properties of Ferromagnetic substance

1. They are strongly attracted by the magnets. They tend to move from region of weaker magnetic field to the region of stronger magnetic field.

2. A bar of ferrow magnetic substance suspended in a magnetic field comes to rest along the direction of magnetic field.

3. A ferromagnetic substances in powdered form gets collected near the magnetic poles when kept in a watch glass placed on two magnetic poles separated 10 cm apart.

4. A ferromagnetic liquid moves up in the limb of a U-tube placed in magnetic field.

5. They are magnetised in the direction of the magnetising field.

6. I is not proportional to H.

7. $\mu \gg 1$ (much greater than)

8. $B \gg H$

9. K is positive

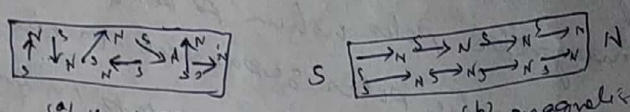
10. susceptibility of ferrow magnetic substances changes with temperature. Above certain temperature, K decreases with rise in tempr. Above certain Tempr, called Curie point, the substance starts behaving like a paramagnetic substance. On cooling it below curie point, the ferro magnetic properties are regained.

~~Intensity of magnetisation !-~~

~~Intensity of mag~~

Magnetisation

Every atom of a magnetic substance is a magnetic dipole. In an unmagnetised piece, these magnetic dipoles form closed chains, thus neutralising each other's effect. The process of magnetisation consists in arranging these dipoles in regular manner. So that their magnetic moments are directed in one direction as shown in the fig. (8)



(a) ~~Unmagnet~~ Unmagnetised. (b) magnetised

As a result of this one face of the specimen acquires a north polarity and the other one acquires a south polarity. The specimen is said to be magnetised and the process is known as magnetisation. The resultant magnetic moment 'M' of the specimen is given by

$$M = 2ml.$$

where m = pole strength of the specimen

$2l$ = Distance between the two poles.

magnetic moment is a vector quantity. Its direction is from South to the north pole.

Intensity of Magnetisation:-

As magnetic field of strength 'H' is applied to an unmagnetised specimen, the field tries to bring the magnetic dipole along its direction. On increasing the strength of field, more and more no. of dipoles get aligned in order, thereby increasing the strength of induced magnetic pole on the two ends and hence increasing the resultant magnetic moment 'M' of the specimen. Intensity of magnetisation 'I' is a measure of the magnetism induced in the specimen at any time.

It is defined as the magnetic moment developed per unit volume of the specimen, when subjected to a uniform magnetic field.

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

If 'a' is the area of cross section and '2l' is the length of the specimen, its volume is $V = a \times 2l$.

$$\therefore I = \frac{M}{a \times 2l} = \frac{2ml}{a \times 2l} = \frac{m}{a}.$$

ie Intensity of magnetisation 'I' is also defined as the pole strength per unit area of the specimen, when it is subjected to a uniform magnetic field, area being held, normally to the lines of force.

I is said to be positive if the substance is magnetised in the direction field and negative if it is magnetised in opposit direction.

Susceptibility
Magnetic ~~Susceptibility~~ (X)

The magnetic susceptibility (X) of a specimen is a measure of how easily a specimen can be magnetised in a magnetic field. It is the ratio of the intensity of magnetisation (I) induced in it, ~~to the~~ to the magnetising field (H).

$$\text{ie } \chi = \frac{I}{H}$$

If $H = 1$, then $\chi = I$.

ie susceptibility of a magnetic specimen is defined as the intensity of magnetisation produced in it by a magnetising field of unit strength.

Permeability (μ) :- The magnetic permeability of a substance measures the degree to which it can be penetrated by a magnetic field. If a piece of iron is taken in a magnetising

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~~the~~ field, the maximum lines will be concentrated in iron than in air. Hence the permeability of a substance is the ratio of magnetic induction (B) inside the substance to the magnetising field (H) $\therefore \mu = \frac{B}{H}$.

μ can also defined as how many times a substance produces lines of induction than vacuum. The permeability of vacuum is 1. whereas μ of iron is 1500.

For paramagnetic and ~~diamagnetic~~ ferromagnetic substances $B > H$.
$\therefore \mu > 1$

For diamagnetic substances $B < H$ $\therefore \mu < 1$.

~~Relation bet μ and K~~ :-

Magnetic Induction :- (B)

Magnetic induction (B) at any point, inside the matter is defined as the number of lines of force associated per unit area at that point, when the area is held at right angles to the lines of force. B is also known as magnetic flux density.

According to Gauss law in magnetism, a unit magnetic pole is associated with 4π lines of force.

$\therefore$ Number of lines of force starting from pole of strength 'm' $= 4\pi m$.

$\therefore$ No. of lines of force per unit area due to induced magnetism $= \frac{4\pi m}{a}$

$$\therefore B = \begin{pmatrix} \text{no. of lines of force} \\ \text{per unit area due} \\ \text{to magnetic field} \end{pmatrix} + \begin{pmatrix} \text{No. of lines of force} \\ \text{per unit area due} \\ \text{to induced magnetism} \end{pmatrix}$$

$$\text{or } B = H + \frac{4\pi m}{a}$$

Since $\frac{m}{a} = I$

$\therefore B = H + 4\pi I$.

In case of para and ferromagnetic substances 'I' is positive $\therefore B > H$

In case of diamagnetic substances I is negative $\therefore B < H$.

Relation betn μ and K.

We know that $B = H + 4\pi I$

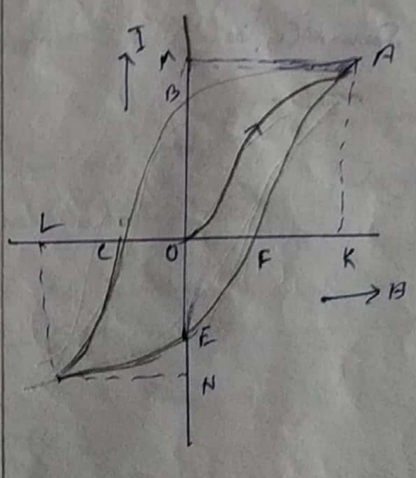
Dividing throughout by H,

$$\frac{B}{H} = 1 + 4\pi \frac{I}{H}$$

$$\text{or } \mu = 1 + 4\pi K.$$

$$\therefore \mu = \frac{B}{H} \text{ and } K = \frac{I}{H}$$

Hysteresis :-



Consider a ferromagnetic to a magnetising field, which can be varied, in magnitude and can be reversed in direction. As magnetising field H increased, intensity of magnetisation I of the sample increases. Variation of I with H is represented along curve OA. At this stage magnetising field is OK while intensity of magnetisation is OM. A further increase in H does not produce any increase in I. The sample is said to have aquired saturation.

As H is reduced from OK to zero, variation of I takes place along AB, indicating that when field is reduced to zero, I is not zero. To reduce I to zero a field equal to OC has to be applied in the reverse direction. On varying the magnetising field from OC to OL

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back to zero and then to OK again, variation of I is represented by curve CDEFA. On observing the curve carefully it can be seen that I and H do not move in step with each other. I is found to lag behind H throughout the Complete cycle of magnetisation.

The phenomenon by virtue of which intensity of magnetisation lags behind the magnetising field, when a magnetic substance is taken through a complete cycle of magnetisation, is called hysteresis.

Some characteristics of Hysteresis loop:—

See in the page No 73

from 83 - Coercivity of a magnetic substance is that value of magnetising field, which is required to reduce the residual intensity of magnetisation to zero in the sample.

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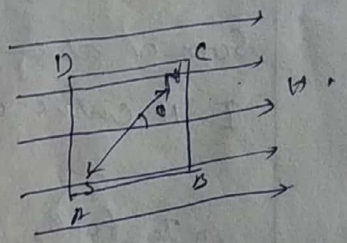
Hysteresis loss

When magnetic substance is subjected to a magnetising field, the magnetic di-poles of the substance experience torque which tends to rotate them to get them oriented in the direction of the of the field. ~~to zero~~, to achieve this some energy has to be spent. On reducing the field to zero, some residual magnetism is retained by the substance. So the total energy spent is not recovered. As such there is some loss of energy in this process. This energy is lost in the form of heat produced in the sample.

The loss of energy which takes place when a magnetic substance is taken over a complete cycle of magnetisation is called hysteresis loss.



Consider a unit volume ABCD of the material subjected to a magnetising field. H. Let one of its magnetic di-poles of magnetic moment M be inclined at an angle θ with the direction of field.

Component of magnetic moment of the di-pole parallel to the field = $M\cos\theta$

Since sum of the components of magnetic moments per unit volume parallel to the field is called the intensity of magnetisation $I = \Sigma M\cos\theta$

Differentiating w.r.t θ $dI = -\Sigma M\sin\theta d\theta$ ——— (1)

Torque τ acting on the di-pole is

$\tau = MH\sin\theta d\theta$

Work done in rotating the di-pole through an angle dθ

$= MH\sin\theta(-d\theta)$.

The -ve sign is due to the fact the field tends to decrease the angle.

∴ Work done in rotating all the di-poles in unit volume through an angle dθ $= -\Sigma MH\sin\theta d\theta$.

$= H\Sigma -M\sin\theta d\theta$

$= H dI$ [using (1)]

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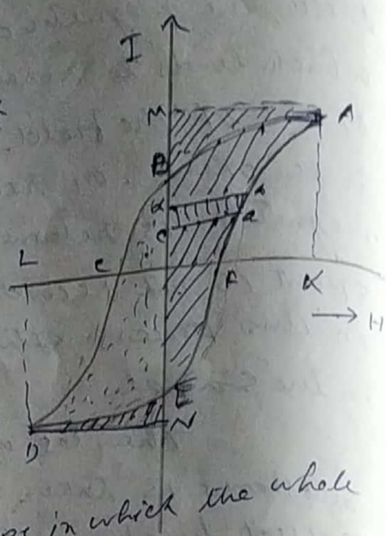
~~Now~~ Net work done in changing the intensity of magnetisation of the unit volume of sample from I_1 to I_2

$$= \int_{I_1}^{I_2} H\,dI$$



Let a and b be two points situated very close to each other on part FA of the hysteresis loop ABCDEFA

$ac \simeq bd \simeq H$ and

$cd = dI$

$\therefore H\,dI = ac \times cd$

$=$ area of strip ABCD.

Therefore $\int H\,dI$ represents the sum of areas of these type of strips in which the whole I-H curve can be divided.

Whole cycle of magnetisation can be divided in to four parts

(i) When field increases from O to K: work done on the sample

$$W_1 = \int_E^M H\,dI$$

$= +$ Area ~~of~~ EFAMBE

(ii) When field decreases from K to zero, work done W_2 by the sample $W_2 = -\int_M^B H\,dI$ = Area AMBA

(iii) When field is increased from zero to L in opposite direction work done W_3 on the sample is

$$W_3 = \int_B^N H\,dI = \text{Area BCDNEB}$$

(iv) When field is decreased from L to zero, work done by the sample $W_4 = -\int_N^E H\,dI = -\text{Area DNED}$

If W is the net work done on the sample during one complete cycle of magnetisation

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$W = W_1 + W_2 + W_3 + W_4$

W = Area EFAMBE − Area AMBA + Area BCDNEB − Area DNED

= Area ABCDEFA

= Area enclosed by I − H loop.

Thus the loss of energy per unit volume when the sample is taken through a complete cycle of magnetisation is equal to the area enclosed by I−H loop.

We can write $W = \oint H\,dI$ ——— (ii)

The $\oint$ denotes that the integration is carried around a complete cycle. Eqn (ii) is called Warburg's law.

Hysteresis loss in terms of B-H curve

Magnetic induction B is given by

$$B = H + 4\pi I$$

Differentiating both sides

$$dB = dH + 4\pi dI$$

Multiplying both sides by H and performing the integration over a complete cycle.

$$\oint H\,dB = \oint H\,dH + 4\pi \oint H\,dI$$

Since a graph of H plotted against H is a straight line

$$\therefore \oint H\,dH = 0$$

$$\therefore \oint H\,dB = 4\pi \oint H\,dI$$

or Area of B−H curve = 4π × Area of I−H curve.

or Area of B−H curve = 4π × (loss of energy per unit volume)

$\therefore$ Loss of energy per unit volume = $\frac{1}{4\pi}$ (area of B-H curve).