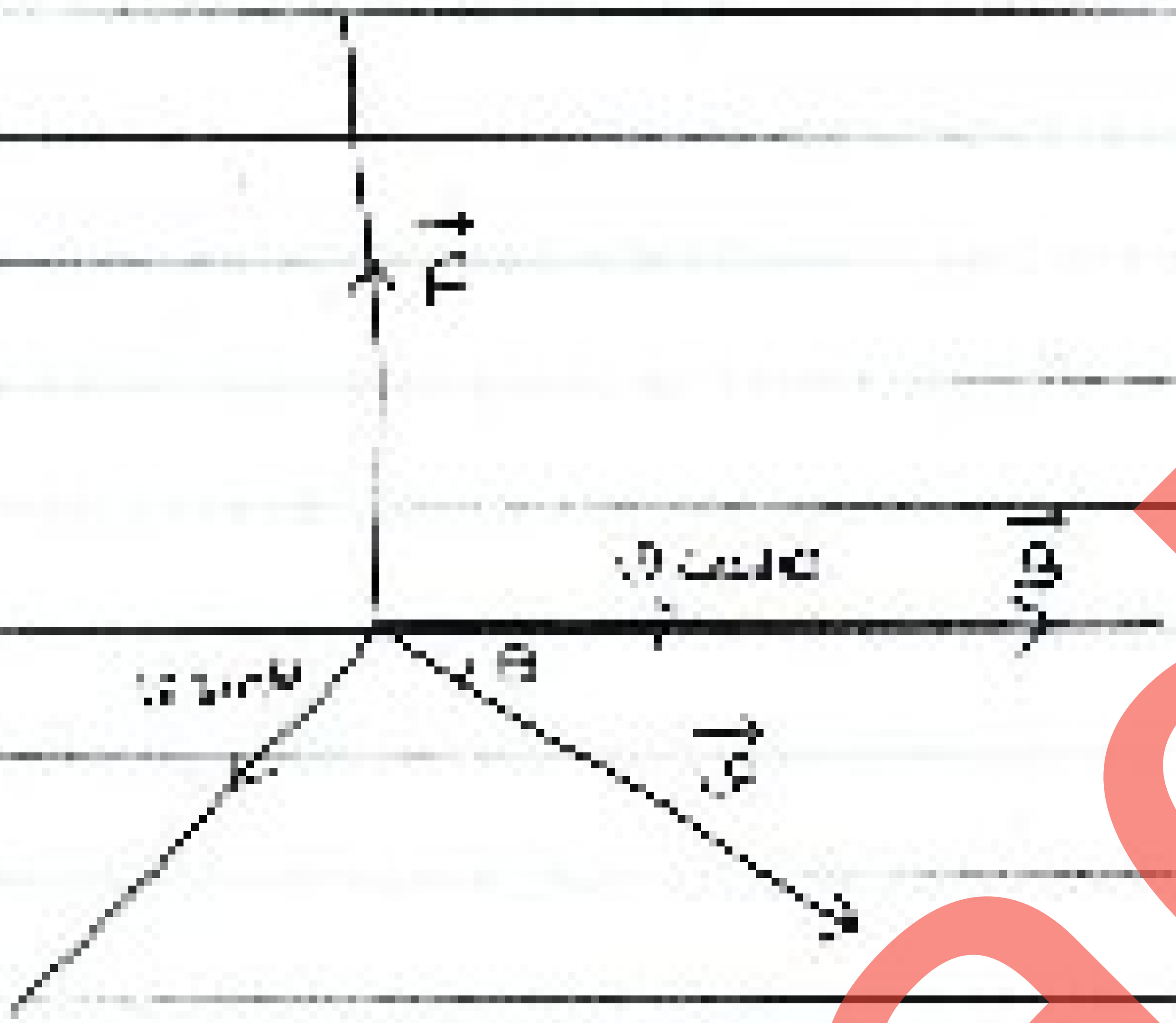
Magnetic Field Due to Current

Magnetic field ($\vec{B}$)

The space around a magnet in which its magnetic effect can be experienced.



Consider a positive charge q moving in a uniform magnetic field $\vec{B}$ with velocity $\vec{v}$.

Let the angle bet^n $\vec{v}$ & $\vec{B}$ be θ.

Due to interaction bet^n magnetic field produced due to moving charge & magnetic field applied, the charge q experiences a force $\vec{F}$ which depends upon:

$$\vec{F} \propto q$$

$$\vec{F} \propto v\sin\theta$$

{ $v\sin\theta$: Component of velocity perp^r to $\vec{B}$ }

$$\vec{F} \propto \vec{B}$$

So,

$$\vec{F} \propto q v B \sin\theta$$

$$\vec{F} = k q v B \sin\theta$$

$k = 1$

$$\vec{F} = q v B \sin\theta$$

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

* Direction of $\vec{F}$ is given by Right Hand Rule
For a +vely charged particle — upward
-vely — downward

If $v = 1\,ms^{-1}$, $q = 1C$ & $\theta = 90°$
$F = B$

So, magnetic field is equal to the force experienced by a unit charge moving with a unit velocity $\perp$ to the direction of magnetic field

Special Cases

1) If $\theta = 0°$ or $180°$, $F = 0$
2) $\theta = 90°$; $F = qvB$ (max)
3) $v = 0$, $F = 0$

Unit of $\vec{B}$

S.I. unit — Tesla (T) or Wb/m²

$$1T = \frac{1N}{1C \times 1ms^{-1}}$$

C.G.S unit — gauss (G) , $1G = 10^{-4}T$

Dimensions of B

$$B = \frac{F}{qv\sin\theta} = \frac{MLT^{-2}}{(LT^{-1})(AT)}$$

$$\boxed{B = [MA^{-1}T^{-2}]}$$

Biot-Savart's law

(It deals with the magnetic field at a point due to a small current element)

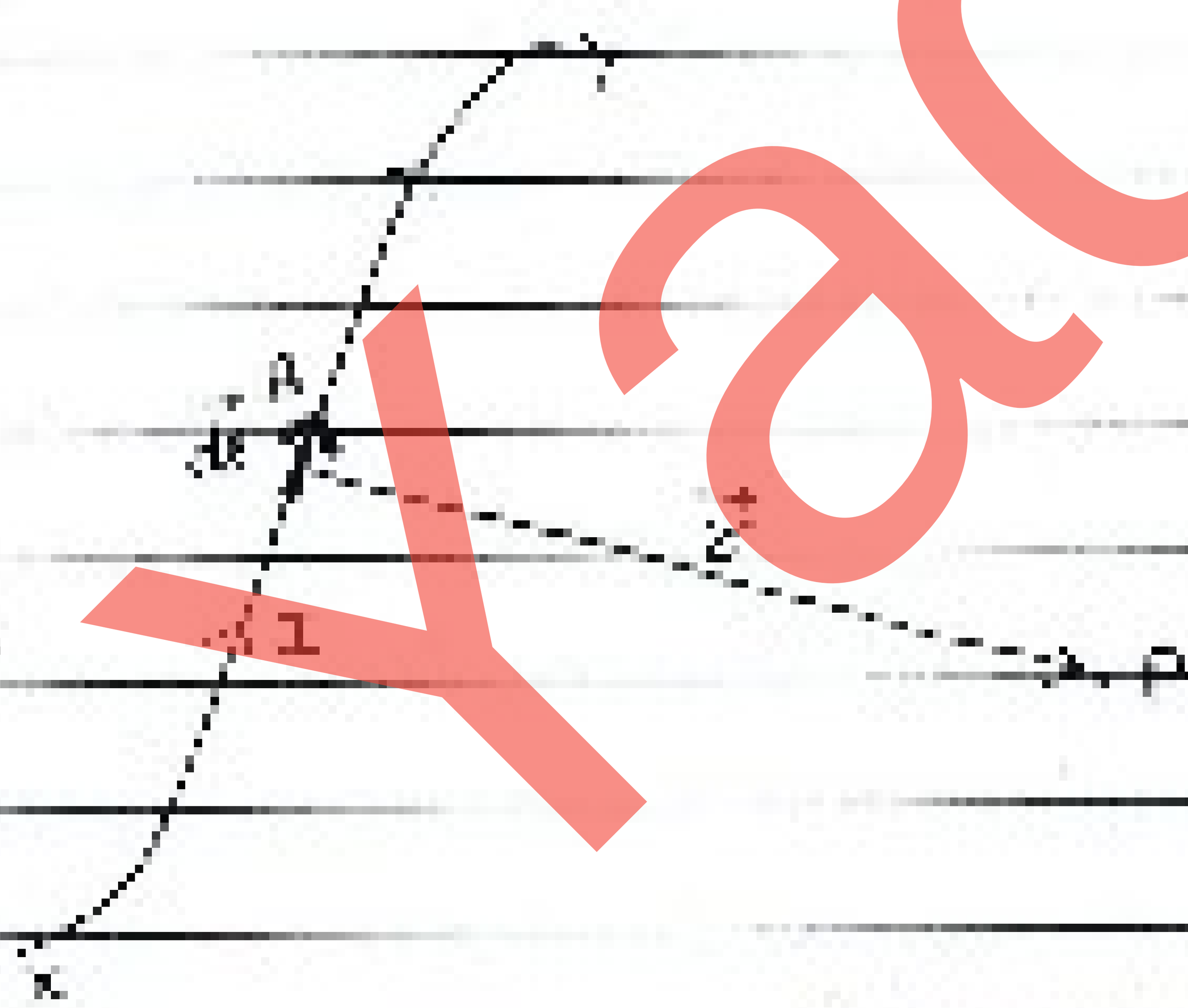
* Current element :- product of current & length of small segment of current carrying wire.

$= I\,\vec{dl}$

Consider a small element AB (length dl) of conductor XY carrying a current I.

Let $\vec{r}$ - position vector of pt. P from current element

θ - angle betn $\vec{dl}$ & $\vec{r}$



Acc. to Biot-Savart's law, the magnitude of magnetic field dB at pt. P due to current element depends upon

$$dB \propto I$$

$$dB \propto dl$$

$$dB \propto \sin\theta$$

$$dB \propto \frac{1}{r^2}$$

So, $$dB \propto \frac{I\,dl\sin\theta}{r^2}$$

$$dB = K \cdot \frac{I\, dl \sin\theta}{r^2}$$

In S.I. $K = \frac{\mu_0}{4\pi}$ $\rightarrow$ $dB = \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$

C.G.S. $K = 1$ $\rightarrow$ $dB = \frac{I\, dl \sin\theta}{r^2}$

* $\mu_0 = 4\pi \times 10^{-7}\ Wb\, A^{-1} m^{-1} = 4\pi \times 10^{-7}\ T\, A^{-1} m$
= magnetic permeability of free space

Direction of dB

$$dB = \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$$

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, (d\vec{l} \times \vec{r})}{r^3}$$

- Direction of $d\vec{B}$ would be the direction of cross product of $d\vec{l} \times \vec{r}$
- can be found by using Right hand screw rule
if P left of $I\, dl$ → $d\vec{B}$ ($\odot$) outward
right → inward ($\otimes$)

* Magnetic field at pt. P due to current through entire wire is

$$\vec{B} = \int \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$$

Some important features of Biot-Savart law

1. It is valid for a symmetrical current distribution
2. It is analogous to Coulomb's law in electrostatics
3. Direction of $d\vec{B}$ is $\perp$ to the pl. of $d\vec{l}$ & $\vec{r}$

4) If $\theta = 90^\circ$, $dB = \frac{\mu_0}{4\pi} \frac{I\,dl}{r^2}$ = max

$\theta = 0^\circ$ or 180°, $dB = 0$ = min

Similarities & Dis-similarities bet^n B-S law & Coulomb's law

Similarities

① Both the laws are for fields are long range as $E \propto \frac{1}{r^2}$ & $dB \propto \frac{1}{r^2}$

② Both the fields obey superposition principle.

③ dB is linear in the source $I\,d\vec{l}$
E " " " " " q
(electric field also)

Dis-similarities

① Electrostatic field produced by scalar source q
Magnetic " " " vector $I\,d\vec{l}$

② Electrostatic field acts along displacement vector $\vec{r}$
Magnetic " $\perp r$ to $I\,d\vec{l}$ & $\vec{r}$

③ Coulomb's law independent of θ
B-S law depends on θ

Magnetic field due to a straight wire

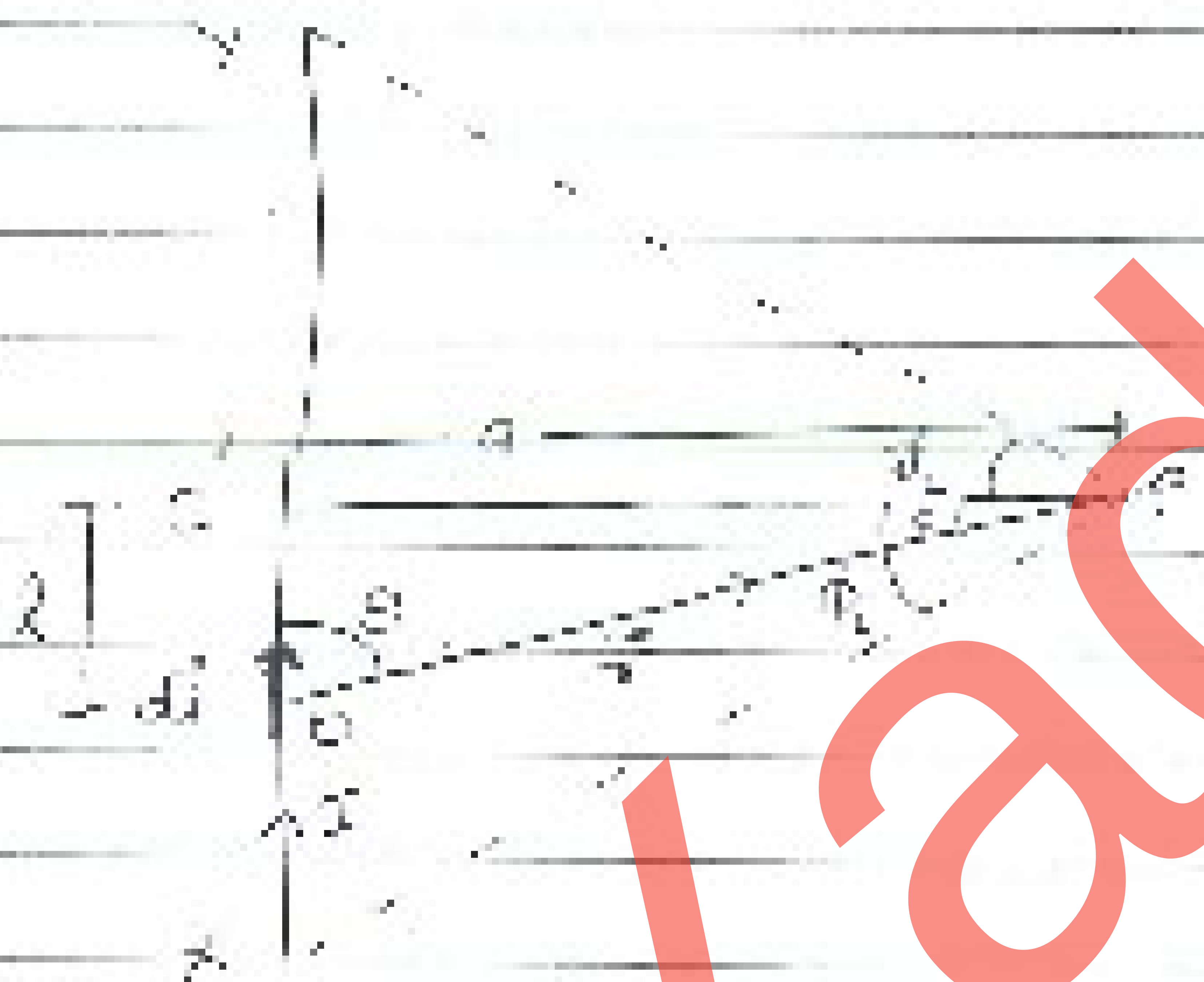
Consider a straight wire XY carrying current I.
Let P = pt. at a $\perp$ distance 'a' from wire.
PC = a.

Let the conductor be made of small current elements & consider a small current element $I\vec{dl}$ at O.

Let $\vec{r}$ = position vector of P w.r.t. $I\vec{dl}$

θ = angle bet^n $I\vec{dl}$ & $\vec{r}$

$CO = l$



Acc to Biot-Savart's law, the magnetic field $d\vec{B}$ at pt P due to $I\vec{dl}$ is

$$dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2} \quad \text{---} (1)$$

In $\triangle PCO$

$\phi + \theta = 90^\circ \Rightarrow \theta = 90^\circ - \phi$

$\sin\theta = \sin(90 - \phi) = \cos\phi$

Also, $\cos\phi = \frac{a}{r}$, $r = \frac{a}{\cos\phi}$

$\tan\phi = \frac{l}{a}$, $l = a\tan\phi \Rightarrow dl = a\sec^2\phi\, d\phi$

put the values of r, dl & $\sin\theta$ in (1)

$$dB = \frac{\mu_0}{4\pi} \frac{I\,(a\sec^2\phi\, d\phi)\cos\phi}{\frac{a^2}{\cos^2\phi}}$$

$$= \frac{\mu_0}{4\pi} \frac{I}{a} \cos\phi\, d\phi$$

The total magnetic field at P (as all current element will produce in same direction) is

$$B = \int_{-\phi_1}^{\phi_2} \frac{\mu_0}{4\pi} \frac{I}{a} \cos\phi\, d\phi$$

$$= \frac{\mu_0}{4\pi} \frac{I}{a} [\sin\phi]_{-\phi_1}^{\phi_2}$$

$$= \frac{\mu_0}{4\pi} \frac{I}{a} [\sin\phi_2 - \sin(-\phi_1)]$$

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{I}{a} (\sin\phi_1 - \sin\phi_2)}$$

Special cases

(a) When XY is of infinite length & P lies near the centre

$$\phi_1 = \phi_2 = 90^\circ$$

$$\boxed{B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{a}}$$

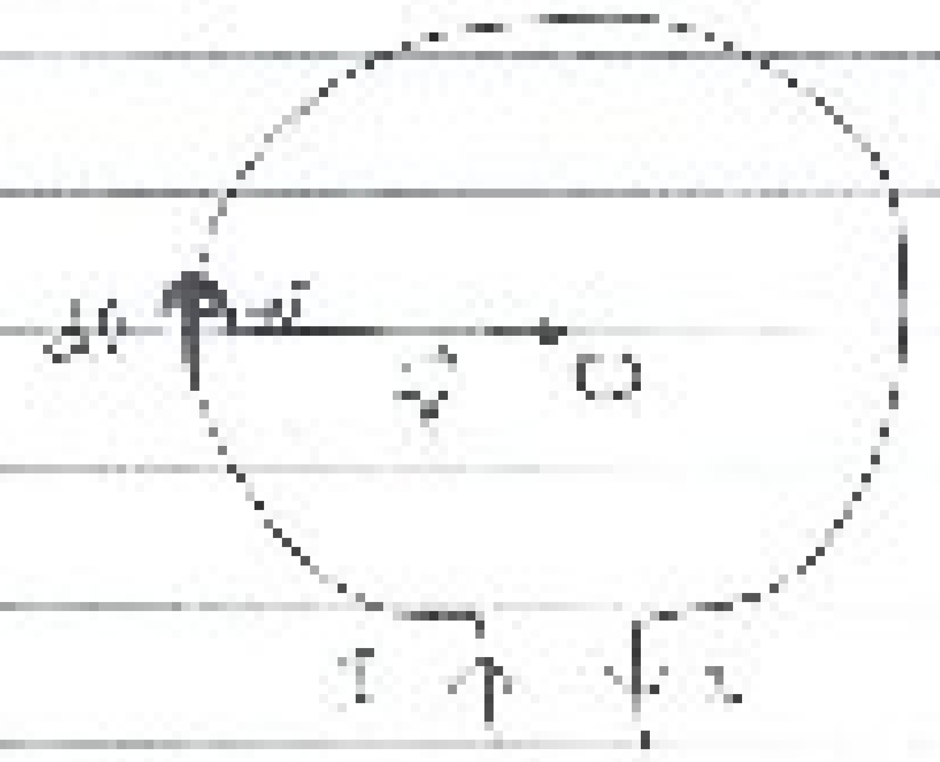
(b) XY of infinite length but P lies near X or Y

$$\phi_1 = 90^\circ$$

$$\phi_2 = 0$$

$$B = \frac{\mu_0}{4\pi} \frac{I}{a}$$

Magnetic field at the centre of a circular coil carrying current



Magnetic field at the centre of circular coil due to current element $I\vec{dl}$ is

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$$

$$= \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}\sin 90^\circ$$

$$= \frac{\mu_0}{4\pi}\frac{I}{r^2}\,dl$$

Total magnetic field at O is

$$B = \frac{\mu_0}{4\pi}\frac{I}{r^2}\int dl$$

$$= \frac{\mu_0}{4\pi}\frac{I}{r^2}\times 2\pi r$$

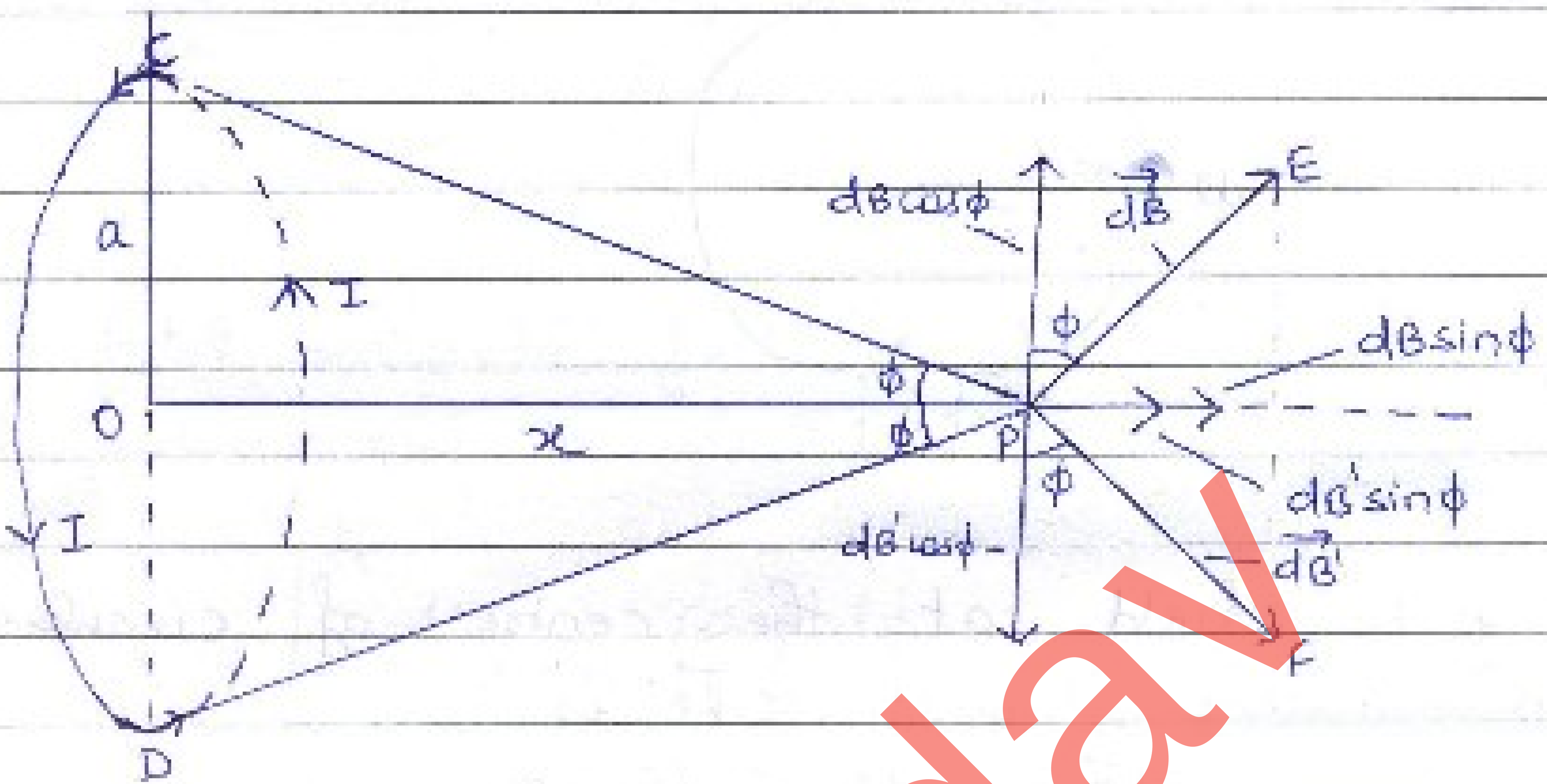
$$B = \frac{\mu_0 I}{2r}$$

If the coil has n turns

$$\boxed{B = \frac{\mu_0 n I}{2r}}$$

- Direction of $\vec{B}$ at O is $\perp$ to the plane of paper & directed outwards.

Magnetic field at a pt on the axis of a circular coil carrying current



Consider a circular coil of radius 'a' with centre O. Let P is any point on the axis of the circular coil at a distance 'x' from O.

$$OP = x$$

Consider 2 small current elements of length $\vec{dl}$ at C & D

$$PC = PD = r = \sqrt{a^2+x^2}$$

Acc. to Biot-Savart's law, dB at P due to $I\vec{dl}$ at C is

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin 90^\circ}{r^2}$$

$$= \frac{\mu_0}{4\pi} \frac{I\,dl}{(a^2+x^2)} \quad (1)$$

direction of $d\vec{B}$ → acting along PE ⊥ CP [think 3D (out of page)]

Similarly, dB at P due to $I\vec{dl}$ at D is

$$dB' = \frac{\mu_0}{4\pi} \cdot \frac{I\,dl}{(a^2+x^2)} \quad (2)$$

direction of $d\vec{B'}$ → acting along PF ⊥ DP [think 3D (out of page)]

From ① & ②

$$dB = dB_r = \frac{\mu_0}{4\pi} \frac{I\, dl}{(a^2+x^2)}$$

Resolving $\vec{dB}$ → $dB\cos\phi$ (along PY) & $dB\sin\phi$ (along PX)
$\vec{dB}'$ → $dB'\cos\phi$ (along PY') & $dB'\sin\phi$ (along PX)

Total magnetic field at P due to current through whole circular coil is

$$B = \int dB\sin\phi$$

$$= \int \frac{\mu_0}{4\pi} \frac{I\, dl\sin\phi}{(a^2+x^2)}$$

$$= \frac{\mu_0}{4\pi} \frac{I\sin\phi}{(a^2+x^2)} \int dl$$

$$= \frac{\mu_0}{4\pi} \frac{I}{(a^2+x^2)} \times \frac{a}{(a^2+x^2)^{1/2}} \times 2\pi a$$

$$B = \frac{\mu_0 I}{4\pi (a^2+x^2)^{3/2}}\, 2\pi a^2$$

If the coil has n turns

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{2\pi n I a^2}{(a^2+x^2)^{3/2}}}$$ along PX

Special cases

(i) If P lies at the centre of coil, $x = 0$

$$B = \frac{\mu_0}{4\pi} \frac{2\pi n I}{a}$$

(ii) If P lies far away from centre of coil

$x >> a$

$a^2 + x^2 \approx x^2$

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi n I a^2}{x^3}$$

$$= \frac{\mu_0}{4\pi} \cdot \frac{2 n I A}{x^3} \qquad [\because A = \pi a^2]$$

$$\boxed{B = \frac{\mu_0}{4\pi} \cdot \frac{2M}{x^3}}$$

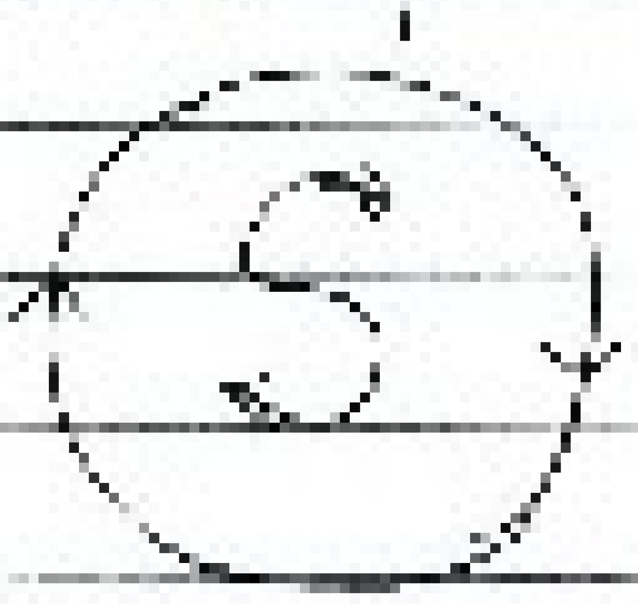
where $M = nIA$ → magnetic dipole moment of current loop

Thus the current loop can be regarded as a magnetic dipole which produces its magnetic field & magnetic dipole moment of the current loop is equal to product of ampere turns (nI) & area of current loop (A)

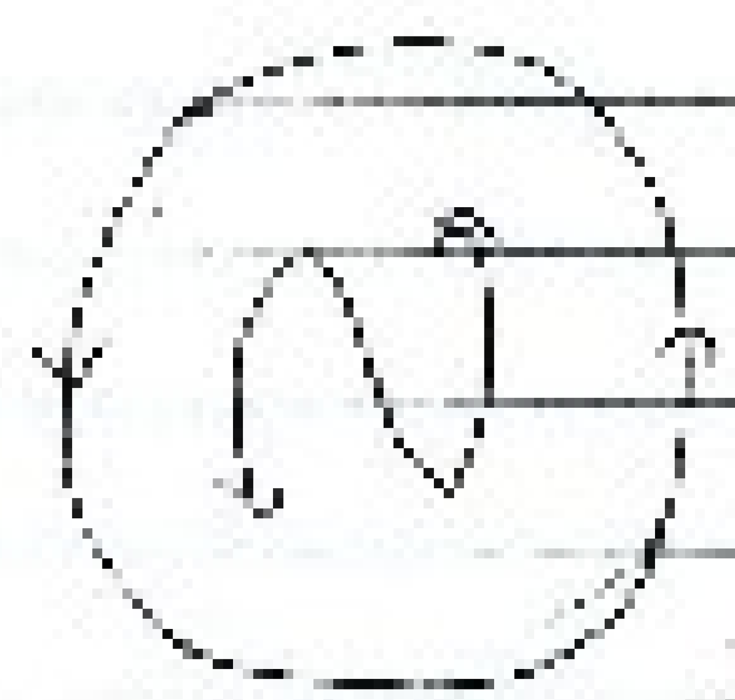
* S.I. unit of m.d. moment → $A \cdot m^2$

* Polarity of magnetic dipole due to circular loop

→ Look at one face of coil. If the direction of current through the coil is clockwise then the face has South polarity.



→ anti-clockwise North



Magnetic Dipole

A magnetic dipole consists of 2 unlike poles of equal strength separated by a small distance.

Magnetic dipole moment ($\vec{M}$)

→ product of strength of either pole & magnetic length

$(\vec{M} = m(2\vec{l}))$

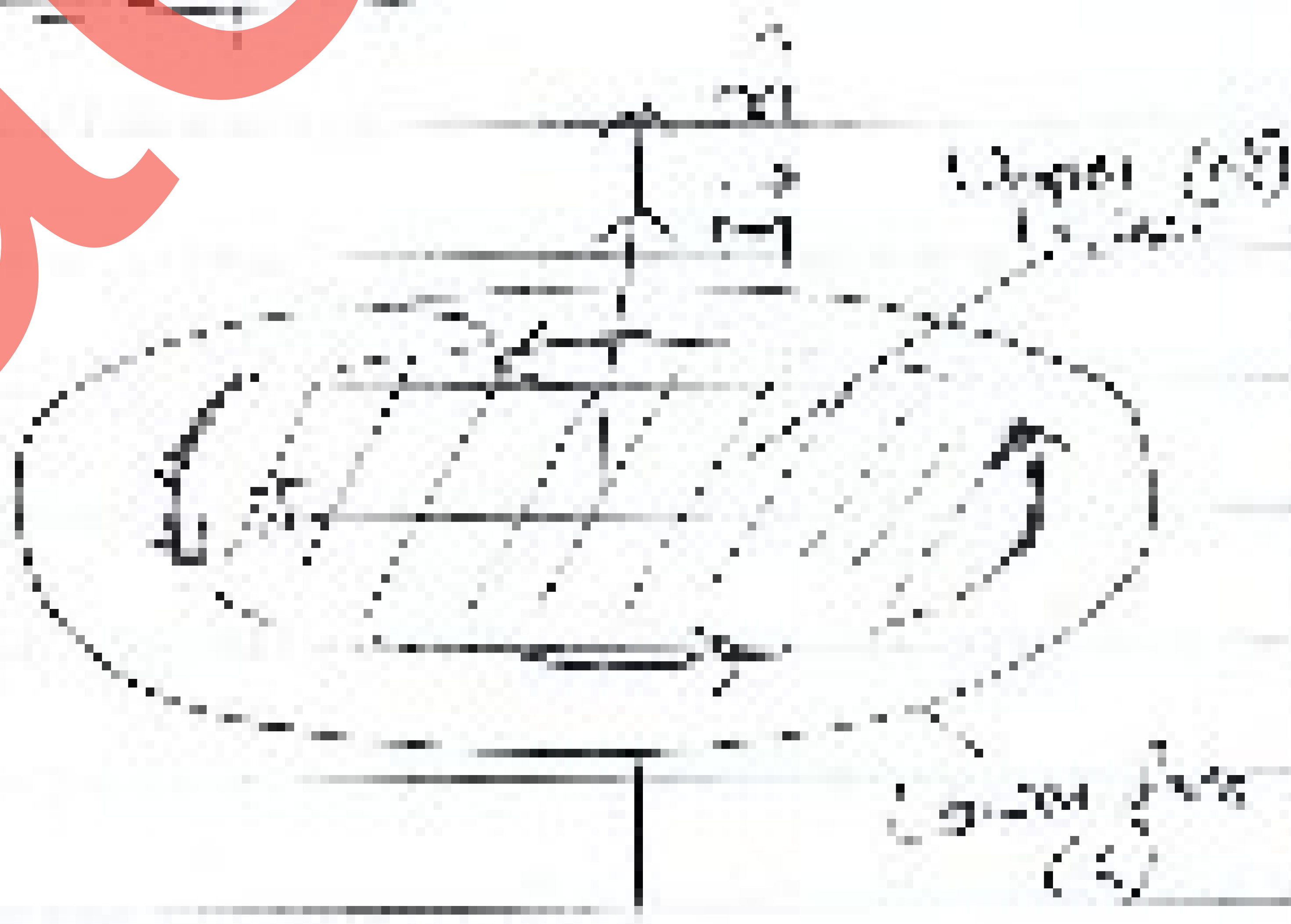
→ Vector quantity directed from south to north pole of the magnet.

→ S.I. unit → Am^2

∗ Unit of m → Am

Current Loop as a magnetic dipole

A current carrying loop behaves as a system of 2 equal & opp. magnetic poles (upper north (if current anticlockwise) & lower south (if current clockwise))



The magnetic dipole moment M of the current loop is

(i) directly proportional to I

(ii) A (area enclosed by loop)

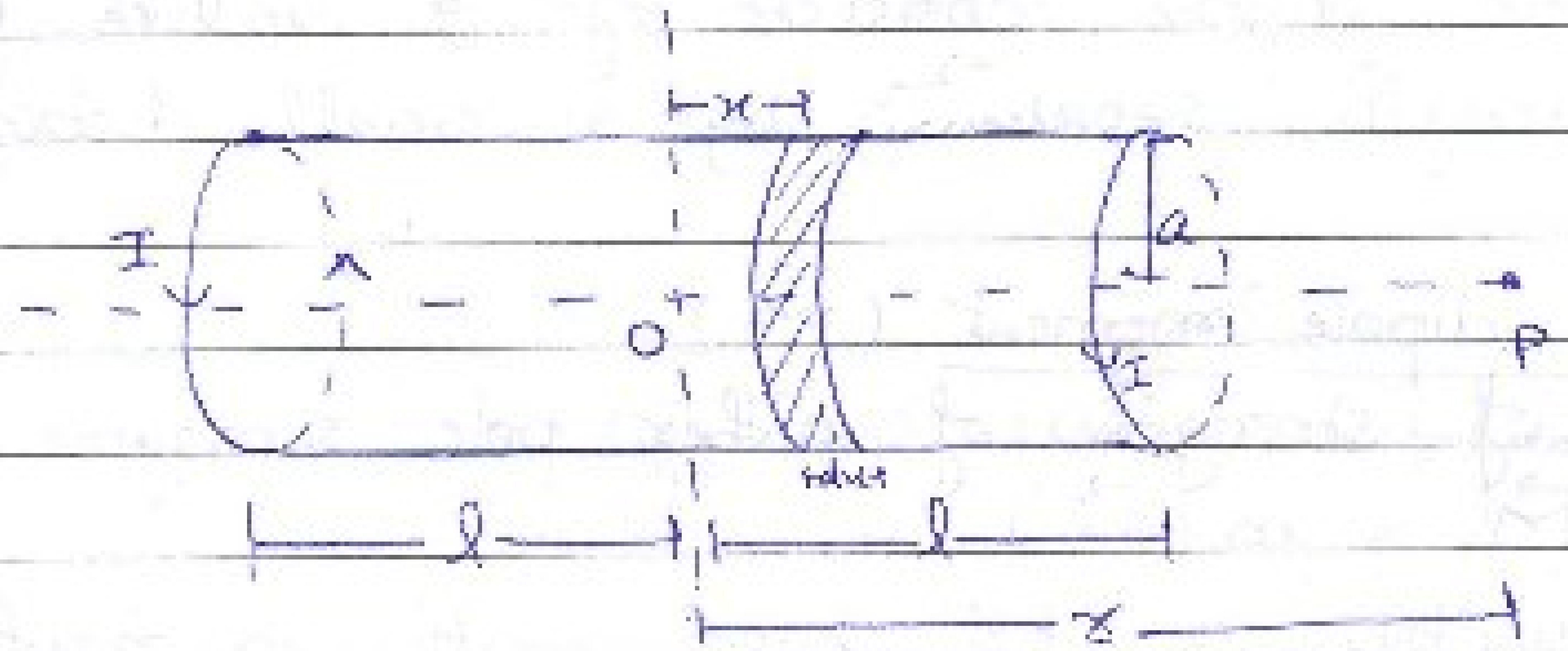
$$M \propto IA$$

$$M = KIA$$

$K = 1$ $$\boxed{M = IA}$$

for N turns $$\boxed{M = NIA}$$ unit → Am^2

Bar magnet as an equivalent solenoid



Let a - radius of solenoid

$2l$ - length " " with centre O.

n - no of turns per unit length

I - current passing through the solenoid

Consider a small element of thickness dx of the solenoid, at a distance 'x' from O.

No. of turns in the element $= n\,dx$

The magnitude of magnetic field at P due to the current element is

$$dB = \frac{\mu_0 I a^2 (n\,dx)}{2[(r-x)^2+a^2]^{3/2}}$$

If P lies at a very large distance from O

$r >> a$ & $r >> x$

so, $[(r-x)^2+a^2]^{3/2} \simeq r^3$

$$dB = \frac{\mu_0 I a^2 n\,dx}{2r^3}$$

$$B = \frac{\mu_0 n I a^2}{2r^3}\int_{-l}^{l} dx$$

$$B = \frac{\mu_0 n I a^2}{2r^3} [x]^{l}_{-l}$$

$$= \frac{\mu_0 n I a^2 (2l)}{2r^3}$$

$$= \frac{\mu_0}{4\pi} \frac{2n(2l) I \pi a^2}{r^3}$$

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{2m}{r^3}}$$

where m = total no. of turns × current × area of cross-section (magnetic moment of solenoid) = $n(2l) \times I \times \pi a^2$

This is the expression for magnetic field on the axial line of a bar magnet.
Thus the axial field of a finite solenoid carrying current is same as that of a bar magnet.

* Derivation of potential energy of a magnetic dipole is same as that for electric dipole

$$U = -\vec{m} \cdot \vec{B}$$

Gauss Law in magnetism

Acc. to this law the net magnetic flux (ϕ_B) through any closed surface is always zero

$$\phi_B = \oint \vec{B} \cdot \vec{ds} = 0$$

It implies that the no. of magnetic field lines leaving any closed surface is always equal to the number of magnetic field lines entering it.
The fact that $\phi_B = 0$ indicates that the simplest magnetic element is a dipole & magnetic monopoles do not exist.

Conclusion of Gauss law.

(i) Isolated magnetic poles called monopoles do not exist.

or

In magnetism, there is no counterpart of isolated free charge in electricity.

or

Magnetic poles always exist in unlike pairs of equal strength.

* Read example 5.5 & 5.7 (p-184) from NCERT

Magnetic Field of Earth.

→ Sir William Gilbert was the first to suggest that the earth itself is a huge magnet.

→ The statement was based on the following evidence:

(a) A magnet suspended from a thread & free to rotate in a horizontal plane comes to rest along the N-S direction.

(b) When a soft iron piece is buried under the earth's surface in N-S direction, it is found to acquire the properties of a magnet after some time.

(c) When we draw magnetic field lines, we come across neutral points (points at which magnetic field due to the magnet is cancelled exactly by the magnetic field of earth). If earth has no magnetism of its own, we would never observe neutral points.

Cause of earth's magnetism (exactly not known)

(i) Earth's magnetism may be due to rotation of earth about it's axis

→ Every substance is made up of charged particles.

→ So, a substance rotating about an axis is equivalent to circulating currents, which is responsible for magnetisation.

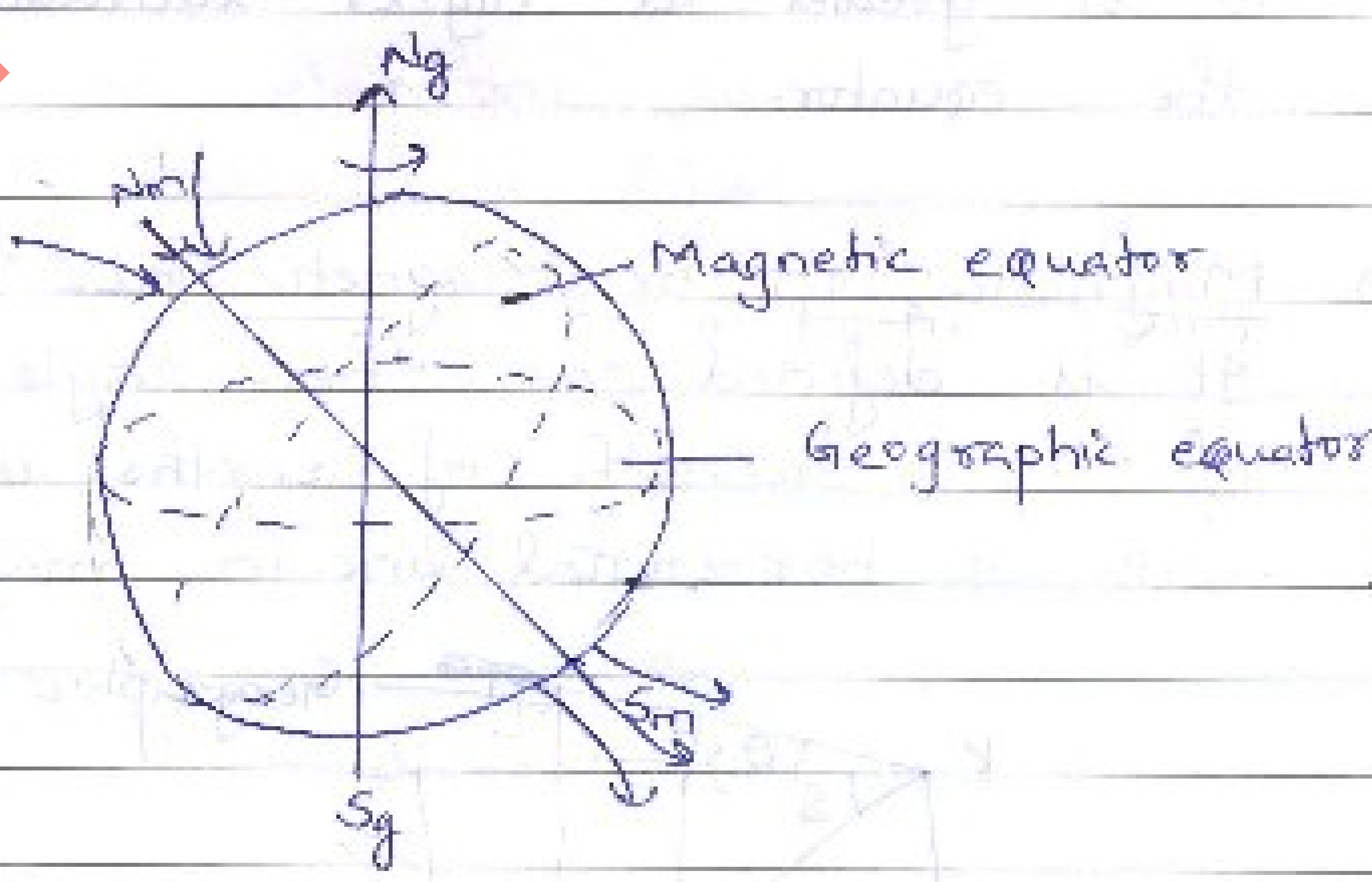
(b) In the outer layers of earth's atmosphere, gases are in the ionised state (because of cosmic rays)

→ As earth rotates, strong electric currents are set up due to movement of ions

→ These currents might be magnetising the earth.

(c) • Earth's core is extremely hot & molten

• Circulating ions of iron & nickel in the core might be forming current loops & producing earth's magnetic field.

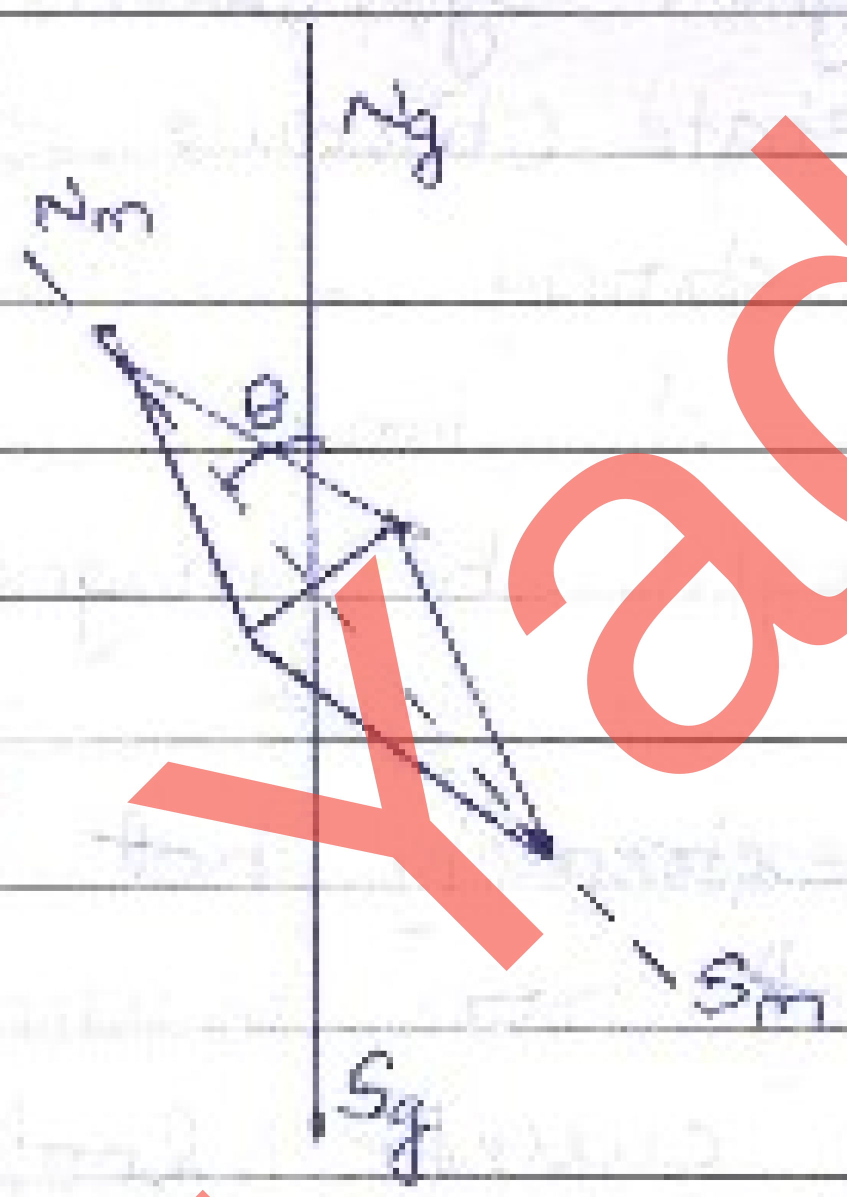


Magnetic elements

Magnetic elements of earth at a place are the quantities which describe completely in magnitude and direction the magnetic field of earth at that place.

(a) Magnetic declination (θ)

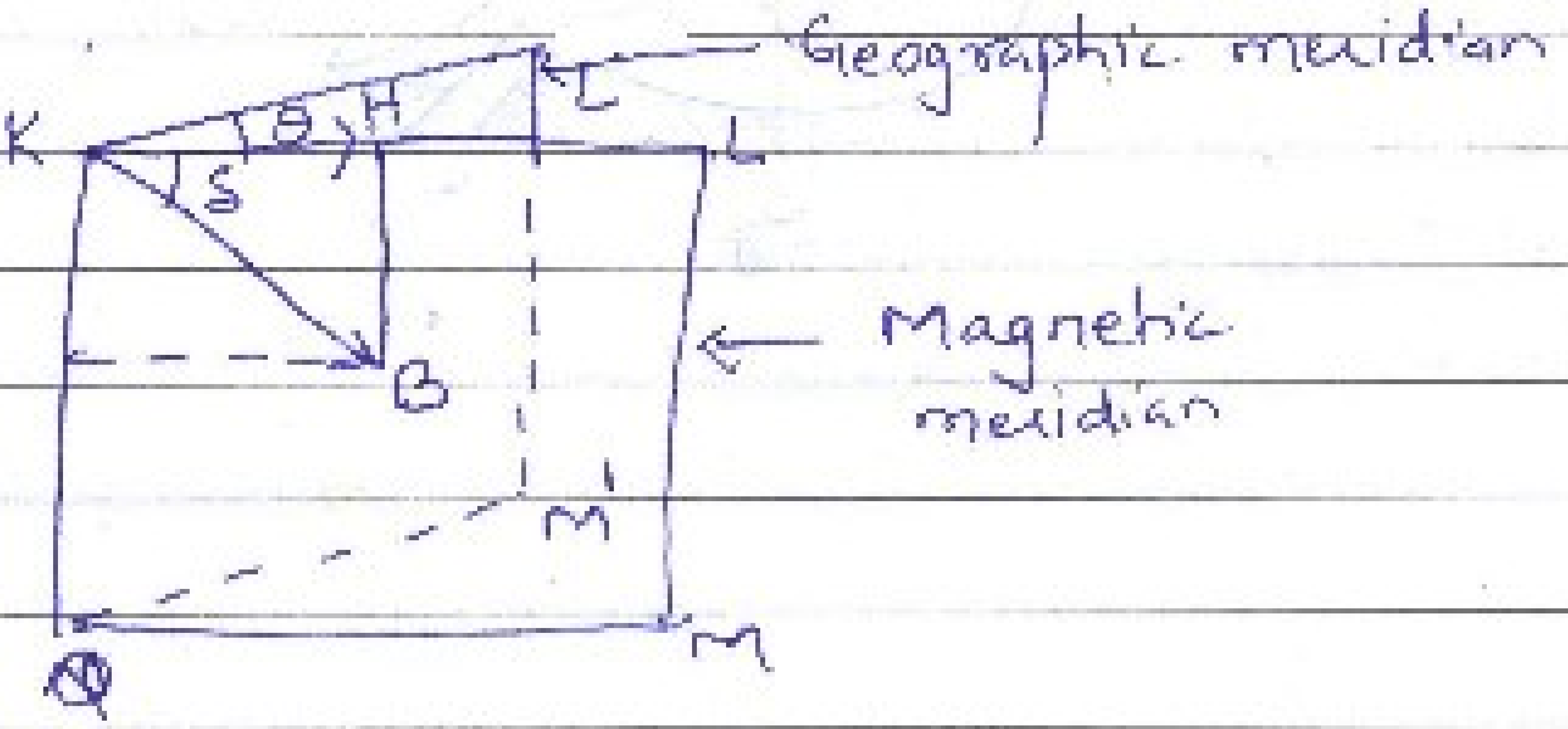
The small angle betⁿ magnetic axis and geographic axis at a place is defined as the magnetic declination at that place.



θ is greater at higher latitudes & smaller near the equator.

(b) Magnetic Dip or Magnetic ~~Dec~~ Inclination (δ)

It is defined as the angle which the direction of total strength of earth's magnetic field makes with a horizontal line in magnetic meridian.



* Magnetic meridian - Vertical plane passing through N-S line of a freely suspended magnet.
Geographic " - Vertical plane passing through the geographic N-S direction.

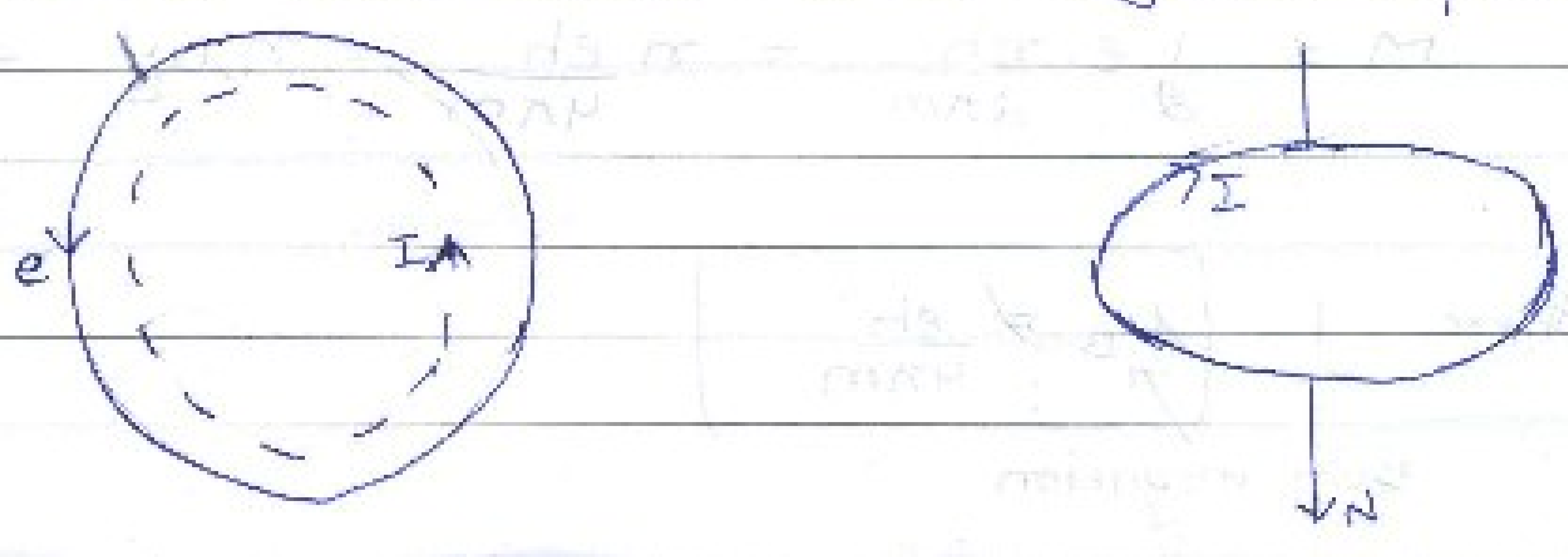
(c) Horizontal component (H)
It is the component of total intensity of earth's magnetic field in the horizontal direction in magnetic meridian.

* $$\tan \delta = \frac{V}{H}$$

δ - magnetic dip
V - vertical component of total intensity of earth's m.f.
H - horizontal " " " "

Magnetic dipole moment of an atom due to revolving electron

- In every atom electrons revolve around nucleus.
- A revolving electron is like a loop of current, which has a definite magnetic dipole moment.
- When electron revolves in anti-clockwise direction, the equivalent current is clockwise.
- So, the upper face of electron loop acts as south pole & lower face as north pole.
- Hence an atom behaves as a magnetic dipole.



If 'e' is the charge on an electron revolving in an orbit of radius 'r' then the equivalent current is

$$I = \frac{e}{T} = \frac{e}{2\pi/\omega} = \frac{e\omega}{2\pi}$$

The area of the orbit is $A = \pi r^2$

So, the magnetic moment of the atom is

$$M = IA$$
$$= \frac{e\omega}{2\pi} \pi r^2$$
$$= \frac{1}{2} e\omega r^2$$

According to Bohr's theory, an electron in an atom can revolve only in certain stationary orbits in which angular momentum of electron is an integral multiple of $\frac{h}{2\pi}$

i.e. $mvr = \frac{nh}{2\pi}$

$$m(r\omega)r = \frac{nh}{2\pi}$$

$$\omega r^2 = \frac{nh}{2\pi m}$$

$$M = \frac{1}{2} e \cdot \frac{nh}{2\pi m} = \frac{neh}{4\pi m} = n\mu_B \quad \text{--- (1)}$$

where $\boxed{\mu_B = \frac{eh}{4\pi m}}$

Bohr magneton

It is clear from ① that Magnetic moment of an atom (M) is quantised having values $1\mu_B, 2\mu_B$ - so on where μ_B is the least value of magnetic dipole moment.

$$\mu_B = \frac{eh}{4\pi m}$$

$$= \frac{1.6\times10^{-19} \times 6.6\times10^{-34}}{4\times3.14\times9\times10^{-31}}$$

$$= 9.27\times10^{-24}\ Am^2$$

So, Bohr magneton is the minimum magnetic dipole moment associated with an atom due to orbital motion of an electron in the 1^{st} stationary orbit of atom.

* Gyromagnetic ratio of electron $= \frac{M}{L}$

$$= \frac{eh/4\pi m}{h/2\pi} \quad \left[\because L = mvr = \frac{nh}{2\pi}\right]$$

$$= \frac{e}{2m}$$

$$= 8.8\times10^{10}\ C\,kg^{-1}$$

Ampere's Circuital law

The line integral of magnetic field ($\vec{B}$) around a closed path in vacuum is equal to μ_0 times the total current I threading the closed path

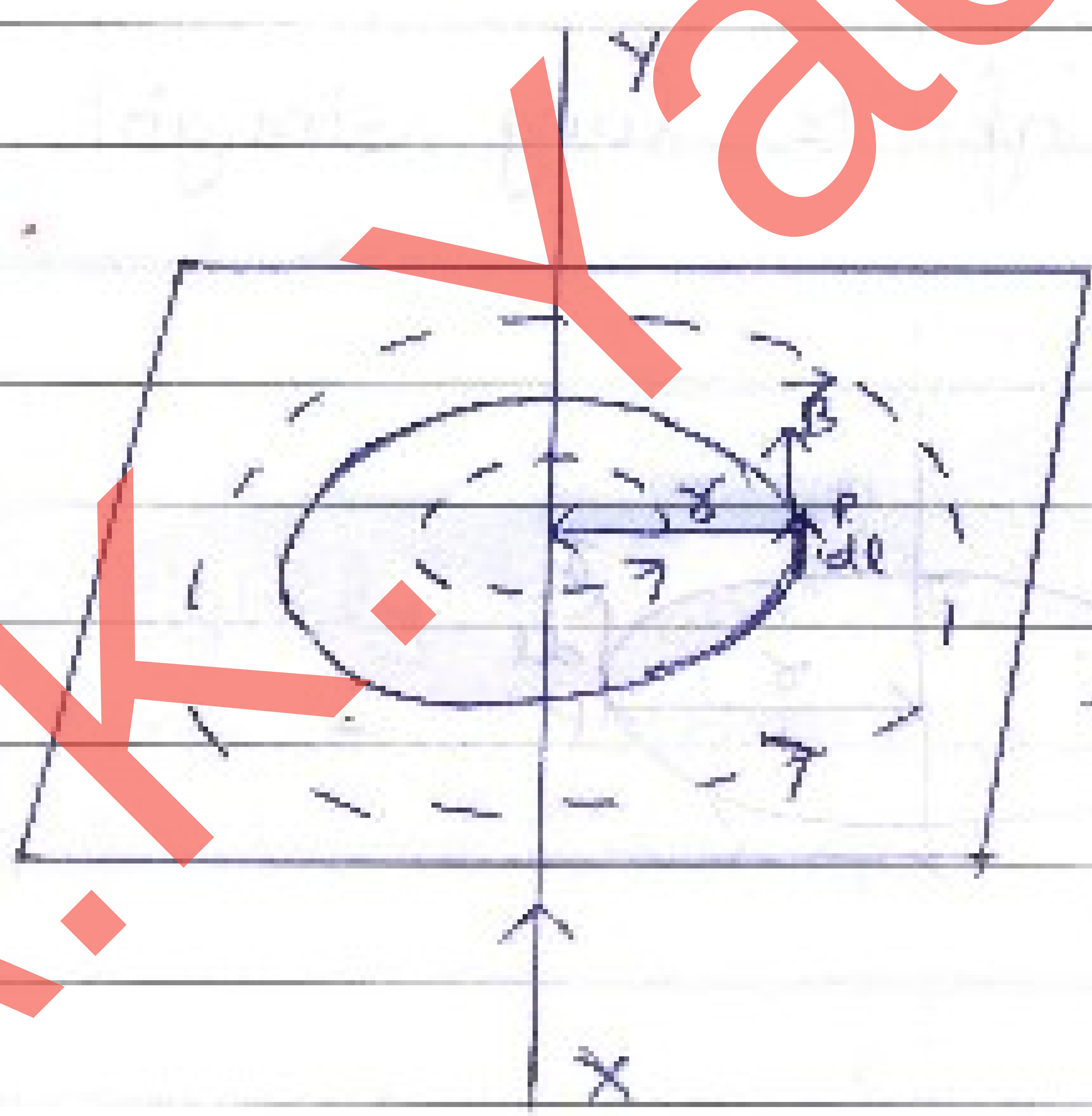
$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

Proof :

Consider a long thin straight conductor XY lying in the plane of paper.

Let I be the current flowing from X to Y.

Magnetic field is produced & the magnetic field lines are represented by dotted circles.



Consider an amperian loo[p] of radius 'r' whose centre lies on XY. (curve)

Take a small element of length dl of the closed path at P.

The magnitude of magnetic field produced at pt. P is

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{r}$$

The direction of $\vec{B}$ is along the tangent ~~of~~ to magnetic field line at P.

The direction of $\vec{B}$ & $\vec{dl}$ are same so $\theta = 0°$

~~Consider an~~

$\therefore$ Line integral of $\vec{B}$ around the closed circular path of radius r is

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\cos 0$$

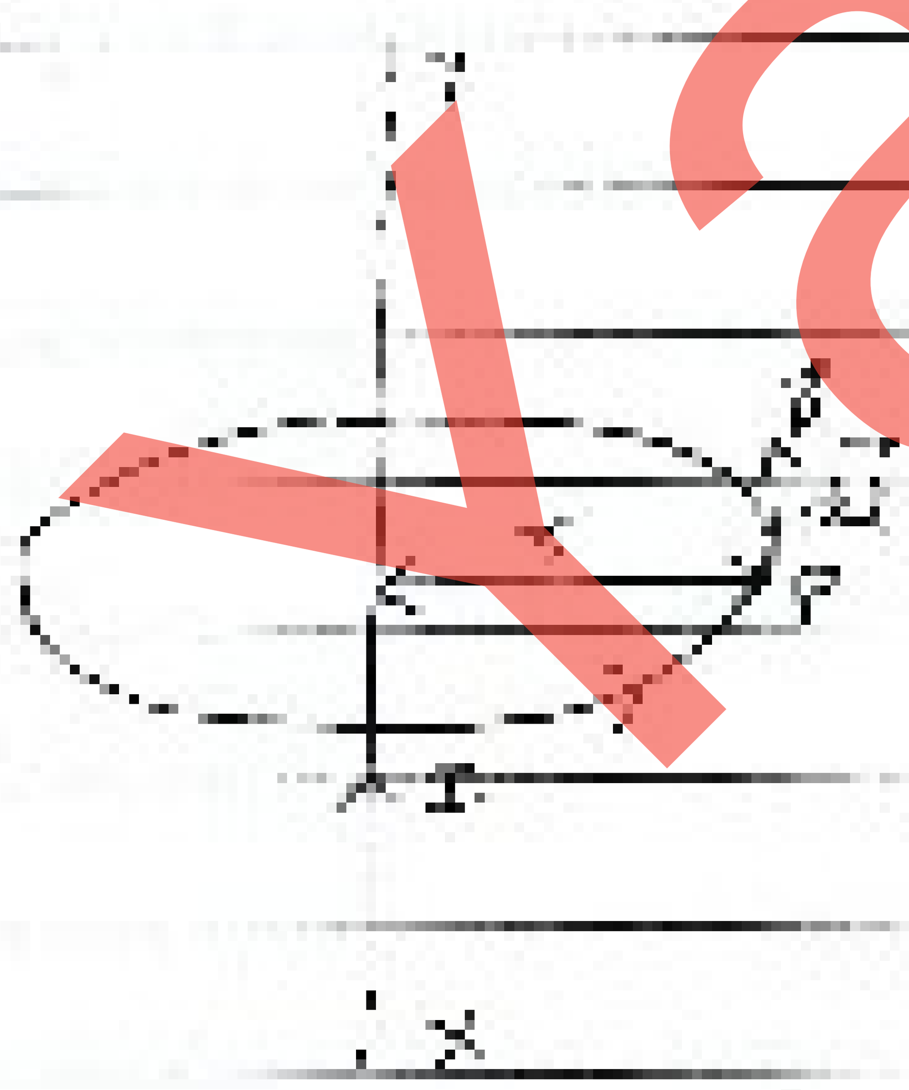
$$= B\oint dl$$

$$= \frac{\mu_0 I}{2\pi r} \times 2\pi r$$

$$\boxed{\oint \vec{B}\cdot\vec{dl} = \mu_0 I}$$

Magnetic field due to infinite long straight wire carrying current

Consider an infinite long straight wire XY having current I.



Consider an amperian loop as a circle of radius r such that pt P lie on the loop.
The line integral of $\vec{B}$ around the closed loop is

$$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\cos 0 = B\oint dl = B\times 2\pi r$$

Using Ampere's circuital law

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I$$

$$B\times 2\pi r = \mu_0 I$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0}{4\pi}\cdot\frac{2I}{r}}$$

Conclusions

1) It tells that the magnitude of magnetic field at every point on a circle of radius 'r' is same. It means the magnetic field due to current through infinite straight wire has a cylindrical symmetry.

2) The direction of magnetic field at every point on the circle is tangential to it & lines of constant magnitude of magnetic field form concentric circles. These circular lines are called magnetic field lines.

2) Do example 4.8 from NCERT p-149

Solenoid

It is a tightly wound helical loop from an insulated wire such that its length is very large as compared to its diameter.

Magnetic field due to a solenoid

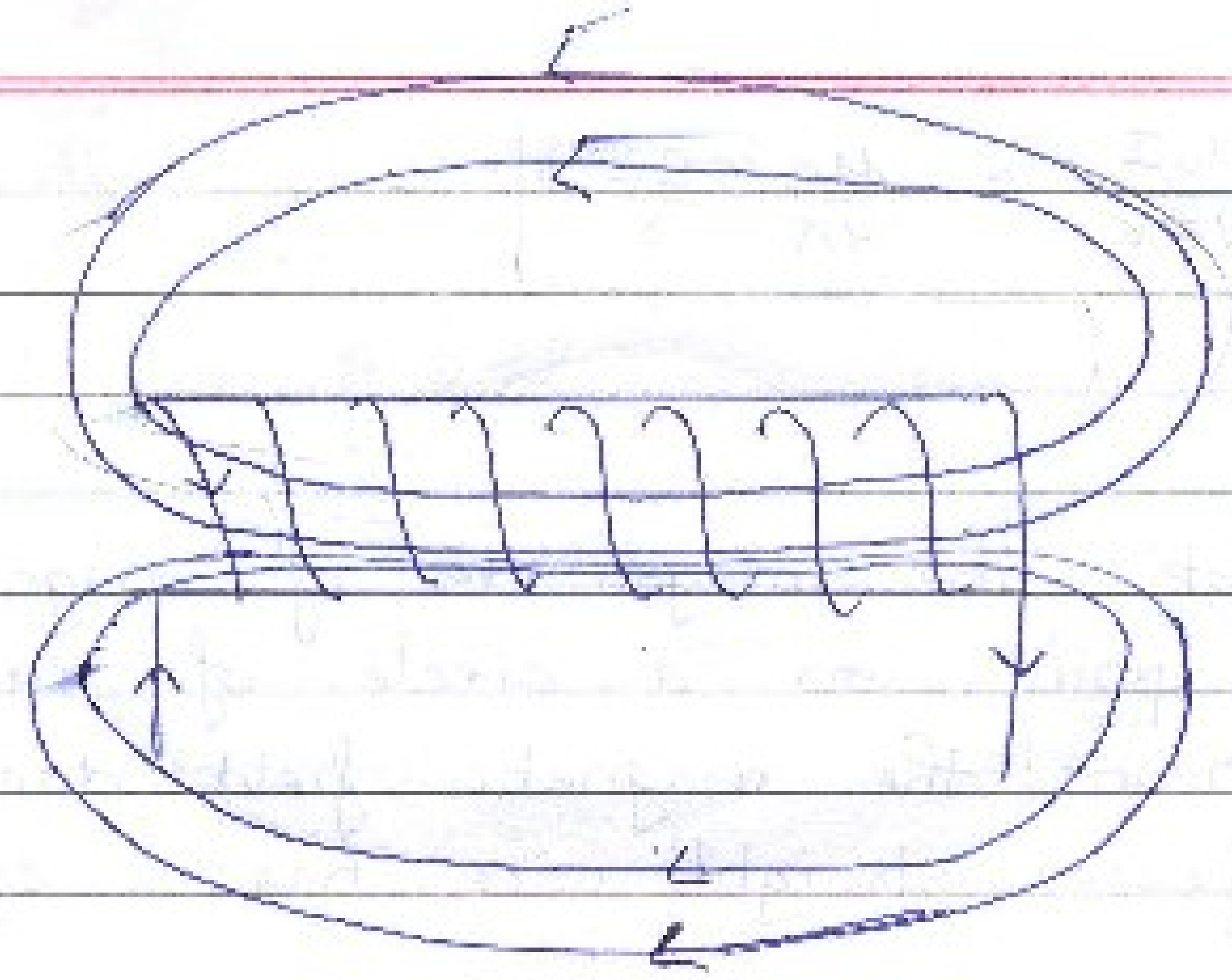
→ Consider a long straight solenoid of circular cross-section.

→ Each 2 turns of the solenoid are insulated from each other.

→ When current is passed through the solenoid, then each turn of the solenoid can be regarded as a circular loop carrying current & producing m.f.

→ The total magnetic field is the vector sum of all the m.f. due to currents through all the turns in the solenoid.

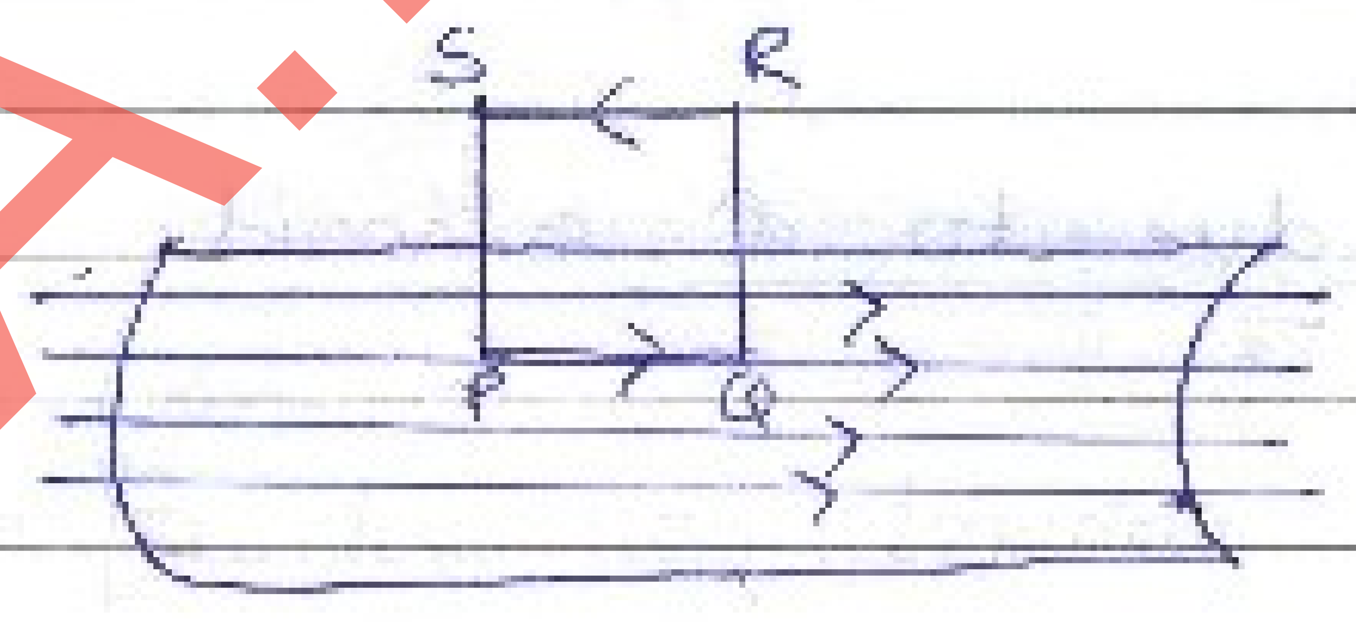
Just for understanding



→ At a pt. outside the solenoid, the magnetic fields due to neighbouring loops oppose each other & at a point inside the solenoid, magnetic field lines are in same direction

→ Due to this
outside the loop, effective magnetic field becomes weak
inside " " " " " strong acting along the axis of solenoid.

→ When the solenoid is more & more tightly packed, magnetic field outside it is zero



Consider a rectangular amperian loop PQRS
Let PQ = L
n - no. of turns per unit length of solenoid
I = current flowing through the solenoid

Total no of turns in length L = nL

The line integral of $\vec{B}$ over closed path PQRS is

$$\oint_{PQRS} \vec{B}\cdot\vec{dl} = \int_P^Q \vec{B}\cdot\vec{dl} + \int_Q^R \vec{B}\cdot\vec{dl} + \int_R^S \vec{B}\cdot\vec{dl} + \int_S^P \vec{B}\cdot\vec{dl} \quad -(1)$$

Now, $\int_P^Q \vec{B}\cdot dl = \int_P^Q B\,dl\cos 0^\circ = B\int_P^Q dl = BL$

$$\int_Q^R \vec{B}\cdot dl = \int_S^P \vec{B}\cdot\vec{dl} = \int B\,dl\cos 90^\circ = 0$$

$$\int_R^S \vec{B}\cdot\vec{dl} = 0 \qquad [\because \text{outside the solenoid, } B=0]$$

So, eq^n (1) becomes

$$\oint_{PQRS} \vec{B}\cdot\vec{dl} = BL$$

Acc. to Ampere's circuital law

$$\oint_{PQRS} \vec{B}\cdot\vec{dl} = \mu_0 nLI$$

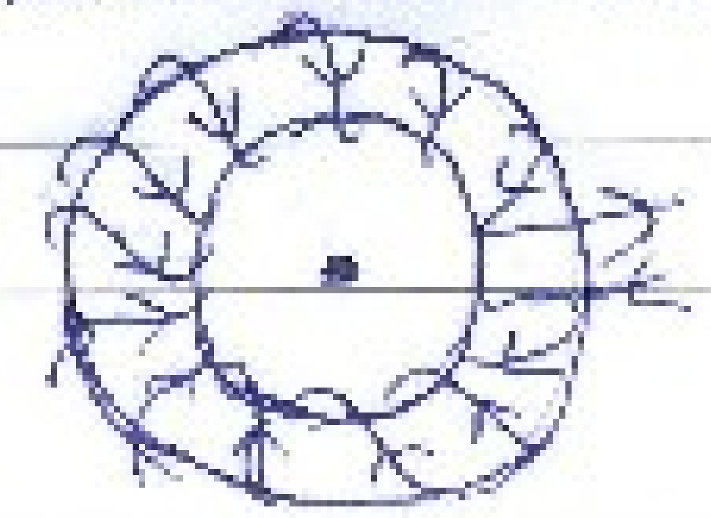
$$BL = \mu_0 nLI$$

$$\boxed{B = \mu_0 n I}$$

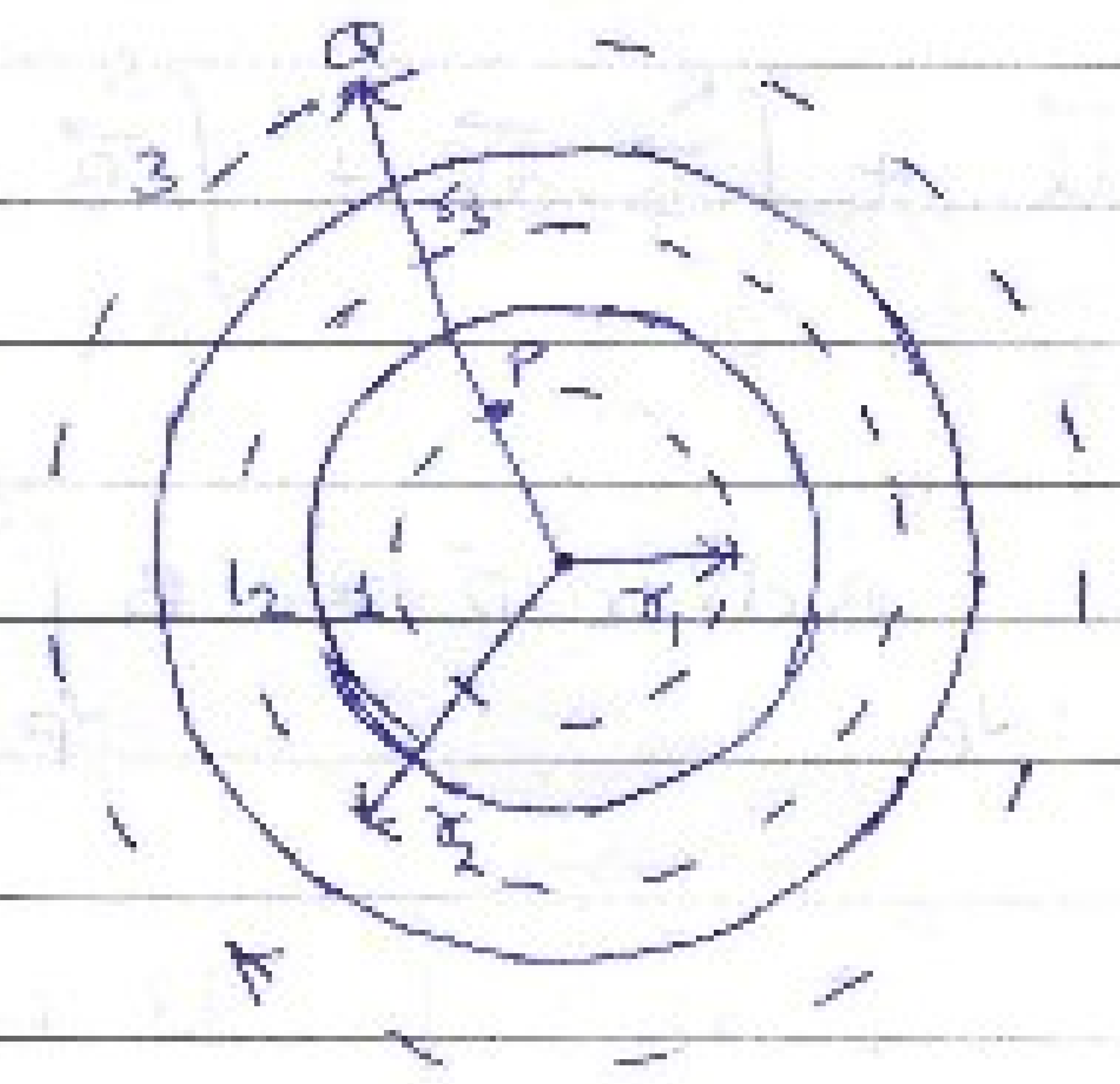
Toroid

→ It is a hollow circular ring on which a large no. of insulated turns of metallic wire are closely wound.

→ It is an endless solenoid in the form of a ring.



Magnetic field due to an ideal toroid



Let n - no. of turns per unit length of toroid
I - current

Draw 3 circular amperian loops 1, 2 & 3 of radii r_1, r_2 and r_3 (to be traversed in clockwise direction & as shown by dashed circles) so that P, S & Q lie on them.
The circular area bounded by loops 2 & 3, both cut the toroid.
Each turn of current carrying wire is cut once by loop 2 & twice by loop 3.

For loop 1

$$\oint \vec{B_1} \cdot \vec{dl} = \mu_0 I = 0$$ [$\because$ Loop 1 encloses no current]

or $B_1 = 0$

For loop 3 [current coming out of plane ~~eq~~ cancels current entering]

$$\oint \vec{B_3} \cdot \vec{dl} = \mu_0 I = 0$$

or $B_3 = 0$

[Simply also outside the toroid/solenoid $B = 0$]

For loop 2

$$\oint \vec{B_2} \cdot \vec{dl} = \mu_0 I$$

Now, I = no. of turns × current in each turn
$= n \times 2\pi r_2 I$

$$B_2 \oint d\vec{l} = \mu_0 n \times 2\pi r_2 I$$

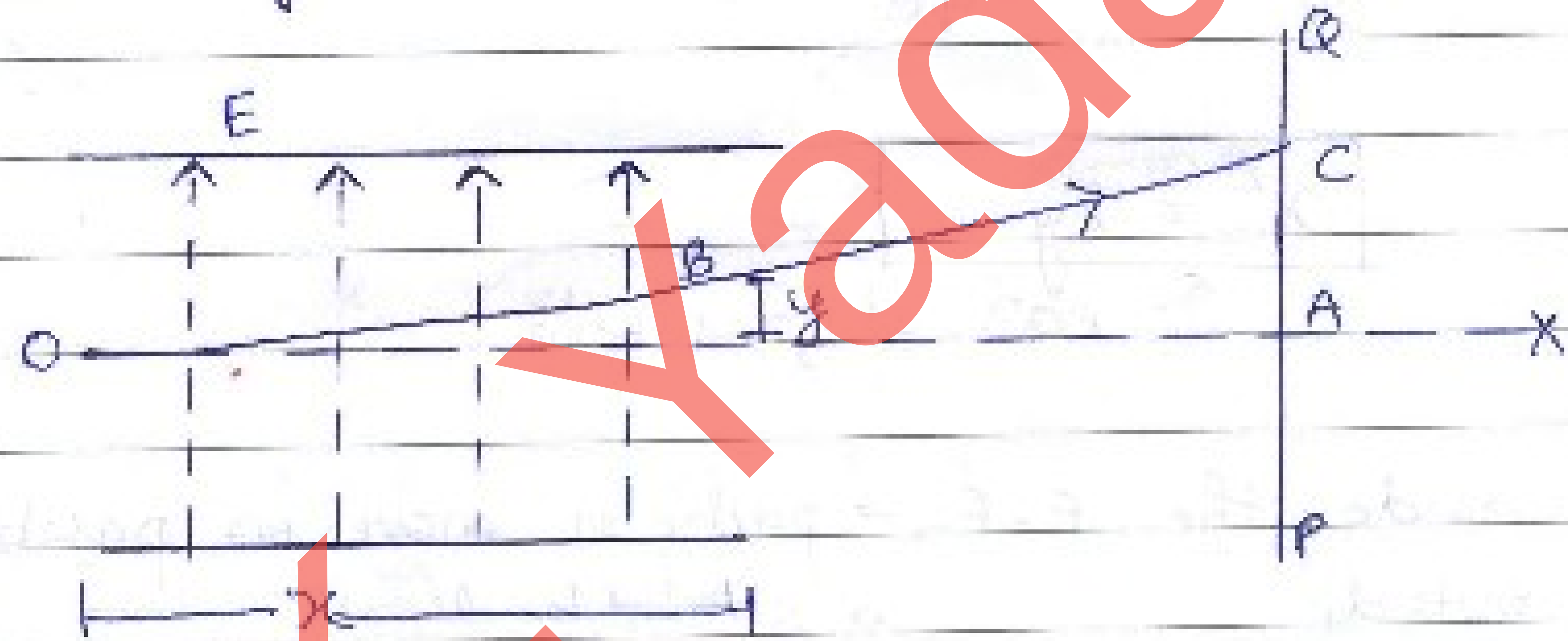
$$B_2 \times 2\pi r_2 = \mu_0 n I \times 2\pi r_2$$

$$\boxed{B_2 = \mu_0 n I}$$

same as that of solenoid

Motion of a charged particle

(a) In a uniform electric field



Suppose a charged particle having charge $+q$ & mass m is moving with velocity v along OX.
In the absence of an E.F. it meets PQ at A.
Let the charged particle be subjected to a uniform electric field E, acting along OY.

Due to electric field the charged particle experiences a force

$F = qE$ along direction of $\vec{E}$.

or $ma = qE$

$$a = \frac{qE}{m}$$

If x - length of the region of electric field, then time taken by the particle to cross it is

$$t = \frac{x}{v}$$

Now, $S_y = u_y t + \frac{1}{2} a_y t^2$

$$y = 0 + \frac{1}{2} \times \frac{qE}{m} \times \frac{x^2}{v^2}$$

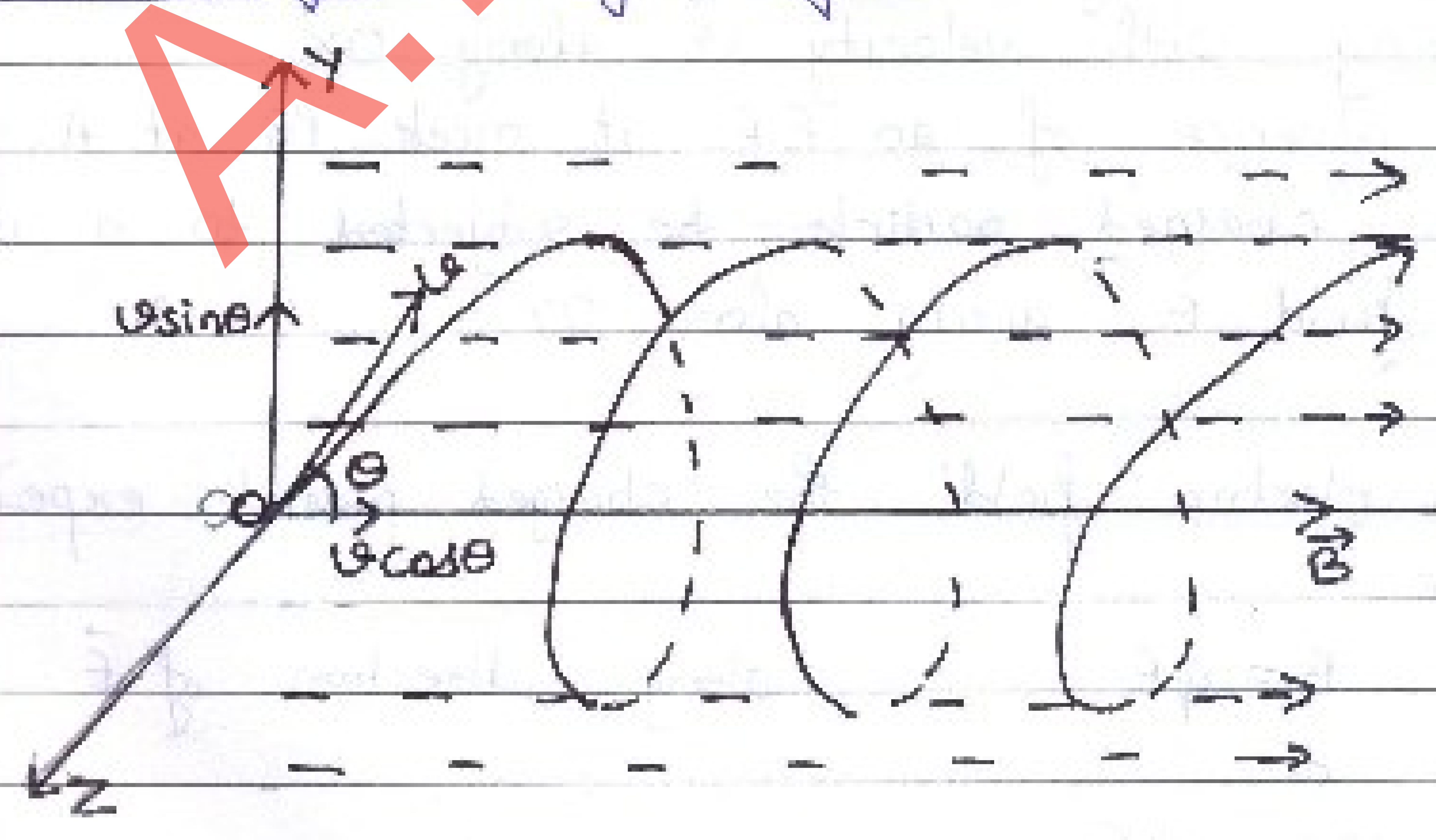
$$x^2 = \frac{2mv^2}{qE} y$$

$$\boxed{x^2 = ky}$$

⇐ eqⁿ of parabola

So, inside the E.F → particles move on parabolic path
outside → straight line

(b) In a uniform magnetic field



Suppose a particle of mass 'm' & charge 'q' enters a uniform magnetic field $\vec{B}$ at O with velocity $\vec{v}$ making an angle θ with $\vec{B}$.

Vertical motion

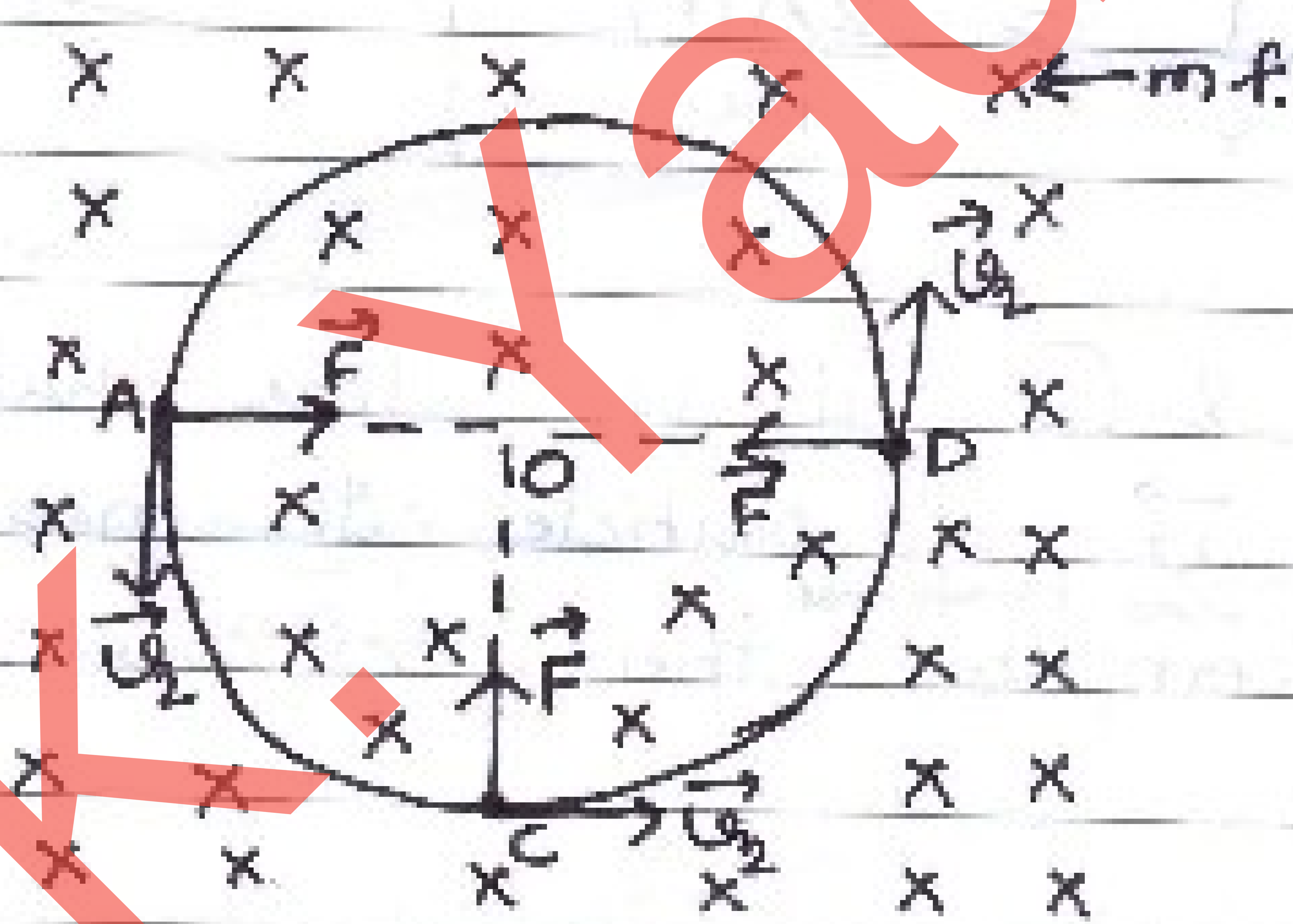
The force acting on the particle is

$$\vec{F} = q\,(v\sin\theta)B$$

The direction of $\vec{F}$ is $\perp^r$ to the plane containing $\vec{B}$ & $v\sin\theta$.

As this force always remain $\perp^r$ to $v\sin\theta$, it will not perform any work & hence can't change the magnitude of $v\sin\theta$ but changes the direction of motion of the particle.

Due to this, the charged particle moves in a circular orbit.



In the diagram

- particle is moving in the plane of paper
- m.f is $\perp^r$ to plane of paper directed inwards

When the particle is at A, C & D direction of force is along AO, CO & DO i.e directed towards the centre of circular path.

The force F on the charged particle due to magnetic field provides the required centripetal force

$$qvB\sin\theta = \frac{m(v\sin\theta)^2}{r}$$

$$v\sin\theta = \frac{Bqr}{m}$$

The angular velocity of rotation is

$$\omega = \frac{v\sin\theta}{r} = \frac{Bq}{m}$$

The frequency of rotation is

$$\boxed{\nu = \frac{\omega}{2\pi} = \frac{Bq}{2\pi m}} \quad \text{---} (1)$$

The time period of revolution is

$$\boxed{T = \frac{1}{\nu} = \frac{2\pi m}{Bq}} \quad \text{---} (2)$$

from (1) & (2) it is clear that ν & T do not depend on $\vec{v}$ of particle. It means that all same particles very large complete their circular path in same time.

Horizontal motion

No force on $v\cos\theta$ as angle bet^n $v\cos\theta$ & B is zero. So, the charged particle covers the linear distance in the direction of $\vec{B}$ with constant speed $v\cos\theta$

So, under the combined effect of $v\cos\theta$ & $v\sin\theta$, the charged particle in magnetic field will cover linear path as well as circular path i.e the path of the charged particle will be helical.

* The linear distance covered by charged particle in magnetic field in time equal to one revolution

of its circular path (called pitch of helix) is

$$d = v\cos\theta \times T$$

$$= v\cos\theta \cdot \frac{2\pi m}{Bq}$$

Lorentz force

The force experienced by a charged particle moving in space where both electric & magnetic fields exist is called Lorentz force.

$$\vec{F}_e = q\vec{E} \quad \text{along direction of } E$$

$$\vec{F}_m = q(\vec{v} \times \vec{B}) \quad \text{direction } \perp^r \text{ to plane containing } \vec{v}\ \&\ \vec{B}$$

Total force experienced by charged particle is

$$\vec{F} = \vec{F}_e + \vec{F}_m$$

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

$$\boxed{\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})}$$

Velocity selector

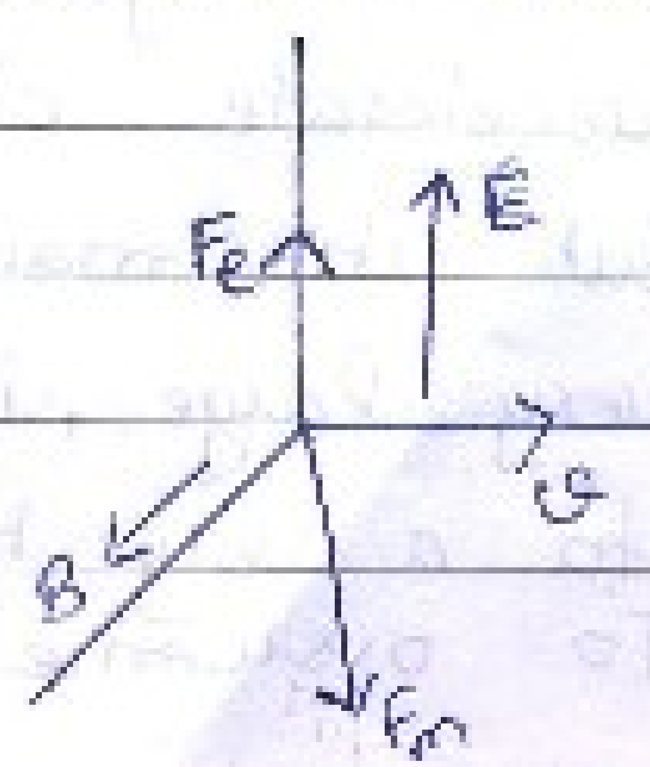
$$\vec{F} = qE + q(\vec{v} \times \vec{B})$$

Let electric field & magnetic fields are $\perp^r$ to each other as well as perpendicular to the velocity of the particle.

$\vec{E} = E\hat{j}$

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

$v = v\hat{i}$



$$F_e = qE = qE\hat{j}$$
$$F_m = q(\vec{v} \times \vec{B}) = q(v\hat{i} \times B\hat{k}) = -qB\hat{j}$$

$$\therefore \quad F = q(E - vB)\hat{j}$$

So, F_m & F_e are in opposite direction

Let the value of E & B are so adjusted that the mag. of F_m & F_e are equal, then total force on the particle is zero & it will go undeflected.

i.e. $F = 0$ if $F_e = F_m$

$$qE = qvB$$

$$v = \frac{E}{B}$$

→ This condition can be used to select charged particles of a particular velocity (from a beam containing charges moving with different speeds).

→ Crossed E & B serve as velocity selector.

→ This method

(a) was used by J. J. Thomson to determine e/m ratio of electron

(b) is used in mass spectrometer [Device that separates ions acc. to their e/m ratio]

Cyclotron

Intro

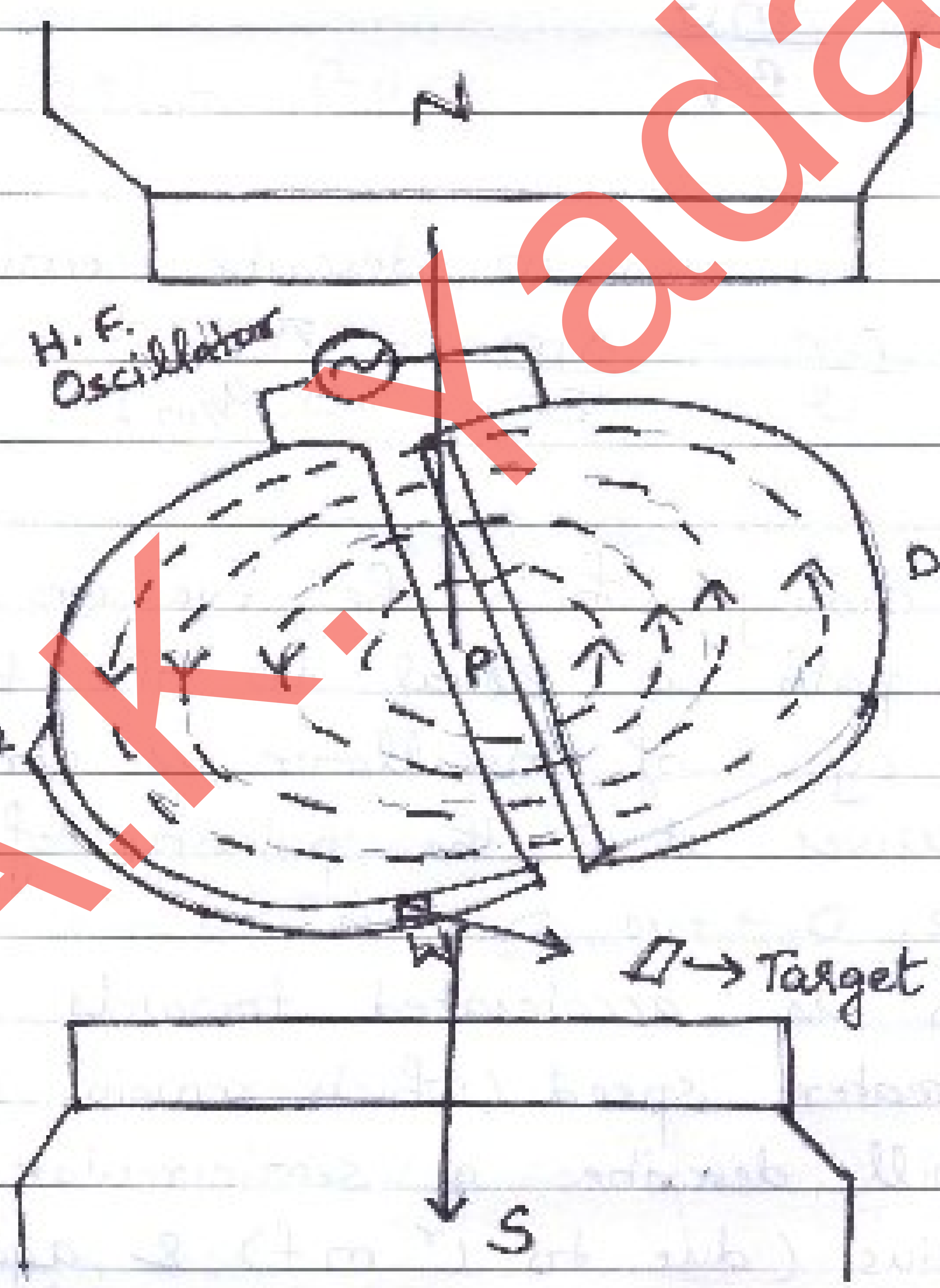
- An accelerator is used for accelerating charged particles so that they acquire energy large enough to carry out nuclear reactions.
- Historically, linear accelerator was developed to accelerate charged particles.
- But its main drawback was that its length has to be very large, if the charged particles are to be accelerated to a very high energy.
- To overcome this drawback cyclotron was designed

"Cyclotron is a machine to accelerate charged particles or ions to high energies."

Principle

If a charged particle is time & again moved in a strong electric field of high frequency as well as strong magnetic field, the particle acquires large energy & gets accelerated.

Construction



→ D_1, D_2 → D-shaped hollow evacuated metal chambers
→ connected to H.F. oscillator which produces p.d. of 10^4 V at 10^7 Hz frequency.

N, S - pole pieces of a strong electromagnet.
P - place of +vely charged particle.

Working

i) The +ve ion (to be accelerated) is produced at P.

ii) At at that instant D_1 = -ve & D_2 = +ve potential. So, ion accelerates towards D_1.

iii) Inside D_1 (i.e. field free space) it moves with a constant velocity v.
But due to ⊥ magnetic field, the ion describes a circular path.

$$Bqv = \frac{mv^2}{r}$$

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

Time taken by ion to describe semicircular path

$$t = \frac{\pi r}{v} = \frac{\pi m}{Bq} = \frac{\pi}{q(B/m)} = \text{const}$$

iv) The time during which the +ve ion describes a semicircular path is equal to the time during which half cycle of oscillator is completed, then as the ion arrives at P the polarity of the 2 Dees is reversed i.e. D_1 → +ve, D_2 → -ve.

v) The +ve ion is accelerated towards D_2 & it enters D_2 with greater speed (which remains const. in D_2)

vi) The ion will describe a semicircular path of greater radius (due to $r \propto v$) & again will arrive at Q at the instant the polarity of the 2 dees is reversed.

vii) Thus the positive ion will go on accelerating every time it comes into the gap b/w the dees & will go on describing circular path of greater & greater radius with greater & greater speed and finally acquires a sufficiently high energy to hits the target.

Max. energy of the ion

Let v_0 = max velocity
r_0 = max. radius of circular path followed } by the ion

So $\frac{m v_0^2}{r_0} = B q v_0$

$$v_0 = \frac{B q r_0}{m}$$

Max K.E $= \frac{1}{2} m v_0^2$

$$= \frac{1}{2} m \frac{B^2 q^2 r_0^2}{m^2} = \frac{B^2 q^2 r_0^2}{2m}$$

Cyclotron frequency

If T is the time period of oscillating e.f. then
$$T = 2t = \frac{2\pi m}{qB}$$

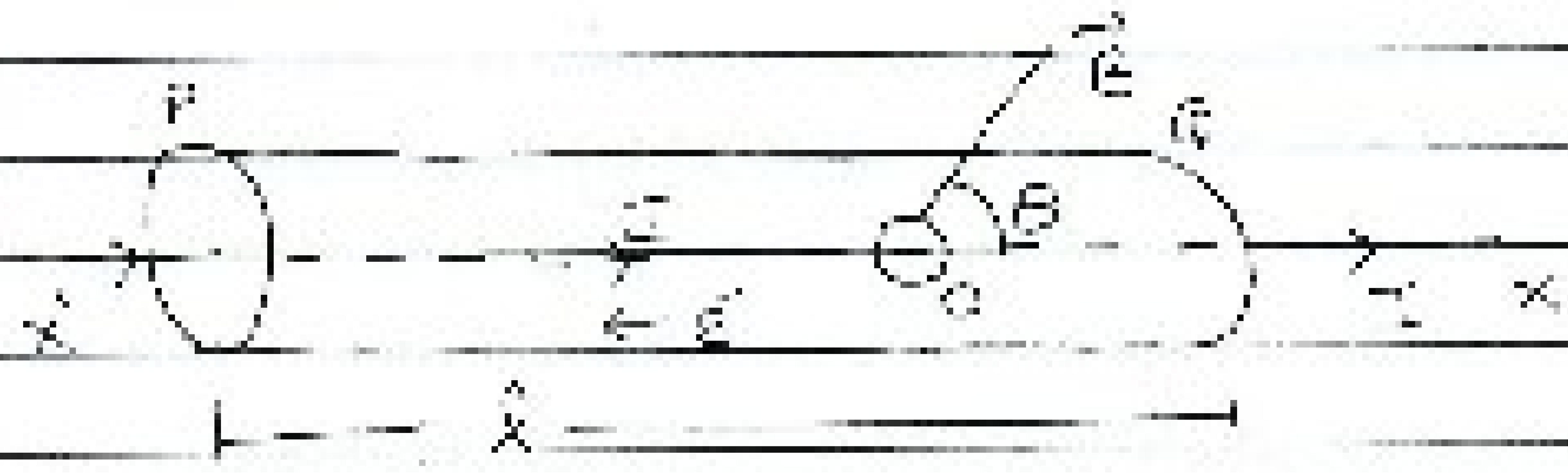
So cyclotron frequency is $\boxed{\nu = \frac{1}{T} = \frac{qB}{2\pi m}}$

* Also called magnetic resonance frequency

Limitations

1. It can't accelerate uncharged particles like neutrons
2. Ions can't move at unlimited speed
3. Electrons can't be accelerated due to lesser mass.

Force on a current carrying conductor placed in a magnetic field



Consider a straight cylindrical conductor PQ of length 'l', area 'A', carrying current 'I' placed in a magnetic field $\vec{B}$.

Let $v_d \to$ drift velocity of electrons

$-e \to$ charge on each electron, then

Magnetic Lorentz force on an electron is

$$\vec{f} = -e(\vec{v}_d \times \vec{B})$$

If 'n' is the no. density of free electrons, then total no. of free electrons in the conductor is

$$N = n(Al) = nAl$$

Total force on the conductor is

$$\vec{F} = N\vec{f}$$

$$= nAl(-e(\vec{v}_d \times \vec{B}))$$

$$= -nAle(\vec{v}_d \times \vec{B})$$

Now as we know

$$I = Ane v_d$$

$$Il = Ane v_d l$$

Since $I\vec{l}$ & $\vec{v}_d$ have opp. directions so $I\vec{l} = -nAle\vec{v}_d$

$\therefore \vec{F} = I\vec{l}\times\vec{B}$

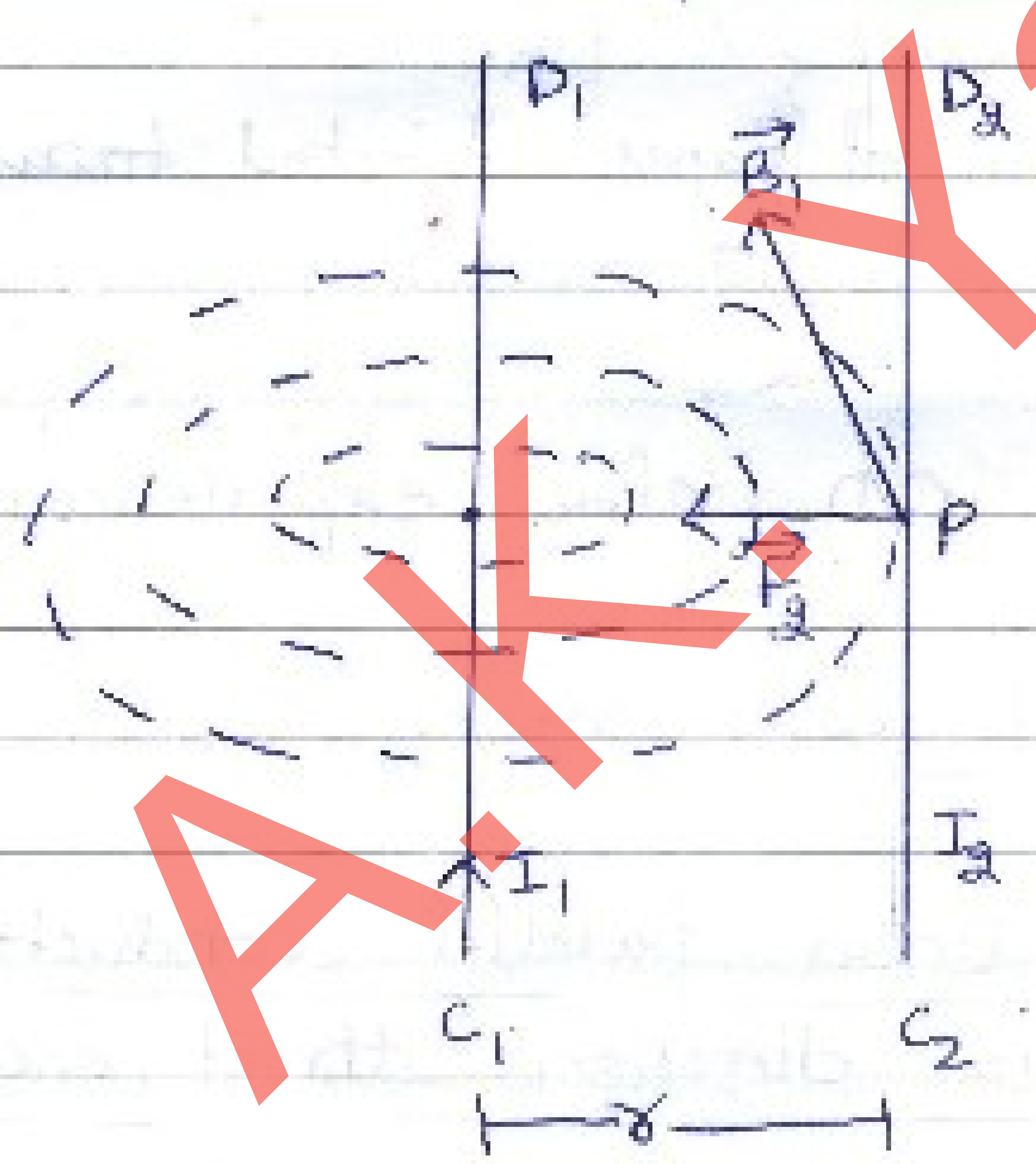
$|\vec{F}| = I|\vec{l}\times\vec{B}|$

$\boxed{F = IlB\sin\theta}$

Case 1 If $\theta = 0°$ or $180°$, $\sin\theta = 0$, $F = 0$ (min) - no force experien
$= 90°$, $\sin\theta = 1$ $F = IlB$ (max)

* Direction of force by Right hand screw rule or Fleming's left hand rule.

Force betn 2 parallel straight conductors



Consider 2 infinite long straight conductors carrying currents I_1 & I_2 in same direction separated by a distance 'r'

Since each conductor is in the magnetic field produced by the other, so each conductor experiences a force.

Magnetic field at pt P on conductor C_2D_2 due to current I_1 passing through C_1D_1 is

$$B_1 = \frac{\mu_0}{4\pi} \frac{2I_1}{x}$$

Direction → ⊥ to plane of paper directed inwards (right hand ...)

Force experienced by unit length of C_2D_2 in the magnetic field $\vec{B}_1$ of C_1D_1 is

$$F_2 = B_1 I_2 \times 1$$

$$= B_1 I_2$$

$$= \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{x}$$

Direction → ⊥ to the plane of paper directed towards C_1D_1 (Fleming's left hand rule)

Similarly the conductor C_1D_1 also experiences a force directed towards C_2D_2.
Hence C_1D_1 & C_2D_2 attract each other.

It means that the 2 linear parallel conductors carrying currents in same direction attract each other.

Definition of ampere

If $I_1 = I_2 = 1A$, $x = 1m$ then

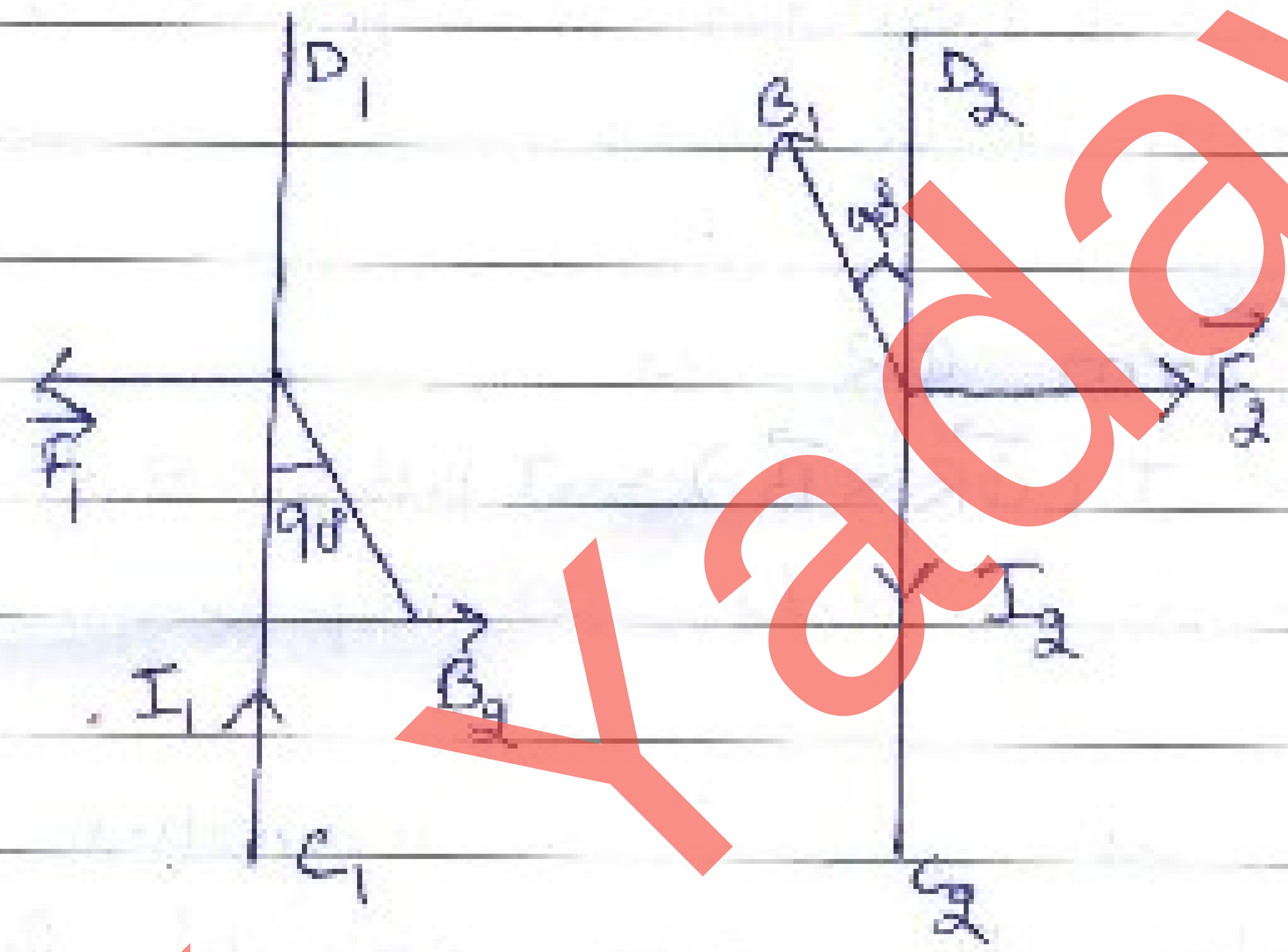
$$F = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{x}$$

$$= \frac{10^{-7} \times 2 \times 1 \times 1}{1}$$

$$F = 2 \times 10^{-7}\ Nm^{-1}$$

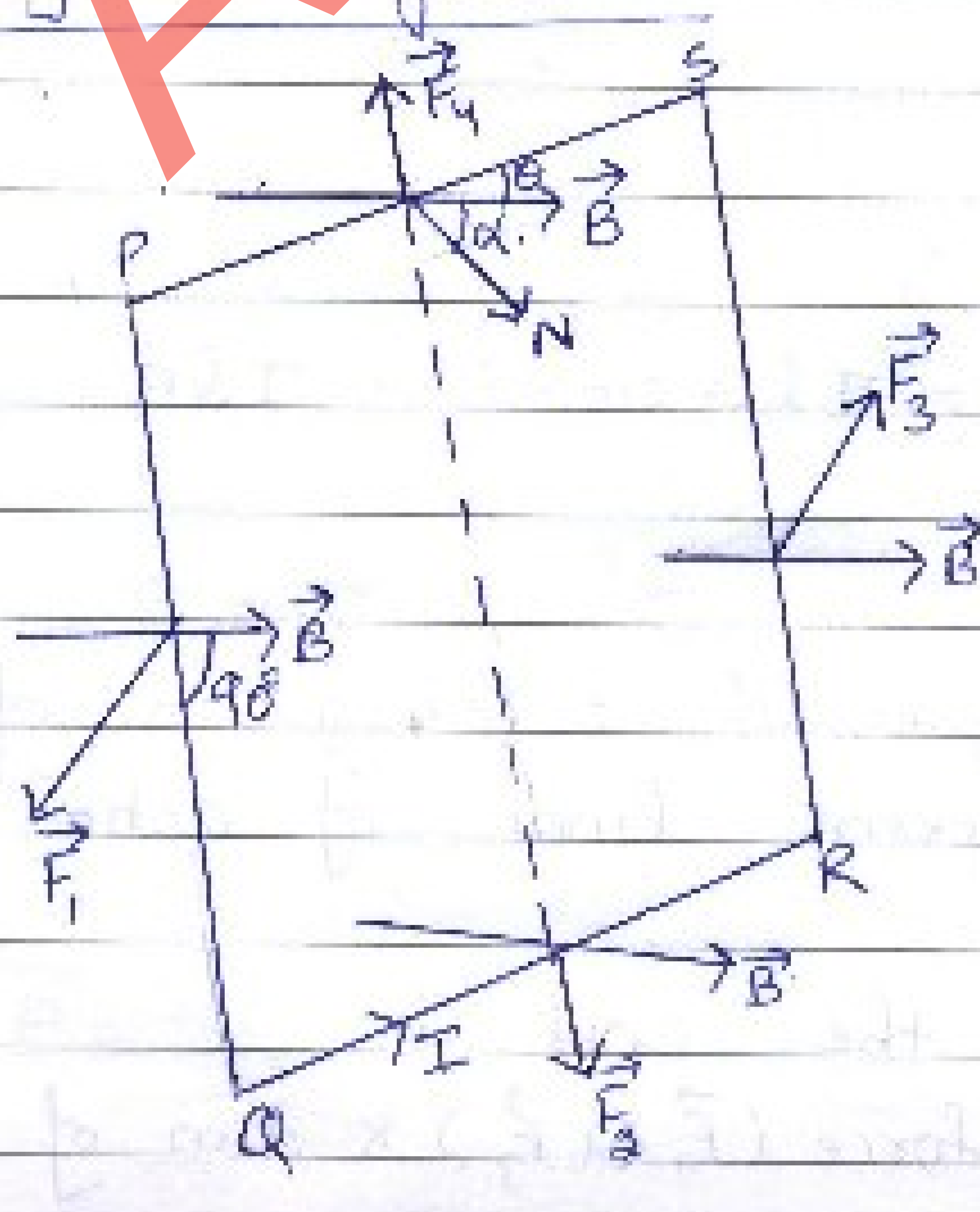
So, one ampere is that much current which when flowing through each of the 2 parallel uniform long linear conductors placed in a free space at a distance of 1 m from each other will attract or repel each other with a force of 2×10^{-7} N per meter of their length.

* If currents in C_1D_1 & C_2D_2 are in opp. direction



they repel each other.

Torque on a current carrying coil in a magnetic field



Consider a rectangular coil PQRS suspended in a uniform magnetic field B

Let $PQ = RS = l$

$QR = SP = b$

I - current flowing through the coil

θ - angle which plane of coil makes with B.

The force on arm SP is

$\vec{F_1} = I(\vec{SP} \times \vec{B}) = IbB\sin(180-\theta) = IbB\sin\theta$

direction - upwards

Force on arm QR is

$\vec{F_2} = I(\vec{QR} \times \vec{B}) = IbB\sin\theta$

direction - downwards

As $\vec{F_1}$ & $\vec{F_2}$ are equal in magnitude & acting in opposite directions along the same straight line, they cancel out each other.

Now force on arm PQ is

$\vec{F_3} = I(\vec{PQ} \times \vec{B}) = IlB\sin 90 = IlB$

direction - inwards

Force on arm RS is

$\vec{F_4} = I(\vec{RS} \times \vec{B}) = IlB\sin 90 = IlB$

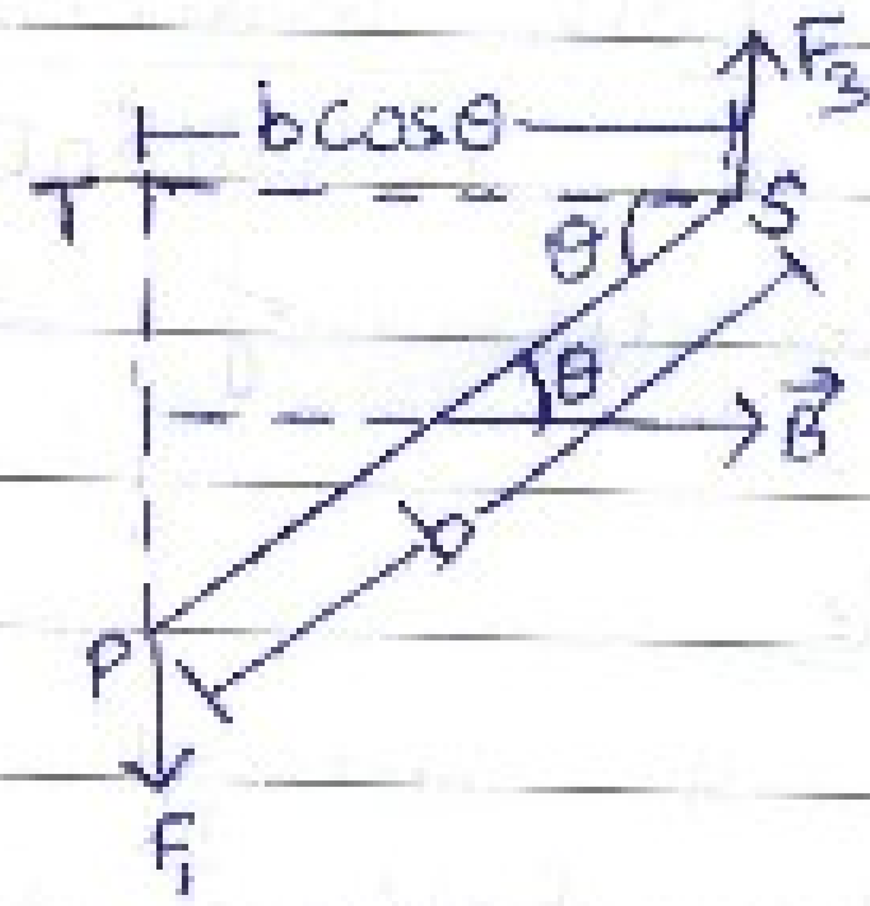
direction - outwards

$\vec{F_3}$ & $\vec{F_4}$ are equal, parallel & acting in opposite directions, having different lines of action, form a couple.

So, the torque on the coil is

τ = either force (F_3 or F_4) × arm of couple.

Arm of couple
$ST = PS\cos\theta$
$= b\cos\theta$



$\therefore \tau = Il B \times b\cos\theta = IBA\cos\theta$ $[\because A = l \times b]$

If the coil has 'n' turns

$$\boxed{\tau = nIBA\cos\theta}$$

If the normal drawn on the plane of the coil makes an angle α with $\vec{B}$ then

$\theta + \alpha = 90^\circ$

$\theta = 90^\circ - \alpha$

$\cos\theta = \cos(90^\circ - \alpha) = \sin\alpha$

$$\boxed{\tau = nIBA\sin\alpha = MB\sin\alpha = |\vec{M} \times \vec{B}|}$$

where $M = nIA$

magnitude of magnetic dipole moment

Special cases

① If the coil is set with its plane parallel to the direction of B

$\theta = 0^\circ$, $\tau = nIBA$ (max)

This is the case with a radial field.

② $\perp^r$ to $\vec{B}$

$\theta = 90^\circ$, $\tau = 0$ (min.)

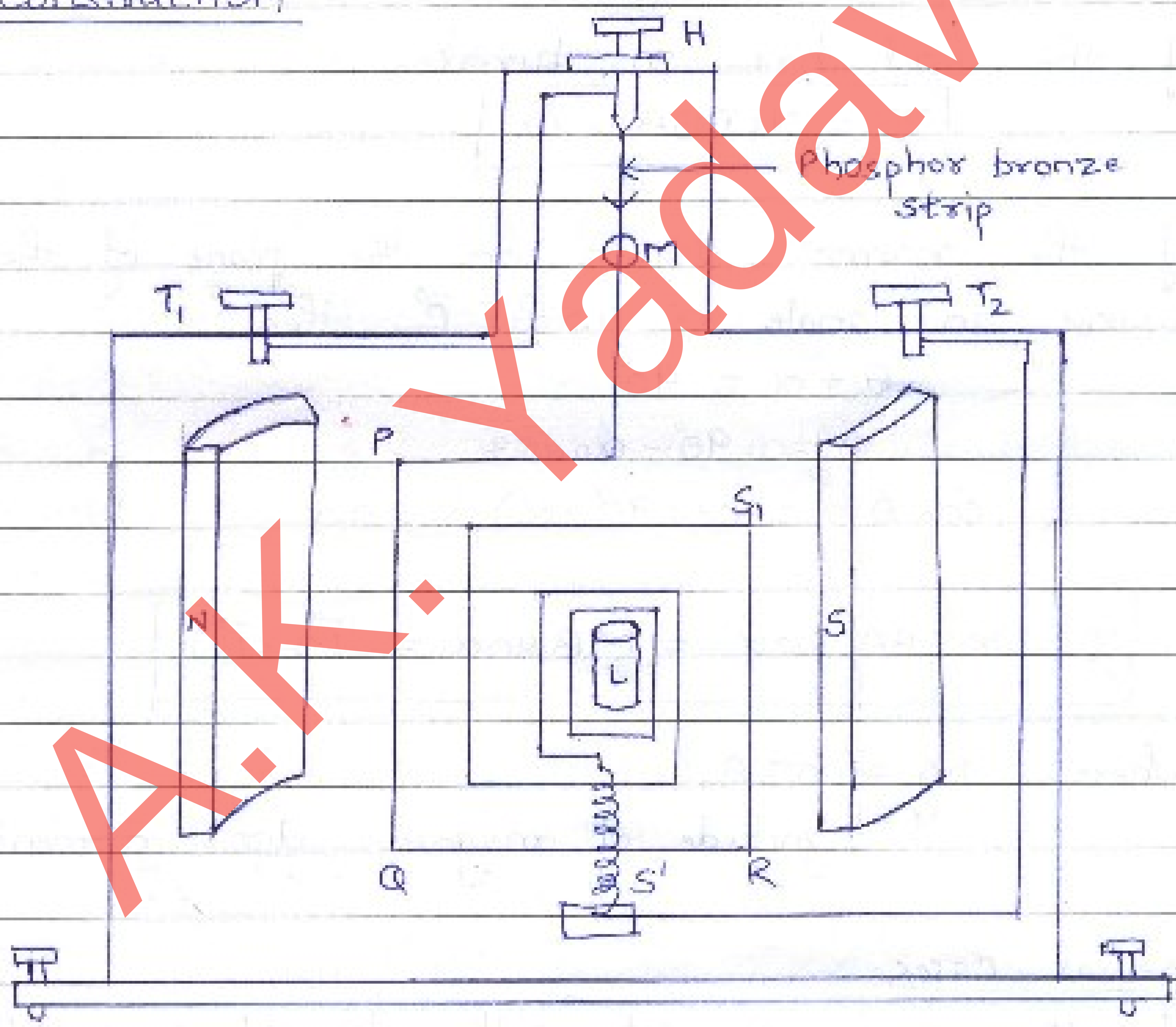
Moving Coil Galvanometer

It is an instrument used for detection and measurement of small currents.

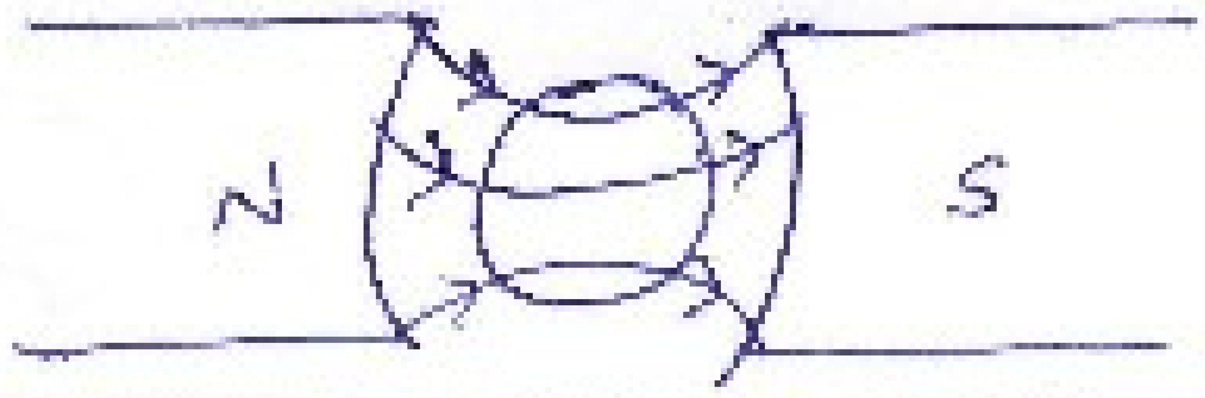
Principle

When a current carrying coil is placed in a magnetic field, it experiences a torque.

Construction



- It consists of a coil $PQRS_1$ having large no of turns of insulated copper wire.
- The coil is suspended from a movable torsion hea
  H by means of phosphor bronze strip in a unifor
  magnetic field (produced by pole pieces N & S)
- The lower end of coil is connected to one end of hair spring S (quartz or phosphor bronze)



← Diagram showing radial field

- The other end of 'S' is connected to terminal T_2.
- L is a soft iron core (can be spherical or cylindrical). It is so held within the coil, that the coil can rotate freely without touching the iron core & pole pieces.
  This makes the magnetic field linked with the coil to be radial field.
- M is a concave mirror (attached to phosphor bronze strip) used to note the deflection of the coil.
- The whole arrangement is enclosed in a non-metallic case to avoid disturbance due to air.

Theory

Let l - length of PQ/RS,
b - breadth of QR/S,P
n - no. of turns in the coil
B - strength of magnetic field
I - current passing through coil along PQRS.

Let, at any instant, α be the angle which the normal drawn on the plane of coil makes with the direction of $\vec{B}$.

The torque experienced by a rectangular coil in a magnetic field is

$$\tau = nIBA\sin\alpha$$

As the field is radial $\alpha = 90^\circ$

$$\tau = nIBA$$

- Due to this torque, the coil rotates & the phosphor bronze strip gets twisted.

• As a result of it, a restoring torque comes into play in the phosphor bronze strip which would try to restore the coil back to its orginal position

i.e., total restoring torque $= k\theta$

where θ - twist produced in phosphor bronze strip

k - torsional constant of spring (restoring torque per unit twist)

In equilibrium position of coil

deflecting torque = restoring torque

$$nIBA = k\theta$$

$$I = \frac{k}{nBA}\theta$$

$$\boxed{I = G\theta}$$

where $G = \frac{k}{nBA}$ → galvanometer constant

So, $\boxed{I \propto \theta}$

It means deflection produced is directly proportional to the current flowing through the galvanometer.

Current sensitivity

It is defined as the deflection produced in the galvanometer when a unit current flows through it.

$$I_s = \frac{\theta}{I}$$

$$= \frac{nBA}{k}$$

unit → rad. A^{-1}

Voltage sensitivity

It is defined as the deflection produced in the galvanometer when a unit voltage is applied across the 2 terminals of the galvanometer.

$$V_s = \frac{\theta}{V}$$

$$= \frac{\theta}{IR} = \frac{nBA}{kR} = \frac{I_s}{R}$$

unit = rad V^{-1}

Conditions for a sensitive galvanometer

A galvanometer is said to be very sensitive if it shows large deflection even if very small current is passed through it.

Now $\theta = \frac{nBA}{k} I$

For a given value of I, θ will be large if n, B & A are large & k is small.

(i) The value of n can't be increased beyond a certain limit because it results in an increase of the resistance of the galvanometer.

(ii) The value of B can be increased by using strong horse shoe magnet.

(iii) The value of A can't be increased beyond a limit because in that case the coil will not be in a uniform magnetic field.

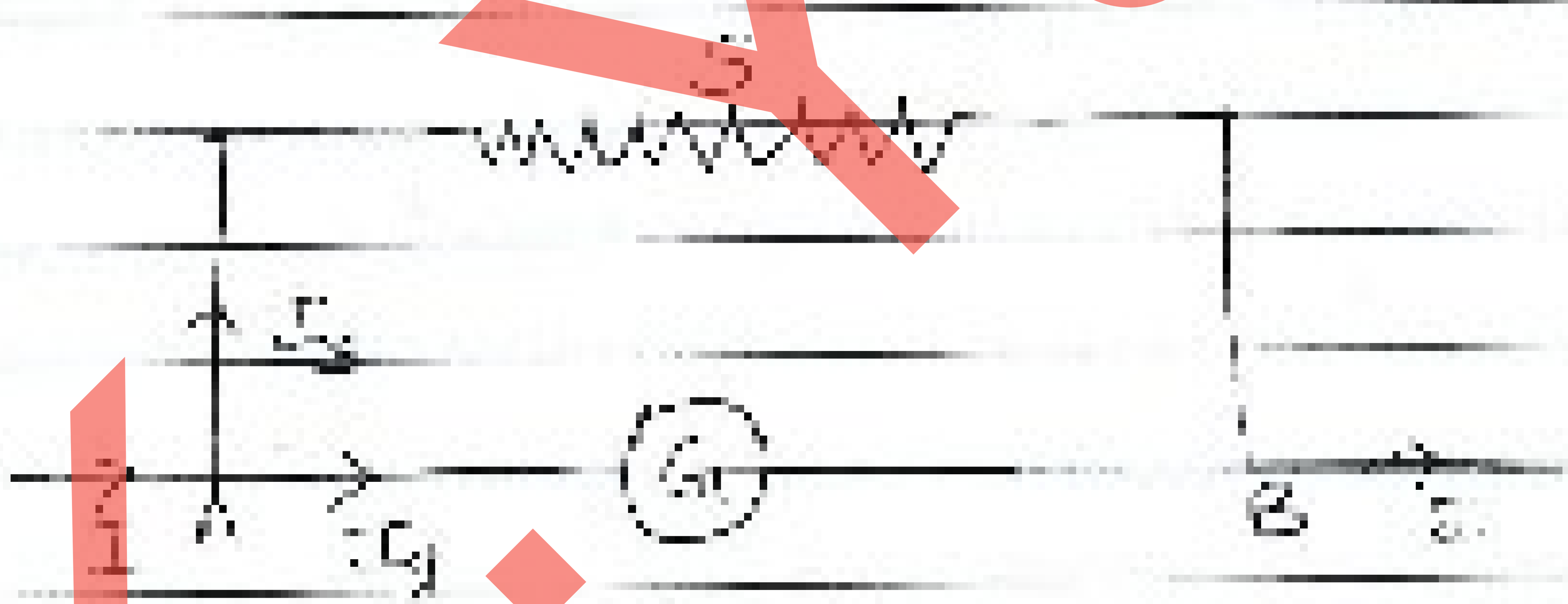
(iv) The value of k can be decreased.

Value of k depends upon nature of material of suspension strip. Value of k is very small for quartz or phosphor bronze. So they are used as suspension strip in sensitive galvanometer.

Shunt

It is a low resistance connected in parallel with the galvanometer or ammeter.
It protects the galvanometer or ammeter from the strong currents.

- If the current flowing in a circuit is strong, a galvanometer (or low range ammeter) can't be put directly in series because that will damage the instrument.
- To overcome this difficulty, a low resistance (shunt) is connected in parallel with the instrument.
- So, a major portion of current passes through the shunt & only a small portion passes through the instrument.
- Due to it the galvanometer remains safe.



Potential difference betⁿ A & B is

$$I_g G = I_s S$$
$$I_g G = (I - I_g) S$$
$$I_g = I\left(\frac{G}{G+S}\right)$$

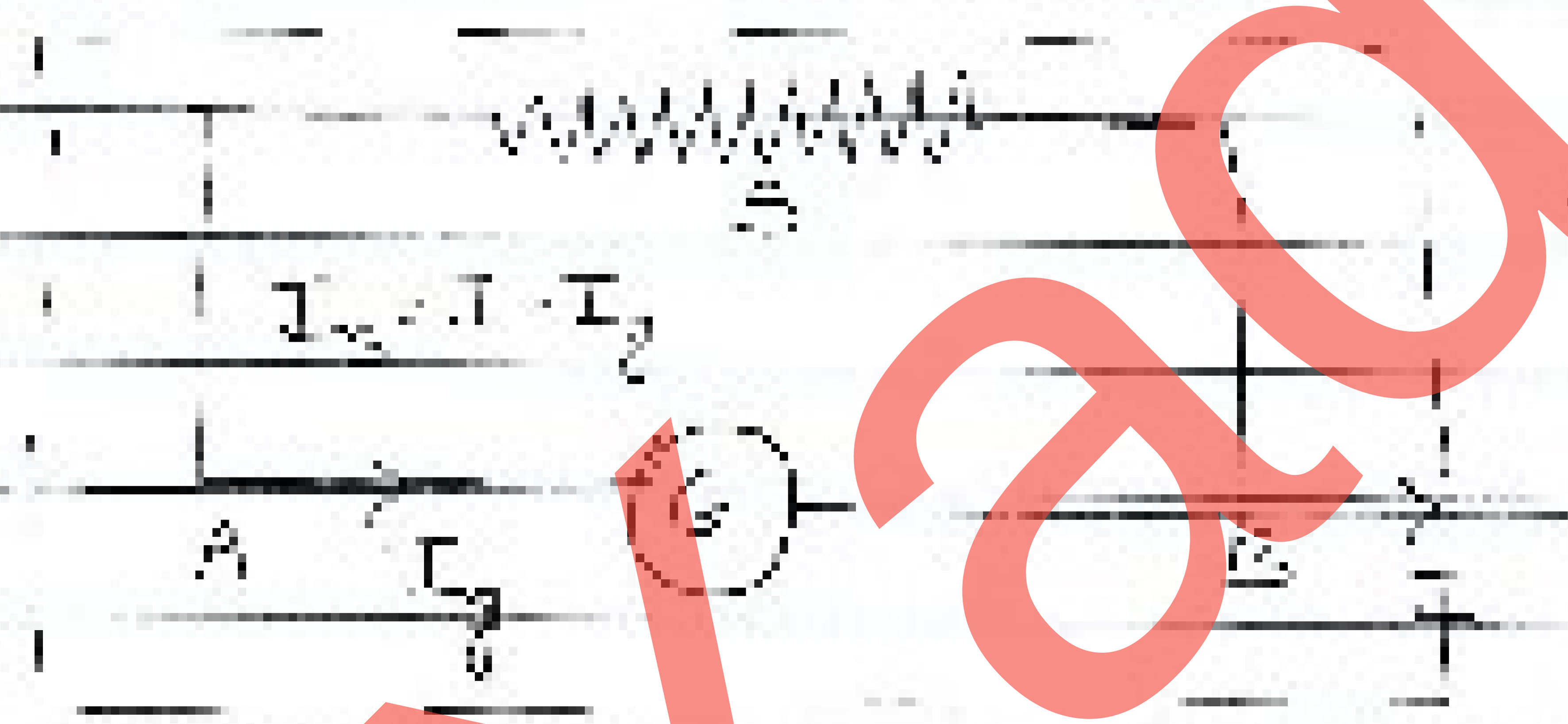
Also, we can get $I_s = I\left(\frac{G}{G+S}\right)$

Uses

1) It is used to protect the galvanometer from strong currents.
2) to convert a galvanometer to ammeter
3) for increasing the range of ammeter

Ammeter

It is a low resistance galvanometer which is used to measure current in a circuit in ampere.



$$I_g G = (I - I_g) S$$

$$\boxed{S = \left(\frac{I_g}{I - I_g}\right) G}$$

Effective resistance R_p of ammeter

$$\frac{1}{R_p} = \frac{1}{G} + \frac{1}{S}$$

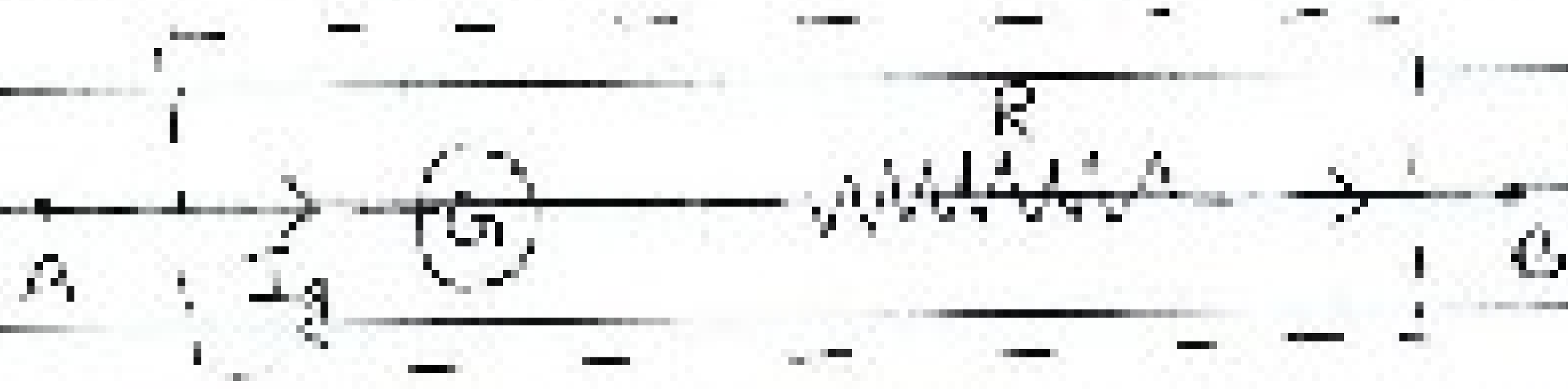
$$\boxed{R_p = \frac{GS}{G+S}}$$

If S is low, R_p is low, so resistance of ammeter < resistance of galvanometer.

* Ideal ammeter = zero resistance.

Voltmeter

It is a high resistance galvanometer which is used to measure p.d. betⁿ 2 points of a circuit



Total voltage betⁿ A & B = V

resistance = G + R

Acc. to ohm's law

$$V = I_g (G+R)$$

$$\boxed{R = \frac{V}{I_g} - G}$$

→ Resistance of voltmeter > Resistance of galvanometer

→ Resistance of ideal voltmeter = ∞

Classification of Magnetic Material

Some important terms

① **Magnetic permeability (μ_r)**

- It is the ability of a material to permit the passage of magnetic lines through it.

or

The degree or extent to which magnetic field can penetrate a material.

- It is defined as the ratio of the no. of magnetic field lines per unit area (i.e. B) in that material to the no. of magnetic field lines per unit area in vacuum.

$$\mu_r = \frac{B}{B_0}$$

② **Magnetising force or Magnetising Intensity ($\vec{H}$)**

The degree to which a magnetic field can magnetise a material.

for a toroid $B = \mu n I$

$B = \mu H$

$$\boxed{H = nI}$$

It is defined as the no. of ampere turns flowing through unit length of toroidal solenoid to produce magnetic field in the solenoid.

Unit - Am^{-1} (SI)

Oersted (cgs)

③ Intensity of magnetisation (I)

- It represents the extent to which a specimen is magnetised when placed in a magnetising field.
- It is defined as the magnetic moment per unit volume of the material

$$I = \frac{M}{V}$$

Unit : $I = \frac{M}{V} = \frac{Am^2}{m^3} = Am^{-1}$

④ Magnetic susceptibility (χ_m)

- It is a property which determines how easily a specimen can be magnetised.
- It is defined as the ratio of I to H

$$\chi_m = \frac{I}{H}$$

Unit - No unit

Relation betn μ_r & χ_m

The total magnetic field in a material is

$$B = B_0 + B_m$$
$$= \mu_0 H + \mu_0 I$$
$$= \mu_0 (H + I)$$
$$= \mu_0 (H + \chi_m H)$$
$$B = \mu_0 H (1 + \chi_m)$$
$$\mu H = \mu_0 H (1 + \chi_m)$$
$$\frac{\mu}{\mu_0} = 1 + \chi_m$$
$$\boxed{\mu_r = 1 + \chi_m}$$

* $I = \frac{M}{V} = \frac{m \times 2l}{a \times 2l} = \frac{m}{a} = \frac{\text{pole strength}}{\text{area}}$

Types of magnetic material

(a) Diamagnetic substances

- Those substances in which the individual atoms do not possess any net magnetic moment on their own.
- When such substances are placed in an external magnetising field, they get feebly magnetised in a direction opposite to the magnetising field.
- Example : Cu, Pb, Au, Ag

(b) Paramagnetic Substances

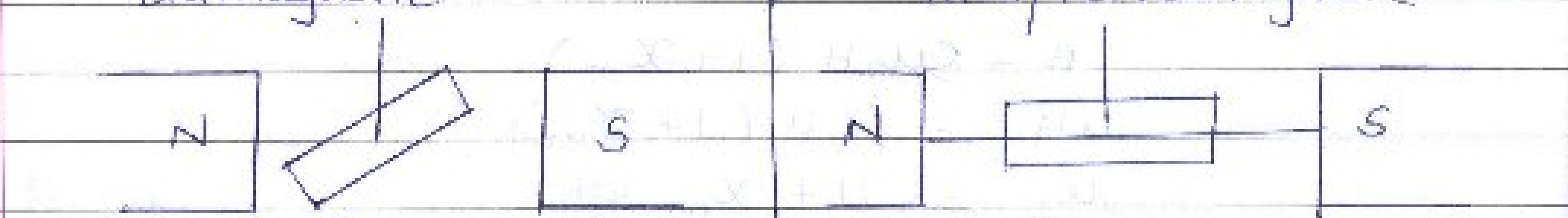
- Those substances in which each individual atom has a net non-zero magnetic moment of its own
- When such substances are placed in an external m.f, they get feebly magnetised in the direction of magnetising field
- Example : Al, Cr, Mg, Mn

(c) Ferromagnetic Substances

- same as paramagnetic (1st point)
- strongly magnetised (2nd pt.)
- Example : Fe, Co, Ni

Diamagnetic | Para/Ferromagnetic

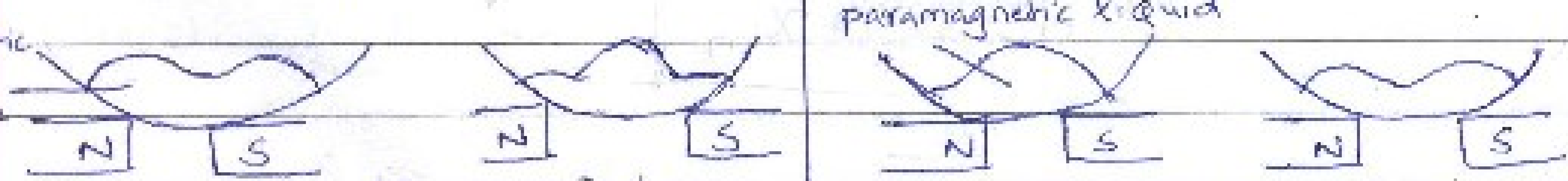
Alignment



In a uniform m.f

diamagnetic liquid substance

paramagnetic liquid



Stronger to weaker | weaker to stronger

In a non-uniform m.f

Property	Diamagnetic	Paramagnetic	Ferromagnetic
1) Attraction	weakly Repelled by a magnet	weakly attracted	strong attracted
2) When placed in magnetic field	M.f. lines do not prefer to pass through them	Most of m.f.l prefer to pass	All prefer to pass

Property	Diamagnetic	Paramagnetic	Ferromagnetic
3) Flux density (B) inside the material	less than that in air	larger than in air	much larger than in air
4) Magnetisation	Gets weakly magnetised in the direction opp. to the direction of magnetising field	weakly magnetised in the direction of magnetising field	strongly magnetised
5) μ	< 1	> 1	$>>> 1$
6) I & χ_m	$-ve$	$+ve$ (small)	$+ve$ (large)
7) Effect of tem.	No change in properties with tem. Don't obey Curie's law	With rise in tem. lose magnetic property. Obey	With rise in tem. Start behaving as paramagnetics. Obey
8) When placed in non uniform m.f.	Move from stronger to weaker field	Weaker to stronger	Weaker to stronger

Curie Law

It states that magnetic susceptibility of a material is inversely proportional to the tem. (in K) of the material

$$\chi_m \propto \frac{1}{T}$$

$$\boxed{\chi_m = \frac{C}{T}}$$

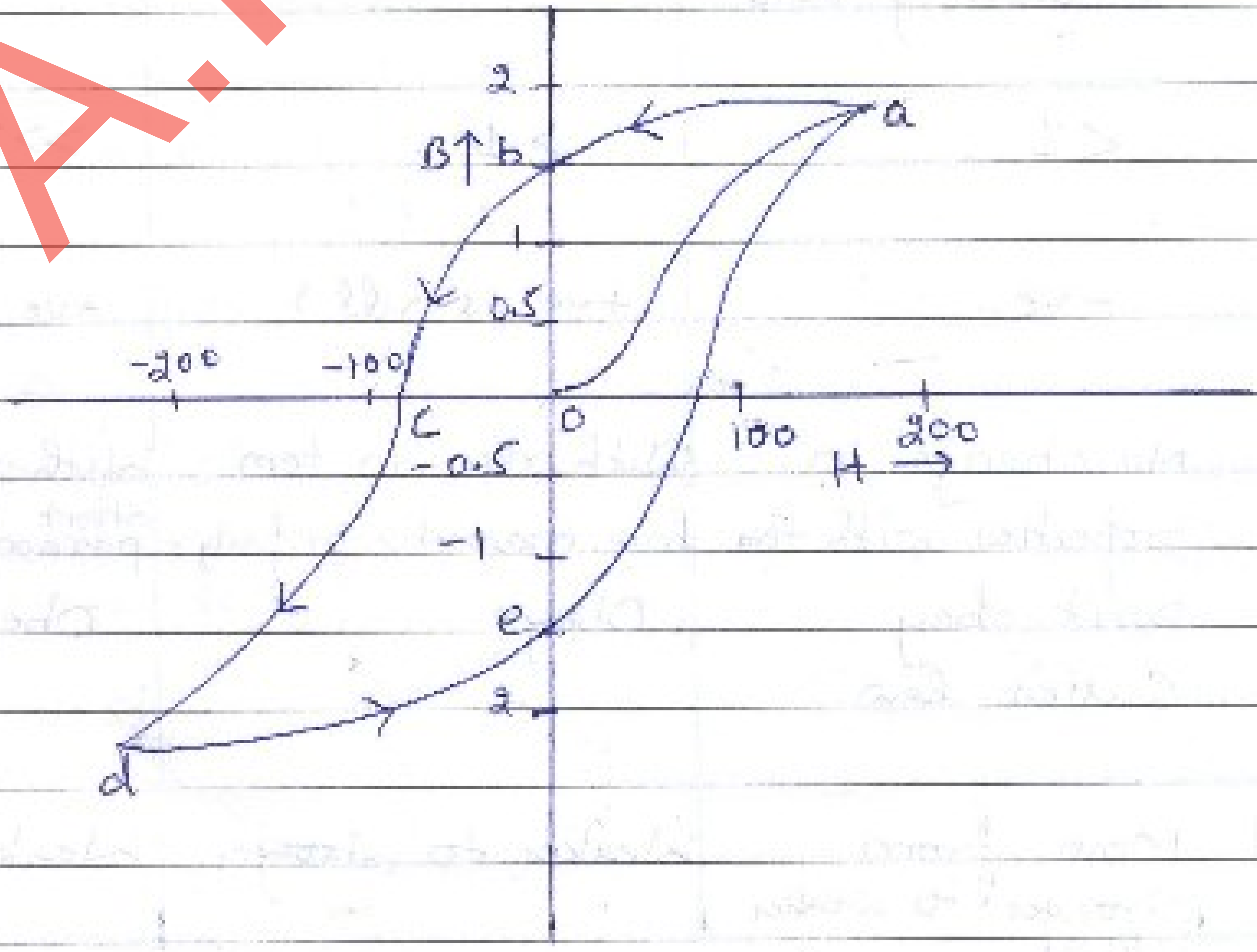
C - curie constant

Curie temperature

The tem. at which a ferromagnetic substance changes to paramagnetic

Hysterisis Curve

- It represents the relation bet^n $\vec{B}$ (or $\vec{I}$) of a ferromagnetic material with $\vec{H}$.
- It represents the behaviour of a material as it is taken through a cycle of magnetisation.



(i) Suppose the material is unmagnetised initially i.e. $\vec{B} = 0$ & $\vec{H} = 0$

(ii) Place the material in a solenoid & increase the current through the solenoid gradually.
With increase in $\vec{H}$, $\vec{B}$ increases & saturates (Curve Oa)
[This behaviour represents alignment & merger of domains of ferromagnetic material until no further enhancement in $\vec{B}$ is possible]

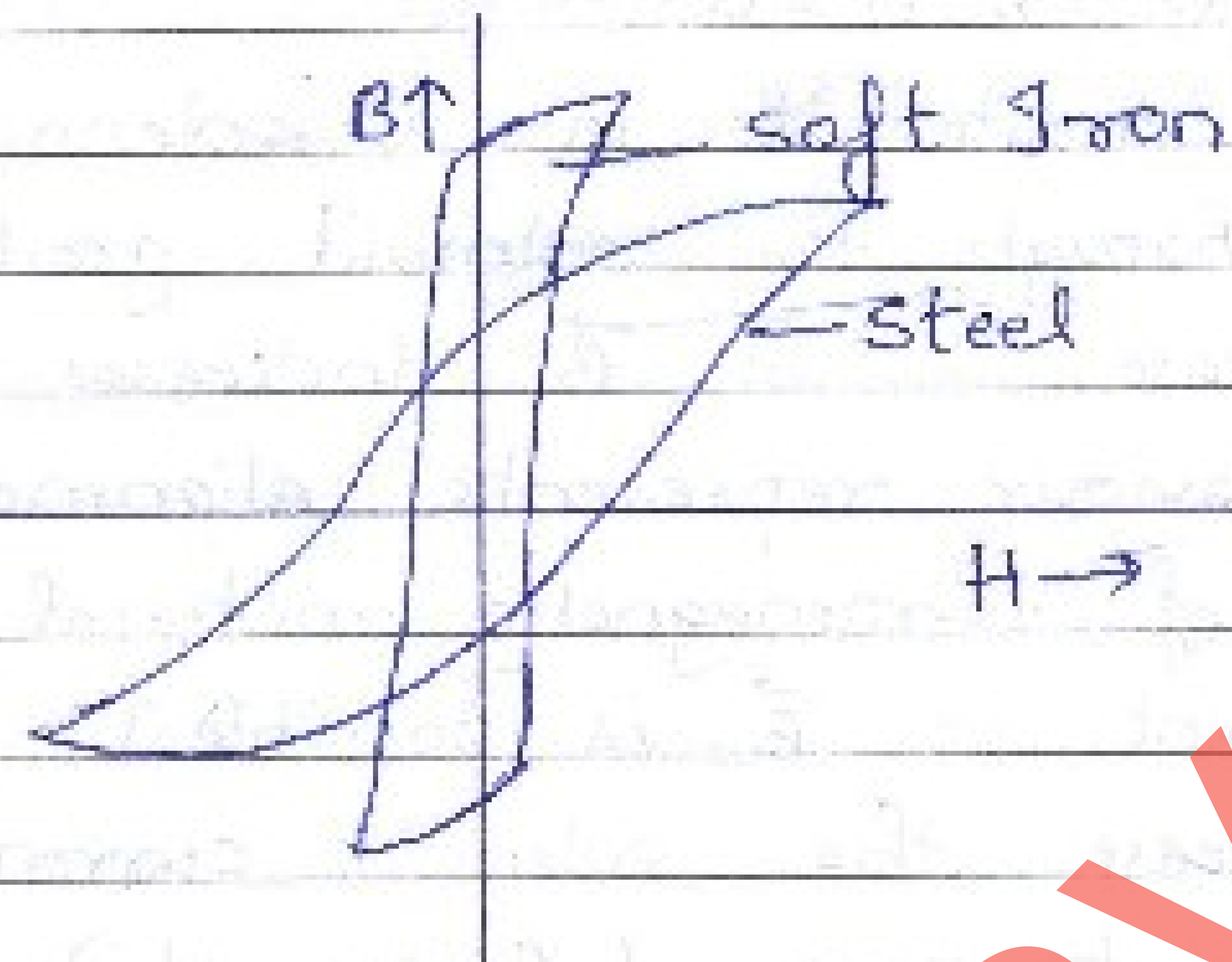
(iii) Now, decrease the solenoid current and hence $\vec{H}$ till it reduces to zero. (Curve ab)
" The value of $\vec{B}$ left in the specimen when the magnetising force is reduced to zero is called Retentivity or Residual magnetism of the material "
[This behaviour shows that the domains are not completely randomized even when $\vec{H}$ is removed]

(iv) Current in the solenoid is reversed & increased slowly till $\vec{B} = 0$ (Curve bc)
" To reduce Retentivity to zero we have to apply a magnetising force (Oc) in opp direction. This value of magnetising force is called Coercivity of material "

(v) Increase reverse current till saturation at (Curve cd) & reduce (Curve de) & increase (Curve ea)
The cycle repeats itself

* Hysteresis: The phenomenon of lagging of B behind H when a specimen of a magnetic material is subjected to a cycle of magnetisation.
* The loss of energy (in the form of heat) per unit volume of specimen per cycle of magnetisation is equal to the area of B-H loop of the specimen.

* Hysteresis loop for soft iron & steel



(i) Retentivity of soft iron > Retentivity of steel
(ii) Soft iron more strongly magnetised than steel.
(iii) Coercivity of soft iron < Coercivity of steel
Soft iron loses its magnetism rapidly than steel
(iii) Area of B-H loop (soft iron) < Area of B-H loop (steel)
Hysteresis loss less in soft iron

Uses of Ferromagnetics

(a) Permanent Magnets
The material chosen should have
(i) high retentivity (for strong magnet)
(ii) high coercivity (for long lasting magnetism)
(iii) high permeability (for easy magnetisation)

Steel is preferred for making permanent magnets because its coercivity is much larger than that of soft iron

(b) Electromagnets (Soft iron)
→ high permeability
– low retentivity

(c) Transformer cores

- The materials used for making transformer cores are subjected to A.C. cycle of magnetisation for a long period, so it should have a low hysteresis loss.
- Soft iron is used