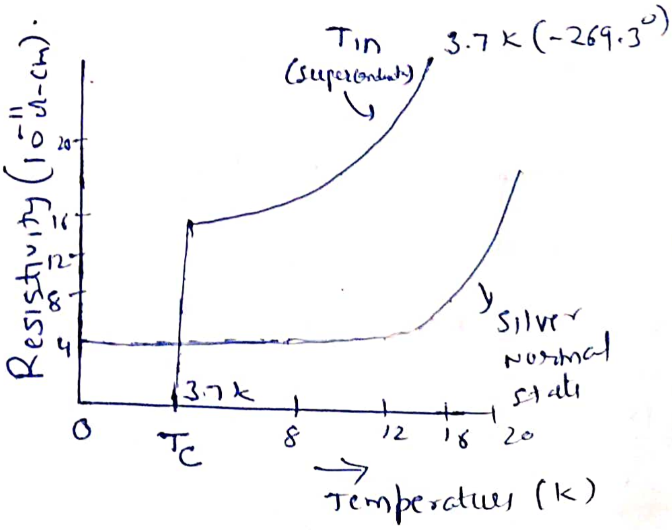
Super conductivity

In 1911, Onnes found that the electrical resistance of some metals, alloys and Compound drops suddenly to zero when the specimen is cooled below a certain Temperature. This phenomenon is called "super conductivity" and cooled specimen is called "super conductor"

Temperature dependence of Resistivity in super conducting material →

1) In the superconducting state the resistivity of material is zero
2) The Temperature called critical temperature (T_c) below which a material undergoes a Transition from state of normal conducting to a superconducting state.
3) Critical Temperature varies from 23.3K for the alloy Nb_3Ge to 0.01K for some semi-conductor

* In Fig. It has shown that The Tin super conductor shown the Resistivity is equal to zero at Temperature less then 3.7K. Called critical Temperature (T_c).



* Normal metal Silver have residual resistivity at absolute zero kelvin.

So The normal Conductor like Cu, Ag, Au, Li does not show super conductivity.

The highest critical temperature as much as 134 K are found in certain ceramic material.
Oxides of lanthanum, barium and cu for which $T_c = 30K$.

Material	T_c
liquid He	4K
liquid N_2	77K
Mercury (Hg)	4.15K
TIN	3.7K
alloy Nb_3Ge	23.3K
ceramic ~~Ceramic~~	134K

Note - The electrical resistivity of all the metal and alloys decrease when are cooled.

When the temperature is lowered, the thermal vibration of atoms decreased and conduction electrons are less frequently scattered.

Effect of Magnetic field :→

Super conducting state of material mainly depends on the temperature and magnetic field. It exist only in a particular range of Temperature and field strength.

(*) Super Conducting state disappear if the temperature of speciman is ~~raised~~ raised above its critical Temperature (T_c)

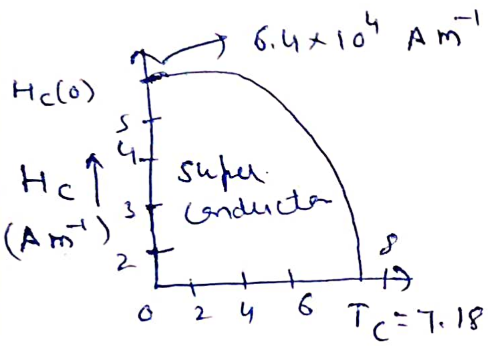
(*) Critical magnetic field at a given temperature at which super conducting properties are disappears called critical magnetic field (H_c

* **Critical Magnetic field** :- It is the field at which the super conducting properties are disappears and denoted as H_c and written as

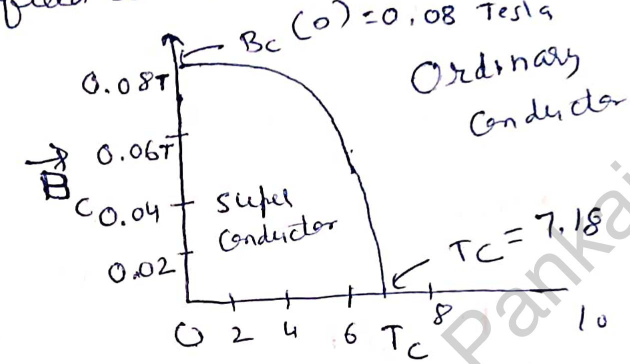
$$\boxed{H_c = H_0\left(1-\left(\frac{T}{T_C}\right)^2\right)}$$

	T_C	$B_C(0)$ Tesla
Al	1.18	0.0105
Hg	4.15	0.0411
Pb	7.18	0.08

H_C is the maximum critical field at temperature T and H_0 is the maximum critical field at absolute temp. T.



variation of critical Magnetic field intensity H_c with temperature for Lead

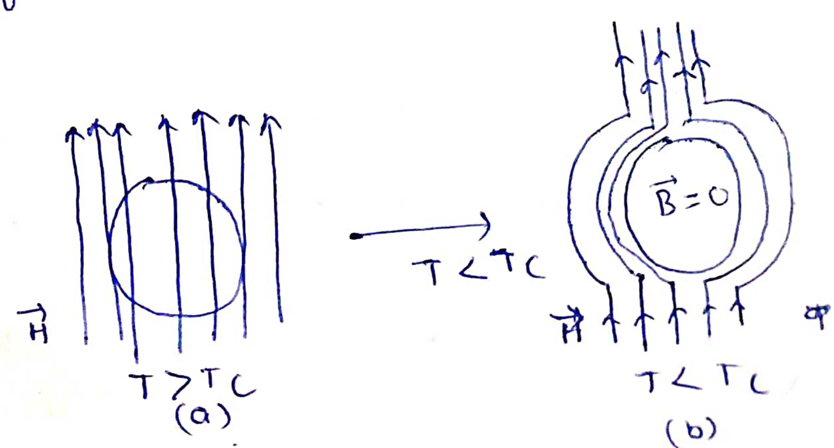


variation of critical field B_C with temperature for Lead.

Meissner effect – (Flux exclusion).

In 1933, Meissner observed that if a superconducting material is placed in a magnetic field and cooled below its critical Temperature, it expels all the originally present magnetic flux from its interior it called "Meissner effect".

* Bulk superconductor in weak magnetic field behave as a Diamagnetic in nature



where the magnetic induction ($\vec{B}$) is zero inside the material.

we know

$$\vec{B} = \mu_0 (\vec{H} + \vec{M}) \rightarrow (1)$$

$$\vec{B} = 0$$

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

$$\vec{M} = -\vec{H} \rightarrow (2)$$

where $\vec{H}$ is the magnetising field intensity

Magnetic susceptibility →

we know

$$\vec{M} \propto \vec{H}$$

$$\vec{M} = \chi \vec{H} \rightarrow (3)$$

Now put the value of $\vec{M} = -\vec{H}$ from eq (2) in eq (3)

$$\chi = \frac{\vec{M}}{\vec{H}} = \frac{-\cancel{\vec{H}}}{\cancel{\vec{H}}} = -1$$

Hence susceptibility will be ~~...~~ -ve (negative) and it is the propertifies of diamagnetic material.

Hence super conductor is a Perfect diamagnetic Material.

Note : Perfect diamagnetism and zero resistivity are two independent and essential properties of super conductor

Acc. to ohm law

$$\vec{E} = \rho \vec{J} \qquad \text{as } \vec{E} = 0$$

~~E~~ = 0 because $\rho = 0$

Acc. to Maxwell. $\frac{d\vec{B}}{dt} = -\vec{\nabla} \times \vec{E}$

Hence $\frac{d\vec{B}}{dt} = 0$ $\qquad \vec{B} = \text{Constant}.$

Critical current →

An electric current flowing through a superconducting specimen itself may be produced for the necessary magnetic field. When magnetic field produced $H_I > H_C$ the superconductivity disappears and material goes to normal state. According to Amper's law

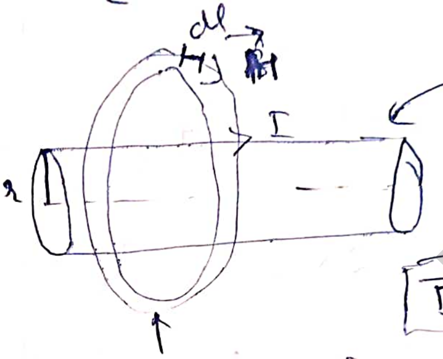
$$\oint \vec{H_I} \cdot \vec{dl} = I$$

$$\vec{H_I} \cdot 2\pi r = I$$

$$H_I = H_C$$

$$I = I_C$$

$$\boxed{I_C = 2\pi r \vec{H_C}}$$ → Silsbees Rule



(Magnetic lines of force)

$$\vec{H_I} = \frac{I}{2\pi r} \ A/m$$

$$B_I = \frac{\mu_0 I}{2\pi r} \ \text{Tesla}$$

$$\boxed{\vec{B} = \mu_0 \vec{H}}$$

Hence "minimum current that can be passed in a specimen without destroying its superconductivity is called critical current"

$$\boxed{I_C = 2\pi r H_C}$$

H_C is critical magnetic field.

Q1 Calculate the critical current, critical current density and critical magnetic field of Lead sample of diameter 1mm at 4.2K. The critical Temperature is 7.18K and critical magnetic field at 0K is $6.5 \times 10^4 \ Am^{-1}$.

$$H_c = H_0\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

$T = 4.2\,K$

$T_c = 7.18\,K$

$H_0 = 6.5\times10^4\,Am^{-1}$

$$H_c = 6.5\times10^4\left[1-\left(\frac{4.2}{7.18}\right)^2\right] = 4.276\times10^4\,Am^{-1}$$

Critical current

$$I_c = 2\pi r H_c$$

$$I_c = 2\times3.14\times\left(\frac{1}{2}\times10^{-3}m\right)\times4.276\times10^4\,Am^{-1}$$

$$= 134.3\,A$$

Critical current density

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

$$J_c = \frac{2\times4.276\times10^4}{0.5\times10^{-3}} = 1.71\times10^8\,A/m^2$$

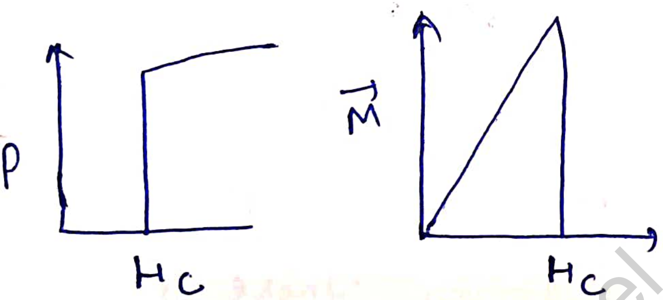
Persistent current :- If current is set up in a perfect superconductor, it can persiste for a long time without any applied emf.

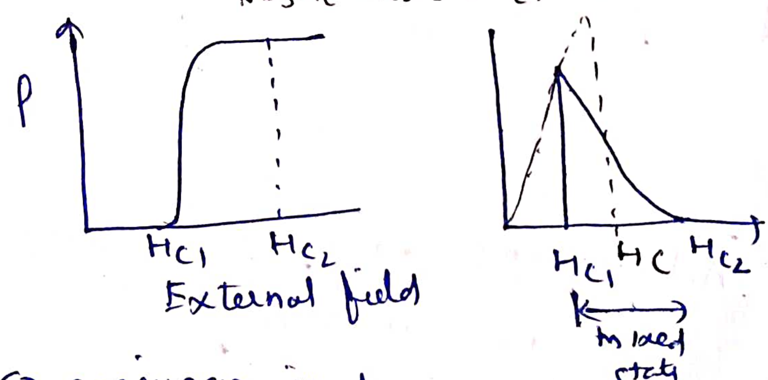
A current can be induced in a ring of superconducting material by cooling them in a magnetic field below a transition temperature and then by switching off the field.

When we switch off the field the flux outside the ring disappears. but the inside the ring it will trapped and leads to current flow for ~~too~~ long time up to 10^5 years

Types of super conductor. according to behaviour in external magnetic field.

(1) Type 1 (soft) super conductor	Type II (hard) super conductor
* This type of super conductor called soft super conductor	* Type II super conductor are called Hard super conductor
	* losses magnetization gradually rather than suddenly.
* They exhibit complete Meissner effect or they never allow a magnetic flux density to exist in its interior	* They exhibit incomplete (partially) Meissner effect or paratially admit magnetic flux density and have zero resistivity.
* They behave as perfect diamagnetic	* These super conductor have two critical fields called lower or upper critical field called H_{c_1} and H_{c_2}
* The critical values of magnetic field H_c at which magnetisation drops are very low.	Example - Nb-Zr, Nb-Tc alloys Nb_3Ge - 23.2 (T_c)





* The maximum known critical field for type 1 superconductors are of the order of 0.1 Tesla (1000 gauss)	* speciman is diamagnetic below H_{c_1} (Magnetic fields completely excluded)
* Low value of H_c makes these material unsuitable for use in high field superconducting magnets.	* At H_{c_1} the flux ~~begins to~~ beings to penetrate and the penetration of flux increase untill the upper critical field H_{c_2} is reached.
	* The value of H_{c_2} for type II material may be 100 times then H_c of

High temperature Super conductor

Those super Conductor mainly called metal-alloys having transition Temperature above 40k.

In 1987 the compound of yittrium barium copper oxide was found to have a super conductivity temperature nearly 90k.

Most high T_c materials are type II

In $YBa_2Cu_3O_7$ unit cell there will be one atom of a rare earth metal, two barium atoms, three copper atoms and seven oxygen atom also known as Y123.

other known High T_c super conductor are

$BiSrCaCuO$ - 110 k

$Tl_2Ba_2Cu_3O_{10}$ - 125 k

Advantage → High temperature super conductor can be cooled by using liquid Nitrogen where as the previously known super conductors require expensive and hard to handle the coolants like liquid Helium.

Application - Since They retain their super conductivity in higher magnetic field, They are used for constructing super conducting magnets.