Magnetization
Lecture 2

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Magnetization Curves:

A plot of the different values of *I* against *H* gives the magnetization curve (*I*-*H*) as shown in $Fig\ (i)$. 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.

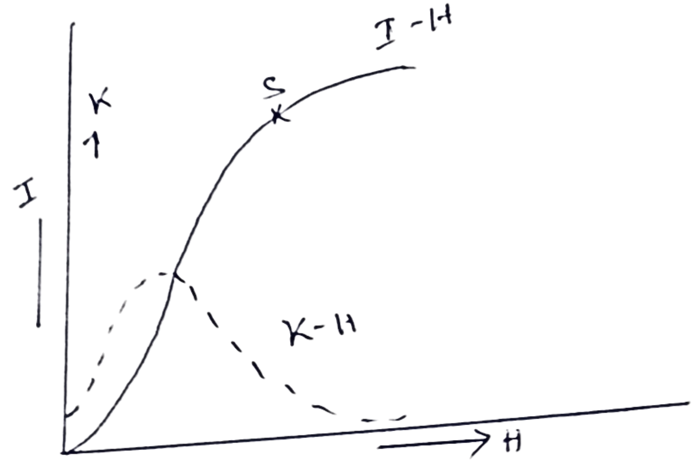

Fig 1

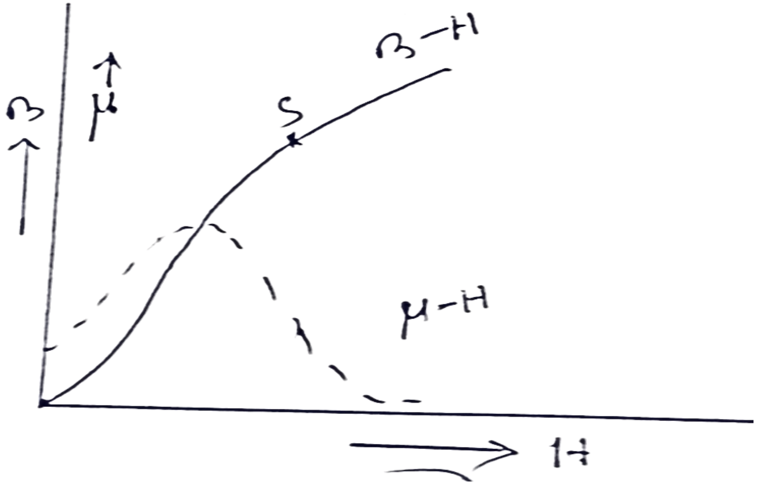

Fig 2

Similarly it can be drawn a curve $B - H$, since $B = \mu_0(H + I)$. The nature is shown in $Fig\ (ii)$ 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.

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.

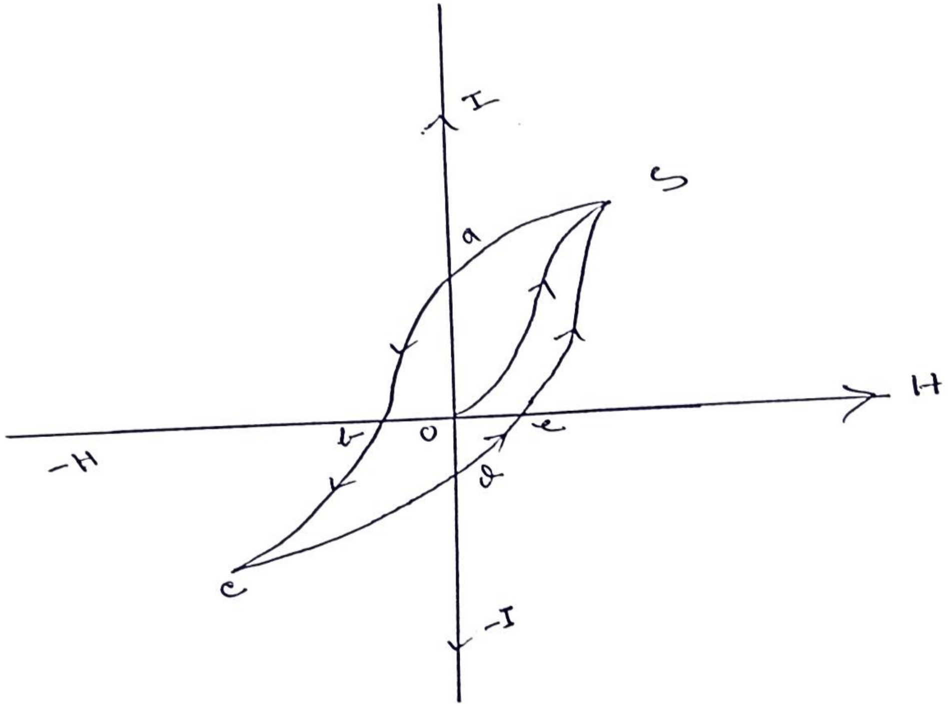

Fig 3

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.

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

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.

Quantum Numbers:

Principal quantum number (n) will determine the orbital energy. It has only the integer value as like $n = 1,2,3, \dots$ which represent the $K\ , L, M, \dots$.

Angular momentum quantum number (l) determine the angular momentum of the orbit and it takes the values $l = 0,1,2,3, \dots (n-1)$, which represent by $s, p, d, \dots f$ state of electron

Magnetic quantum number (m_l) determine the possible components of angular momentum along the direction of external field. It takes the values $m_l = l, (l-1), \dots .0, \dots . , -l$

Spin quantum number (s) leads to $s = \pm\frac{1}{2}$, because the possible angular momentum components of electron are $\pm\frac{\hbar}{2}$. Magnetic moment of the spin along the external field is given by

$$\mu_s = g\left(\frac{e}{2me}\right)\frac{\hbar}{2}$$

Where g is known as spectroscopic spitting factor or gyromagnetic ratio. For electron $g = 2.0023$

The total angular momentum quantum number j is obtained by adding vectorially orbital angular momentum quantum number l and spin quantum number s.

$$j = l \pm s$$

If an atom has a number of electrons , the l vectors are combined to form a resultant L and the spin vectors are combined to form a resultant S. The coupling is known as Russel-Saunders Coupling. L and S combine to form to give total angular momentum J . For such an atom the gyromagnetic ratio

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$

To find out the magnetic moment of the dipole for a given atom the above coupling must be according to Pauli's Principle and Hund's Rule. According Pauli only one electron can occupy a state defined by the quantum number n, l, m and s. Filled electron shell does not contribute to the magnetic moment of the atom. Incomplete electron shell will contribute to the magnetic moment of the atom. Hund's Rule states that for ground state of atom

- Spins add to give maximum possible value for S.
- Orbital moment will contribute to give maximum value for L consistent with S.

- For an incomplete filled shell

$$J = L - S \text{ for a shell less than half occupied}$$
$$J = L + S \text{ for a shell more than half occupied}$$

- The orbital motion and spin of the electrons will contribute to the magnetic moment of the atoms. Another contribution results from nuclear spin.

Langevin's Theory of Diamagnetism:

Let an electron having mass m and charge e is rotating in a circular orbit of radius r with an angular velocity ω.

Then

$$F = m\omega^2 r$$

Where F is the force of attraction towards the centre. The moving charge e will be equivalent to a circular current $i = \frac{\omega e}{2\pi}$ and from Ampere's Law of magnetic moment associated with it will be $M = \pi r^2 i = \frac{\omega e r^2}{2}$ and directed normal towards the plane. Now a magnetic field H is applied perpendicular to the plane. The force on the electron will be $Hev = He\omega r$ towards the centre. Therefore the force towards the centre will be $F + He\omega r$. At the same time suppose the angular velocity is increased by $d\omega$. Therefore

$$F + He\omega r = m\omega^2 r + 2m\omega r d\omega$$

$$2m\omega r d\omega = He\omega r$$

$$d\omega = \frac{He}{2m}$$

The corresponding magnetic moment of the shell will be

$$M + dM = \frac{r^2 e}{2}(\omega + d\omega)$$

Therefore

$$dM = \frac{r^2 e}{2} d\omega$$

$$dM = \frac{r^2 e}{2} . \frac{He}{2m} = \frac{He^2 r^2}{4m}$$

The magnetic moment due to this field is opposite to the direction of the field and hence equal to $\left(-\frac{He^2r^2}{4m}\right)$. If the angle between the normal on the orbit and the direction of the field H be θ, then

$$dM = -\frac{e^2 r^2}{4m} \cos\theta$$

Therefore magnetic moment opposite to the direction of the field will be

$$\frac{e^2r^2}{4m}Hcos^2\theta$$

Therefore

$$Intensity\ of\ magnetisation = \frac{e^2H}{4m}\sum r^2cos^2\theta$$

And susceptibility

$$\chi = -\frac{e^2}{4m}\sum r^2cos^2\theta$$

Therefore it seems that diamagnetic susceptibility is negative and independent of temperature.