Magnetic propeties of materials

Magnetic field :-

The region around a magnet in which it exerts forces on other magnets and on object made of iron is called a magnetic field. Its unit is amp/m or orested, 1 orested = $10^3/4\pi$ amp/m.

To specify the magnetic property of material, let us consider the following fundamental terminologies :-

1. Magnetic Induction or flux density :-

The total no. of lines of forces/unit area due to magnetising field and due to induced in the substance is called flux density (B) and is measured in waber/m^2 or tesla.

2. Intensity of Magnetisation :-

It is defind as total magnetic moment per unit volume. Its unit is amp/m and denoted by I.

$$I = \frac{M}{V} = \frac{m \times 2l}{a \times 2l} = \frac{m}{a} = \frac{\text{pole strength}}{\text{unit area}}$$

$$= \frac{\text{amp. turn}}{m^2}$$

3. Magnetic Susceptibility :-

Magnetic moment per unit volume or magnetisation (M or I) is directly proposional to applied magnetic field (H)

$$I \propto H$$

$$I = \chi_m H$$

or $$M = \chi_m H$$

$$\chi_m = \frac{I}{H} \text{ or } \frac{M}{H}$$

for vaccum $\boxed{\chi_m = 0}$ (Because $I = 0$)

4. Magnetic Permeability :-

Magnetic flux density ($\vec{B}$) is directly proposional to magnetic field strength (H).

$$B \propto H$$

$$B = \mu H \quad \text{--- (1)}$$

μ is called constant of permeability and is called permeability of the medium.

In vaccum

$$B_0 = \mu_0 H \quad \text{--- (2)}$$

$$\boxed{\mu_r = \frac{\mu}{\mu_0} = \frac{B}{B_0}}$$

$\mu_r > 1$ paramagnetic
$\mu_r >>> 1$ ferromagnetic

$\mu_r < 1$ Diamagnetic

The resultant magnetic induction in (B) a magnetised material is related with both magnetisation I and applied magnetic field strength $\vec{H}$ as -

$$B = \mu_0 (H + I) \quad \text{--- (1)}$$

But $I = \chi_m H$

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

$$\frac{B}{H} = \mu_0 (1+\chi_m)$$

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

$$\frac{\mu}{\mu_0} = 1+\chi_m$$

$$\boxed{\mu_r = 1+\chi_m}$$

Classification of magnetic material:-

Diamagnetic

Diamagnetic material do not have permanent magnetic dipoles, when a diamagnetic material placed in an external magnetic field, the induced magnetic dipoles act in a direction opposite to the applied field direction.

Ex- Zinc (Zn), Copper (Cu) Silver (Ag) etc

Paramagnetic

Paramagnetic material is placed in a magnetic field acquire feeble magnetism in the direction of magnetic field are known as para-magnetic substance.

Ex- Aluminium (Al) Manganese (Mn), Oxygen (O_2) etc

Ferromagnetic

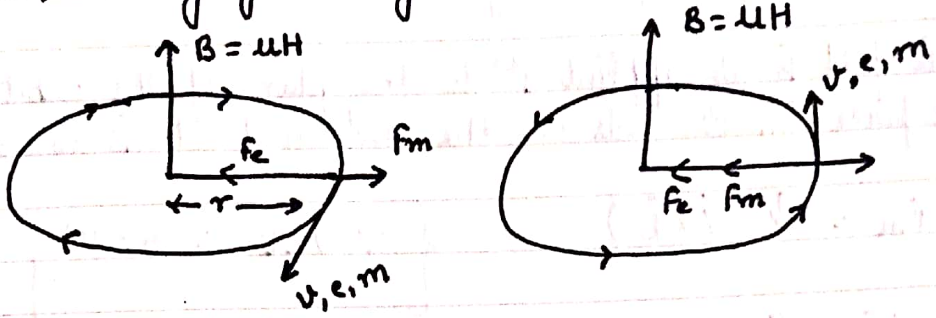
Ferromagnetic material is placed in a magnetic field become strongly magnetised in the direction of field are known as ferro-magnetic substance.

Ex- Iron (Fe), Nickle (Ni) Cobalt (Co), Magnetite (Fe_3O_4) etc.

No

Date

Langevin's theory of Diamagnetic Material :-



Those substance which are weekly magnetised in opposite direction to that of applied magnetic field $\vec{B}$ are called diamagnetic substances.

Prof. Langevin calculated the atomic susceptibility.

The revolving orbital electron is equivalent to a current loop, the current produced is given by -

$$i = \frac{q}{T} = e\left(\frac{1}{T}\right) = e\nu \quad \text{———} \ (1)$$

where e = charge of electron and ν = frequency of revolution

→ The magnetic moment produced to this current is given by

$$P_m = i \cdot A$$

$$p_m = e\nu \cdot A = e\nu(\pi r^2) \quad \text{———} \ (2)$$

$$p_m = e\left(\frac{\omega}{2\pi}\right) \cdot \pi r^2$$

$$p_m = \frac{1}{2} e\omega r^2 \quad \text{———} \ (3)$$

The electrostatic force (F_e) acting on the electron is given by -

$$F_e = \frac{m v_0^2}{r} = \frac{m\omega_0^2 r^2}{r}$$

$$F_e = m\omega_0^2 r \quad \text{———} \ (4)$$

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where ω = Initial angular frequency

Let a magnetic field $\vec{B}$ is applied $\perp^{ar}$ to the plane of the orbit. Now an additional force F_m also acts on the electron due to $\vec{B}$ can be given as -

$$F_m = q(\vec{v} \times \vec{B}) \qquad \left\{ \because v \perp B \therefore \theta = 90^\circ \right\}$$

$$F_m = \pm q v B$$

$$F_m = \pm e v B \quad \text{———} \quad (5)$$

Thus net force acting on the electron -

$$F = F_e \pm F_m$$

or -

$$F = m\omega_0^2 r \pm evB$$

$$m\omega^2 r = m\omega_0^2 r \pm evB$$

$$\pm evB = m(\omega^2 - \omega_0^2) r$$

$$\pm evB = m(\omega + \omega_0)(\omega - \omega_0) r$$

$$\pm evB = m(2\omega)(\Delta\omega) r$$

$$\Delta\omega = \frac{\pm evB}{2m\omega r} = \frac{\pm e r \omega B}{2m r \omega}$$

$$\boxed{\Delta\omega = \pm \frac{eB}{2m} = \omega_L}$$

ω_L is known as Larmour frequency ie change in angular frequency

No.
Date

of electron due to magnetic field.

Due to change in angular frequency, there is a change in magnetic moment known as induced magnetic moment.

$$\therefore \quad \Delta P_m = \frac{1}{2} e r^2 (\Delta \omega)$$

$$\Delta P_m = \frac{1}{2} e r^2 \times \left(\pm \frac{eB}{2m} \right) \quad \text{(Taking single orbital electron)}$$

For different orbital electrons, we have -

$$\Sigma (\Delta P_m) = (\Delta P)_{atom} = \frac{1}{2} e z (\Sigma r^2) \left(\pm \frac{eB}{2m} \right)$$

where $\Sigma r^2 = \frac{2}{3} R^2$, (R = avarage radius of all orbit)

(z = atomic no. = no. of electrons)

$(\Delta P_m)_{atomic}$ = Induced atomic magnetic moment

$$(\Delta P)_{atom} = \frac{1}{2} e z \left(\frac{2}{3} R^2 \right) \left(\pm \frac{eB}{2m} \right)$$

$$(\Delta P)_{atom} = -\frac{1}{6} z e^2 \left(\frac{\mu H}{m} \right) R^2 \quad \text{———} \quad (7)$$

$\therefore$ $(\Delta P)_{atom}$ is opposite of $\vec{H}$, therefore -ve sign is used.

Let n is no. of atoms per unit volume then

$$\frac{\text{Atomic magnetic moment}}{\text{volume}} = I = \text{Intensity of magnetisation}$$

$$(\Delta P)_{atom} = \vec{I} = -\left(\frac{1}{6}\frac{4\pi Z}{m}\right) e^2 R^2 \vec{H}$$

Thus magnetic susceptibility of diamagnetic ~~and~~ substance

$$\chi_m = \frac{I}{H}$$

$$\boxed{\chi_m = -\frac{1}{6}\frac{4\pi Z}{m} e^2 R^2} \text{ --- } (5)$$

From equ^n (5) is clear that χ_m of diamagnetic substance is negative and is independent to the absolute temp of specimen and field from the above discussion. So we conclude that :-

(i) The magnetisation M acquired by a diamagnetic substance is in a direction opposite to $\vec{H}$.

(ii) M is directly proportional to $\vec{H}$.

(iii) Magnetic susceptibility χ_m is nearly independent of temperature.

(iv) Diamagnetic effect is a small effect and it arises due to the orbital motion of electron.

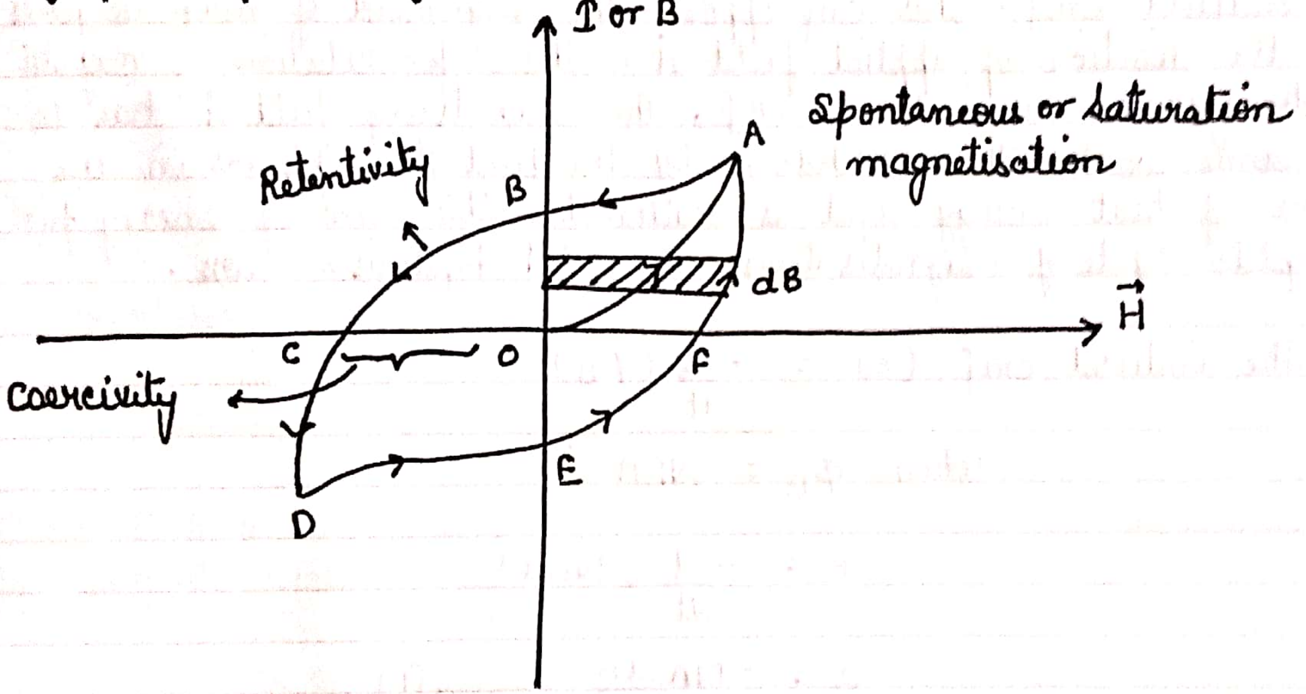
(v) Diamagnetism is a universal property of matter.

Phenomenon Of Hysterisis :-

A curve showing the variation of magnetic flux density (B) as a function of $\vec{H}$ is called as a magnetisation curve.

In a ferromagnetic material, the intensity of magnetisation I and the flux density B do not vary linearly with H or in other words, the susceptibility ($\chi_m = I/H$) and the permeability ($\mu = B/H$) of the material are not constant but vary with H and also depends on the pasted history of the material. The plot of $\vec{B}$ versus $\vec{H}$ in which the material is magnetised in one direction and then in opposite direction is called Hysterisis curve of the spacimen.

Significant features of hysterisis Curve :-



1. Hysterisis is defined as the lagging of magnetic induction $\vec{B}$ behind the corrasponding magnetising field $\vec{H}$.
2. The value of intensity of magnetic material when the magnetising field is reduced to zero is called retentivity or residual magnetism.
3. The value of magnetising field required to reduce residual magnetism to zero is called coercivity of the material. This happens when $H = -H \Rightarrow H = H_c$ {coercive field to make I or B zero}

4. On further increasing H in opposite direction following path CD and by decreasing the field to zero and reversing the direction,

No

Date

magnetising curve ABCDEFA is obtained, which is called hysterisis curve or hysterisis loop.

Hysterisis Loss :-

When ferromagnetic substances undergoes to cycle of magnetisation then magnetic flux changes which produces an enduced emf. This emf opposes the alignment of magnetic poles in the direction of applied field $\vec{H}$. Thus for rotation of magnetic dipole against an induced emf, the magnetising field $\vec{H}$ has to do some work. This workdone by the field $\vec{H}$ appears in the form of heat energy and is radiated. This loss of energy for complete cycle of magnetisation is called hysterisis loss.

The induced emf $(e) = -\frac{d}{dt}(\phi_B)$

When $\phi_B = NBA$

(ii)

$$e = -\frac{d}{dt}(NBA)$$

(iii)

(iv)

$$e = -NA\frac{dB}{dt} \quad \text{——— (1)}$$

(v)

Small workdone against this emf

$$dW' = \text{charge} \times \text{emf}$$

$$= i\,dt \times e$$

$$= i\cancel{dt}\left(NA\frac{dB}{\cancel{dt}}\right)$$

$$dW' = NiA\,dB \quad \text{——— (2)}$$

Now magnetic field produced due to current

$$H = \frac{Ni}{l}$$

$$i = \frac{Hl}{N}$$

$$\therefore \quad dw' = \left(\frac{Hl}{\cancel{N}}\right) \times (\cancel{N} A\, dB)$$

$$dw' = HV\,dB$$

Workdone per unit volume

$$dw = \frac{dw'}{V} = H\,dB \quad \text{———} \quad (3)$$

Thus $H\,dB$ is area of strip in hysteresis loop. Thus net workdone for complete cycle of magnetisation

$$W = \oint_c dw = \oint H\,dB$$

$$\boxed{W = \text{area of B-H curve}} \quad \text{———} \quad (4)$$

But we know that

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

$$B = \mu_0 I + \mu_0 H$$

$$dB = \mu_0\, dI + \mu_0\, dH$$

No

Date

$$\because W = \oint_c H\,dB$$

$$W = \mu_0 \oint_c H\,dH + \mu_0 \oint_c H\,dI$$

But $\oint_c H\,dH = 0$ Because H versus dH is a straight line

$$W = \mu_0 \oint H\,dI$$

$$\boxed{W = \mu_0 \times \text{area of I-H curve.}}$$

Application of Hysterisis Curve -:

1. It helps us to select the material which has minimum hysterisis loss.
2. It gives us a fair idea of the magnetic properties like susceptibility, retentivity, coercivity, permeability etc.
3. The material which gives minimum hysterisis loss will be most suitable for using as the core of the transformers and the armatures of dynamics and motors.