DSE CLASS

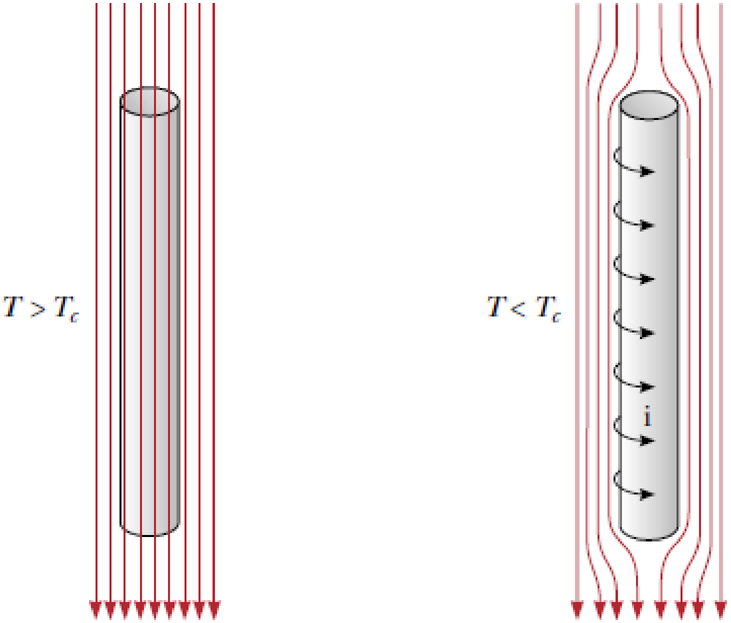
CONDENSED MATTER PHYSICS

Lecture-3

17/09/2020

Superconductors

- Carry current perfectly
- Do not lose energy
- Current in a loop will run *forever*
- **Expel magnetic fields (Meissner effect)**



A good conductor expels static electric fields by moving charges to its surface.

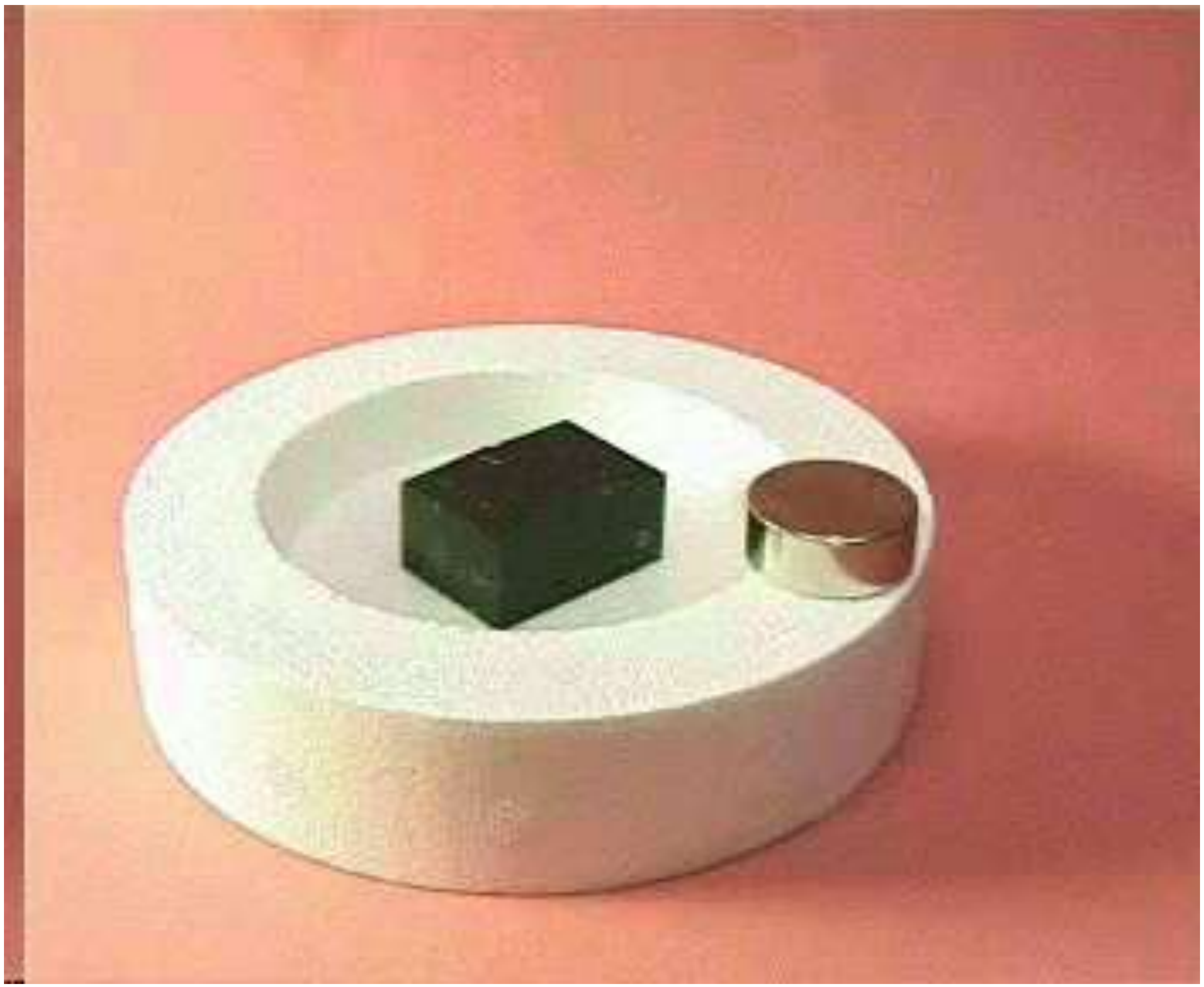
In effect, the surface charges produce an electric field that exactly cancels the externally applied field inside the conductor.

In a similar manner, a superconductor expels magnetic fields by forming surface currents.

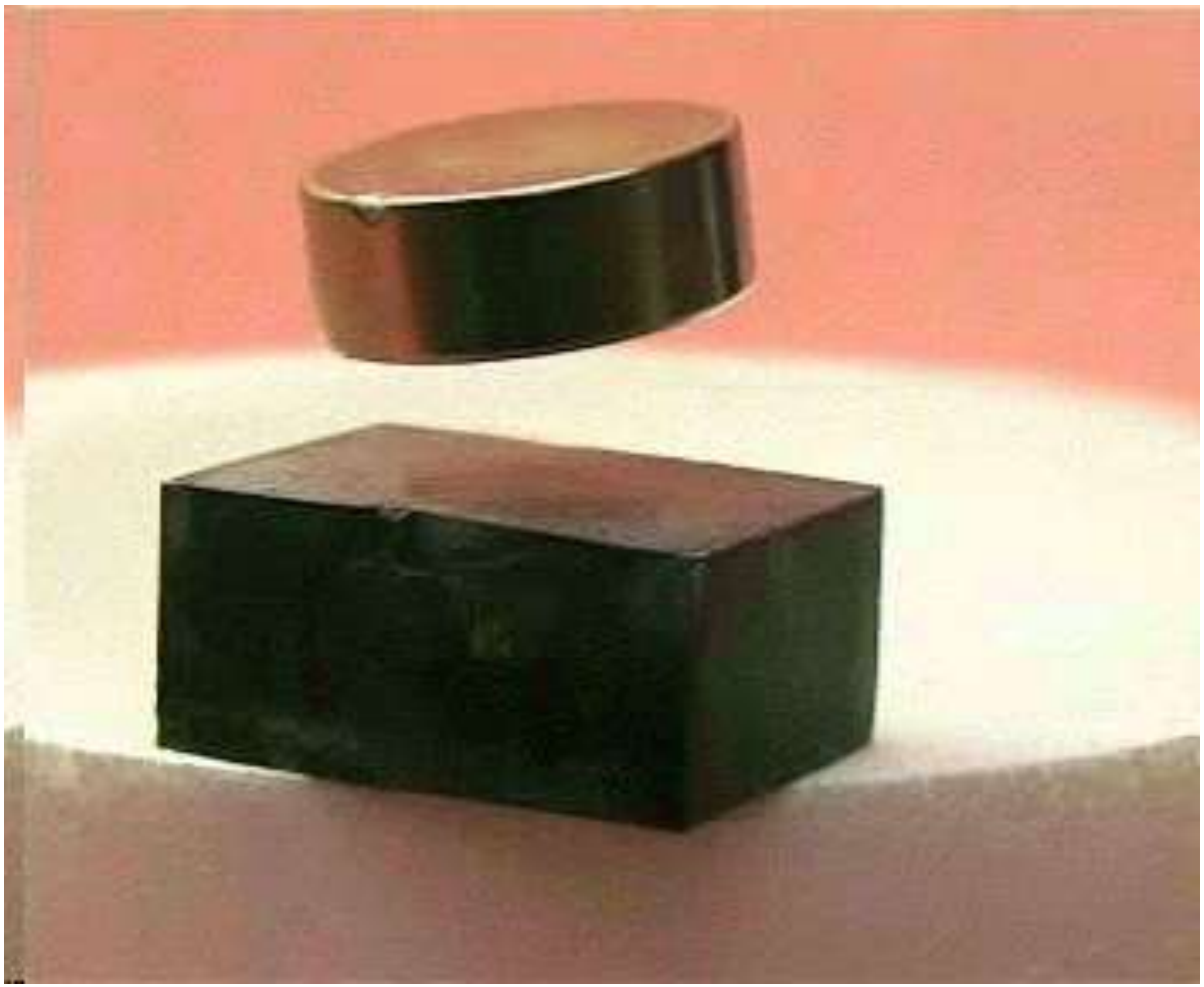
In this case, surface currents are induced on the superconductor, producing a magnetic field that exactly cancels the externally applied field inside the superconductor.

The surface currents disappear when the external magnetic field is removed.

Levitation



Levitation



Magnetic-levitation is an application of superconductors.

Transport vehicles such as trains can be made to "float" on strong superconducting magnets, virtually eliminating friction between the train and its tracks.

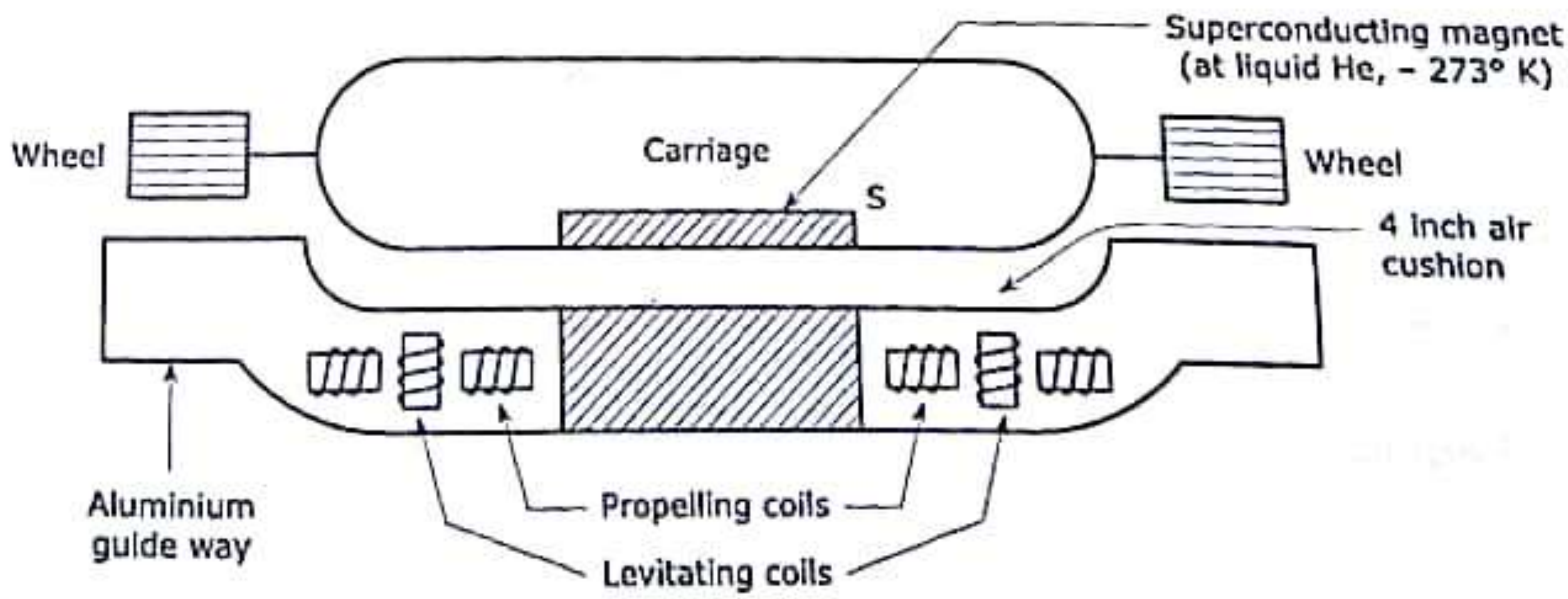
A landmark for the commercial use of MAGLEV technology occurred in 1990 when it gained the status of a nationally-funded project in Japan.

The Japanese Maglev: World's fastest bullet train

603 km/hour

MAGLEV is an acronym of magnetic levitation.

The coaches of the train do not slide over steel rails but float above the track using Meissner effect of super conducting magnets.



- The train has a superconducting magnet built into the base of the carriages.
- An aluminium guide way is laid on the ground and carriers electric current.
- The walls of the guide way have a series of horizontal and vertical coils mounted inside the guide way. These coils are made up of normal conductors
- The current flowing through its horizontal coils produce a vertical magnetic field. By Meissner effect the superconducting magnet S expels the vertical magnetic flux. This levitates the train and keeps it afloat.
- On the other hand current passing through the vertical coil produce a horizontal magnetic field which pushes the train forward. Thus the vertical coils are called propelling coils.

Effect of Magnetic Field

Critical magnetic field (H_C) – Minimum magnetic field required to destroy the superconducting property at any temperature

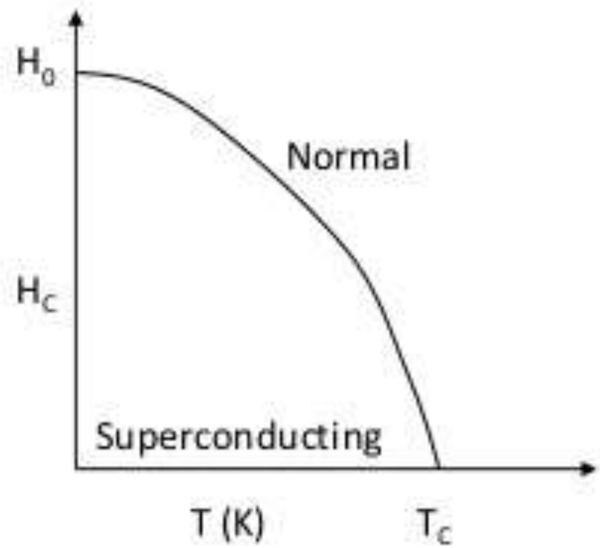
Element	H_C at 0K (mT)
Nb	198
Pb	80.3
Sn	30.9

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

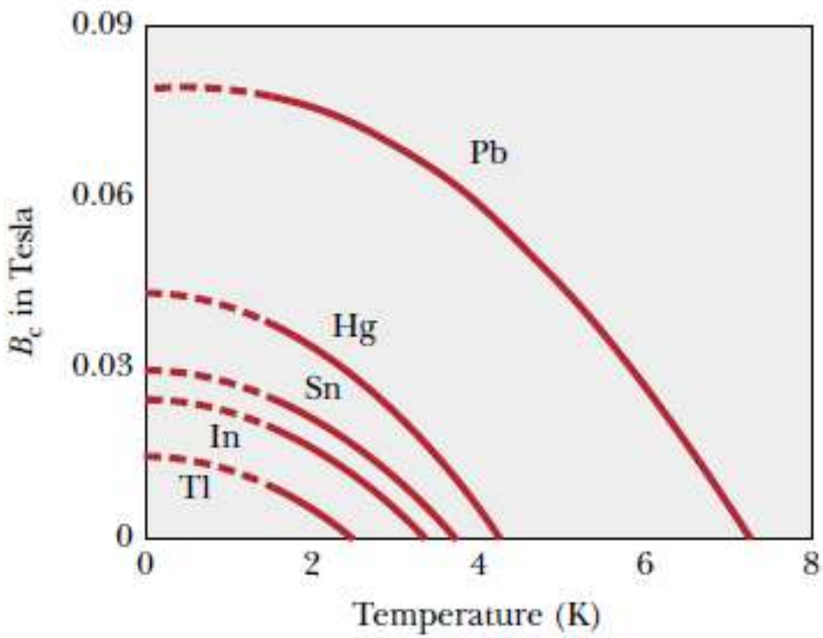
H_0 – Critical field at 0K

T - Temperature below T_C

T_C - Transition Temperature



Superconductor	T_c (K)	$B_c(0)$ (T)
Al	1.196	0.0105
Ga	1.083	0.0058
Hg	4.153	0.0411
In	3.408	0.0281
Nb	9.26	0.1991
Pb	7.193	0.0803
Sn	3.722	0.0305
Ta	4.47	0.0829
Ti	0.39	0.010
V	5.30	0.1023
W	0.015	0.000115
Zn	0.85	0.0054



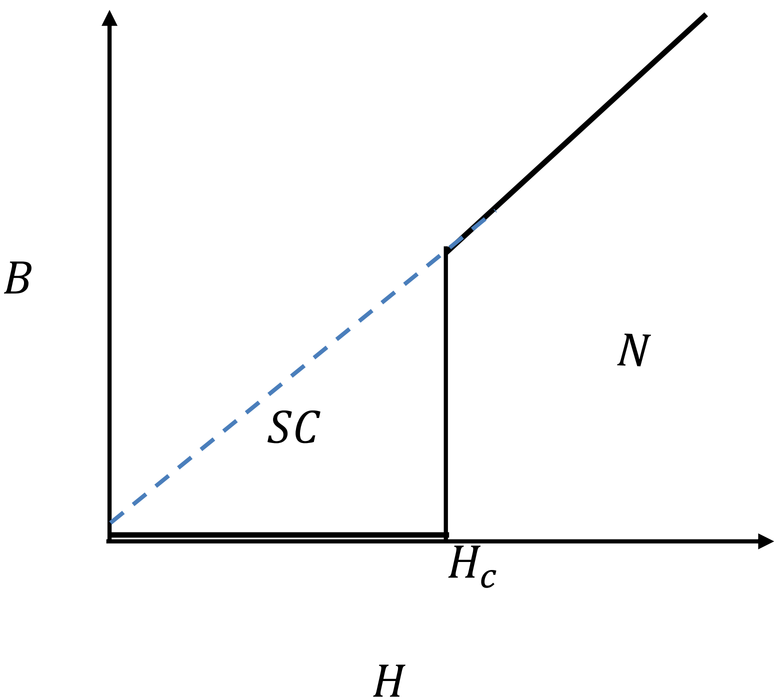
Describe state as a PERFECT DIAMAGNET :

$$\vec{B} = \mu_0(\vec{H} + \vec{M})$$ [MKS]

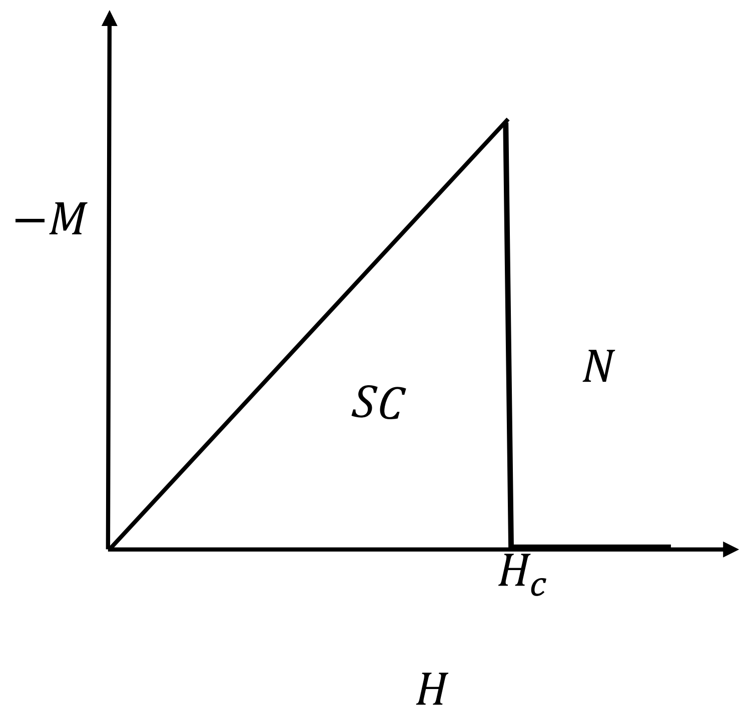
$$\vec{B} = 0 \;\rightarrow\; \vec{M} = -\vec{H}$$

$$\vec{B} = \vec{H} + 4\pi\vec{M}$$ [cgs]

$$\vec{B} = 0 \;\Longrightarrow\; \vec{M} = -\frac{1}{4\pi}\,\vec{H}$$



B-H curve



Magnetization curve

The Classification of Superconductors

Type 1 superconductors (all elementals s/c's except Nb)

Type 2 superconductors (high-T_c oxides)

Type 1 Superconductors

- Only one critical magnetic field Hc.
- They excludes magnetic field until superconductivity is destroyed suddenly at Hc, and then the field penetrates completely.
- After that, it will become like a normal conductor.
- They are also named as soft superconductors due to the reason of loss of superconductivity.
- These superconductors obey the Meissner effect completely.

Type II superconductors

Discovered in 1962 this has two critical magnetic fields.

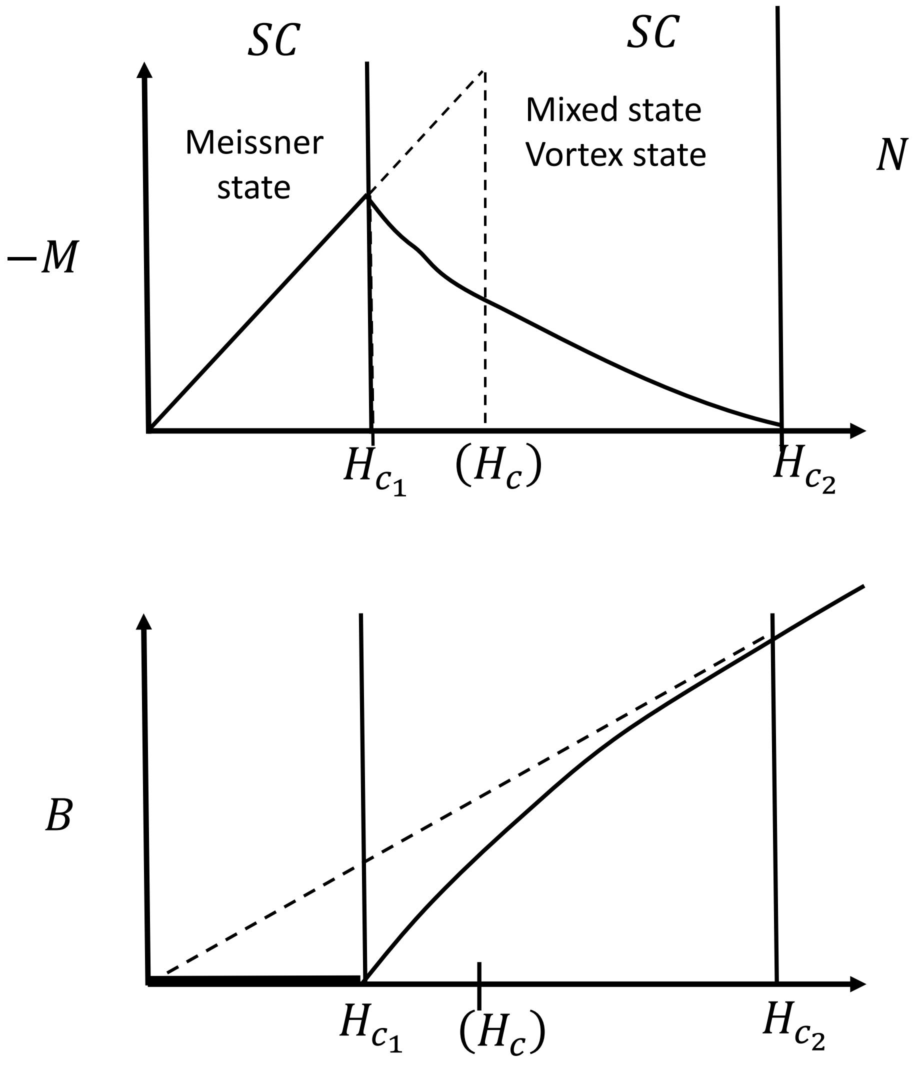
Below the first value H_{c1}, the material will be a diamagnetic superconductor.

Above the upper critical field H_{c2}, superconductivity and diamagnetism are destroyed.

However, in between the two critical magnetic fields, the superconductor exists in a mixed state where it exhibits zero electric resistance, but is no longer a perfect diamagnet.

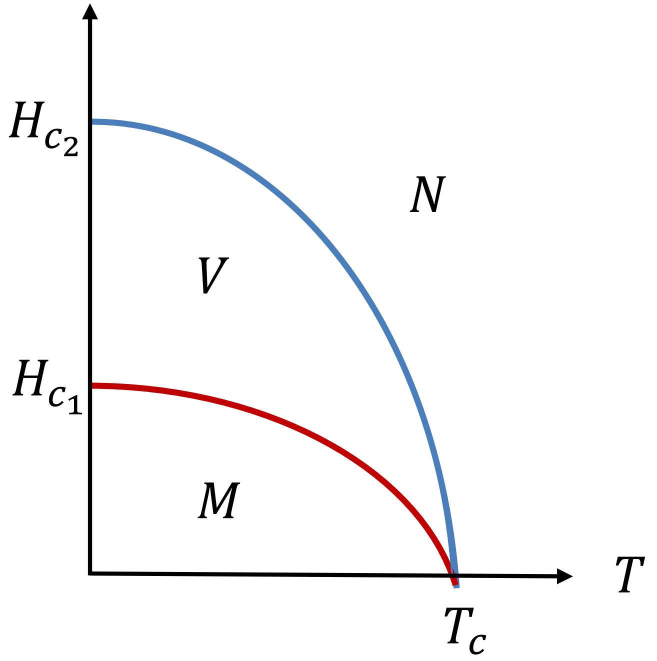
This type of semiconductor is also named as hard superconductors.

Two critical magnetic fields (Hc_1, Hc_2)

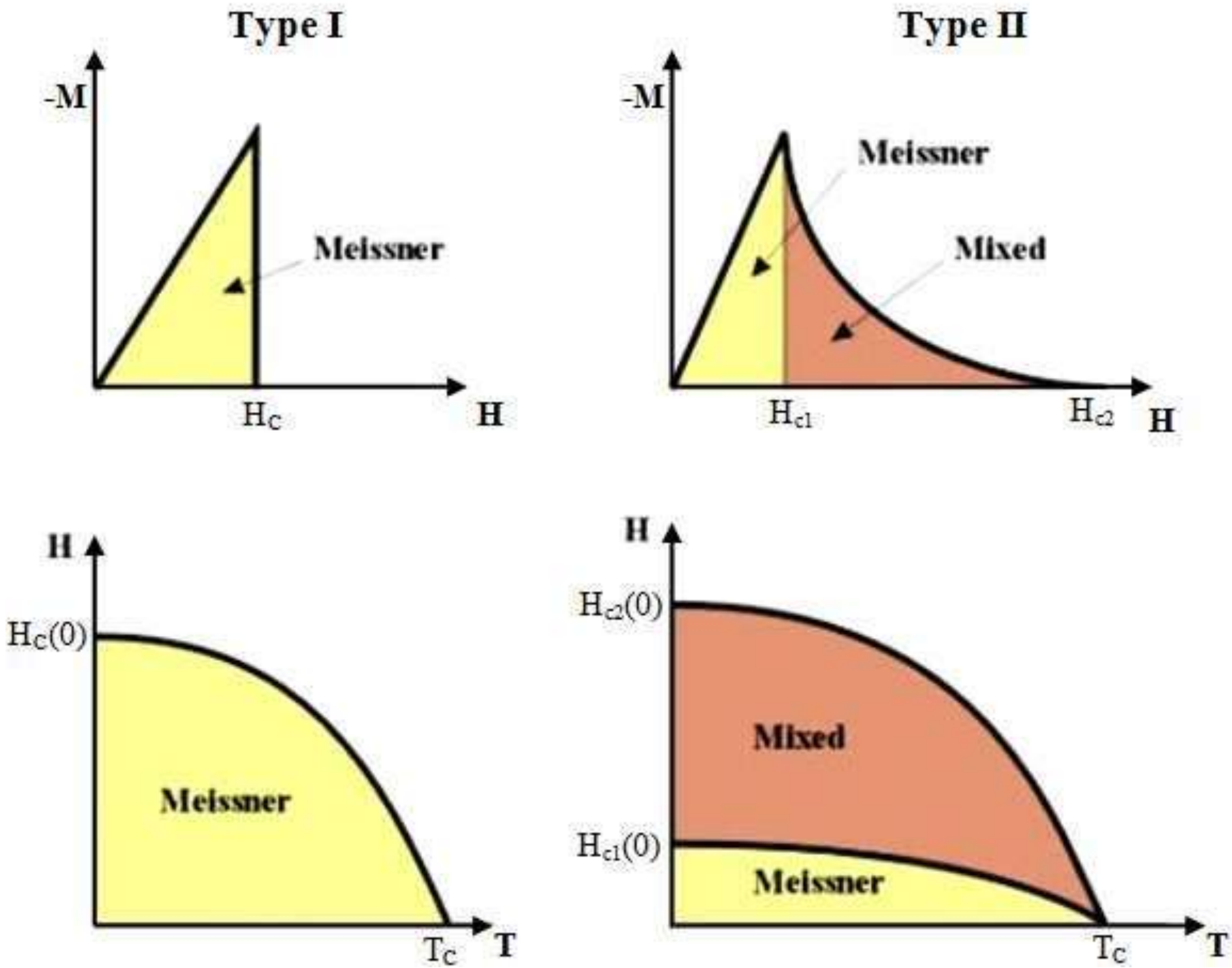


Hc_1 field starts to penetrate

Hc_2 field fully penetrates (normal state)



Superconductors

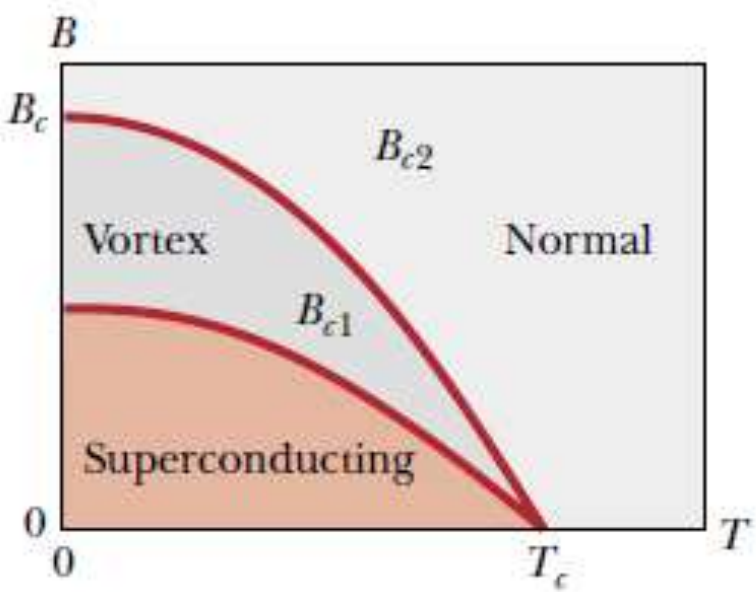


(a) A good type **II** superconductor excludes the field completely up to a field $\boldsymbol{H}c1$.

(b) Above $\boldsymbol{H}c_1$ the field is partially excluded, but the specimen remains electrically superconducting.

(c) At a much higher field, $\boldsymbol{H}c2$, the flux penetrates completely and superconductivity vanishes.

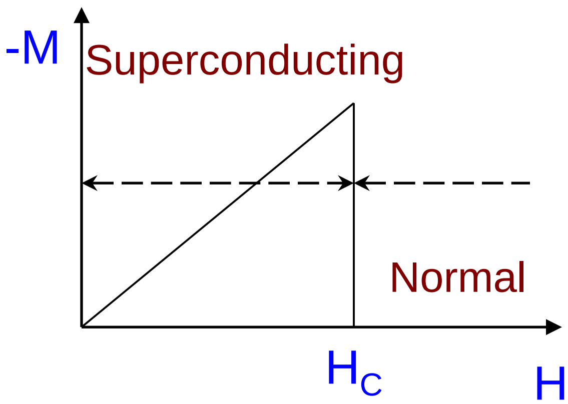
(d) An outer surface layer of the specimen may remain superconducting up to a still higher field $\boldsymbol{H}c3$.



Types of Superconductors

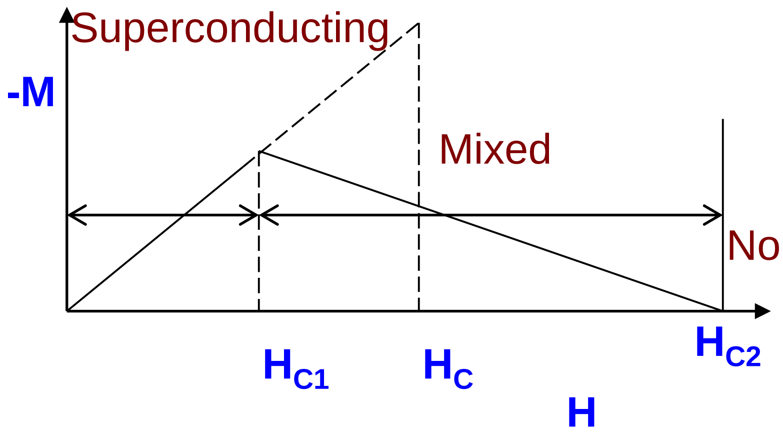
Type I

- Sudden loss of magnetisation
- Exhibit Meissner Effect
- One H_C = 0.1 tesla
- No mixed state
- Soft superconductor
- Eg.s – Pb, Sn, Hg



Type II

- Gradual loss of magnetisation
- Does not exhibit complete Meissner Effect
- Two H_C – H_{C1} & H_{C2} (≈30 tesla)
- Mixed state present
- Hard superconductor
- Eg.s – Nb-Sn, Nb-Ti



- ➢ Superconductors are characterized by a material-dependent magnetic field *H*, above which the superconducting state disappears.

- ❑ The critical field is a function of temperature. All the HTS materials are *type II superconductors*. When the applied field $H < H_{c1}$, the material is in the superconducting Meissner state whereas in the mixed state, the magnetic field penetrates partly into the material in the form of *vortices*.

- ❖ Type II superconducting materials have usually higher critical fields than type I superconductors which makes them suitable for many advanced applications.