Magnetism

Lecture 3

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Theories of Magnetism:

The magnetic properties of solids are classified into three categories

(i) Diamagnetism

(ii) Paramagnetism

(iii) Ferromagnetism

Let *s* 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

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

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

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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 $x = \frac{q\mu_B H J}{KT}$, 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

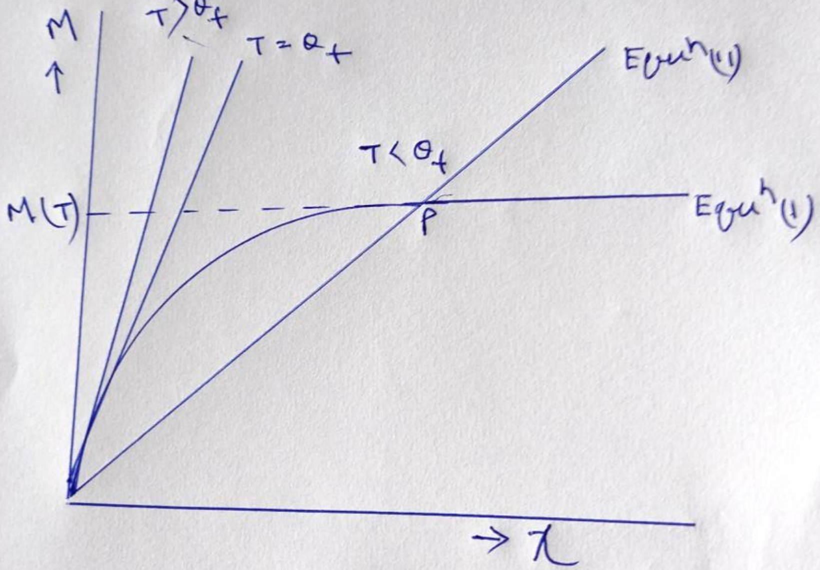
$$x = \frac{q\mu_B J\gamma M}{KT}$$

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.



Fig(1)

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 $\frac{K\theta_{\mathrm{f}}}{q\,\mu_B J\gamma}$.

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 $x \rightarrow \infty, B_J(x) \rightarrow 1$. Again it is found that maximum magnetization occurs for $T = 0$.

Magnetization Curves:

A plot of the different values of *I* against *H* gives the magnetization curve (*I*-*H*) as shown in Fig (ii). For a low value of *H* , the slope of the curve is also small but with an increase of *H* it steepens and finally reaches the point S after which *I* remains almost constant with a further increase of *H*. At S the magnet is said to have attained magnetic saturation.

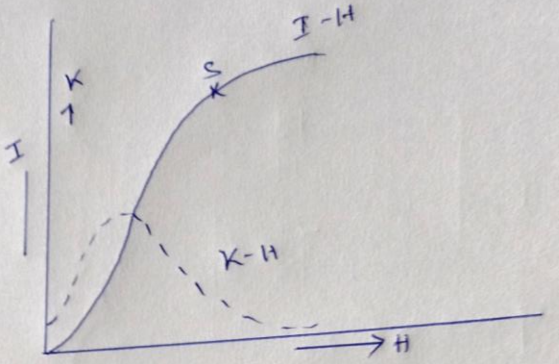


Fig-(II)

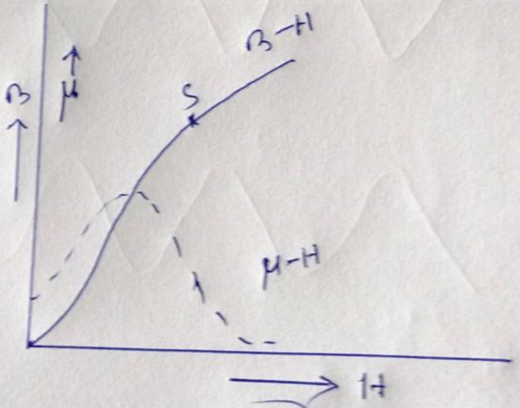


Fig-(III)

Simillarly it can be drawn a curve B-H, since $B = \mu_0(H + I)$. The nature is shown in Fig (iii) where the magnetic saturation is reached at the point S. Since $K = \frac{I}{H}$ and $\mu = \frac{B}{H}$,it may be drawn the (*K*-*H*) and (μ-*H*) curve as shown by the dotted line.

Cycle of Magnetization: Hysteresis:

If a magnetic material is subjected to a number of cyclic operations of magnetization and demagnetization, the specimen takes up a steady state. Starting from the zero value the specimen is subjected to a gradually increasing magnetizing field until the saturation is attained at S.

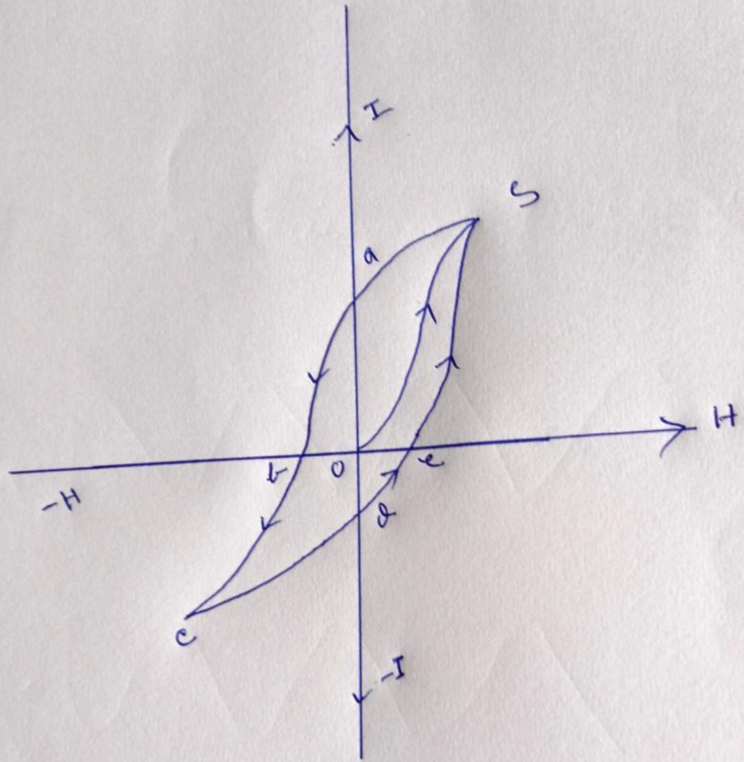


Fig (IV)

The field is then decreased gradually to zero value when the intensity of magnetization retained in the sample Oa and then the curve is traced as Sa. That Ce field is now reversed when the curve ab is obtained. *I* is reduced to zero at b. The reverse field is now further increased till in the revered direction the saturation is obtained at C. With the fall of the negative field to zero the curve Cd is obtained. Next by applying the field in the positive direction again, the saturation point S is restored and thus the complete cycle operation describes a closed loop SabCdeS. The above loop is characteristic of the specimen & is known as Hysteresis loop.

The ascending and descending portions of the loop are exactly symmetrical. It is also seen that when *H* reduces to zero, the intensity of magnetization has a definite value Oa as shown in figure. Thus *I* lags behind *H* in a cycle of magnetization and demagnetization. Such lagging of *I* behind *H* is known as the phenomenon of Hysteresis and the characteristic loop is known as Hysteresis Loop.

Hysteresis Loss:

Some energy is expanded during the cyclic process of magnetization and demagnetization. This energy exhibits itself in the form of heat within the specimen.

Since this energy is not possible to recover and is lost during a cyclic process of magnetization, it is known as Hysteresis Loss.

$$\oint HdI = \frac{1}{\mu_0}\oint HdB \rightarrow (vi)$$

From this equation it may conclude that the hysteresis loss of cycle per unit volume of the material is $\frac{1}{\mu 0}$ times the area of the *B*-*H* loop.

The energy loss per second $= \frac{m}{\rho} nS$ earg

Here S is energy loss per cycle per unit volume of the material.

n is the frequency of the cyclic operation per second, *m* is the mass of the specimen, ρ is the density of specimen.

The above energy is converted into heat and raises the temperature of the material. If θ^0 C be the raise of temperature, then

$$Heat\ generated = mc\theta \text{ cal}$$

If whole energy is utilized in heating up the specimen then

$$Jcm\theta = \frac{m}{\rho} nS$$

$$Jc\theta=\frac{nS}{\rho}$$

$$\theta=\frac{nS}{Jc\ \rho}\ ^{0}\text{C per second}$$

Where *J* is the Mechanical Equivalent of Heat.