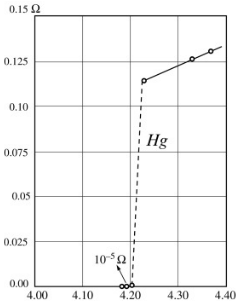
SUPERCONDUCTIVITY

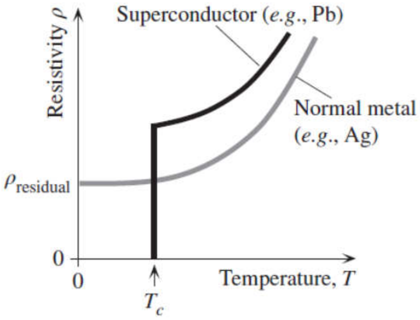
Superconductivity

- Superconductivity is a phenomenon in which the resistance of the material to the electric current flow is zero.
- Kamerlingh Onnes made the first discovery of the phenomenon in 1911 in mercury (Hg).



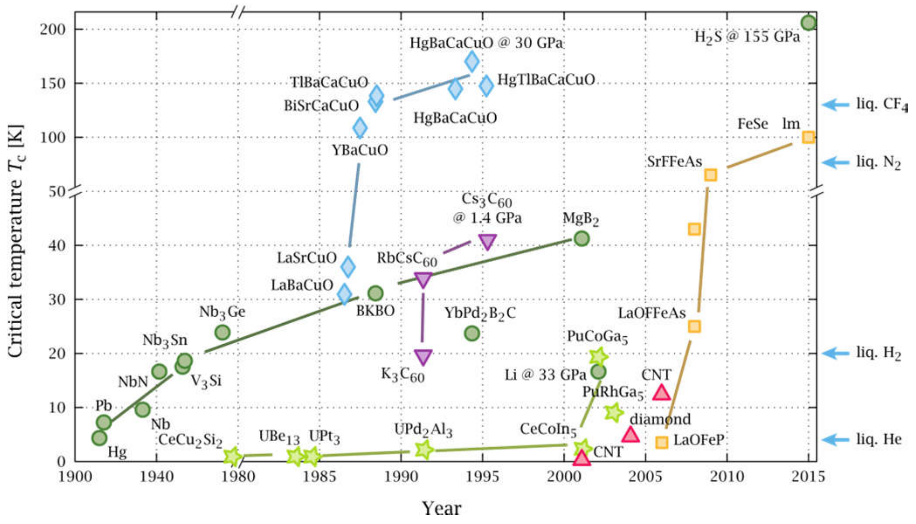
- Superconductivity is not relatable to periodic table, such as atomic number, atomic weight, electro-negativity, ionization potential etc.
- In fact, superconductivity does not even correlate with normal conductivity. In some cases, a superconducting compound may be formed from non-superconducting elements.

Critical Temperature



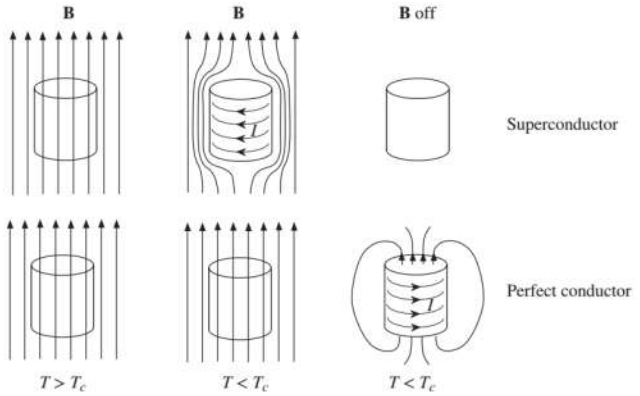
- The quest for a near-roomtemperature superconductor goes on, with many scientists around the world trying different materials, or synthesizing them, to raise T_c even higher.
- Silver, gold and copper do not show conductivity → at low temperature, resistivity is limited by scattering and crystal defects.

Critical Temperature



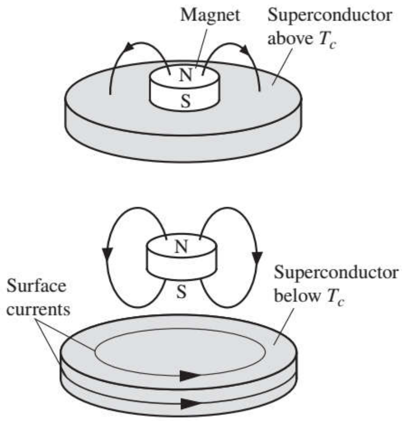
Meissner Effect

- A superconductor below T_c expels all the magnetic field from the bulk of the sample → perfectly diamagnetic substance → **Meissner effect.**
- Below T_c a superconductor is a perfectly diamagnetic substance ($\chi m = -1$).
- A superconductor with little or no magnetic field within it is in the Meissner state.

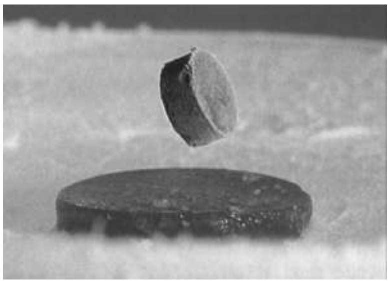


Levitating Magnet

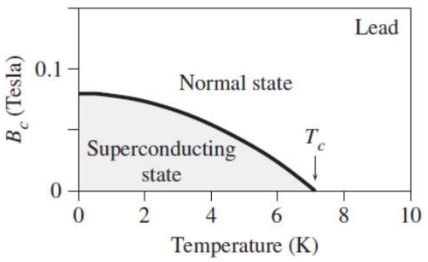
- The "no magnetic field inside a superconductor" levitates a magnet over a superconductor.

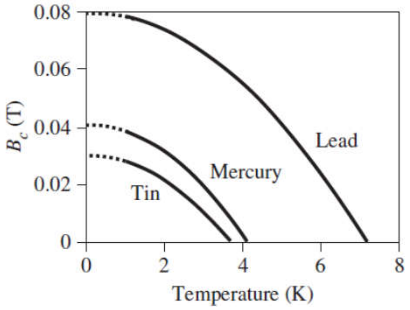


- A magnet levitating above a superconductor immersed in liquid nitrogen (77 K).



Critical Field vs. Temperature





Penetration Depth

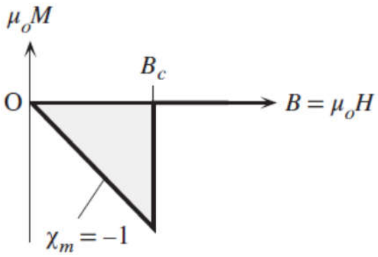
- The field at a distance *x* from the surface:

$B(x) = B_0 \left(-\frac{x}{\lambda}\right)$ λ: Penetration depth

- At the critical temperature, the penetration length is infinite and any magnetic field can penetrate the sample and destroy the superconducting state.
- Near absolute zero of temperature, however, typical penetration depths are 10–100 nm.

Type I Superconductors

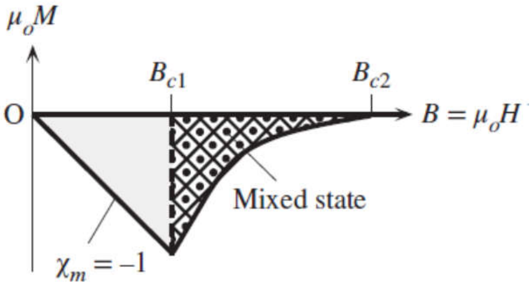
- Meissner state breaks down abruptly.
- In Type I superconductors, as the applied magnetic field *B* increases, so does the opposing magnetization *M* until the field reaches the critical field *Bc*, whereupon the superconductivity disappears.



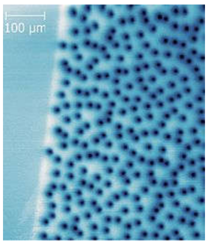
- Most pure elemental superconductors (aluminium, lead, and mercury.), except niobium and carbon nanotubes, are type I.

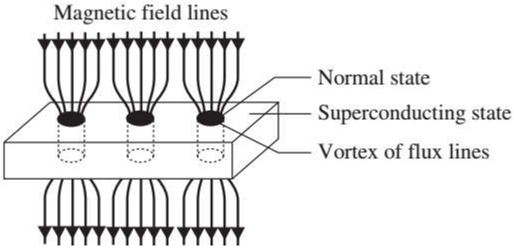
Type II Superconductors

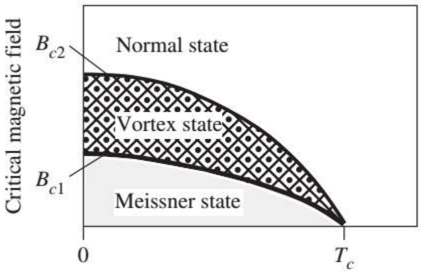
- The transition does not occur sharply from the Meissner state to the normal state but goes through an intermediate phase in which the applied field is able to pierce through certain local regions of the sample.
- The mixed state is also called a vortex state.
- Type II superconductors therefore have two critical fields *Bc*1 and *Bc*2.



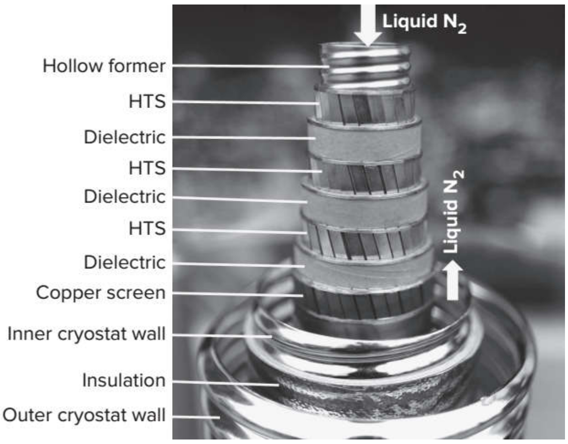
Type II Superconductors







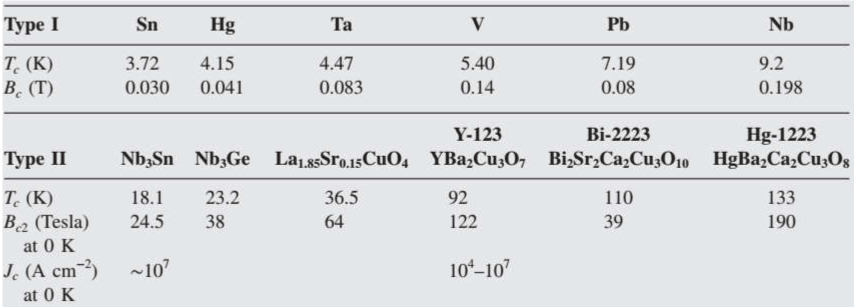
High Temperature Superconductors



- A HTS (Bi223) power cable for use at 10 kV and 2,300 A in Germany since 2014.

Critical Current Density

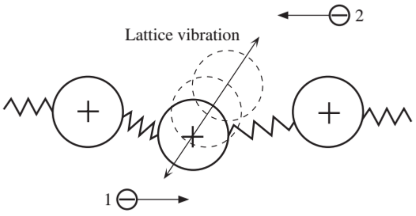
- When the current density through the sample exceeds a critical value J_c, it is found that superconductivity disappears.
- J_c is very high for type II superconductors.



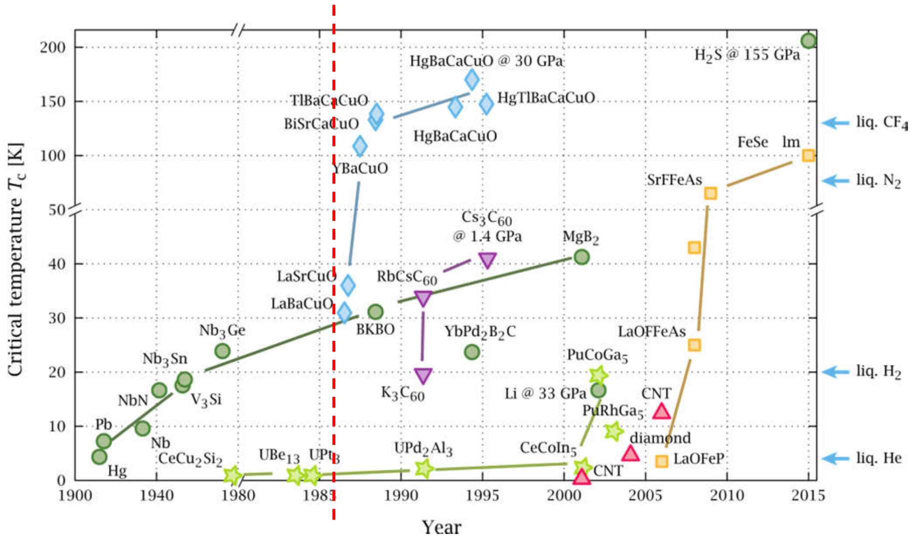
Type I	**Sn**	**Hg**	**Ta**	**V**	**Pb**	**Nb**
T_c (K)	3.72	4.15	4.47	5.40	7.19	9.2
B_c (T)	0.030	0.041	0.083	0.14	0.08	0.198
Type II	**Nb_3Sn**	**Nb_3Ge**	**$La_{1.85}Sr_{0.15}CuO_4$**	**Y-123** **$YBa_2Cu_3O_7$**	**Bi-2223** **$Bi_2Sr_2Ca_2Cu_3O_{10}$**	**Hg-1223** **$HgBa_2Ca_2Cu_3O_8$**
T_c (K)	18.1	23.2	36.5	92	110	133
B_{c2} (Tesla) at 0 K	24.5	38	64	122	39	190
J_c (A cm^{-2}) at 0 K	~10^7			10^4–10^7		

Superconductivity Origin

- **Bardeen, Cooper, and Schrieffer (BCS) Theory:**
- At sufficiently low temperatures, two oppositely spinning and oppositely traveling electrons can attract each other indirectly through the deformation of the crystal lattice of positive metal ions.
- This indirect interaction at sufficiently low temperatures is able to overcome the mutual Coulombic repulsion between the electrons and hence bind the two electrons to each other.
- The two electrons are called a **Cooper pair.**



Critical Temperature



- BCS theory applies.
- Accurate theory is still challenging.