MAGNETIC PROPERTIES OF MATERIALS

Diamagnetic and Paramagnetic

The magnetic moment of a free atom has 3 basic processes namely:

(i) the spin with which electrons are moving.

(ii) the orbital angular momentum of electrons around the nucleus.

(iii) the change in orbital momentum induced by an applied field.

Magnetisation

This is defined as the magnetic moment per unit volume.

Magnetic Susceptibility, χ_m

A magnetic field can be described either by magnetic induction B or magnetic field strength $\vec{H}$; i.e $\vec{B} = \mu_0 \vec{H}$. When a material is placed in a magnetic field the medium is magnetised and the magnetic induction inside the medium is given by $\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M}$, where $\mu_0 \vec{H}$ is the external applied magnetic field and M is the magnetisation of the medium. System magnetisation is induced by the field. M is considered to be proportional to the field strength, H. i.e $\vec{M} \propto \vec{H}$, $\vec{M} = \chi_m \vec{H}$, where χ_m is a dimensionless quantity called magnetic susceptibility.

Thus it is defined as the magnetic moment per unit field strength.

From $\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M}$ and $\vec{M} = \chi_m \vec{H}$.

$\Rightarrow \vec{B} = \mu_0 \vec{H}(1 + \chi_m)$.

In any medium $\vec{B} = mu\vec{H}$.

$\Rightarrow \mu_r = \frac{\mu}{\mu_0} = 1 + \chi_m$, where μ_r is the relative susceptibility.

CLASSIFICATION OF MATERIALS BY MAGNETIC PROPERTIES

Magnetic materials may be grouped into 3 magnetic classes depending on the sign of magnitude of magnetic susceptibility.

(i) If $\mu_r = 1 + \chi_m$ and $\mu_r \approx 1$ (but less than 1) then χ_m is a very small negative number. The material is diamagnetic.

(ii) If $\mu_r \approx 1$ but greater than 1, then χ_m is a very small positive number and the material is paramagnetic.

(iii) If $\mu_r >>> 1$ then χ_m is a large positive number and the material is ferromagnetic.

DIAMAGNETIC

Diamagnetic is the occurrence of a negative magnetic susceptibility which is associated with the tendency of electrical charges partially shielding the interior of the body from an applied magnetic field. This can be viewed according to Lenz's law of electromagnetic induction whereby the induced magnetic moment always opposes the applied field thus resulting in reduction in magnetic flux density.

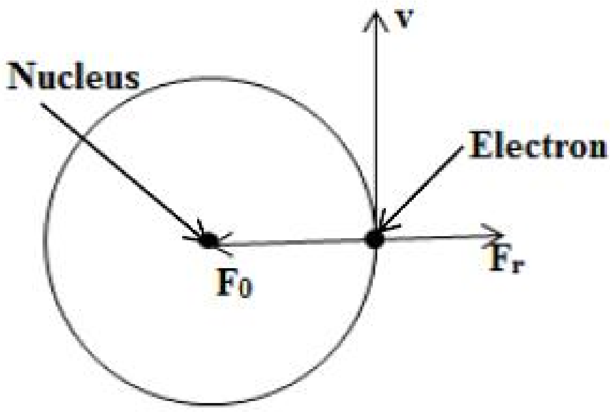
In the atoms of a diamagnetic material, the electrons are arranged symmetrically so that the magnetic moments due to the spin and orbital motion cancel out leaving the atom which no net magnetic moment in absence of an externally applied magnetic field.

Diamagnetism arises mainly from the orbital motion of electrons within an atom and is present in all materials. In most materials it is too weak to be of any practical importance. Thus diamagnetic materials exhibit no permanent magnetism and the induced magnetic moment disappears when the applied field is withdrawn.

LANGEVIN DIAMAGNETISM

Consider an electron rotating about the nucleus in a circular orbit. Let a magnetic field be applied perpendicular to the plane of paper as shown in the figure below:

Before applying this field, Newton's law gives $F_0 = mw_0^2r$, where F_0 is the attractive



coulombs force between the nucleus and the electron and w_0 is the angular frequency. When the electric field is applied an additional force starts to act on the electron. This Lorentz force is given by $F_L = -e(E + \vec{v} \times \vec{B})$, $F_L = -e(E + \vec{v} \times \vec{B})$.

The resultant of these forces is radial outward and given by $F_r = eBwr$. Thus from $F_0 + F_r = mw^2r$, then $F_0 - eBwr = mw^2r$

$mw_0^2r - eBwr = mw^2r$

$mw_0^2r = mw^2r + eBwr$

$mw_0^2 = mw^2 + eBw$

$mw^2 + eBw - mw_0^2 = 0$ which is quadratic.

$\Rightarrow w = w_0 - \frac{eB}{2m}$.

The rotation of an electron is slowed down.

PARAMAGNETISM

This arises mainly from the magnetic dipole moments of the spinning electrons. The paramagnetic defect is temperature dependent being stronger at lower temperatures where there is less thermal collision. An external applied in addition to causing a very weak diamagnetic effect