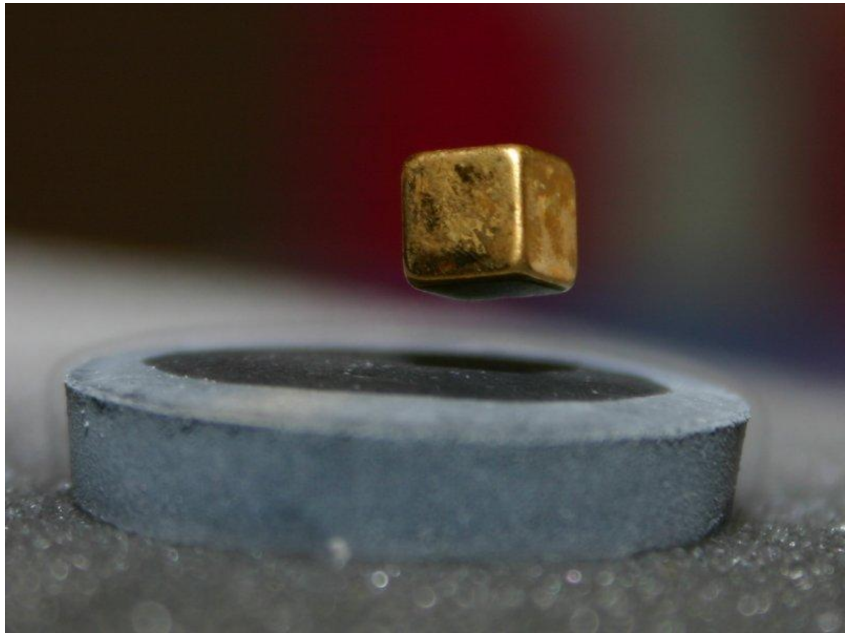
Superconductivity



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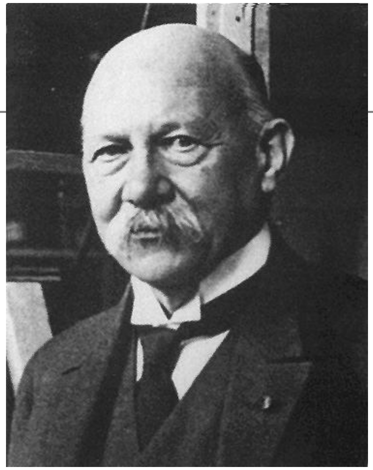
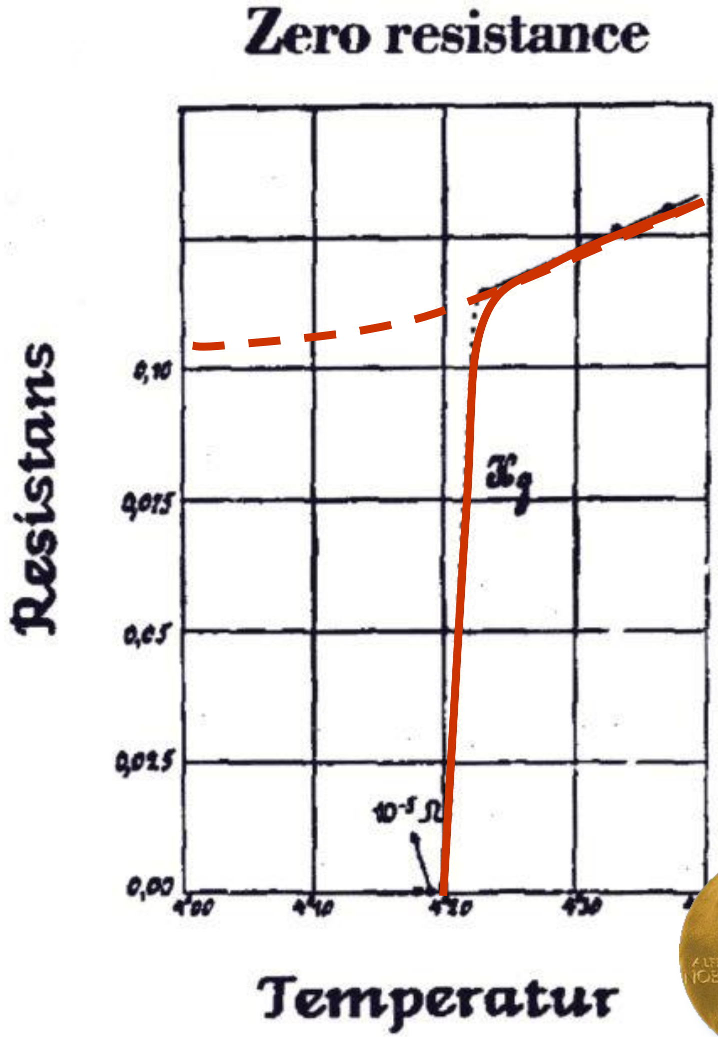
1911: discovery of superconductivity

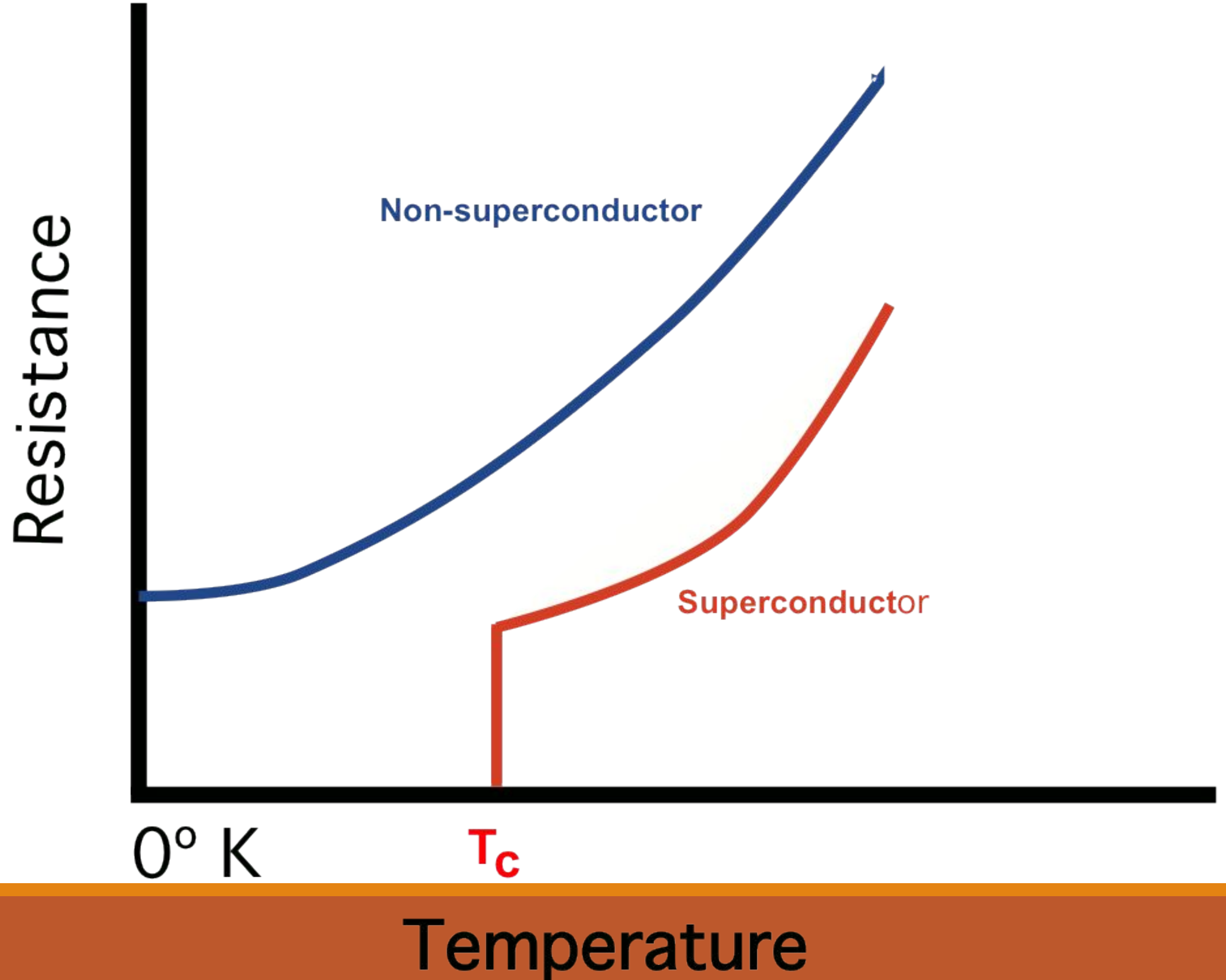


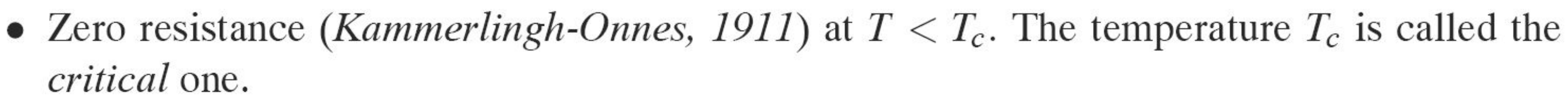
- Discovered by **Kamerlingh Onnes** in 1911 during first low temperature measurements to liquefy helium
- Whilst measuring the resistivity of “pure” Hg he noticed that the electrical resistance dropped to zero at 4.2K



1913

HOW IT DIFFER FROM OTHER METAL CONDUCTORS





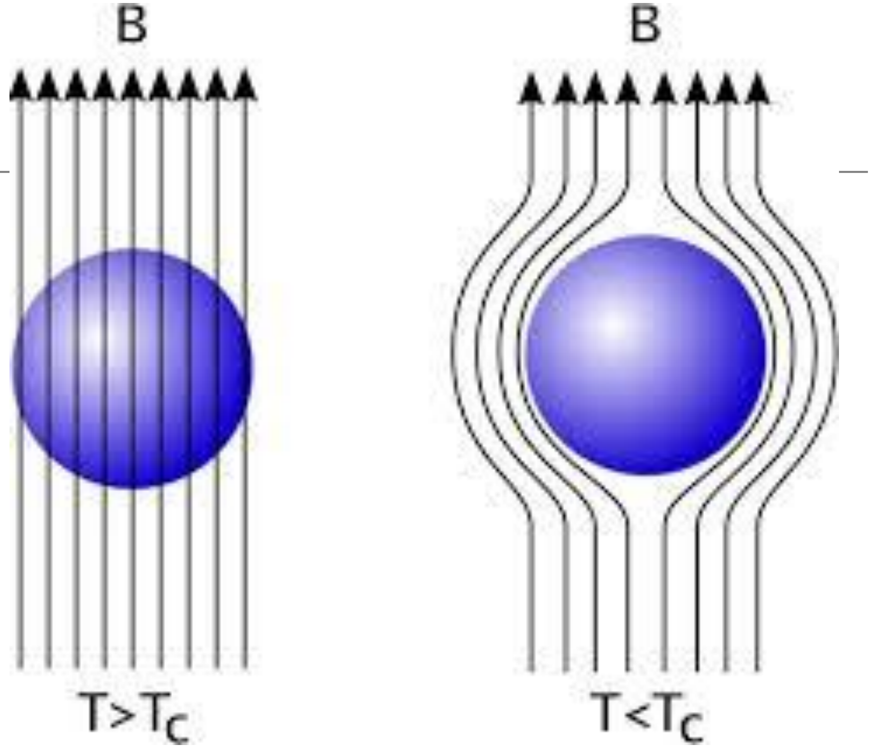
- Zero resistance (*Kammerlingh-Onnes, 1911*) at $T < T_c$. The temperature T_c is called the *critical* one.

Critical Temperatures of materials	
Mercury	4.2 K
Aluminium	1.2 K
Tin	3.7 K
Tungsten	.01 K
YBa2Cu3O7	90 K
Ceramic superconductors	125 K

THEORY OF SUPERCONDUCTIVITY (BCS)

BCS theory suggests that superconductors have zero electrical resistance below critical temperatures because at such temperatures electron pass unhindered through the crystal lattice and therefore lose energy. The theory states that super current in superconductors is caused by many millions of bound electrons called Cooper pairs.

Meissner effect



- **The Meissner effect is the expulsion of a magnetic field from a superconductor during its transition to the superconducting state.**
- **The superconductor acts as a perfect diamagnet when kept in magnetic field**
- **Meissner effect is reversible**

Meissner effect shows that in a superconductor, the magnetic flux density $B=0$

Magnetic flux density in a substance is given by

$B=\mu_0(H + M)$

Where H is the magnetic field intensity and M is the magnetization in a specimen.

Magnetization is related to magnetizing field intensity as $M=XH$ where X is the magnetic susceptibility

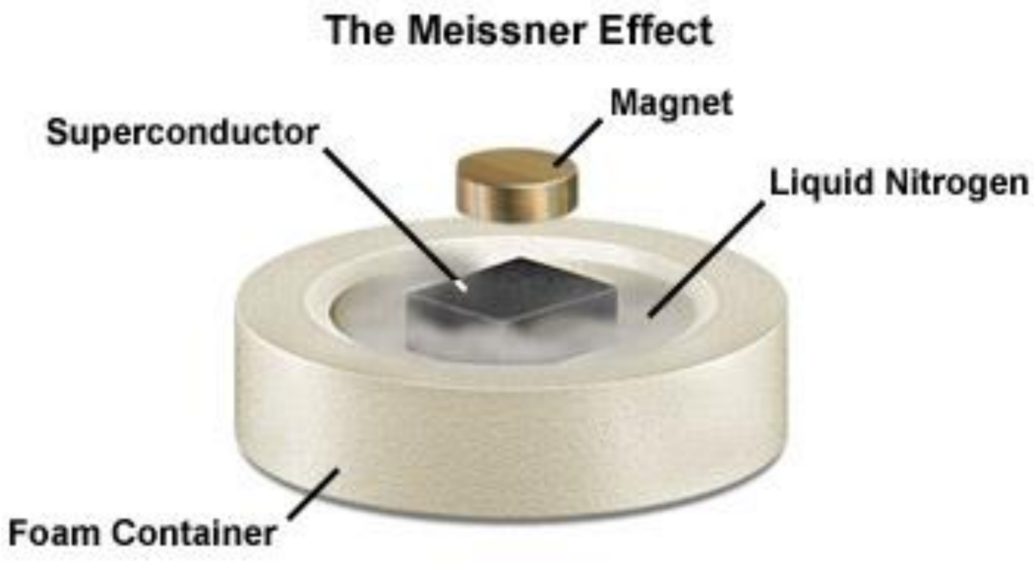
So $B=\mu_0(H + M)=\mu_0(H + XH)= \mu_0 H (1+ X)$

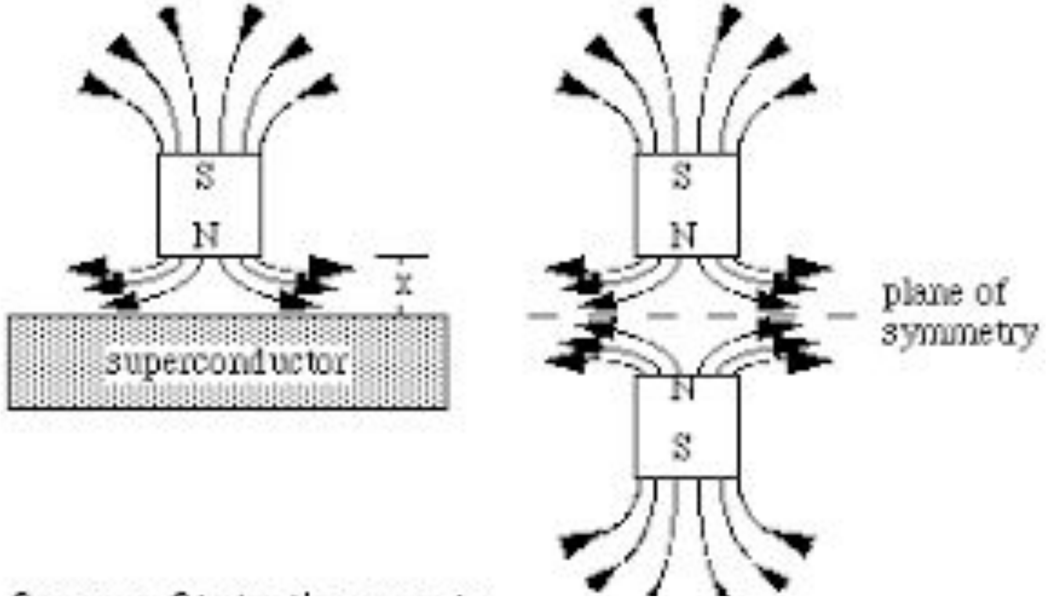
Since $B=0$ inside a superconductor, above eqn becomes

$$0=\mu_0 H (1+ X)$$

$$X=-1$$

Which is the condition for a perfect diamagnet


The Meissner Effect
Magnet
Superconductor
Liquid Nitrogen
Foam Container


S
N
x
superconductor
S
N
N
S
plane of symmetry

EFFECT OF MAGNETIC FIELD ON SUPERCONDUCTORS

When the magnetic field is applied to a superconductor is gradually increased to a critical or threshold value, often denoted as Hc, the superconductivity is destroyed.
The magnetic field at which superconductivity vanishes is called the critical field. The critical field is a dfunction of temperature, denoted by Hc(T) and the variation of critical field with temperature is given by the relation :

$$H_c(T) = H_c(0)\left[1-(T/T_c)^2\right] .$$

Here, Hc(0) is the maximum value of the critical field at T=0K

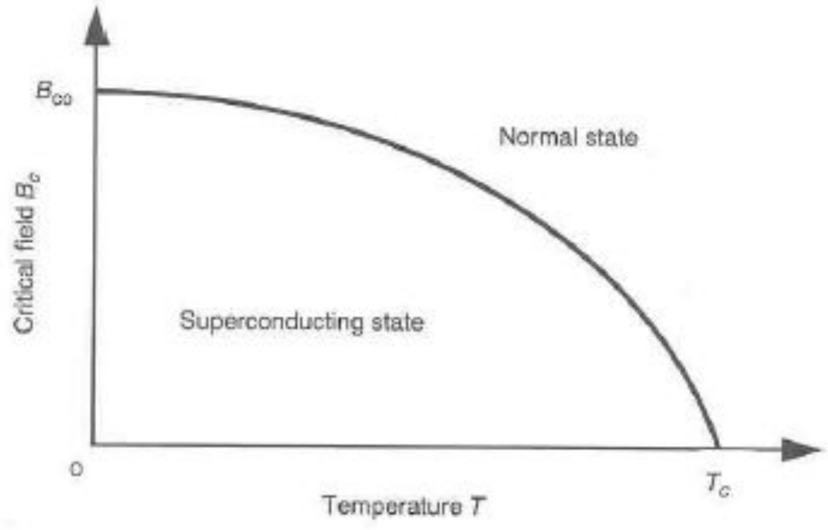


Figure 2: The critical magnetic field as a function of temperature

ISOTOPE EFFECT

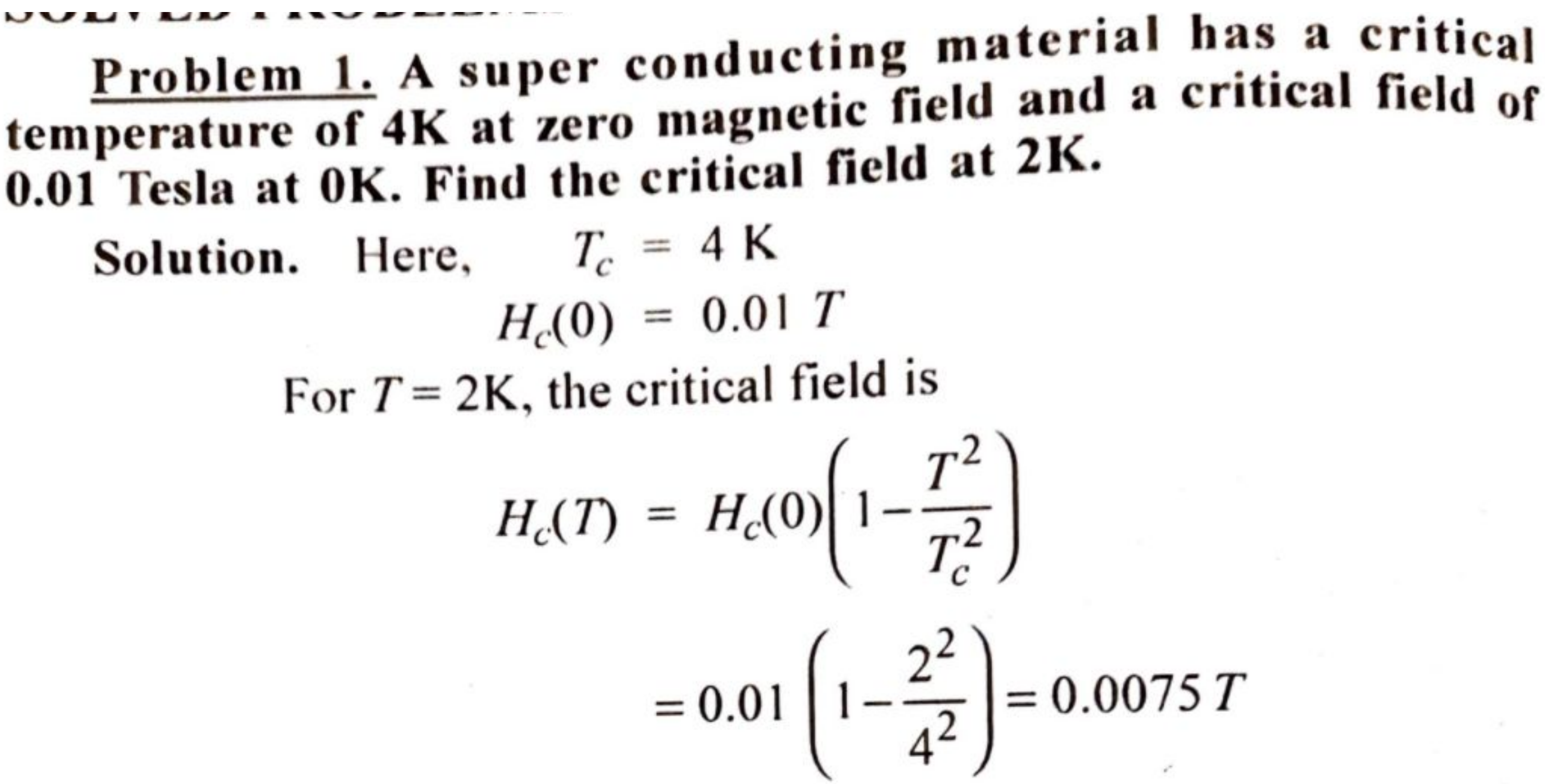
Critical temperature for various isotopes of a superconductor varies with isotopic mass. The larger the isotopic mass, the lower the transition temperature.

Eg: In mercury, Tc varies from 4.185 K to 4.146 K as atomic mass varies from 199.5 amu to 203.4 amu.

The experimental results on isotope effect can be fitted using the relation

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

Where $\alpha=0.5$ for most of the materials



Problem 1. A super conducting material has a critical temperature of 4K at zero magnetic field and a critical field of 0.01 Tesla at 0K. Find the critical field at 2K.

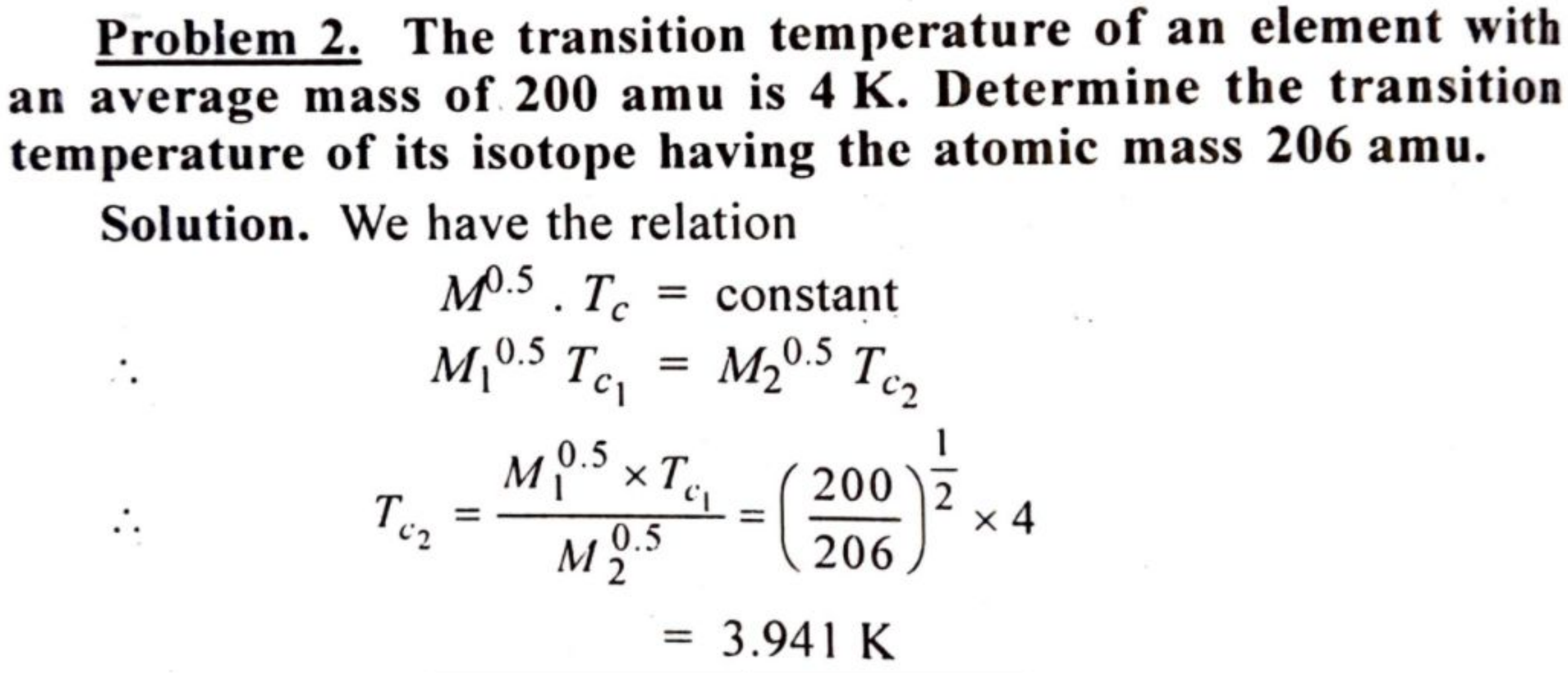
Solution. Here, $T_c = 4\text{ K}$

$$H_c(0) = 0.01\ T$$

For $T = 2\text{K}$, the critical field is

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

$$= 0.01\left(1 - \frac{2^2}{4^2}\right) = 0.0075\ T$$



Problem 2. **The transition temperature of an element with an average mass of 200 amu is 4 K. Determine the transition temperature of its isotope having the atomic mass 206 amu.**

Solution. We have the relation

$$M^{0.5} \, . \, T_c = \text{constant}$$

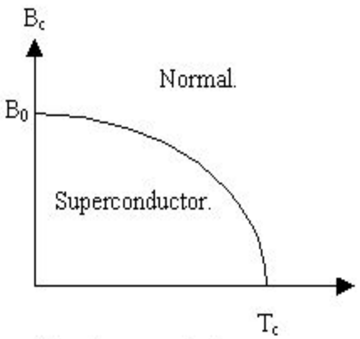
$$\therefore \qquad M_1^{0.5} \, T_{c_1} = M_2^{0.5} \, T_{c_2}$$

$$\therefore \qquad T_{c_2} = \frac{M_1^{0.5} \times T_{c_1}}{M_2^{0.5}} = \left(\frac{200}{206}\right)^{\frac{1}{2}} \times 4$$

$$= 3.941 \text{ K}$$

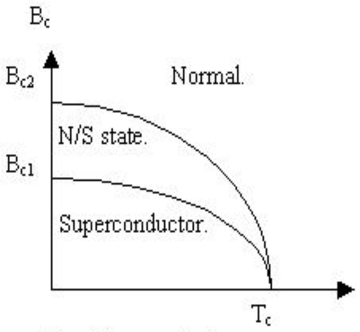
TYPES OF SUPERCONDUCTORS

Difference between type 1 and type 2 superconductors

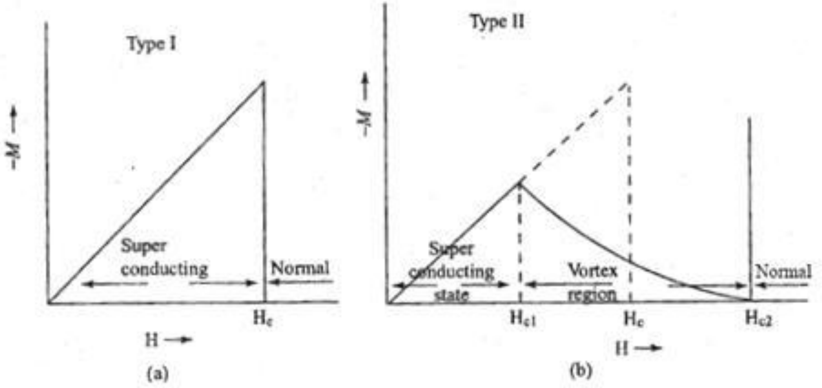


A type 1 superconductor.

Type 1 *(Soft superconductors)*	**TYPE 2** *(Hard superconductors)*
•Tolerate impurities without affecting its properties.	•Cannot tolerate impurities and affects its properties.
•Low critical field.	•High critical field.
•Show complete Meissner effect.	•Trap magnetic flux and ME is not complete.
•Also called soft superconductors	•Hard superconductors
•Eg : Aluminium , Tin	•Eg : Tantalum , Neobium

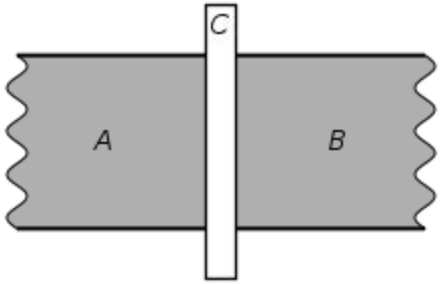


A type 2 superconductor.



Josephson Effect

Josephson junction is an superconductor-insulator-superconductor (SIS) layer structure placed between two electrodes

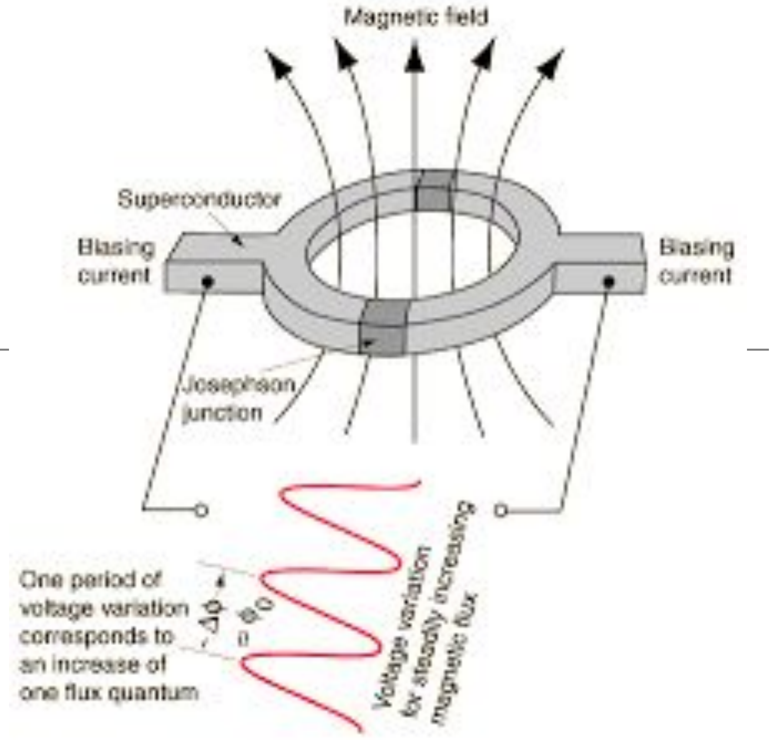


- **DC Josephson effect** : The DC Josephson effect is a direct current crossing the insulator in the absence of any external field, owing to tunneling. This DC Josephson current is proportional to the sine of the phase difference between the wavefunctions of the cooper pairs on either side of the junction and can be expressed as
  - $I=I_{max}$ Sinϕ, where I_{max} isthe maximum value of the Josephson current

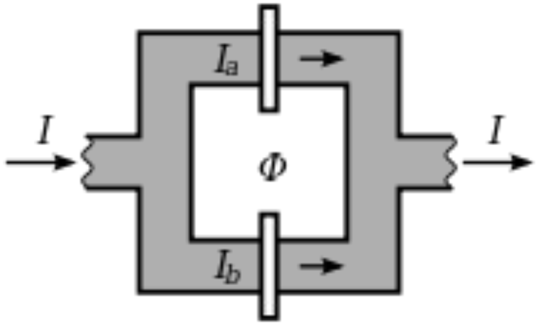
AC Josephson effect

When dc voltage is applied across a josephson junction ,the phase difference between cooper pairs on either side of the junction varies with time. Thus ac current flows across the junction

SQUID



- SQUID (for superconducting quantum interference device) is a very sensitive magnetometer used to measure extremely subtle magnetic fields, based on superconducting loops containing Josephson junctions.
- A dc magnetic field applied through a superconducting circuit containing two junctions causes interference effect as a function of the magnetizing field intensity



High temperature superconductors (HTS)

Low critical temperature puts limits to use of superconductors

HTS are superconductors with high critical temperatures

German Physicist Georg Bednorz and Swiss physicist Alex Muller were awarded Nobel prize for their work on HTS

First HTS was $La_{(2-x)}M_xCuO_4$(M=Ba, Sr, Ca)-Temp range (25-30K)

First material which attained superconductivity above boiling point of liquid nitrogen(77K) was Yttrium Barium Copper Oxide(YBCO)- Tc-90K

Other examples are BSCCO and TBCCO (70-125K)

Fullerene containing compounds (upto 48K)

OTHER APPLICATIONS OF SUPERCONDUCTORS

Low loss Power cables .

Communication.

Superconducting wires.

Levitation-Maglev

Nuclear magnetic resonance machines.

Reference

1. Solid StatePhysics, R.K.PuriV.K.Babbar, S Chand &Co
2. Solid State Physics, SO Pillai, New Age Publications
3. https://www.secretsofuniverse.in/superconductivity-and-its-applications/
4.