Unit-3 Magnetic Materials and Dielectric Materials

Magnetic Materials

Introduction

A magnet is one which is associated with a magnetic field. The strength of the magnetic field is greater at the poles of the magnet. Higher the pole strength of a magnet, higher will be the intensity of a magnetic field. When two magnets are close to each other with their fields, a force is experienced by each other.

Magnetic pole Strength

A magnetic pole strength of a pole of a magnet is said to be unity, if it experiences a force of 1 Newton when placed at a distance of 1 m from a similar one in air (or vaccum).

Magnetic moment (m)

Magnetic moment of a magnet is the product of magnetic pole strength & the distance b/n the two poles.

The magnetic moment per unit volume of a magnet is called magnetisation.

$$M = \frac{m}{V}$$, $V \rightarrow$ Volume of magnetic material.

Magnetic Susceptibility

The ratio of magnetisation to the strength of the field is called magnetic susceptibity of the material.

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

Magnetic field is the region where a magnetic pole experiences a force. The magnetic field can be visualised in the form of magnetic flux lines. These magnetic flux lines come out from north pole & reenter into the south pole, so as to reach the north pole.

This movement forms a closed path. For a strong magnet, the flux lines will be crowded & for a weaker magnet, the flux lines are very minimum.

Magnetic Induction

Magnetic Induction is the magnetic flux over a unit area of a surface held normally to the flux.

$$B = \frac{\phi}{A} \ (\text{weber}/m^2) \text{ or Tesla}$$

$\phi \rightarrow$ Magnetic flux

$A \rightarrow$ Area of the plane surface through which the flux lines are imagined to pass normally.

The magnetic flux has the ability to pass through matter. The freeness with which the flux can permeate through a given material depends on the material.

The permeability of vaccum or free space is taken as the standard reference with respect to which permeability of other materials are expressed.

The permeability of vaccum or free space is given by

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

Relative permeability (μ_r)

The permeability of any given media is calculated related to μ_0 & is called as relative permeability.

Absolute permeability (μ)

The absolute permeability of a medium is defined as the ability of a medium to permit the magnetic flux to permeate through itself.

$$\mu = \mu_0 \mu_r \quad H/m$$

Magnetic Materials

Magnetism

Magnetism is the force excerted by magnets when they attract or repel each other. Magnetism is caused by the motion of electric charges.

Classification of Magnetic materials and properties

The magnetic materials are generally classified into three types based on the behaviour of materials in a magnetising field.

They are,

a) Diamagnetic material

b) paramagnetic material

c) Ferromagnetic material

Diamagnetic Material

Diamagnetic materials are the one which are repelled by a magnetic field. An applied magnetic field creates an induced magnetic field in them in the opposite direction which causes a repulsive force.

Diamagnetism is a quantum mechanical effect that occurs in all materials; when it is the only contribution to the magnetism, the material is called diamagnetic.

Ex Bismuth, Copper, water etc.

properties

i) Magnetic susceptibity is negative.

ii) Relative permeability is slightly less than unity.

iii) The magnetic field lines are repelled or expelled by diamagnetic materials when placed in a magnetic field.

iv) Susceptibility is nearly temperature independent.

Paramagnetic Material

Paramagnetic materials are the one which are weakly attracted by an externally applied magnetic field and form internal induced magnetic fields in the direction of the applied magnetic field.

Paramagnetism is due to the presence of unpaired electrons in the materials, so most atoms with incompletely filled atomic orbitals are paramagnetic. Paramagnetic materials include most chemical elements and some compounds.

Ex: Aluminium, platinum, Chromium etc

Properties

i) Magnetic susceptibility is positive & small.
ii) Relative permeability is greater than unity.
iii) The magnetic field lines are attracted into the paramagnetic materials when placed in a magnetic field.
iv) Susceptibility is inversely proportional to temperature

Ferromagnetic Material

Ferromagnetic materials are the one which are strongly attracted by an externally applied magnetic field

Ferromagnetism is the basic mechanism by which certain materials form permanent magnets, or are attracted to magnets.

Ex: Iron, Nickel, cobalt etc.

properties

i) Magnetic susceptibility is positive & large.

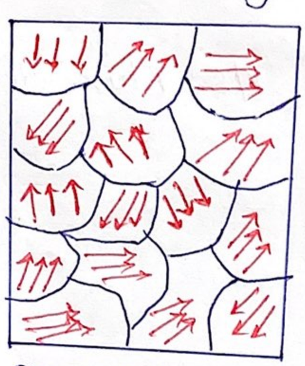
ii) Relative permeability is large.

iii) The magnetic field lines are strongly attracted into the ferromagnetic materials when placed in a magnetic field.

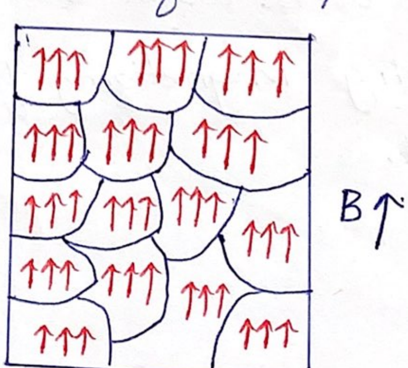
iv) Susceptibility is inversely proportional to temperature.

Ferromagnetic Materials - Concept of Domain

An atom or a molecule in a ferromagnetic material possesses net magnetic dipole moment as in a paramagnetic material. A ferromagnetic material is made up of smaller regions, called as ferromagnetic domain. within each domain, the magnetic moments are spontaneously aligned in a direction. This alignment is caused by strong interaction arising from electron spin which depends on the inter-atomic distance. Each domain has net magnetisation in a direction. However the direction of magnetisation varies from domain to domain and thus net magnetisation of the specimen is zero.



Domains randomly arranged



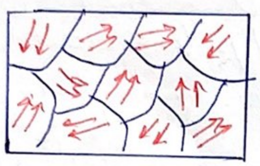
Domains aligned with External field

In the presence of external magnetic field, two processes take place.

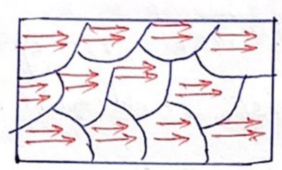
a) The domains having magnetic moments parallel to the field grow in size.

b) The other domains (not parallel to field) are rotated so that they are aligned with the field.

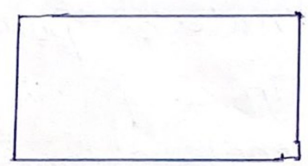
As a result of these mechanisms, there is a strong net magnetisation of the material in the direction of the applied field.



Unmagnetised Iron Nail



Magnet

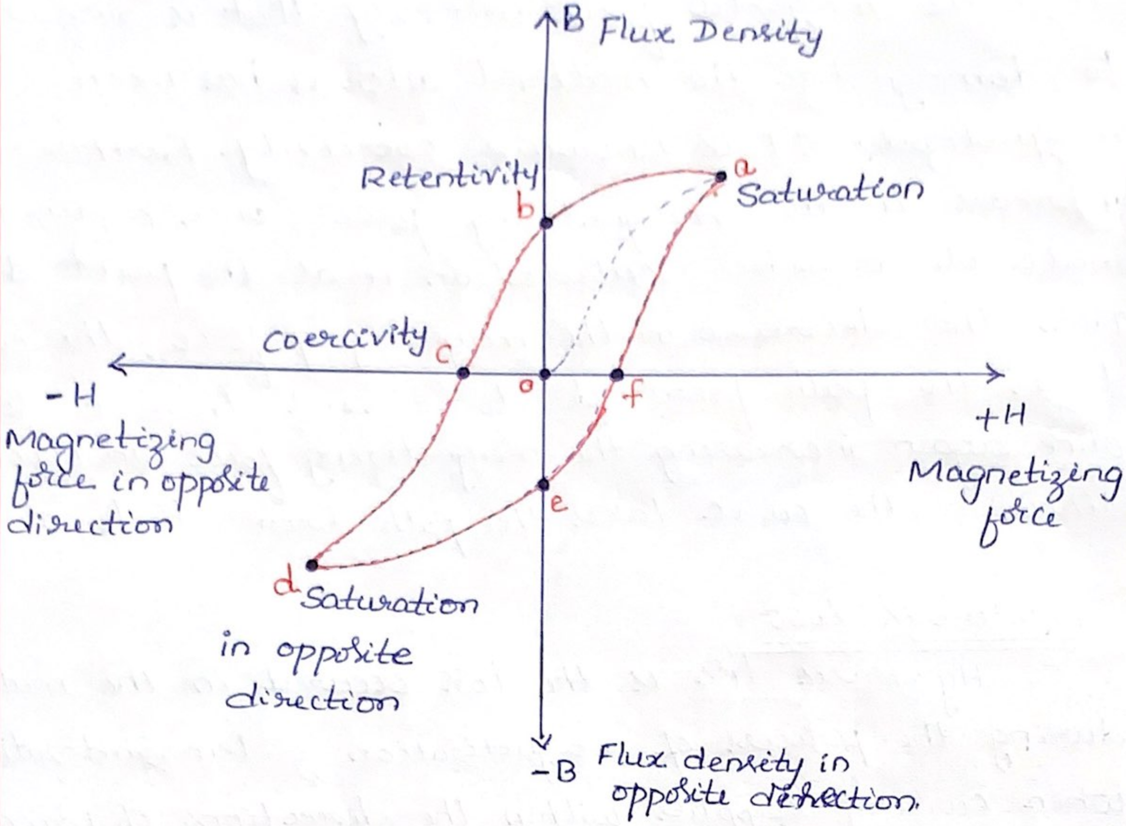


Non magnetic material (No domains)

B – H curve

B-H curve is the curve characteristic of the magnetic properties of a material or elelement or alloy. It tells about how the material responds to an external magnetic field.

In other words B-H curve is the curve obtained by ploting Magnetizing force v/s Flux density for a material.



At the point 'o', both magnetizing force and flux density are zero. But as the magnetizing force is applied & increased, the flux density also increases gradually from 'o' to 'a'. The point 'a' is referred as saturation beyond which flux density remains constant with increase in magnetizing force.

When the magnetizing force is decreased, the flux density also decreases. But for zero magnetizing force, flux density is not zero at the point 'b'. It indicates, the residual magnetism or the flux density that is left within the material after it is magnetized. It is known as remanence or retentivity.

Then the magnetizing force is increased in the opposite direction. At the point 'c', the flux density is zero for a certain value of magnetizing force.

It is the magnetic field intensity that is required to demagnetize the material after it has been magnetized. It is known as Coercivity. Further increase in the magnetizing force, once again the material reaches saturation ~~in~~ at the point 'd'. Then the decrease in the magnetizing force, the curve takes the path from 'd' to 'e' and then 'e' to 'f'. Once again increasing the magnetizing force in opposite direction, the curve takes the path from 'f' to 'a'.

Hysteresis Loss

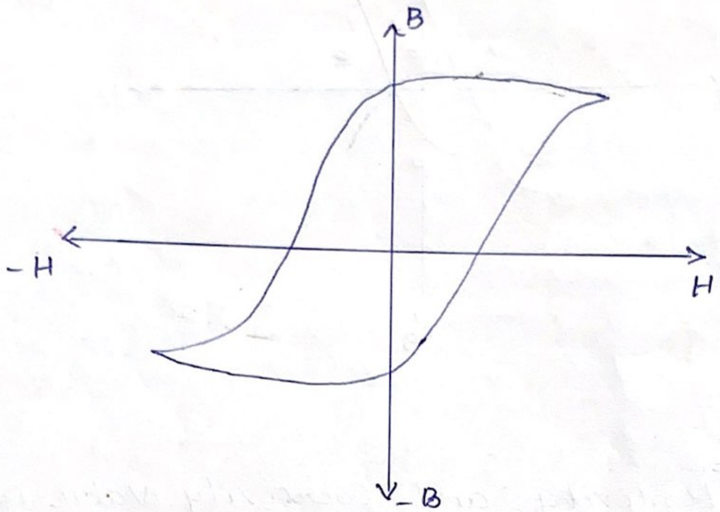
Hysteresis loss is the loss occured in the material during the process of magnetization & demagnetization when current supplies within the directions of forward and reverse.

Hard Magnetic Materials

Hard magnetic materials are the one which cannot be magnetized and demagnetized easily. The area enclosed by the B-H curve is very high & hence they have high hysteresis loss.

Ex: Alloy of Aluminium, Nickel & Cobalt (Alnico)

Rare earth alloys



properties

i) The retentivity and coercivity value is very high.

ii) Hysteresis loss is very high.

iii) Small initial permeability.

iv) B H loop is nearely rectangle.

Applications

i) Used to manufacture permanent magnets.

ii) Used in microphones, loud speakers, telephone ringers etc.

iii) Used in Energy meter disc, Sensors, Dampers etc.

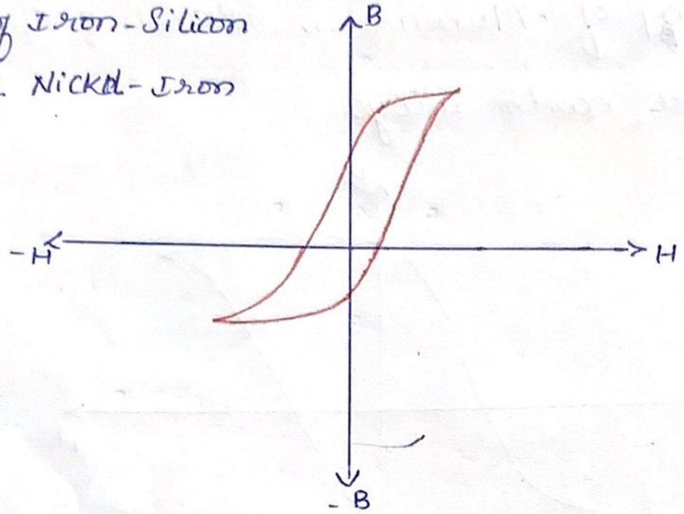
iv) Used in printers, NMR/MRI body scanner.

v) Used in computers, clocks, DC Motors for showers.

Soft Magnetic Materials

Soft magnetic materials are the one which can be magnetized & demagnetized easily. The area enclosed by the B-H curve is small, so it has low hysteresis losses.

Ex: Alloy of Iron-Silicon
Alloy of Nickel-Iron



properties

i) The retentivity and Coercivity value is very less.

ii) The saturation magnetism is high.

iii) Hysteresis loss is small.

iv)

Applications

i) Used in power supply transformer.

ii) Used in manufacturing temporary magnets.

Dielectric Materials

Dielectric Materials

Dielectric materials are referred as insulators, but under certain conditions acts as very poor conductor of electric current.

When dielectrics are placed in an electric field, practically no current flows in them because, unlike metals, they have no loosely bound, or free electrons that may drift through the material. Instead, electric polarization occurs.

Ex: Glass, rubber, plastic, mica.

Dielectric Constant / Relative Permittivity (ε_r)

Dielectric constant is a quantity measuring the ability of a substance to store electrical energy in an electric field.

$$\vec{D} = \varepsilon_r \varepsilon_0 \vec{E}$$

Where $\vec{D}$ → Flux Density

ε_0 → Absolute permittivity

ε_r → Relative permittivity

$\vec{E}$ → Applied Electric Field

Polarization

The displacement of charges in the atoms or molecules of a dielectric under the action of an applied electric field leads to the development of dipole moment is called polarization.

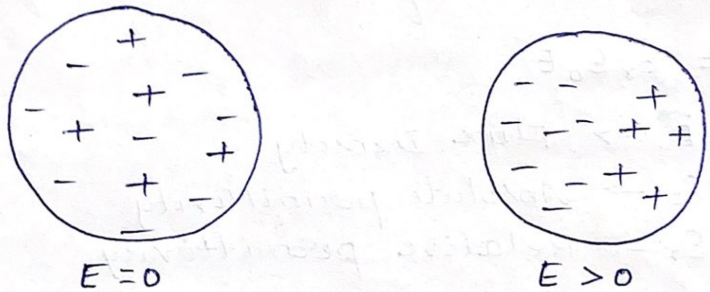
Types of polarization Mechanisms

There are four types of polarization mechanisms.

1) Electronic polarization
2) Ionic polarization
3) orientational polarization
4) Space charge polarization

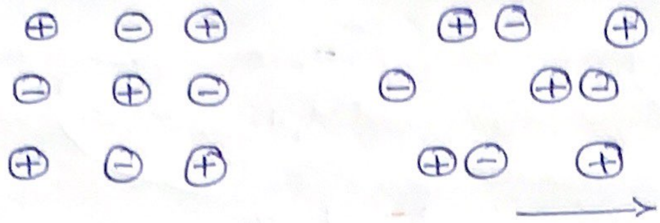
Electronic polarization

The electronic polarization occurs due to displacement of the positive & negative charges in a dielectric material with the application of external Electric field, which leads to development of dipole moment.



Ionic polarization

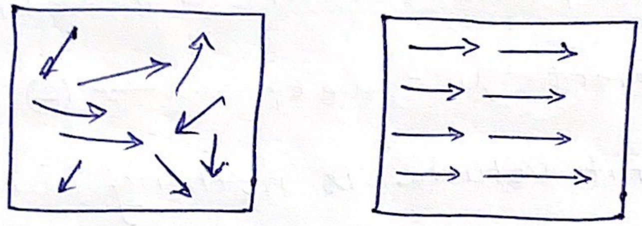
This is a kind of polarization occurs in some dielectric materials which have ionic bonds like NaCl. when ionic solids are subjected to an external electric field, the adjacent ions of opposite sign undergo displacement.



E = 0 E > 0

Orientational polarization

This type of polarization occurs in polar dielectric material. The orientation of molecules is random in the absence of electric field, therefore net dipole moment in the material is zero. But under the influence of an applied electric field, each dipole reorient along the field direction. Thus the material develops an electrical polarization.



E = 0 E > 0

Clausius - Mossotti Equation

Consider a solid dielectric material with dielectric constant ε_r. If 'n' is the number of atoms / unit volume and 'μ' is the dipole moment of the atoms in the material.

$\therefore$ Dipole moment / unit volume $= n\mu \longrightarrow (1)$

Let E_i be the internal field experienced by the atom and α_e be the electronic polarizability of the atoms.

Dipole moment / unit volume $= N \alpha_e E_i$

Dipole moment $\mu = \alpha_e E_i \longrightarrow (2)$

Dipole moment / unit volume is nothing but polarization.

$$\therefore P = N \alpha_e E_i$$

$$E_i = \frac{P}{N\alpha_e} \longrightarrow (3)$$

we have, $P = \varepsilon_0 (\varepsilon_r - 1) E$

$$E = \frac{P}{\varepsilon_0 (\varepsilon_r - 1)} \longrightarrow (4)$$

The Expression for internal field for 3D material is given by,

$$E_i = E + \frac{P}{3\varepsilon_0} \longrightarrow (5)$$

Substituting eqn 3 & 4 in 5, we get

$$\frac{P}{N\alpha_e} = \frac{P}{\varepsilon_0(\varepsilon_r - 1)} + \frac{P}{3\varepsilon_0}$$

$$\frac{1}{N\alpha_e} = \frac{1}{\varepsilon_0(\varepsilon_r - 1)} + \frac{1}{3\varepsilon_0}$$

$$\frac{1}{N\alpha_e} = \frac{1}{\varepsilon_0}\left[\frac{1}{(\varepsilon_r - 1)} + \frac{1}{3}\right]$$

$$= \frac{1}{\varepsilon_0}\left[\frac{3 + \varepsilon_r - 1}{3(\varepsilon_r - 1)}\right]$$

$$= \frac{1}{\varepsilon_0}\left[\frac{\varepsilon_r + 2}{3(\varepsilon_r - 1)}\right]$$

$$\frac{1}{N\alpha_e} = \frac{1(\varepsilon_r + 2)}{3\varepsilon_0(\varepsilon_r - 1)}$$

$$\boxed{\frac{(\varepsilon_r - 1)}{(\varepsilon_r + 2)} = \frac{N\alpha_e}{3\varepsilon_0}}$$

Above equation is called Clausius Mossotti equation

Ferroelectric Materials

Ferroelectric materials are materials that Exhibit ferroelectricity. Ferroelectricity is the ability of the material to have a spontaneous electric polarization, that can be reversed by the application of an external electric field.

Ferroelectric materials can maintain the polarization even once the electric field is removed. Ferroelectric materials have some similarities over ferromagnetic materials, which reveal permanent magnetic moment. The hysteresis loop is almost same for both materials.

Ex : $BaTiO_3$ = Barium titanate

Properties

1) All ferroelectrics are pyroelectric, with the additional property that their natural electrical polarization is reversible.

2) Below a transition temperature called the curie temperature ferroelectric are polar & posses a spontaneous polarization.

Applications of Dielectric Materials

Dielectric material can be Solid, liquid or gas. High vaccum can also be used as a dielectric.

a) Solid dielectrics are most commonly use like glass, rubber, mica etc.

b) As a liquid dielectric material transformer oil, cable oil, capacitor oil, Vegetable oil etc can be used.

c) Gaseous dielectric materials are used for both as insulators and also as a cooling agents.

Ex : Hydrogen, Air, nitrogen, Helium etc.