Magnetic Properties of Matter

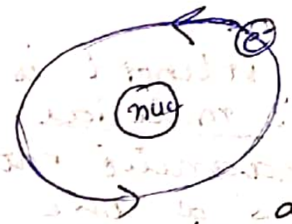
ZOOM

Matter/material body → Composed of large No. of e⁻s and nucleus in atoms

Consider e⁻s & nucleus in 1 atom

Analogy of sun & earth

→ e⁻s Revolute about Nucleus in its orbit



→ Forms a tiny atomic current loop (Amperian current)

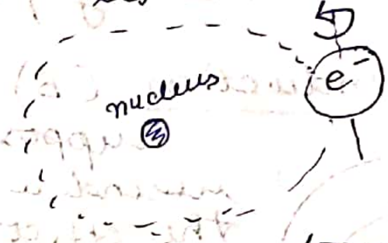
→ Thus has a magnetic field and associated magnetic moment m.

$m = IA$

A = Area of orbit

→ such magnetic moment is called orbital magnetic moment

e⁻ Rotate about its axis



Forms a tiny atomic current loop (Amperian current)

Thus has a magnetic field and associated magnetic moment m.

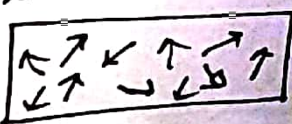
~~A = Area of orbit~~

Such magnetic moment is called spin magnetic moments.

→ So we infer that any material body consists of orbital and spin magnetic dipoles having orbital and spin magnetic moments respectively because of such motion of various e⁻ inside atoms. (Atom is Neutral so No charge Transport)

In absence of H (Magnetic Field Intensity), such dipoles of individual atoms are randomly oriented due to the thermal energy and Net Magnetic moment is 0.

In some materials, this cancellation is NOT complete which leads to the magnetic moment.

 → Net moment = 0

When an External magnetic field intensity H is applied, two processes can occur

1. The atoms with non-zero magnetic moment align along direction of H. This process increases the magnetic moment of the material

2. If the atom has a zero magnetic moment, the applied magnetic field distorts the e^- orbit and thus induces magnetic moment which is in direction opposite to H.

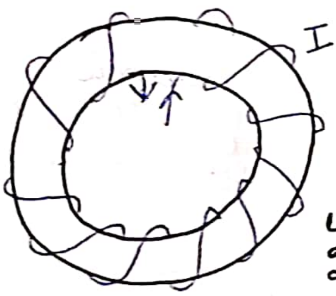
Magnetising Field (B_0)

When a magnetic material is placed in a magnetic field, a magnetism is induced in it. The magnetic field that exists in vacuum and induces magnetism is called magnetising field. For example, consider a toroidal solenoid carrying current I and placed in vacuum. If the solenoid has n turns per unit length, then the magnetic field set up in solenoid

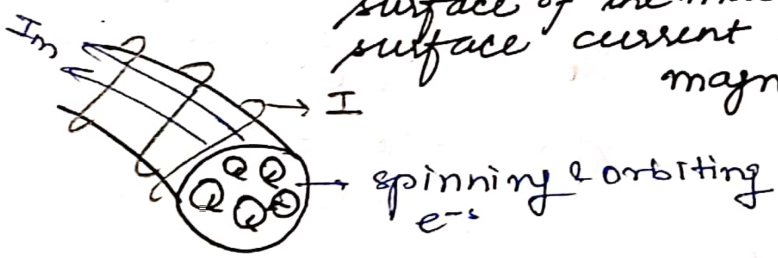
i.e $B_0 = \mu_0 n I$

(This is caused by free current in solenoid)

Magnetic Induction (B)



suppose the toroidal solenoid is wound round a ring of magnetic material. Under the effect of $\vec{B_0}$, the magnetic moments of the atomic current loops of the magnetic material tend to align themselves with or against the magnetising field B_0. This gives rise to a net current on the surface of the material & is called magnetising surface current I_m. The current induces magnetic field $\vec{B_M}$ inside the material



$$B_M = \mu_0 n I_M$$

Total Magnetic field / Magnetic Induction $\vec{B} = B_0 + B_M$

B_0 = External magnetising field

B_M → additional magnetic field produced by magnetisation of material

$\vec{B}$ is therefore called magnetic induction

It is total no. of magnetic lines of force crossing per unit area normally through a material.

SI unit → Tesla or $Wb/m^2 \equiv N m^{-1} A^{-1}$ or $J A^{-1} m^{-2}$

Magnetising Field Intensity (H) or Magnetic Intensity

The ability of magnetising field to magnetise a material medium is expressed as a vector $\vec{H}$

$$B_0 = \mu_0 n I = \mu_0 H$$

where $H = nI$. Its magnitude may be defined as no. of ampere turns flowing round the unit length of the solenoid required to produce the given magnetising field.

Note: It is independent of the nature of magnetic material, depends only on the applied current I

$B = \mu H$ in the presence of magnetic material

Units: $Am^{-1} \equiv N m^{-2} T^{-1}$ $J m^{-1} Wb^{-1}$

Intensity of Magnetisation (M) / Magnetisation

When magnetic material is placed in a magnetising field, it gets magnetised. The magnetic moment developed per unit volume of a material when placed in a magnetising field.

$$M = \frac{m}{V} = \frac{n I_m A}{A} = n I_m$$

I_m = surface magnetisation current.

n = no. of turns per unit length

A = Area (cross-section)

$B_M = \mu_0 n I_m = \mu_0 M$

Units: $A m^{-1}$ (same as H)

$B = B_0 + B_m$
$= \mu_0 H + \mu_0 M$

$$\boxed{B = \mu_0 (H+M)}$$

<u>Magnetic Permeability</u> (μ). It is the measure of the extent to which a material can be penetrated by a magnetic field.

$B = \mu H$

$\Rightarrow \mu = \frac{B}{H} \rightarrow$ Ratio of magnetic induction (B) to magnetic intensity (H).

units $\frac{\text{Tesla}}{\text{Am}^{-1}}$ = Tesla. Amp^{-1}. m.

<u>Relative Permeability</u> (μ_r) Ratio of permeability of medium to that of free space

$\mu_r = \frac{\mu}{\mu_0}$ (No units)

For vacuum, $\mu_r = 1$
air $\mu_r = 1.0000004$
Iron $\mu_r > 1000$

<u>Magnetic Susceptibility</u> (χ_m) It measures the ability of a substance to take up magnetisation when placed in a magnetic field.

$\chi_m = \frac{M}{H}$ (No units)

<u>Relation b/w μ & χ:</u>

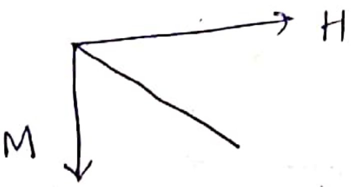
$B = \mu_0 (H+M)$ — (1)
$B = \mu H$ — (2)

compare (1) & (2)
$H\mu = \mu_0 (H+M)$
$\mu = \mu_0 \left(1 + \frac{M}{H}\right) \Rightarrow$

$$\boxed{\begin{aligned} &\mu = \mu_0 (1 + \chi_m) \\ \Rightarrow &\frac{\mu}{\mu_0} = \mu_r = 1 + \chi_m \end{aligned}}$$

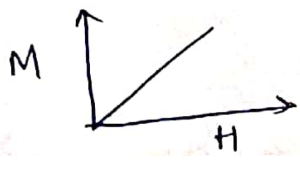
Classification of Materials.

1. **Diamagnetic substances** – are those which

1. Develop weak magnetisation in the opposite direction of the magnetising field.
2. Here the individual atoms donot have intrinsic magnetic moment. When an external H is applied, the induce moment is set up opposite to H.
3. Weakly repelled by magnets
4. Tend to move from stronger to weaker parts of a magnetic field.
5. Egs. Bi, Copper, Lead, Zinc, Gold, Silicon Water, NaCl, N_2
6. 

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

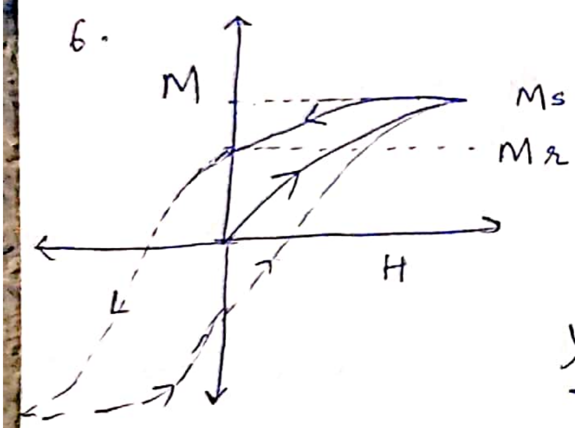
2. **Paramagnetic substances**

1. Develop weak magnetisation in the direction of magnetising field.
2. Here materials have intrinsic/permanent magnetic moments & cancellation of magnetic moments is not complete. In presence of $\vec{H}$ (external), the alignment of magnetic moments occur along $\vec{H}$ & the induced moment is produced opposite to $\vec{H}$.
The Resultant is the former which is dominant
Hence Resultant magnetic moment is always in the direction of magnetic field.
3. Weakly attracted by magnets
4. Tend to move from weaker to strong field region
5. Egs- Mn, Al, Chromium, Platinum, Na, O_2
6. 

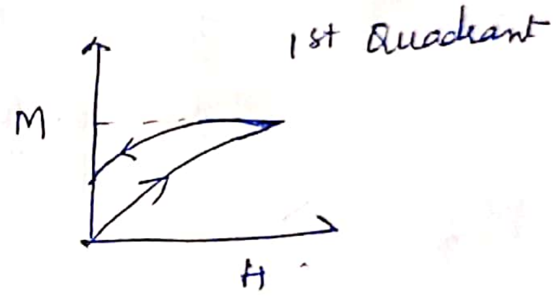
χ is +ve

3. <u>Ferromagnetic substances</u>

1. Develop strong magnetisation in the direction of magnetising field.
2. Here the material has intrinsic magnetic moment which is larger than that of paramagnetic. With application of H, magnetic moment increases enormously.
3. Strongly attracted by magnets
4. Tend to move from weaker to stronger parts of a magnetic field
5. eg - Iron, Cobalt, Nickel
6.



→



<u>X very high</u>

Comparative Study

Property	Diamagnet	Paramagnet	Ferromagnet
1) Effect of magnets	Weakly repelled by magnets	Weakly attracted	Strongly attracted
2) In external mag. field	acquire weak M in opposite dirn to field	Acquire weak M in the direction of field	Acquire strong M in dirn of field.
3) In Non Uniform mag field	Tend to move slowly from stronger to weaker parts of field.	Tend to move slowly from weaker to stronger field	Move quickly from weak to strong-field.
4) In Uniform mag. field	Freely suspended diamag. rod aligns its ⊥ to field	Parallel to field	Parallel to field
5) χ_m	$-1 \leq \chi_m \leq 0$	$0 < \chi_m < \epsilon$, ϵ is small	$\chi_m > 1000$
6) μ_r	$0 \leq \mu_r < 1$	$1 < \mu_r < 1+\epsilon$	$\mu_r > 1000$
7) μ	$\mu < \mu_0$	$\mu > \mu_0$	$\mu >> \mu_0$
8) Effect of Temp.	Independent	$\chi \propto \frac{1}{T}$	$\chi \propto \frac{1}{T-T_c}$ $(T>T_c)$
9) Removal of mag. field	Mag. Lost as mag. field is removed	Mag. lost as magnetising field is removed	Magnetisation Retain even after mag. field is removed
10) Variation of M with H	M changes linearly with H	M changes linearly with H & attains saturation @ low T & in very strong fields	M changes with H non linearly & ultimately attains saturation
11) Hysteresis	No	No	Yes
12) Physical State	Solid Liquid or Gas	Solid Liquid or Gas	Normal Solids
13) Examples	Bi, Cu, Pb, Si, N_2, H_2O, NaCl	Al Na Ca O_2 $CuCl_2$	Fe Ni, Co Gd Fe_2O_3 Alnico