Fundamentals of Solid State Physics

Superconductivity

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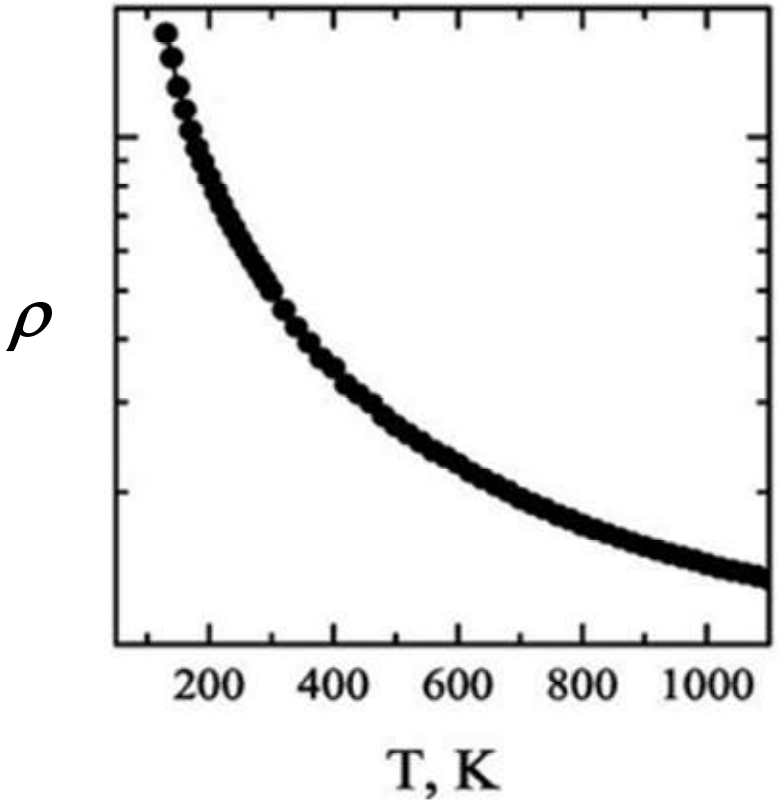
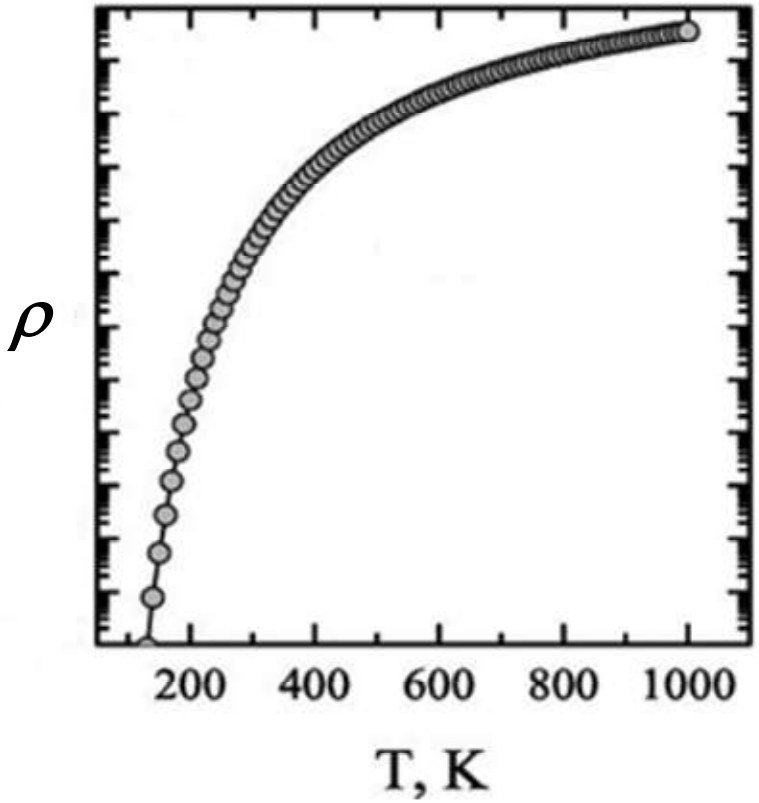
Resistivity ρ vs. Temperature

Metals and semiconductors have different temperature dependences of ρ

$$\sigma = ne\mu$$



Intrinsic Semiconductors



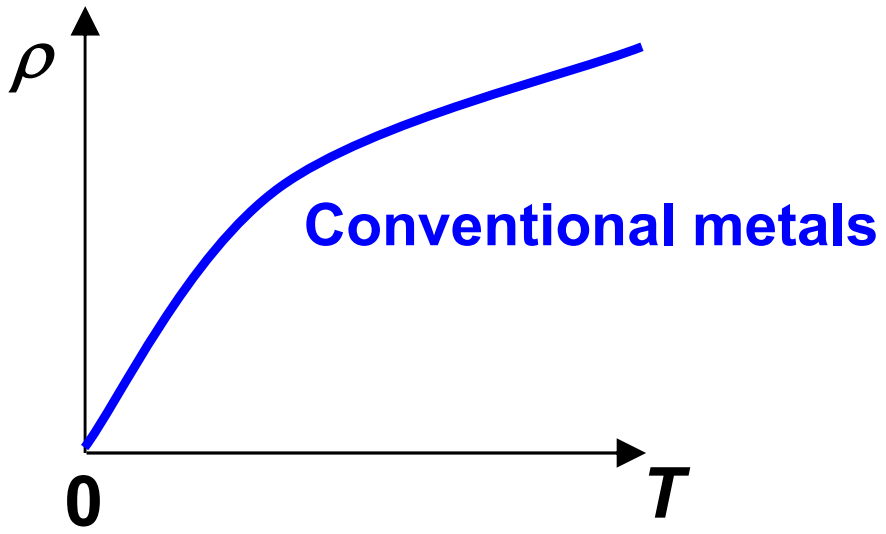
Metals

Resistivity ρ of Metals

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

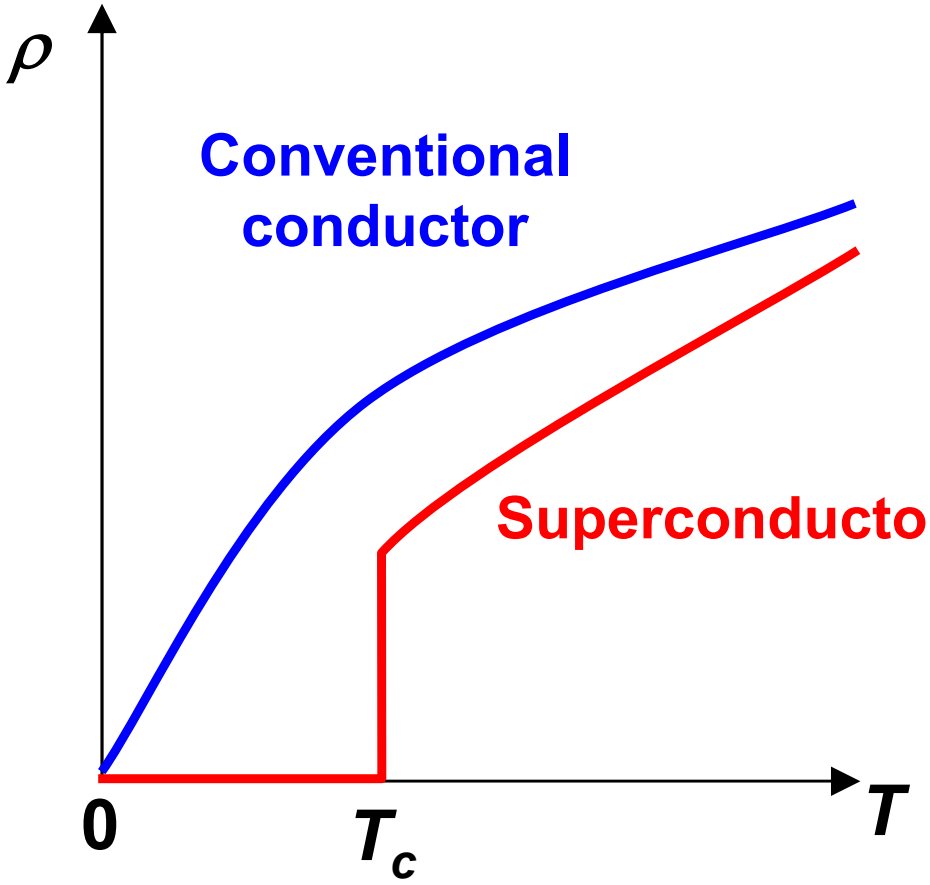
$$\sigma = ne^2 \frac{\tau}{m} \qquad \rho = \frac{1}{\sigma}$$

when T decreases → τ increases → ρ decreases

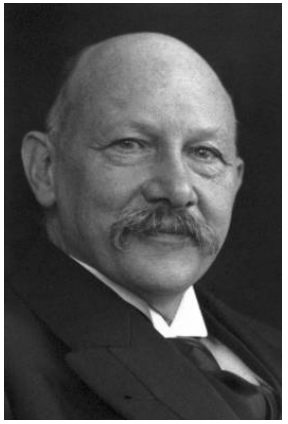


Superconductor 超导体

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



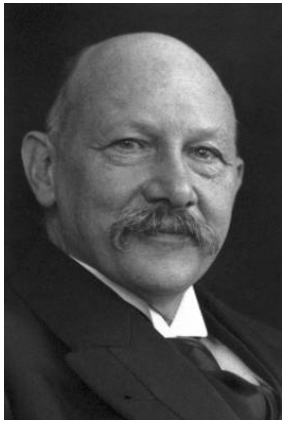
	T_c (K)
Hg	4.2
Al	1.1
Li	0.0004



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 an accident



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Nobel Prizes in Superconductivity

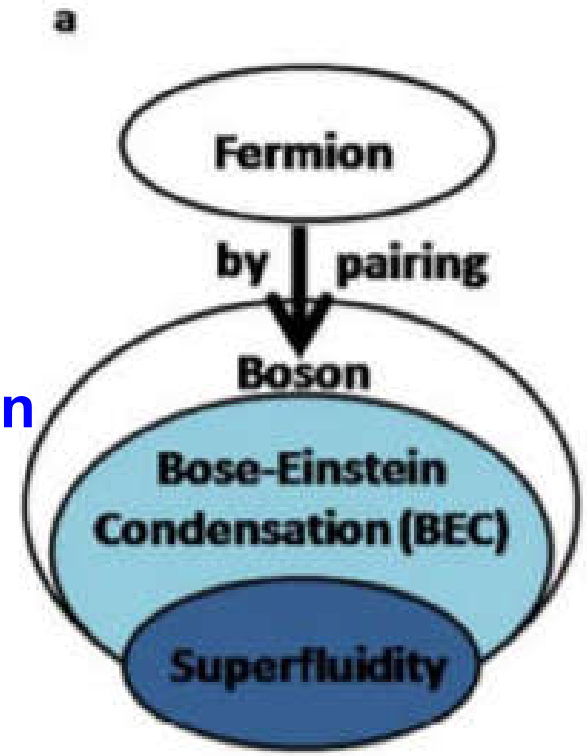
- 1913 Low temperature physics
- 1972 BCS theory of superconductivity
- 1973 Tunneling effects in superconductors
- 1987 High temperature superconductors
- 2003 Theory of superconductors
- ...

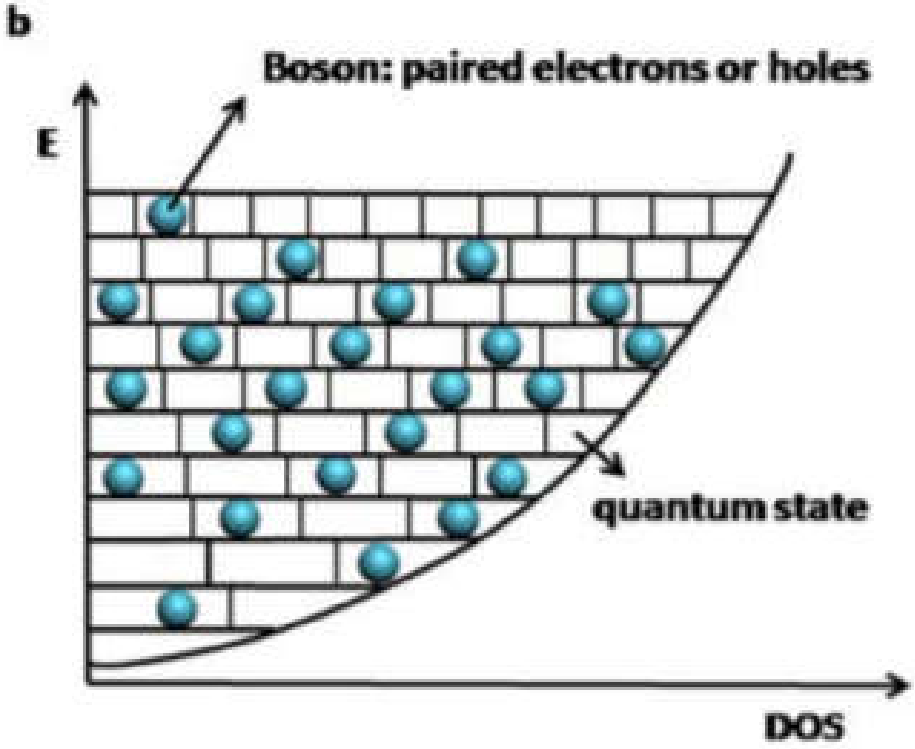
BCS Theory

- **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

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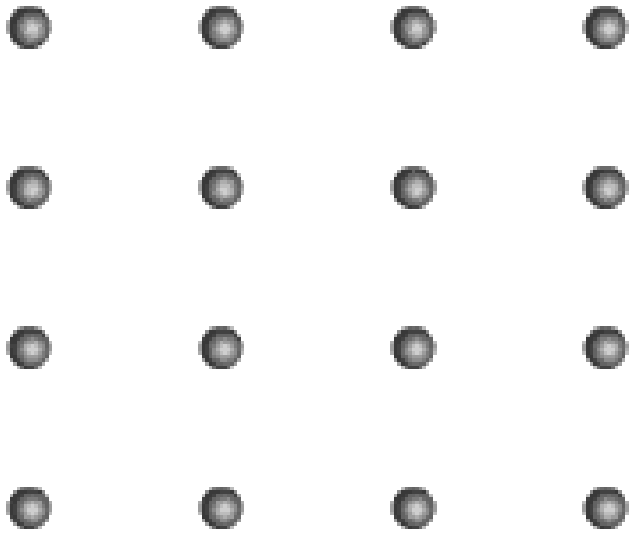

A Cooper Pair of electrons moving in the lattice

Bardeen, Cooper and Schreiffer 1972 Nobel Prize in Physics

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

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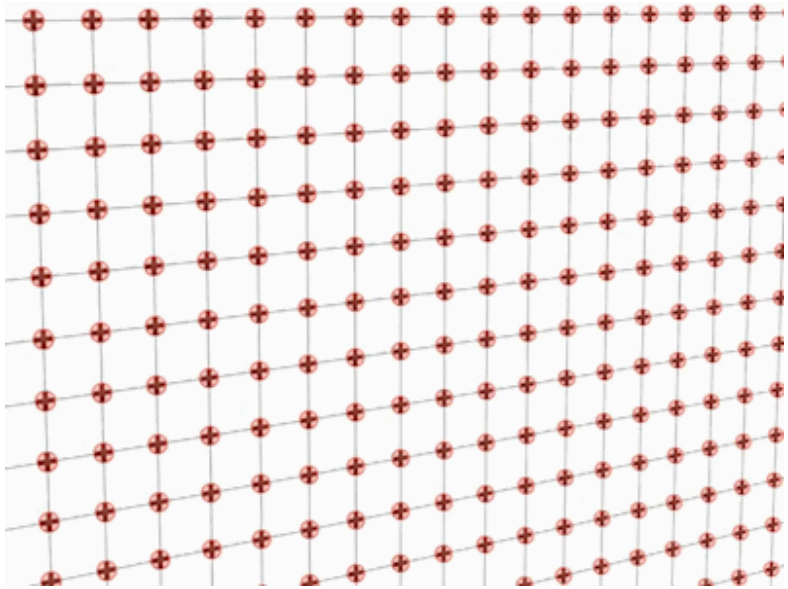

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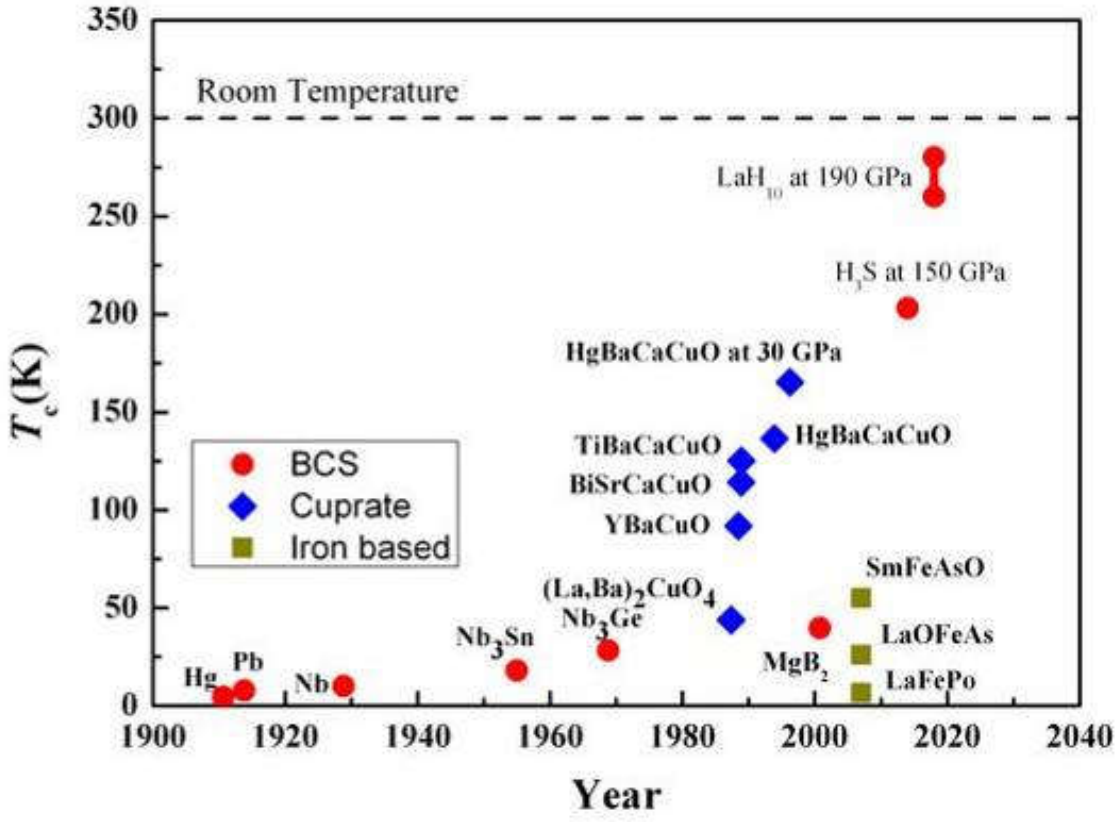
Chasing High T_c

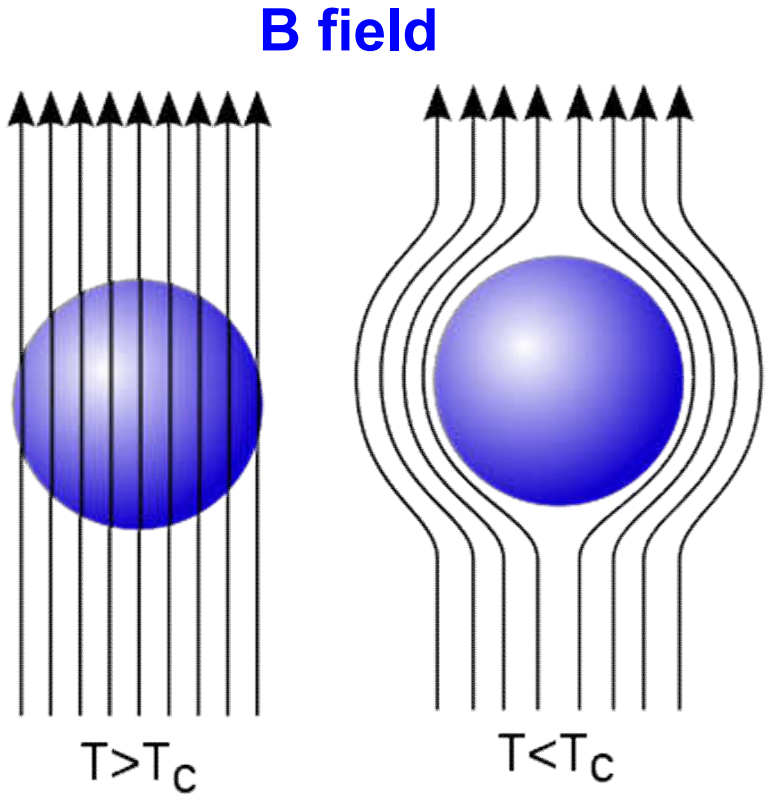
- The BCS theory cannot explain superconductors with T_c > 40 K
- Theory for high T_c superconductors is still not complete

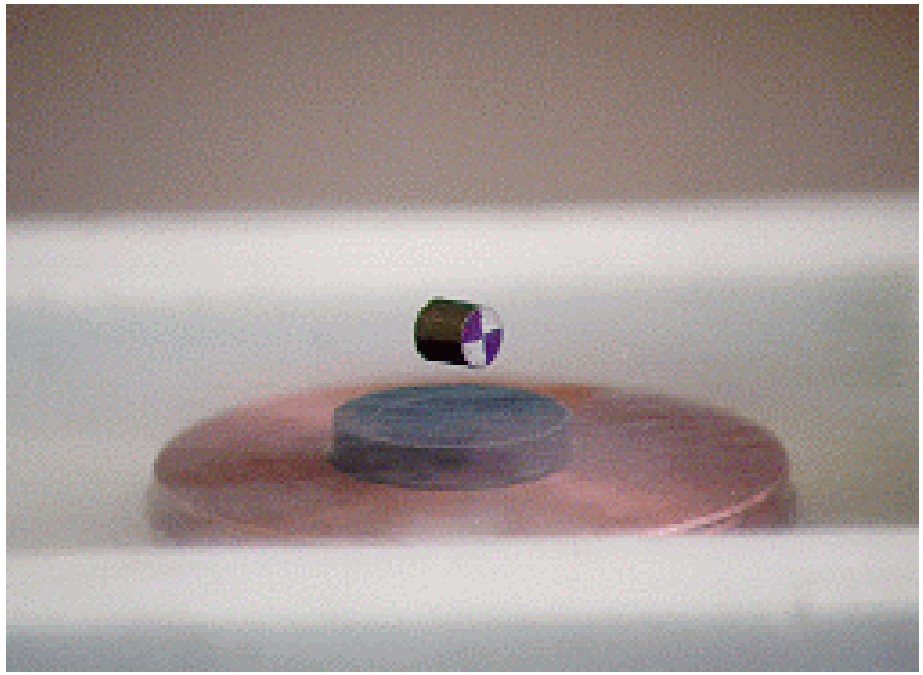


R. Hemley, et. al., *Proc. Ramon Areces Symp.* (2018)

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**





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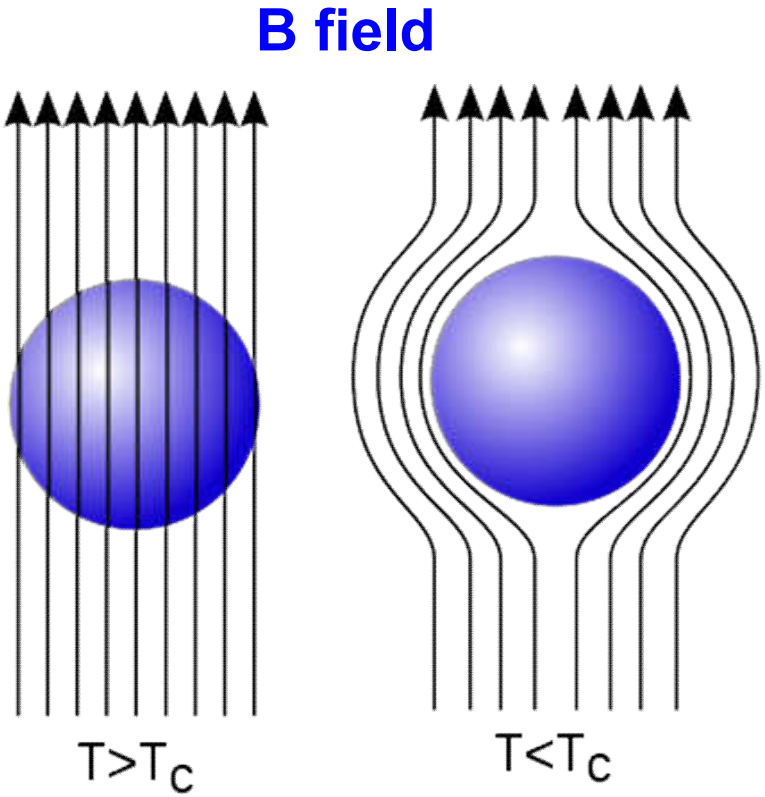

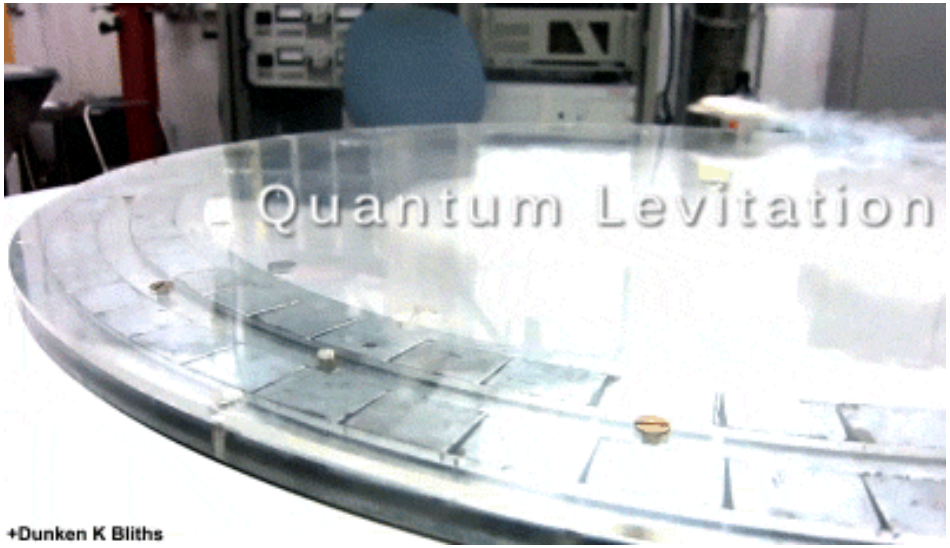

https://wonderfulengineering.com/these-15-magnet-gifs-will-show-you-the-power-of-magnetism/

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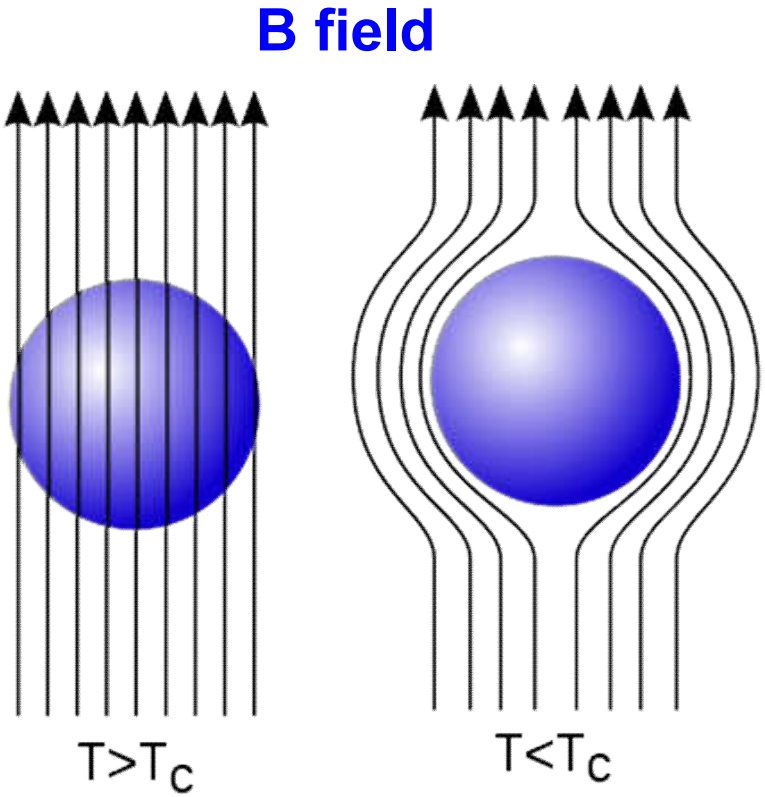

MagLev (磁悬浮列车)

Thank you for your attention