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**Lecture for M. Sc. Physics IV Semester students**

**Paper-I: Condensed Matter Physics**

**Unit 4-: Superconductivity**

The Meissner effect is particularly interesting because it contradicts classical laws.

## Thermodynamic effects

There are a number of thermodynamic effect of interest in the superconducting and normal states which are primarily important from the stand point of the development of the fundamental theory of superconductivity. These effects are essentially reversible in nature and all are predicted by phenomenological theories.

1. **Latent Heat of transition:** When superconductivity is destroyed isothermally by a magnetic field (at constant temperature), the superconductor absorbs heat. For the adiabatic case (constant heat) the specimen temperature becomes lower.

In the isothermal case, when the field is reduced again, this latent heat of transition is given up by the superconductor.

$$Q = -\frac{\rho T H_c}{4\pi w_A} \cdot \frac{dH_c}{dT} \times 10^{-7} \qquad \text{.......... (1)}$$

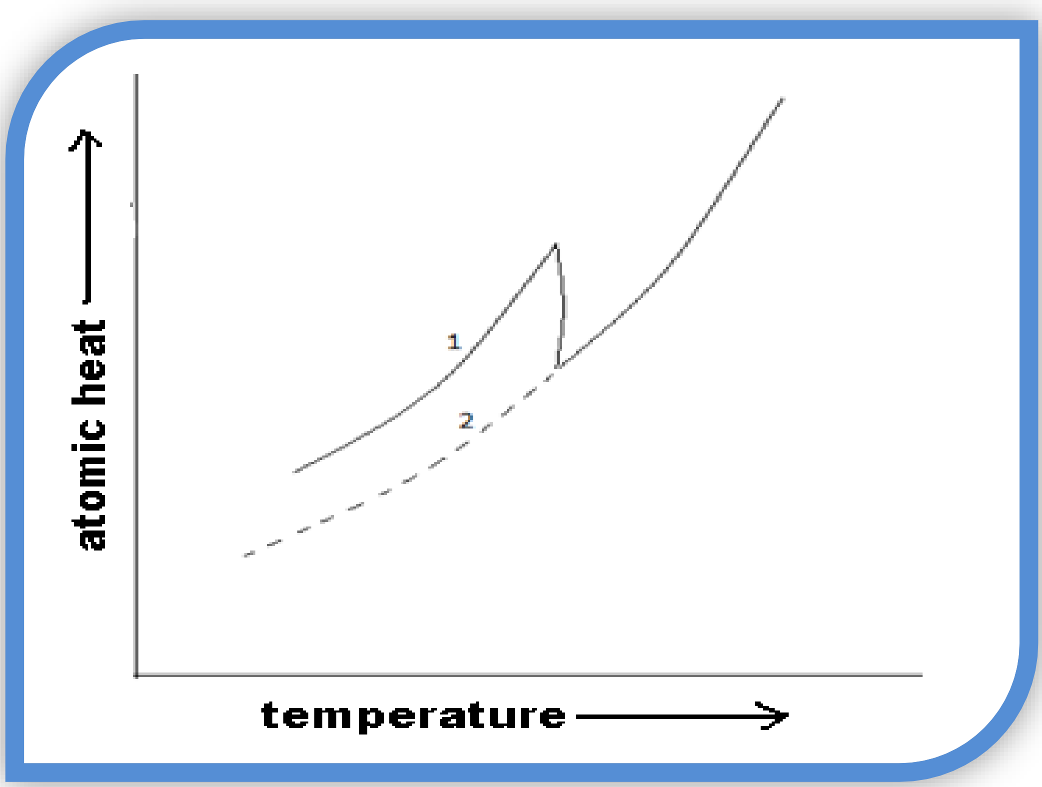
$Q -$ Latent heat of transition, $\rho =$ Density

$w_A -$ Atomic weight , $T =$ Temperature

$H_c -$ Bulk critical field.

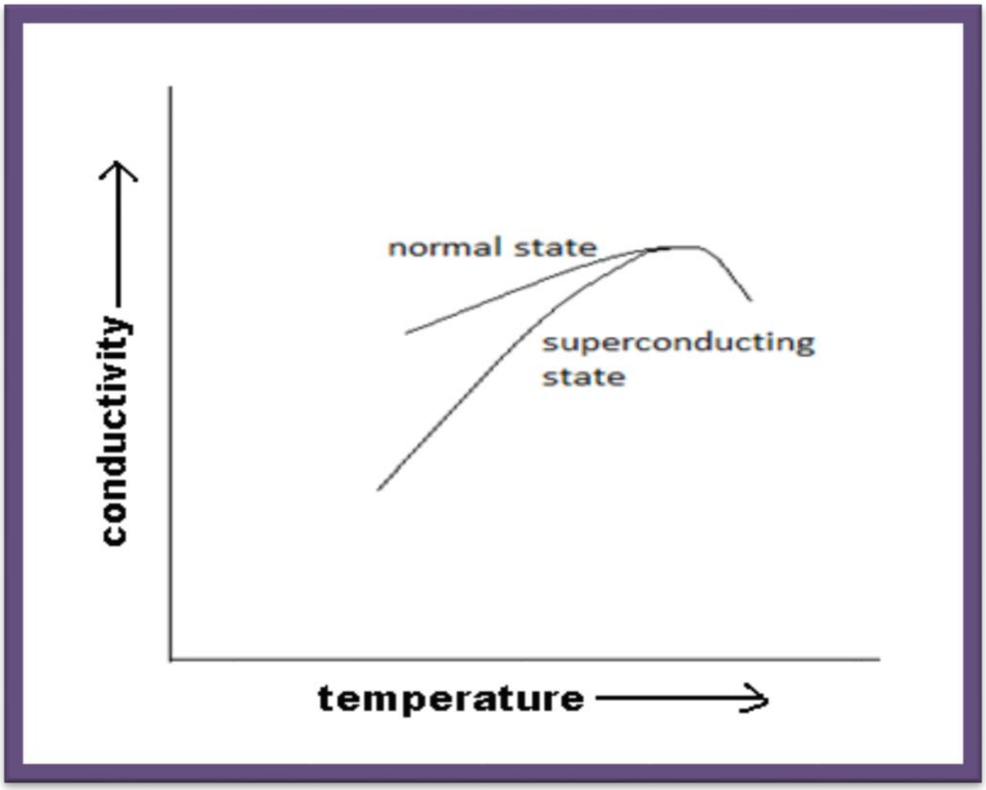
Since $H_c$ is 0 at $T_c$ , there is no latent heat of transition in the absence of magnetic field.

**2. <u>Specific Heat:</u>**




The specific heat of a superconductor is discontinuously higher just below $T_c$ .

3. **Thermal Conductivity :**




The thermal conductivity of superconductors undergoes a continuous change between the two phases and is usually lower in superconducting phase.

## Thermodynamics of Superconducting Transition

The thermodynamics of a superconducting transition in a magnetic field is perfectly analogous to that of any other phase transition. One may start with the fact that two phases are in equilibrium when their Gibb's free energies $G$ are equal.

The Gibb's free energy per unit volume in the magnetic field is given by-

$$G = U - TS - HM \qquad \text{...........(1)}$$

M- Magnetization

S- Entropy; the term $pV$ is neglected.

Since the internal energy density in the presence of a magnetic field from second law of Thermodynamics is

$$dU = TdS + HdM \qquad \text{.......... (2)}$$

which can be compared with the standard expression

$$dU = TdS - pdV \qquad \text{.......... (3)}$$

Thus it is clear from (2) and (3) that the substitution $p = -H$ and $V = M$ in the standard relation

$$G = U - TS - pV \qquad \text{……….. (4)}$$

gives expression (1).

Differentiating eq(1) we get

$$dG = dU - TdS - SdT - HdM - MdH$$

Substituting for $TdS + HdM$ from (2) we get

$$dG = dU - dU - SdT - MdH$$

$$dG = -SdT - MdH \qquad \text{……….. (5)}$$

Now substituting $M = -\frac{1}{4\pi}H$ and integrating eq (5) for the superconducting state we get

$$G_S(H) = G_S(0) + \frac{H^2}{8\pi}$$

Thus for volume V, the above relation becomes

$$G_S(H) = G_S(0) + \frac{H^2 V}{8\pi}$$

$G_S(0)$ - Gibb’s free energy in absence of magnetic field.

In normal state the susceptibility is generally vanishingly small

$$G_n(H) = G_n(0)$$

But the condition of equilibrium at critical field

$$G_n(H_C) = G_n(0) = G_S(H_C)$$

Then we have,

$$\boxed{G_n(0) - G_S(0) = \frac{{H_c}^2 V}{8\pi}} \qquad \text{............. (6)}$$

This is the basic equation as obtained by Gorter and Casimir.

As, $S = -(\frac{\partial G}{\partial T})_{p,H}$, differentiating (6) yields

$$S_n(0) - S_s(0) = -\frac{VH_c}{4\pi} \cdot \frac{dH_c}{dT} \qquad \text{............. (7)}$$

At $T = T_c;\ H_c = 0 \quad \therefore \quad S_n = S_s$

At any lower temperature,

$H_c > 0$ and $\frac{dH_c}{dT} < 0$ ; $S_S < S_n$

Thus, the entropies of two phases are equal at the critical temperature in zero field. But at any lower temperature the entropy of superconducting phase is less than the normal ones indicating that superconducting state is the state of higher order.