Magnetic Properties of Matter

Physics (H), Sem = II Paper = C3T

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FERROMAGNETISM (FERRITIES)

The transition metals Fe, Co and Ni exhibit magnetisation even when the magnetising field is removed. This phenomena is called ferromagnetism. The ferromagnetic substances thus posses a magnetic moment even in the absence of applied mag. field. This magnetisation is called spontaneous magnetisation and it is stable only below a critical temp^r, called Currie temperature.

Classical theory of ferromagnetism — V.U - 2002, 2007, 2005

As like Paramagnetism — both Langevin theory and Weiss theory.

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$$\boxed{\chi = \frac{C}{T-\theta}}$$ Called Currie-Weiss law.

Where θ is called Curie temperature.

From the above relation at $T = \theta$ then, $\chi \to \infty$

and ~~temp~~ T is less than θ, the relation does not signify any meaning).

This means there exists a spontaneous magnetisation even in the absence of external mag. field. The material is ferromagnetic below Curie temp^r (θ) and becomes paramagnetic above curie temp^r.

Spontaneous magnetisation —

(Thermal agitation opposes the tendency of Weiss molecular field to align the molecular magnets. But below Curie temp^r, Weiss field energy overpowers the thermal agitation. Hence, most of the molecular magnets ~~temporary~~ alignment gives rise to the magnetisation of the material even in the absence of applied field. This phenomena is called spontaneous magnetisation.

Temperature dependence of the spontaneous magnetisation

V.U - 2007

When external field is zero, then $H_e = \lambda M$. ——— (1)

Where M is called spontaneous magnetisation.

Then $M = \mu n L(a)$

or $M = M_s L(a)$. Where M_s is saturation magnetisation $= \mu n$.

or $\frac{M}{M_s} = L(a)$ ——— (2)

Further for ferromagnetics, $a = \frac{\mu H_e}{KT}$ ——— (3)

From equation (1) and (3), $a = \frac{\mu \lambda M}{KT}$ ——— (4)

or, $M = \frac{KTa}{\mu \lambda}$ ——— (4)

Hence $\frac{M}{M_s} = \frac{KTa}{\mu\lambda \cdot \mu n} = \frac{aKT}{\mu^2 n \lambda}$ again $\theta = \frac{n\mu^2\lambda}{3K}$

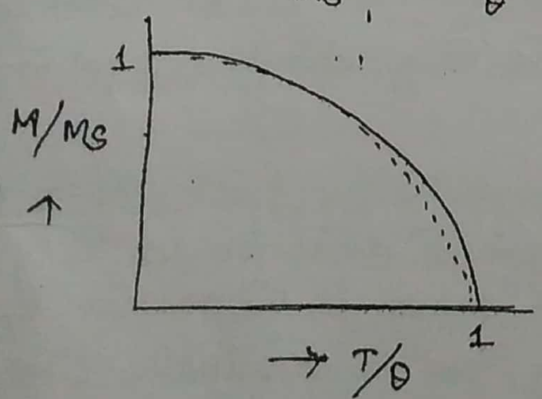
or $\frac{K}{\mu^2 n \lambda} = \frac{1}{3\theta}$

or, $\frac{M}{M_s} = \frac{aT}{3\theta}$

or, $\frac{M}{M_s} = \frac{a}{3}\left(\frac{T}{\theta}\right)$ ——— (5)

Combining equation (2) and (5), $\frac{M}{M_s} = f\left(\frac{T}{\theta}\right)$.

A plot of $\frac{M}{M_s}$ Vs. $\frac{T}{\theta}$ is shown—



i) When $T = 0$, $\frac{M}{M_s} = 1$ ie $M = M_s$. Saturation magnetisation.

ii) When $T = \theta$, $\frac{M}{M_s} = 0$ i.e spontaneous magnetisation vanishes.

Hence tempr is low, Weiss field overpowers the thermal energy and at $T=0$ gives rise to maximum magnetisation. As tempr increases, thermal energy increases which destroy the alignment of magnetic molecules more and more resulting zero spontaneous magnetisation at $T = \theta$.

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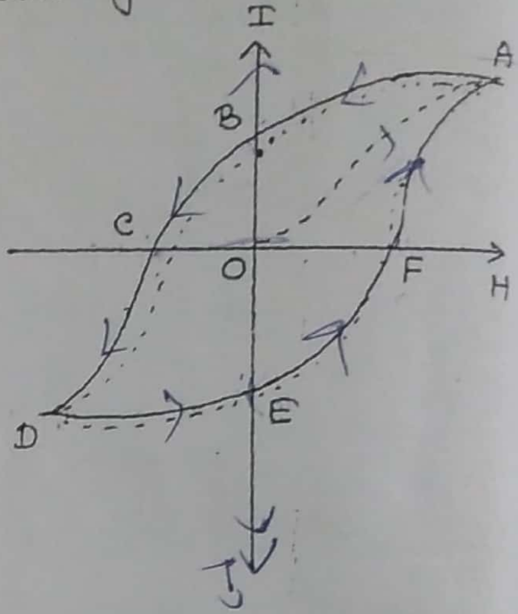
HYSTERISIS :

Explain "cycle of magnetisation" and "hysterisis"

Cycle of magnetisation :—



When the magnitude of the magnetising field (H) be increased then intensity of magnetisation (I) or magnetic induction through an magnetic material (iron) increases along the curve OA and become saturated at A.

If H is now gradually decreased, the intensity of magnetisation gradually decreases. but does not vanish even if the magnetising field be withdrawn which is shown in the portion AB. Some magnetisation (OB) retains even when the magneting field (H) is withdrawn. This residual magnetisation is called retentivity.

To destroy this residual magnetisation, we apply a reverse magnetising field, shown in portion BC. The reverse magnetising field (OC) to destroy the magnetisation (I=0) is called coersivity.

Further increase of reverse magnetising field, the intensity of magnetisation increases in the opposite direction until a state of saturation is reached which shown in the portion CD.

Now if the reverse magnetising field is gradually decreased I decreases, shown in the portion DE. But there is a residual magnetisation OE even when H = 0.

To destroy this residual magnetisation (opposite) a forward magnetising field is necessary shown in portion EF.

Further increase of magnetising field I increases and become saturated shown in the portion EA.

The loop "ABCDEFA" is called cycle of magnetisation.

Why it is called hysterisis?

Cycle of magnetisation shows that —
The magnetic induction or intensity of magnetisation always lag behind the magnetising field producing it when a specimen of iron is taken through a cycle of magnetisation. Hence it is called hysterisis.

Hysterisis Loop :—

The graph showing I or B increases with H from zero to a maximum in one direction and then taken through zero to a maximum in the opposite direction and finally back again through zero to the first maximum is called hysteris loop.

Define retentivity (remanence) and coercivity.

Retentivity :— The value of magnetic induction (B) which remains after the material has been magnetised and magnetising field has been reduced to zero, is known as retentivity.

Coercivity : The coersive force is the magnitude of the reverse field required to reduce the remanent induction (retentivity) to zero

The limiting value of coercive force required to reduce remanence to zero is known as coercivity.

Hysteresis loss :—

The act of magnetisation of a magnetic substance (ferromagnetic) in a cycle involves the expenditure of some energy. This is due to the fact that some of the molecular magnets remains in the aligned position even when the magnetising field is withdrawn. To tear out them a coersive force is necessary. Thus we have always some loss of energy in the cycle of magnetisation. This loss of energy is called "hysterisis loss"

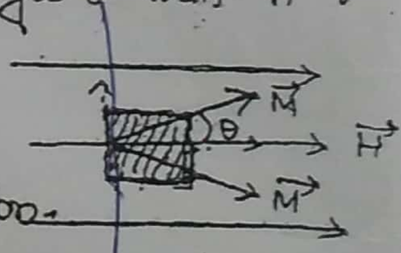
This loss of energy i.e. hysterisis loss comes out in the form of heat energy.

Calculation of hysterisis loss per cycle :—

We consider unit volume of a ferromagnetic substance placed in a magnetic field $\vec{H}$. Let the magnetic dipole moment of the element is $\vec{M}$ which makes an angle θ with $\vec{H}$.

Now $\vec{M}$ has two components —

i) $M\cos\theta$, along the field direction.
It contributes the intensity of magnetisation.



ii) $M\sin\theta$, perpendicular to the field direction.

Summing up all such, we get, $\Sigma M\sin\theta = 0$

$\Sigma M\cos\theta = I$, Intensity of magnetisation

$\therefore \quad dI = -\Sigma M\sin\theta\, d\theta$

or. $H\,dI = -\Sigma MH\sin\theta\, d\theta$ —— (1)

Torque acting on the dipole in the field, $\tau = MB\sin\theta$

$= \mu_0 MH\sin\theta$

Workdone to align the dipole further by an angle $d\theta$

$$\Delta w = \tau(-d\theta)$$
$$= -\mu_0 MH \sin\theta \, d\theta$$

For all the dipoles per unit volume of specimen,

$$dw = \sum \Delta w = -\sum \mu_0 MH \sin\theta \, d\theta$$
$$= \mu_0 H \, dI \quad \text{using equation (1)}$$

$\therefore$ Total workdone in the comple cycle,

$$\boxed{W = \mu_0 \oint H \, dI} \quad \text{—— (2)}$$

For $\vec{I} - \vec{H}$ curve

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

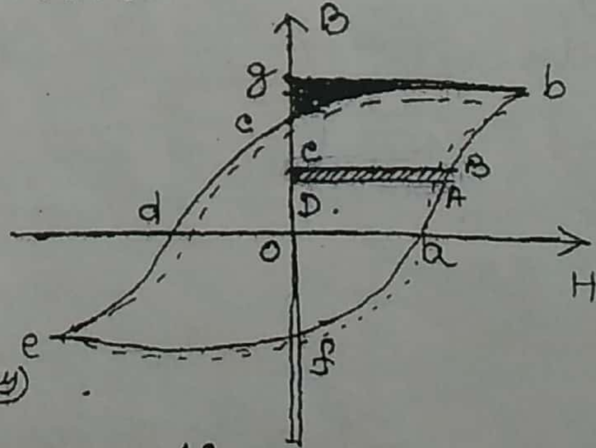
$\therefore dB = \mu_0 \, dI$ Since H is constant.

$$\therefore \boxed{W = \oint H \, dB} \quad \text{—— (3)}$$

for $\vec{B} - \vec{H}$ curve

Show that hysteresis loss is equal to area of B-H loop.

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



For the B-H loop "adcdefa" let us take a strip ABCD, where $AB = CD = dB$ and $AD = BC = H$ (say).

$\therefore H \, dB = DA \times CD =$ area of ABCD portion.

Thus for magnetisation from a to b,
workdone = area of portion "oabgo"

At the time of demagnetisation, we return back the workdone (along the path bc) = area of the portion "bgcb"

Thus for magnetisation from a to b and demagnetisation from b to c,

$$\text{workdone} = \text{area "oabgo"} - \text{area "bgcb"}$$
$$= \text{area of the portion "abcoa"}$$

Summing up, we get total workdone for the cycle of magnetisation, = area of whole B-H loop.

$$\therefore \quad W = \oint H\,dB = \text{area of B-H loop.}$$

Problem
C.U - 2010

A specimen of iron of density 7700 kg/m³ and specific heat 462 Joule/kg/K is magnetised by an ac field of frequency 50 Hz. Assuming no loss of heat calculate rise in temperature of the specimen per minute. Given that the area enclosed by the B-H loop of the specimen is equivalent to 5000 J/m³/cycle.

Solution: Energy loss per unit volume per cycle = 5000 Joule.

If m be the mass of the specimen, then energy loss per minute $= 5000 \times 50 \times 60 \times \dfrac{m}{7700}$ Joule.

If θ be the rise in temperature (°c) per minute,

then $$\cancel{m} \times 462 \times \theta = \frac{5000 \times 5\cancel{0} \times 6\cancel{0} \times \cancel{m}}{77\cancel{0}\cancel{0}}$$

$$\text{or, } \theta = \frac{5000 \times 30}{462}\ {}^\circ\text{c/min} = 4.22\ {}^\circ\text{c/min}$$