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Conductive Materials

Electrical Conductivity

A very important electrical property of a material is its resistivity.

$$\boxed{R = \rho . \frac{l}{A}}$$

Electrical resistivity is reciprocal of electrical conductivity and denotes by σ

Where, R = Resistance of conductor, Ω

ρ = Resistivity of the material, Ω-m

l = Length of conductor, m

A = Area of cross section, m^2

σ = Conductivity of material Ω^{-1}-m^{-1}.

Ohm's Law

$$\boxed{J = \sigma E = \frac{I}{A}} \; A / m^2 \; \ldots \text{ Point form}$$

J = current density, A/m^2

σ = conductivity of material, Ω^{-1}-m^{-1}

E = Applied electric field, v/m

I = current, A

Joule's Law

Volume density of heat developed per second

$$\boxed{W = \sigma E^2 = JE} \; \text{Watts} / m^3$$

Remember:

This is the energy which the electrons transfer to the lattice in the collision process and is converted into heat.

Mobility and Conductivity

It is the magnitude of the average drift velocity per unit field.

$$\boxed{\mu_e = \frac{e\tau_c}{m}} \quad \text{also} \quad \boxed{\sigma = \frac{ne^2\tau_c}{m}}$$

Mobility and conductivity have the relation

$$\boxed{\sigma = ne\mu_e}$$

Where, n = Number of electrons per unit volume,
τ_c = collision time, sec
e = charge of electron
m = mass of electron
μ_e = mobility of electron, $m^2\ volt^{-1}\ sec^{-1}$

Drift Velocity of Electron

This velocity is associated with the electric field and is called drift velocity (V_d)

$$\boxed{V_d = \frac{e\tau_c E}{m} = \mu_e E}\ m/sec$$

Mean Free Path (d)

It is average distance travelled by electron before the collision takes place

$$\boxed{d = V\tau_c}$$

Where, V = Average electron velocity

Velocity of an electron

$$\boxed{V_p = \sqrt{\frac{2E_F}{m}}}$$

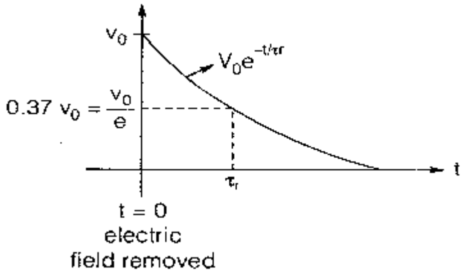
Where, E_F = Fermi energy

Note:

At absolute zero, all energy levels below a certain value E_F are filled, and all those above E_F being empty: E_F is the Fermi level of electron.

Relaxation time (τ_r)

It is defined as, the time at which the drift velocity of electrons reduces to 37% of its initial value after the removal of the field.



Note:

For isotropic materials, the mean time of collision is the same as the relaxation time.

Mean free path at Fermi level:

$$\boxed{d_F = \tau_c\sqrt{\frac{2E_F}{m}}}$$

Thermal conductivity

- Flux of thermal energy

$$\boxed{Q = -K\left(\frac{dT}{dx}\right)}\ \text{Watts/m}^2$$

where, K = Thermal conductivity, Watts/m°C
$\frac{dT}{dx}$ = Temperature gradient, °C/m

- Thermal conductivity

$$\boxed{K = \frac{1}{3}\frac{n\pi^2k^2\tau T}{m}}\ \text{Watt/mK}$$

where n = Number of conduction electrons per m^3
T = Temperature
K = Boltzmann's constant

Note:

τ varies as T^{-1} above Debye temperature.

Super Conductors

In the state of super conductivity material exhibit zero resistivity and perfect diamagnetism.

Super conductivity appears at low temperature and in a magnetic lower than a particular level.

Example: Hg, Pb, Zn, PbAu, $PbTL_2$, ZrC, CuS

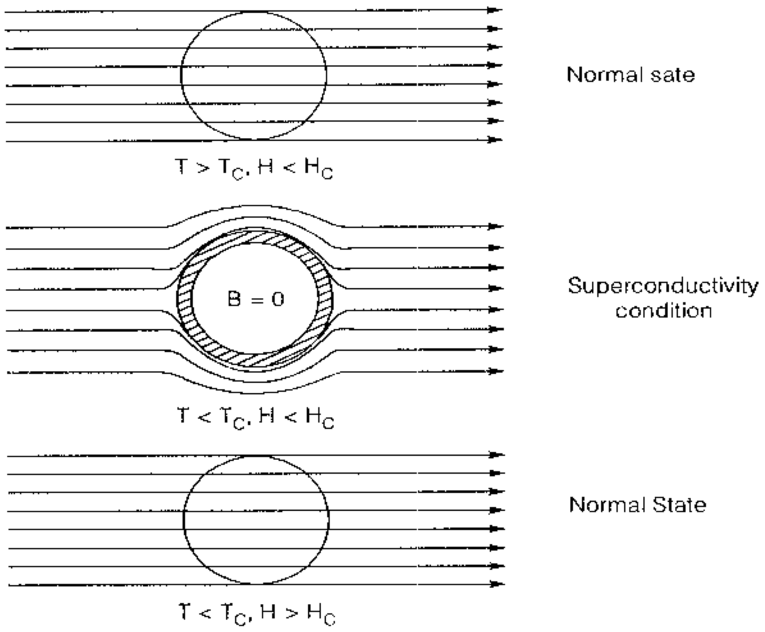
Transition temperature (T_c)

The critical temperature (T_c) is the temperature at which there is change of state from normal to super conducting and vice-versa is known as transition temperature.

Meissner's Effect

Magnetic susceptibility in a super conductor is negative. This is referred to as perfect diamagnetism. This phenomenon is called Meissner effect.

Flux lines in a sphere under different conditions of temperature and field

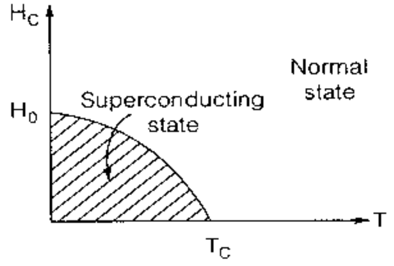


Critical Field (H_C)

It is possible to destroy superconductivity by the application of sufficiently strong magnetic field.

$$\boxed{H_C = H_0\left[1-\left(\frac{T}{T_C}\right)^2\right]}$$

where, H_0 = Critical field at absolute zero temperature
H_C = Critical field at any temperature T
T_C = Transition temperature



Silsbee's Rule

In a long superconductor wire of radius R, the superconductivity may be destroyed when a current I exceeds the critical current value I_C

$$\boxed{I_C = 2\pi RH_C}$$

Factors Affecting the Super Conductivity

1. **Frequency effect**

   When frequency increases above 10^{13} Hz (infrared region); material loses its super conductivity.

2. **Entropy effect**

   Increase in entropy results in, change in state from super conducting to normal.

3. **Isotope Effect**

   It has been observed that the critical temperature of a super conductor varies with isotopic mass as

$$\boxed{T_C \propto \frac{1}{\sqrt{M}}}$$

where M is the mass of isotope

Types of Super Conductors

Type-I

- It is an ideal super conductor; also called soft super conductor.
- Their critical field and transition temperature values are low.
- They exhibits almost complete Meissner effect and Silsbee's rule.
- The change in state from normal to super conducting is abrupt.

  Example: Th, Pd, Pb, V, Hg etc.

Type-II

- It is a non-ideal super conductor; also called hard super conductor.
- Their critical field and transition temperature values are high.
- They exhibits incomplete Meissner effect and Silsbee's rule.
- The change in state from normal to super conducting is gradual.

  Example: Nb_3Sn.

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