UNIT-2

Part B : Magnetics

Syllabus:

Introduction to Magnetics-Magnetic dipole moment-Magnetization-Magnetic susceptibility and permeability- Origin of permanent magnetic moment -Classification of Magnetic materials-Weiss theory of ferromagnetism (qualitative)-Hysteresis-soft and hard magnetic materials-Ferrites-Magnetic device applications (transformer core and hard disc).

Magnetic dipoles:

All magnetic phenomenon are due to electric charges in motion. At atomic scale, tiny currents due to electrons orbiting around the nuclei and the electrons spinning about their axes are treated as magnetic dipoles. These dipoles cancel each other because of random orientation of atoms. But when magnetic field is applied these dipoles either orient in the field direction or opposite to the field direction magnetizing the material. This is called magnetic polarization or **magnetization**.

Magnetic dipole moment:

The torque applied on a current loop in magnetic field is

$\tau = IABsin\theta$

Or $\tau = \bar{m} \times \bar{B}$ where **m =I A** is called magnetic dipole moment.

Units: A-m^2

Magnetic Flux density ($\bar{B}$):

The number of magnetic flux lines passing normally through unit area is called flux density B.

$$\bar{B} = \frac{\emptyset}{A}$$

Units: weber/m^2

Magnetizing field ($\bar{H}$) :

The magnetic field that magnetizes a material is called magnetizing field. Its units are A/m

Magnetization vector ($\bar{M}$):

The magnetic dipole moment per unit volume is called magnetization vector.

$$\bar{M} = \frac{\bar{m}}{V} \quad \text{Units: A/ m}$$

Magnetic Susceptibility:

It is defined as magnetization produced in the material per unit applied magnetic field.

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

It is the measure of ease with which the material can be magnetized.

Magnetic Permeability:

It is defined as ratio of magnetic induction **B** to the magnetizing field **H.**

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

It is a measure of the degree of which the field lines permeate the material.

Paramagnetic materials:

In Paramagnetic materials, atoms possess permanent magnetic dipole moment but these dipoles do not interact among themselves. When external magnetic field is applied, these permanent dipoles align parallel to the field and feebly magnetized. Paramagnetic susceptibility is positive and greatly depends on temperature. Relative permeability is slightly greater than one.

Eg. Alkali metals, Transition metals, Rare earths.

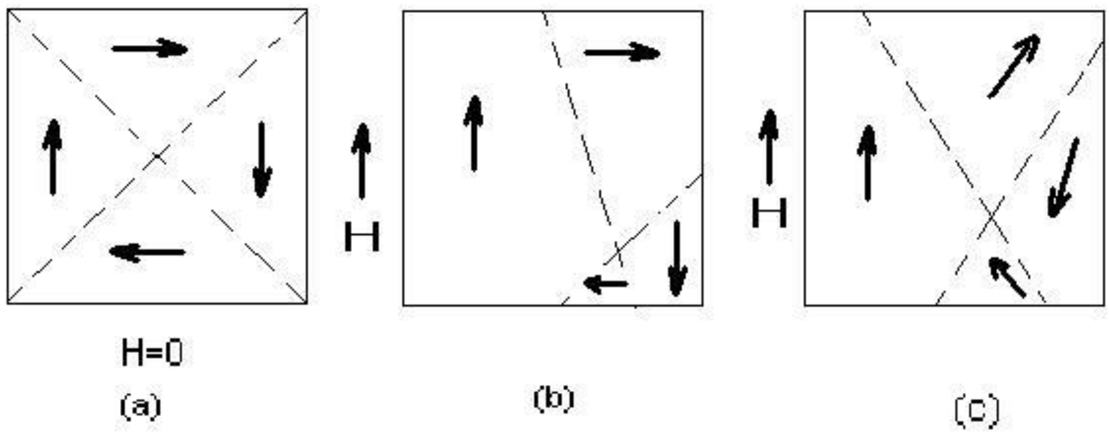
Diamagnetic materials:

These materials are feebly magnetized opposite to field direction when placed in external magnetic field. Permanent dipoles are absent. Diamagnetism is found in the substances whose atoms have even number of electrons which form pairs. Magnetic moment of one electron is cancelled by the other due to opposite spin. So the net magnetic moment of an atom of diamagnetic substance is zero. The Magnetic susceptibility is small and negative. Susceptibility is independent of applied field strength and temperature. Relative permeability is less than one.

Eg. Cu, Zn, Bi, Ag, Au, H_2O etc. Superconducting materials are diamagnetic in nature.

Ferromagnetic materials:

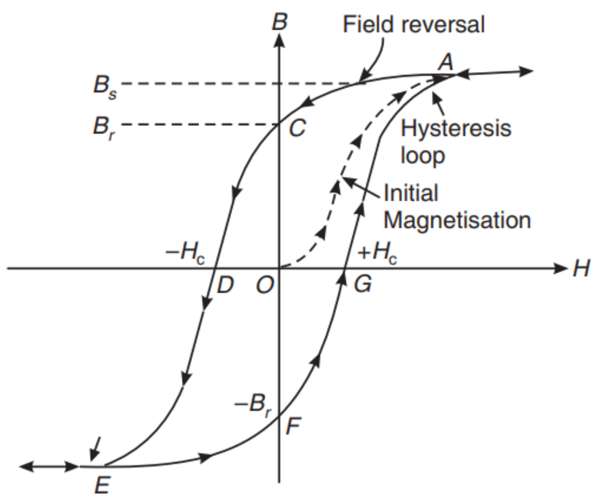
Ferromagnetic materials are strongly magnetized in the field direction when subjected to external magnetic field. It consists of a number of regions or domains which are spontaneously magnetized due to special form of interaction called exchange coupling. When external field is applied the volume of domains that are favourably oriented with respect to magnetizing field increases at the cost of those unfavourably oriented.



Relative permeability is much greater than unity.They have high susceptibility value which is independent of magnetizing field. Beyond Curie temperature T_c they turn into paramagnetic.

Eg. Fe, Co, Ni, AlNiCo

Hysteresis loop:



These materials exhibit hysteresis loop. When a ferromagnetic material is subjected to increasing or decreasing magnetic fields, the magnetic field induction B varies as a function of H along a closed loop called hysteresis loop. The curve begins at O. As H increases the field B increases slowly, then more rapidly and finally attaining saturation value and becoming independent of H. The maximum value of B is saturation flux density B_s and the corresponding magnetization is the saturation magnetization M_s. If H is now decreased, B also decreases but following the path AC instead of original path AO. Thus B lags behind H. When H becomes zero B does not become zero but has a value equal to OC(B_r).This magnetic flux density remaining in the materials is called residual magnetism. It indicates that the material remains magnetized even in absence of external field H. The power of retaining magnetism is called retentivity or remanance of the material. If H is now increased in reverse direction B decreases along the path CD. B becomes zero when H attains a value equal to OD. To reduce magnetic induction within the material to zero a field of magnitude H_c must be applied opposite to original magnetizing field. H_c is called coercivity. On reversing the variation of field H, the curve follows the path EFGA. The closed curve ACDEFGA is called hysteresis loop.

Differences between para, dia and ferromagnetic materials.

S.No	Ferromagnetic	Paramagnetic	Diamagnetic
1	Strongly attracted towards magnetic field.	Feeble attraction towards magnetic field.	Feeble repulsion from the magnetic field.
2	Field lines are concentrated in the material.	More number of field lines pass through the material than outside.	Less number of field lines pass through the material than outside.
3	Set along the direction of the magnetic field.	Tend to align along the magnetic field direction.	Tend to align perpendicular to the magnetic field direction.
4	Susceptibility, χ is large and positive.	Susceptibility, χ is less than 1 but positive.	Susceptibility, χ is small but negative.
5	Relative permeability, μ_r is greater than unity.	Relative permeability, μ_r is slightly greater than unity.	Relative permeability, μ_r is less than unity.
6	Susceptibility, χ decreases with temperature.	Obey's Curie law, $\chi = 1/T$	Susceptibility, χ is independent of temperature.
7	Have definite Curie point above which they become paramagnetic.	No Curie point.	No Curie point.
8	Exhibit phenomenon of Hysteresis.	Hysteresis is not exhibited.	Hysteresis is not exhibited.
9	Possess retentivity.	No retentivity.	No retentivity.
10	Ex: Iron, cobalt, nickle	Ex: Platinum, Chromium, Aluminium etc.	Ex: Bismuth, mercury, silver, copper, water etc.

Ferrites (Ferrimagnetic materials)

In these materials the net magnetization of magnetic sublattices is not zero since antiparallel moments are of different magnitudes. Above a particular temperature called curie temperature T_c thermal energy randomizes the individual magnetic moments and the material becomes paramagnetic.

Ferrites consist chiefly of ferric oxide Fe_2O_3 , combined with one or more oxides of divalent metals . They are represented by the general formula MFe_2O_4 (or) $MOFe_2O_3$ in which M represents any metallic elements such as Fe^{2+}, Co^{2+}, Mn^{2+}, Zn^{2+}, Cd^{2+}, Mg^{2+} etc.

Eg. $Fe^{2+}Fe_2O_4$ (Magnetite), $Zn^{2+}Fe_2O_4$ (Zinc Ferrite), $Ni^{2+}Fe_2O_4$ (Nickel Ferrite)

Composite ferrites which are solid solutions of one simple ferrite in another shows best magnetic properties. Ferrites exhibit hysteresis loop. They are polycrystalline samples and the coercivity , retentivity and permeability depend on grain size.

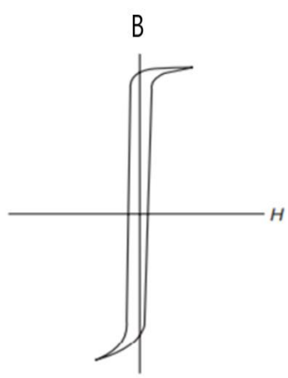
Ferrites have high resistivity ranging from 10^2 to 10^{10} Ohm-m

Applications :

1) As the eddy current losses is much less severe in ferrites they can be used in transformer cores for frequencies upto microwaves.
2) They are used in radio receivers.
3) They are used in digital data storage devices.

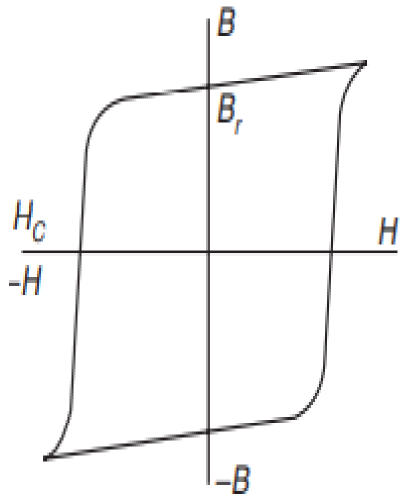
Soft magnetic materials:

Magnetic materials, which are easily magnetized and demagnetized are known as soft magnetic materials. They are characterized by thin hysteresis loop. A soft magnetic material should have a high initial permeability and a low coercivity. In view of these properties, the material reaches its saturation magnetization with a relatively low applied field, and exhibits low hysteresis energy losses. This becomes an important consideration when the material is used in alternating current applications, since the area of hysteresis loop represents the energy lost as heat during a cycle. The smaller the area, the lower are the power losses and the greater the possibility of using the material at higher frequencies.



Hard Magnetic Materials :

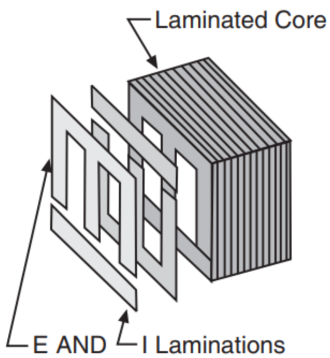
Hard magnetic materials are those, which have a high resistance to demagnetization. A high remanence, high permeability, a high coercive field and a large hysteresis loop characterize the hard magnetic materials. The hard magnetic materials are magnetized in a magnetic field strong enough to orient the magnetic moments of their domains in the direction of the applied field. Part of the energy of the applied field is converted into potential energy, which is stored in the permanent magnet produced. A permanent magnet in the fully magnetized condition is thus in a relatively high-energy state as compared to a demagnetized state. The power or external energy of a hard magnetic material is directly related to the size of its hysteresis loop. The magnetic potential energy of a hard material is measured by its maximum energy product (BH)max.



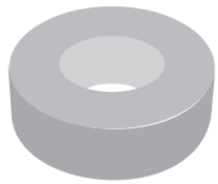
Magnetic Device Applications:

1. **Transformer core**

   The core makes up the bulk of a transformer. A magnetic core is a piece of magnetic material with a high permeability used to confine and guide magnetic fields in electrical devices. It is usually made of ferromagnetic metal such as iron, or ferrimagnetic compounds such as ferrites. The high permeability, relative to the surrounding air, causes the magnetic field lines to be concentrated in the core material. The presence of the core can increase the magnetic field of a coil by a factor of several thousand over what it would be without the core. A range of cores exist, such as steel laminated, solid, toroidal, pot and planar cores.

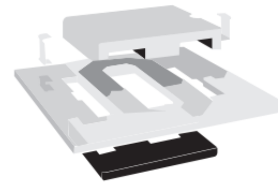


Steel Laminated core



Toroidal core

Pot Core



Planar core

Steel laminated cores have high level of permeability and are used for transmitting voltage at the audio frequency level. Solid cores, particularly the powdered iron cores used in circuits, have high magnetic permeability as well as electrical resistance. For high frequencies such as beyond the VHF (very high frequency) band, powdered iron is replaced by ferrites. A range of materials are available for use in toroidal cores, including steel, coiled permalloys, powdered iron, or ferrites. Pot shaped core has a shielding effect which reduces electromagnetic interference. A planar core consists of two flat pieces of magnetic material, one above and one below the coil. It is typically used with a flat coil that is part of a printed circuit board.

2. **Hard disks:**

A magnetic disk is a flat circular plate called platter which has a surface coated with magnetic iron oxide particles. A hard disk is one or more platters and their associated read write heads. The platters rotate at a speed of 3600 rpm. Information is recorded in the form of bands. Each band of information is called track. The tracks are divided into sectors. The tracks and sectors are created when the hard disk is first formatted before use. The drive spins the disk and a thin layer of air rotates along with the disk. The head riding on this cushion of air writes or reads the tracks. The storage capacity can be increased by mounting several disks on common drive unit. Hard disks of size 80 to 250GB have become common in personal computers.