Superconductivity

- **Super conductor**: It is a conductor whose ~~resi~~ resistance and hence resistivity falls to zero at and below a particular low temperature called critical temperature.

Critical temperature (T_c): It is the highest temperature at which resistance and hence resistivity falls to zero.
Conductors have zero resistance at temperatures $\leq T_c$

Super conductivity:. It is that state of body in which its resistivity is zero.

or

Super conductivity of a body is zero resistivity state of body.

or

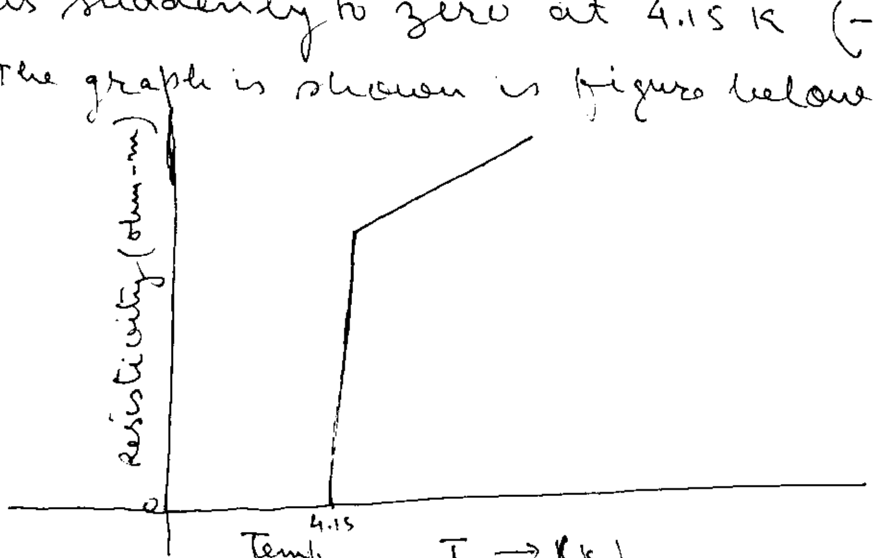
super conductivity is a phenomenon due to which its resistivity falls to zero at a temperature less than or equal to critical temperature.

Note:- critical temperature depends upon the nature of material and the strength of external magnetic field. For a given material under the influence of fixed external magnetic field, there is fixed critical temperature. It is normally much below the temp. of ice

Temperature - Resistivity Graph of mercury

when temperature of Hg is lowered and its resistivity is measured all the temperature, it is found that resistivity falls suddenly to zero at 4.15 K (−268.85°c).

The graph is shown is figure below



Note:- To study superconductivity of Hg, we require liquid Helium whose boiling point is 4K.

Liquid Nitrogen has a boiling point of 77K (−196°c) and can be used to study the superconducting properties of all those materials whose critical temperature is above 77K.

Critical magnetic field (H_c)

It is the minimum magnetic field applied on the superconductor to destroy its superconductivity.

Note:- When external magnetic field is applied on the super conductors then on increasing the magnetic field, the superconductor looses its superconducting property and comes to normal state (i.e becomes normal conductor), At a field called critical field. The conductor remains in normal state at magnetic field larger than H_c.

Dependance of critical field on temperature:-

If H_0 = critical magnetic field at 0°K

H_c = critical magnetic field at T K

and T_c = critical temperature

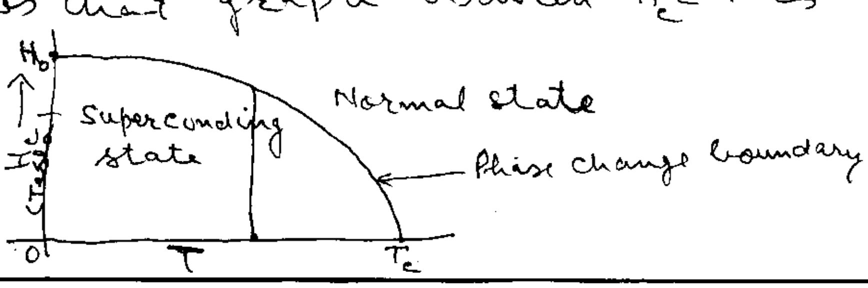
then H_c, H_0, T & T_c are found to be related by formula

$$H_c = H_0\left(1 - \frac{T^2}{T_c^2}\right) \qquad (1)$$

At $T=0$ $\quad H_c = H_0$

& At $T = T_c$ $\quad H_c = 0$

Equation (1) shows that graph between H_c & T is parabolic



Below the curve the material is in superconducting state and above the curve, the material is in normal conducting state.

Persistent current :- It is the current which continues to flow in superconductor without decrease in its strength.

If some current is established in superconducting ring by changing magnetic flux through it, the current produced in the ring will continue to flow with fall in the strength. This is because energy loss I^2Rt will be zero ($R=0$ for superconductors).

This constant current is called persistant current.

Critical current density ($\vec{J}_c$) when current flows through a superconductor, a magnetic field is always produced. If the current density in superconductor is such that the magnetic field produced by it is equal to critical magnetic field H_c, then current density is called critical current density.

Since $B = \frac{\mu_0 I}{2\pi r}$

& $B = \mu_0 H$

$\therefore \mu_0 H = \frac{\mu_0 I}{2\pi r}$

$\Rightarrow 2\pi r H = I$

$J = \frac{I}{A} = \frac{2\pi r H}{\pi r^2}$

$J = \frac{2H}{r}$

For $H = H_c$ $J = J_c =$

$\therefore J_c = \frac{2H_c}{r}$.

Since H_c (critical field) depends upon temperature, the current density J_c also depends upon temperature

Also $J_c \propto \frac{1}{r}$

1 **Penetration Depth**: It is the depth from the surface of superconducting where magnetic field falls to $\frac{1}{e}$ times the field at the surface.

When a magnetic field is applied on a superconductor, it does not suddenly drop to zero at the surface of superconductor, but penetrates into the material and falls off exponentially according to formula

$$H = H_0 e^{-\frac{x}{\lambda}}$$

where H_0 = magnetic field at the surface of superconductor ($x=0$)

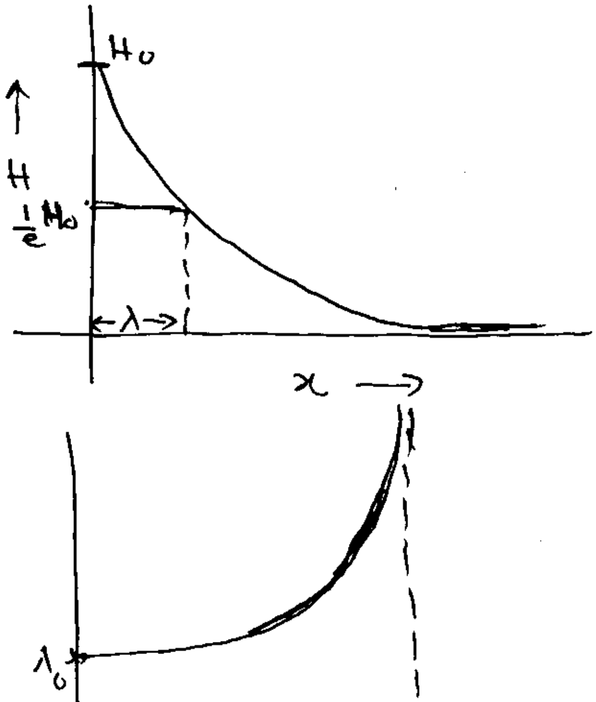
H = magnetic field at a distance x from the surface and into the material.

λ = Penetration length

λ varies from 300 to 5000 Å

At $x = \lambda$ $\quad H = H_0 e^{-\lambda/\lambda} = H_0 e^{-1} = \frac{1}{e} H_0$.

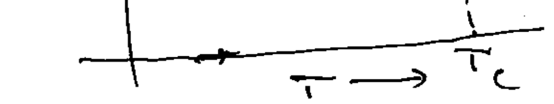
i.e. $H = \frac{1}{e} H_0$.



Penetration length λ is temperature dependent and becomes very large as $T \to T_c$

It is found that

$$\frac{\lambda_T}{\lambda_0} = \left[1 - \left(\frac{T}{T_c}\right)^4\right]^{-1}$$



λ_0 = Penetration depth at 0K

i.e. at $T=0$ $\lambda_T = \lambda_0$

At $T = T_c$ $\quad \frac{\lambda_T}{\lambda_0} = [0]^{-1} = \frac{1}{0} = \infty$

i.e. magnetic field penetrates material completely