SUPERCONDUCTIVITY.

It was discovered by a Dutch physicist 'Heike Kammerlinh Onnes' in the year 1911.

→ It was first observed in Mercury (Hg) at 4.2K (The resistivity was of an order of 10^{-5} Ωm - approx).

(Temperature of liquid N_2)

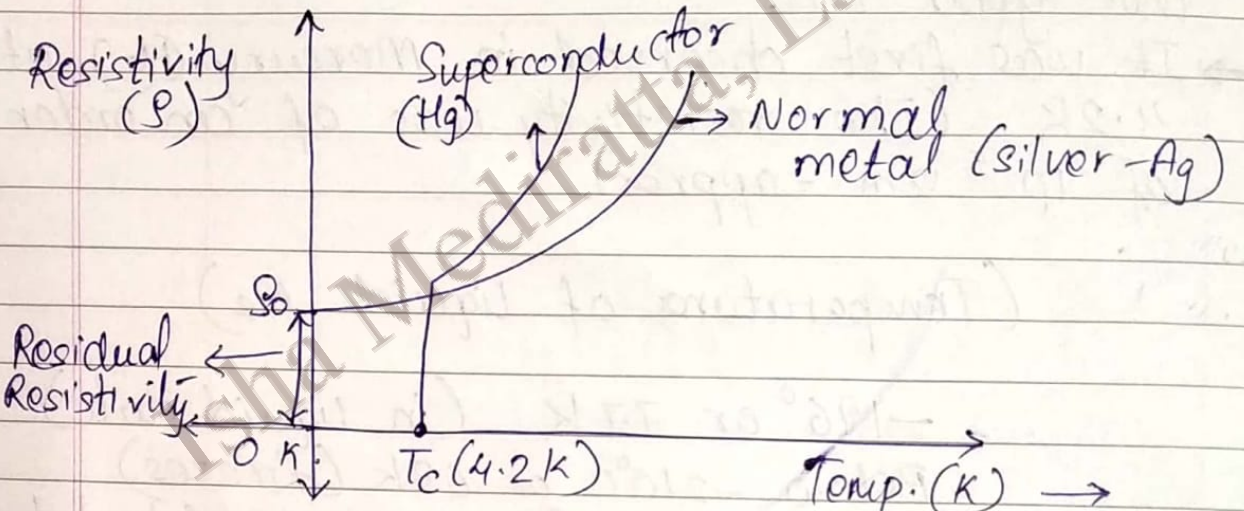
−196° or 77K (in liquid state)
Below −210°C or 63K (freezes)
Above −195.8°C or 77.2K (starts boiling)

* Superconductivity:
The phenomena in which certain metals, alloys or ceramics conduct electricity without resistance, when they are cooled below a certain temperature called critical temperature is called 'Superconductivity'.

* Superconductor:
A superconductor is a material that loses almost all its resistance (offers almost zero resistance) to the flow of electric current, when it is cooled down below a certain temperature called critical temperature.
eg: Mercury (Hg), Zinc (Zn), Vanadium (V), Niobium (Nb)

★ Critical Temperature (T_c):

The temperature at which a material's electrical resistivity drops down to absolute zero is called critical or transition temperature.



→ From the above graph, it can be seen that electrical resistivity of normal metal (Ag) decreases steadily or gradually as temperature is decreased and reaches a low value at 0 K. (This resistivity is called residual (remanent) resistivity.)

→ Whereas, resistivity of a superconductor (Hg) decreases suddenly at critical temperature (T_c).

⇒ A superconductor remains in superconducting state (almost no resistance) at T_c or lower than T_c.

③

★ Properties of superconductors :.

① Electrical Resistance / Resistivity.

We know,

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

m = mass of electron
n = density (no. of free electrons per V)
e = charge of electrons
τ = Relaxation time.
↓
(Time between two successive collisions)

explanation only

→ In relation to this, as T increases, kinetic energy of electrons increases. As a result of this vibrations increase and so Relaxation time(τ) decrease. Due to this resistivity (an hence resistance) increases.

→ In other words, when vibrations increase, electrons find difficulty in moving, as a result of which resistance increases.

→ On the other hand, when temp is decreased, system becomes much more stable. τ increases and so resistivity (and hence resistance) decreases.

$$T\uparrow \rightarrow \tau\downarrow \rightarrow \rho\uparrow$$

$$\boxed{T\downarrow \longrightarrow \tau\uparrow \longrightarrow \rho\downarrow}$$ Base of superconductivity.

→ Electrical resistivity of a superconductor is very low.

→ It is of an order of $10^{-7}\,\Omega m$.

② Effect of Impurities :

→ When impurities are added to a superconducting material, its superconducting property is not lost, but value of T_c is lowered.

Explanation [ie: we have to decrease the temperature to maintain its superconductivity.
→ When impurities are added, no. of charge carriers and charge on carriers will remain same, but due to distortion of lattice, mobility decreases. As a result resistivity (and hence resistance) will increase. So, value of temperature has to be lowered further to maintain superconductivity.]

③ Effect of Pressure and stress :

Certain materials are found to exhibit superconductivity on increasing pressure over them.
eg: Cesium(Cs) is found to exhibit superconductivity at $T_c = 1.5K$ on applying a pressure of 110kBar.

Explanation [On increasing pressure, the atoms come closer. In some materials the lattice vibrations are reduced, as a result of this, the electrons can move freely. ie: resistivity (and hence resistance) decreases.]

4. Isotopic effect.

The critical temperature is found to vary with its isotopic mass.
This variation in T_c with is isotopic mass is called 'Isotopic effect'.

$$T_c \propto \frac{1}{M^{\alpha}}$$

where,
α = isotopic constant.
(Its value is approx 0.5)

$$\therefore T \propto \frac{1}{\sqrt{M}}$$ or

$T_c\sqrt{M}$ is constant.

Explanation
[Isotopes have different no. of neutrons in the nucleus. As a result of this, they have same atomic number, but different atomic mass.
Isotopes may be natural or artificial. Nuclei of isotopes are unstable so they breakdown or decay and emit radiation. (They may have extra or less neutrons).]

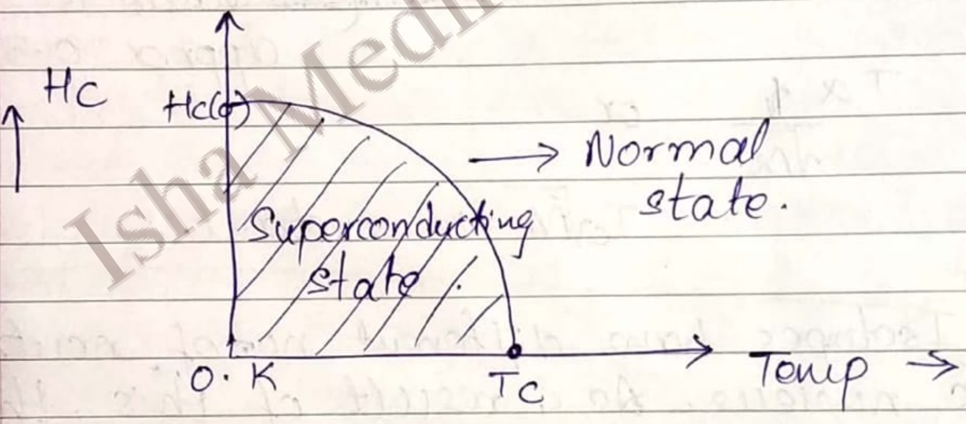
5. Magnetic field effect:
If a sufficiently strong magnetic field is applied to a superconductor at any temperature below its T_c, the superconductor undergoes a transition to normal state.

This minimum magnetic field required to destroy the superconducting state is called critical magnetic field (H_c).

→ H_c is a function of temperature.

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

where $H_c(0)$ is critical field at 0 K



It is seen from graph that critical field decreases with increase in temperature and it becomes zero at $T = T_c$.

⑥ Critical Current Density (J_c)

→ When current density through a superconductor exceeds a critical value J_c, the superconducting state is found to disappear in the sample.

→ This is because, when current flows through the superconductor, it itself generates a magnetic field and at sufficiently high current density, the magnetic field will start exceeding the value of H_c, hence superconducting state will start disappearing.

Ampere's circuital law : It states that the line integral of magnetic field $\vec{H}$ around a closed path is the net current enclosed by this path.

Current Density (Jc)

It can be defined as the max. current per unit area that can be permitted in a superconducting material without destroying its superconducting state.

→ It is the function of temperature.
ie: Lower the temperature of superconductor, more is the current it can carry.

Silsbee's law or Silsbee's effect.

To derive the relation between critical current field, consider a superconductor wire of radius 'r' carrying a current 'I'.
This current will produce a magnetic field

$$H = \frac{I}{2\pi r}$$ (according to Ampere's circuital law)

Explanation

If current through the wire is such that $H > H_c$, then superconductor will go to normal state.
So, if I_c is the current for which $H = H_c$, then I_c (critical current) is given by

$$\boxed{I_c = 2\pi r H_c}$$

Current Density is given by

$$J_c = \frac{I_c}{Area} = \frac{2\pi r H_c}{\pi r^2}$$

$$\therefore \boxed{J_c = 2H_c/r}$$

(7) Persistent Current:

When current is made to flow through a superconducting ring (say a loop of wire) which is at a temperature equal to or less than its critical temperature, it is observed that current flows through the material without any significant loss in it value.

This steady flow of current in a super-conducting material is called 'Persistent current.'

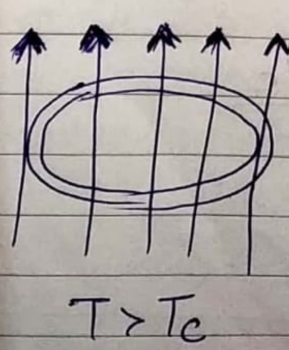
Current can be induced in a superconductor by applying magnetic field to it and then switching off the magnetic field.

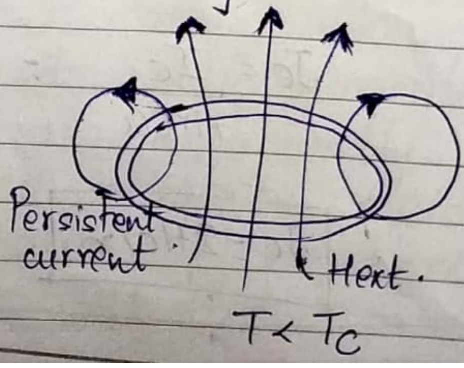
Explanation

→ When the magnetic field is switched off, the field outside the ring disappears, but field inside the ring is trapped.

→ The collapse of magnetic field outside the ring induces a large current inside the ring itself and because of extremely low resistivity, maintains the trapped flux.

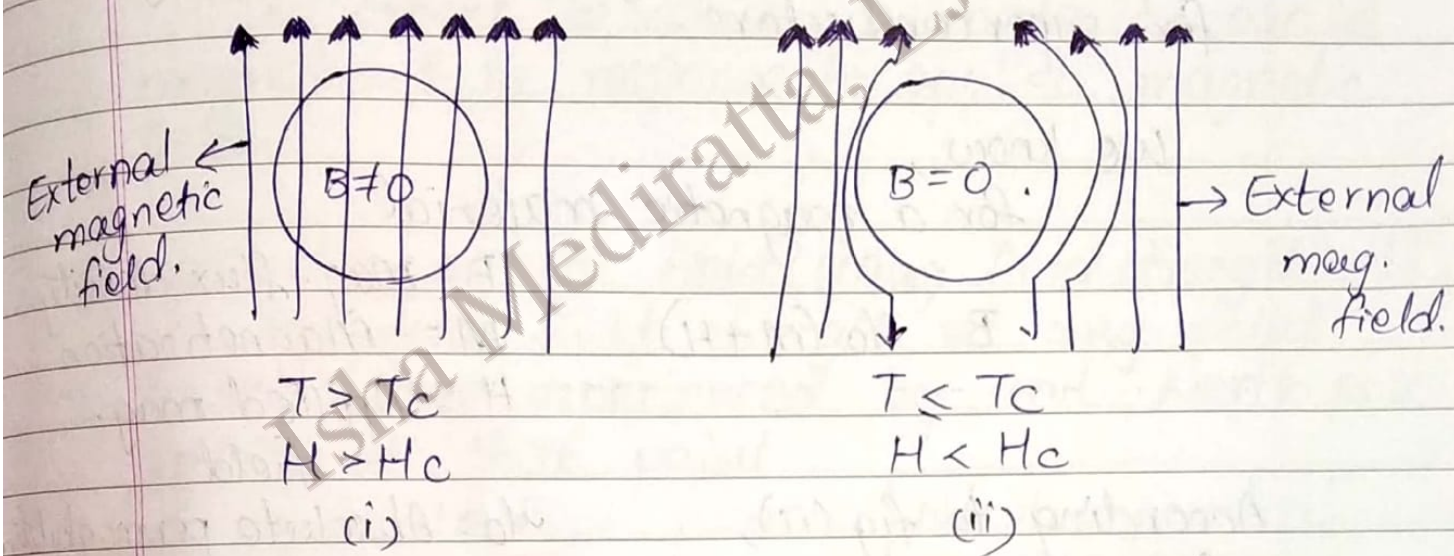
→ Once current is induced, even though the field is switched off, it persists for indefinite period (till its superconducting state is maintained)





8. Meissner Effect:

The complete expulsion of all magnetic field lines by a superconducting material is called Meissner effect.



→ From figure (i), it can be seen that when a superconducting material at room temperature is placed in magnetic field, magnetic field lines penetrate throughout the material normally.

→ But from figure (ii), it can be seen that when temperature is lowered to Tc and with H<Hc, material is found to reject all magnetic field through it.

→ what actually happens is that when magnetic field is applied, due to surface currents, magnetic field is created within the superconducting material.

→ This magnetic field will exactly counter the applied magnetic field, cancelling all the flux in its interior.

→ So we can say superconductor behaves as a diamagnetic material.
- This phenomenon only takes place when the applied field is less than H_c

★ To prove that χ_m (magnetic susceptibility) = -1 for superconductors.

We know,
for a magnetic material

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

B = Mag. flux density
M = Magnetisation
H = Applied mag. field
μ_0 = Absolute permeability

According to fig (ii),
for a superconductor
$B = 0$ (as it is in superconducting state because $H < H_C$ & $T \leq T_C$)

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

But $\mu_0 \neq 0$ (It has a value $4\pi \times 10^{-7}$ H/m)

$$\therefore M + H = 0$$

$$\therefore M = -H$$

$$\therefore \frac{M}{H} = -1 \quad (M/H = \chi_m)$$

$$\therefore \boxed{\chi_m = -1}$$

For a superconductor, as $\chi_m = -1$, it is 'perfectly dimagnetic'

Some Basic terms.

① magnetic permeability (μ)
Ability of a material to support the formation of magnetic field within itself.

② magnetic susceptibility (χ_m)
The extent to which, a material can be magnetised in response to applied magnetic field.

③ Applied magnetic field (mag. field strength) - H:
Magnetic field strength at any point is the force experienced by unit North pole place at that point.

Explanation

$H = \frac{F}{m}$ unit $\boxed{N/wb \text{ or } A/m}$

④ magnetic flux density (B)
It is the no. of lines of force passing through a unit area of cross section perpendicularly.

$B = \frac{\phi}{A}$ unit $\boxed{wb/m^2 \text{ or Tesla}}$

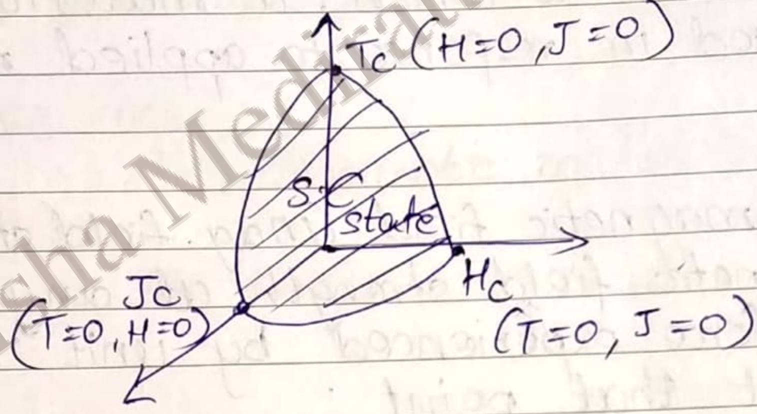
⑤ Magnetisation (M)
The magnetic moment per unit volume

$M = \frac{\mu_m}{V}$ unit $\boxed{A/m}$.

⑥ Magnetic moment
The torque that a magnet experiences in ext. magnetic field $\mu_m = IA$ unit ~~A/m²~~ $\boxed{A\text{-}m^2}$

★ Three factors that are important to define a superconducting state.

1.) Critical temperature (T_c)
2.) Critical magnetic field (H_c)
3.) Critical current density (J_c)



To sustain a superconducting state, it is necessary to have all above factors below their critical values.

→ The values of H_c and J_c are max at $T = 0$ K while highest value of T_c occurs when H and J are at value 0.

→ The above plot refers to as 'critical surface'.

→ Within this surface, material is in superconducting state and outside this surface, it is in normal state.

NUMERICALS (Till this topic)

1.) For mercury of mass 202, value of 'α' is 0.5 and T_c is 4.2K. Find transition temperature for isotope of mercury of mass 200.

$M_1 = 202$ $\quad T_{c_1} = 4.2K \quad T_{c_2} = ?$

$M_2 = 200$ $\quad \alpha = 0.5$

$\because T_c M^\alpha = \text{constant}$

$\therefore T_{c_1} M_1^\alpha = T_{c_2} M_2^\alpha$

$$T_{c_2} = \left(\frac{M_1}{M_2}\right)^\alpha T_{c_1}$$

$$= \left(\frac{202}{200}\right)^{0.5} (4.2)$$

$\therefore T_{c_2} = 1.004987 \times 4.2$

$\therefore \boxed{T_{c_2} = 4.2209 \text{ K}}$ Ans.

2.) The critical temperature of Nb is 9.15 K. At 0.K critical field is 0.196T. Calculate the critical field at 6 K.

$T_c = 9.15K$

$T = 6 K$

$H_c(0) = 0.196T$

$H_c = ?$

we know, $H_c = H_c(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$

$$\therefore H_c = 0.196\left[1 - \left(\frac{6}{9.15}\right)^2\right]$$

$$= 0.196\,(1 - 0.4299)$$
$$= 0.196\,(0.5701)$$

$$\therefore \boxed{H_c = 0.1117\ T}$$ Ans.

③ The critical temperature of a metal with isotopic mass 199.5 is 4.185 K. Calculate the isotopic mass if critical temperature falls to 4.133 K.

$M_1 = 199.5$ $\qquad T_{c2} = 4.133\ K$

$T_{c1} = 4.185\ K$ $\qquad M_2 = ?$

$$T_{c1} M_1^{\alpha} = T_{c2} M_2^{\alpha}$$

$$\therefore M_2^{\alpha} = \frac{T_{c1}\,(M_1^{\alpha})}{T_{c2}}$$

But, $\alpha = 0.5$

$$\therefore \sqrt{M_2} = \left(\frac{T_{c_1}}{T_{c2}}\right)\sqrt{M_1}$$

$$= \left(\frac{4.185}{4.133}\right)\sqrt{199.5}$$

$$\therefore \sqrt{M_2} = 1.01258\,\sqrt{199.5}$$
$$= 14.301$$
$$\therefore M_2 = (14.301)^2$$
$$\therefore \boxed{M_2 = 204.55}$$ Ans.

Date ___ Page ___

(5.)

(4.) Calculate the critical current through a long thin superconducting wire of radius 0.5 mm. The critical field is 7.2 kA/m.

$H_c = 7.2 \text{ kA/m} = 7.2 \times 10^3 \text{ A/m}$
$r = 0.5 \text{ mm} = 0.5 \times 10^{-3} \text{ m}$
$I_c = ?$

According to Silsbee's law,

$$I_c = 2\pi r H_c$$

$$= (2\pi)(0.5 \times 10^{-3})(7.2 \times 10^3)$$

$$\therefore \boxed{I_c = 22.608 \text{ A}} \text{ Ans.}$$

(5.) Superconducting Tin (Sn) has a critical temperature of 3.7 K at zero magnetic field and a critical field of 0.0306 T. at 0 K. Find critical field at 2 K.

$T_c = 3.7 \text{K} \quad H_c(0) = 0.0306 \text{ T} \quad H_c = ?, \ T = 2\text{K}$

We know,

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

$$= 0.0306\left[1 - \left(\frac{2}{3.7}\right)^2\right]$$

$$= 0.0306(1 - 0.29218)$$

$$= 0.0306(0.70782)$$

$$\therefore \boxed{H_c = 0.02615 \text{ T}} \text{ Ans.}$$

6. Calculate the critical current for a super-conducting wire of lead (Pb) having a diameter of 1mm at 4.2K. Critical temperature for lead is 7.18K and $H_c(0) = 6.5 \times 10^4$ A/m

$H_c(0) = 6.5 \times 10^4$ A/m
$T_c = 7.18$ K
$r = 0.5$ mm $= 0.5 \times 10^{-3}$ m
$T = 4.2$ K
$I_c = ?$
$H_c = ?$

We know,

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

$$= 6.5 \times 10^4 \left[1 - \left(\frac{4.2}{7.18}\right)^2\right]$$

$$= 6.5 \times 10^4 (1 - 0.34217)$$

$$= 6.5 \times 10^4 (0.06573)$$

$$\therefore \boxed{H_c = 42.758 \text{ kA/m}}$$

Now, according to Silsbee's law,

$$I_c = 2\pi r H_c$$

$$= (2\pi)(0.5 \times 10^{-3})(42.758 \times 10^3)$$

$$\therefore \boxed{I_c = 134.26 \text{ A}}$$ Ans.

7. The critical field of Vanadium is 10^5 A/m at 8.58K and 2×10^5 A/m at 0 K. Determine Tc value.

$H_c = 10^5$ A/m $\quad H_{c(0)} = 2\times10^5$ A/m

$T = 8.58$ K, $\quad T_c = ?$

We know,

$$H_c = H_{c(0)}\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

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

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

$$= 1-\left(\frac{10^5}{2\times10^5}\right)$$

$$\left(\frac{T}{T_c}\right)^2 = 0.5$$

$$\therefore \frac{T}{T_c} = \sqrt{0.5}$$

$$\therefore T_c = \frac{8.58}{\sqrt{0.5}}$$

$$\therefore \boxed{T_c = 12.133 \text{ K}} \text{ Ans.}$$

8. Two isotopes of lead of mass 206 and 210 have Tc values of 7.193K and 7.125K respectively. Calculate the isotopic constant for lead (Pb).

$M_1 = 206 \qquad M_2 = 210$

$T_{C1} = 7.193$K $\qquad T_{C2} = 7.125$ K.

$$T_{c_1} M_1^{\alpha} = T_{c_2} M_2^{\alpha}$$

$$\therefore \left(\frac{T_{c1}}{T_{c2}}\right) = \left(\frac{M_2}{M_1}\right)^{\alpha}$$

$$\therefore \left(\frac{7.193}{7.125}\right) = \left(\frac{210}{206}\right)^{\alpha}$$

$$\therefore 1.00954 = (1.0941)^{\alpha}$$

$$\therefore \log(1.00954) = \alpha \log(1.01941)$$

$$\therefore 4.12519 \times 10^{-3} = \alpha (8.3488 \times 10^{-3})$$

$$\therefore \alpha = \frac{4.1259}{8.3488}$$

$$\therefore \boxed{\alpha = 0.4941} \text{ Ans.}$$

(9) Calculate critical current density for a superconducting wire of lead having diameter of 1.5 mm at 5.3K. The value of critical temperature of lead is 7.8K and critical magnetic field at 0.K is 6.5×10^4 A/m.

$T_c = 7.8K$ $\quad$ $T = 5.3K$.

$H_{c(0)} = 6.5 \times 10^4$ A/m

$$r = \frac{1.5}{2} \text{ mm} = 0.75 \text{ mm} = 0.75 \times 10^{-3} \text{ m}.$$

$J_c = ?$

$$H_C = H_{C(0)}\left[1-\left(\frac{T}{T_C}\right)^2\right]$$

$$= 6.5\times10^4\left[1-\left(\frac{5.3}{7.8}\right)^2\right]$$

$\therefore H_C = 3.498\times 10^4$

$\therefore \boxed{H_C = 34.98\ kA/m}$

Now,

$$I_C = 2\pi r H_C$$

$$= (2\pi)(0.75\times10^{-3})(34.98\times10^3)$$

$\therefore \boxed{I_C = 164.75\ A}$

Current density

$$J_C = \frac{I_C}{A}$$

$$= \frac{I_C}{\pi r^2}$$

$$= \frac{164.75}{(\pi)(0.75\times10^{-3})^2}$$

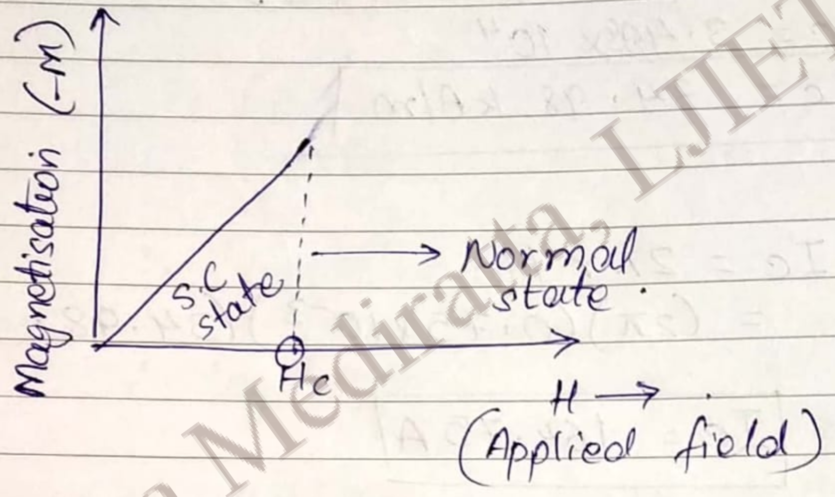
$\therefore \boxed{J_C = 93.28\times10^6\ A/m^2}$ Ans.

10.) Critical temperature of a superconductor is 78K and critical field is 0.518T at 0K. Find critical field at 25K and 58K.

(0.4604 T) (~~0.2082~~ T) 0.2314 T

* Types of Superconductors:

Type-I Superconductors (Soft superconductors)



→ Type-I superconductors are also known as soft superconductors.

→ They exhibit complete Meissner effect.

→ The transition from superconducting state to normal state occurs sharply at critical value 'H_c'.

→ The curve or graph above shows that transition at H_c is reversible

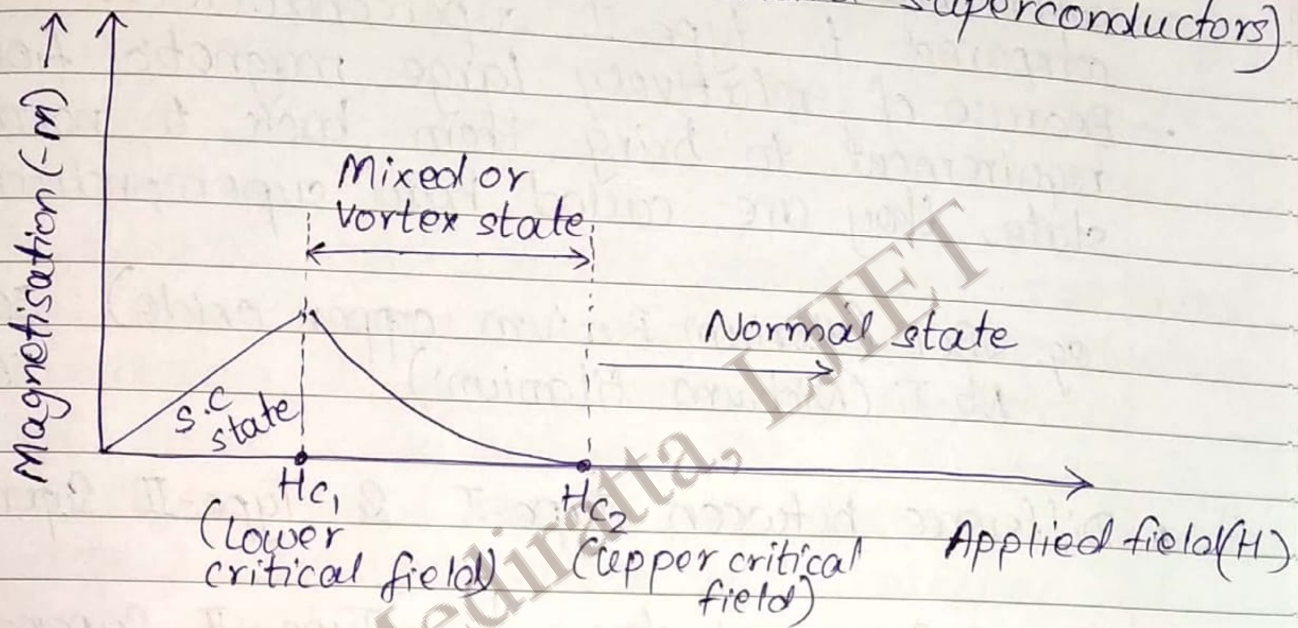
ie: if magnetic field is lowered below H_c the material again acquires superconducting properties.

→ Value of H_c for type-I superconductor is very low (of an order of 0.1 Tesla)

→ They allow field penetration easily

eg: Lead (Pb), Tin (Sn), Vanadium (V)

Type - II Superconductors (Hard superconductors)



→ Here, H_{c_1} is called the lower critical field and H_{c_2} is called the upper critical field.

→ Till the applied magnetic field is equal to H_{c_1} the material is perfectly dimagnetic and excludes all magnetic field lines.

→ If the applied magnetic field is increased further beyond H_{c_1}, field lines start penetrating the material. This process takes place till H_{c_2}.

→ If the applied field is increased beyond this point, the field inside the superconductor and the applied field become equal. Above this, the superconductor returns to its normal state (ie: resistance increases).

→ In between H_{c_1} and H_{c_2}, the superconductor is in mixed or vortex state.
ie: it has both superconducting and normal behaviours. Zero resistance and partial penetrating field lines.

→ Thus, Meissner effect is partial.

→ Value of upper critical field (H_{c_2}) for type-II supercondutors is 100 times ore even more as compared to type-I superconductors.

→ Because of relatively large magnetic field requirement to bring them back to normal state, they are called hard superconductors.

eg: YBCO (Yttrium Barium copper oxide) 300 Tesla
Nb-Ti (Niobium titanium) 13 Tesla.

★ Difference between Type-I & Type-II Superconductors.

Type-I Superconductor	Type-II Superconductor
1) They are called soft superconductors	They are called hard superconductors
2) Only one critical field exists for these superconductors	Two critical field H_{c_1} (lower critical field) and H_{c_2} (upper critical field) exists for these superconductors.
3) The critical field value is very low.	The critical field value is very high.
4) They exhibit perfect and complete Meissner effect.	They do not exhibit perfect and complete Meissner effect.
5) They have limited applications because of low field strength value eg: Pb, Hg, Zn, Nb	They have wider technical applications because of wider or high strength field values. eg: Nb_3Si, $Y_1Ba_2Cu_3O_7$, NbTi

★ Mechanism of Superconductivity - BCS Theory.

In 1957, John Bardeen, Leon Cooper and Robert Schrieffer proposed a microscopic theory called the BCS theory

→ It explains most of the phenomena associated with superconductivity. It involves the electron interaction through Phonons as mediators.

→ The main idea behind the BCS theory is the experimental results of the two effects namely Isotopic effect and Variation of specific heat with temperature.

★ Isotopic effect and Variation of specific heat with T

From this one can infer that the transition resulting in superconducting state must involve dynamics of ion motions, lattice vibrations (phonons)

→ T_c attains a value zero when M approaches infinity. This suggests that non-zero transition temperature is a consequence of finite mass of ions which can contribute phonons by their vibrations.

→ In 1950, Frolich and Bardeen showed the existence of self energy of electrons accompanied by virtual phonons when it moves through crystal lattice.

→ This means that an electron moving through the lattice distorts the lattice and lattice, in turn, acts on the electron by virtue of electrostatic forces between them.

→ The oscillatory distortion of the lattice is quantised in terms of phonons and so one can interpret the interaction between lattice and electron as constant emission and re-absorption of phonons.

This is called Phonon-electron interaction.

⇒ BCS theory showed that the basic ~~transition~~ interaction responsible for superconductivity appears to be that of a pair of electrons by means of an interchange of virtual photons.

Explanation:

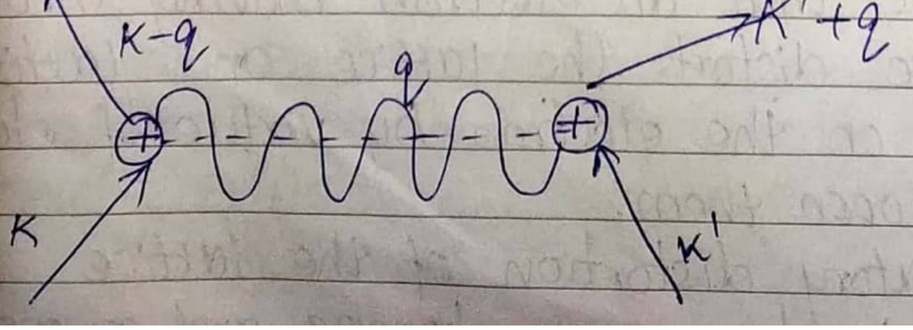
→ Suppose an electron approaches a positive iron core it suffers attractive coulomb interaction. Due to this ~~iron~~ ion core is set in motion and consequently distorts the lattice. Smaller the mass of ion core, greater will be the distortion.

→ Suppose another electron comes in this distorted lattice, the interaction between electron and distorted lattice occurs, which in turn, lowers the energy of second electron

→ Thus we can say that the two electrons attract via lattice distortion, resulting in lower energy for electrons.

→ This lowering of energy implies that the force between electrons is attractive.

This is the phonon-electron interaction.



As shown in the diagram, suppose an electron with wave vector 'k' emits a virtual phonon 'q' which is absorbed by k'. Thus K is altered as (K-q) and k' as (k'+q)

→

→ The indirect interaction proceeds when one electron interacts with lattice and deforms it, a second electron sees the deformed lattice and adjusts itself to take advantage of deformation to lower its energy.

→ The nature of the resulting electron-electron interaction depends on the relative magnitudes of electronic energy and phonon. If this phonon energy exceeds electronic energy, the interaction is attractive.

★ Cooper pairs.

According to BCS theory, superconductivity occurs when an attractive interaction between two electrons, by means of phonon exchange occurs.

Two such electrons which interact alternatively in phonon field are called 'Cooper pairs'.

★ Energy gaps.

→ The energy difference between the free state of an electron (ie: energy of individual electrons in normal case) and the paired state (energy of paired electrons - superconducting state) appears as the energy gap at the fermi surface.

→ Normal electron states are above the energy gap and superconducting electrons are below the energy gap at fermi surface.

→ Here, this energy gap is a function of temperature.

→ As the pairing is complete at 0 K, the difference in energy of free and paired electron states is maximum.

We can say energy gap is maximum at absolute zero.

→ As T approaches T_c, pairing is dissolved and the gap reduces to zero.

★ Coherence length.

→ The paired electrons are not scattered as they smoothly move through the lattice imperfections without exchanging energy with them.

→ Coherence states that superconductivity is due to mutual interaction and correlation of electrons which extends to a considerable distance.

The maximum distance upto which the pair of electrons are correlated to produce superconductivity is called coherence length (ξ_0)

→ The spacing ~~of~~ or distance can be of an order of 0.001nm.

★ Penetration depth.

→ In 1935, London brothers described the meissner effect and zero resistivity by adding the two conditions ($E=0$, from absence of resistivity) and ($B=0$, from Meissner effect), to Maxwell's electromagnetic equations.

→ According to them, the field does not suddenly drop to zero at the surface, but decays exponentially according to eq^n.

$$H = H_0 \exp(-x/\lambda)$$

where, H_0 is the magnetic field at the surface.
λ is the characteristic length (also called penetration length)

→ It is the distance for H to fall from H_0 to H_0/e.

→ London penetration depth refers to the exponential decay of magnetic field at the interior surface of superconductor.
It is related to the density of supercondu[cting] electrons.

Applications of Superconductors.

① Magnetic levitation.

It is the process by which an object is suspended above another object with no other support, but magnetic fields.

→ In this method, magnetic levitation occurs when a superconductor is placed in an external magnetic field.

→ Due to Meissner effect, the magnetic field lines are opposed or repelled by the super-conducting material.

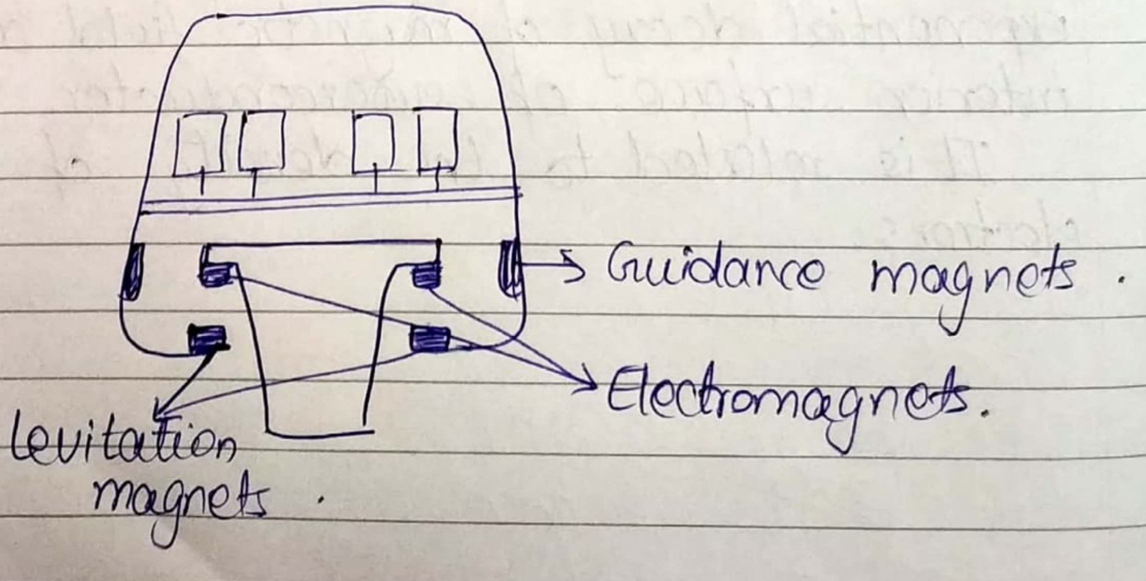
This is what produces levitation.

→ Maglev train is the example based on this concept.

Maglev train.

① EMS (Electromagnetic suspension)

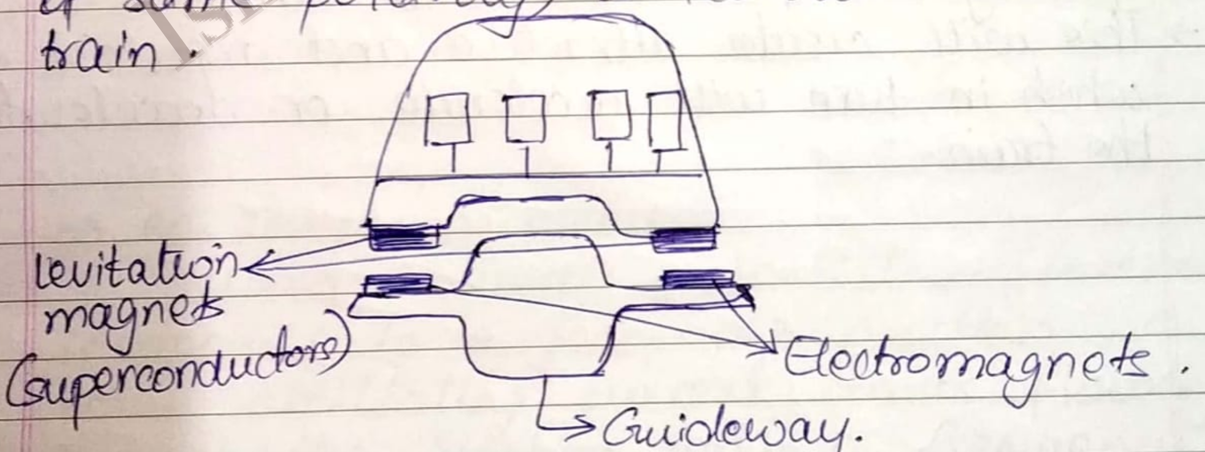
→ This system uses attractive forces to levitate the train.



→ The levitation magnets on the train will be attracted to electromagnets on the guideways.
→ This attractive force will overcome the gravitational force and levitate the train on the track.
→ The guidance magnet guides the train so that sides of track do not have any contact with the train.

② EDS (Electrodynamic suspension)

→ This system uses repulsive forces (magnets of same polarity) to levitate the train.

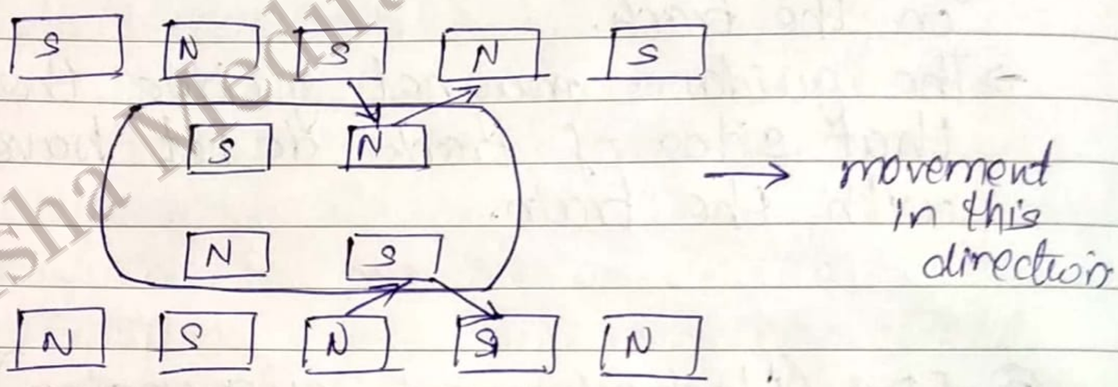


→ Magnets of same polarity create a repulsive force between levitation magnets and guideways
→ This force is strong enough to overcome the gravitational force, and thereby achieve levitation.
→ Powerful superconducting electromagnets are used.
→ Because of superconducting materials used,

conduction is possible even when there is no power.

→ Levitation upto 4 inches (10 cms) can be achieved

Acceleration or Decceleration of train.



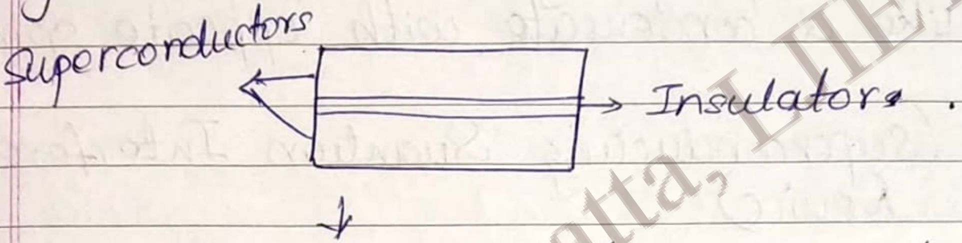
→ Alternating current is passed through guideways

→ Depending upon current polarity, direction of magnetic field lines will change.

→ This will create attractive and repulsive forces which in turn will accelerate or decelerate the train.

(2.) Josephson effect.

→ was defined by Brian Josephson, in the year 1962.



This is called a josephson junction or SIS junction.

a) DC Josephson effect.

If a constant current is made to flow through a josephson junction, no voltage drop occurs as long as the current stays below its critical value.

This is known as DC Josephson effect.

b.) AC Josephson effect

When a small potential difference is applied to a josephson junction, a small oscillating current starts flowing through the junction with a frequency equal to 2ev/h.

This is known as AC Josephson effect.

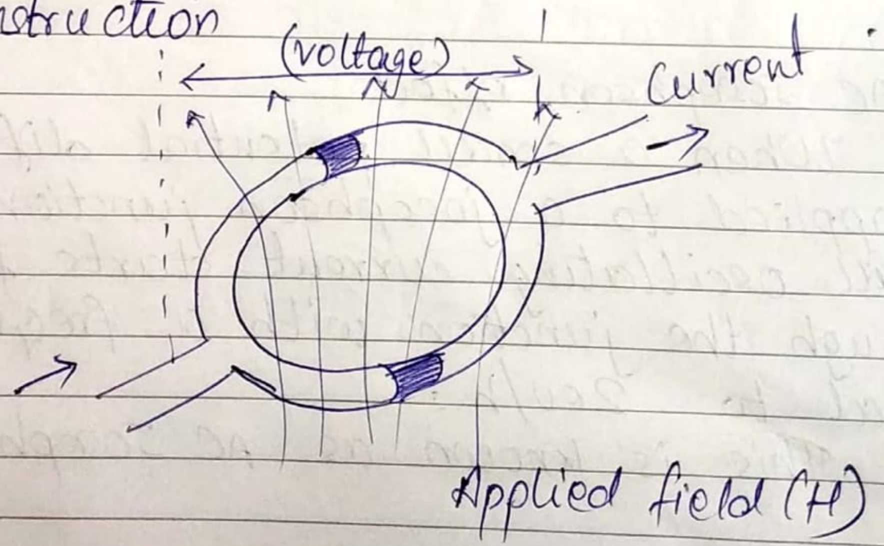
ev = It is the amount of energy gained or lost by charge of single electron moved accross a potential difference of 1 volt)

→ What actually happens is that electrons tunnel through the junction because of their wave nature
→ Electrons form pair (by virtue of phonons) and behave like a condensate with opposite spins.

★ SQUID (Superconducting Quantum Interference Device)

→ It works on the principle of Josephson effect.
→ When current is passed through one side of superconductor, it flows equally through the josephson junction.
→ It is very sensitive to magnetic flux. Any small change in flux will lead to a change in current and hence voltage is developed across junction

★ Construction



→ As shown in the diagram, it is seen that squid is formed when two superconductors and insulators are arranged in such a way that they form two parallel josephson junctions.

→ It is connected to measuring device which can measure nominal changes in voltage and magnetic fields across junction.

★ Working:

→ Current through the squid is highly sensitive to magnetic flux through the closed circuit. Even an extremely small magnetic flux can be detected with this device.

→ As magnetic field, voltage and current are dependent on each other, we can measure any one when the other is known.

→ It can detect changes as small as 10^{-15} V and 10^{-21} T.

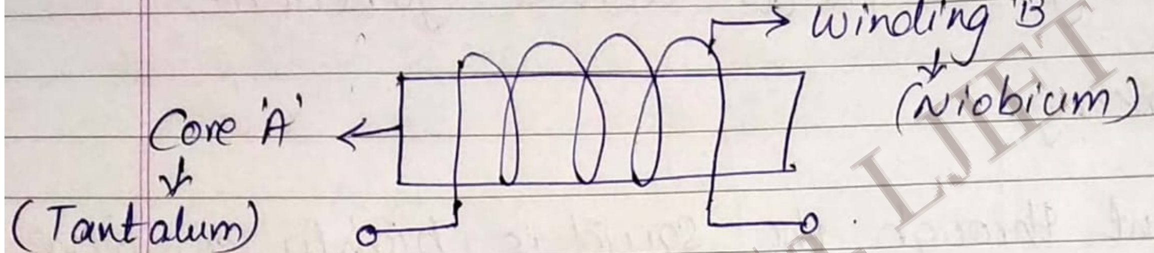
★ Applications:

→ Used to measure Earth's magnetic field.

→ It can detect weak magnetic fields produced by biological currents like human brain.

→ Detection of iron deposits in liver.

③ Cryotron.
By Allen Buck.



→ Two different superconducting materials are taken such that

$$H_{CA} < H_{CB}.$$

→ If current passes through winding B, it induces some magnetic field.
→ If this induced magnetic field is greater than H_{CA}, its superconducting state is destroyed, thereby increasing resistivity and hence decreasing the current.
→ Thus we can say that current through the winding controls superconducting state of core.

uses:
used in circuit breakes, relays etc.