Unit-4

Magnetic Materials

Introduction:

- Magnetism arises from the Magnetic Moments or Magnetic dipoles of Magnetic Materials.
- When the electrons revolve around the nucleus Orbital magnetic moment arises, similarly when the electron spins, spin Magnetic moment arises.
- The permanent Magnetic Moments can arise due to
  - The orbital magnetic moment of the electrons
  - The spin magnetic moment of the electrons, and
  - The spin magnetic moment of the nucleus.

Magnetic Induction or Magnetic flux Density(B):

- The number of lines of magnetic force (or) flux passing through unit area perpendicularly is known as Magnetic Induction.

Magnetic field intensity (H):

- The force experienced by a unit north pole placed at a point in a Magnetic Field is known as Magnetic field strength (or) Magnetic Field Intensity.

Classification of Magnetic materials:

Diamagnetic Materials:

- Diamagnetic materials create an induced magnetic field in a direction opposite to an externally applied magnetic field.
- They are repelled by the applied magnetic field. • The permanent dipoles are absent in Diamagnetic materials
- In a non-uniform magnetic field, The are repelled away from stronger parts of the field. •
- The magnetic susceptibility χ of these materials is always negative.
- The relative permeability μr is always less than one. **($\mu_r < 1$)**
- χ is small but negative. Independent of temperature.
- Examples:-Bismuth,Copper,Lead,Zinc etc.

Paramagnetic Materials:

- Paramagnetic materials exhibit magnetism when the external magnetic field is applied.
- Paramagnetic materials loose magnetization in the absence of an externally applied magnetic field. These materials are weakly attracted towards magnetic field.
- Paramagnetic materials experiences a feeble attractive force when brought near the pole of a magnet
- These materials possess some permanent dipole moment which arise due to some unpaired electrons. • The magnetic susceptibility χ is small and +ve.
- Obeys Curie law i.e., $\chi = C/T$
- $\mu_r > 1$.
- Examples:-Platinum,Aluminium,Copper sulphate etc.

Ferromagnetic Materials:

- Ferromagnetism It is the phenomenon in which a material gets magnetized to a very large extent in the presence of an external field.
- The direction in which the material gets magnetised is the same as that of the external field. Ferromagnetic materials experience a very strong attractive force when brought near the pole of a magnet.
- Permeability is very much greater than one. $\mu_r >>> 1$
- Susceptibility is +ve and high.
- χ decreases with temperature in complex manner. i.e., $\chi = C/(T-\theta)$.
- Examples:-Fe,Co,Ni,MnAs etc.

Antiferromagnetic Materials:

- It is refer to a phenomenon in which the magnetic interaction between any two dipoles align themselves anti-parallel to each other.
- Since all dipoles are of equal magnitude,the net magnetisation is zero.
- Like ferromagnetic materials antiferromagnetic materials also possess dipole moment due to spin of the electron.
- The susceptibility is very small and is +ve. $\chi_m = C/(T+\theta)$
- Examples: Salts

Ferrimagnetic materials:

- Ferrimagnetism is a phenomenon in which the magnetic interaction between any two dipoles align anti-parallel to each other.
- But since the magnitude of dipoles are not equal.
- Ferrimagnetic materials possess magnetic dipoles moment due to the spin of the electron.
- The susceptibility is very Large and +ve. $\chi_m = C/(T\pm\theta)$ Examples: Ferrites

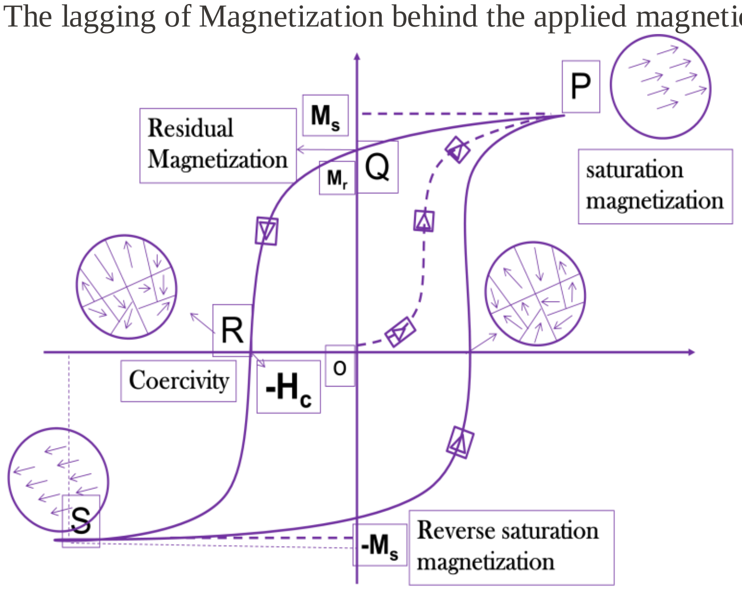
Weiss molecula field theory on ferromagnetism:

- It gives a relation between susceptibility and temperature of a ferromagnetic material.
- According to weiss, the atomic magnets of a ferromagnetic substance are grouped into certain regions called domains.

- Within a domain the atomic dipoles are aligned in the same direction and the adjacent domains have dipoles in other directions.
- Weiss assumed that in a ferromagnetic substance, the molecules are mutually influenced by their magnetic moments and consequently there should exist a molecular field within a substance called internal molecular field(H_i).
- The field produced at any point by all the neibouring molecules is proportional to the intensity of magnetization(M). i.e. $\mathbf{H_i \alpha\ M}$.
- $\mathbf{H_i = \lambda M}$ where λ is molecular field coefficient.
- Net effective magnetic field $\mathbf{H_{eff} = H + H_i}$, where H is the applied field.
- $\mathbf{H_{eff} = H + H_i = H + \lambda M}$, **but** $\mathbf{M = \frac{\mu_0 \mu^2 N\, Heff}{3KT}}$, where N is no.of molecules in unit volume.
- $\mathbf{M = \frac{\mu_0 \mu^2\, N\, Heff}{3KT} = \frac{\mu_0 \mu^2 N\,(H+\lambda M)}{3KT}}$.
- $\boldsymbol{M}\left(\mathbf{1 - \frac{\mu_0 \mu^2\, N\, \lambda}{3KT}}\right) = \mathbf{\frac{\mu_0 \mu^2\, NH}{3KT}}$.
- **Then** $\boldsymbol{M}\left(\mathbf{1 - \frac{T_C}{T}}\right) = \mathbf{\frac{CH}{T}}$, **where** $\mathbf{C = \frac{\mu_0 \mu^2\, N}{3K}}$ **and** $\mathbf{T_C = C\lambda}$.
- $\chi = \frac{M}{H} = \frac{C}{T - T_C}$.

Hysteresis Curve:

- The lagging of Magnetization behind the applied magnetic field is called the Hysteresis



- If we start with no Magnetized specimen (**M=0**) with the increasing values of magnetizing field H.
- The Magnetization of the specimen increases from zero to higher values and attains its maximum value at a point P, at this point the Magnetization referred as Saturation Magnetization.When we increase Magnetic field **H** there is no further increment in Magnetic moment.

- When we decrease Magnetic field **H to Zero**, the Magnetization **M** attains point **Q**. At this point Magnetization referred as **Residual Magnetization** $\mathbf{M_r}$.
- Further if we increase the Magnetic field from zero to negative values, the Magnetization of material becomes zero at a point **R**, at that point the Magnetic field $\mathbf{-H_c}$ is referred as **Coercivity** of the specimen.
- If we increase Magnetic field H in reverse direction Magnetization of material reaches its peak value at a points **S**.
- On reversing the polarities of Magnetic field and increasing its strength the Magnetization slowly decreases first to residual value then to zero and finally increases to saturation state and touches the original saturation curve.
- The area of loop indicates the amount of energy wasted in one cycle of operation is called Hysteresis Curve .

Hard and Soft Magnetic Materials:

Hard Magnetic Materials:

- Hard magnetic materials have large hysteresis loss due to large hysteresis loop area
- The coercivity and retentivity are large
- These materials have small values of permeability and susceptibility
- They do not easily magnetized or Demagnetized.

Soft Magnetic Materials:

- Soft Magnetic materials have low hysteresis loss due to small hysteresis loop area.
- The coercivity and retentivity are small
- These materials have large values of permeability and susceptibility.
- They can be easily magnetized and demagnetized.

Ferrites and their applications:

Superconductivity:

Introduction:

- Certain metals and alloys exhibit almost zero resistivity (infinite conductivity) when they are cooled to sufficiently low temperatures. This phenomenon is called Superconductivity.

General Properties of Superconductors:

Transition Temparature(T_c):

- The temperature at which a normal substance changes to a superconducting substance and vice-versa is called the critical temperature (T_c) or the transition temperature.
- Different materials have different transition temperature(T_c) values.

Critical magnetic field (H_c)

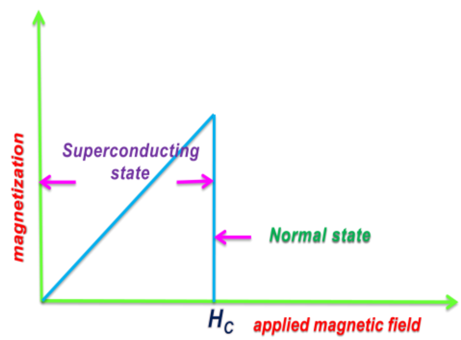
- The state of superconductivity that exists for a given magnetic field at a given temperature is called critical magnetic field.
- Superconducters are perfect Diamagnetic materials.

Meissner Effect:

- When a weak Magnetic field is applied to a superconducting specimen at a temperature T_c , the magnetic flux lines are expelled & the specimen acts as an ideal Dia magnet. This effect is called Meissner effect.

Type - I or Soft superconductors and Type – II or Hard superconductors:

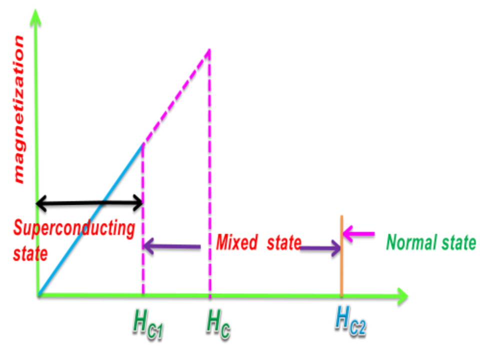
Type - I or Soft superconductors:



- Superconductors exhibiting a complete Meissner effect (perfect diamagnetism) are called type I superconductors.

- When the magnetic field strength is gradually increased from its initial value $H < H_c$, at H_c the diamagnetism abruptly disappear and the transition from superconducting state to normal state is sharp as shown in Fig.

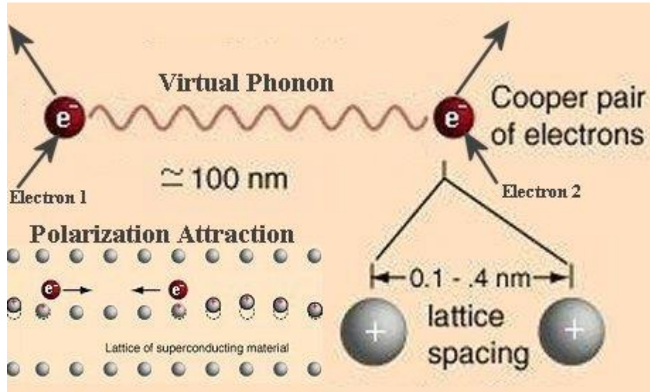
Type – II or Hard superconductors:



- In type II superconductors as shown in the above Fig, up to field H_{C1} the specimen is in a pure superconducting state. The magnetic flux lines are rejected.
- When the field is increased beyond H_{C1} (the lower critical field), the magnetic flux lines start penetrating. The specimen is in a mixed state between H_{C1} and H_{C2} (the upper critical field). Above H_{c2}, the specimen is in a normal state. This means that the Meissner effect is incomplete in the region between H_{C1} and H_{C2}. This region is known as ***Vortex-region***.

BCS theory:

- BCS theory of Superconductivity wsa put forwarded by Bardeen, Cooper and Schrieffer in 1957 which explain how the Superconductivity arises at very low temperature.
- Let us consider an electron passing through the lattice of positive ions. The electron is attracted by the neighbouring positive ion form a positive ion core and gets screened by them.
- Due to attraction between electron and positive ion core the lattice gets deformed.
- Now if another electron passes by the side of assembly of above said electron and positive core, it gets attracted towards the assembly. The second electron interacts with the first electron.
- This interaction is said to be due to the exchange of a virtual phonon q between the two electrons. This interaction process interms of wave vectors k (k1-q=k’ and k2+q=k’2).
- The momentum transferred between two electrons, These two electrons together form a Cooper pair and and is known as Cooper electron.



Applications of Superconductors:

- In electric generators
- In Low loss transmission lines and transformers
- In magnetic levitation
- In generation of high magnetic fields
- In fast electrical switching
- In SQUIDS

SQUIDs (Superconducting Quantum Interference Devices):

- SQUIDS is a double junction quantum interferometer. Two Josephson junctions mounted on a superconducting ring forms this interferometer.
- The SQUIDS are based on the flux quantization in a superconducting ring. Total magnetic flux passing through the ring is quantized.
- The SQUIDs are used to study tiny magnetic signals from the brain and heart.