Unit – III

Based on their magnetic properties the magnetic substances have been classified as

Diamagnetic materials,
Paramagnetic materials &
Ferromagnetic materials, Antiferromagnetic Ferrimagnetic
Antiferromagnetic & Ferrimagnetic

This classification is done on basis of the **sign & magnitude of susceptibility**

\# materials for which χ is +ve. i.e M parallel to H are paramagnetic

\# materials for which χ is -ve i.e M is antiparallel to H are diamagnetic.

Diamagnetic materials Ionic & covalent crystals are diamagnetic. These substances have atoms or ions with complete shells, and their diamagnetic behaviour is due to the fact that a magnetic field acts to ~~dont~~ disort the orbital motion. Thus the source of diamagnetism is the orbital motion of $\bar{e}$'s in atoms.

Paramagnetic materials The best known examples of paramagnetic materials are the ions of transition and rare-earth ions. Now paramagnetic (or permanent) moments of atoms result from

a) Intrinsic or spin Moment of the electrons
b) Orbital motion moment and
c) Nuclear magnetic moment.

The fundamental requirement for the existance of paramagnetism in solids is that the individual magnetic moments possess some degree of isolation. (If it is not so then wave fns overlap and Paulis Exclusion Principle pairs them). In Transition and rare earth elements, the isolation is the result of the shielding of the unfilled inner shells by the outer shells. In radicals the single $\bar{e}$ is isolated by complicated and huge molecular structures.

In paramagnetism, at lower temperatures it is possible to distinguish between three different subclasses of magnetic materials called as FERROMAGNETS, ANTI FERROMAGNETS or FERRIMAGNETS the distinction is on basis of alignment of spontaneous atomic or molecular moments w.r.t one another and w.r.t the crystallographic axes. (Detailed explanation given) ~~ahead~~)

Important Magnetic Properties

\# Magnetic Susceptibility χ_m

Now the Magnetic Induction B and Magnetic Field Intensity H are related as

$$B = \mu_0 H \quad — ① \qquad \mu_0 = 4\pi \times 10^{-7}\ H/m$$

when the material is placed in a magnetic field, the medium gets magnetised given by Magnetization vector M (dipole moment per unit Volume). The magnetic induction B inside the medium is given by

$$B = \mu_0 H + \mu_0 M \quad — ②$$

here $\mu_0 H$ is due to external sources & $\mu_0 M$ due to magnetization of medium.

Now $M \propto H \Rightarrow M = \chi_m H$

χ_m is magnetic susceptibility

$$\text{i.e } \chi_m = \frac{M}{H} \quad — ③$$

from eq's ② & ③ we get

$$B = \mu_0 (1 + \chi_m) H \quad — ④$$

Thus $B \propto H \Rightarrow B = \mu H$

$$\text{where } \mu = \mu_0 (1 + \chi_m) \quad — ⑤$$

Called as "permeability of the medium"

Also commonly used term is relative permeability

$$\mu_r = \frac{\mu}{\mu_0} = 1 + \chi_m \quad —⑥$$

$$\Rightarrow \mu = \mu_r \mu_0$$

$$\Rightarrow \vec{B} = \mu_0 \mu_r \vec{H}$$

and for free space $\vec{B} = \mu_0 \vec{H}$ —⑦

for paramagnetic material χ_m is +ve.

for diamagnetic materials χ_m is −ve.

for ferromagnetic materials $\mu >> 1$

for paramagnetic materials $\mu > 1$

& for diamagnetic materials $\mu < 1$

Atomic Magnetic Moment

Since paramagnetism depends upon magnetic moments of atoms or ions, which in turn are due to **orbital** and **spin** motion of e^-'s

Now an e^{-1} in orbit can be considered as a small circulating current $i = \frac{e}{T} = e\nu$

The primitive magnetic moment (μ_m) due to circulating e^{-1} is

μ_l = current x area.

$$\mu_l = iA = i \times \pi r^2$$

if v_0 is orbital vel $= \frac{2\pi r}{T} = 2\pi r \nu$

$$\Rightarrow \nu = \frac{v_0}{2\pi r}$$

$$\therefore \mu_l = \frac{e v_0}{2\pi \cancel{r}} \cdot \pi r^{\cancel{2}} = \frac{e v_0 r}{2}$$

Now angular momentum

$$L = m v_0 \times r = m v_0 r$$

$$\mu_l = \frac{eL}{2m} \quad \left[\begin{array}{l}\mu_m \text{ is opp to } L \\ \text{as } e^{-1} \text{ is -vely charged}\end{array}\right]$$

Thus $\mu_l = \frac{|e|}{2m} L$ —⑧

Bhor megneton

$$\mu_B = \frac{e}{2m} \frac{h}{2\pi} = \frac{eh}{4\pi m} = 9.27 \times 10^{-24} \text{ A m}^2 \quad —⑨$$

also for simple charge distributions

$$\gamma_L = \frac{\mu_m}{L} = \frac{-|e|}{2m} = \text{Gyromagnetic Ratio} \quad —⑩$$

Spin Magnetic Moment

Similarly the magnetic moment associated with spin is

$$\vec{\mu}_s = -\left(\frac{e}{m}\right)\vec{S} \quad —⑪.$$

$$\mu_s = -\frac{2\mu_B}{\hbar}\vec{S} \quad \text{from eq}(9)$$

$$\mu_s = -g_s \frac{\mu_B}{\hbar}\vec{S}$$

Now $g_s = 2$ for spin

$\gamma_s = \frac{\mu_s}{S}$ = gyromagnetic ratio for spin

$$\boxed{\gamma_s = -\frac{e}{m} = -\frac{2\mu_B}{\hbar}}$$

Clearly $\gamma_s = 2\gamma_L$

i.e its value is twice that of orbital motion of e^{-1}.