Fundamentals of Solid State Physics

Superconductivity

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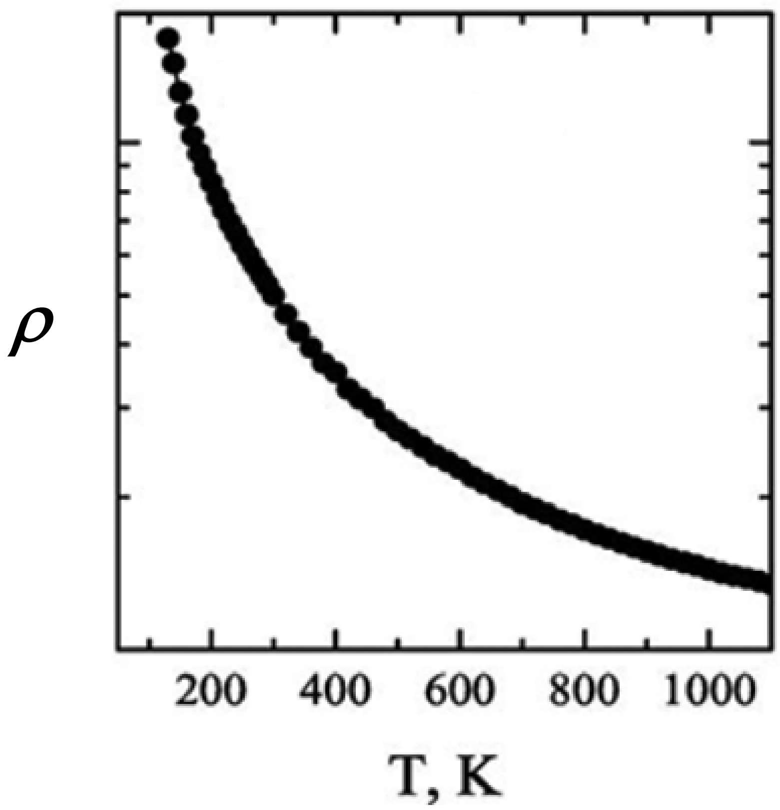
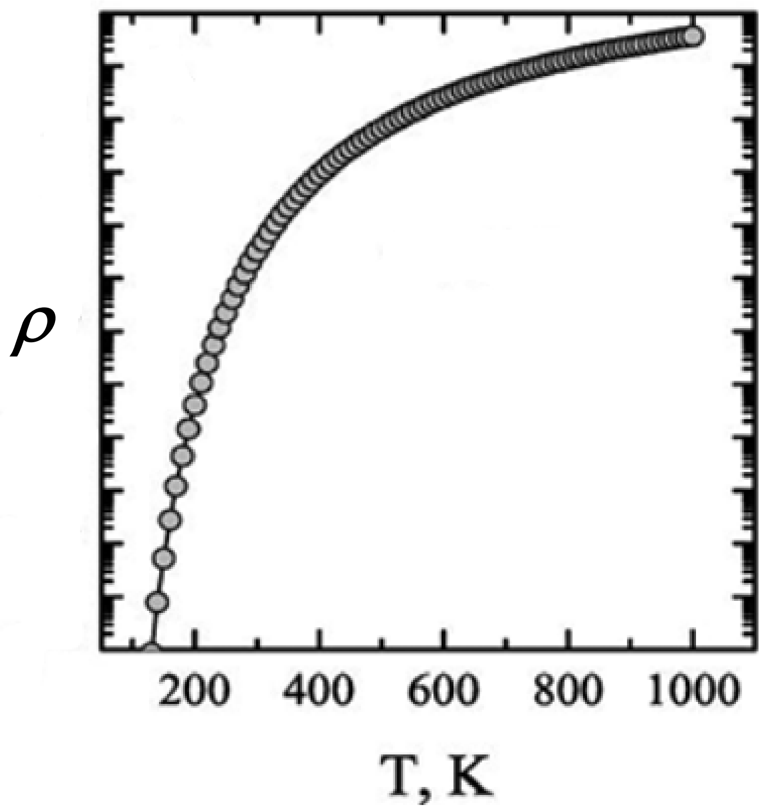
Resistivity ρ vs. Temperature

Metals and semiconductors have different temperature dependences of ρ

$$\sigma = ne\mu$$



Intrinsic Semiconductors



Metals

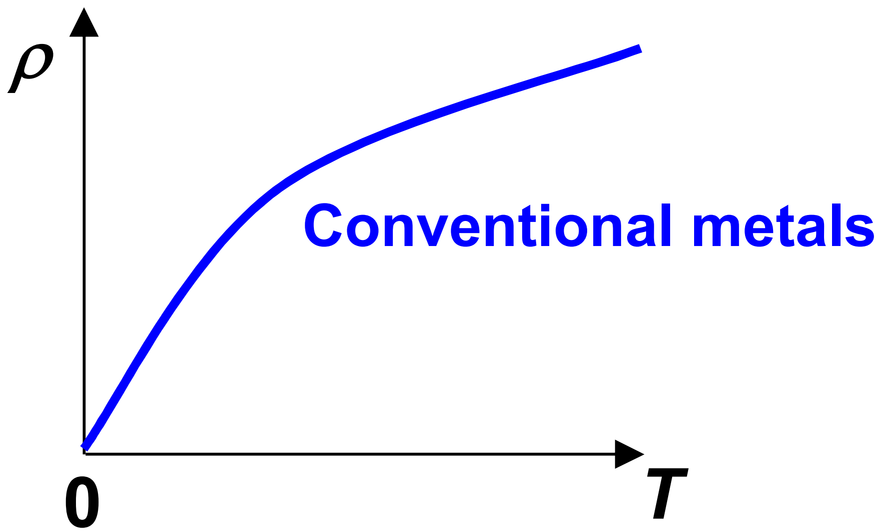
Resistivity ρ of Metals

- **The Classical Model**
  - **Resistivity is always > 0 for metals, because of phonon scattering**

$$\sigma = ne^2 \frac{\tau}{m}$$

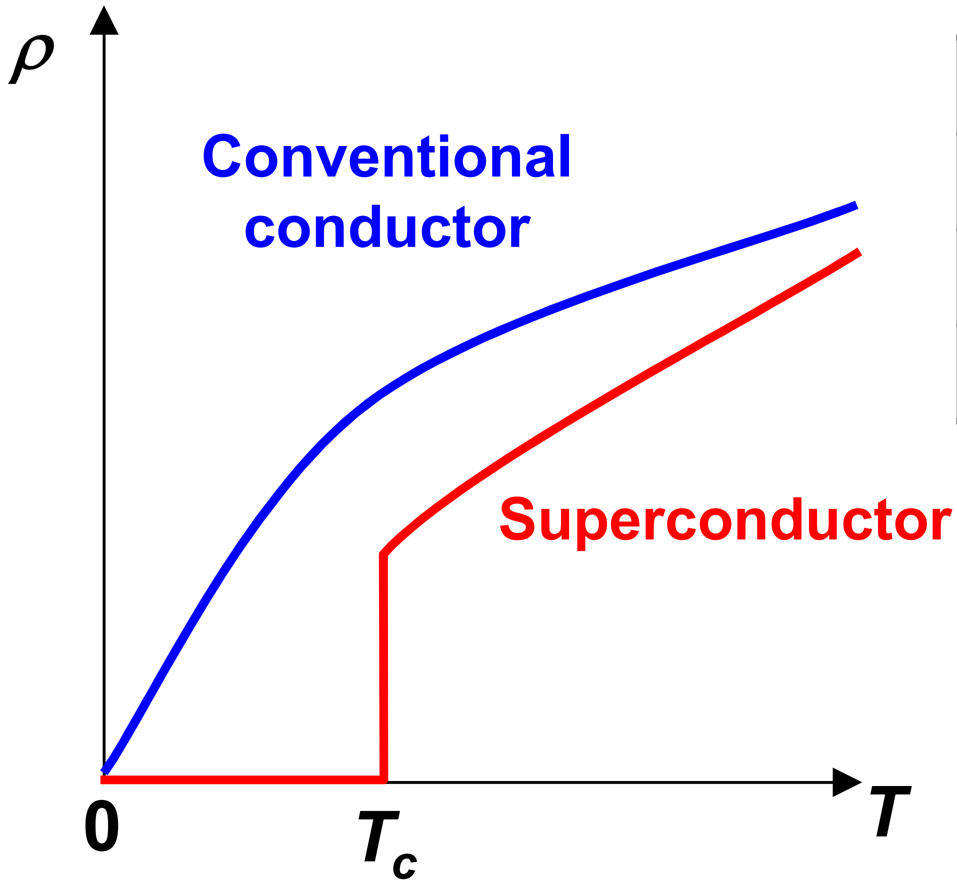
$$\rho = \frac{1}{\sigma}$$

when T decreases → τ increases → ρ decreases

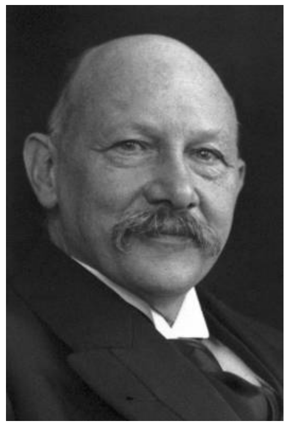


Superconductor 超导体

- Resistivity drops to 0 at transition temperature T_c
- Phonon scattering suddenly disappears



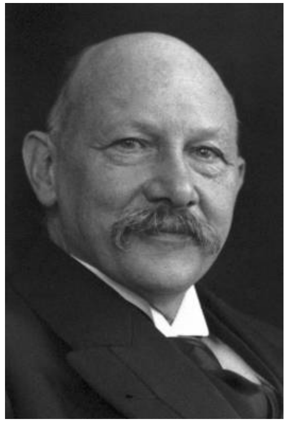
	T_c (K)
Hg	4.2
Al	1.1
Li	0.0004



H. Onnes (昂尼斯)
1913 Nobel Prize in Physics
for Low Temperature Physics

Superconductor 超导体

- Onnes's main focus is to get liquid helium (T = 4 K).
- Discovery of superconductivity is serendipity



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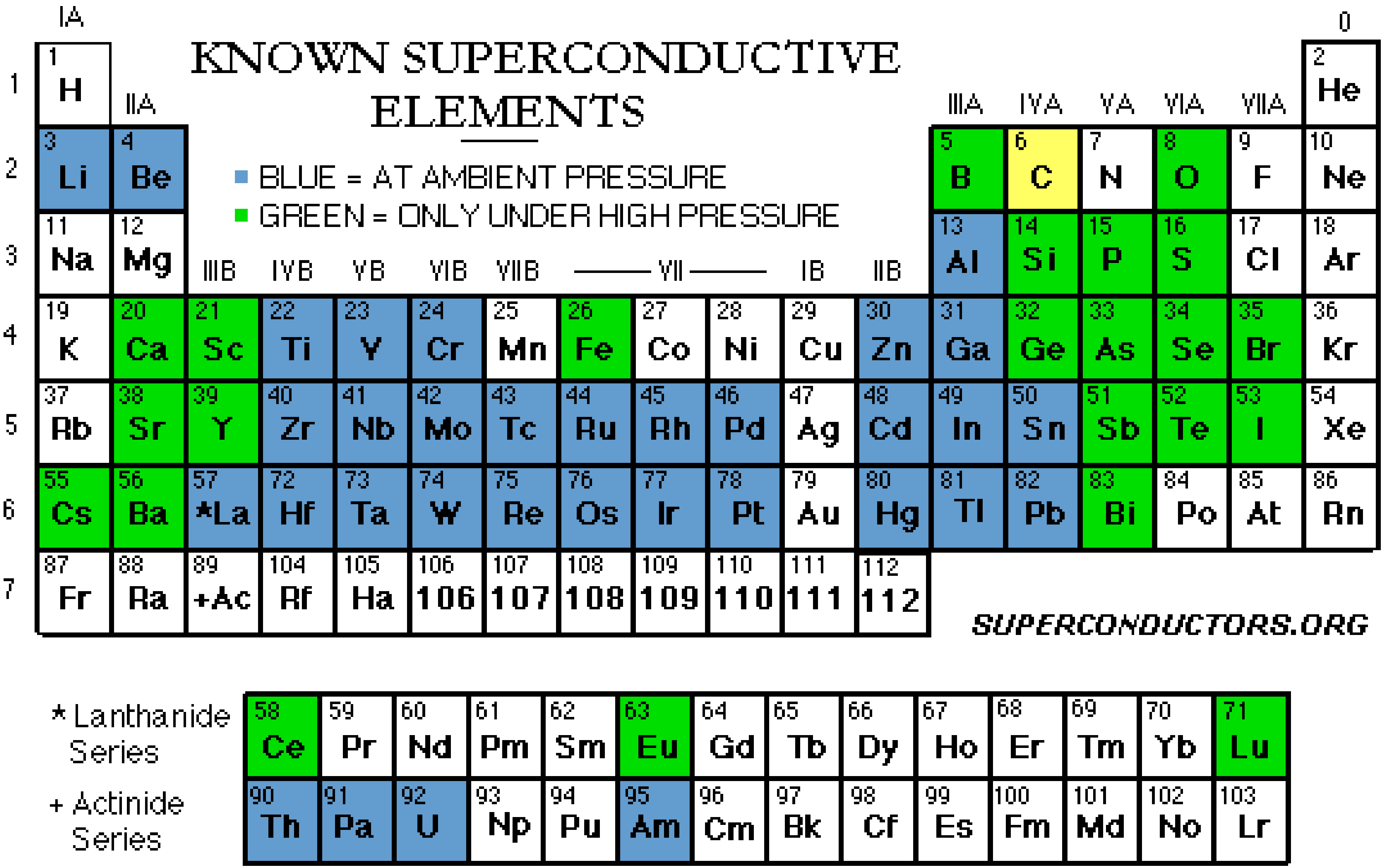


Nobel Prizes in Superconductivity

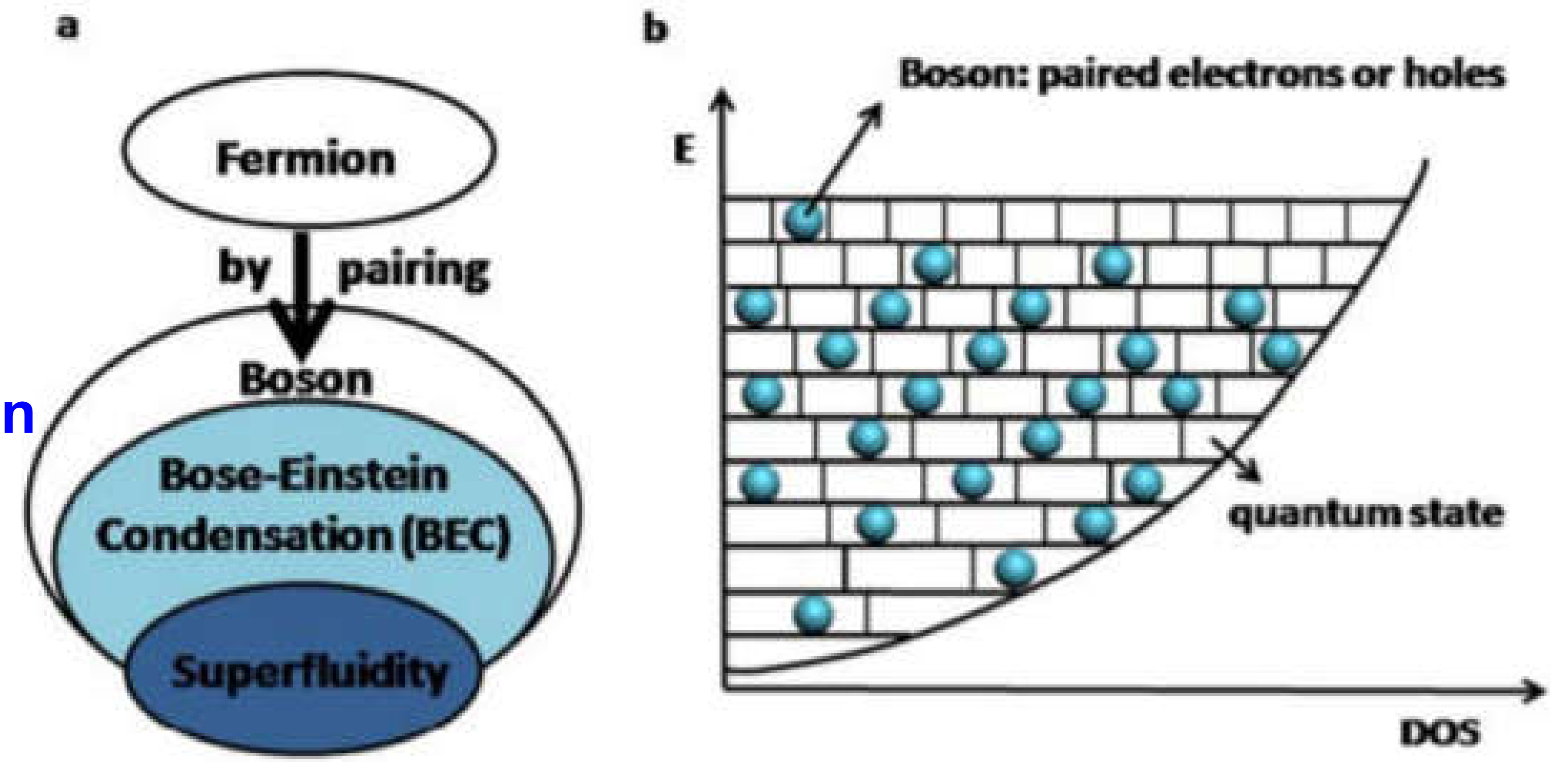
- 1913 Low temperature physics
- 1972 BCS theory of superconductivity
- 1973 Tunneling effects in superconductors
- 1987 High temperature superconductors
- 2003 Theory of superconductors
- …

BCS Theory

- Pairs of electrons (Cooper's Pairs) move in the lattice coherently without phonon scattering

electron spin
= 1/2 or –1/2
= Fermion

cooper pair spin
= 1 or 0
= Boson



https://arxiv.org/abs/1306.3547

BCS Theory

- **Pairs of electrons (Cooper's Pairs) move in the lattice coherently without phonon scattering**

A Cooper Pair of electrons moving in the lattice

Bardeen, Cooper and Schreiffer
1972 Nobel Prize in Physics

J. Bardeen, L. Cooper, J. Schreffer, *Phys. Rev.* **108,** 1175 (1957)

BCS Theory

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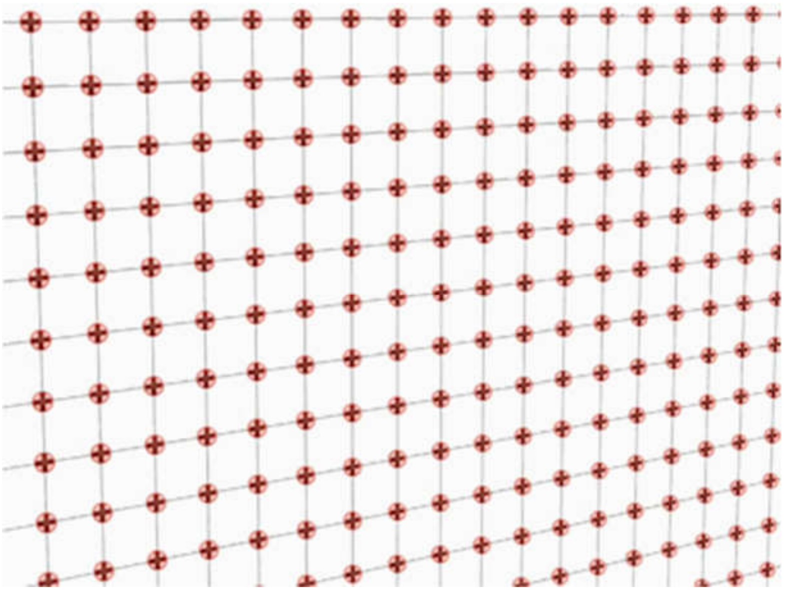


A Cooper Pair of electrons moving in the lattice

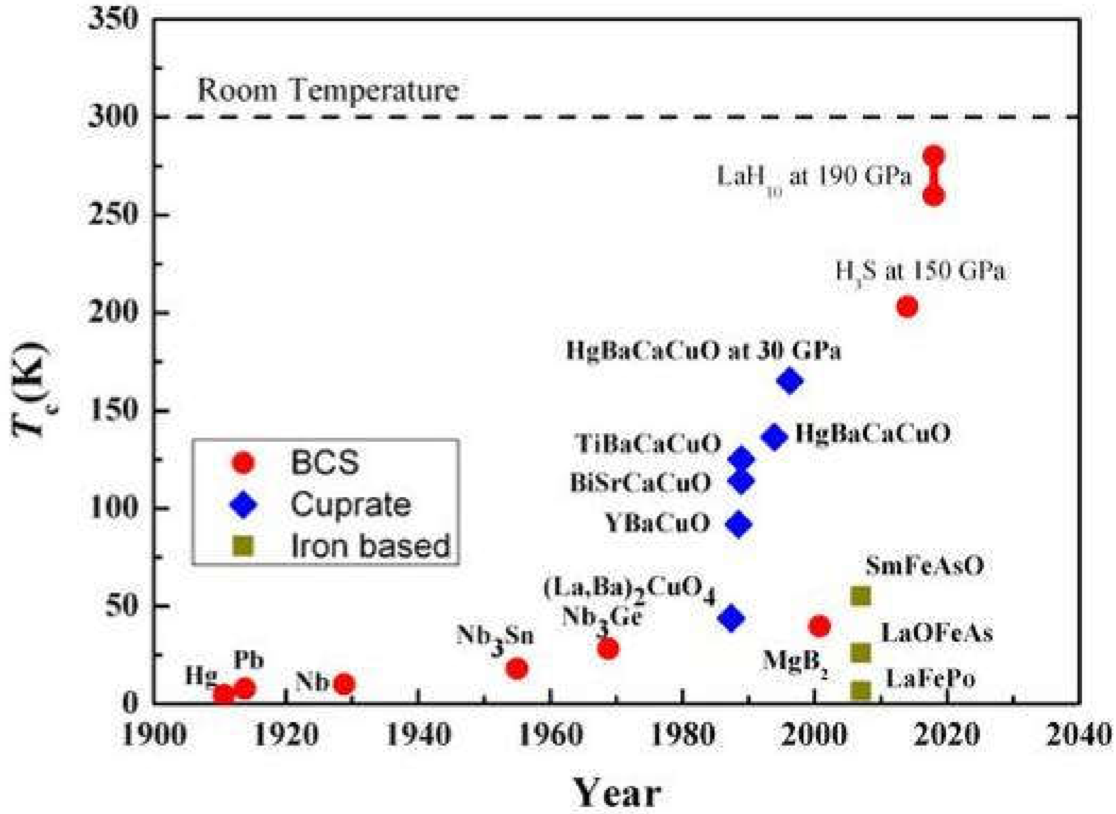
The Physicist Who Won the Nobel Prize Twice!

Bardeen, Cooper and Schreiffer
1972 Nobel Prize in Physics

J. Bardeen, L. Cooper, J. Schreffer, *Phys. Rev.* **108,** 1175 (1957)

Chasing High T_c

- The BCS theory cannot explain superconductors with T_c > 40 K
- Theory for high T_c superconductors is still not complete

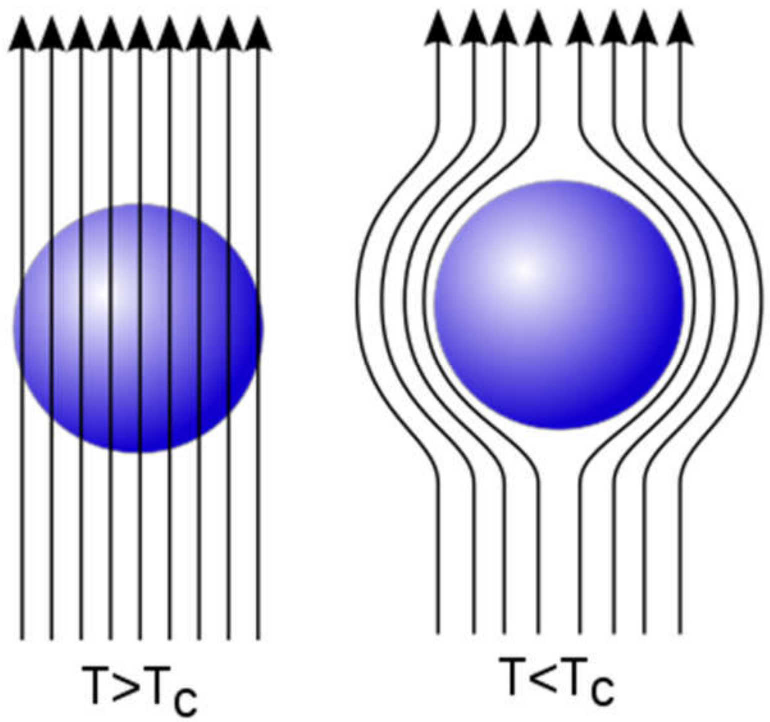


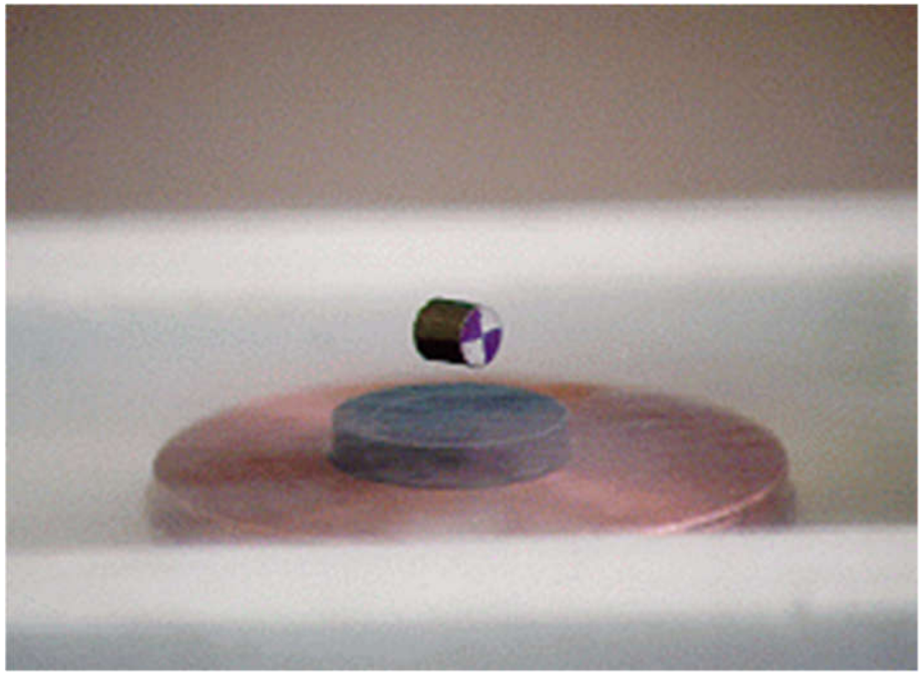
R. Hemley, et. al., *Proc. Ramon Areces Symp.* (2018)

Superconductor 超导体

- **Meissner effect 迈斯纳效应**
  - Superconductors repel all the magnetic field inside
  - perfectly diamagnetic ($\chi = -1$)
  - Inside, B = $\mu_0\mu_r$H = $\mu_0(1+\chi)$H = 0

B field





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- **A superconductor is not just a perfect conductor**
  - Meissner effect cannot be simply explained by $\rho = 0$
  - It can only be understood by quantum mechanics

https://en.wikipedia.org/wiki/Meissner_effect

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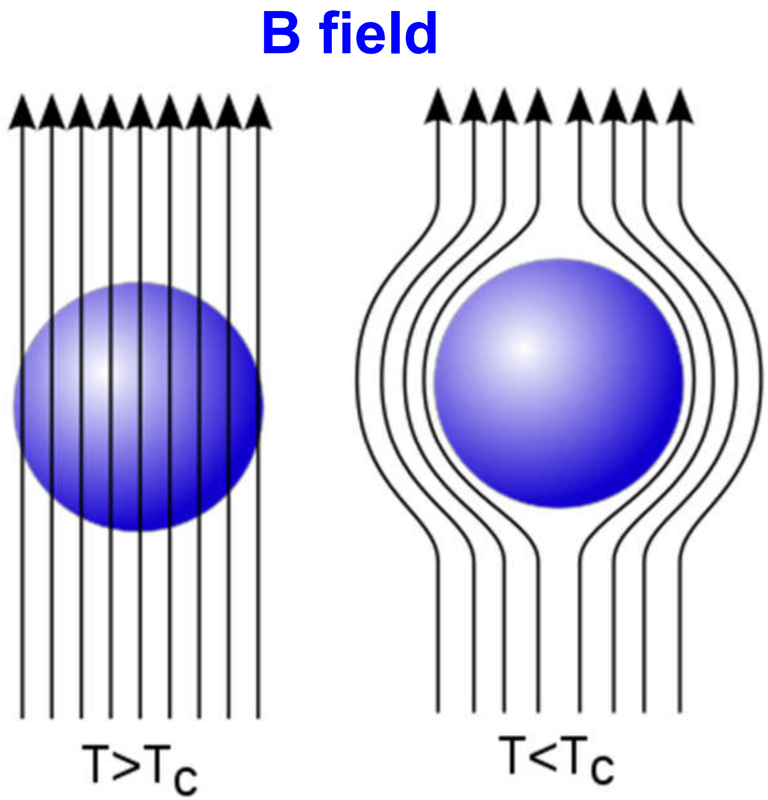

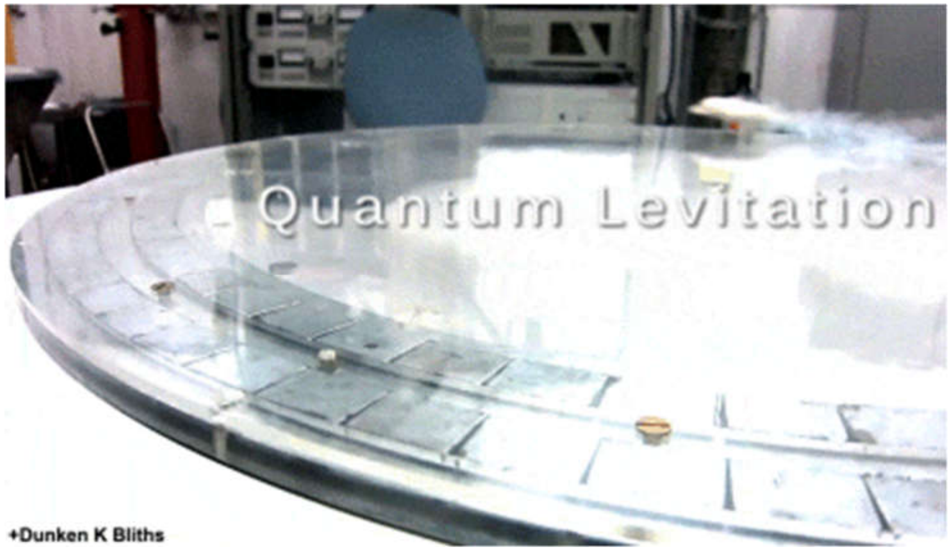

https://wonderfulengineering.com/these-15-magnet-gifs-will-show-you-the-power-of-magnetism/

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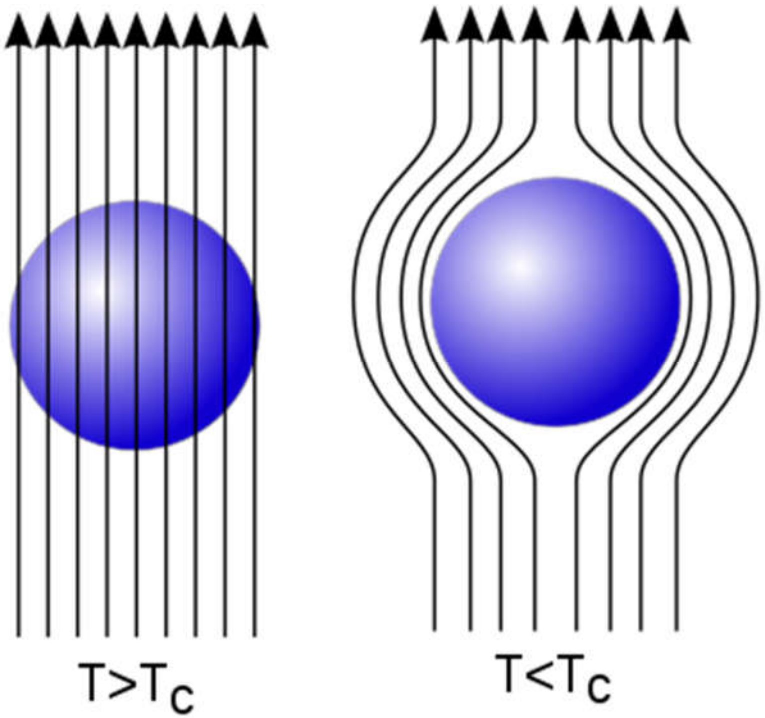

MagLev (磁悬浮列车)

Thank you for your attention