Magnetic Materials

Terminology and classification

Derivation of magnetic moments of an atom

Ferromagnetism and related phenomena

Ferrites, The Domain Structure

The Hysterisis loop

Types of magnetic materials soft & hard magnet

Applications of magnetic materials in Engineering

## Introduction

① All materials (metals, semiconductors, insulators) reveal the phenomena of magnetism.

② Magnetic materials → play an important role in modern technology

Magnetism of materials

① This is mainly an outcome of the interactions of magnetic moments of their constituent atoms or molecules.

## Classification of Magnetic Materials

(On the basis of permeability or susceptibility)

| Diamagnetic | Paramagnetic | Ferromagnetic |
|---|---|---|
| $\chi_m$ = Negative | $\chi_m$ = Positive | $\chi_m >> 0$ |
| $\mu_r \leq 1$ | $\mu_r \geq 1$ | $\mu_r >> 1$ |

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Non magnetic materials

$\chi_m = 0$

## ⟸ Magnetic Materials ⟹

Classification on the basis of Alignment of magnetic moments

- Diamagnetic
- Paramagnetic
- Ferromagnetic
- Antiferromag
- Ferrimagnetic

Dia, Para, Anti ferro → Weak effects ⟹ Non magnetic materials

Ferromagnetic, Ferrimagnetic → ~~Strong Effects~~ ⟹ prominently utilized in a large no. of phenomena

↓

information Storage devices

Note: To realize the operating principle of different magnetic devices, it is essential to understand the magnetic phenomena.

## Definitions of some important terms

**① Intensity of magnetization (I)**

$$\boxed{I = \frac{M}{V}}$$ magnetic moment per unit volume

$$\boxed{I = \frac{m \times 2l}{a \times 2l} = \frac{m}{a}}$$ for a substance of length '2l' and cross sectional area a

$m \rightarrow$ pole strength (measure of a dipoles ability to ~~(strength of~~ turn itself into alignment with a given external field.

(Chi)

**② Magnetic susceptibility ($\chi_m$)**

"The degree to which a material can be magnetized in an external magnetic field is known as magnetic susceptibility".

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

$I \rightarrow$ magnetic moment per unit volume

$H \rightarrow$ magnetic field strength (measure of the intensity of magnetic field) $\rightarrow$ Amp/meter

$\chi_m \rightarrow$ positive (paramagnetic materials)

$\rightarrow$ negative (diamagnetic materials)

**③ Relative Permeability ($\mu_r$)**

$$\mu_r = \frac{\mu \text{ (magnetic permeability of substance)}}{\mu_0 \text{ (mag " " free space)}}$$

Mag. Permeability $\rightarrow$ the measure of magnetization that a material obtains in response to applied magnetic field.

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Magnetic Flux Density (B) : Force acting per unit ~~length~~ current per unit length ~~of a~~ wire ~~placed at right angles to the~~ magnetic field.

Mag Flux: No. of magnetic field lines passing through a given surface.

## Difference between magnetic permeability and magnetic succeptibility



**Mag. permeability :-** describes the ability of a material to support the formation of magnetic field inside itself

**Magnetic susceptibility :-** describes whether a material is attracted to a magnetic field or is repelled from it.

### Relation between Permeability and Susceptibility

$$B = \mu_0 (H + I) \quad \text{--- (1)}$$

$I \rightarrow$ intensity of magnetization

$H \rightarrow$ magnetic field strength

$B \rightarrow$ magnetic flux density

$$\chi_m = \frac{I}{H} \quad \text{--- (2)}$$

Therefore,

$$B = \mu_0 (H + \chi_m H)$$

$$B = \mu_0 H (1 + \chi_m)$$

$$\frac{B}{H} = \mu_0 (1 + \chi_m)$$

or $\boxed{\mu = \mu_0 (1 + \chi_m)}$ $\quad \because \frac{B}{H} = \mu$

$$\frac{\mu}{\mu_0} = 1 + \chi_m \quad \text{or}$$

$$\boxed{\mu_r = 1 + \chi_m}$$

Magnetic moment of an electron



# Magnetic properties of solids originates due to the motion of electrons

# An atom is made up of a positively charged nucleus surrounded by negatively charged electrons moving around it

# The orbital motion of each electron around the nucleus may be treated as a current loop. As a result, it sets up a magnetic field.

The current produced, $i = \frac{\text{charge}}{\text{time period}} = \frac{e}{T}$

Time period, $T = \frac{2\pi r}{v} \frac{(\text{distance})}{(\text{velocity})}$ — (2)

$\therefore \quad i = \frac{ev}{2\pi r}$ — (3)

$M = NiA$ current carrying loop

Magnetic moment of a magnetic dipole

$$M = iA = \frac{ev}{2\pi r} \times \pi r^2 \Rightarrow \boxed{M = \frac{evr}{2}} \quad (4)$$

$A \rightarrow$ area

Acc. to Bohr, ~~magnetic moment~~

$$mvr = \frac{nh}{2\pi} \Rightarrow \boxed{vr = \frac{nh}{2\pi m}} \quad (5)$$

Eqn (4) and (5), give

$$\boxed{M = n\left[\frac{eh}{4\pi m}\right]} \quad n = 1, 2, 3, \ldots$$

$\rightarrow$ Bohr magneton

This is the relation for magnetic moment of an electron orbiting around a nucleus.

# Classification of Magnetic Materials:

## ① Diamagnetic Materials

* On placing in an external magnetic field, the materials which acquire feeble magnetism in the direction opposite to the applied field are called diamagnetic materials.
* This property ~~has~~ is found in the materials whose outermost orbit has an even number of $e^-$. Since electrons have spins opposite to each other, the net magnetic moment of each atom is zero.
* The magnetism of diamagnetic materials is known as diamagnetism.
* If these materials are brought close to the pole of a powerful magnet (electromagnet), they are repelled away from the magnet.

Examples :- Bi, Zn, Cu, Ag, Au, Pb, water etc.

## ② Paramagnetic Materials

On placing in an external magnetic field, the materials which acquire feeble magnetism ~~field~~ in the direction of external field are called paramagnetic materials & their magnetism → paramagnetism.

* Outermost orbit ⇒ odd number of electrons
* The source of paramagnetism is the permanent magnetic moment possessed by the atoms of these materials.

Examples :- Al, Mn, Pt, liquid oxygen, copper chloride



## (3) Ferromagnetic Materials

* On placing in an external magnetic field the materials which acquire strong magnetism in the direction of applied field.
* This property is found in substances which are generally like paramagnetic materials.

Examples :- Fe, Ni, Co, magnetite ($Fe_3O_4$) etc.

## (4) Antiferromagnetic Materials

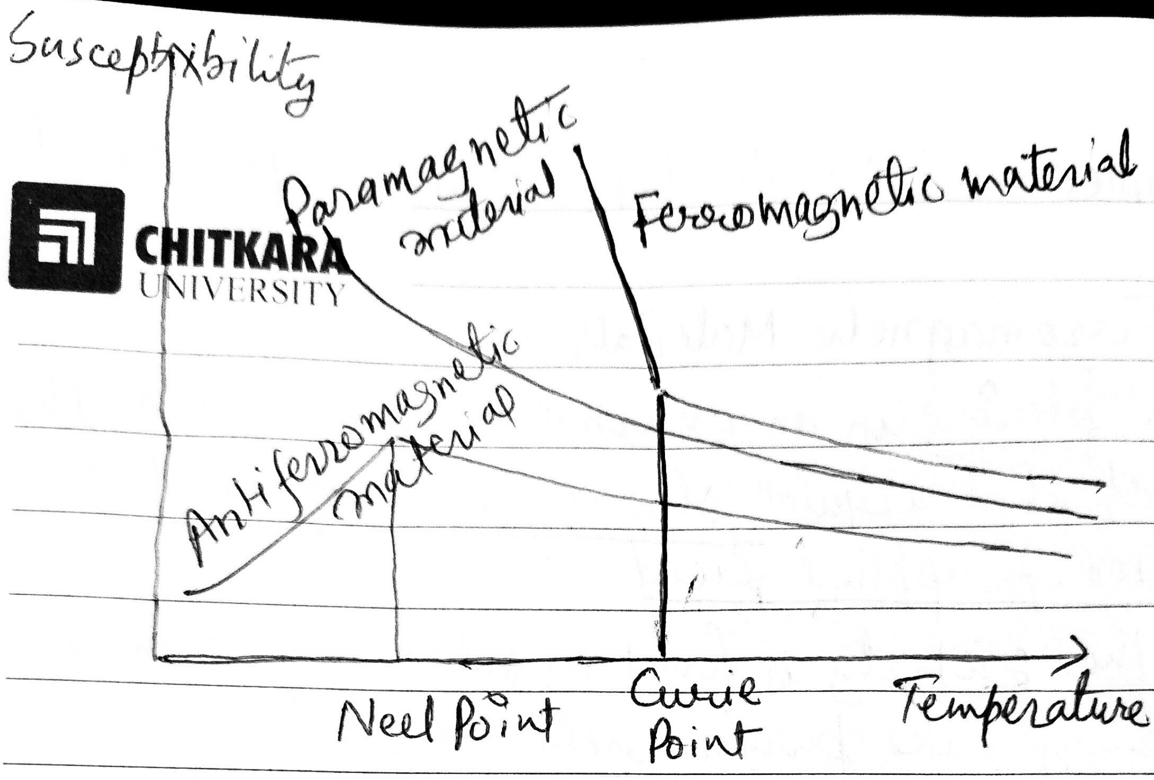
On placing in an external magnetic field, these materials are feebly magnetized in the direction of the field.

* Crystalline materials
* In these materials the dipole moments of the neighbouring dipoles are equal and opposite in orientation so that the net magnetism vanishes.

Examples: MnO, FeO, CoO, NiO, $MnO_4$, MnS etc.

* Susceptibility of these materials vary with temp.

It increases with increasing temp and reaches a maximum at a particular temperature called the Neel temperature ($T_N$). Above this temp these materials behave like paramagnetic materials.




(5) Ferrimagnetic Materials

If the spins of the atoms are such that there is a net magnetic moment in one direction, the magnetic materials are called ferrimagnetic materials.

Examples: Ferrites, which consists of mainly ferric oxide ($Fe_2O_3$) combined with one or more oxides of divalent metals.