MAGNETIC MATERIALS

INTRODUCTION

Any materials that can be magnetized by an applied by an applied external magnetic field is called a magnetic material. Magnetic materials can be easily magnetized because they have permanent or induced magnetic moment in the presence of applied magnetic field. Magnetism arise from the magnetic moment or magnetic dipole of the magnetic materials. Among the different eleven types of magnetic materials, only five magnetic materials are the most important for the practical application.

They are:

- Diamagnetic materials.
- Paramagnetic materials.
- Ferromagnetic materials.
- Antiferromagnetic materials.
- Ferrimagnetic materials or ferrites.

TERMS AND DEFINITIONS

Magnetic flux (φ)

Total number of magnetic lines of force passing through a surface is known as magnetic flux. Itis represented by the symbol 'φ' and its unit is weber.

Magnetic flux density (or) Magnetic induction (B)

Magnetic flux density at any point in a magnetic field is defined as the magnetic flux (φ) passing normally through unit area of cross section (A) at that point. It is denoted by the symbol B and its unit is weber / metre^2 or tesla.

$$\mathbf{B = [\varphi / A]}$$

Intensity of magnetization (I)

The term magnetization means the process of converting non-magnetic material on magnetic material.When some amount of external magnetic field is applied to the metals such as iron, steel and alloys etc., they are magnetized to different degrees. The intensity of magnetization (I) is the measure of the magnetization of a magnetized specimen. It is defined as the magnetic moment per unit volume.

$$I = M / V \text{ weber / metre}^2$$

Magnetic field intensity (or) strength (H)

Magnetic field intensity at any point in a magnetic field is the force experienced by unit northpole placed at that point.

It is denoted by H and its unit is Newton per weber or ampere turns per metre (A/m).

Magnetic permeability (μ)

Magnetic permeability of a substance measures the degree to which the magnetic field can penetrate through the substance. It is found that magnetic flux density (B) is directly proportional to the magnetic field strength (H)

$$\mathbf{B \propto H}$$

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

Where is a constant of proportionality and it is known as permeability or absolute permeability of the medium **$\mu = B / H$**

Hence, the permeability of a substance is the ratio of the magnetic flux density (B) inside the substance to the magnetic field intensity (H).

Absolute permeability

Absolute permeability of a medium or material is defined as the product of permeability of free space (μ_0) and the relative permeability of the medium (μ_r).

$\mu = \mu_0 \times \mu_r$

7. Relative permeability (μ_r) of a medium

Relative permeability of a medium is defined as the ratio between absolute permeability of a medium () to the permeability of a free space ()
$\mu_r = \mu / \mu_0$

Magnetic susceptibility (χ)
Magnetic susceptibility (χ) of a specimen is a measure of how easily a specimen can be magnetized in a magnetic field. It is the ratio of intensity of magnetization (I) induced in it to the magnetizing field (H). $\chi = I / H$

Retentivity (or) Remanence
When the external magnetic field is applied to a magnetic material is removed, the magnetic material will not loss its magnetic property immediately. There exits some residual intensity of magnetization in the specimen even when the magnetic field is cut off. This is called residual magnetism (or) retentivity.

Coercivity
The residual magnetism can be completely removed from the material by applying a reverse magnetic field. Hence coercivity of the magnetic material is the strength of reverse magnetic field (-Hc) which is used to completely demagnetize the material.

3.3 ORIGIN OF MAGNETIC MOMENT AND BOHR MAGNETON

3.3.1 Origin of magnetic moment

Any matter is basically made up of atoms. The property of magnetism exhibited by certain materials with the magnetic property of its constituent atoms. We know that electrons in an atom revolve around the nucleus in different orbits.
Basically, there are three contributions for the magnetic dipole moment of an atom.

- The orbital motions of electrons (the motion of electrons in the closed orbits around the nucleus) are called orbital magnetic moment.
- Spin motion of the electrons (due to electron spin angular momentum) is called spin magnetic moment.
- The contribution from the nuclear spin (due to nuclear spin angular momentum) is nearly 10 3times smaller than that of electron spin; it is not taken into consideration.

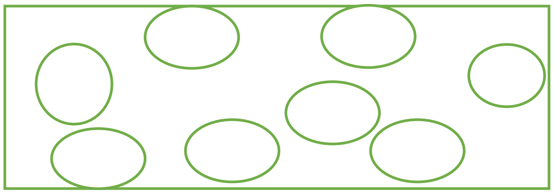
3.3.2 Bohr Magneton

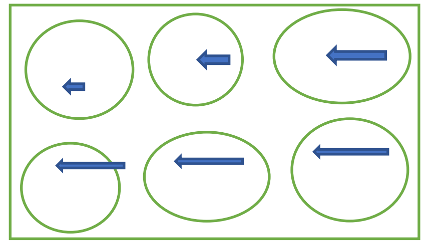
The magnetic moment contributed by an electron with angular momentum quantum number n =1 is known as Bohr Magneton.

DIFFERENT TYPES OF MAGNETIC MATERIALS

DIAMAGNETIC MATERIALS

Diamagnetism is exhibited by all the materials. The atoms in the diamagnetic materials do not possess permanent magnetic moment.
However, when a material is placed in a magnetic field, the electrons in the atomic orbits tend to counteract the external magnetic field and the atoms acquire an induced magnetic moment.
As a result, the material becomes magnetized. The direction of the induced dipole moment is opposite to that of externally applied magnetic field. Due to this effect, the material gets very weakly repelled, in the magnetic field. This phenomenon is known as diamagnetism.
When a magnetic field Ho is applied in the direction shown in fig., the atoms acquire an induced magnetic moment in the opposite direction to that of the field.
The strength of the induced magnetic moment is proportional to the applied field and hence magnetization of the material varies directly with the strength of the magnetic field.
The induced dipoles and magnetization vanish as soon as the applied field is removed.





H = 0 **H = Ho**

Properties of diamagnetic material

- Diamagnetic magnetic material repels the magnetic lines of force. The behaviour of diamagnetic material in the presence of magnetic field.
- There is no permanent dipole moment. Therefore, the magnetic effects are very small.
- The magnetic susceptibility is negative and it is independent of temperature and applied magnetic field strength.

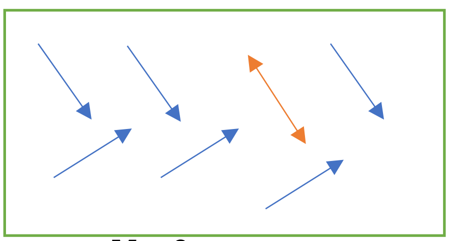
PARAMAGNETIC MATERIALS

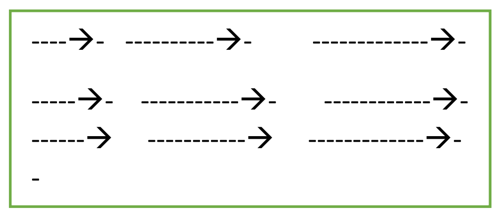
In certain materials, each atom or molecule possesses a net permanent magnetic moment (due to orbital and spin magnetic moment) even in the absence of an external magnetic field.

The magnetic moments are randomly oriented in the absence of external magnetic field. Therefore, the net magnetic moment is zero, and hence the magnetization of the material is zero.

But, when an external magnetic field is applied, the magnetic dipoles tend to align themselves in the direction of the magnetic field and the material becomes magnetized. As shown in fig. This effect is known as Para magnetism.

H = 0 **H = Ho**





M = 0 **M = +Mo**

Thermal agitation disturbs the alignment of the magnetic moment. With an increase in temperature, the increase in thermal agitation tends to randomize the dipole direction thus leading to a decrease in magnetization.

This indicates that the paramagnetic susceptibility decreases with increases in temperature. It isnoted that the paramagnetic susceptibility varies inversely with temperature.

$$\chi \propto 1 / T$$

$$\chi = C / T$$

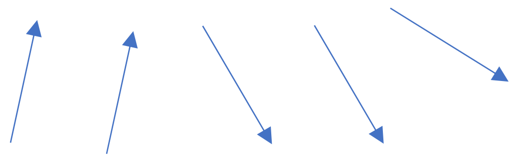
This is known as Curie law of para magnetism and C is a constant called Curie constant

Properties of paramagnetic materials

- Paramagnetic materials attract magnetic lines of force.
- They possess permanent dipole moment.
- The susceptibility is positive and depend on temperature is given byB ≠ 0 B = 0

$$\chi = C / T - \theta$$

The spin alignment is shown in fig.



Example- Manganous sulphate, ferric oxide, ferrous sulphate, nickel sulphate, etc.

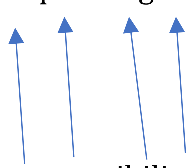
FERROMAGNETIC MATERIALS

Certain materials like iron, cobalt, nickel and certain alloys exhibit high degree of magnetization. These materials show spontaneous magnetization. (i.e) they have small amount of magnetization even in the absence of external magnetic field.

This indicates that there is strong internal field within the material which makes atomic magnetic moments with each other. This phenomenon is known as ferromagnetism.

Properties of ferromagnetic materials:

- All the dipoles are aligned parallel to each other due to the magnetic interaction between the two dipoles.
- They have permanent dipole moment. They are strongly attracted by the magnetic field.
- They exhibit magnetization even in the absence of magnetic field. This property of ferromagnetic material is called as spontaneous magnetization.
- They exhibit hysteresis curve.
- On heating, they lose their magnetization slowly.
- The dipole alignment is shown in fig.



- The susceptibility is very high and depends on the temperature. It is given by

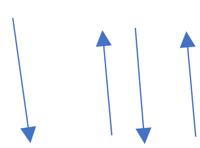
$\chi = C / T - \theta$ [for $T>\theta$; paramagnetic behavior;
for $T<\theta$; ferromagnetic behavior]
Where C is the Curie constant and θ is the paramagnetic Curie temperature.

ANTIFERROMAGNETIC MATERIALS

Antiferromagnetic materials are magnetic materials which exhibit a small positive susceptibility of the order of 10 -3 to 10-5.

In antiferromagnetic materials, the susceptibility increases with increasing temperature and it reaches maximum at a certain temperature called Neel Temperature, T_N.

With further increase in temperature, the material reaches the paramagnetic state. The material is
antiferromagnetic below T_N.



Properties of antiferromagnetic materials

- The electron spin of neighboring atoms are aligned antiparallel. (i.e) the spin alignment is antiparallel.
- Antiferromagnetic susceptibility is mainly depends on temperature.
- The susceptibility of the antiferromagnetic material is small and positive. It is given by

$$\chi = C / T + \theta \text{ when } T > T_N$$

$\chi \propto T$ when $T < T_N$

The susceptibility initially increases slightly with the temperature and beyond Neel temperature, the susceptibility decreases with temperature.

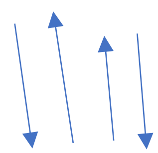
FERRIMAGNETIC MATERIALS

Properties of ferrites

- Ferrites have net magnetic moment.
- Above Curie temperature, it becomes paramagnetic, while it behaves ferromagnetic material blow Curie temperature.
- The susceptibility of ferrite is very large and positive. It is temperature dependent and is given by

$$\chi = C / T \pm \theta \text{ for } T > T_N$$

- Spin alignment is antiparallel of different magnitudes as shown fig.



- Mechanically it has pure iron character.
- They have high permeability and resistivity.
- They have low eddy current losses and low hysteresis losses.

3.5 FERROMAGNETISM

The materials which have finite value of magnetization even if the external magnetic field is absent are called ferromagnetic materials. This phenomenon is called ferromagnetism. The ferromagnetic materials exhibit high degree of magnetization.

Explanation

In a ferromagnetic material, the magnetic interactions between any two dipoles align themselves parallel to each other. Ferromagnetism arises due to the special form of interaction called exchange coupling between adjacent atoms. This exchange coupling is favorable for spin alignment they coupling their magnetic moments together in rigid parallelism.

A ferromagnetic material exhibits ferromagnetic property below a particular temperature called ferromagnetic. Curie temperature (f_θ). Above f_θ they behave as paramagnetic material.