UNIT IV

[Topics mentioned in Syllabus:

Superconductivity: Essential properties of Superconductors, Zero resistivity, Type I, Type II superconductors and their properties.

Electromagnetism: Displacement current, Three electric vectors (**E**, **P**, **D**,), Maxwell's equations in integral and differential forms. Electromagnetic wave propagation in free space.]

Dear students

- *As the Magnetism subtopic of this unit has been shared already.*
- *To discuss the one of the property of superconductors, Maxwell's equation is required. Therefore the subtopic **Electromagnetism** was taken prior to superconductivity.*

Superconductivity:

1911 K. Onnes observed that the electrical resistance for pure mercury dropped abruptly nearly to zero (of the order **10^{-25} ohm**) at 4.15 K. This sudden drop was not in accordance with the expectations and was completely new phenomenon "**superconductivity**".

The specific conditions of low temperature (a critical temperature T_C below which the specimen behaves as super conductor) and applied external magnetic fields (H) are required for this phenomenon. Superconducting state can be changed by varying stress, impurity, atomic structure, size, frequency of excitation of electric field as well as isotope mass. Generally, the metals which are good conductors (Cu, Ag, Au etc.) do not exhibit this phenomenon even at 0.05K. Whereas the poor conductors as Be (beryllium), Al (aluminum), Mo (molybdenum), Zn (zinc) exhibit **superconductivity** phenomenon. Semiconductors like Si, GE, Se (selenium) and tellurium (Te) metals at very high pressure and at low temperatures become superconductors. In 1973, the highest T_c was known for Nb3Ge alloy as 23.2 K. In 1986 a T_c of 35 K was reported for La-Ba-Cu-O system.

Alloys and ceramic materials also exhibit superconductivity phenomenon. In 1987 IBM researchers ***Georg Bednorz and K. Alex Muller*** were awarded the **Nobel Prize in physics** in the discovery of ***superconductivity in ceramic materials***.

In 2008 HTS (high temperature superconductors) such as **Bismuth Strontium Calcium Copper Oxide** (BSCCO) and **Yttrium Barium Copper Oxide** (YBCO) were discovered.

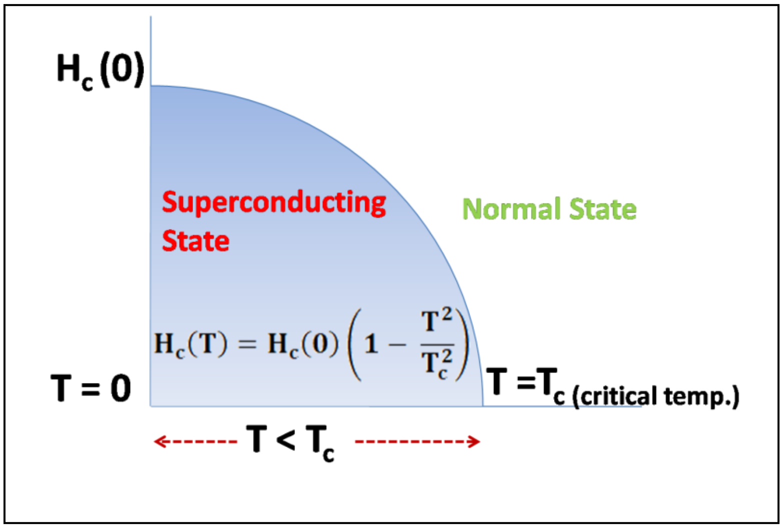
In 2015 H_2S under extremely high pressure (150 giga Pascal) was found to undergo a superconducting transition near 203 J (-70^{o}C) due to formation of H_3S, a new record high temperature superconductor.

Q.1 Discuss the type –I and type –II superconductors.

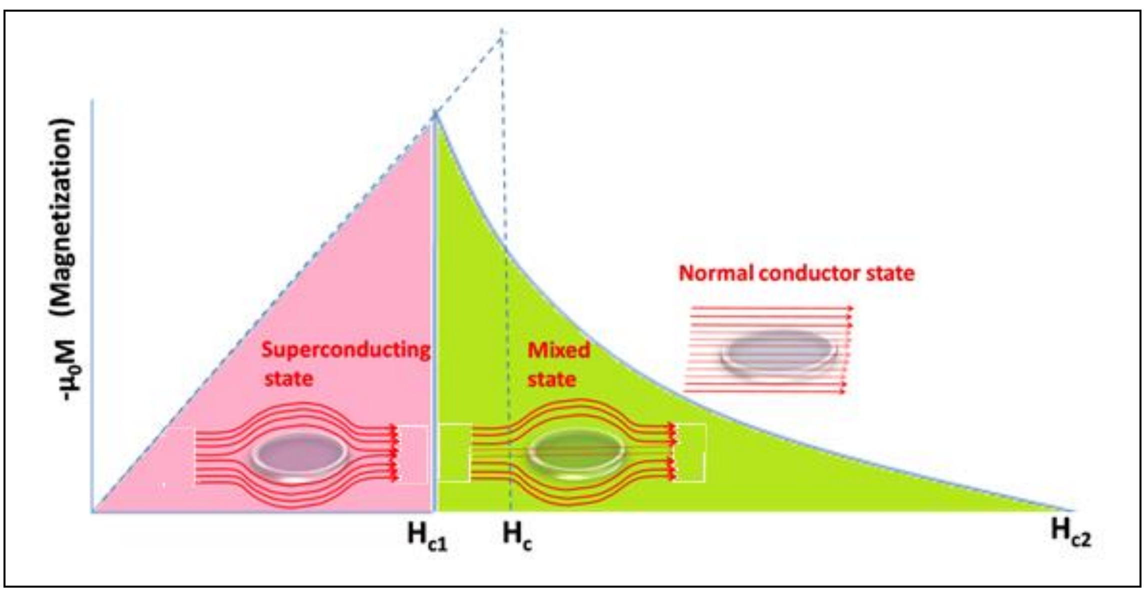
Ans. **Type –I** are pure superconducting materials. They are perfect diamagnetic materials mean they completely exclude the magnetic flux at superconducting state ($T<T_c$) (called Meissner effect). The relation between applied

magnetic field [$H_c(T)$] at temperature ($T<T_c$) and magnetic field [$H_c(0)$] at temperature (T=0) of a superconducting specimen is

$$\mathbf{H_c(T) = H_c(0)\left(1 - \frac{T^2}{T_c^2}\right)}$$



Type –II -these are alloys of materials. They show variation in magnetization with extremely applied field as shown in Fig. . There are two critical magnetic fields e.g. H_{c1} (lower critical field) and H_{c2} (higher critical field) below H_{c1} (lower critical field) behaves as pure superconductor (there sexist a complete exclusion of magnetic field (B=0) inside the specimen and between H_{c1} to H_{c2} a mixed state in which partially magnetic exist between specimen refer
Fig. below. Above Hc_2 the specimen behaves as normal conductor.



Applications:

1. Medical Diagnostics, e.g. MRI, NMR.
2. Enormously power electromagnetic.

3. Supercomputers and information processing.
4. Magnetic levitation.
5. Magnetic energy storage.
6. Electromagnetic shielding
7. Superconducting transformers
8. Generation and transmission electricity(for saving power loss)

Q. 2 ***Discuss the London's first equation and its interpretation.***
Or
Show that current can flow even if the Electric field (E) is removed from superconducting specimen in super conducting state.
Or
Discuss how persistent current can established in a superconducting state.

Ans. To explain the Meissner effect London (1935) assumed that there are two types of electrons, namely normal (n_n) and super electrons (n_s) exists in super conductors. Therefore, the density of super conductor can be written as

$n= n_n+ n_s$

It is assumed that both electron flow in parallel. Super current flow without resistance, while normal electron flow remains quite inert and are thus ignored in superconducting state.

Since the force on an super electron is

$$F = ma = m\frac{dv}{dt}$$

$$I_s = n_s A e v_s$$

$$\Rightarrow \ J_s = n_s e v_s \qquad \boxed{I_s = \frac{J_s}{A} = \frac{n_s e \cancel{A} v_s}{\cancel{A}}}$$

$$\Rightarrow \text{or } \ v_s = -\frac{J_s}{n_s e}$$

$$F = ma$$

$$\Rightarrow m\frac{dv_s}{dt} = -eE$$

$$\Rightarrow m\frac{d\left(-\frac{J_s}{n_s e}\right)}{dt} = -eE$$

$$\boxed{\mathbf{\frac{dJ_s}{dt} = \left(\frac{n_s e^2}{m}\right)E}}$$

This relation is known as London's First equation. This equation describes that even if the electric field (E) is removed (i.e. E = 0) at super conducting state i.e.

$$\mathbf{\frac{dJ_s}{dt} = 0}$$

Or $J_s = \text{constant}$

Still current can flow. This current is called **persistent current** at superconducting state.

This is very **useful for superconducting magnets** as it **does not require power supply to maintain it Magnetic Field**.

Q. 3 ***Show that superconductors behaves as perfect diamagnetic materials in superconducting state.***

Since for a magnetic material the relation between **B** (magnetic induction), **H** (Magnetic field intensity) and **M** (Magnetization –magnetic moment per unit volume; unit: Amp.-m²) is

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$$

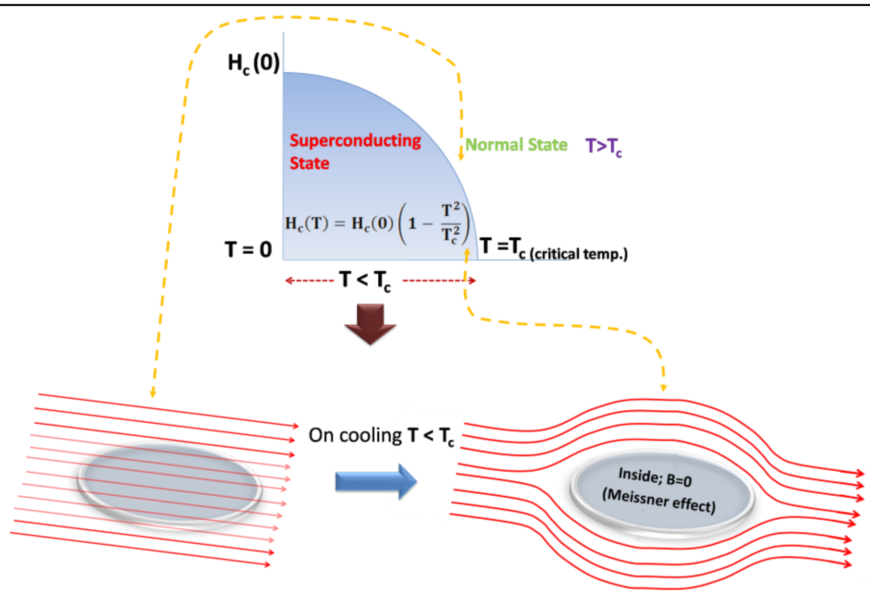
And at superconducting state, there exists no magnetic field (**B=0**) (**Meissner Effect**) inside the superconducting material. Therefore

$$\mathbf{0} = \mu_0(\mathbf{H} + \mathbf{M})$$

Or $\mathbf{M} = -\mathbf{H}$

Or $\chi_m = \frac{\mathbf{M}}{\mathbf{H}} = -1$

At this state a superconducting material can be regarded as **perfect diamagnetic material** (since for a perfect diamagnetic material magnetic susceptibility is $\chi_m = -1$.



At **Normal state of super conducting specimen** when $T>T_c$ the *magnetic field lines passes through ring*)

At **Superconducting state when** $T < T_c$ **the** ***magnetic Flux (B) inside the ring is excluded this is called Meissner effect. At superconducting state material behaves as perfect diamagnetic material (*** $\chi_m = -1$***).***

The Type I super conductors (pure materials) exhibit the Meissner effect at superconducting state whereas the Type II exhibit both super conducting and mixed state of materials(superconducting property are exhibited within H_{C1} ***applied external Field and within*** H_{C1} ***to*** H_{C2} ***exhibit the property of a superconducting as well as a normal conductor) above*** H_{C2} ***the type II behaves as a normal conductor***