Unit 2 Magnetic materials

⇒ **Magnetism :-**
The attractive property exhibited by the magnet.

⇒ **Magnetic dipole :-**
Magnet has two poles and are separated by a finite distance is called magnetic dipole.

⇒ **Magnetic dipole moment (μ_m) :-**
It is defined as product of magnetic pole strength and length of the magnet. $\boxed{\mu_m = m \times 2l}$

When a current of I amp flows through a circular coil of 1 turn whose area is A, then magnetic dipole moment is $\boxed{\mu_m = I \times A \text{ Amp m}^2}$

⇒ **Magnetic field :-**
The space surrounding the magnet upto which it's attracting influence is felt is called magnetic field.

⇒ **Magnetic field strength (H) :-**
The force experienced by unit north pole when placed at a given point in a magnetic field. Units :- Amp/m

⇒ **Magnetisation (M) :-**
It is defined as ratio of magnetic moment per unit volume.

$$\boxed{M = \frac{\mu_m}{Vol.}} = \frac{Am^2}{m^3} = A/m$$

⇒ **Susceptibility (χ) :-**
It is defined as ratio of magnetisation to the magnetic field strength.
Units :- no units

⇒ **Magnetic Flux Density (B) :-**
It is defined as the no. of lines of forces passing through unit area crosssection of the material.

$$B = \frac{\phi}{A} = Wb/m^2, \text{ Tesla}$$

⇒ **Magnetic permeability (μ)**
It is defined as ratio magnetic flux density of the material to the magnetic field strength.

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$$\mu = \frac{B}{H} \quad H/m$$

Magnetic permeability of a free space :-

It is defined as the ratio of magnetic flux density of free space to the magnetic field strength.

$$\mu_0 = \frac{B_0}{H} \qquad \mu_0 = 4\pi \times 10^{-7}\ H/m$$

Relative permeability (μ_r) :-

It is defined as ratio of magnetic permeability of a material to the magnetic permeability of free space.

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B_0/H} = \frac{B}{B_0}$$

Relation b/w B, H, M :-

$$\mu = \frac{B}{H}$$

$$B = \mu H \qquad \left(\because \mu_r = \frac{\mu}{\mu_0} \Rightarrow \mu = \mu_0\mu_r\right)$$

$$= \mu_0\mu_r H + \mu_0 H - \mu_0 H$$

$$= \mu_0 H(\mu_r - 1) + \mu_0 H$$

$\because$ From $M = H(\mu_r - 1)$

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

$$\therefore B = \mu_0(M+H)$$

Relation b/w μ_r & χ

$$\mu_0 = \frac{B}{M+H} \quad (\because \text{From above})$$

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B/M+H} = \frac{M+H}{H} = \frac{M}{H} + 1 = \chi + 1$$

$$\therefore \mu_r = \chi + 1$$

Q) The magnetic field in the interior of certain solenoid has the value of 6.5×10^{-4} Tesla when solenoid was empty. When it is filled with iron it becomes 1.4 Tesla. Find relative permeability (μ_r).

$\mu_r = ?$

$B_0 = 6.5 \times 10^{-4}$ T

$B = 1.4$ T

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B_0/H} = \frac{B}{B_0}$$

$$\mu_r = \frac{1.4}{6.5 \times 10^{-4}} = \boxed{2153.84}$$

☆

Q) Find the μ_r of ferro magnetic material if a field of strength is 220 m/Amp and produce magnetisation 3300 Amp/m with it.

$\mu_r = ?$

$H = 220$ m/Amp

$M = 3300$ Amp/m

$$\boxed{\mu_r = \frac{M}{H} + 1}$$

$$\mu_r = \frac{3300}{220} \Rightarrow \boxed{\mu_r = 15}$$

Q) Magnetic material has magnetisation of 3300 A/m & flux density 0.0044 T find field strength and relative permeability.

$M = 3300$ A/m

$B = 0.0044$ T

$\mu_r = ?$

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

$$\boxed{\mu_0 = 4\pi \times 10^{-7}}$$

$$0.0044 = 4\pi \times 10^{-7} [3300 + H]$$

$$0.0044 = 4\pi \times 10^{-7} (3300) + 4\pi \times 10^{-7} (H)$$

$$0.0044 = 4.1448 \times 10^{-3} + 4\pi \times 10^{-7} (H)$$

$$H = \frac{2.552 \times 10^{-4}}{4\pi \times 10^{-7}}$$

$$H = 203.1847$$

Q) A circular loop of copper having a diameter of 10 cm carries a current 500 mA. Find the magnetic moment associated with.

$I = 500 \times 10^{-3}$ A

$d = 10$ cm

$r = 5$ cm $= 5 \times 10^{-2}$ m

$A = \pi r^2$

$\mu_m = IA$

$= 500 \times 10^{-3} \times \pi \times 25 \times 10^{-4}$

$\mu_m = 3.926 \times 10^{-3}$ Amp m^2

Q) Calculate magnetisation (M) and flux density of a material placed in a magnetic field of intensity 1000 Amp/m & $\chi = -0.42 \times 10^{-3}$

$\boxed{\chi = \frac{M}{H}} \Rightarrow -0.42 \times 10^{-3} = \frac{M}{1000}$ $\Rightarrow M = -0.42 \times 10^{-3} \times 10^{3}$

$\boxed{M = -0.42}$

$B = \mu_0 [M + H]$

$= 4\pi \times 10^{-7} (-0.42 + 1000)$

$= 4\pi \times 10^{-7} \times 999.58$

$\boxed{B = 1.25 \times 10^{-3}}$ Wb/m^2

Origin of Magnetic moment - Bohr Magneton

Materials - atoms - nucleus - electrons revolve around the nucleus - orbital motion - spin motion

Nucleons = P + N - spin Motion of protons

Because of orbital motion of electron and spin motion of electrons and protons — current — magnetic field — magnetic moment

Orbital Magnetic moment due to electrons

Let us consider an electron whose charge is e and mass m revolving around the nucleus in a circular orbit of radius r in anticlockwise direction

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let 'v' be the linear velocity & 'w' be the angular velocity of the electron, then the linear frequency of electron is

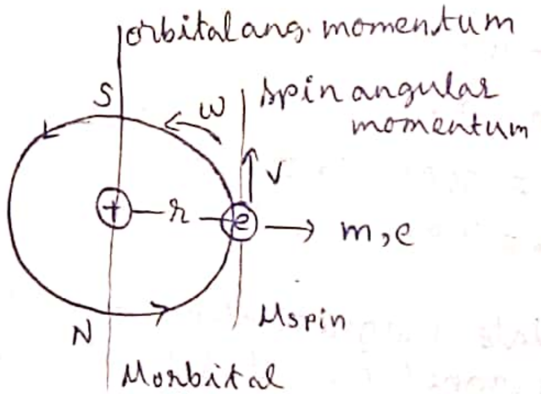
$$f = \frac{\omega}{2\pi}$$

$$f = \frac{1}{T}$$

$$\Rightarrow T = \frac{2\pi}{\omega}$$

The revolving electron will establish a current i.e, given by

$$I = \frac{\text{charge}}{\text{Time period}}$$



$$I = \frac{e\,\omega}{2\pi}$$

↓

I → Magnetic field

↓

$$\mu_m = I\,A$$

$$= \frac{e\omega}{2\pi}(\pi r^2)$$

$$\mu_{m\ \text{orbital}} = \frac{e\omega r^2}{2}$$

Angular momentum, $L = P \times r$ (P → Linear momentum)

$$L = mvr \quad (\because P = mv)$$

$$L = (m\omega r)r \quad (V = \omega r)$$

$$L = m\omega r^2$$

$$\mu_{orbital} = \frac{e\omega r^2}{2} \times \frac{m}{m}$$

$$\mu_{orbital} = -\frac{e}{2m}(L)$$

↓

Orbital Gyro Magnetic Ratio

$$\gamma = \frac{\text{Magnetic moment}}{\text{Orbital ang. momentum}} = \frac{\frac{e\omega r^2}{2}}{m\omega r^2} = \frac{e}{2m}$$

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According to Quantum theory.

$\boxed{L = l\hbar}$: l = orbital quantum no.

$l = 1, 2, 3 \ldots$

$\hbar = \frac{h}{2\pi}$

$\therefore \mu_{orbital} = \frac{-e}{2m}(L)$

$= \frac{-e}{2m}(l\hbar)$

$= \frac{-e}{2m}\left(l\frac{h}{2\pi}\right)$

$= \frac{-eh}{4\pi m}(l)$

$\mu_{orbital} = -\mu_B(l)$

$\mu_{orbital} = -\mu_B, -2\mu_B, -3\mu_B \ldots$

$\mu_B = \frac{eh}{4\pi m} = \frac{1.6\times10^{-19}\times6.626\times10^{-34}}{4\pi\times9.1\times10^{-31}}$

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

(where μ_B is Bohr Magneton)

Bohr Magneton (μ_B) :-
It is defined as fundamental unit of magnetic moment and its value is $9.27\times10^{-24}\ Am^2$

→ Spin Magnetic moment due to electrons

$\mu_{spin} = \frac{-e}{2m}(S)$

$S = s\hbar$

$s = \pm\frac{1}{2}$

$\mu_{spin} = -9.4\times10^{-24}\ Am^2$

Due to spinning of electrons about it own axis current is established and hence we get magnetic field and thereby magnetic moment is established which is known as spin magnetic moment due to electrons.

→ Spin Magnetic moment due to nucleus :-
Due to spin motion of nucleons magnetic field is developed and hence magnetic moment develops which we call it as spin magnetic moment due to nucleus.

$\mu_{nucleus\ spin} = \frac{eh}{4\pi m_p} = 5.05\times10^{-27}\ Am^2$

Classification of magnetic materials

Magnetic material :-

The materials that are affected by the magnet are called magnetic materials

1) Diamagnetic – repelled by the magnet
2) Paramagnetic – weakly attracted
3) Ferromagnetic – strongly attracted

1) Diamagnetic

⇒ The no. of orbits and their orientation is such that the vector sum of magnetic moment is zero

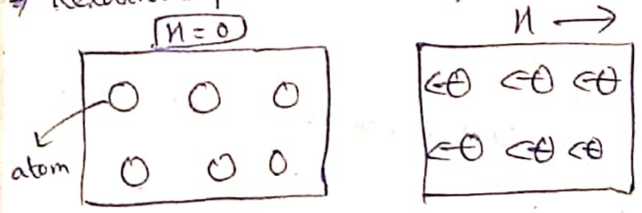
⇒ It does not have permanent magnetic moment or magnetic moment in each atom is zero at $H = 0$

⇒ When an external magnetic field 'H' is applied then magnetic moment induced in the direction opposite to the applied field.

⇒ Since the magnetic moment is in the direction opposite to the applied field then intensity of magnetisation is -ve

⇒ Susceptibility (χ) is -ve and does not depend on temperature.

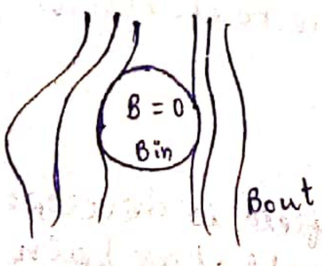
⇒ Relative permeability (μ_r) is less than 1 ($\mu_r < 1$).



⇒ No spin allignment is present.

⇒ When diagmagnetic material is placed in a magnetic field, then magnetic lines of forces does not pass through the material or repelled or pulled away from the material.

$B_{in} < B_{out}$ (or) $B_{in} = 0$

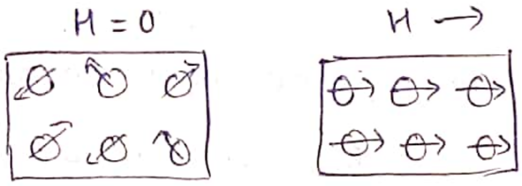


⇒ Above super conducting transition temperature, diamagnetic material behaves like a normal conductor.

Ex :- Gold, silver, water, etc.

2) Para Magnetic material

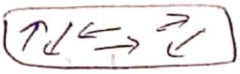
- The no. of orbits and their orientation is such that the vector sum of magnetic moment is not equal to zero.
- It has permanent magnetic moment at $H = 0$.
- When an external magnetic field 'H' is applied then magnetic moment induced is in the same direction to the applied field.



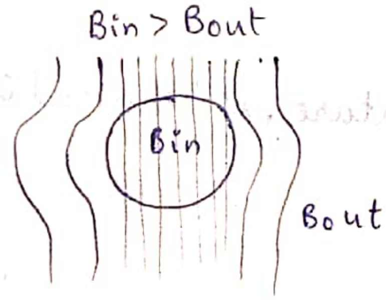
- Since the magnetic moment is in the same direction of the applied field then intensity of magnetisation is +ve.
- Susceptibility (χ) is +ve and low. It also depends on the temperature

$$\chi = \frac{C}{T}$$

- Relative permeability (μ_r) is greater than 1 ($\mu_r > 1$)
- Spin allignment is randomly oriented.



- When para magnetic material is placed in a magnetic field, magnetic lines of forces are attracted towards the centre.



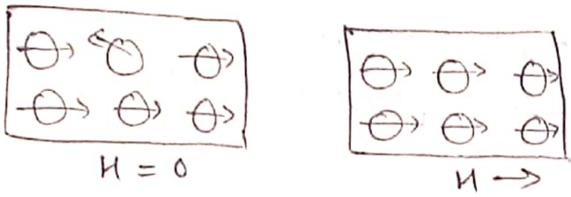
- Below super conducting transition temperature, para magnetic material behaves like a diamagnetic material.

Ex:- Platinum, Alluminium, etc.

3) Ferro Magnetic material

- When all the orbits of single electron are oriented in a systematic manner such that the atoms as a whole posess large magnetic moment, such type of materials are called ferromagnetic material
- It posess large magnetic moment even in the absence of magnetic field.

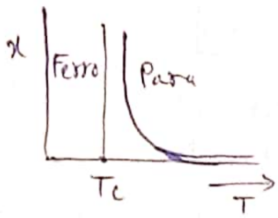
⇒ When an external magnetic field 'H' is applied, then all the magnetic moments are alligned in the same direction of magnetic field.



⇒ Intensity of magnetisation is +ve.

⇒ Susceptibility (χ) is +ve and high. It also depends on temperature

$$\chi = \frac{C}{T - T_C}$$

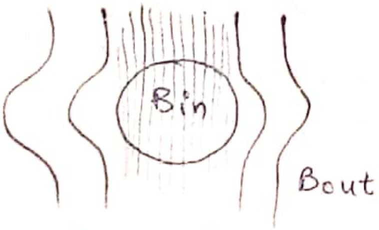


Above curie temp. (T_C) it behave like a para magnetic material

⇒ Relative permeability, $\mu_r >> 1$

⇒ Spin allignment is orderly oriented. ↑↑↑↑

⇒ When ferro magnetic material is placed in a magnetic field, the magnetic lines of forces are strongly attracted towards the centre of the material



Bin >> Bout

⇒ Above super conducting transition temperature, it behaves like a para magnetic material.

Ex:- Iron, Cobalt, Nickel

Important Features

⇒ They exhibit spontaneous magnetisation

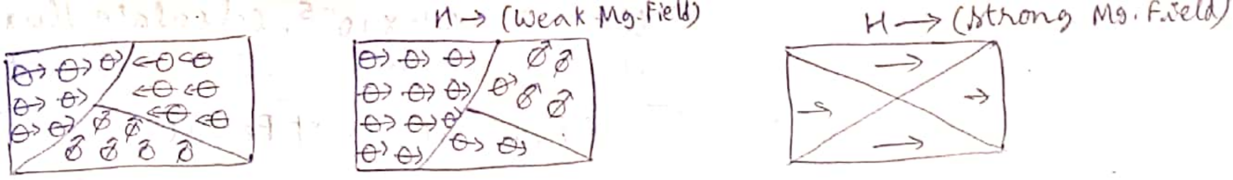
⇒ They exhibit hysteresis.

⇒ The above two are explained by Weiss theory (or) Domain theory.

⇒ The material consist of small region called domain

⇒ When weak magnetic field is applied ~~the maximu~~ growth of favourable domain and shrinkage of unfavourable domain takes place.

⇒ When a strong magnetic field is applied all the magnetic moments are alligned in the same direction to the applied field.



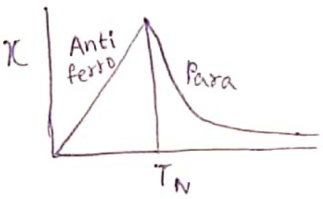
Classification of Ferro Magnetic materials

⇒ **Anti Ferro Magnetic material :-**

⇒ The material with anti parallel magnetic moment of same magnitude is called anti ferro magnetic material.

⇒ Spin allignment is antiparallel. ↑↓↑↓↑

⇒ Susceptibility is positive and low, it depends on temperature. $\chi = \frac{C}{T+T_c}$



As the temp. increases, susceptability increases and reaches maximum at T_N (Neel temp). Above this temp. material behaves like paramagnetic material.

Ex :- FeO, MnO, Cr_2O_3

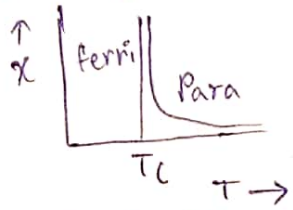
⇒ **Ferri Magnetic Material (Ferrites) :-**

⇒ The material with anti parallel magnetic moment of different magnitude is called ferrimagnetic

⇒ Spin allignment is antiparallel ↑↓↑↓↑↓

⇒ Susceptibity is +ve and high, it depends on temperature.

$$\chi = \frac{C}{T \pm T_C}$$



Ex :- XFe_2O_4, X = Mn, Mg, Co, Cu, Ni ..

Properties of Ferrites :-

⇒ They are metal oxides but not metals.

⇒ They have high resistivity raising from 10^3 to 10^8 Ω m

⇒ They have high dielectric constant ranging from 10 to hundreds.

⇒ They have high magnetic moment and hysteresis.

⇒ They exhibit spontaneous magnetic moment and hysteresis.

Q) The Para mag. material has 10^{28} atoms/m³ its susceptibility at 350 K is 2.8×10^{-4}. Calculate susceptibility at 300K.

$T_1 = 350K \rightarrow \chi_1 = 2.8 \times 10^{-4}$

$T_2 = 300K \rightarrow \chi_2 = ?$

$\chi = \frac{C}{T} \Rightarrow \chi_1 T_1 = \chi_2 T_2 \Rightarrow \chi_2 = \frac{\chi_1 T_1}{T_2} = 3.26 \times 10^{-4}$

Q) The magnetic susceptibility of Silicon is -0.4×10^{-5}. Calculate flux density (B) and magnetic moment per unit volume. When magnetic field of intensity is $+5 \times 10^{+5}$ Amp/m

$\chi = -0.4 \times 10^{-5}$

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

$M = \chi H$

$= -0.4 \times 10^{-5} \times 5 \times 10^{5}$

$$M = -2 \text{ Amp/m}$$

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

$= 4\pi \times 10^{-7} \left[-2 + 5 \times 10^{5}\right]$

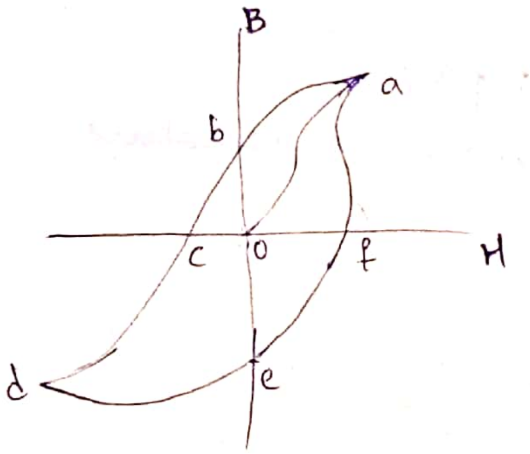
$$B = 0.628 \text{ Tesla}$$

*** Applications of Ferrites**

⇒ They are used in antennas to increase the selectivity & sensitivity of receivers.

⇒ They are used as magnetic cores in transformers.

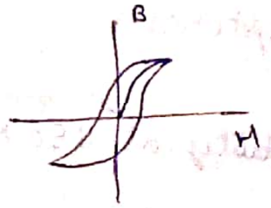
⇒ Hysteresis (B-H curve)



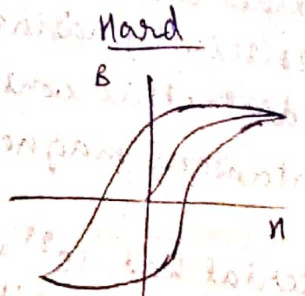
Magnetising force
Magn. field strength
Mag. field intensity
~~Mag. field~~
} H

Based on the area of the hysteresis loop ferromagnetic materials are classified into 2 types

Soft



Hard



Soft	Hard
⇒ It can be easily magnetised and demagnatised.	⇒ It is difficult to magnetise and demagnatise.
⇒ To magnetise (or) demagnatise material, weak magnetic field is required	⇒ To magnetise (or) demagnetise material strong magnetic field is required.

⇒ Hysteresis curve is steep (sharp)	⇒ Hysteresis curve is broad.
⇒ Area of the hysteris curve is small, hence the loss is less.	⇒ Area of the hysteresis curve is large, hence the loss is more.
⇒ Retentivity, coersibity values are small.	⇒ Retentivity, coersivity values are large.
⇒ Susceptibility & permeability values are large	⇒ Susceptibility & permeability values are small.
⇒ It is used in the preparation of magnetic core materials - which are used in transformers, electric motors, magnetic amplifiers, etc.	⇒ It is used for the preparation of permanent magnets - which are used for microphones, loudspeakers, magnetic detector, etc.
⇒ Ex:- Iron-Silicon alloy Ni - iron alloy iron - cobalt alloy	⇒ Ex:- C - steel Tungston-steel Cr - steel

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