UNIT - IV

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MAGNETISM

Magnet :- current carrying wire

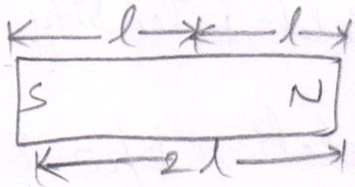
Magnetic material :- A material which is attracted/repelled by a magnet is called magnetic material they are 5 types of magnetic material they are

1. Dia, 2. Para, 3. Ferro, 4. Anti Ferro, 5. ferri

Magnetism :- the process of attraction & repulsion b/w magnet & magnetic materal

Magnetic dipole :- slight displacement of Nor the pole & south pole is called magnetic dipole

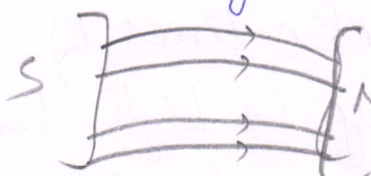
Magnetic dipolemoment ($\vec{\mu}$) :-



$$\vec{\mu} = m \times 2d$$

product of strength of the one pole & the distance b/w two poles is called magnetic dipole-moment

Units :- (A-m²)



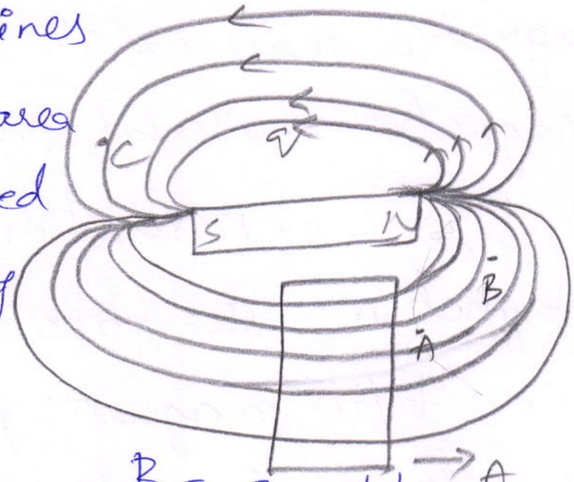
Magnetic lines of force :- the path of unit north pole in the magnetic field is called magnetic line of force

Magnetic flux (ø) :- the total no. of magnetic line of force in a particular area is called magnetic flux

units : webers

the magnetic flux density (or) magnetic Induction (B) :-

the no. of magnetic lines of force crossing unit area perpendicularly is called magnetic flux intensity

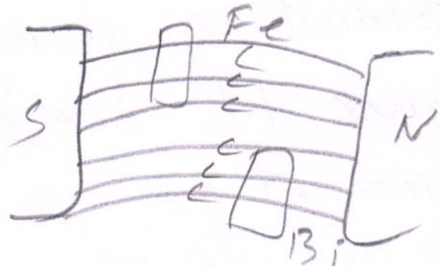


B = 3 wb/m²

Magnetic field Intensity : (H) :- the force superienced by a unit North pole placed at field intensity at that point Units : Ampere/meter

Relation b/w B & H

Magnetic permeability : (μ) :- the allowing nature of of magnetic lines of force



If μ is high then they can easily allow the magnetic lines of force

If μ is less the material does not allow the magnetic lines of force easily

In vaccum :- $B = \mu_0 H$

MAGNETIZATION

Magnetization refers to the process of converting a non-magnetic sample in to a magnetic sample. The intensity of magnetization (M) of a sample of a material is the magnetic moment per unit volume. It's a unit is Am^{-1}. The intensity of magnetisation is directly related to the applied field 'H' through the susceptibility of the medium x by.

$$X = \frac{M}{H}$$

Thus the magnetic susceptibility (X) of a material is the ratio of the intensity of magnetization produced in the sample to the magnetic field intensity which produces the magnetization. It has no units.

$$B = \mu H$$

$$= \mu_0 \mu_r H$$

$$\text{i.e, } B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$$

$$= \mu_0 H + \mu_0 H(\mu_r - 1)$$

$$= \mu_0 H + \mu_0 M$$

Where the magnetisation M is equal to $H(\mu_r - 1)$

$$\text{i.e } B = \mu_0 (H + M)$$

The first term on the right side of Eq (5) is due to external field. The term is due to magnetisation.

Thus the Magnetic Induction (B) in a solid is

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

$$\text{Hence } \mu_0 = \frac{B}{H+M}$$

The relative permeability,

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B/H+M} = \frac{H+M}{H} = 1 + \frac{M}{H}$$

$$\mu_r = 1 + \chi$$

The magnetic properties of all substances are associated with the orbital and spin motions of the electrons in their atoms. Due to this motion, the electrons become elementary magnets of the substance. In few materials these elementary magnets are able to strengthen the applied magnetic field, while in few other materials they orient themselves such that the applied magnetic field is weakened.

The magnetic field in the interior of a certain solenoid has the value of 6.5×10^{-4} T when the solenoid is empty. when it is filled with iron, the field becomes 1.4T. Find the relative permeability of iron.

sol:-

$$\chi = \frac{M}{H} = \frac{1.4}{6.5 \times 10^{-4}} = 2000$$

$$\mu_r = 1 + \chi = 1 + 2000$$

$$= 2001$$

Find the relative permeability of a ferromagnetic material if a field of strength 220 amp/metre produces a magnetization 3300 amp/metre in it.

sol:-

$M = 3300$ amp/metre

$H = 220$ amp/metre

$$\mu_r = \frac{M}{H} + 1$$

$$= \frac{3300}{220} + 1$$

$$= 16$$

The magnetic field intensity in a piece of ferric oxide is 10^6 amp/metre. If the susceptibility of the material is 1.5×10^{-3}, calculate the magnetisation of the material and the flux density

sol:- Given $H = 10^6$ amp/metre

$\chi = 1.5 \times 10^{-3}$

$\chi = M/H$

Hence magnetisation of the material

$M = \chi H$

$= 1.5 \times 10^{-3} \times 10^{6}$

$= 1.5 \times 10^{3}\ A/m$

flux density

$B = \mu_0 (M+H)$

$= 4\pi \times 10^{-7}(1.5 \times 10^{3} + 10^{6})$

$= 1.257\ T$

A paramagnetic material has a magnetic field intensity of $10^4\ A/m$. If the susceptibility of the material at room temperature is 3.7×10^{-3}, calculate the magnetization and flux density in the material.

sol:- $\chi = \frac{M}{H}$ and $B = \mu_0 (M+H)$

Hence $M = \chi H$

$= 3.7 \times 10^{-3} \times 10^{4}$

$= 3.7 \times 10$

$= 37 Am^{-1}$

Hence magnetization $= 37 Am^{-1}$

flux density $B = \mu_0 (37 + 10^4)$

$= (4\pi \times 10^{-7} \times 10037)$

$= 126179.43 \times 10^{-7}$

$= 0.0126\ Wb/m^2$

Classification of Magnetic materials:

Very first distinction is based on whatever the atoms carry permanent magnetic dipoles or not. Materials which lack permanent dipoles are called diamagnetic. If the permanent dipoles dont interact among themselves, the material is paramagnetic. If the interaction among permanent dipoles is strong such that all the dipoles line up in parallel, the material is ferromagnetic. If the permanent dipoles line up in anti parallel, the material is antiferromagnetic or ferrimagnetic.

Diamagnetism.

When an external magnetic field is applied the motion of ~~zero~~ in electrons in their orbital changes resulting in induced magnetic moment in a direction opposite to the direction of applied field.

properties of diamagnetic materials.

1. permanent dipoles are absent
2. Effect is weak and often masked by other kinds of magnetism.

3. When placed inside a magnetic field, magnetic lines of forces are repealed. as.

4.

magnitude of susceptibility	Temperature dependence	examples
small, negative	Independent	organic materials, light elements
Intermediate, negative	Below 20K varies with field and temperature	Alkali earths, Bismuth
Large, negative	Exists only below critical temperatures (meissner effect)	superconducting materials.

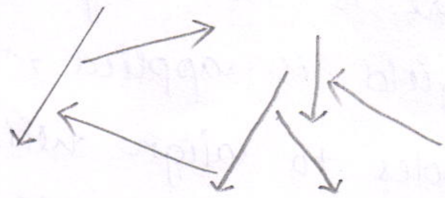
5. magnetic susceptibility is independent of applied magnetic field strength.

6. Relative permeability is slightly less than unity.

Paramagnetism.

In the absence of external magnetic field the net moments of the atoms are arranged

5. spin alignment is random.



6. paramagnetic susceptibility is independent of the applied magnetic field strength.

7. paragnagnetic atoms form a collection of non-interacting magnetic dipoles.

Ferromagnetism.

The net spin magnetic moment of ferromagnetic atoms is of the same order as magnetic moment of paramagnetic atoms. Then how to account for the large magnetization of ferromagnetic substances even in the absence of external applied field? This is due to spontaneous magnetization. There is a special form of interaction called exchange coupling.

Properties of ferromagnetic materials.

1. Due to a special form of interaction called exchange coupling between adjacent atoms, even in the absence of external applied field,

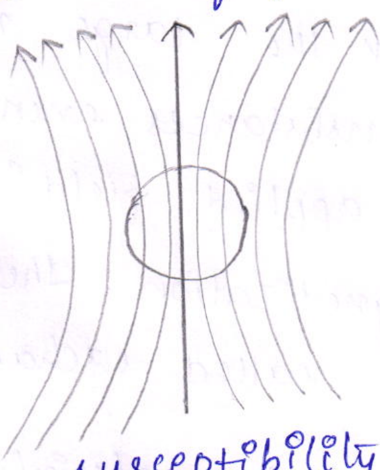
in random directions because of thermal directi fluctuations. Hence there is no magnetization. When external magnetic field is applied, there is a tendency for the dipoles to align with the field giving rise to an induced positive dipole moment.

<u>properties of paramagnetic materials:</u>

1. paramagnetic materials possess permanent magnetic dipoles.

2. In the absence of an external applied field, the dipoles are randomly oriented. Hence the net magnetization in any given direction is zero.

3. When placed inside a magnetic field, it attracts the magnetic lines of force as shown.



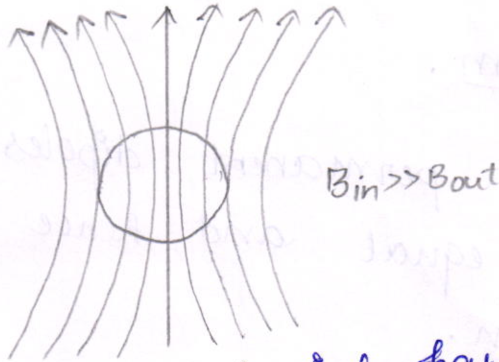
$B_{in} > B_{out}$

4. paramagnetic susceptibility is positive and depends greatly on temperature as detailed below.

magnitude of susceptibility	Temperature dependence	Examples.
small, positive	Independent	Alkali metals and Transition metals
Large, positive	$\chi = C/T$ curie law	Rare earths

exhibits strong magnetisation.

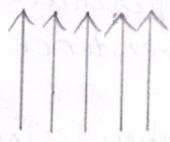
2. when placed inside a magnetic field, it attracts the magnetic lines of forces very strongly as shown.



3. Each ferromagnetic material has a characterstic temperature called the ferromagnetic curie temperature θ_f. Ferromagnetic susceptibility depends greatly on temperature. Above θ_f its properties are quite different from those below.

magnitude of susceptibility	Temperature dependence	examples.
very large, positive	$\chi = \frac{C}{T-\theta}$ i) for $T > \theta_f$, paramagnetic behaviour ii) for $T < \theta_f$, ferromagnetic behaviour	Iron, cobalt, nickel, gadolinium.

4. spin alignment is parallel in the same direction.



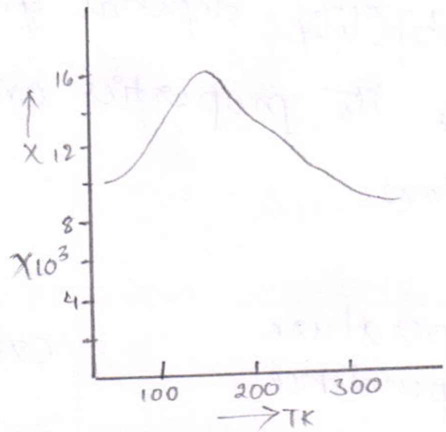
5. exhibits hyteresis.

6. consists of a number of small regions which are spontaneously magnetized called domains.

Antiferromagnetism.

If the permanent dipoles line up in antiparallel are equal and hence it is called Antiferromagnetism.

$$\chi = \frac{c}{T+\theta}$$



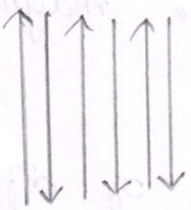
Properties of antiferromagnetic materials.

1. Electron spin of neighbouring atoms are aligned antiparallel
2. Antiferromagnetic susceptibility depends greatly on temperature.

magnitude of susceptibility	Temperature dependence	example
small, positive	$\chi = \frac{c}{T+\theta}$ when $T > T_N$. $\chi \propto T$ when $T < T_N$.	salts of transition elements

3. Intially susceptibility increases slightly with temperature and beyond Neel temperature the susceptibility decreases with the temperature.

4. spin alignment is antiparallel.



Ferrimagnetism.

This is a special case of antiferromagnetism. The net magnetization of magnetic sublattices is not zero since antiparallel moments are of different magnitudes. Hence ferrimagnetic material possesses a net magnetic moment. This moment disappears above a curie temperature T_c analogous to the Neel temperature.

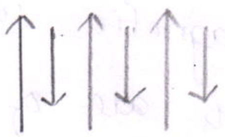
properties of ferrimagnetic materials.

1. Ferrimagnetic materials posses net magnetic moment.
2. Above curie temperature becomes paramagnetic while below it behaves as ferrimagnetic material.

magnitude of susceptibility	Temperature dependence	examples.
Very large, positive.	$\chi = \frac{C}{T \pm \theta}$ for $T > T_N$ paramagnetic for $T < T_N$.	ferrites

3. Ferrimagnetic domains become magnetic bubbles to act as memory elements.

4. spin alignment is antiparallel of different magnitudes.



medium: $B = \mu H$

Relative Permeability: $\mu_r = \frac{\mu}{\mu_0}$

$\mu_0 = 4\pi \times 10^{-7}$ H/m.

(1) Find the relative Permeability of Ferro magnetic material if the field strength ~~220~~ ampere/meter produces a magnetisation 3 300 Am²/m init

Sol: $\mu_r = ?$

$M = 3300$

$H = 220$

$\therefore \mu_r = X_m + 1$

$\mu_r = 15 + 1$

$\mu_r = 16$

$\frac{M}{H} = \frac{3300}{220} = 15$

$X_M = \frac{M}{H} = 15$

2. the magnetic field intensity in a pieces of Ferric oxide is 10^6 amp/meter. If the $X_m = 1.5 \times 10^{-3}$, calculate the magnetisation of the material & total flux density

Sol: $X = \frac{M}{H}$

$1.5 \times 10^{-3} = \frac{M}{10^6} \Rightarrow M = 1.5 \times 10^3$

$B = \mu_0 H + \mu_0 M$

$= 4\pi \times 10^{-7} \times (10^6 + 1.5 \times 10^3)$

$\Rightarrow 4\pi \times 10^{-7} \times 10^3 [10^3 + 1.5]$

$= 4\pi \times 10^{-4} [10^{3} + 1.5]$

$B = 1.25$

Origin of magnetic moment :-

The magnetism arises in the atom due to three reasons 1. Orbital motion of electron due to Orbital motion the atom gets Orbital

(2) Spin motion of electron — Spin magnetic momentum of electron

(3) Spin motion of nucleus - Spin magnetic moment of nucleus.

ORBITAL MAGNETIC MOMENT OF ELECTRON :-

The Orbital magnetic moment of electron arises due to orbital motion of electron.

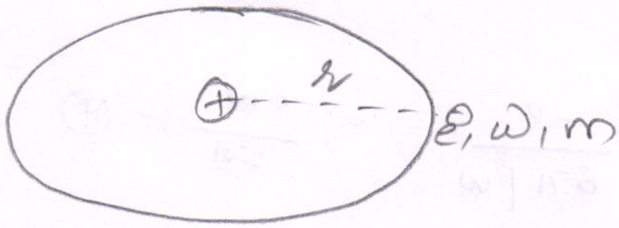
Assume that r = radius of Orbital

m = mass of electron

$e^{\ominus}$ = charge of electron

v = velocity of electron in the Orbital

w = angular Velocity of electron.



The magnetic moment of electron due to motion is called Orbital magnetic moment

i.e. $\mu_l = I \cdot A$ —①.

here μ_l = Orbital magnetic moment of $e^{\ominus}$

I = Current in the Orbital due to $e^{\ominus}$ motion in the Orbital.

A = area of the Orbital

$$I = \frac{q}{t} = \frac{-e}{T} \quad -② $$

Here T is the time period But

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\therefore T = \frac{2\pi}{\omega} \quad -③$$

$$I = \frac{-e}{2\pi/\omega} = \frac{-e\omega}{2\pi} \quad -④$$

Area of the Orbital $A = \pi r^2$ — ⑤

Sub ④ & ⑤ in ①

$$\mu_l = IA$$

$$= \frac{-e\omega}{2\pi} \times \pi r^2$$

$$\mu_l = \frac{-e\omega r^2}{2} \times \frac{m}{m}$$

$$\mu_l = -\left(\frac{e}{2m}\right)(mr^2\omega)$$

$$\mu_l = \left(\frac{-e}{2m}\right)(\vec{L}) \quad -⑦$$

According to Bohr's $m_v r = m_l \hbar = m_l \frac{h}{2\pi}$

But $v = r\omega$

$\therefore \vec{L} = mr^2\omega = m_l \frac{h}{2\pi}$

$\therefore \vec{L} = m\omega r^2 = m_l \frac{h}{2\pi}$ — (8)

$\therefore \mu_l = \left(-\frac{e}{2m}\right)\left(m_l \frac{h}{2\pi}\right)$

$\mu_l = -\left(\frac{eh}{4\pi m}\right) m_l$

$\therefore \mu_m = -\mu_B \cdot m_l$ — (9)

Here $\mu_B = \frac{eh}{4\pi m}$

$= \frac{1.6 \times 10^{-19} \times 6.625 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31}}$

$\mu_B = 9.27 \times 10^{-24}$ $(A \cdot m^2)$

where μ_B is called Bohr magneton.

The Bohr magneton is the accepted a unit for measuring the magnetic moments of atom system.

ii) Spin magnetic moment of electron:-

$$\mu_s = g\left(\frac{eh}{4\pi m}\right) m_s \quad \text{—} ①$$

$$\mu_s = g(\mu_B)\, m_s \quad \text{—} ②$$

Here μ_B = Bohr magneton $\mu_B = \frac{eh}{4\pi m}$

$m_s = +\frac{1}{2}$ or $-\frac{1}{2}$

g = Lande's splitting factor

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

J = Total angular momentum of electron

S = Spin , L = Orbital

iii) Spin magnetic moment of nucleus:- (μ_N).

$$\rightarrow \mu_N = \mu_{BN} = \frac{eh}{4\pi m_p} = \frac{1.6 \times 10^{-19} \times 6.625 \times 10^{-34}}{4 \times 3.14 \times 1.67 \times 10^{-29}}$$

m_p = mass of proton = $\mu_N = \mu_B = 5.05 \times 10^{-29}\ A\text{-}m^2$.

$\mu_N << \mu_B$ ∴ we can neglect μ_N

The total magnetic moment of the atom

atom is the algebraic sum of Orbital,

Spin of magnetic moment of $e^{\ominus}$ & spin magnetic

moment of nucleus.

1. Magnetic Susceptability of silicon is -0.5×10^{-5}

What is the intensity of magnetisation and

magnetic flux density in a magnetic field of

intensity 9.9×10^4 Amph/m.

Sol:- $\chi_m = \frac{M}{H}$

$0.5 \times 10^{-5} = \frac{M}{9.9 \times 10^4}$

$\Rightarrow 0.5 \times 9.9 \times 10^{4-5} = M$

$\Rightarrow 49.5 = M = 0.495$ A/m.

Magnetic flux density (B) $= \mu_0 H + \mu_0 m$

$= \mu_0 (H + M)$

$= 4\pi \times 10^{-7} [9.9 \times 10^4 + 0.495]$

$= 4\pi \times 10^{-7} (9.9 \times 10^{4} + 4.9 \times 5 \times 10)$

$B = 0.124$ (Tesla)

$B = \mu H$

$= \mu_0 \mu_r H$

$= \mu_0 (1 + \chi) H$

$= 4\pi \times 10^{-7} [1 - 0.05 \times 10^{-5}] \, 9.9 \times 10^{4}$

$B = 0.124$ (Tesla)

(2) A paramagnetic material has a magnetic field intensity 10^{4} Amp/m. If the susceptibility of material at room temperature is 3.7×10^{-3} calculate magnetisation and flux density in the material.

Sol: $H = 10^{4}$ Amp/m. $\chi = 3.7 \times 10^{-3}$

$M = \chi \times H = 3.7 \times 10^{-3} \times 10^{4} = 3.7 \times 10$

$= 37$ Amp/m

$B = \mu H = \mu_0 (1 + \chi) H$

$= 4\pi \times 10^{-7} (1 + 3.7 \times 10^{-3}) 10^4$

$= 0.012.$

(3) A circular loop conductor of radius 0.04 m carries current of 1000 milliamps. calculate the magnetic dipole moment of the loop.

Sol:- $\mu = I \cdot A$

$= 1000 \times 10^{-3} \times \pi (0.04)^2$

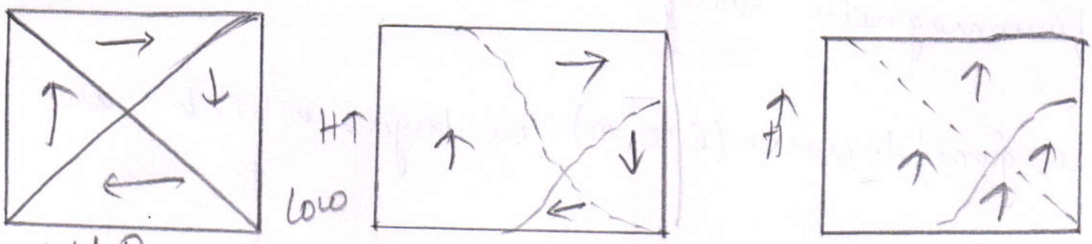
$= 5.024 \times 10^{-3}$ Amp. m².

Domain theory of Ferromagnetism :-

According to weiss the specimen of ferromagnetic material consists of no. of regions/domain (10^{-6} m) or larger. which are spontaneously magnetised. In each domain

Speontaneous magnetisation due to parallel alignment of all magnetic dipoles. The direction of spontaneous magnetisation varies from domain to domain. The resultant magnetisation may be zero. when an external feild is applied. there are two Possible ways of alignment of domains

① Pay motion of Domain walls: The Volume of domains that are favourably Oriented with respect to the magnetising field increases at the cost of those are Unfavourably Oriented as shown in fig



M 0
ferro magnetic material

M = 0
domain

M ≠ 0
by rotation

(2) Pury Rotation of domains :-

As shown in fig (3) when the applied magnetic field is strong rotation of the direction of magnetisation addressing. the direction of magnetic field

Retent magnetisation (Or) Retentivity :- The magnetisation Remained in the material after decreasing the magnetic field from saturation value to zero.

Coercivity :- The amount of magnetic field Intensity Required (or) Retained magnetisation in the value from saturation Value to zero.

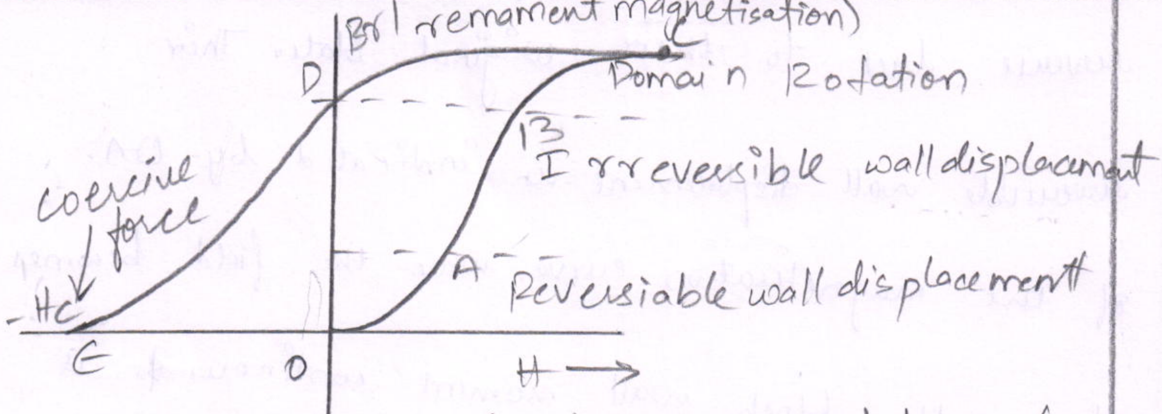
* Explanation of hysterisis on the basis of Domain theory:-

The hysterisis of ferromagnetic materials refers to the lag of magnetisation (M) behind the magnetising field (H).

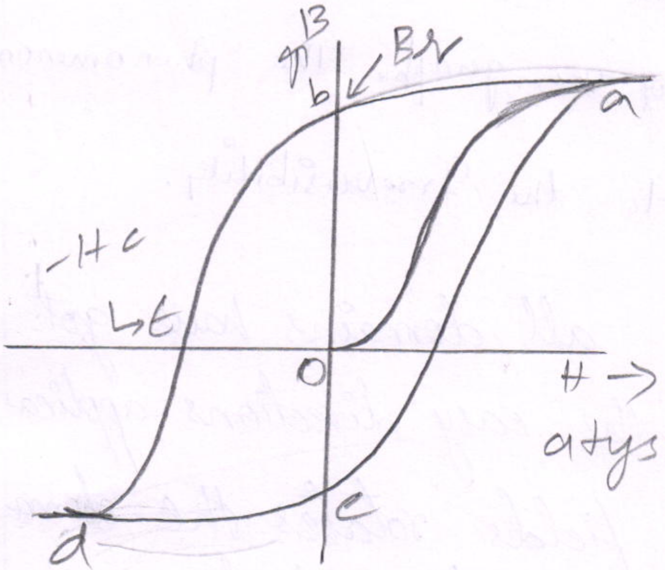
When the temperature of the ferro-magnetic substance is less than the curie temperature the substance exhibits hysterisis.

The Domain concept is well suited to explain the phenomenon of hysterisis. The increase in the value of resultant magnetic moment of specimen under the action of applied magnetic field can be attributed to

1. The motion of Domain walls
2. Rotation of Domains



Typical magnetisation curve of the ferro magnetic speci-men



a hysteresis curve

When a weak magnetic field is applied to the domains that are aligned parallel to the field and in the easy direction of magnetisation grow in size at the expense of less favourably oriented ones. This results in the bloch wall moment and when the weak field is removed the domains reverse back to their original state. Their

reversible wall displacement is indicated by OA.

of the magnetisation curve. when the field becomes

stronger the bloch wall moment continous & it

is mostly irreversible moment. this is indicated

by the part AB of the graph. The phenomenon

of hysterisis is due to the Irreversibility.

At the point B all domains have got magnetised along the easy directions application of still higher fields rotates the domains into the field direction. which may be away from the easy direction there by storing Anisotropic energy.

In Some Materials

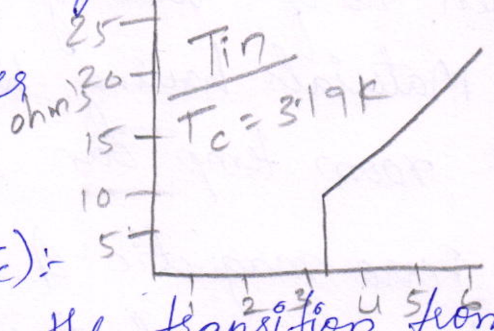
the resistivity is proportional to temp conductivity $\propto \frac{1}{\text{resistivity}}$

If you decrease the temp of particular material goes to zero.

$\therefore$ conductivity $= \frac{1}{0} \Rightarrow$ conductivity $\sigma = \infty$

Certain materials and alloys Exhibit almost zero resistivity like (infinite conductivity) when they are cooled to sufficiently low temperatures. this phenomenon is called super conductivity this phenomenon was first observed by Kimarling annes in mercury at 4.K

General properties of super conductors.



Transition temperature: (T_c):-

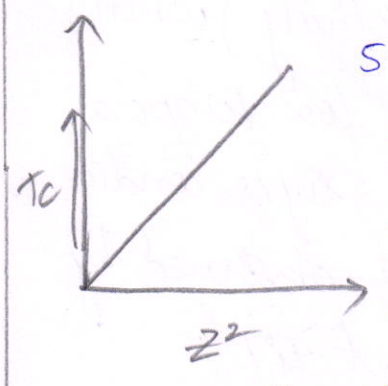
the temp at which the transition from normal state is super conducting state takes place on cooling in the absence of magnetic field is called the critical temp (or) trasition temperature.

Properties :- 1. Transition temp is different from diff temperatures for different substances.

2. Super conductivities found to occur in metallic elements in which the no. of valency electrons (Z) lies in b/w 2 & 8.

3. Super conducting elements, in general, lie in inner columns of periodic table

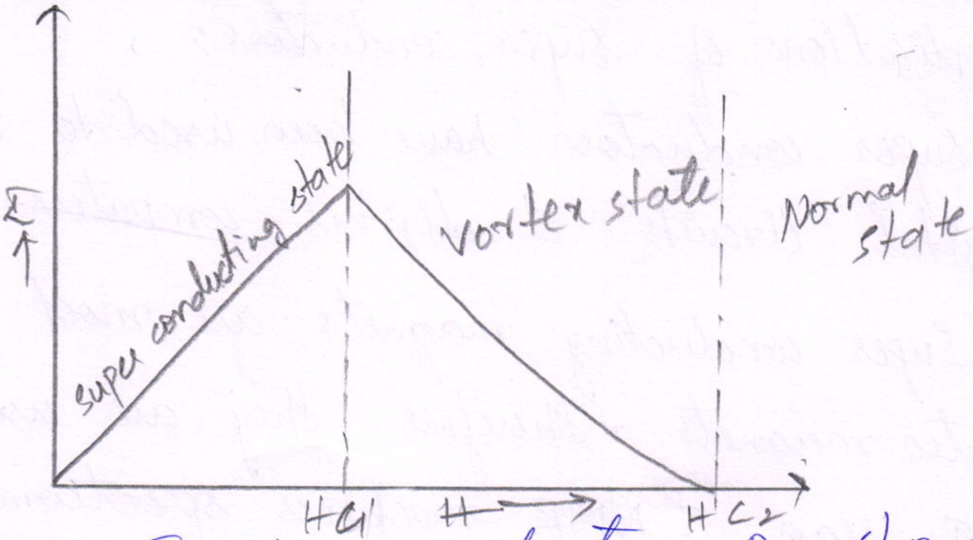
4. For elements in a given low in the periodic table T_c Vs Z^2 give straight line



5. Transition metals having odd no. of valence electrons are favarable to exhibit super conductivity while metals having even no. of valency electrons.

6. Materials having high normal resistivities at room temp can Exhibit super conductivity

7. Ferro magnetic & antiferro magnetic are not super conductors.



In type -II super conductors. As shown in fig ① upto field H_{C_1} the specimen is in a pure super conducting state. when the field is increased behind H_{C_1} the magnetic flux lines start to penetrating. The specimen is in a mixed state b/w H_{C_1} & H_{C_2}. above H_{C_2} the specimen is in a normal state this means that the meissner effect is incomplete in the region b/w H_{C_1} & H_{C_2}. this region is called vertex region. the type-II super conductors are known as hard super conductors.

Eqn: Zr, Ni

Applications of super conductors:-

1. super conductors have been used to make dizital circuits & digital computers.

2. Super conducting magnets are most powerful electro magnets. Therefore. they are used in MRI scan & NMR machines spectrometers & beam stirring magnets used in particle accelarators

3. super conductors are used to build josephson junctions which are the building bloocks of S Q UIDS

SQUIDS are most sensitive mgnet to meters

4. super conductors can be used as photon dectors

5. super conductors are used for producing very high magnetic fields of the order 50 Tsla.

Magnetic Leviatation:- the super conchiling materi-ial can be suspended in air against the repul-sive force from permanent magnet this magnet-tic leviation effect can be used for high speed transportation.

low loss transmission lines & transformers since the resistance is almost zero at the super conducting phase. If the super conductors are used for winding of a transformer. the power losses will be very small.

NANO TECHNOLOGY

Synthesis of nono materials:-

1. Top down methods - Ball milling
2. Bottom up method

↓

① C.V.D → chemical vapour deposition techniques.

② P.V.D → physical vapour deposition

③ sol gel method

Materials can be produced synthesised by top down techniques, producing very small structure from larger pieces of materials

Nano materials can be synthesized by bottom of techniques, atom by atom and molecule by molecule. one way of doing this is to allow the atoms (or) molecules arrange themselves into a structure due to their natural properties.

Eg:- crystal growth.

Bottom of fabrication methods:-

1. C.V.D (chemical vapour deposition)

In this method Nano particles are deposited from gas phase. Material is heated to