Superconductivity

Q) What is Meissner effect?
Q) Explain in brief about Type-I & Type-II Superconductor
Q) Define critical magnetic field and critical current in a super-conductor with mathematical-relation involved.
Q) What is Superconductor? Differentiate betn Type-I & Type II superconductor.

Introduction :

The electrical resistance of metal and alloys increases with increase in tempr & vice versa. At low tempr, the thermal vibrations of the atom decreases. So, due to the decrease in randomness of free electrons, in turn the resistance reduces. When a specimen is cooled sufficiently low tempr, then the dc resistance drops down to zero.

The phenomenon was first observed by Dutch ~~Physicits~~ physicist Kamerlingh onnes who discovered that the electrical Resistance

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of mercury drops to zero at a temp^r of about 4K; Such a new state of mercury is achieved where the resistance has practically vanished. Such extraordinary properties may be called as superconductive state.

* Def^n of Superconductor?

Superconductor is an element, metallic alloy or compound that will conduct electricity without resistance below a certain temp^r and external magnetic field strength.

What is Superconductivity?

Superconductivity is a phenomenon of exactly zero electrical resistance and expulsion of magnetic flux fields occuring in certain materials when cooled below a characteristics critical temp^r.

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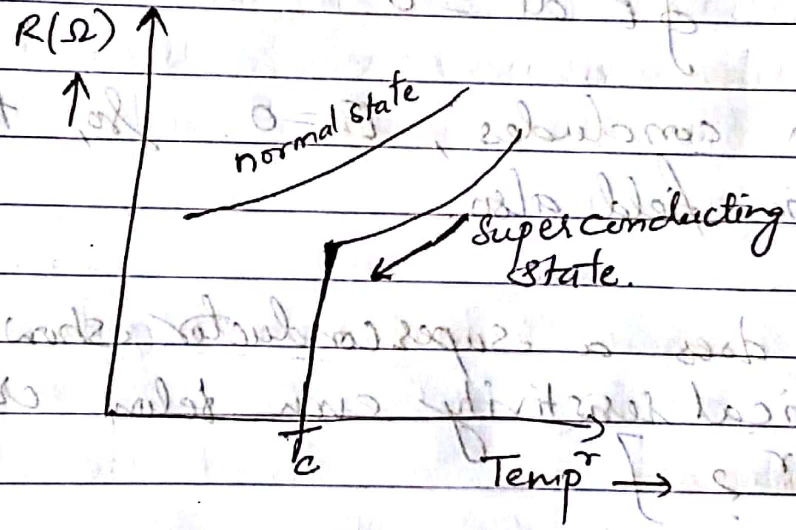
Zero resistance :-

Thermal ~~resistance~~ vibrations increase the resistance. So when the temp^r is lowered, the thermal vibrations of the atoms decrease and so the electrons are less frequently scattered. Below a critical temp^r (T_c) DC resistivity of the material vanishes.



T_c → critical temp^r.

Below critical temp^r, because there is no resistance in the circuit there is no electric field. Because there is no electric field, the electrons are not accelerating.

The effect can be explained in terms of Faraday's law

$$\oint \vec{E} \cdot \vec{dl} = -\frac{d\phi}{dt}$$

Here, $\frac{d\phi}{dt}$ would be zero as the flux is not changing due to the application of dc.

$$\oint \vec{E} \cdot \vec{dl} = 0$$

which concludes, $E = 0$. So, there is no electric field also.

[Why does a superconductor show ac electrical resistivity even below critical temp^r ?]

If the current in superconductor is changing or ac, an electric field must be present in superconductor to accelerate electrons. This electric field is caused by electrons moving perpendicular to the flow of rest of the current. These electrons will then collide with other electrons and this creates resistance.

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Therefore, ac current in superconductor creates resistance. Zero resistance occurs with DC current, which does not require an electric field.

Meissner Effect :-

The Meissner effect is the expulsion of a magnetic field from a superconductor during its transition to the superconducting state.

German physicist Walther Meissner and Robert Ochsenfeld discovered this phenomenon in 1933 by measuring magnetic field distribution outside superconducting tin & lead samples.

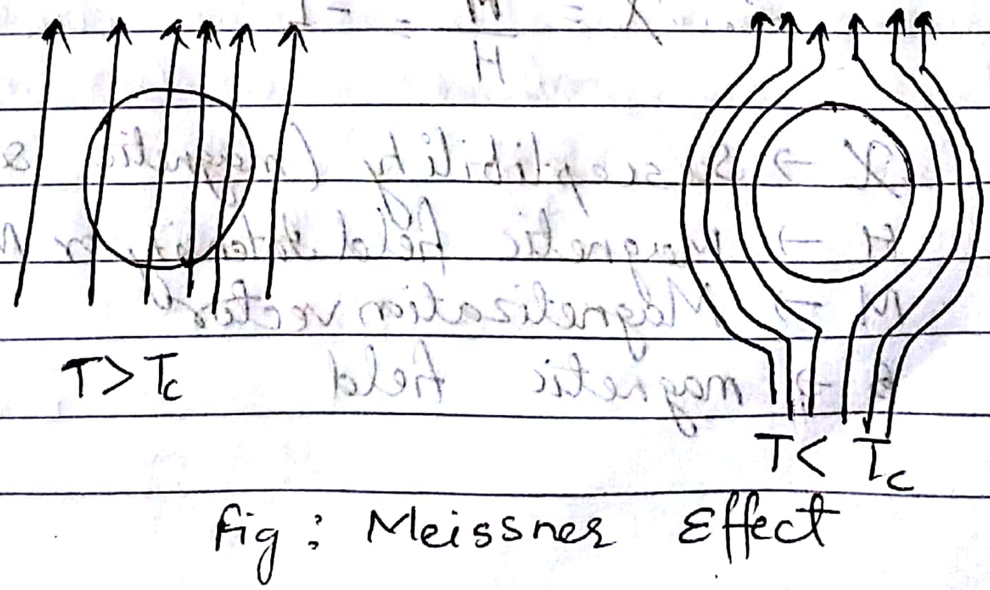

Fig : Meissner Effect

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Note: A superconductor with little or no magnetic field within it is said to be in Meissner state. Meissner ~~effe~~ state breaks down at large applied field.

In a <u>weak applied field</u>, a superconductor expels nearly all magnetic flux. It does this by setting up electric current near its surface. The magnetic field of these surface current cancels the applied magnetic field within the bulk of superconductor.

Since, magnetic field inside superconductor $B=0$, $B = \mu_0 (H+M)$

Thus,

$$\mu_0 (H+M) = 0$$

or, $H+M = 0$

or, $H = -M$

$$\therefore \chi = \frac{M}{H} = -1$$

$\chi \rightarrow$ Susceptibility (magnetic susceptibility)

$H \rightarrow$ Magnetic field Intensity or Magentizing field

$M \rightarrow$ Magnetization vector

$B \rightarrow$ magnetic field

So, the Superconductor shows perfect diamagnetism.

Now, Considering zero resistivity, we get relaxation time $(\tau) = \frac{Vm}{eE}$ —— (i)

Electric field accelerate super conducting electrons, then

$$m\frac{dv}{dt} = eE \quad \text{—— (ii)}$$

$$J_s = n_s e V \quad \text{—— (iii)}$$

From (ii) & (iii)

$$m\frac{\partial}{\partial t}\left(\frac{J_s}{n_s e}\right) = eE$$

$$\frac{\partial J_s}{\partial t} = \left(\frac{n_s e^2}{m}\right)E$$

from maxwell's Equation,

$$\nabla \times E = \frac{-\partial B}{\partial t} = 0$$

$$\text{or } \frac{-\partial B}{\partial t} = 0$$

$$\text{or } \frac{\partial B}{\partial t} = 0$$

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Integrating,
$$B = \text{Constant}$$

But the value of this constant is zero in accordance with Meissner effect.

$\therefore B = 0$ and $E = 0$.

Critical Magnetic field:

At a fixed temperature below the critical tempʳ (T_c), Superconducting material cease to superconduct when an external magnetic field is applied which is greater than critical magnetic field.

Below critical tempʳ, there is a threshold or critical value of applied magnetic field above which superconductivity is lost. So, critical magnetic field is function of tempʳ.

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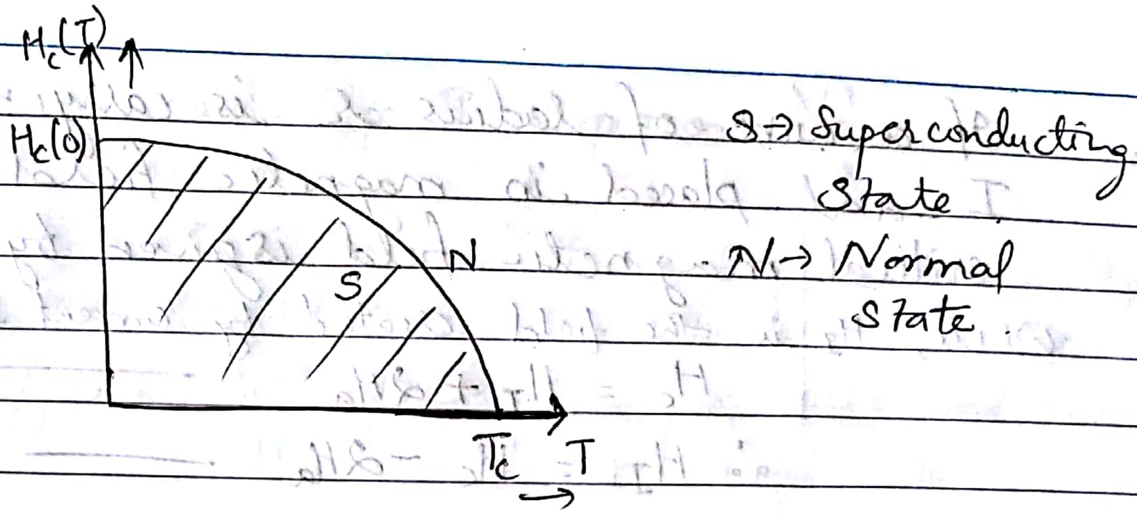

Fig: Variation of critical field with tempr.

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

where,

$H_c(0)$ → critical field at 0K.

Critical Current :→

→ The maximum current that a super conductor can pass at a given temperature and external magnetic field without losing super conductivity is called critical current.

→ Critical current & critical magnetic field are closely related because on passing electric current, magnetic field is produced.

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If a wire of radius r is carrying current I and placed in magnetic field (H_a), then critical magnetic field is given by,

where, H_I is the field created by current I on the surface.

$$H_c = H_I + 2H_a$$

$$\therefore H_I = H_c - 2H_a \quad \text{------} \quad (2)$$

where,

$$H_I = \frac{I}{2\pi r}, \text{ at critical value, } I = I_c$$

eq^n (1) can be written as

$$\frac{I_c}{2\pi r} = H_c - 2H_a$$

$$\therefore I_c = 2\pi r (H_c - 2H_a)$$

When applied field, $H_a = \frac{H_c}{2}$, $I_c = 0$. this means no current should flow through wire to maintain superconductivity. It is called Silsbee's Rule.

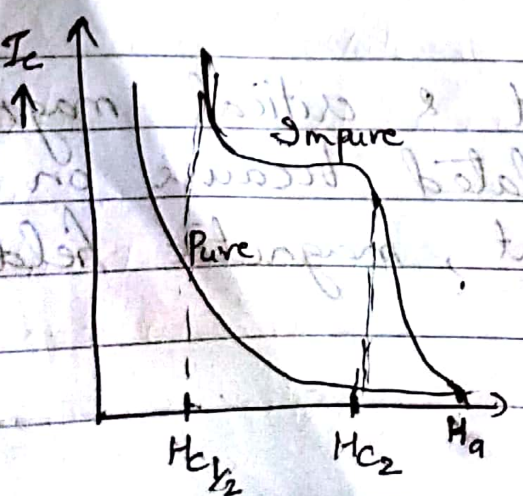

fig: Variation of critical current of pure & impure materials with transverse applied field.

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Type I and Type II Superconductors.

→ In type I superconductor, superconductivity is abruptly lost/destroyed when the strength of applied field rises above a critical value H_c.

→ Type I superconductors are also called Soft superconductors.

→ Type I superconductors mainly comprise of pure metals & metalloids.

→ Type I superconductors incredible low tempr (cold) to slow down molecular vibrations sufficiently to facilitate free electron flow. So they are reffered to as soft superconductors.

→ Surface energy is positive for type-I superconductors.

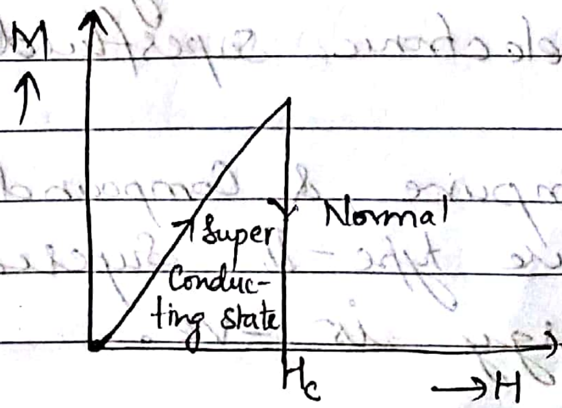

Fig: Magnetization curve for type-I superconductors.

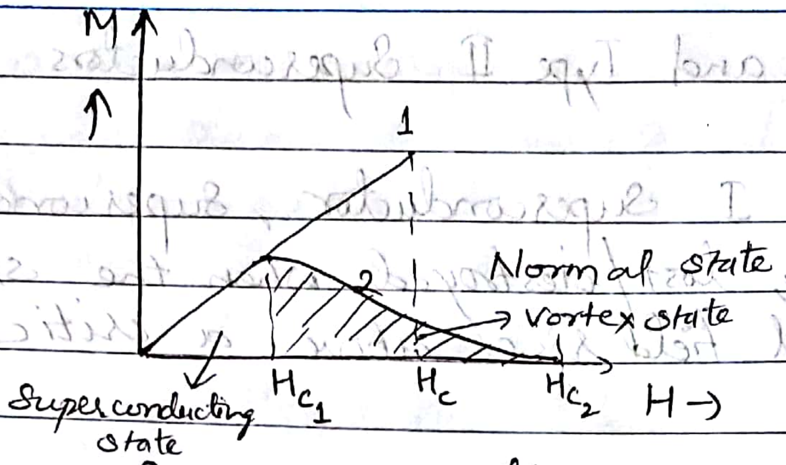

fig: Magnetization curve

→ In type II superconductors, raising the applied field past a critical value H_{c_1} leads to a mixed state in which an increasing amount of magnetic flux penetrates the material, but there remains no resistance to the flow of electric current as long as the current is not too large. At second critical strength H_{c_2} superconductivity is destroyed.

→ The mixed state is actually caused by vortices in electronic superfluid i.e impurities.

→ Almost all impure & compound superconductors are type-II superconductors.

→ Surface energy is -ve.

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