SUPERCONDUCTING MATERIALS

III – REGULAR

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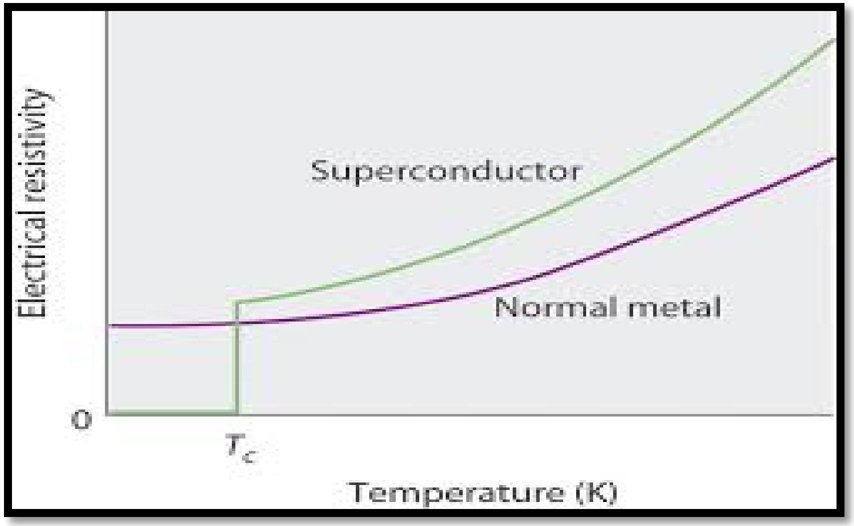
SUPERCONDUCTORS

Substances having zero electric resistance.

Superconductivity first observed by Kamerlingh Onnes (1911).

Theoretical explanation – Bardeen, Cooper & Schrieffer (1957).

BCS Theory



Transition temperature or Critical temperature Tc

Temperature at which resistivity of material suddenly changes to zero (Superconductors).

T_c varies for different materials (metals , semiconductors etc).

At T_c following changes are observed in a material

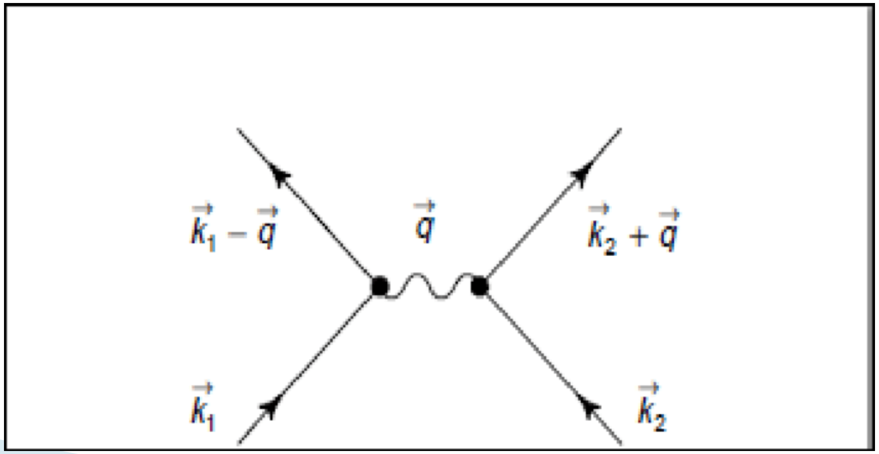
1) Electric resistivity drops to zero.
2) Magnetic flux lines are excluded from the material.
3) There is a discontinuous change in specific heat.
4) Small changes in thermal conductivity and volume of material.

Explanation for the occurrence of superconductivity

1. At extremely low temperatures – vibration of the nuclei of certain atoms slow down so much and synchronise with flowing electrons (current) and resistance completely disappears.

2. **BCS Theory** - Superconductivity occurs when cooper pair of electrons are formed.

Cooper pair electrons - Electrons with opposite spin and momentum form a pair through electron-electron interaction via lattice deformation or phonon field.



3. **RVB Theory** - Resonating Valence Bond Theory by American physicist P.W. Anderson and Indian theoretical physicist Ganapathy Bhaskaran in 1987

Explains superconductivity at higher temperatures $T_c = 80K$.

Based on the idea that short range repulsion between electrons in a narrow band gives rise to superconductivity .

But electron pair can exist in ordinary materials too, hence the material has to be doped to create holes which form pair and undergo Bose Condensation, making superconductivity possible!

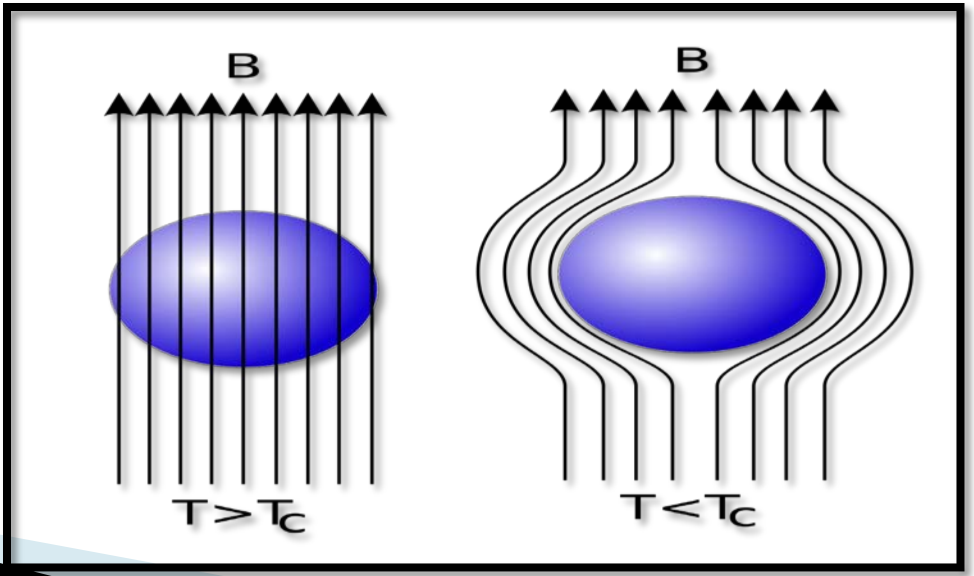
High temperature superconductors are called p-type superconductors since charge carriers are holes.

Recently n-type superconductors are invented with $T_c = 20K$

General properties of superconductors.

1. **Electrical resistance** – At T_c resistivity drops to zero, experimentally proved by Dr. Collins.

2. **Diamagnetic property -** The superconductor is a perfect diamagnet, when it is placed in an uniform magnetic field and cooled below T_c, the magnetic flux inside the material is excluded. This effect is called the MEISSNER EFFECT.



Thus a material can behave as a superconductor only when

i. The resistivity of material is zero and

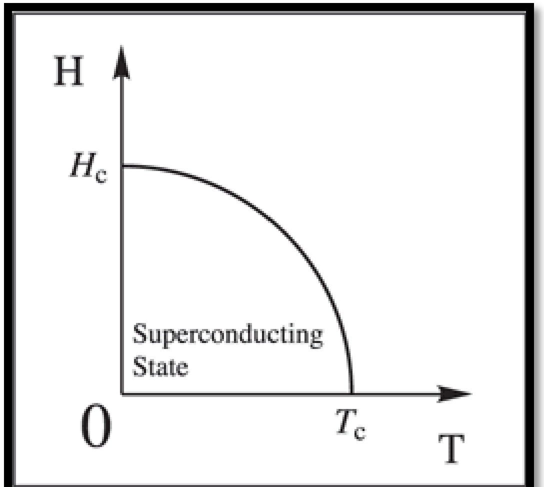
ii. The magnetic induction of the material is completely excluded when placed in an uniform magnetic field.

Both these 2 conditions should exist simultaneously.

3. **Effect of magnetic field -** Superconductivity will be destroyed on application of strong magnetic field below T_c .

Minimum field required to destroy superconductivity is called critical field (H_c). Value of H_c depends on temperature and is given by

$$H_c = H_o\left[1 - T^2 / T_c^2\right]$$



4. **Effect of heavy current –** Superconducting properties of conductors disappear.

According to Silsbee's rule for superconducting wire

$$\mathbf{I_c = 2\pi\ r\ H_c}$$

5. **Effect of heavy current –** If we increase the pressure T_c also increases.

T_c Reaches room temperature.

6. **Isotope effect –** Maxwell found that transition temperatures are inversely proportional to the square roots of the atomic weights of isotopes of single superconductor.

$$\mathbf{M^{\alpha}\ T_c = a\ (constant)}$$

α – constant approximately equal to 0.5

Other general observations.

1. The value of the transition temperature of the material is a function of the position of the material in the periodic table.
2. Generally good electric conductors are not good superconductors (Cu, Au). At the same time good superconducting materials are not good conductors at room temperature (Zn, Pb).
3. The thermal conductivity of superconductor has marked drop in its value. This shows that superconducting electrons play no role in heat transfer.
4. Generally monovalent metals (Cu, Ag, Au), ferromagnetic metals (Fe, Co, Ni) and antiferromagnetic metals (CoO, NiO) are not good superconductors.

5. Below T_c the specific heat of the SC increases discontinuously. For example above the specific heat of Tin is about 0.191 J/kg/K. But below , the specific heat of Tin is about 0.274 J/kg/K.
6. Keeping temperature as constant , when the superconducting property of a superconductor is destroyed by a magnetic field, the superconductor absorbs heat. Meanwhile magnetic field becomes zero, the superconductor regains its superconducting property by giving out latent heat of transition.
7. The superconducting property of a material is a function of its crystal structure. For ex white Tin is tetragonal crystal in structure and is a superconductor. But the grey cube Tin is not a superconductor. Similarly Berylliumm will become a superconductor when it is in the form of thin film. Whereas Bismuth will become a superconductor when it is in bulk form and simultaneously pressure should be applied on it.


Thank you