Magnetization
Lecture 1

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Magnetic Intensity:

Force experienced by a unit $N - pole$ around it is called intensity at that point. SI unit is Newton/Weber

Lines of force:

Path along which a unit $N - pole$ placed in a magnetic field is directed called line of force. The tangent at any point on this curve gives direction of intensity at that point.

Flux:

Magnetic lines of force lie in all planes around a magnet is known as flux. SI unit is Weber.

$$1 Weber = 10^8\ Maxwell$$

The flux per unit area is flux density, it is denoted by B and known as Magnetic Induction. It depend on magnetic field & nature of medium. $B = \mu H$

Magnetic Moment:

It is the product of one of pole strength and magnetic length.

$$M = m \times 2l = 2ml$$

Here m is pole strength and $2l$ is length of magnet

Magnetic Potential:

The work done to bring unit $N - pole$ to a certain point is known as magnetic potential at that point.

Let $\emptyset_A$ and $\emptyset_B$ be the potential at point A and B respectively, then the magnetic intensity

$$H = \frac{\emptyset_A - \emptyset_B}{AB}$$

If AB is very small and the field is non uniform then

$$H = -\frac{d\emptyset}{dx}$$

$$d\emptyset = -Hdx$$

Where $d\emptyset$ is the potential difference across AB, dx is distance between them and (–) indicates that work is done against the force. So intensity of magnetic field is define as rate change of magnetic potential at that point.

Intensity of Magnetization:

If a magnetic substance is placed in a magnetic field, it acquires magnetism due to induction. So the substance possesses a magnetic moment. This moment per unit volume is called the intensity of magnetization.

Let a circular cylinder SN of length $2l$ and cross-sectional area A, its $S-end$ acquires south polarity $(-m)$ and $N-end$ acquires north polarity $(+m)$, so magnetic moment $M = 2ml$ and Intensity of magnetization

I_m= Magnetic moment/Volume

$$I_m = \frac{2ml}{2l \times A} = \frac{m}{A}$$

Therefore intensity of magnetization may also be defined as the pole strength acquired by the magnetic substance per unit area.

Magnetic Shell:

Magnetic shell is the thin sheet of ferromagnetic materials and uniform thickness and magnetized so that the direction of magnetization is everywhere normal to the surface of the sheet.

Shell are made up of large number of dipoles situated in such a way that materials have opposite polarities at two faces. Magnetic moment are the vector sum of constituent dipoles

The strength of the shell is equal to the magnetic moment per unit area.

Now

$$I_m = \frac{Magnetic\ Moment}{Volume}$$

$$I_m = \frac{M}{V}$$

$$I_m = \frac{m \times t}{A \times t}$$

$$I_m = \frac{m}{A}$$

$$m = I_m \times A$$

Therefore

$$Magnetic\ Moment\ of\ the\ shell = m \times t = I_m \times A \times t$$

So strength of the shell

$$\Omega = \frac{Magnetic\ Moment}{Area}$$

$$\Omega = \frac{I_m \times A \times t}{A} = I_m \times t$$

Here I_m is the intensity of magnetization, t is the thickness of shell, A is the surface area, V is the volume, m is the pole strength.

Magnetic Permeability & Susceptibility:

If a magnetic substance is placed in a magnetic field the two types of lines of force may be taken into consideration

First one is due to magnetizing field and second one is due to magnetization of substance

Let a cylindrical bar of cross-sectional area A is placed in a magnetic field H. If the bar is non magnetic, the lines of force crossing the cylinder will be $A \times H$. But if bar is magnetic substance the substance itself will be magnetized by induction. Then in addition of original lines of force, a certain number of lines of force enter into the substance due to magnetization. Therefore the degree to which the lines can penetrate into a magnetic substance is known as permeability. It depends on the nature of the substance.

In other words the ratio of magnetic induction (B) produced in a magnetic substance to the magnetizing field (H) is called the permeability of the medium.

Therefore

$$Permibility\ (\mu) = \frac{B}{H}$$

Here $\mu = \mu_0 \mu_r$

$\mu_0$is the permeability for free space and μ_r is the relative permeability of the medium

Again the ratio of magnetization of a magnetic substance to the magnetizing field is called susceptibility of the medium.

$$Susceptibility(\chi)= \frac{I_m}{H}$$

The relation between them is

$$\mu = \mu_0(1 + \chi)$$

Theories of Magnetism:

The magnetic properties of solids are classified into three categories

(i) Diamagnetism

(ii) Para magnetism

(iii) Ferromagnetism

Let *AB is* magnetic substance in a magnetic field *H*. If the magnetic moment per unit volume is *M*, Where *M* is known as Magnetisation.

For isotropic substances *M* and *H* are parallel & their relation is

$$M = \chi H$$

Where χ is known as magnetic susceptibility.

Now in case of diamagnetic substance, the induced moment produces a negative susceptibility.

In case of paramagnetic substances the susceptibility is positive and it depends on temperature.

Again the magnetic induction B can be written as

$$B = \mu_0(H + M)$$

Where μ is known as permeability of the substance.

For diamagnetic & paramagnetic substances the permeability is constant. But for ferromagnetic it is not constant.

From the above two relation it is established that

$$\mu = \mu_0(1 + \chi)$$

Ferromagnetism:

In case of ferromagnetic materials the magnetization and the magnetic field will exhibit hysteresis. Above a Critical temperature (Curie ferromagnetic temperature) the magnetization is zero.

Above a critical temperature θ_f the magnetization is zero.

Here θ_f is known as Curie ferromagnetic temperature.

Above the Curie temperature the susceptibility satisfies the relation which is known as Curie-Weiss Law

$$\chi = \frac{C}{T - \theta}$$

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Where C is known as Curie constant and θ is paramagnetic Curie temperature.

Above the Curie temperature the susceptibility satisfies the Curie-Weiss Law

$$\chi = \frac{C}{T-\theta}$$

Where C is Curie constant and θ is paramagnetic Curie temperature.

This law actually explains the ferromagnetic property as

(A) A macroscopic dimension of ferromagnetic material containing a small regions each of which are spontaneously magnetized.

The amount of magnetization is obtained from the sum of magnetic moment of each regions.

(B) Within each region, there exists a molecular field. So the dipoles are in parallel orientation as a result the specimen is spontaneously magnetized.

The molecular field H_m can be given by the relation

$$H_m = H + \gamma M$$

Where *H* is the intensity of applied magnetic field and γ is molecular field (Weiss constant) and *M* is the magnetization.

Let the solid contains N numbers of atoms per unit volume, each of which has total angular momentum number *J*. Then the magnetization will be

$$M = Nq\mu_B J B_J(x) \rightarrow (i)$$

Where $x = \frac{q\mu_B HJ}{KT}$, Here *H* is replaced by H_m .

Therefore

$$x = \frac{q\mu_B J(H + \gamma M)}{KT}$$

In case of spontaneous magnetization, $H = 0$

Therefore

$$x = \frac{q\mu_B J\gamma M}{KT}$$

So

$$M = \frac{xKT}{q\mu_B J\gamma} \rightarrow (ii)$$

Therefore *M* must satisfy both the equation (i) and (ii)

Now a graph is drawn with *M* against χ which is shown in the $Fig\ (i)$. The value of *M* at a given temperature will be obtained from the interaction of two curves. For $T \geq \theta_{\mathrm{f}}$ spontaneous magnetization is zero.

Only for $T < \theta_{\mathrm{f}}$ spontaneous magnetization occurs.

The relation between the ferromagnetic Curie temperature θ_f and the Weiss constant γ is obtained in the region $x \ll 1$. In this case

$$BJ(x) \cong \frac{(J+1)}{3J} \rightarrow (iii)$$

So the tangent of the curve related to equation (i) will have a slop $\frac{Nq\mu_B(J+1)}{3}$ and the slop of equation (ii) is $\frac{K\theta_\mathrm{f}}{q\,\mu_B J\gamma}$.

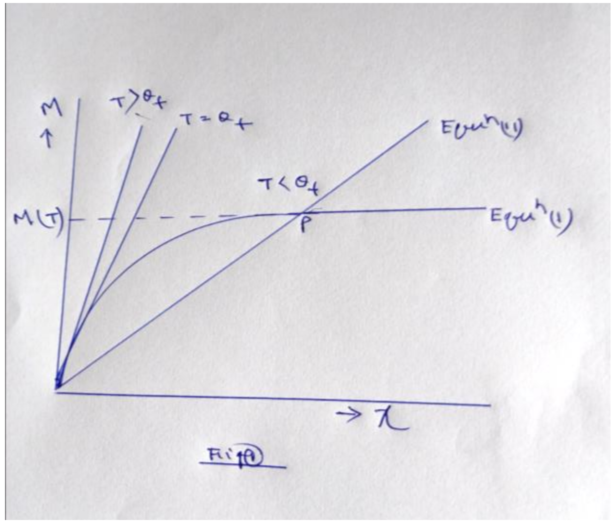

Fig 1

Therefore

$$\frac{Nq\mu_B(J+1)}{3} = \frac{K\theta_{\mathrm{f}}}{q\mu_B J\gamma}$$

$$\frac{3K\theta_{\mathrm{f}}}{\gamma} = Nq^2{\mu_B}^2 J(J+1) = N{\mu_j}^2 \rightarrow (iv)$$

From this relation it is seen that θ_{f} is proportional to the Weiss constant γ. Now it is seen that for $T > \theta_{\mathrm{f}}$, the magnetization occurs only after the application of applied magnetic field. For low fields it may be used the approximation of equation (iii).

Therefore

$$M = \frac{Nq\mu_B(J+1)x}{3}$$

$$M = \frac{Nq\mu_B(J+1)q\mu_B(H+\gamma M)J}{3KT}$$

$$M = \frac{Nq^2\mu_B{}^2J(J+1)(H+\gamma M)}{3KT}$$

$$M[3KT - Nq^2\mu_B{}^2J(J+1)\gamma] = Nq^2\mu_B{}^2J(J+1)H$$

$$M[3KT - N\mu^2\gamma] = N\mu_J{}^2H$$

$$\frac{M}{H} = \frac{N{\mu_J}^2}{3KT - N{\mu_J}^2\gamma} = \frac{\frac{N{\mu_J}^2}{3K}}{T - \frac{N{\mu_J}^2\gamma}{3K}}$$

$$\frac{M}{H} = \frac{C}{T - \theta} \rightarrow (v)$$

Where $C = \frac{N{\mu_J}^2}{3K}$ and $\theta = \frac{N{\mu_J}^2\gamma}{3K}$

This equation (v) is known as Curie-Weiss Law.

Now maximum value of spontaneous magnetization is $Nq\mu_B J$ because for $x \rightarrow \infty, BJ(x) \rightarrow 1$. Again it is found that maximum magnetization occurs for $T = 0$.