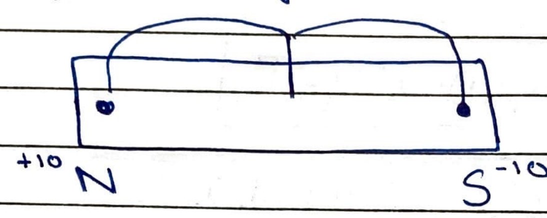
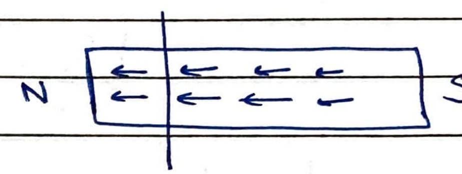
Ch-5

MAGNETISM

Properties of Bar magnet





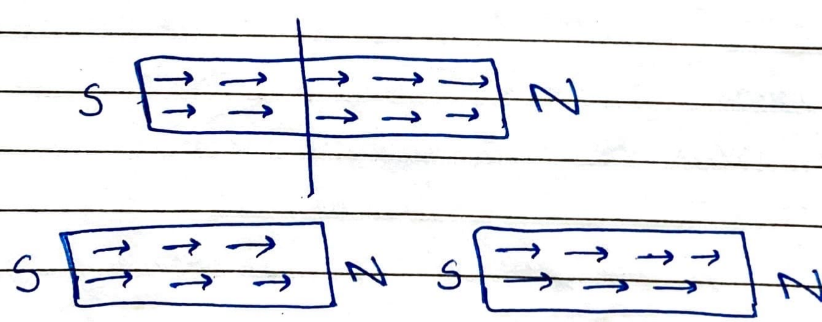
① Attractive property → A bar magnet always attracts iron towards it.

② Directive property → When a magnet is suspended freely, it alligns itself along Earth's N-S axis.

③ Like poles repel each other and unlike poles attract each other

④ In a magnet, maximum attraction or repulsion is at poles and minimum at the centre.

⑤



When we cut a magnet in two parts, two magnets are formed, but poles are not isolated

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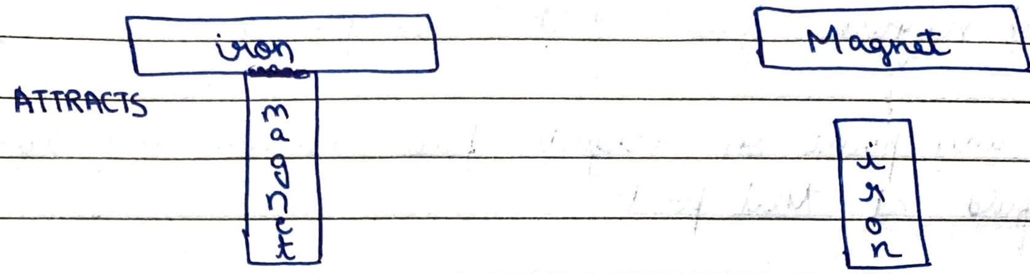
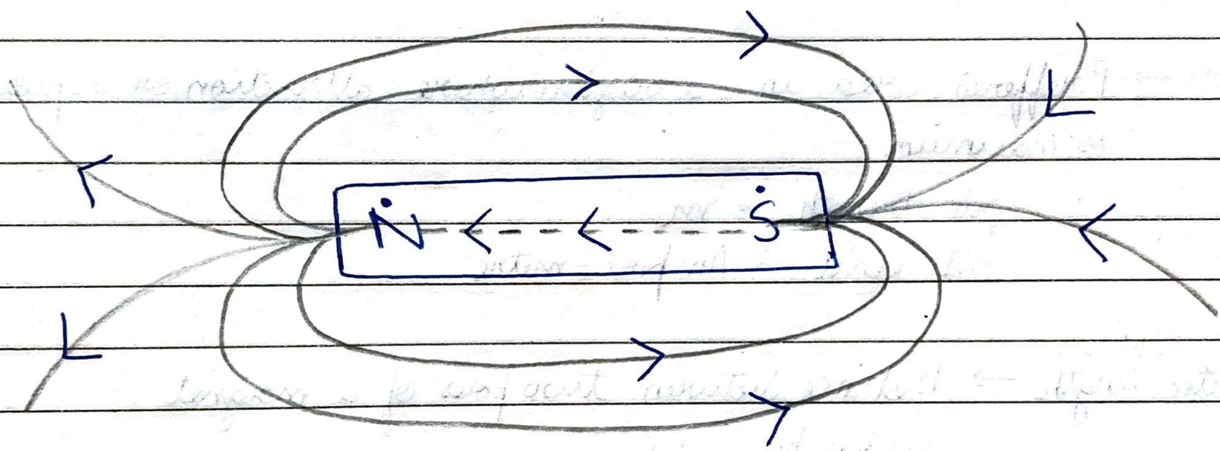
⑥ Repulsion is the surest test for magnetism.



PROPERTIES OF MAGNETIC FIELD LINES



① Outside the magnet, magnetic field lines move from North pole to South pole.

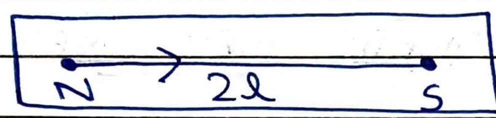
② Inside the magnet, magnetic field lines move from South pole to North pole i.e. they form closed loops.
(unlike electric field lines)

③ Closer the magnetic field line, stronger is the magnetic field and vice versa.

(4) No two magnetic field lines can even intersect each other, if they do so at the point of intersection there will be two direction of magnetic field which is not possible.

(5) Tangent at any point on magnetic field lines gives direction of magnetic field at that point.

SOME TERMINOLOGY IN MAGNET



(1) Pole → Preffered area in a region where attraction or repulsion is maximum.

pole strength = m

SI unit = Ampere-metre

(2) Magnetic length (M.L.) → Distance between two poles of a magnet.

Given by '2l'

SI unit = m

(3) Magnetic Moment (M) → It is defined as the product of either of the pole. Strength (m) and dis b/w poles

$$\vec{M} = m \times \vec{2l}$$

Vector quantity (N → S)

SI unit = Ampere-m^2

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(4) Geometric length (G.L.) → Actual length of a magnet

G.L. > M.L

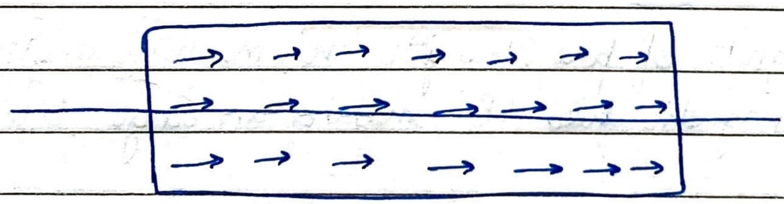
Poles are not exactly at ends.

Q1 If a bar magnet is cut into two halves :-

(i) longitudinally (ii) transversally

How its (i) poles strength
(ii) magnetic moment are effected ?

Ans
(i) Longitudnal Cut



m → Halved (pole strength halved)

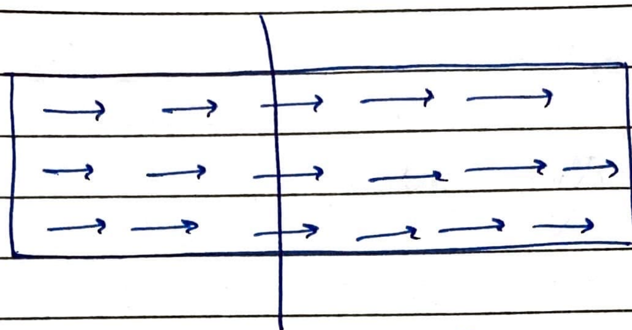
2l → Same

$M = m \times 2l$

M → Halved (magnetic moment)

Spiral

(ii) Transversal Cut



$m \rightarrow$ Same (pole strength same)

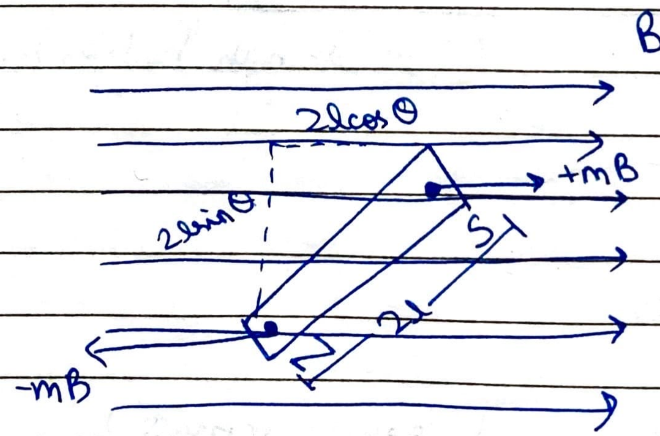
$2l \rightarrow$ Half

$M = m \times 2l$

$M \rightarrow$ Halved (Magnetic Moment halved)

TORQUE ON A ~~UNIFORM~~ BAR MAGNET KEPT IN UNIFORM MAGNETIC FIELD

Consider a bar magnet of pole strength 'm', magnetic length '2l' kept in uniform magnetic field 'B' making an angle θ with it.



$F = qE$
$= mB$

Total force $= -mB + mB$
$= 0$

Since the line of action is different, it experiences Torque.

$\tau = F \times \perp \text{dis}$
$\tau = mB \times 2l\sin\theta$

$$\boxed{\tau = MB\sin\theta}$$

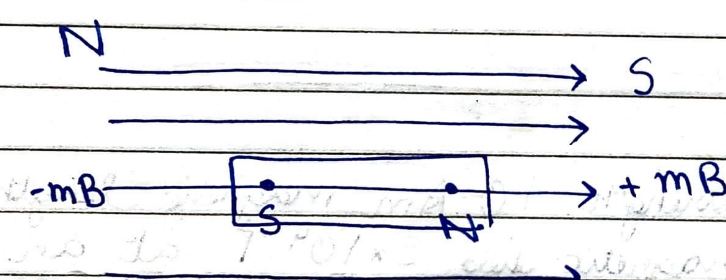
$$\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$$

$\{ m \times 2l = M \}$
↓
Magnetic Moment

$\therefore \tau \perp M$
$\tau \perp B$

Case I → when $\theta = 0°$

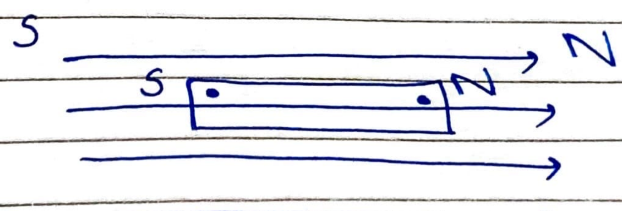
$$\boxed{\tau = 0}$$



$F = 0$ & $\tau = 0$

Stable Equillibrium

Case II $\theta = 180°$ (anti parallel)



$F = 0$
$\tau = 0$

Unstable Equillibrium

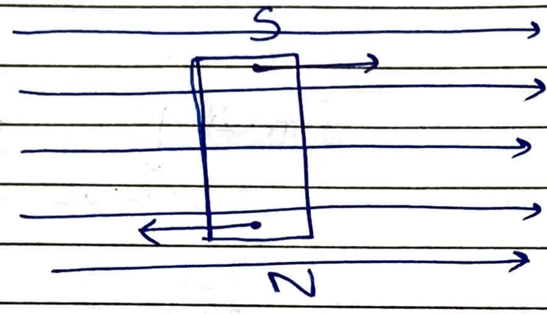
Date

Case

$\theta = 90^\circ$

$\tau = MB\sin 90^\circ$

$\boxed{\tau_{max} = MB}$ —— (1)



$\tau = MB\sin\theta$ (MB → from (1))

$\boxed{\tau = \tau_{max}\sin\theta}$

Q A bar magnet of pole strength 10 Am magnetic length 5cm is kept in magnetic field 5×10^4 T at an angle 30° with it. Find torque?

Ans

$m = 10\,Am$

$2l = 5\times10^{-2}\,m$

$B = 5\times10^4\,T$

$\theta = 30^\circ$

$\tau = MB\sin\theta$

$\tau = m\times 2l\,B\sin\theta$

$\tau = 10\times5\times10^{-2}\times5\times10^4\times\frac{1}{2}$

$\boxed{\tau = 125\times10^2\,Nm}$

Spiral

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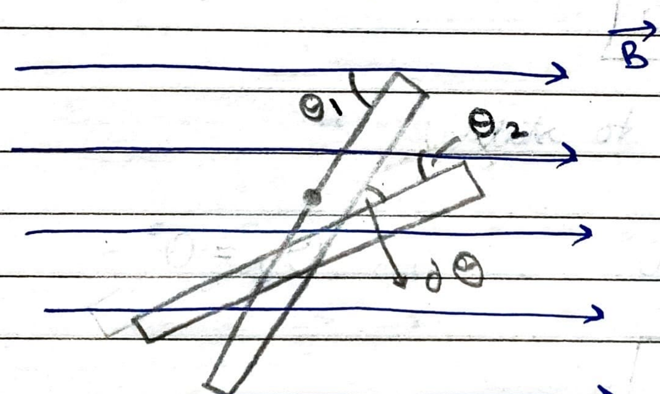
Q2 Maximum torque at a bar magnet is 50J. Find torque when same magnet is kept at 30°

Ans
$$\tau = \tau_{max} \sin\theta$$
$$= 50 \times \frac{1}{2}$$
$$\boxed{\tau = 25J}$$

WORK DONE / POTENTIAL ENERGY OF BAR MAGNET KEPT IN UNIFORM MAGNETIC FIELD

A Bar magnet of magnetic moment 'M' kept in magnetic field "B" at angle θ_1, Due to torque it rotates and makes angle θ_2.



$$dW = \tau d\theta$$
$$dW = MB\sin\theta\, d\theta$$
$$W = \int_{\theta_1}^{\theta_2} MB\sin\theta\, d\theta$$
$$W = MB\,[-\cos\theta]_{\theta_1}^{\theta_2}$$

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$W = -MB[\cos\theta_2 - \cos\theta_1]$

$W = MB[\cos\theta_1 - \cos\theta_2]$

↓

stored as potential energy

$$U = MB[\cos\theta_1 - \cos\theta_2]$$

Case I → from stable to unstable

$\theta_1 = 0°$ $\theta_2 = 180°$

$U = MB[1+1]$

$$U = 2MB$$

(on the system)

Case II → unstable to stable

$\theta_1 = 180°$ $\theta_2 = 0°$

$$U = -2MB$$

Case III → From maximum torque to any angle θ

$\theta_1 = 90°$ $\theta_2 = \theta$

$U = MB[\cos 90° - \cos\theta]$

$U = -MB\cos\theta$

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

RELATION B/W MAGNETIC MOMENT & CURRENT

Torque produced by bar magnet

$$\tau = MB\sin\theta \quad \text{--- (1)}$$

Torque produced by rectangular coil carrying current kept in magnetic field :

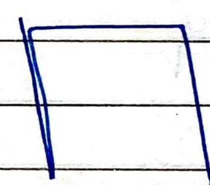
$$\tau = NBIA\sin\theta \quad \text{--- (2)}$$

Comparing (1) & (2),

$$M\cancel{B}\cancel{\sin\theta} = N\cancel{B}IA\cancel{\sin\theta}$$

$$\boxed{M = NIA}$$

If coil has one turn,
(N = 1)



$$\boxed{M = IA}$$

SI unit of M : Amp m^2

Soft iron is used to make electromagnetics because low coercivity & low ~~restr~~ retentivity

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GAUSS'S LAW IN MAGNETISM

Surface integral of magnetic field over a closed loop is always zero.

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

- This law implies that monopole does not exist.
- Poles always exist in pair.

ANALOGY

	Electric field		Magnetic field
$\vec{E}$	$\frac{1}{4\pi\varepsilon_0}$	$\vec{B}$	$\frac{\mu_0}{4\pi}$
charge	q	pole strength	m
dipole length	$2a$	magnetic length	$2l$
dipole moment	$p = q \times 2a$	dipole moment	$M = m \times 2l$

4

MAGNETIC FIELD AS AXIAL LINE

$$B_{axial} = \frac{\mu_0}{4\pi} \frac{2Mr}{(r^2 - l^2)^2}$$

$$r >>> l$$

$$B_{axial} = \frac{\mu_0}{4\pi} \frac{2Mr}{r^4} = \frac{\mu_0}{4\pi} \frac{2M}{r^3}$$

$$B_{equi} = \frac{\mu_0}{4\pi} \frac{M}{r^3}$$

$$\left\{ \frac{\mu_0}{4\pi} = 10^{-7} \right\}$$

MAGNETIC MATERIALS

- ~~Diag~~ Diamagnetic substance
- Paramagnetic substance
- Ferromagnetic substance

(I) DIAMAGNETIC SUBSTANCE

The substances which when kept in magnetic field are feeble, repelled by magnetic field or they are magnetic in a direction opposite to that of magnetic field.

Eg : bismuth (Bi), copper (Cu), lead (Pb), silicon (Si), nitrogen (N_2), water & sodium chloride (NaCl)

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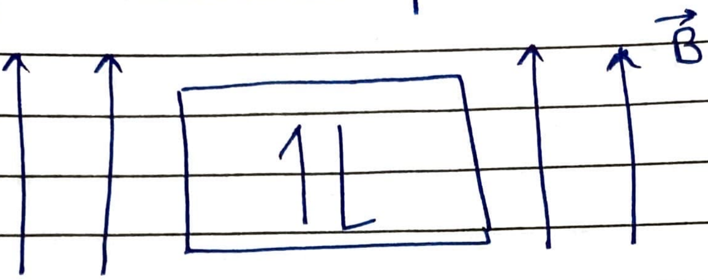
Causes of Diamagnetic

Diamagnetic substances have paired electrons in them



Paired e^-'s have opposite spin

When kept in magnetic field, ~~are~~ some electron will align in the direction of ~~opposite~~ field and the others, opposite to it, having net magnetisation will cancel.

But the e^- is kept in magnetic field ~~so~~ so it experiences force, and there will be a change in its momentum. ~~E~~

∴ Electrons will have no momentum opposite to magnetic field and thus we say that Diamagnetic substances are feeble repelled by magnetic field.

Properties of Diamagnetic Substances

1) These are magnetised in a direction opposite to that of magnetic field.

2) They are feeble repelled by magnetic field.

3) Intensity of magnetisation of diamagnetic substance is small -ve.

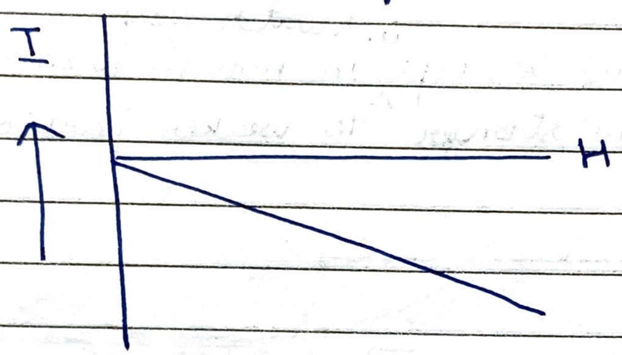
$$\boxed{I = \text{small } -ve}$$

4) Magnetic Susceptibility (X_m)

Magnetic Susceptibility of diamagnetic substance is small -ve

$$-1 \leq X_m < 0$$

5) Graph b/w I & H for diamagnet is as shown

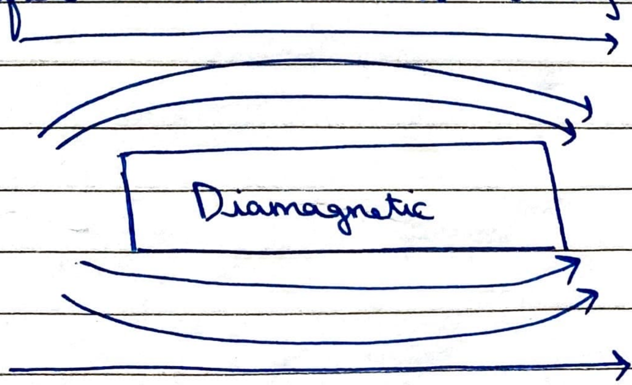


$$X_m = -ve$$

6) Relative Permeability (μ_r)
of diamagnetic substance is less than 1

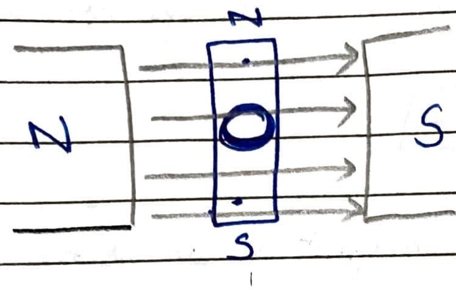
$$\mu_r < 1$$

7) When a diamagnetic rod is kept between magnetic field lines, magnetic field lines will move away from it. → depends on Permeability

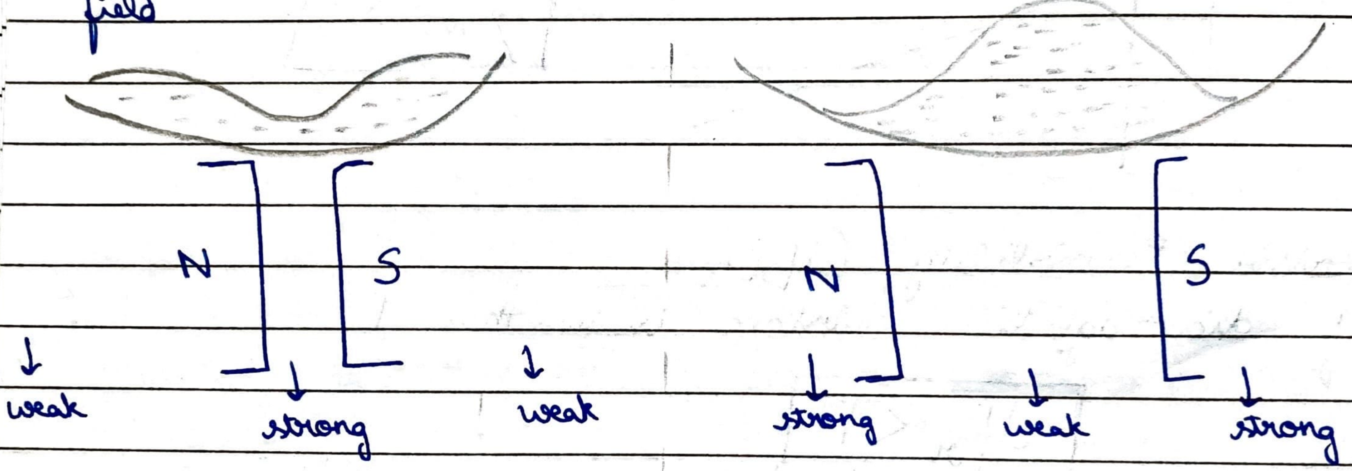


8) Do not obey Curie's Law
↓
Temperature ↑
Magnetic properties ↓

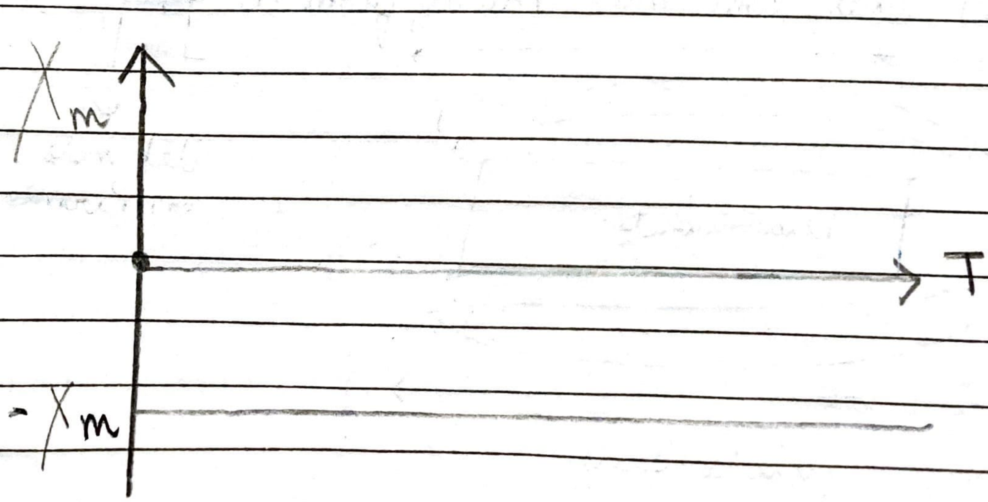
9) When a diamagnetic rod is suspended in uniform magnetic field, it alligns itself perpendicular to magnetic field



10) When a diamagnetic liquid is kept in a watch glass, in non-uniform magnetic field, it aligns itself from stronger to weaker part of magnetic field



11) Graph between Magnetic Susceptibility and Temperature



(II) PARAMAGNETIC SUBSTANCES

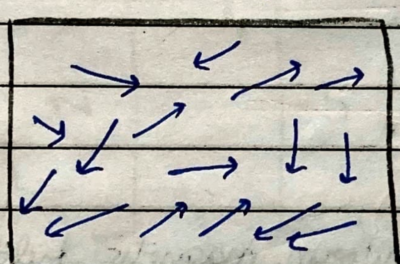
The substances which when kept in magnetic field are feeble ~~attracted~~ attracted towards magnetic field.
They are magnetised in the direction of magnetic field.

Egs: aluminium (Al), Sodium (Na), Calcium (Ca), oxygen (O_2 at STP), Copper chloride ($CuCl_2$)

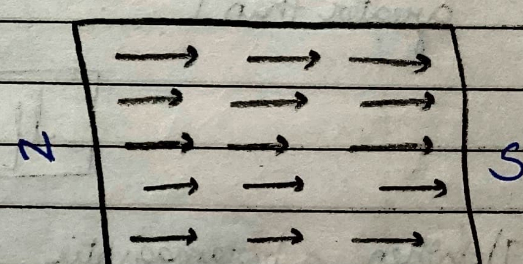
Causes of Paramagnetism

Paramagnetic substances have unpaired e^-'s in them. In the absence of $\vec{B}$, they are moving randomly, but on applying $\vec{B}$, they all move in one direction causing magnetism.

absence of $\vec{B}$



applying $\vec{B}$



Properties of Paramagnetic Substances

1) They are magnetised in the direction of magnetic field.

2) They are feeble attracted towards magnetic field.

3) Intensity of magnetisation (I) of paramagnetic substances is small +ve.

$$I = \text{small } +ve$$

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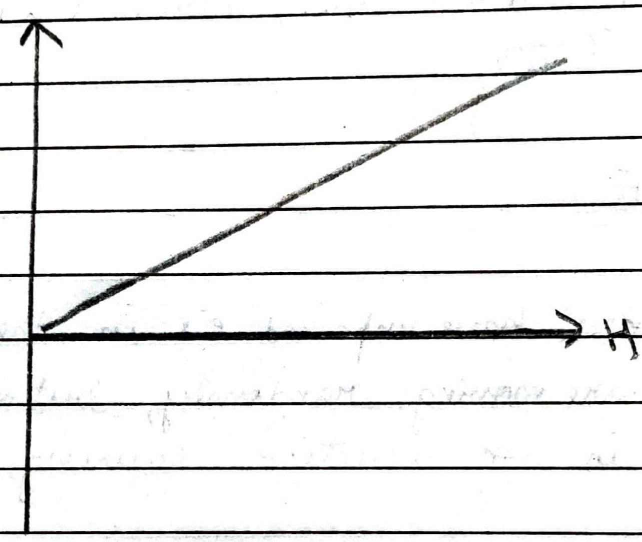
4) Magnetic Susceptibility of paramagnetic substances is small positive and lies between 0 & 1.

$$0 \leq \chi_m < +1$$

5) Graph b/w I & H

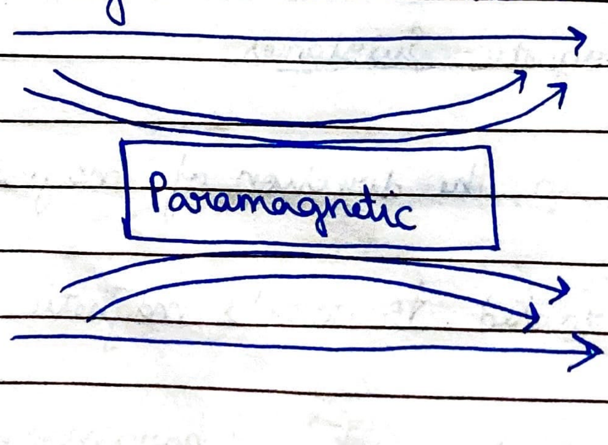


slope = small +ve

6) Relative permeability of ~~para~~ paramagnetic substances is slightly greater than 1.

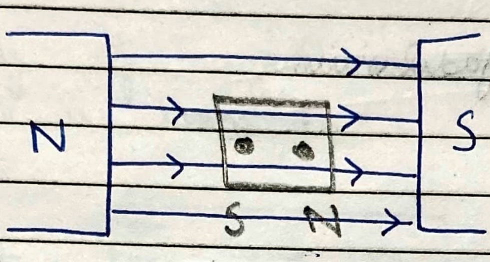
$$\boxed{\mu_r > 1}$$

7) When a paramagnetic rod is kept in uniform magnetic field, magnetic field aligns themselves towards it.

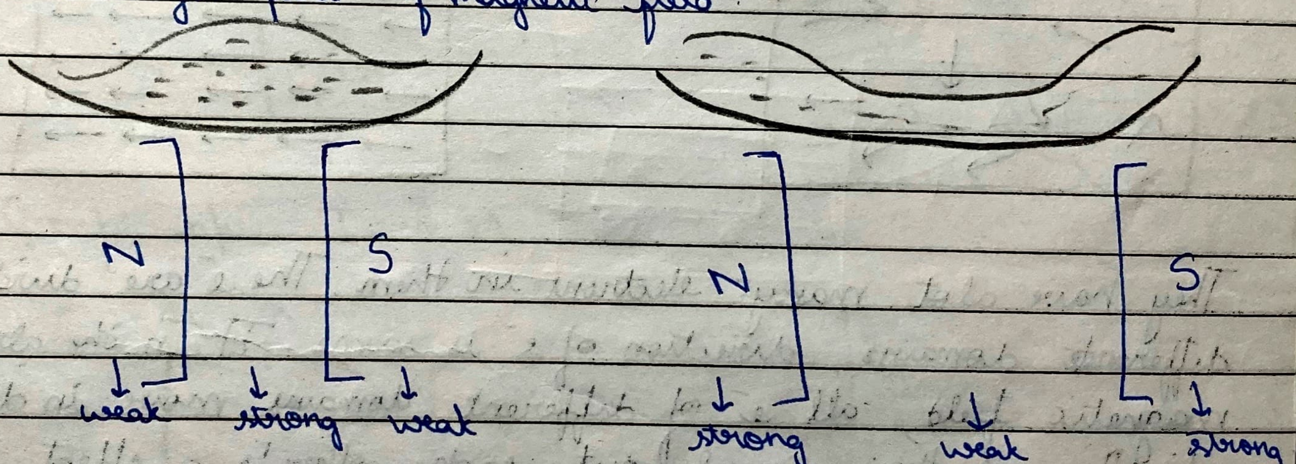


8) obey Curie's law

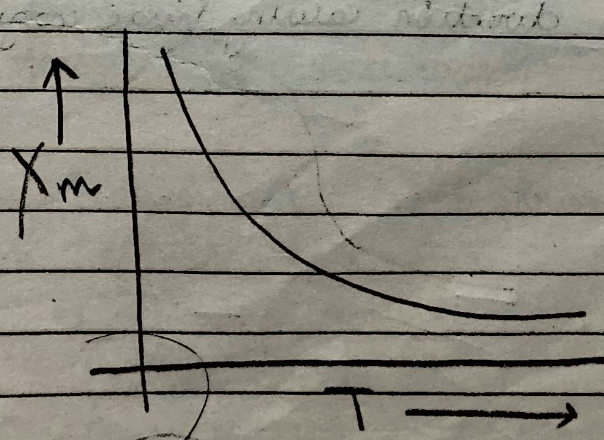
9) When a Paramagnetic rod is suspended freely in uniform magnetic field, it alligns itself parallel to magnetic field.



10) When a paramagnetic liquid is kept in watch glass, in a non uniform magnetic field, it alligns from weaker to stronger part of magnetic field.



11) Graph between Magnetic Susceptibility and temperature



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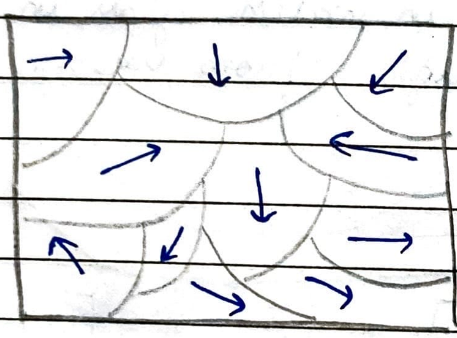
(III) FERROMAGNETIC SUBSTANCES

The substances which when kept in magnetic field are strongly attracted towards magnetic field. They are magnetic in the direction of magnetic field.

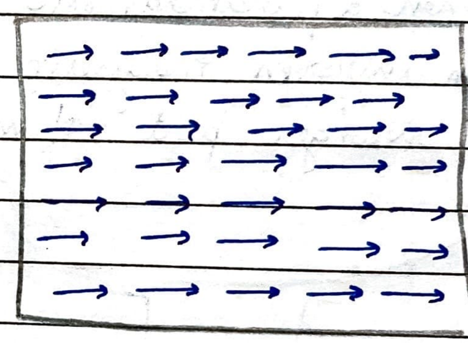
Egs: Iron, cobalt, nickel, gadolinium

Causes of Ferromagnetism

Absence of $\vec{B}$



Presence of $\vec{B}$



They have alot many electrons in them. The e^- are divided in different domains, direction of e^- is same. ~~It~~ In the absence of magnetic field, all e^- of different domains move in different dir^n, so they cancel out each other's ~~a~~ effect.
As and when, magnetic field is applied, all e^- of all domains move in one direction causing huge magnetisation

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Properties of Ferromagnetic ~~Su~~ Substances

1) They are magnetised in the direction of magnetic field

2) They are strongly attracted towards the magnetic field.

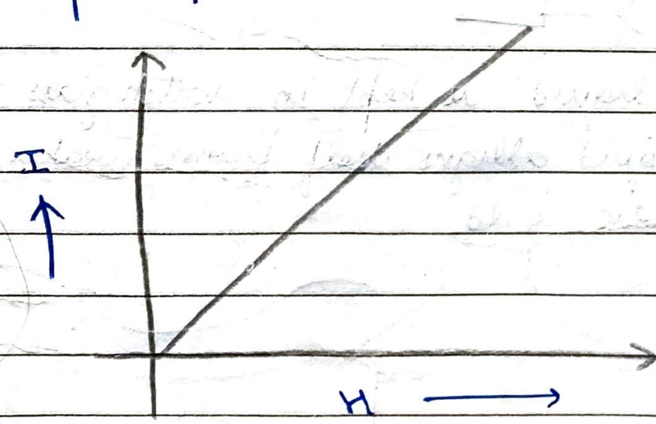
3) Intensity of magnetisation (I) of Ferromagnetic substance is large +ve

$$\boxed{I = \text{large } +ve}$$

4) Magnetic Susceptibility of Ferromagnetic substance is large +ve. and ~~lies between~~

$$\boxed{\chi_m >>> 1}$$

5) Graph b/w I & H



6) Relative permeability of Ferromagnetic substances is much greater than 1.

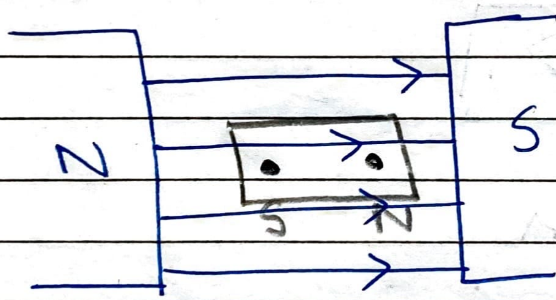
$$\boxed{\mu_r >>> 1}$$

Spiral

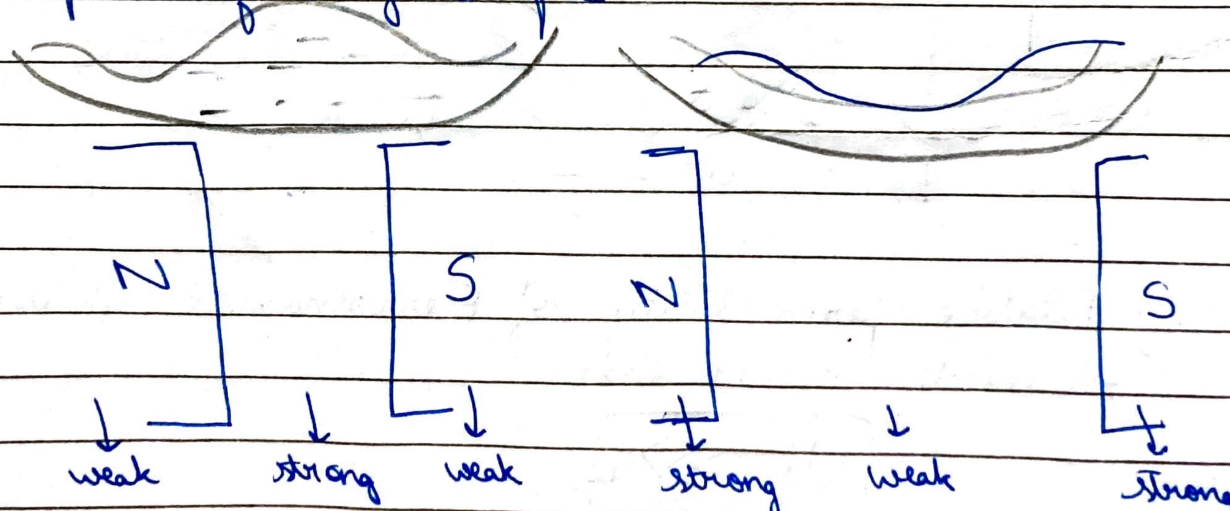
7) When a Ferromagnetic rod is kept in ~~unfi~~ uniform magnetic field, magnetic field allign themselves towards it

8) It obey's Curie's law.

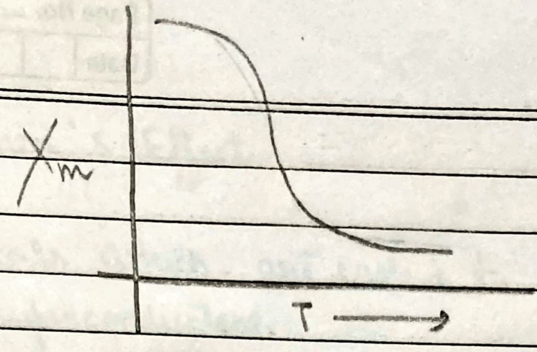
9) When a ~~fe~~ Ferromagnetic rod is suspended freely in uniform magnetic field it alligns itself parallel to the magnetic field.



10) When a ferromagnetic liquid is kept in watch glass in non uniform magnetic field, the liquid alligns itself from weaker to stronger part of magnetic field.



11) Graph b/w Magnetic Susceptibility & temperature



PROPERTY	DIAMAGNETIC	PARAMAGNETIC	FERROMAGNETIC
① Effects of magnets	feebly repelled by magnets	feebly attracted by magnets	strongly attracted by magnets
② In external magnetic field	magnetised in the opposite dir^n of magnetic field	magnetised in the dir^n of magnetic field	strongly magnetised in the dir^n of magnetic field
③ In Non Unifor M.F.	move slowly from stronger to weaker parts of field.	move slowly from weaker to stronger parts of field	quickly from weaker to stronger parts of field
④ Susceptibility	small & negative $-1 \leq X_m < 0$	small & positive $0 < X_m \leq 1$	very large & positive $X_m > 1000$
⑤ Relative Permeability (μ_r)	slightly less than 1 $\mu_r < 1$	slightly greater than 1 $\mu_r > 1$	much greater than 1 $\mu_r >>> 1$
⑥ Intensity of (I) Magnetisation	small -ve	small +ve	large +ve
⑦ In a Uniform Magnetic Field	a freely suspended diamagnetic rod alligns itself ⊥ to the field	a freely suspended paramagnetic rod alligns itself ‖ to the field.	a freely suspended ferromagnetic rod alligns itself ‖ to the field.
Examples	Bi, Cu, Pb, Si, NaCl	Al, Na, CA, O_2 (at STP)	Fe, Ni, Co, Alnico, Fe_2O_3

Date

⇒ Meissner's Effect

- The metals which are cooled to a very low temperature become superconductors.
- They exibit both perfect conductivity and perfect diamagnetism.
- They expel out all magnetic field lines from them.
- $\chi_m = -1$ & $\mu_r = 0$

This phenomenon of perfect diamagnetism in superconductors is called meissner's effect.

QUESTIONS

Ques1 The permeability of a magnetic material is 0.9983. Name the type of magnetic material, it represent.

Ans Diamagnetic material

Ques2 The susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic material it represents.

Ans Paramagnetic material

Ques3 The susceptibility of a magnetic material is -4.2×10^{-6}. Name the type of magnetic material it represents.

Ans Diamagnetic material

Ques4 Define magnetic susceptibility of a material. Name two elements, one having +ve susceptibility and other having negative susceptibility. What does negative susceptibility signify?

Ans It is defined as the ratio of the ~~raten~~ intensity of magnetisation M to the magnetising field intensity H. denoted by χ_m

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

Spiral