UNIT-III

MAGNETIC AND ELECTRICAL PROPERTIES OF MATERIALS

CONTENTS

Introduction

Magnetic materials widely used in nuclear magnetic resonance equipment's and particle accelerators etc. These devices play vital role in our modern living. The knowledge about the origin and the behavior of magnetic materials will be of great help in proper utilization of such devices.

3.1. Basic definitions

Magnetic field

Space around the magnet is called magnetic field.

Magnetic dipole

Magnetic dipole is a system consisting of two equal and opposite magnetic pole separated by a small distance (*l*).

Magnetic dipole moment

The diploe moment of a magnet is defined as the product of its pole strength (m) and the distance between two poles (*l*). Unit -Weber/m.

Magnetic moment = m x *l*

Magnetic flux (*Φ*)

The number of magnetic lines of force passing through a surface is known as magnetic flux. It is represented by the symbol Φ. Unit -*Webber*

Magnetic flux density (or) magnetic Induction (B)

Magnetic flux density is defined as the number of magnetic lines of force passing through a unit area of cross-section.

$$B = \Phi/A \quad (Weber/m^2)$$

Intensity of magnetization (I)

It is the measure of magnetization of a magnetized specimen. It can also be defined as the magnetic moment per unit volume.

$$I = M/V \quad (A/m)$$

Magnetic field intensity (H)

It is defined as the force experienced by a unit north pole placed in a magnetic field.

$$H = F/m \qquad (A/m)$$

Magnetic permeability (μ)

It is defined as the ratio of the magnetic flux density to the applied magnetic field intensity

$$\mu = B/H \quad (Henry/m)$$

Relative permeability (μ_r)

It is the ratio between the absolute permeability of a medium to the permeability of a free space.

$$\mu_r = \mu / \mu_o \qquad (No\ unit)$$

Magnetic susceptibility (χ)

It is the ratio of intensity of magnetization induced in it to the magnetizing field

$$\chi = I/H$$

Relation between χ and μ

We know that the magnetic induction is,

$$B = \mu H$$

This equation can be written in another way as

$$B = \mu_o (I+H)$$

$$= \mu_o H ((I/H) + 1)$$

$$B = \mu_o H (\chi + 1)$$

$$B/H = \mu_o (\chi + 1)$$

$$\mu = \mu_o (\chi + 1)$$

$$\mu_o \mu_r = \mu_o (\chi + 1)$$

$$\mu_r = 1 + \chi$$

3.2. Origin of magnetic moment

The magnetic moment of a material originates from the orbital and spin motion of electrons in an atom. The permanent magnetic moment arises due to the

- Orbital angular momentum of the electron
- Spin angular momentum of the electron
- Nuclear magnetic moment

Orbital angular momentum of the electron

The orbital motion of electron revolving about a nucleus is equivalent to a tiny current loop. This produces a magnetic moment perpendicular to the plane of the orbit.

Let us consider an electron moving with constant speed *"v"* in a circular radius *"r"*. Let *"T"* be time taken for one revolution and *"e"* be the charge of the electron.

Magnetic moment associated with the orbit is,

$$\mu_L = current \times Area\ of\ the\ orbital\ (loop)\ \ldots..(1)$$

The current I across at any point in the orbit is,

$$I\ \frac{Charge\ of\ the\ electron}{Time}$$

$$I = \frac{-e}{T} \qquad \ldots\ldots\ldots\ldots..(2)$$

$$Area\ of\ the\ orbital\ (loop) is = \pi r^2 \quad \ldots\ldots\ldots.(3)$$

Substitute equation (2) and (3) in equation (1), we get

$$\mu_L = -\frac{e\pi r^2}{T} \qquad \ldots\ldots\ldots\ldots.(4)$$

Since, T is time taken by electron for one complete revolution. The distance (Circumference of the orbit) travelled by an electron in a given time (T) is called velocity.

$$Velocity\ (v) = \frac{2\pi r}{T}\ or\ T = \frac{2\pi r}{v}$$

Substitute T in equation (4), we get,

$$\mu_L = -\frac{e\pi r^2}{2\pi r/v}$$

$$\mu_L = -\frac{evr}{2} \qquad \ldots\ldots\ldots\ldots(5)$$

Dividing and multiplying the RHS of equation (5) by *m* (mass of the electron), we get

$$\mu_L = -\frac{mevr}{2m}$$

$$\mu_L = -\frac{eL}{2m} \qquad \ldots\ldots\ldots\ldots.(6)$$

Where, $L = mvr$ is the orbital angular momentum of the electron. The equation (6) is the final expression for the magnetic moment associated with the orbital motion of the electron.

Bohr Magnetron

The magnetic moment associated with the orbital magnetic moment of the electron is

$$\mu_L = -\frac{eL}{2m} \qquad \ldots\ldots\ldots\ldots.(1)$$

According to the quantum theory, orbital angular momentum is,

$$L = n\hbar$$

$$L = \frac{nh}{2\pi} \qquad \ldots\ldots\ldots\ldots..(2)$$

Where, *n* is the orbital angular momentum quantum number and substitute equation (2) in equation (1) we the Bohr magnetron,

$$\mu_B = -\frac{enh}{2\pi m} \qquad \ldots\ldots\ldots\ldots(3)$$

This is the final expression for Bohr magnetron and the value is calculated by the substitution of all the constants in equation (3). The calculated Bohr magnetron value is $\mu_B = 9.724 \times 10^{-24}$.

Spin angular momentum of the electron

Similar to orbital motion, magnetic moment due to spin motion of the electron is given by,

$$\mu_s = -\frac{eS}{m}$$

Where, *S* is the spin angular momentum and it is given by,

$$S = -\frac{sh}{2\pi}$$

Where, *s* is the spin quantum number and it takes +1/2 or -1/2.