Superconductivity

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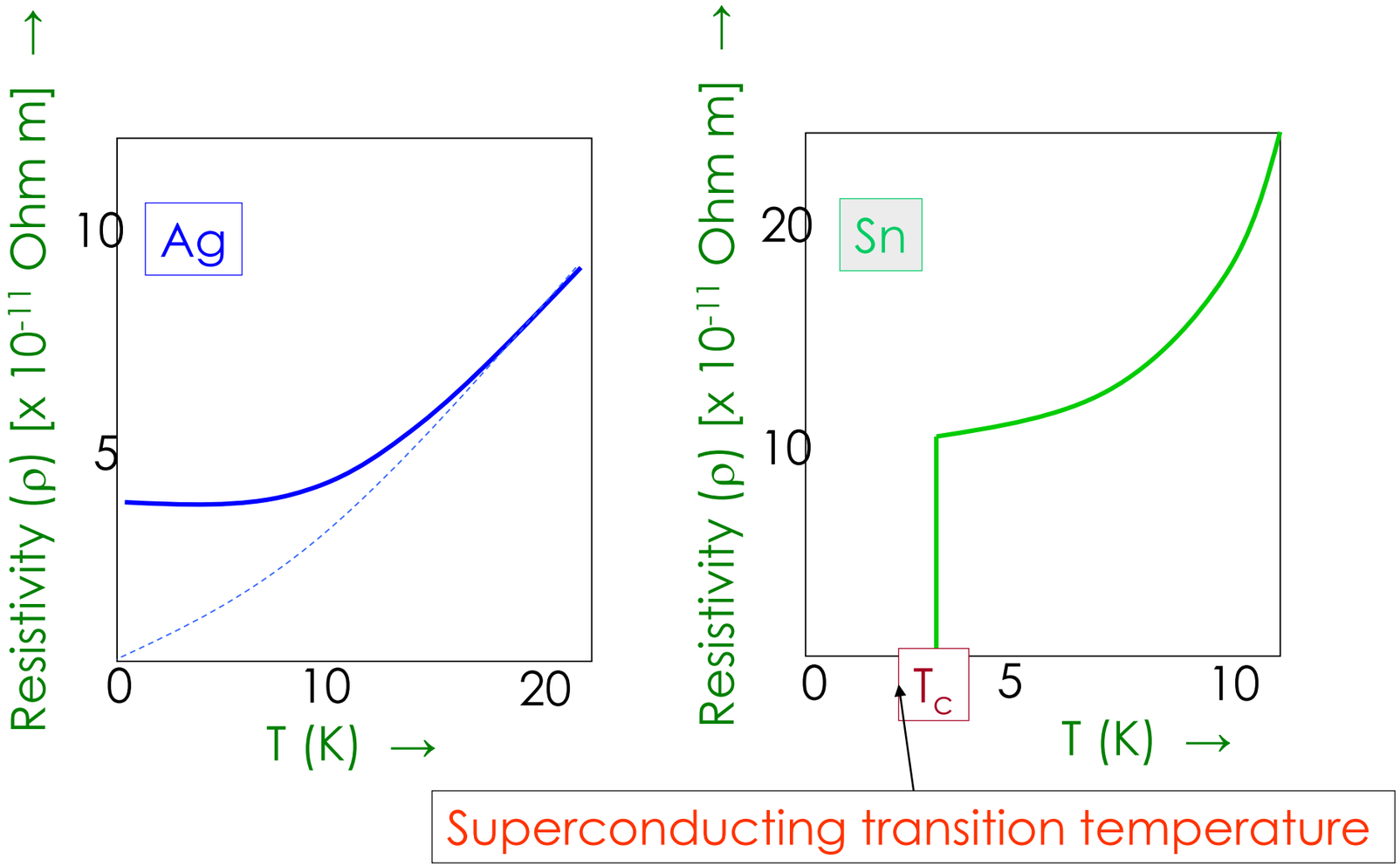
What is superconductivity?

Superconductors shows

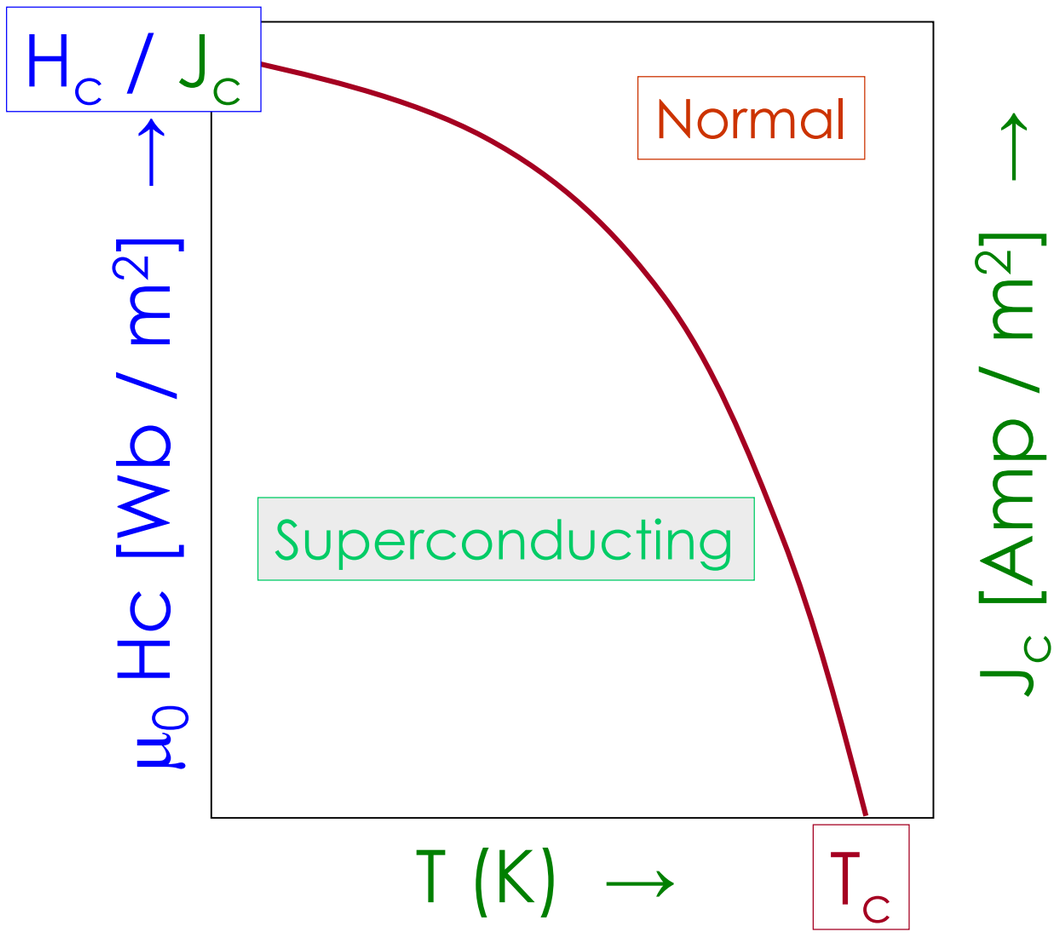
Zero resistivity or

Infinite conductivity below a certain temperature called as critical temperature.



Current carrying capacity

The maximum current a superconductor can carry is limited by the magnetic field that it produces at the surface of the superconductor



Superconducting state if

$T < T_c$

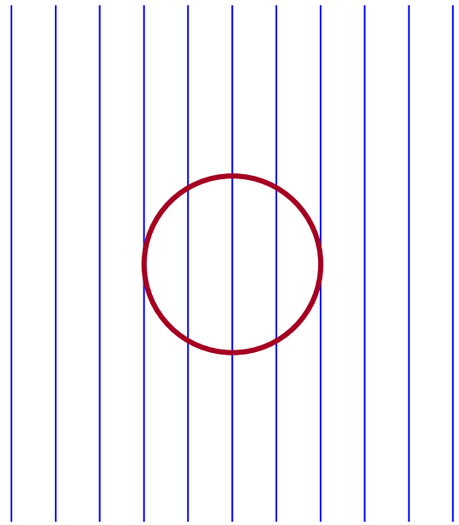
$J < J_c$

$H < H_c$

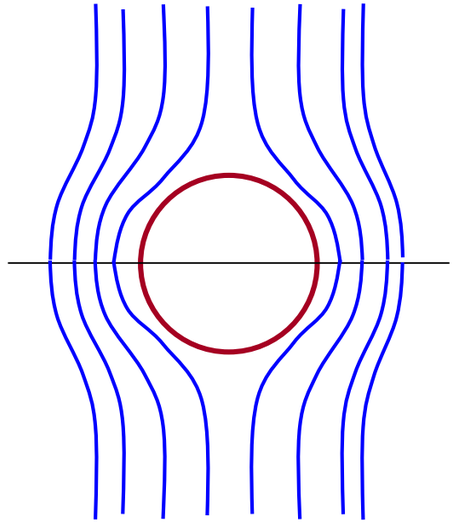
Meissner effect

How to identify a superconductor?

- A superconductor is a perfect diamagnet.
- Magnetic susceptibility $\chi = -1$.
- Flux lines of the magnetic field are excluded out of the superconductor ⇨ Meissner effect



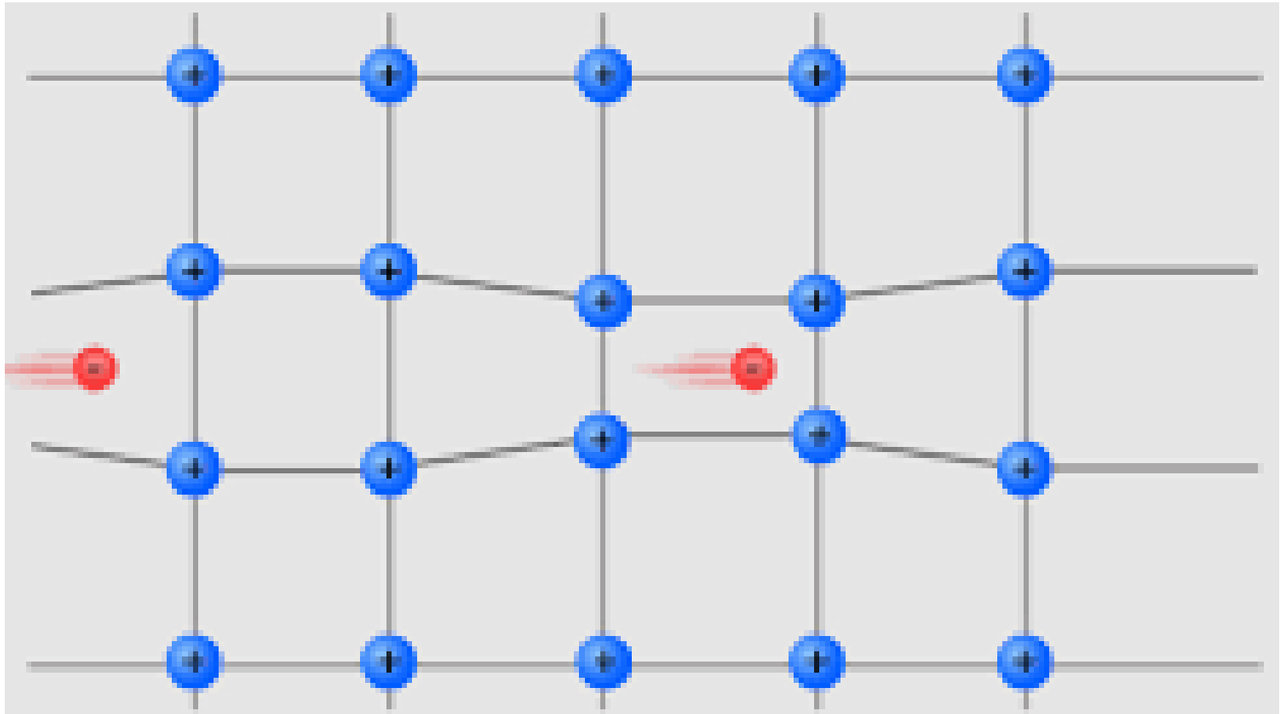
Normal



Superconducting

Electron- Lattice Interaction

1. Phonon is a quanta of lattice vibrations.
2. Analogous to photon – a quanta of light.
3. Produced by a distortion due to lattice vibrations.
4. Can interact with another phonon or electrons.



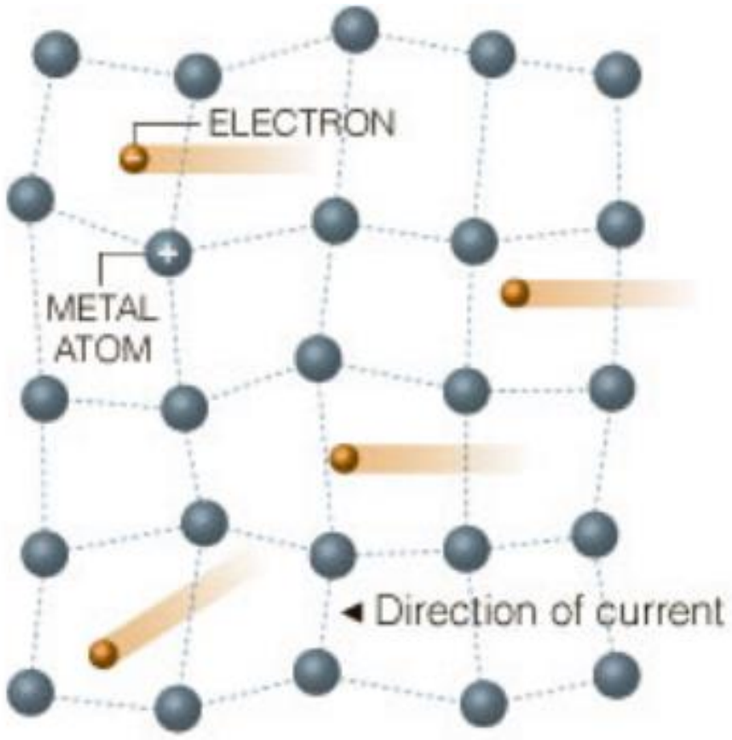
Bardeen-Cooper-Schreiffer (BCS) theory

How superconductors shows zero resistivity?

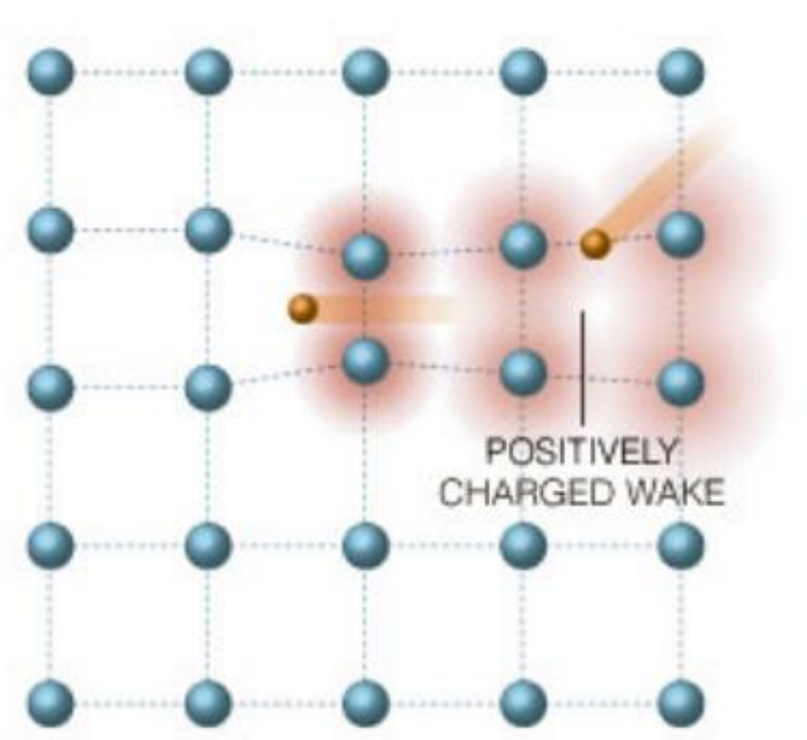
1. Phonon scattering due to lattice vibrations felt by one electron in the Cooper pair is nullified by the other electron in the pair.
2. The electron pair moves through the lattice without getting scattered by the lattice vibrations.
3. The force of attraction between the electrons in the Cooper pair is stronger than the repulsive force between the electrons when $T < Tc$.

Three-way interaction between two electron and a phonon.

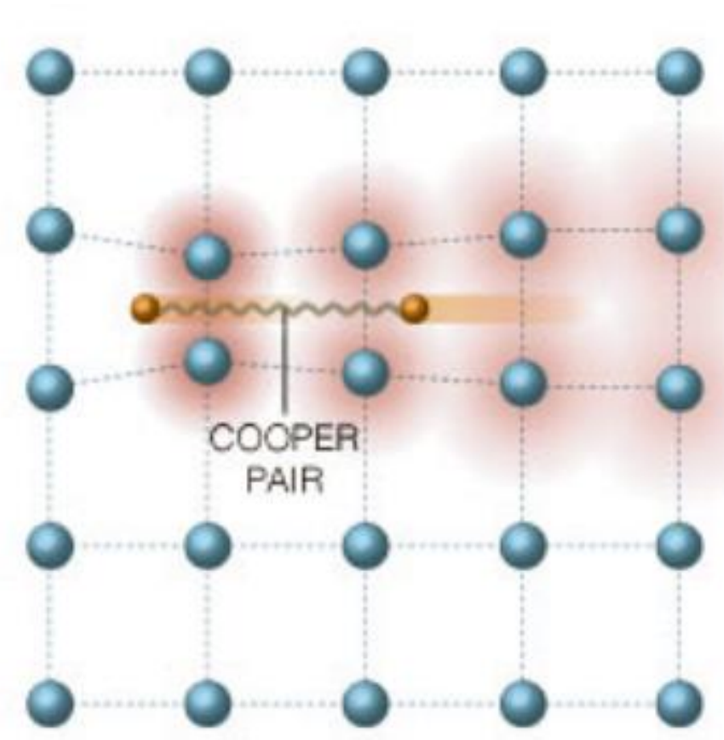
Cooper pair



Normal state



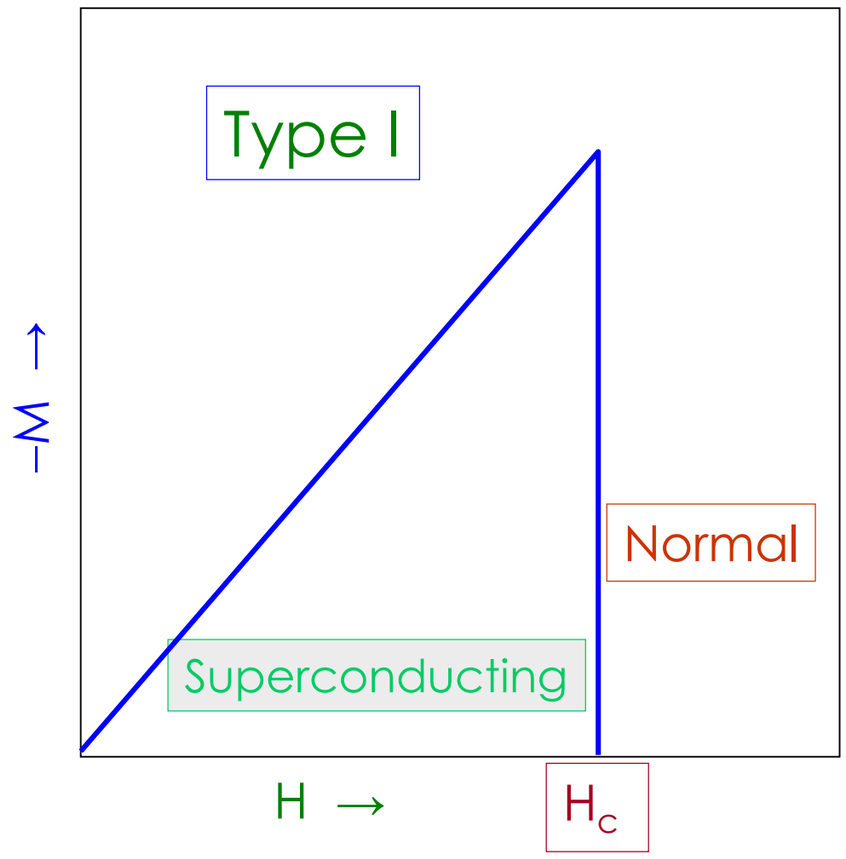
At Tc



Superconducting state

Type-I (Ideal) superconductors

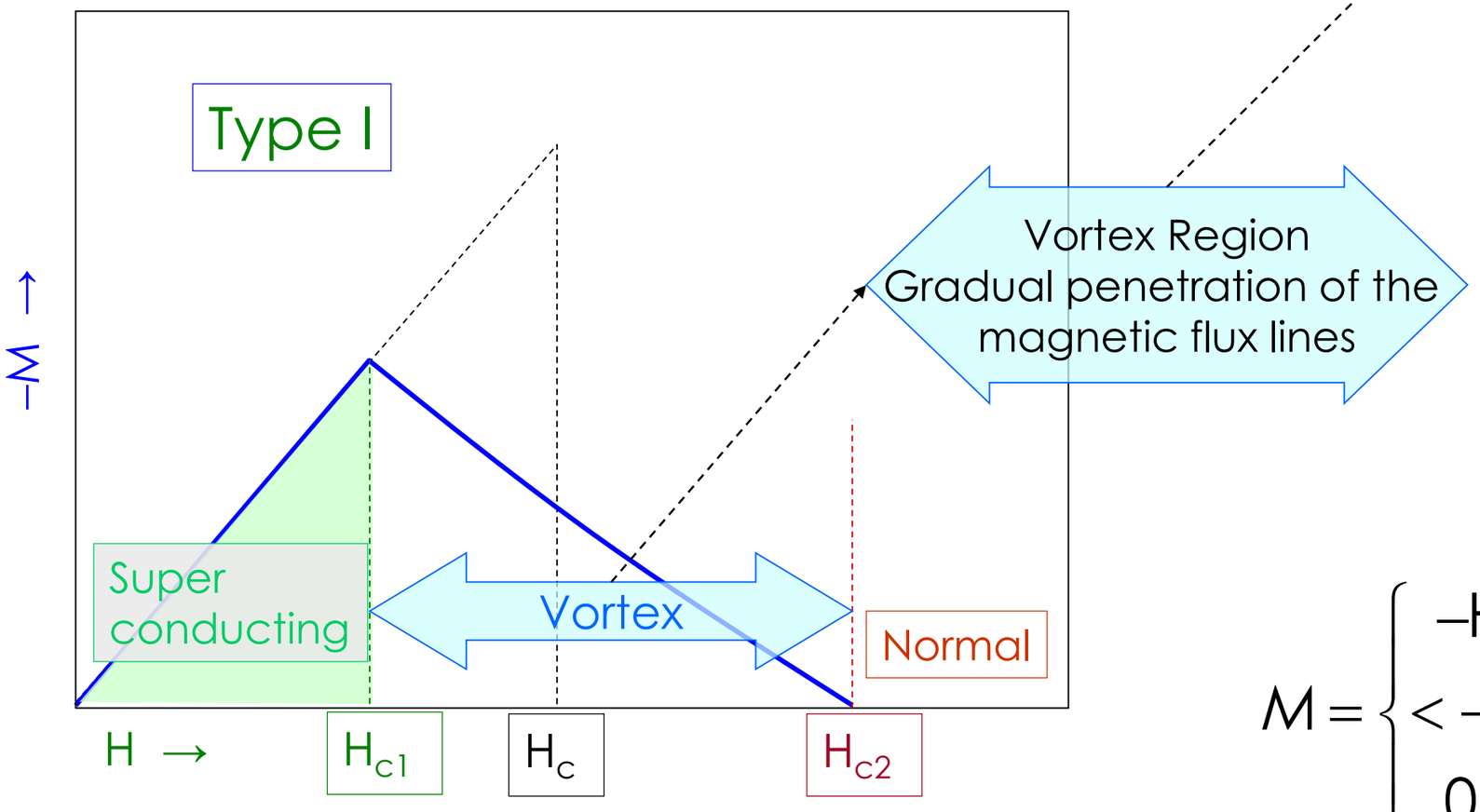
Type I SC placed in a magnetic field totally repels the flux lines till the magnetic field attains the critical value H_c

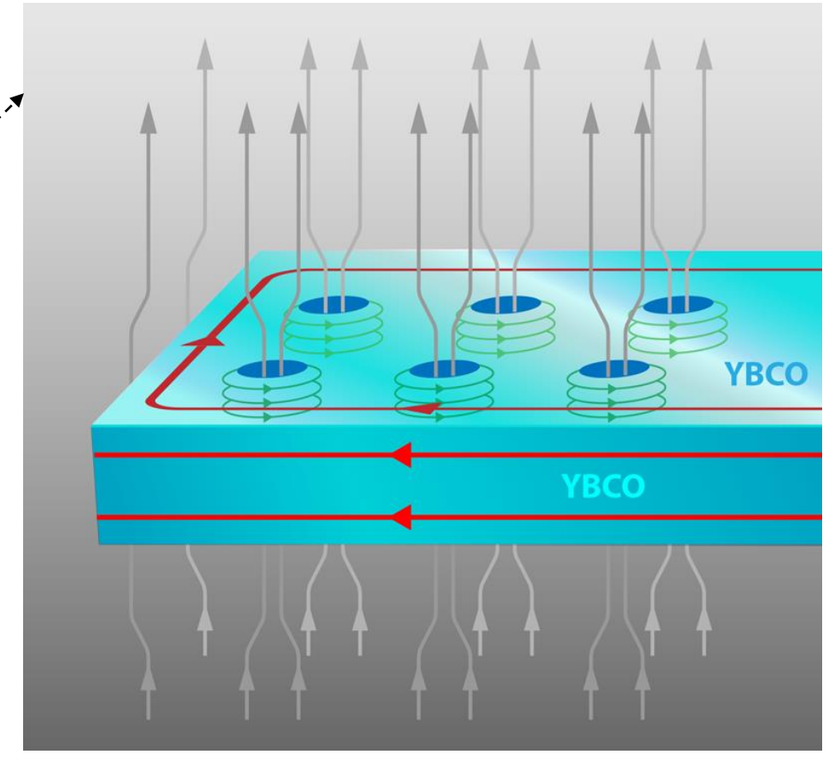


$$M = \begin{cases} -H & \rightarrow \quad H < H_c \\ 0 & \rightarrow \quad H > H_c \end{cases}$$

Type-II (Hard) superconductors

Type II superconductor has three regions





$$M = \begin{cases} -H & \rightarrow & H < H_{c1} \\ < -H & \rightarrow & H \in (H_{c1}, H_{c2}) \\ 0 & \rightarrow & H > H_{c2} \end{cases}$$

Type-II (Hard) superconductors

- As type II SC can carry high current densities *(J_c)* they are of great practical importance

- The penetration characteristics of the magnetic flux lines *(between H_{c1} and H_{c2})* is a function of the microstructure of the material ⇨ presence of pinning centers in the material.

- Pinning centers:

⇨ Cell walls of high dislocation density
(cold worked/recovery annealed)

⇨ Grain boundaries
(Fine grained material)

⇨ Precipitates
(Dispersion of very fine precipitates with interparticle spacing ~ 300 Å)

Applications of superconductors

- Strong magnetic fields → 50 Tesla
  (without heating, without large power input)
- Logic and storage functions in computers
  Josephson junction → fast switching times (~ 10 ps)
- Magnetic levitation (arising from Meissner effect)
- Power transmission

Comparison

	Type I superconductors	Type II superconductors
1	Soft superconductors- can tolerate impurities without affecting properties.	Hard superconductors- cannot tolerate impurities and affects the properties.
2	Low critical field (0.1 T)	High critical field (30 T)
3	Show complete Meissner effect.	Traps magnetic flux, hence, incomplete Meissner effect.
5	Sudden loss of magnetization.	Gradual loss of magnetization.
6	Current flows through the surface only.	Current flows throughout the material.
6	e.g. Tin, Aluminum, Zinc	e.g. Tantalum, Neobium, NbN

High temperature superconductors

Compound	T_c	Comments
Nb_3Ge	23 K	Till 1986
La-Ba-Cu-O	34 K	Bednorz and Mueller (1986)
$YBa_2Cu_3O_{7-x}$	90 K	> Boiling point of Liquid N_2
Tl (Bi)-Ba(Sr)-Ca-Cu-O	125 K	
H_2S	203 K	Gas solidifies on application of high pressure (in Gpa)

Summary

1. Superconductors shows zero resistance below a certain temperature.
2. The superconducting state is limited by a temperature, current and magnetic field called as critical temperature, critical current and critical field.
3. In superconductors, the electrical conduction takes place by a pair of electrons, called as Cooper pair.
4. Type- I superconductors are perfectly diamagnetic and shows Meissner effect.
5. Type-II superconductors are not perfectly diamagnetic and do not show complete Meissner effect.