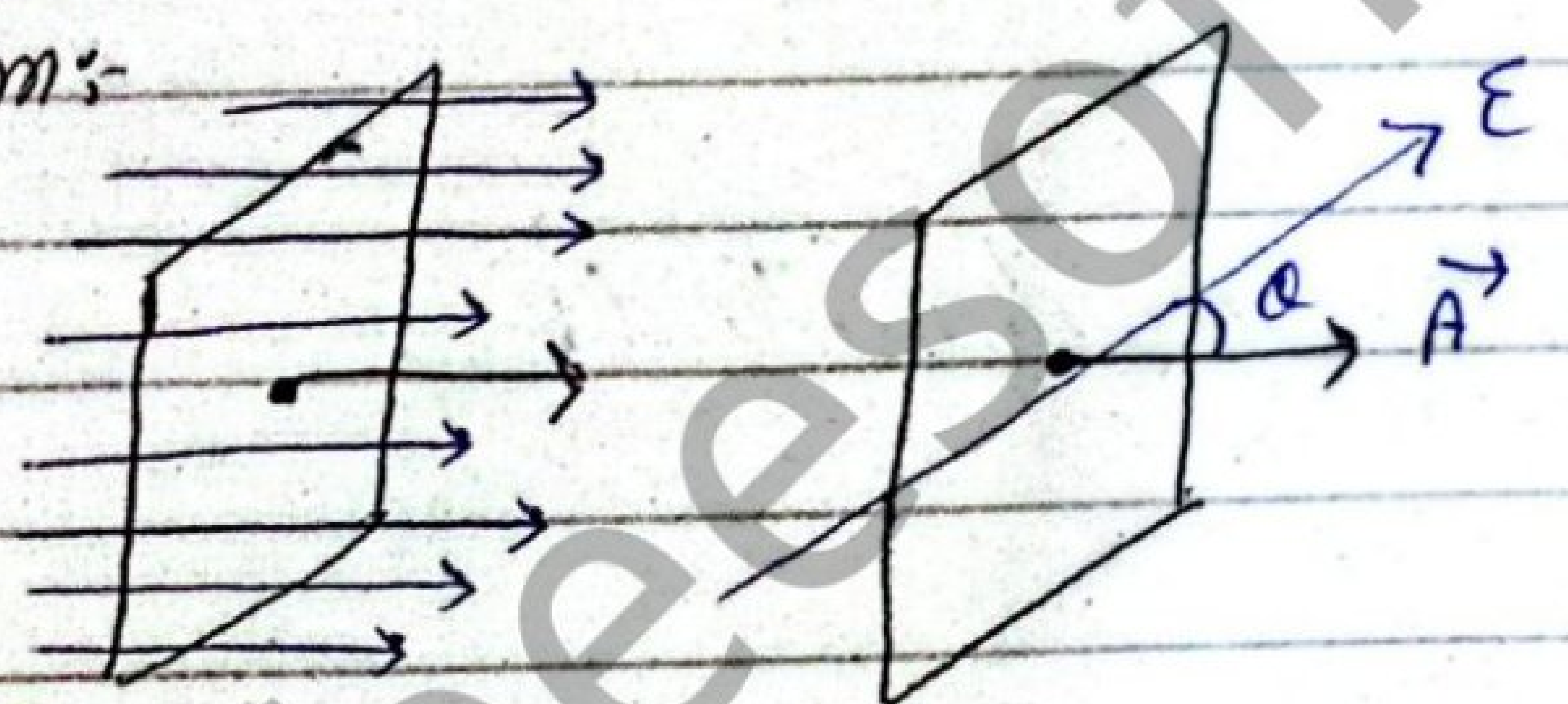
We know that.

$$\phi_B = BA\cos\theta$$

$$\phi_B = T\cdot m^2 = \frac{N}{A\cdot m}\cdot m^2 = \frac{N\cdot m}{A}$$

$$\phi_B = NmA^{-1} = Wb.$$

Diagram:-



Special Cases

Case #1, $\theta = 0°$

$$\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta = BA\cos 0$$

$$\phi_B = BA(1)$$

$$\phi_B = BA.$$

When vector $\vec{A}$ is parallel to external B-field, magnetic flux through area is maximum.

Case #2, $\theta = 90°$

$$\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta = BA\cos 90° = BA(0)$$

$$\phi_B = 0$$

When vector area $\vec{A}$ is perpendicular to external B-field, magnetic flux through area is zero i.e minimum.

Magnetic flux through curved area or due to non-uniform magnetic field.

To calculate the magnetic flux through a curved area or due to non-uniform external B-field, divide the curved area into infinite number of small plane areas and then calculate the flux through each small area and and finally sum them all.

Magnetic flux density ($\vec{B}$):-

Definition:-

The ratio of maximum magnetic flux passing through an area and that area is called magnetic flux / magnetic induction / magnetic field intensity.

Formula:-

Be definition of magnetic flux density.

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

Unit:-

we know that

$$B = \frac{\phi_B}{A} = \frac{Wb}{m^2} = T = \frac{N}{A \cdot m}$$

$$B = \frac{Wb}{m^2} = \frac{N}{A \cdot m} = T.$$

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What is electromagnetic induction?-

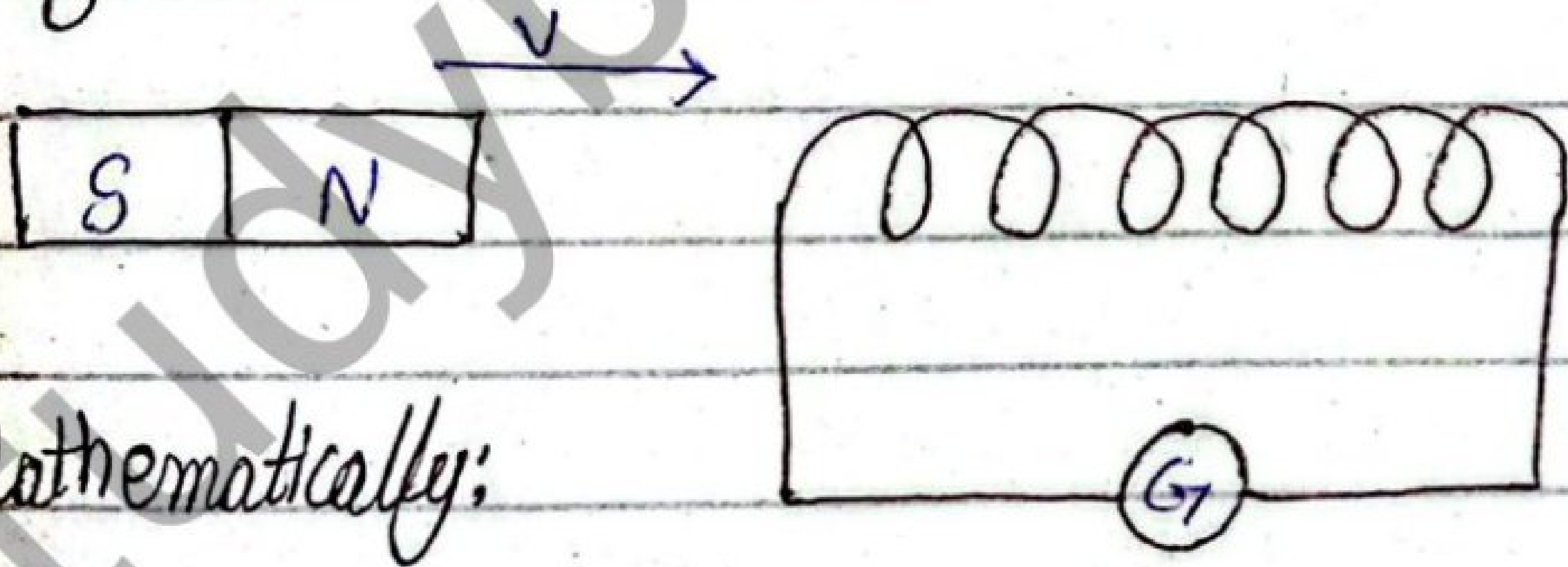
When magnetic flux linked with a coil is changed, an emf is produced inside the coil. This emf is called induced ~~current~~ emf. This physical phenomenon is called electromagnetic induction (EMI). [and corresponding current is called induced current.]

State and explain Faraday's law of electromagnetic induction.

Definition:-

Faraday's law states that the magnitude of induced emf in a coil is directly proportional to the rate of change of magnetic flux through the coil and total number of turn in the coil.

Diagram:-



Mathematically:

By definition of Faraday's law of EMI,

$\mathcal{E} \propto N$ ...(1)

$\mathcal{E} \propto \dfrac{\Delta \phi_B}{\Delta t}$ ...(2)

$$\mathcal{E} \propto N \frac{\Delta \phi_B}{\Delta t}$$

$$\mathcal{E} = \text{Constant } N \frac{\Delta \phi_B}{\Delta t} = KN \frac{\Delta \phi_B}{\Delta t}$$

$$\mathcal{E} = KN \frac{\Delta \phi_B}{\Delta t}$$

In S I units, K = 1

Therefore,

$$\mathcal{E} = -N \frac{\Delta \phi_B}{\Delta t}$$

Negative sign show that, direction of induced current is such that it opposes the change in magnetic flux.

Q. What are the factors affecting induced emf?

Ans. **Factors Affecting induced emf :-**

The induced emf is affected by the following factors :-

- The induced e.m.f is directly proportional to the number of turns in a coil. $\mathcal{E} \propto N$
- It depends on the speed of the movement of conductor through the magnetic field.
- It depends on the length of conductor inside the magnetic field.
- It depends on the rate of change of magnetic flux through the conductor. $\mathcal{E} \propto \frac{\Delta \phi}{\Delta t}$
- It can be increased by increasing the strength of external magnetic field.
- It can be increased by increasing the area of a coil.

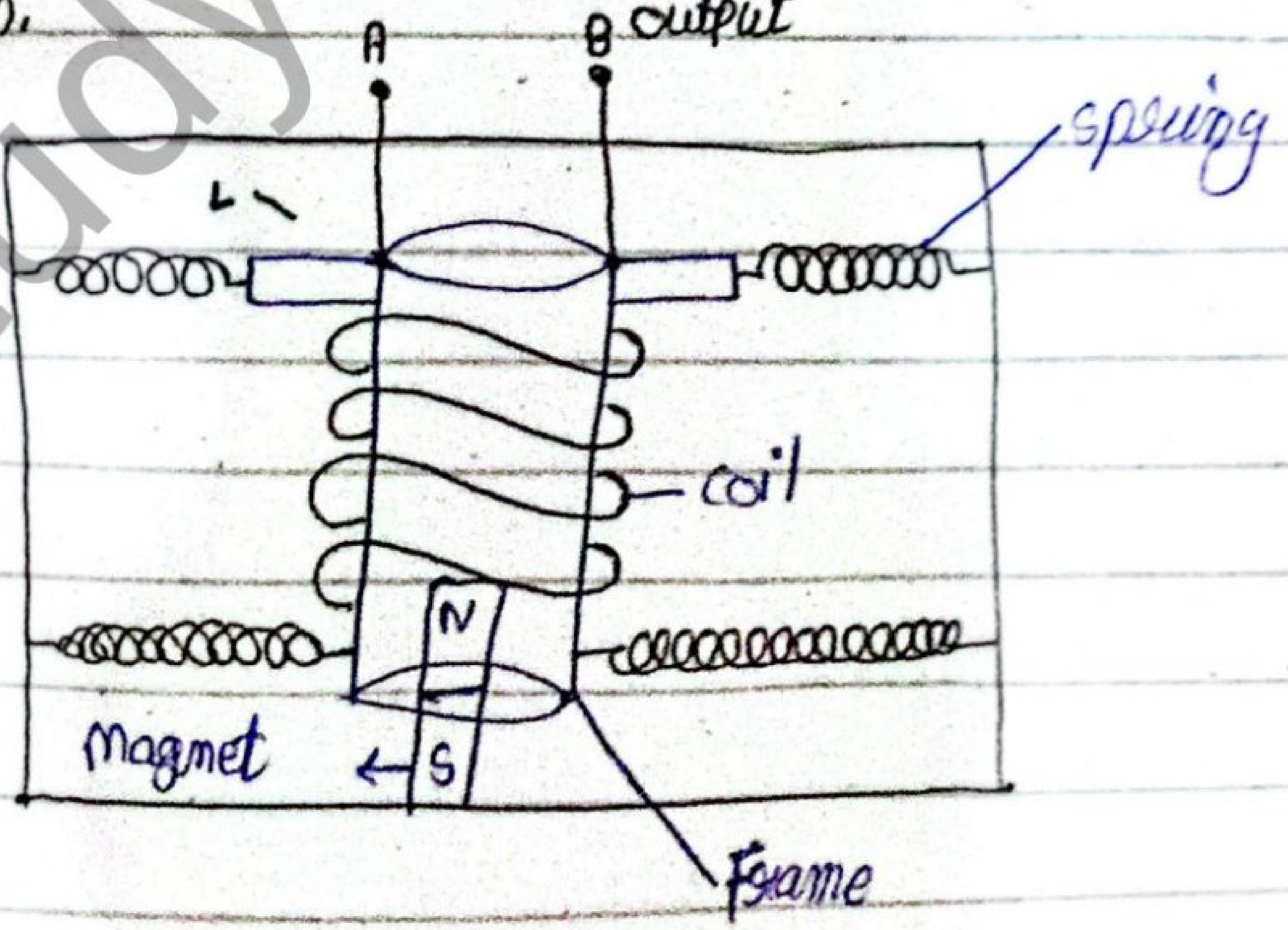
Sesimometer:-

Definition:-
A device which is used to detect seismic waves or detects vibrations of earth and converts into electrical signals is called sesimometer.

Principle:-
Seismometer works on the principle of electro-magnetic induction (Faraday's law). It converts vibrations of earth into electrical signals.

Constructions:-
It consist of a frame on which a coil is wound. The frame is attached to the box of sesimometer through springs. There is a bar magnet present inside the frame and coil that can move freely.

Diagram.



Working :-

When earth vibrates , Seismometer also vibrates. Due to springs , There is a relative motion ~~causes~~ b/w the magnet and coil . This relative motion causes a charge in magnetic flux through the coil and hence an induced emf in the coil and hence an induced emf in the coil is produced which is given to the external circuit to plot graph b/w induced emf and time .

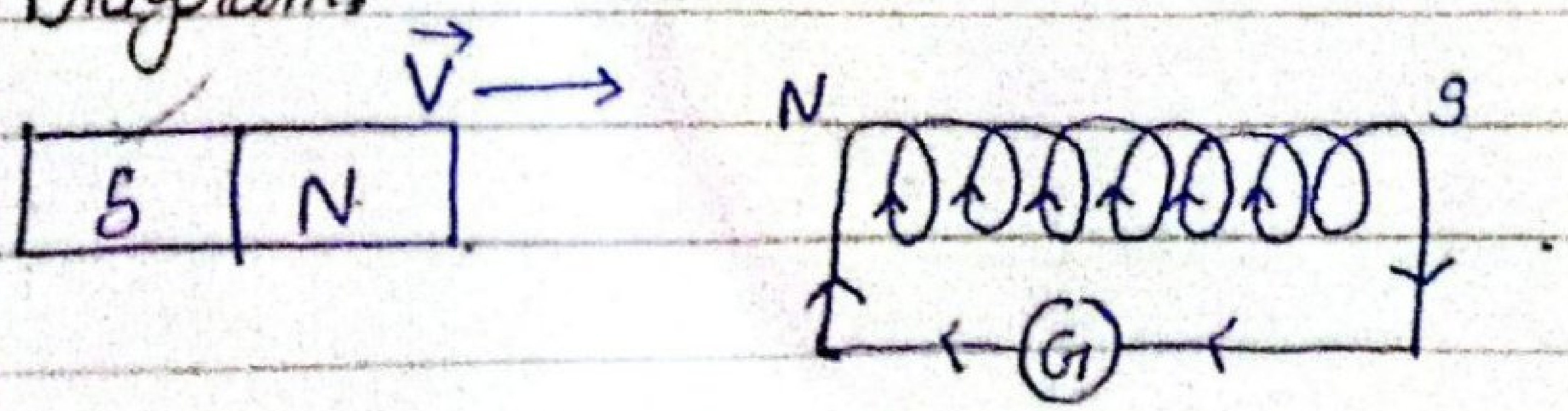
Graph :-

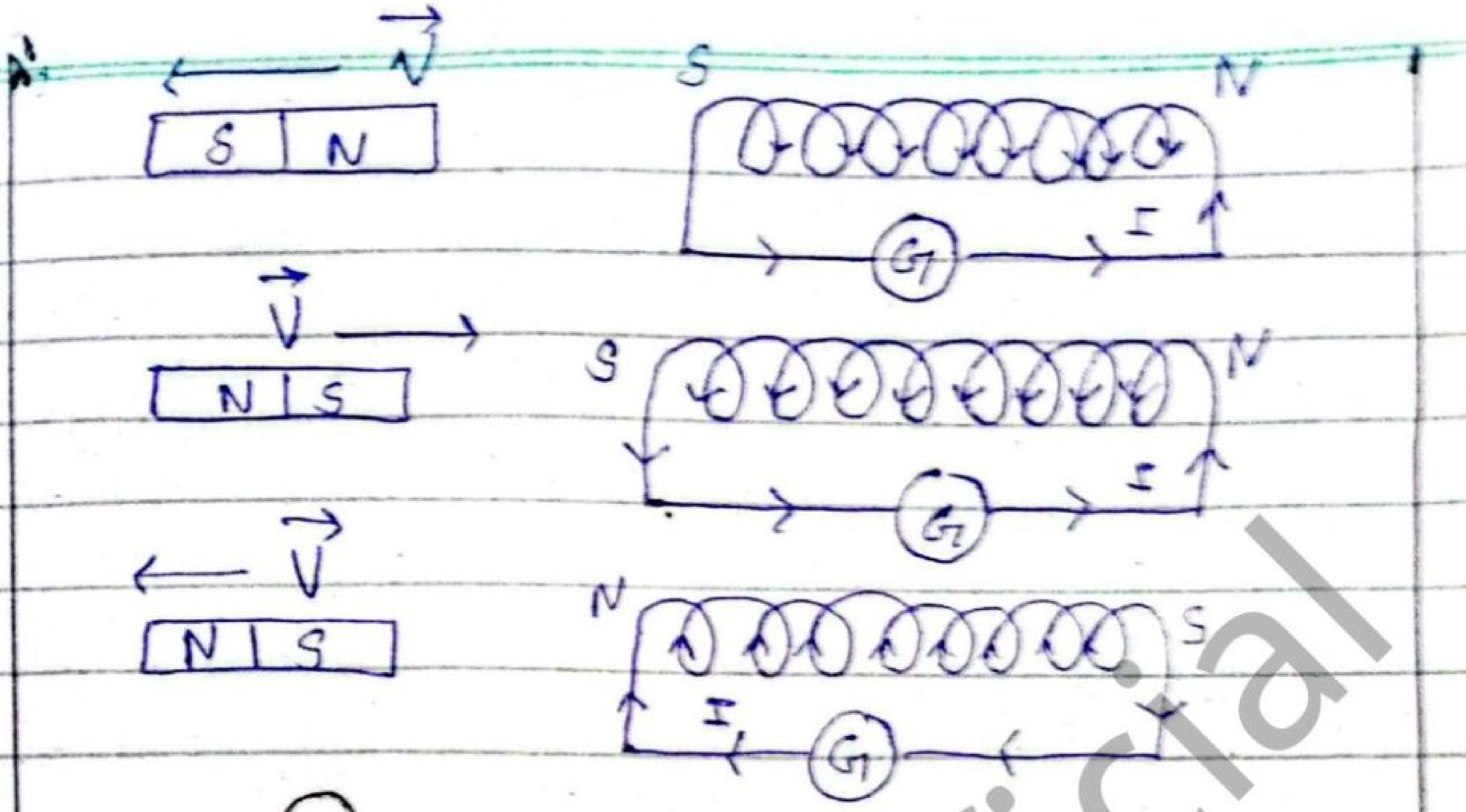
Lenz's law

Definition :-

This law deals with the direction of induced current. It states that, direction of induced current is always such that, it opposes the cause producing.

Diagram :-





Explanation:-

When current passes through the coil / Solenoid, it behaves like a bar magnet with one end as North pole as other end as south pole. The direction of induced is always such that, it opposes the cause producing the induced current as explained in diagrams.

Lenz's law of Conservation of Energy:-

Lenz's law is based on law of conservation of energy. when North pole of magnet approaches the coil, induced current in the coil is such that it repels the approaching North pole. To overcome repulsion and keep magnet moving, we have to do work on moving magnet and this work is being converted electrical signals.