DATE: __/__/____
PAGE: ______

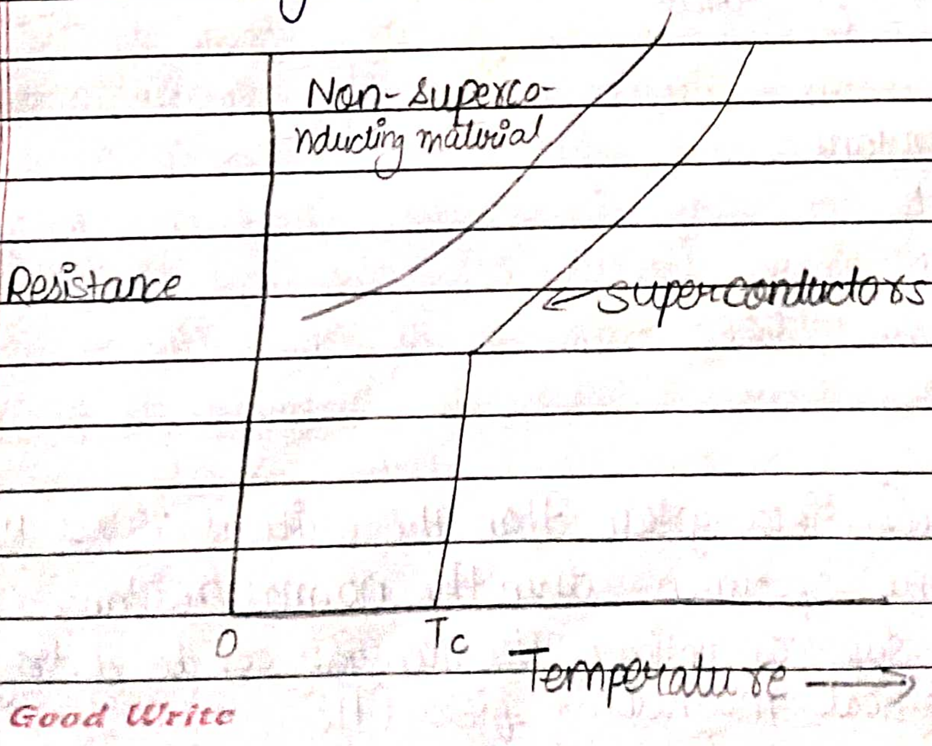
UNIT: 4

Superconductors ~~And Nanomaterials~~

Superconductors:- In 1911, H. Kammerlingh Onnes observed that the resistance of mercury decreases regularly with decrease in temperature and at 4.2K it suddenly reaches to zero. The temperature at which this phase transition occurs and resistance drops to zero is called critical temperature or transition temperature (T_c).

The phenomenona of disappearance of electrical resistance in a given material below a certain temperature is called superconductivity. And material in this state is called superconductors.

Example:- Mercury (Hg) = 4.2K
Lead (Pb) = 7.2K
Niobium (Nb) = 9K
Tungsten (W) = 0.01K



Experimental Facts of Superconductivity

① Zero Resistivity.

The most outstanding property of superconductors is the complete disappearance of the electrical resistivity at critical temperature (T_c). It is the property / nature of superconductors which is also reversible as by increasing the temperature it regains its original phase of conductor.

$T\downarrow \quad R\downarrow \quad V = IR \quad R\downarrow \quad I \to \infty \quad \rho = 0.$

② Persistent current.

As the temperature of superconductor ring or material is lower down then the current flowing through it does not diminish a value which in the limit of measurement even after a period of more than one year this property of superconductor is applied only on its dc behaviour. for AC behaviour a superconductor does exhibit a resistance although at low frequency it is very small.

For current flowing through a superconductor.

$$i = i_0 e^{-(R/L)t}.$$

Here time constant

$$\tau = \frac{L}{R}$$

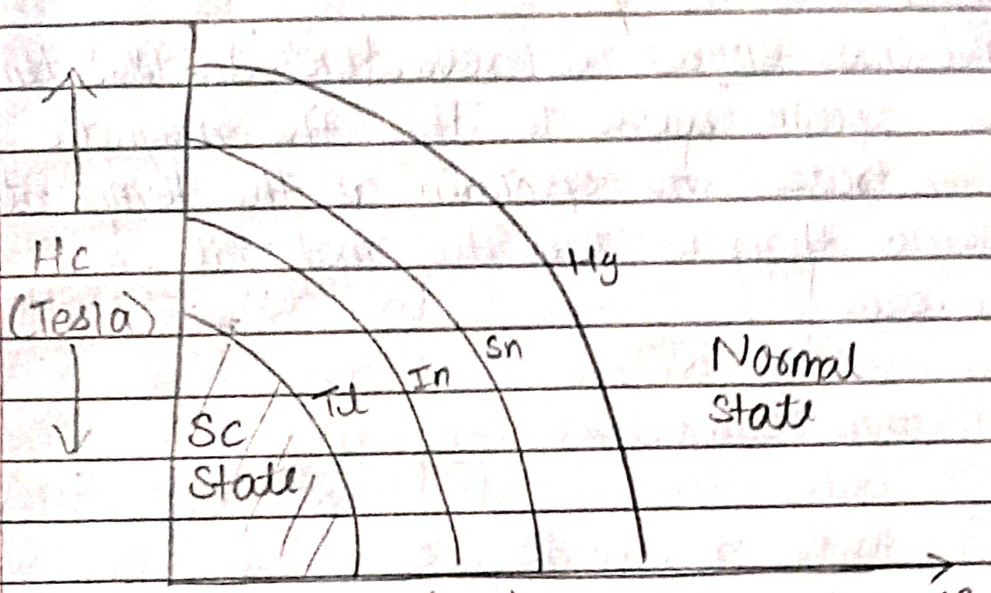
$R \to 0 \quad , \quad \tau \to \infty.$

③ Critical Field

If a magnetising field greater than the critical value H_c is applied to the specimen then the normal resistance can be restored i.e the superconducting of the material can be destroyed by applying ~~a~~ a critical magnetising field (H_c).

$$\boxed{H_c(T) = H_0(T=0)\left[1-\left(\frac{T}{T_c}\right)^2\right]}$$

where
H_0 = Critical field at 0K
T = Temperature below T_c
T_c = Transition temperature.



Nb =	198
Pb =	80.3
Sn =	30.9

④ Critical current density.
Any electric current in a circuit produces a magnetic field. If a superconductor carries a current such that the magnetic field which it produces is equal to critical magnetic field (B_c). Then the resistance of a sample will be restored corresponding current density is called critical current density.
$H_c\uparrow$ $Sc\downarrow$.

$$J_c = \frac{I_c}{A}$$

$$= \frac{I_c}{\pi r^2}$$

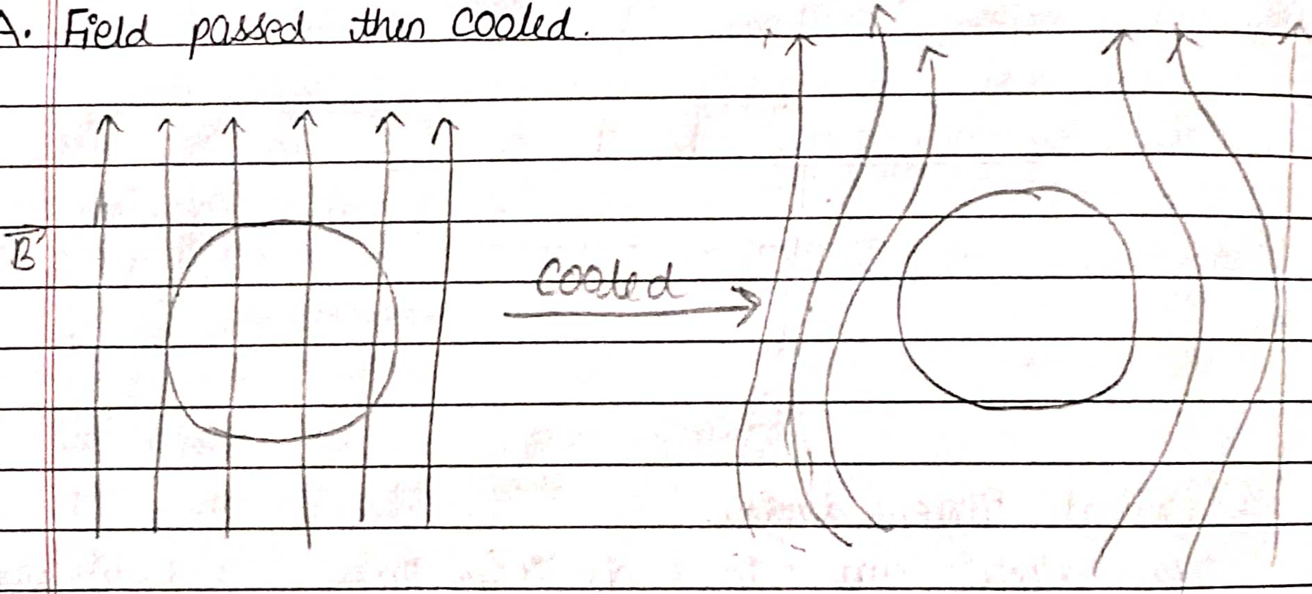
$J_c \rightarrow I \rightarrow \rho$
$\downarrow$
B_c
$Sc \leftrightarrow C$
$J_c = \frac{I_c}{A}$

(5) Meissner Effect

In 1933 Meissner and Ochsenfeld observed that when a long superconductor is cooled in an external magnetic field below the value of transition temperature then at transition stage the magnetic lines of induction are pushed out of the specimen superconductor. This phenomenona is called Meissner effect.

This meissner effect is reversible. If the temperature is increased from below T_c then the magnetic flux suddenly penetrates the specimen as the temperature becomes greater than T_c then the material comes back in the normal state.

A. Field passed then cooled.

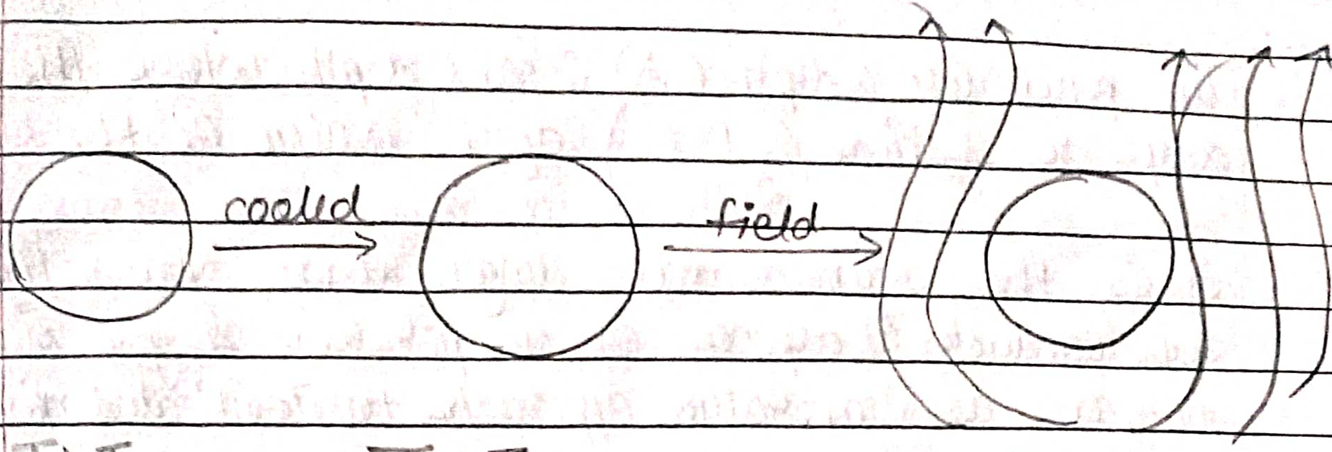


$T > T_c$ Normal state

$T < T_c$ Superconductor

When a specimen was kept at a temperature greater than critical temperature (Normal state) and magnetic lines are passes through it but when the same specimen was cooled while the magnetic lines passing through it. The temperature was kept below the critical temperature, the field lines were repelled out or pushed out of the specimen in superconductor.

B. Cooled then field pass



$T > T_c$ Normal State

$T < T_c$ Superconductor State

$T < T_c$ Superconductor State.

A specimen was kept in the normal state with the temperature greater than transition temperature, then it was cooled at a temperature below transition temperature (superconductor state) & then magnetic field lines were made to pass through it then also the magnetic field lines were repelled out of the specimen.

C. Mathematical Explaination.

$$\vec{B}_{int} = \mu(\vec{H} + \vec{M})$$

where $\vec{H}$ = Magnetising field.
$\vec{M}$ = Magnetic vector potential.
= $\frac{\text{magnetic moment}}{\text{volume}}$.

$\vec{M} = \frac{\text{magnetic moment}}{\text{Volume}}$

For superconductor,

$$\vec{B}_{int} = 0$$

or $0 = \mu(\vec{H} + \vec{M})$

or $\vec{M} = -\vec{H}$

or $\boxed{\chi = \frac{\vec{M}}{\vec{H}} = -1}$ where χ = Mag. susceptibility

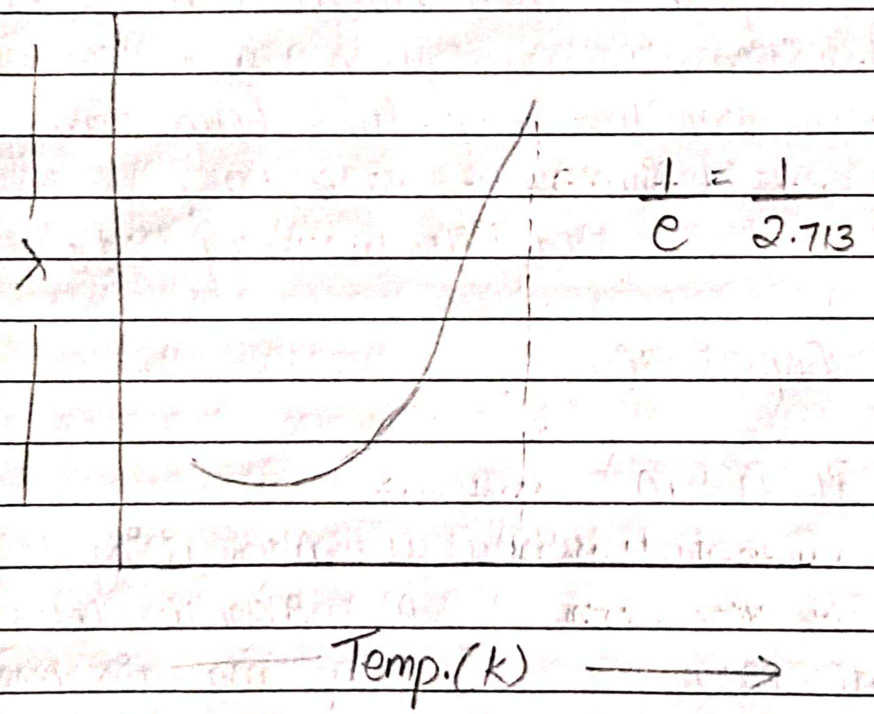
Perfect dimagnet.

Penetration depth.

The penetration depth (λ) is the depth where the current drops to $\frac{1}{e}$ times $\left(\frac{1}{2.713}\right)$ of its value at the surface.

It is the fundamental length that characterise a superconductor. It depends on temperature & gets significantly increase as temperature approaches to Tcritical temperature (T_c)

$$\lambda(T) = \lambda_0(T=0)\left[1 - \left(\frac{T}{T_c}\right)^4\right]^{-1/2}$$



Isotopic Mass Effect

The transition temperature or critical temp. (T_c) is different for different specimen having different masses. This effect is known as isotopic mass effect of superconductors.

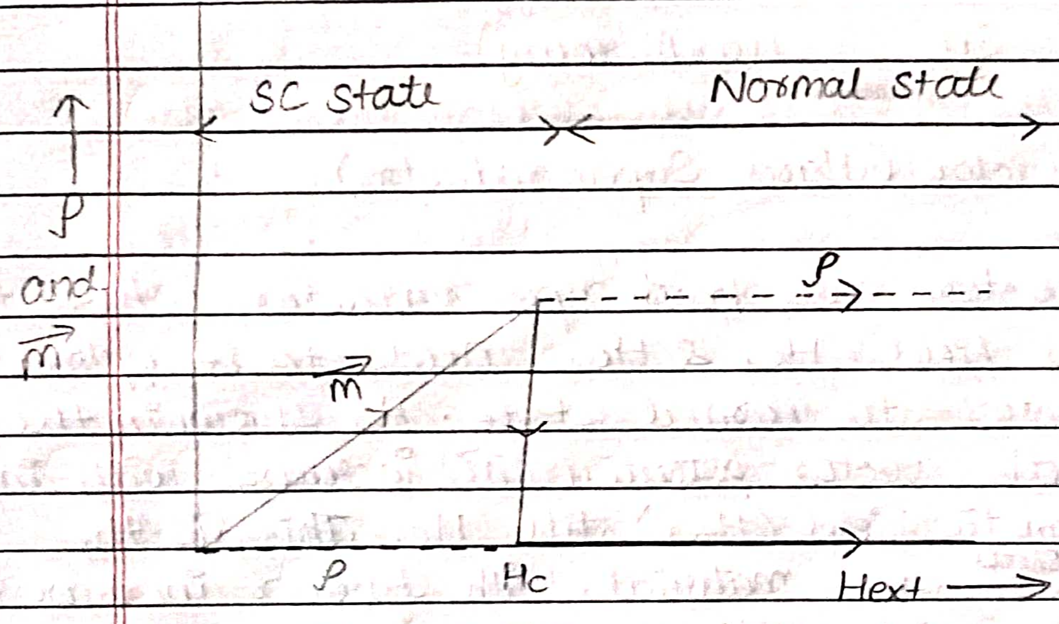
$$\boxed{T_c \propto \frac{1}{\sqrt{M_w}}}$$

for $T_{c_1} \propto \frac{1}{\sqrt{M_1}}$.

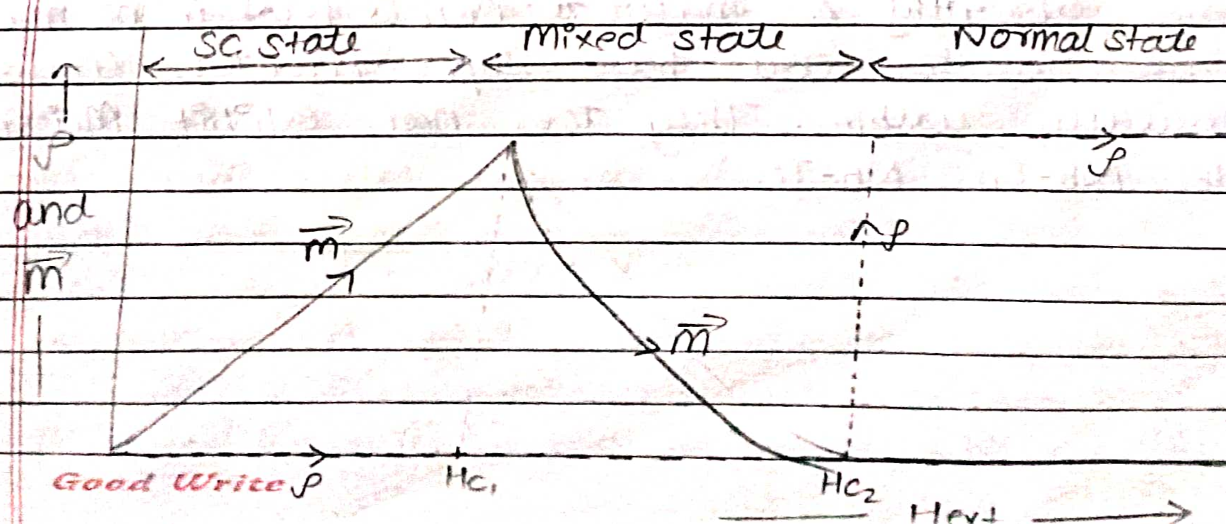
$T_{c_2} \propto \frac{1}{\sqrt{M_2}}$.

$$\boxed{\frac{T_{c_1}}{T_{c_2}} = \sqrt{\frac{M_2}{M_1}}}$$

Type I and Type II Superconductors



Type -I Superconductors
Soft Superconductor.



DATE: / /
PAGE:

① Type-I Superconductor. (Soft Superconductor).

Type-I superconductors are soft superconductors which have only one critical field (H_c) where the material changes its state from superconductor to normal. As shown in the figure the magnetic vector potential ($\vec{M}$) changes abruptly at critical field (H_c) and becomes zero whereas at the same time the resistivity (ρ) of the material goes back to the previous state. Hence, the superconductor converts to the normal material at this transistion field. These superconductors exhibit Meissner effect.
Example:- Pb (lead), Sn, Hg (Mercury)

② Type-II Superconductor (Hard Superconductor).

Type-II superconductors are hard superconductors where two different critical field H_{c_1} & H_{c_2} needs to be applied to convert superconductor to normal state. As shown in the figure the magnetic vector potential ($\vec{M}$) increases with increase in external magnetic field (H_{ext}) till H_{c_1}. This is the superconducting state of the material. With further increase in H_{ext} decrease exponentially till H_{c_2}. This state of the material is mixed state. After that, the resistivity of the material increases abruptly & material comes back in normal state. These superconductor are hard superconductors which are commerically usable. They does not exhibit Meissner effect.
Example:- Nb-Sn, Nb-Ti.

Differences between Type-I superconductor & Type-II superconductor

Type-I Superconductor	Type-II Superconductor.
1. Sudden loss of magnitisation.	Gradual loss of magnitisation.
2. Exhibit Meissner effect	Does not exhibit Meissner effect.
3. No Mixed state.	Mixed state present.
4. Soft superconductor.	Hard superconductor.
5. Example- Pb (lead), Sn, Hg.	Example - Nb-Sn, Nb-Ti.

High Critical Temperature Superconductor (HTSC).

Q.

1. Until 1986, the only available high Tc Superconductor had $T_c = 23.2k$ which was the alloy of Nb, Al, Ge.
2. In 1986, Two scientists Bednorz and Muller gave an idea of superconductivity in a new class of ceramic material at high pressure.
3. In 1987, using the above concept, the rare earth metal oxides were synthesis with high Tc 93k. It was the first time when the superconductor exist above nitrogen boiling point 77k. Before this the liquid helium to cool the superconductor which was very expensive.
4. After this the high Tc superconductivity was achieved using the combination of copper and oxides (Cuprates). A new compound $HgBa_2Ca_2Cu_3O_8$ was formed at high Tc 133k. This compound was subjected to a very high pressure ~ 30 GPa at which its Tc increased and

DATE : __/__/__
PAGE : ____

become 164K. But this compound was not commerically useful at this high pressure.

5. At present highest reported Tc for non cuprates compound i.e MgB_2 at 39K Tc.

6. All copper based high superconductors possess the elemental properties of superconductivity including O(zero) resistivity and meissner effect.