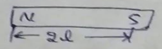
MAGNETIC PROPERTIES

4. Magnetic Properties and Superconductivity

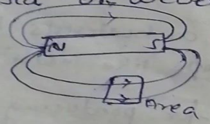
i) magnetic dipole
ii) magnetic dipole moment
iii) magnetic induction
magnetic flux density
iv) Relative Permeability
v) Magnetisation
vi) Susceptability
vii) Magnetic field intensity

Magnetic dipole :- Two equal and opposite poles separated by a small distance 2l is called as magnetic dipole.



Magnetic dipole moment (μ_d) :- The product of magnetic polestrength and distance of separation between the two poles is called magnetic dipole moment. $\mu_d = m \cdot 2l$.
where m is pole strength
2l is distance of separation.
Units of μ_d are Amp-m^2.

Magnetic induction (or) Magnetic flux density (B) :-
The number of lines of force passing perpendicular through unit area of the material is defined as magnetic induction or magnetic flux density.
Units :- Tesla or weber/m^2



Magnetic field Intensity :- H
The force experienced by a unit north pole placed at any point in the magnetic field is defined as magnetic field intensity.
Units :- Amp - meter.

Relative Permeability :- (μ_r)

When the external field H is applied to the bar magnet, its flux density increases i.e., $B \propto H$

$$\Rightarrow B = \mu H$$

where μ is permeability of material in medium

In free space $B = \mu_0 H$ where μ_0 is permeability of material in free space.

and $\mu_0 = 4\pi \times 10^{-7}$ Henry/meter.

Magnetisation :- (M)

The process of converting a non magnetic material into a magnetic material is called magnetisation.

units A-m

Susceptability :-

As magnetic field intensity is increased, magnetisation also increases.

$$M \propto H$$

$$M = \chi H$$

$$\underset{\text{No units}}{\chi} = \frac{M}{H}$$

Magnetisation will have same units as magnetic intensity.

so susceptability has no units.

Susceptability is defined as magnetisation per unit applied magnetic field.

Note :- Prove that $\mu_r = \chi + 1$

We know that $\mu_r = \frac{\mu}{\mu_0} \Rightarrow \mu = \mu_0 \mu_r$

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

$$B = \mu_0 \mu_r H \quad - (1)$$

Add and substract (1) with $\mu_0 H$

$$\mu_0 = \frac{B}{M+H} \quad \text{--- (2)}$$

$$\therefore \mu_r = \frac{B/H}{B/M+H} = \frac{M+H}{H}$$

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

$$\mu_r = \chi + 1$$

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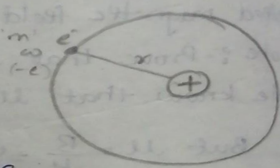
Origin of magnetic moment in an Atom :-

The permanant magnetic moment arises in an ...ue to
1) Orbital magnetic moment due to the electr...
2) Spin magnetic moment due to the electron
3) Spin magnetic moment due to the nucleus

Orbital magnetic moment due to the electron :-

Consider an atom consisting of
moving electron with mass 'm',
...rge '$-e$', moving with angular
...ocity ω



Let r be the radius between the
...eus and the electron,

...ital magnetic moment is given by
... = current associated with moving electron × Area ...

Current associated with moving electron I is given (27)

by $\boxed{I = \frac{\text{number of revolutions made by electron with angular velocity}}{} \times \text{charge}}$ — ②

$\therefore I = \frac{\omega}{2\pi} \times (-e)$

$I = \frac{-\omega e}{2\pi}$ — ③.

Substituting ③ in ① we get

$\mu_d = I \times A$

$= \frac{-e\omega}{2\pi} \times \pi r^2 = -\frac{e\omega r^2}{2}$ — ④.

Multiply and divide ④ with mass of electron 'm'

then ④ becomes $\mu_d = -\frac{e\omega r^2 m}{2m}$

where Angular momentum $L = m\omega r^2$ — ⑤

$\therefore \mu_d = \frac{-eL}{2m}$ — ⑥

-ve sign indicates that angular momentum is always antiparallel to magnetic moment

From ⑥ we can write $\boxed{\gamma = \frac{e}{2m} = \frac{\mu_d}{L}}$ * — ⑦

where γ is called as Gyromagnetic ratio

Gyromagnetic ratio is defined as the ratio between magnetic moment to the angular momentum

Angular momentum L can be defined in terms of orbital quantum number as $L = \frac{lh}{2\pi}$

where l is orbital quantum number

and $l = 0, 1, 2 \ldots (n-1)$

where n is principle quantum number and 28

$n = 1, 2, 3, 4$

1 corresponds to K shell
2,3,4 corresponds to L, M, N shells

∴ (6) becomes

$$\mu_d = \frac{-e}{2m}\frac{lh}{2\pi}$$

$$\mu_d = \frac{-ehl}{4m\pi} \quad \text{---} (8)$$

from (8) $\boxed{\mu_B = \frac{-eh}{4\pi m} = -9.27 \times 10^{-24}\ A - m^2}$

where μ_B is called as Bohr magneton

∴ Orbital magnetic moment interms of Bohr magneton can be written as $\boxed{\mu_D = \mu_B\, l}$ --- (9)

2) Spin Magnetic moment due to the electron :- (μ_{es})

Spin magnetic moment due to the electron is half of the Bohr magneton

ie., $\mu_{es} = \frac{1}{2}$ (Bohr magneton)

$$= \frac{1}{2}(-9.27 \times 10^{-24})$$

$$= -4.635 \times 10^{-24}\ A - m^2$$

3) Spin magnetic moment due to the nucleus :- (μ_{ns})

$$\mu_{ns} = \frac{-eh}{4\pi M_P}$$

$$= -5.04 \times 10^{-24}\ Amp - m^2$$

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Classification of Magnetic Materials :-

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Diamagnetic

1) There are no permanant dipoles in a diamagnetic material and hence the magnetisation $M=0$

Paramagnetic

1) There are permanant magnetic dipoles but there is not interaction between the dipoles. They are randomly oriented when no external field is applied and hence magnetisation $M=0$

↑↙↖↑↖↙↘

When external field is applied, the magnetic dipoles orient along the direction of applied field and hence $M \neq 0$.

↑H ↑↑↑↑↑

Ferromagnetic

1) They have permanant magnetic dipoles and interaction is very strong. The magnetic dipoles are parallel to eachother with same magnitude and hence the magnetisation is very large.

↑↑↑↑↑

ferromagnetic materials are of two types 1) Antiferro and 2) ferrites

1) Anteferro :- If the magnetic dipoles are antiparallel with same magnitude, then the magnetic materials are called as antiferro magnetic materials and $M=0$

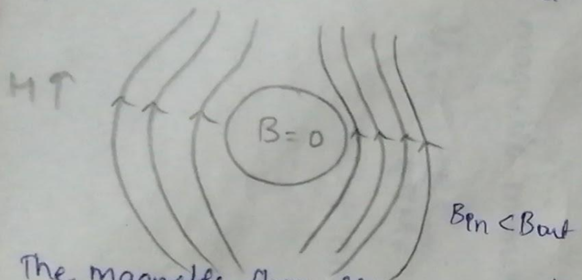
↑↓↑↓↑↓

2) ferrites :- If the magnetic dipoles are antiparallel with unequal magnitude, then the magnetic materials are called as ferrites and $M \neq 0$ ↑↓↑↓↑↓

Diamagnetic

2) Magnetic dipole moment $\mu_d < 1$

3)



The magnetic flux lines are not allowed to pass through the dia magnetic magnetic material.

4) Susceptibility 'X' values are negative.

i) X values are small when it is independent of temperature and applied external magnetic field H.

ii) X values are intermediate, when it is independent of external magnetic field and T = 20 k

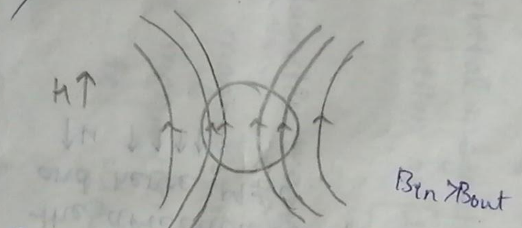
iii) X values are large when it is independent of external magnetic field and when $T < T_c$

where T_c - Critical temperature.

Paramagnetic

2) Magnetic dipole moment $\mu_d \simeq 1$

3)



Paramagnetic material will allow the flux lines to pass through it

4) X is always +ve

X values are small when it is independent of temperature and external magnetic field.

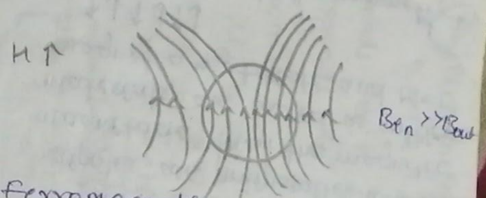
X values are large when X is inversely proportional to T

$X \propto \frac{1}{T} \Rightarrow \boxed{X = \frac{C}{T}} \rightarrow$ Curie law

Ferromagnetic

2) Magnetic dipole moment $\mu_d > 1$

3)



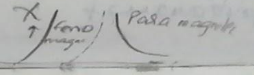
Ferromagnetic materials attracts the magnetic flux lines

4) X value is always +ve and very large since the interaction between the dipoles are very strong $X = \frac{C}{T - T_c}$

where T_c is called as curie temp

* when $T > T_c$, material behaves as paramagnetic

* when $T < T_c$ material behaves as Ferromagnetic.



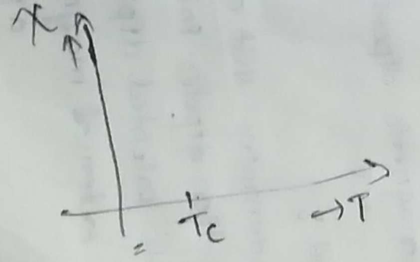
Note: Critical temperature is associated

Note :- Curie temperature is

where T_c - Critical temperature

Note:- Critical temperature is associated only with diamagnetic materials. i.e., below critical temperature, the materials behave as diamagnetic materials.

T_c values are different for different materials



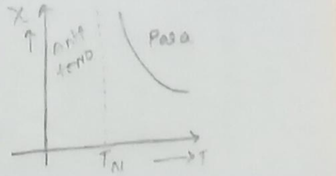
Note:- Curie temperature is different for different materials.

For antiferromagnetic materials

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

where T_N is Neel Temperature

$-T_N$ is for antiferro, $+T_N$ for ferrites



Curie Temperature :- The temperature at which ferromagnetic materials are converted into paramagnetic materials.

Neel Temperature :- The temperature at which paramagnetic materials are converted into antiferromagnetic materials.

5) Only ferromagnetic exhibit hysteresis curve (B vs H graph)

- A ferromagnetic material can be divided into small regions called

Ferromagnetic
domains where magnetic dipoles are randomly oriented. But on application of external magnetic field, they orient themselves in the direction of applied field. This theory is called domain theory of ferromagnetism.

Domain theory of ferromagnetism :-

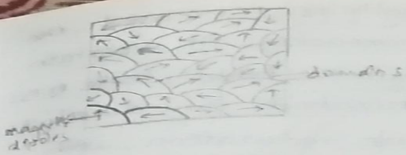
This theory is proposed by Weiss. According to Weiss, a ferromagnetic material can be divided into small regions called domains. In these regions, the magnetic dipoles are randomly oriented and hence, the magnetisation $M = 0$. On application of external magnetic field H, the alignment of magnetic dipoles occurs in two steps.

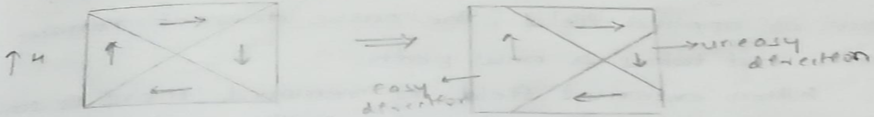
Step 1:- Bloch Wall movement or Motion of domain wall movement

Step 2:- Rotation of magnetic dipoles.

Bloch Wall movement :-

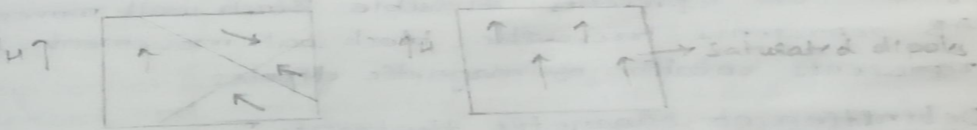
i) The volume of the domains that are favourably oriented or easy direction dipoles increases at the expense of unfavourable oriented dipoles or uneasy direction dipoles when external magnetic field is applied.





Rotation of Magnetic dipoles :-

When the magnetic field is strongly applied, rotation of dipoles occurs in the direction of applied field. When all the diples align along the direction of applied magnetic field, saturation is reached for the material.



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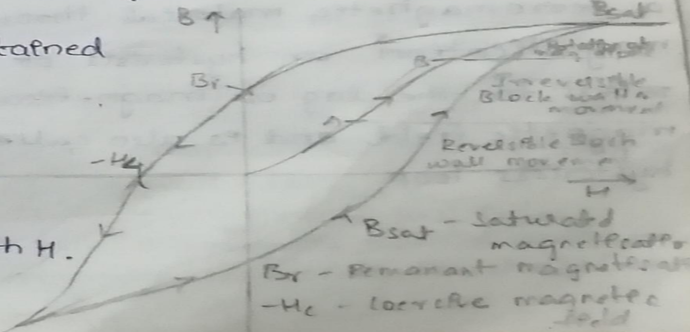
Hysteresis Curve :- (B Vs H graph) :-

Hysteresis curve is obtained by plotting a graph between magnetic flux density B versus magnetic field strength H.



As magnetic field strength is increased, the magnetic flux density also increases. At a certain point with increase in magnetic field, there is no change in flux density i.e., sturated flux density is obtained. Beyond this point of saturation, with decrease of applied field, the curve doesnot retraces its path but takes a new path.

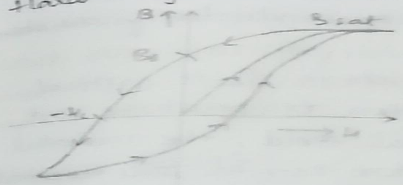
When external field is removed, there is some amount of magnetic flux density in the material which is called as remanant flux density or retentetivety. To make the retentivety zero, negative magnetic field has to be applied which is called as coercive field or coergivity. It is represented by $-H_c$. The loop continues but never reaches to the starting point. From graph, OA represents reversible Bloch wall movement. AB represents irreversible block wall movement. BC represents rotation of magnetic dipoles.

Definition of Magnetic Hysteresis :-

Hysteresis loss is the loss of energy in taking a ferromagnetic material through a complete cycle of magnetisation or hysteresis of ferromagnetic materials refers to the lag of magnetisation behind the applied magnetic field and is also called as hysteresis loss or hysteresis loop.

Hard and Soft Magnetic Materials :-

Hard Magnetic Materials



1) The hysteresis loop area is large in hard magnetic materials.

2) Remanant flux density (B_r) and coercivity ($-H_c$) values are large

3) Susceptibility 'χ' and permeability 'μ' values are small.

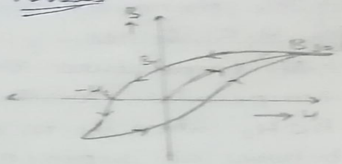
4) They cannot be easily magnetised and demagnetised so they are called as permanant magnets

5) They are used in headphones, voltage regulators, speakers

6) The loss of hysteresis is high.

Soft magnetic materials

Ferrites



1) The hysteresis loop area is small in soft magnetic materials.

2) Remanant flux density (B_r) and coercivity ($-H_c$) values are small

3) Susceptibility 'χ' and permeability 'μ' values are large

4) They can be easily magnetised and demagnetised so they are called as temperary magnets.

5) Soft magnetic materials are used in transformers, computer storage devices, switching circuits, radio receivers, ultrasonic frequency production

6) Hysteresis loss is less.

Soft magnetic material also called as ferrites

Note :- Hard and soft magnetic materials are classified based on hysteresis loop area.

Thank you

HAVE A NICE DAY