(3) (1)

Superconductivity

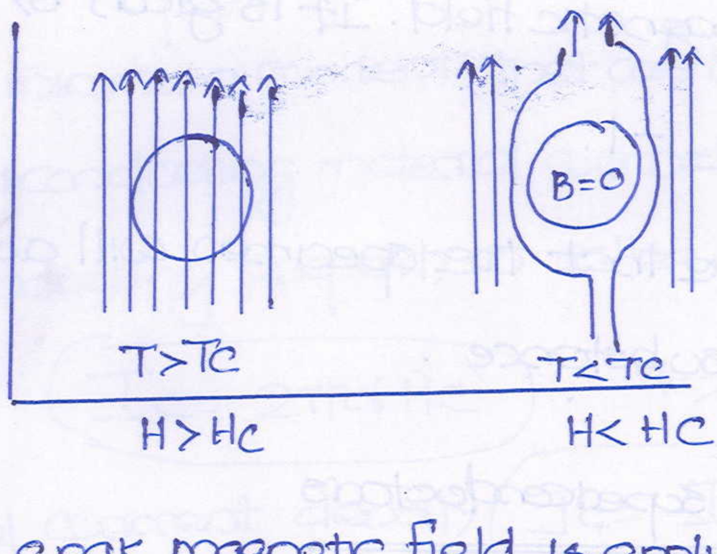
→ The property by which the resistivity of many metals and alloys suddenly falls to zero when they are cooled at particular temperature is called superconductivity.

→ The temperature at which resistivity of substances suddenly falls to zero are called Transition temperature

→ or It is the temperature at which the substance changes from superconducting state to Normal state and vice versa.

→ Transition temperature of Hg is 4.12K.

Meissner Effect



when a weak magnetic field is applied to a super conducting specimen at a temperature below transition transition temperature, the magnetic flux lines are expelled from the superconductor. The specimen then act as a diamagnetic substance. This effect is called Meissner Effect. Under this condition, if the temperature is raised, the magnetic lines starts penetrating and the normal state is retained.

The magnetic induction inside, the material is given by,

$$B = \mu_0 (H + M)$$

where H → Applied magnetic field

M → Intensity of magnetisation

According to Meissner effect $B = 0$

$$\Rightarrow \mu_0 (H + M) = 0$$

$$H + M = 0$$

$$M = -H$$

Susceptibility is the ratio b/w intensity of magnetisation and applied magnetic field. It is given by

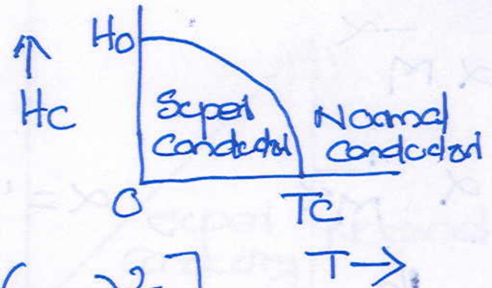
$$\chi = \frac{M}{H} = -1.$$

This will prove that the specimen will act as a diamagnetic substance.

<u>Properties of superconductors</u>

1) <u>Effect of magnetic field Hc:— (critical field Hc)</u>

→ The minimum strength of magnetic field required to destroy the superconducting nature of a metal at a particular temperature is called critical field Hc.



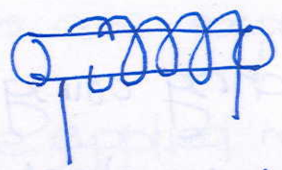
$$Hc = Ho\left[1-\left(T/Tc\right)^2\right]$$

Ho → Maximum critical mag. field at absolute zero Kelvin.

T → Temperature, Tc → Transition temperature.

Hc → critical magnetic field at temperature T Kelvin.

2) Effect of current density - critical current.



The minimum current that can be passed through a superconducting material without destroying the superconducting property is called critical current Ic.

$$Ic = 2\pi r Hc$$ r → radius of rod.

critical current density $$Jc = Ic/A$$

where A → Area of cross section of the solenoid

3) Isotope effect

It is found that transition temperature varies with isotopic Mass.

$$T_c \propto M^{-\alpha}$$

$$T_c \propto \frac{1}{M^{\alpha}} \quad , \alpha = 1/2$$

$$T_c M^{1/2} = \text{constant}$$

$$\boxed{T_{c_1} M_1^{1/2} = T_{c_2} M_2^{1/2}}$$

Example:- Transition temperature of Hg decreases from 4.185 to 4.146 when isotopic mass increases from 199.5 to 203.4 amu.

4) Persistent current

→ When a superconducting ring is placed in a magnetic field, due to electromagnetic induction a current flows through it.

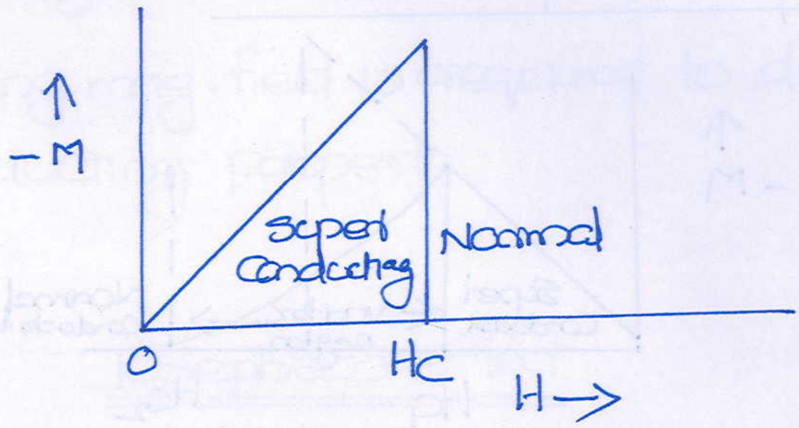
→ When it is cooled below Tc and magnetic field is removed, the current persists for long time.

→ This ~~phe~~ current is called persistent current

→ It is applied in the case of Magnetic levitation or Maglev trains.

Type of superconductors.

Type I / Soft superconductors.



→ Consider a superconducting material is placed in a magnetic field H, the intensity of magnetisation M is induced in it.

→ When H increases M also increases. ie, the relation b/w M & H is linear. (M = −H). ie, magnetic flux lines are expelled from the sup specimen.

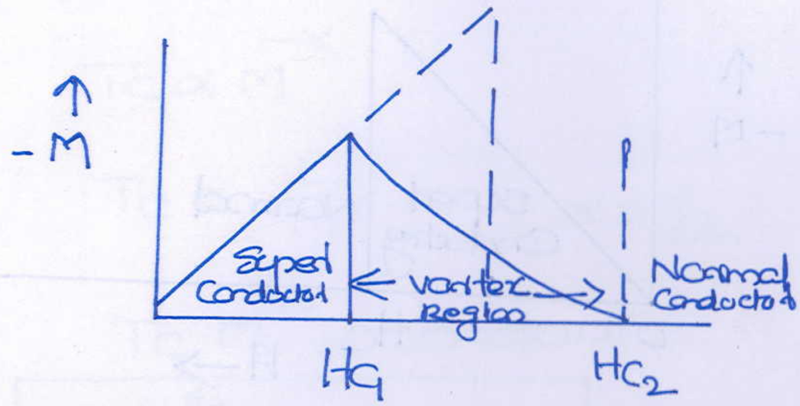
→ When the applied magnetic field reaches a particular value Hc, the intensity of magnetisation drops suddenly to zero. At this stage complete penetration of magnetic flux lines take place. Above Hc the substance acts as a normal conductor.

Properties :-

1. Transition to normal state is abrupt
2. Hc is small of the order of 0.1 T

③ superconductivity can be easily destroyed.

Type II / Hard superconductors.



→ In this case when H increases M also increases.

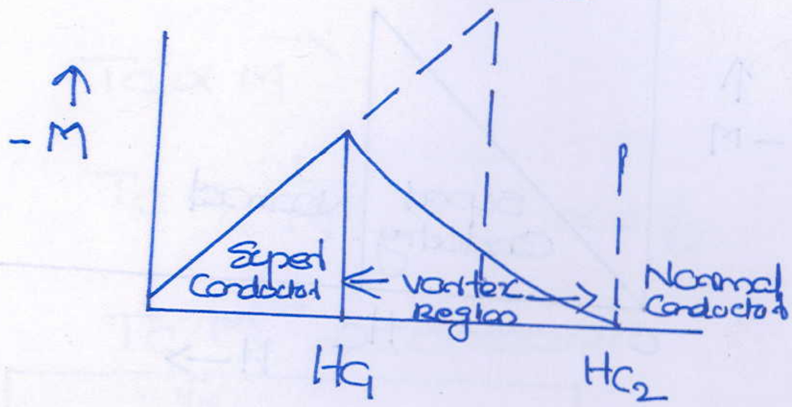
→ Up to H_{C_1} the substance acts as superconductor. magnetic flux lines are expelled from the body of specimen. The relation between M and H is linear.

→ Between H_{C_1} & H_{C_2} the region is called Vortex region. ie, magnetic flux lines starts penetrating. ie, substance is in an intermediate state between superconductor & Normal conductor. when H increases M starts decreasing gradually.

→ Beyond H_{C_2} complete penetration of magnetic flux lines takes place. The substance acts as a normal conductor.

③ superconductivity can be easily destroyed.

Type II / Hard superconductors.



→ In this case when H increases M also increases.

→ up to Hc_1 the substance acts as superconductor. magnetic flux lines are expelled from the body of specimen. The relation between M and H is linear.

→ Between Hc_1 & Hc_2 the region is called Vortex region. ie, magnetic flux lines starts penetrating. ie, substance is in an intermediate state between superconductor & Normal conductor. When H increases M starts decreasing gradually.

→ Beyond Hc_2 complete penetration of magnetic flux lines takes place. The substance acts as a normal conductor.

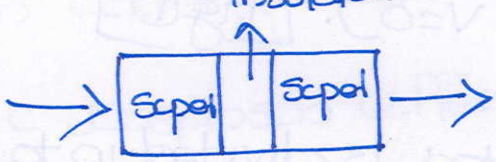
Properties

1) Transition to normal state is gradual.

2) Hc is very high in the order of 10T to 20T

3) Very strong mag. field is required to destroy superconducting property.

Josephson effect



→ When an insulating material (1 to 10nm) is placed in between two superconducting materials, the arrangement is called Josephson arrangement. The junctions are called Josephson junction or weak link.

→ There are two types of Josephson effect
1) dc Josephson effect 2) A.C Josephson effect.

DC Josephson effect

Fig 1

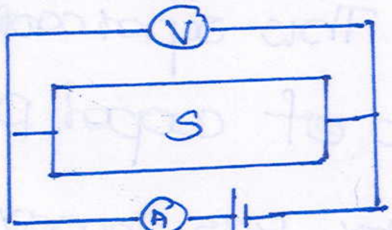
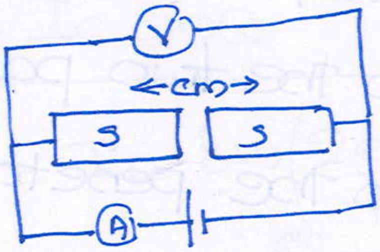


Fig 2



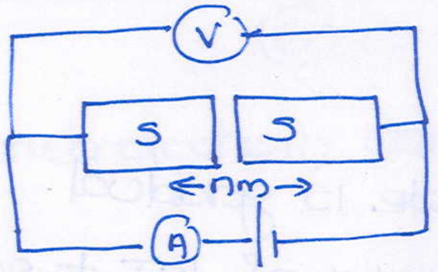


Fig 3.

→ consider a super conducting material is ~~placed~~ connected ~~in series~~ with an ammeter, voltmeter and a cell. The voltmeter shows zero (0V) since there is no voltage drop across the superconductor. (V=IR, R=0, ie, V=0). [Fig①]

→ The superconductor is divided into two part and kept a distance of centimetres. Then the voltmeter shows a reading equal to the open circuit voltage of the cell. [Fig②]

→ When the distance between the two super-conducting part are reduced in terms of nano-meters, again the voltmeter shows a zero reading. [Fig③]

→ It indicates that a supercurrent flows through the two parts. This supercurrent is due to the penetration of cooper pair of electrons. It is explained by BCS theory.

"The flow of super current through a thin insulator separated by superconducting parts even without applying any potential difference is called d.c Josephson effect".

A.C Josephson effect

When a dc voltage is applied across a Josephson arrangement a.c is produced. It is called A.C Josephson effect.

When a voltage 'V' is applied, The energy of cooper pairs is given by

$$E = 2eV \quad \text{—} (1)$$

But $E = h\nu$

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

But $\theta = \omega t = 2\pi\nu t = 2\pi \cdot \frac{2eV}{h} t$

$$= \frac{2eV}{\hbar} t$$

$\boxed{\hbar = h/2\pi}$

Super current $I_s = I_c \sin\theta$

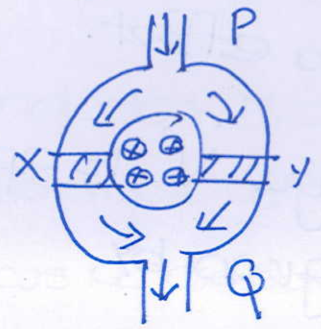
ie, $\boxed{I_s = I_c \sin\left(\frac{2eV}{\hbar}\right) t}$

SQUID - Superconducting Quantum Inter… Device.

→ Expansion of SQUID is superconducting quantum interference device.

→ It is used for finding small changes in magnetic flux ϕ.

→ The working principle is Josephson effect.



→ The arrangement consists of a superconducting ring with two side arms P & Q. X & Y are the two insulating regions which forms the Josephson arrangement. A magnetic flux ϕ is applied perpendicular to the arrangement.

→ When current I enters through P, It is divided in to two and passes through X & Y. At Q these two current Re joins. But the leaving current varies with respect to the variation in magnetic flux. From the variation in current we can detect the change in magnetic flux.

Principle

→ Initially the critical current I_c of insulating region is less than superconducting region.

→ when I_c exceeds the substance changes to normal state and complete penetration takes place.

→ when penetration takes place continuously I_c decreases and the substance changes to superconducting state and complete expulsion takes place.

→ From these alternate penetrations of expulsion we get an interference pattern.

→ Total current entering is given by

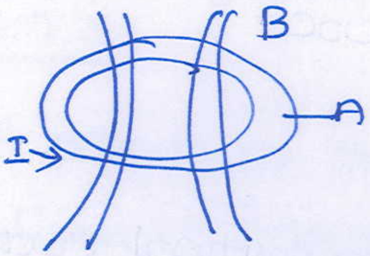
$$I_T = 2I_0 \sin \delta_0$$

→ Total current ~~tearing~~ leaving is given by

$$I_T = 2I_0 \sin \delta_0 \cos\left(\frac{e\phi}{\hbar}\right)$$

where ϕ is magnetic flux. current is maximum when $\frac{e\phi}{\hbar} = n\pi$ and minimum when $\frac{e\phi}{\hbar} = (2n+1)\pi/2$.

Flux quantisation



(for figure see page NO:- 320 of Text)

Consider a superconducting ring of Area A. Ths' A super current I flows through the ring. Then total magnetic flux is $\phi = BA$

By faraday's law $\oint E \cdot dl = -\frac{d\phi}{dt}$

But inside the ring $E = 0$

so $\frac{d\phi}{dt} = 0$

ie, the rate of change of magnetic flux is zero. otherwise the magnetic flux is permanently trapped inside the ring. The total magnetic flux ϕ is given by

$$\phi = n\phi_0 \quad \text{where } \phi_0 = \frac{h}{2e}$$

ie, magnetic flux is integral multiple of $h/2e$.

High temperature super conductors.

→ High temperature superconductors are made up of ceramic substances having a transition temperature greater than 40 K.

→ A single ceramic cell contains one atom of rare earth metal, 2 barium atoms, 3 copper atoms and 7 oxygen atoms. Due to the ratio 1:2:3 of metal atoms they are called 123 superconductors.

[For applications & uses Refer Text]