Physics –II

UNIT – 4 (Part-III)

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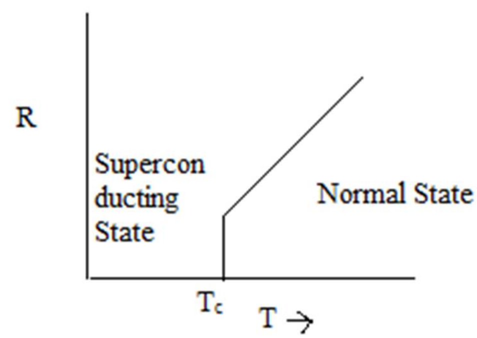
Superconductivity

The phenomenon in which a substance losses its all electrical resistance is known as superconductivity and the conductors having the property of superconductivity (i.e. having no resistance at all) are known as superconductors. Superconductivity was discovered by Heike Kamerlingh Onnes in 1911. Tthe temperature at which the material losses its all electrical



resistance is known as critical temperature or transition temperature (Tc).

The phenomenon of superconductivity was first time explained by using free electron model According to free electron model the resistivity of conductor is defined as:

$$\rho = \frac{m}{ne^2\tau}$$

where, m is mass of the electron, n is number of electron, e is the charge of electron& τ is collision time (time between two successive collision)

As the temperature of the sample is decreased the amplitude of lattice vibration is decreased as a result of which the collision time τ is increased. At sufficiently low temperature lattice vibration ceases. As a result of which collision time become infinity and thus ρ become zero i.e. it isin a a superconducting state. In this way free electron model explains the zero resistivity as superconductivity.

Properties of Superconductors:

1. At room temperature the resistivity of superconductor is very high.
2. Addition of impurity decreases the critical temperature of superconductor.
3. **Isotope Effect**: Critical temperature varies with isotopic mass as given below

    M^{α} Tc = constant , usually $\alpha = 0.5$ and thus

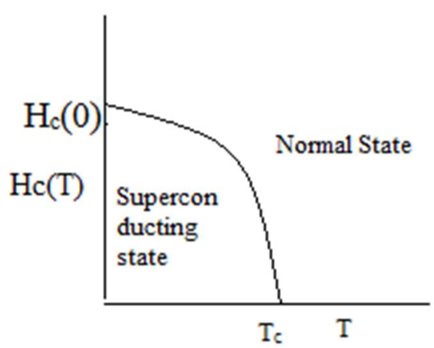
    $Tc \propto 1/\sqrt{M}$
4. There is no change in crystal structure.
5. Thermal expansion and elastic property do not change
6. Thermoelectric effect disappear.
7. Thermal properties like specific heat, entropy changes abruptly.

Persistent Current: If a superconductor is taken in form of a ring and current is induced in it by electromagnetic induction then such current flows for a very long time which is known as persistent current.

Destruction of superconductivity by magnetic field

If superconducting material kept (T<Tc) in a variable magnetic field and magnetic field is increased then there will be a highest magnetic field known as critical magnetic field at which the property of superconductivity is destroyed and material is converted into normal conductor. The critical magnetic field varies with temperature by the following relation (variation can be shown as below):-

$$H_c(T)=H_c(0)[1-(T/T_c)^2]$$



Cases: (1) If T = Tc Then

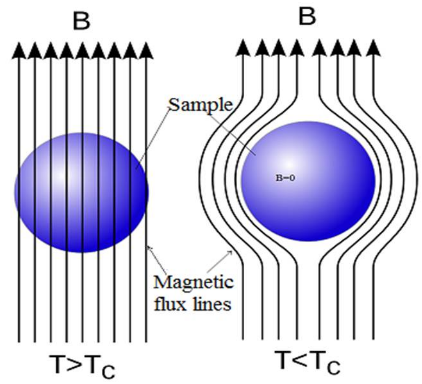
Hc (T)=0 i.e. the required magnetic field is zero.

(2) If T =0 K then

Hc(T) =Hc(0) i.e. it is the highest magnetic field.

Meissner Effect:-

In1933 Walther Meissner and Robert Ochsenfeld discovered this phenomenon. They found that if a superconductor is kept in a constant magnetic field and is cooled then at critical temperature all the magnetic flux line are pushed out from the sample. Thus expulsion of magnetic flux lines from the interior of a piece of superconducting material as it undergoes transition to superconducting phase is known as Meissner effect.



Inside the superconductor magnetic field **(B)** is zero i.e.

$$\mathbf{B}=0 \qquad \qquad \text{................(1)}$$

But $\mathbf{B}=\mu(\mathbf{H}+\mathbf{M})=0$

Where, H is magnetic field intensity and M is magnetization

or $\mathbf{B}=\mu(\mathbf{H}+\chi\mathbf{H})=0$ [$\because$**M=** χ**H** & χ is magnetic susceptibility]

or $1+\chi=0$

or $\chi=-1$ ....(2)

Thus, superconductors are diamagnetic in nature.

We know that Electric field (E) is given by

$$\mathbf{E}=\rho\,\mathbf{J} \qquad \qquad \text{.................(3)}$$

Where, ρ is resistivity and **J** is current density. In case of superconductor resistivity is zero i.e. $\rho=0$

So from equation (3) $\mathbf{E} = 0$ ……………(4)

According to Maxwell's third equation

$$\frac{\partial \boldsymbol{B}}{\partial T} = -\nabla \times \mathbf{E}$$

Since **E**=0 from equation(4); therefore, $\partial \mathbf{B}/\partial t = 0$

$\Longrightarrow$ **B=** constant i.e there is a constant magnetic field inside the sample.

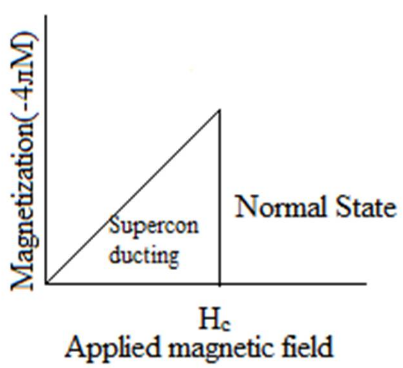
which contradict the Meissner Effect (because **B**=0 inside the sample) . Thus, it is clear that **zero resistivity & perfect diamagnetism** are two **independent** and **essential** properties of superconductors.

Types of superconductors:

On the basis of magnetization behaviour, superconductors are of two types:

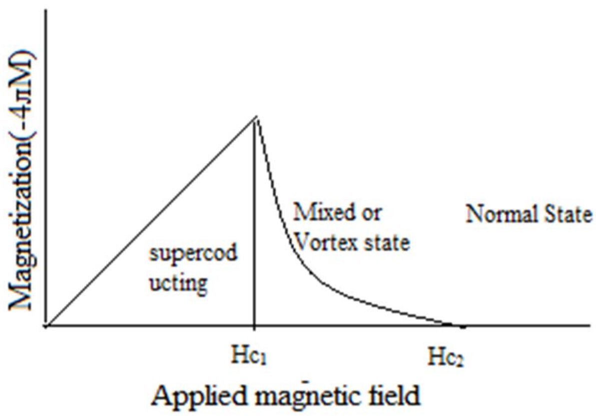
1. Type-I or Soft superconductors
2. Type-II or Hard superconductors

Type-1 or Soft Superconductors: In this type of superconductor magnetic field is totally excluded from the interior of superconductor. They show the Meissner effect in full i.e. no flux lines penetrate the sample. The magnetization behavior of Type-1 superconductor is as shown below.



Below Hc no flux line penetrates the sample but after Hc material is converted into normal state. They are also known as Pure Superconductor. Examples of type-1 superconductor are Lead, Tin, and Mercury. Since the value of Hc is nearly 0.1 Tesla (low) that is why such type of superconductors are also known as Soft superconductors.

Type-2 or Hard superconductors: These types of superconductors are characterized by two critical magnetic fields Hc_1 and Hc_2. Below Hc_1, no flux line penetrates the sample. Between Hc_1 and Hc_2 superconductor are in mixed as vortex state. In mixed or vortex state some flux lines penetrate the sample & some flux lines are repelled by the sample. This type of superconductor shows the Meissner effect partially. The magnetization behaviour of Type-2 superconductors are as shown below.



Transition metal & alloys are the example of type-2 superconductor since, the value of Hc_2 is nearly 50 Tesla (very high), therefore, such type of superconductor are also known as Hard superconductors.

Theory of superconductivity

Two theories were proposed to explain the Superconductivity:

1. London Theory
2. BCS Theory

BCS THEORY:-

This theory was discovered by John Bardeen, Leon N. Cooper and R. Schrieffer in 1957. According to this theory, as an electron approaches a lattice, it is deformed. Another electron is got attracted by this deformed lattice. Two types of energy comes in existence known as interaction energy between lattice and electron and repulsion energy between the two electrons. At low temperature it is found that the value of interaction energy is greater than the repulsion energy. As a result of which being repulsion two electrons are bound with each other and form a pair known as Cooper pair. This cooper pair maintained the coupled motion up to a certain distance in the crystal known as Coherence Length. The cooper pair has a binding energy which is known as **Energy Gap** & this binding energy is 0 K is defined as :

$$Eg = 3.5\ KT_c$$

Where, K is Boltzmann constant and T_c is critical temperature.

This cooper pair has a special property of smoothly sailing over the lattice point without any energy exchange i.e. cooper pairs are not scattered by the lattice point. Hence no transfer of energy takes place from the electron pair to the lattice ion. If an electric field is established inside the substance then electrons gain additional kinetic energy and gives rise to current but they do not transfer their energy to the lattice. So, they do not get slowed down as a consequence of this, this substance does not possess any electric resistance. In this way BCS theory explain the zero resistivity of superconductors.

Application:

1. Superconductors are used as storage of electrical energy as well as in transportation of electrical energy.
2. Superconductors are used in magnetic resonance imaging (MRI) & magnetic levitated trains (Maglev).
3. Superconductors are used in many switching devices.
4. Superconductors are used to measure very small current developed in heart & brain by using SQUID (Superconducting Quantum Interference Devices).
5. Superconductors are used in nuclear fusion etc.

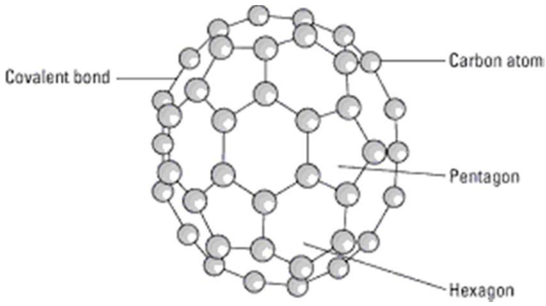
NANOTECHNOLOG

A technology in which materials are designed, fabricated, controlled and applied at nano scale [1-100 nm (1 nm=10^{-9}m)] is known as Nanotechnology. Here we will study only two nanomaterial:

1. Bucky Ball

2. Carbon Nano Tube

1. Bucky Ball: Bucky ball is an allotrope of carbon containing 60 carbon atoms. Bucky Ball was discovered by Richard Smalley, Robert Curl and Harold Kroto in 1985. The name Bucky ball was derived from the famous American architect Buck Minster Fuller who designed the famous geodesic domes. Actually Bucky ball is a truncated icosahedron (a structure having 20 faces) containing 60 carbon atoms at vertices. Bucky ball structure have 12 pentagon surrounded by hexagon (20 in all).



Bucky balls are created by arc discharge of graphite electrodes in the atmosphere of Helium gas. When the vapours are condensed on the wall of water bath then Bucky balls are created.

APPLICATIONS OF BUCKY BALL:-

- Bucky balls are used as a lubricant.
- Because of its cage like structure Bucky balls are used in drug delivery.

Bucky balls are used to encounter the free radicals present in human body

2. Carbon Nano Tube (CNT):

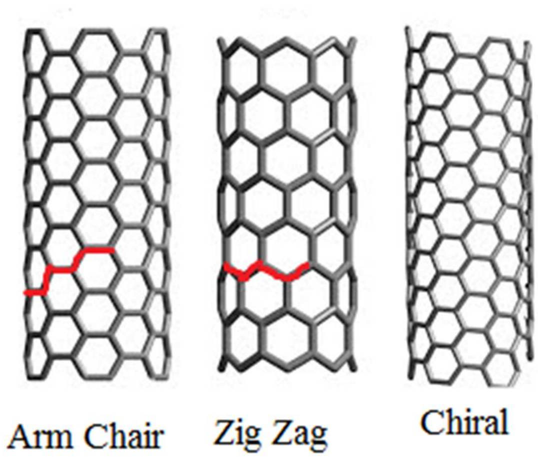
When one atom thick sheet of graphite known as graphene is wrapped (rolled) in form of a seamless cylinder then it is known as Carbon Nano Tube. Carbon Nano Tube was discovered by 'Sumio Iijima' in 1991. On the basis of lattice orientation Carbon nano tube have generally 3-types of structure

1. Arm chair ($n=m$, $\theta = 30^0$)
2. Zig Zag ($m=0$, $\theta = 0^0$)
3. Chiral ($m \neq n, 0^0 < \theta < 30^0$)

1. Arm chair: In this nano-material there is a line of hexagone parallel to the axis of the tube .($n=m$, $\theta = 30^0$)

2. Zig Zag: In this structure there is a line of carbon bond from the center.(m or $n=0$, $\theta = 0^0$)

3. Chiral structure: This nano-tube exhibits a twist or spiral along the axis of tube ($m \neq n$, $0^0 < \theta < 30^0$)



ARC DISCHARGE:

Carbon nano-tube are created using arc discharge of graphite electrode in the atmosphere of helium (500 torr). Cobalt and nickel are mounted in the graphite electrode for the production of single small carbon nano tube. For the production of multi wall carbon nano tube (MWCNT) no catalyst like cobalt and nickel used.

APPLICATION OF CARBON NANO TUBE:-

1. In nano scale 100 time stronger than steel therefore carbon nano tube are used in sports wears, combat jacket and space elevator.
2. In carbon nano tube electrical & thermal conductivity are good along the axis ,therefore carbon nano tubes are used in solar cells
3. Carbon nano tubes are used in transistors.