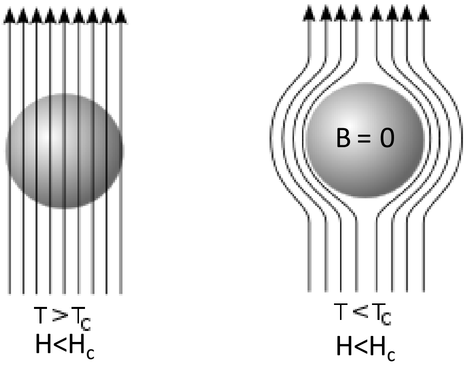
SUPERCONDUCTIVITY

The property by which resistivity of many metals and alloys suddenly falls to zero when they are cooled below a critical temperature is called superconductivity.

Transition temperature or critical temperature is the temperature at which resistivity of the superconducting material suddenly falls to zero and becomes a superconductor.

MEISSNER EFFECT

The sudden and complete expulsion of magnetic field from the interior of superconductor when it is cooled below critical temperature is called Meissner effect.



Magnetic induction $B = \mu_0 [H+M]$

where M-magnetisation

H – Applied magnetic field

Since B=0 inside superconductor

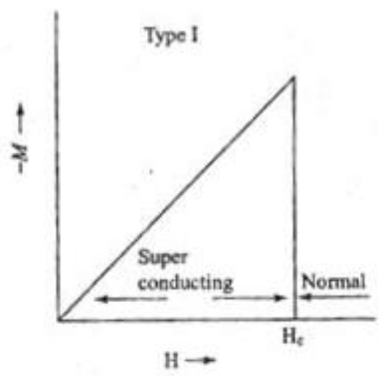
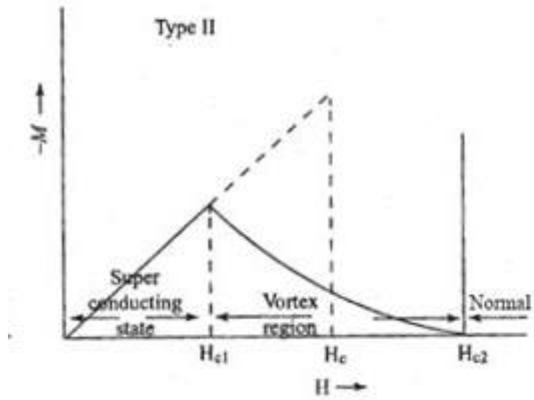
$0 = \mu_0 [H+M]$

$H = -M$

Magnetic susceptibility $\chi = M/H = -1$.

It shows that superconductor is a perfect diamagnet.

COMPARISON OF TYPES OF SUPER CONDUCTORS

Type I Superconductor	Type II Superconductor
	
They are called soft superconductors	They are called hard superconductors
Exhibit complete Meissner effect	Do not exhibit complete Meissner effect
Transition from super conducting to normal state is abrupt	Transition from super conducting to normal state is gradual
No mixed state	Mixed state is present
Only one critical magnetic field exist	Two critical magnetic field exist.
Critical magnetic field is very small (~0.1 Tesla)	Critical magnetic field is high (~ 100 Tesla)
Ex: Lead, Tin,Mercury	Ex: Nb_3Ge, Nb_3Si

CHARACTERISTICS OF SUPERCONDUCTORS

The superconducting state is defined by three very important factors: critical temperature (T_c), critical field (H_c), and critical current density (J_c). Each of these parameters is very dependent on the other two properties present.

1. Critical Temperature (T_c)

It is the highest temperature at which superconductivity occurs in a material. Below this transition temperature Tc, the resistivity of the material is equal to zero.

2. Critical Magnetic field (H_c)

It is the value of externally applied magnetic field above which a superconductor becomes normal conductor.

3. Critical Current Density (J_c)

The maximum value of electrical current per unit of cross-sectional area, which a superconductor can carry without resistance. If the current density is increased above Critical Current Density, the magnetic field due to current flowing through superconductor will exceed the critical magnetic field H_c, and superconductivity will be destroyed.

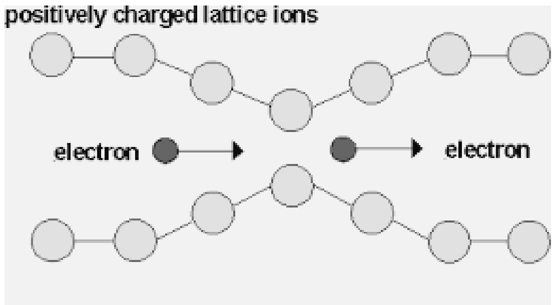
PROPERTIES OF SUPERCONDUCTORS

1. Zero electrical resistance
2. The current in the superconductors is sustained for a very long period.
3. When the current is increased above its critical value, the superconductor behaves like a normal conductor.
4. The magnetic field does not penetrate the superconductor (Meissner effect). However, above the critical magnetic field, the superconductor becomes a normal conductor.
5. In general, good conductors at room temperature are not super conductors and superconducting materials are not good conductors at room temperature.
6. Superconductors exhibit perfect diamagnetism.

BCS THEORY

In superconducting material a finite fraction of electrons forma super fluid (cooper pair).

Consider an electron moving through the array of lattice (ions). The electrons deform the lattice and this distorted lattice attracts another electron. The pair of electron formed by the interaction between two electrons of opposite spin through lattice vibrations (or phonons) is called Cooper pair.

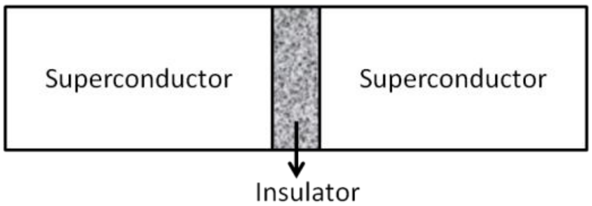


Cooper pair moving through lattice

Cooper pair are bosons and hence many cooper pairs can coexist at same energy level. In super conducting state, cooper pair forms a condensate and they drift collectively through the material with the same velocity. The small velocity of cooper pairs combined with precise ordering minimises collision and leads to vanishing resistivity.

JOSEPHSON JUNCTION

Junction formed by a thin layer of insulator sandwiched between two superconductors is known as Josephson junction.



DC Josephson Effect

A direct current flows through Josephson junction without any applied voltage is known as DC Josephson effect. The current is caused by the quantum mechanical tunnelling of cooper pair.

d.c. current $I = I_m \sin\phi$

where I_m is the maximum current

ϕ is the phase difference of wave functions on either side of the barrier

AC Josephson Effect

When a DC voltage is applied, an AC current will flow across the Josephson junction and this is known as AC Josephson effect.

A.C. current; $I = I_m \text{Sin}\ \{\phi + \frac{2eVt}{\hbar}\}$

Where V is the applied voltage

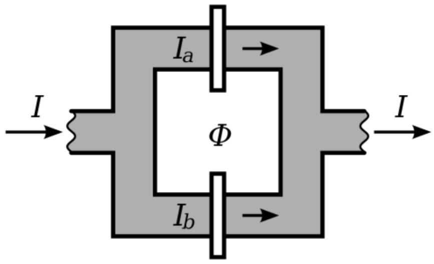
Angular Frequency $\omega = \frac{2eV}{\hbar}$

Frequency $\nu = \frac{2eV}{h}$

Josephson junction acts as a perfect voltage to frequency converter.

SQUID: Superconducting Quantum Interference Device

SQUID is a very sensitive instrument for measuring even small change in magnetic field. It consists of two Josephson junctions connected in parallel in a superconducting loop. Quantum interference takes place when current with different phases are superimposed (interference of wave functions of cooper pairs)



Applications

1. To measure magnetic fields of the order of 10^{-14} Tesla
2. To detect small disturbances in earth's magnetic field
3. In MRI
4. To study gravitons and magnetic monopoles
5. Non Destructive Evolution (NDE)of materials and structures
6. Microscopes for imaging local magnetic fields

HIGH TEMPERATURE SUPERCONDUCTORS (HTS)

High temperature superconductors are ceramic superconductors with high transition temperatures, typically greater than 40k. In2006 – Mercury Thalium Barium Calcium Copper Oxide was found to have a critical temperature of 138K. In 2015, Sulphur hydride (H_2S) under extremely high pressure (around 150gigapascals) was found to undergo superconducting transition near 203K(-70 °C). All known HTS are type-II superconductors only. BCS theory predicts transition temperature only up to 40k and fails to explain high temperature superconductivity. One of the leading theories to HTS is Resonating Valance Band State theory.

APPLICATIONS OF SUPERCONDUCTIVITY

1. Superconductors are used to produce very powerful magnetic fields of the order of 20Tesla & used in
   i. particle accelerators
   ii. magnetic levitation
2. Used for magnetic flux concentration, magnetic shielding and energy storage.
3. Medical Field: MRI
4. SQUIDS are used in;
   i. Mineral explorations & earth quake prediction
   ii. Non Destructive Evolution (NDE)of materials and structures
   iii. Microscopes for imaging local magnetic fields
5. In supercomputers for performing logic operations and storage (fast digital circuits)
6. Small size generators
7. RF and microwave filters (e.g., for mobile phone base stations)
8. Fast fault current limiters