

Fundamentals of Solid State Physics

Superconductivity

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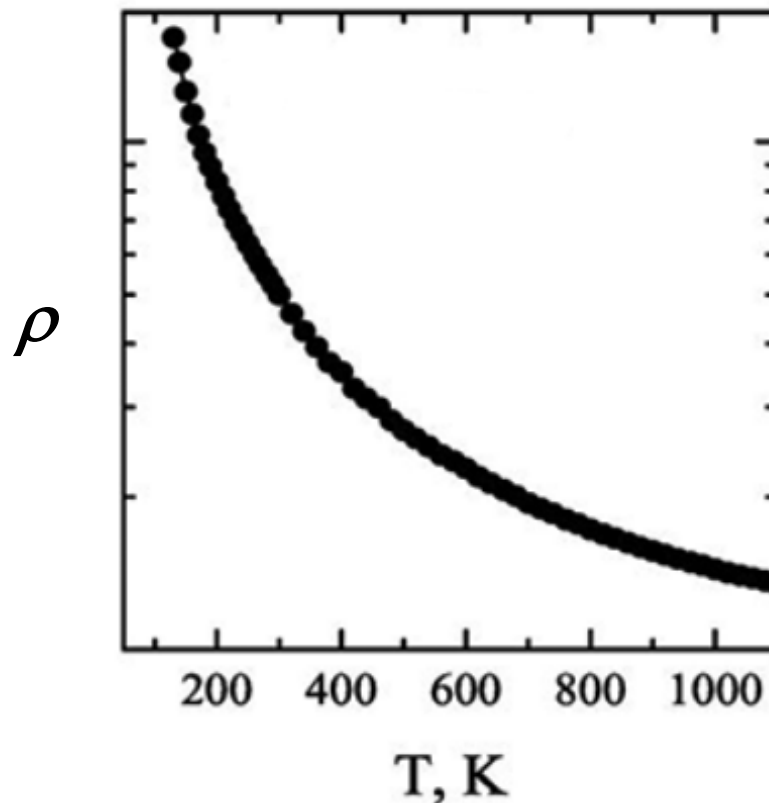
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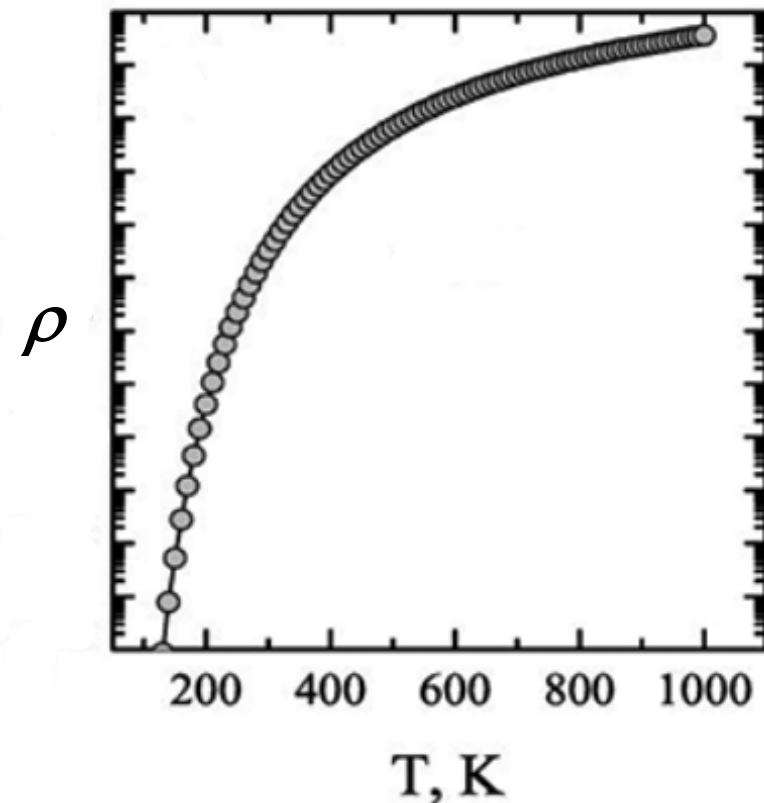
Resistivity ρ vs. Temperature

Metals and semiconductors have different temperature dependences of ρ

$$\sigma = ne\mu$$



Intrinsic Semiconductors



Metals

Resistivity ρ of Metals

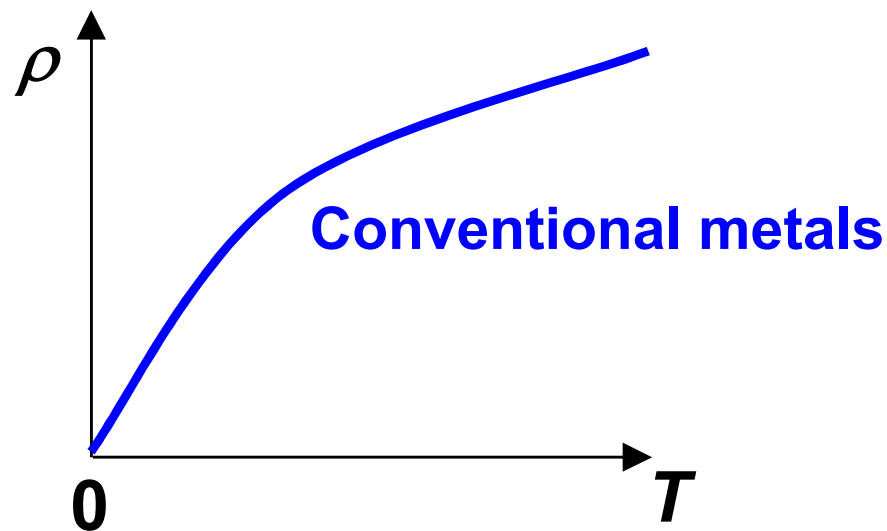
■ The Classical Model

- Resistivity is always > 0 for metals, because of phonon scattering

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

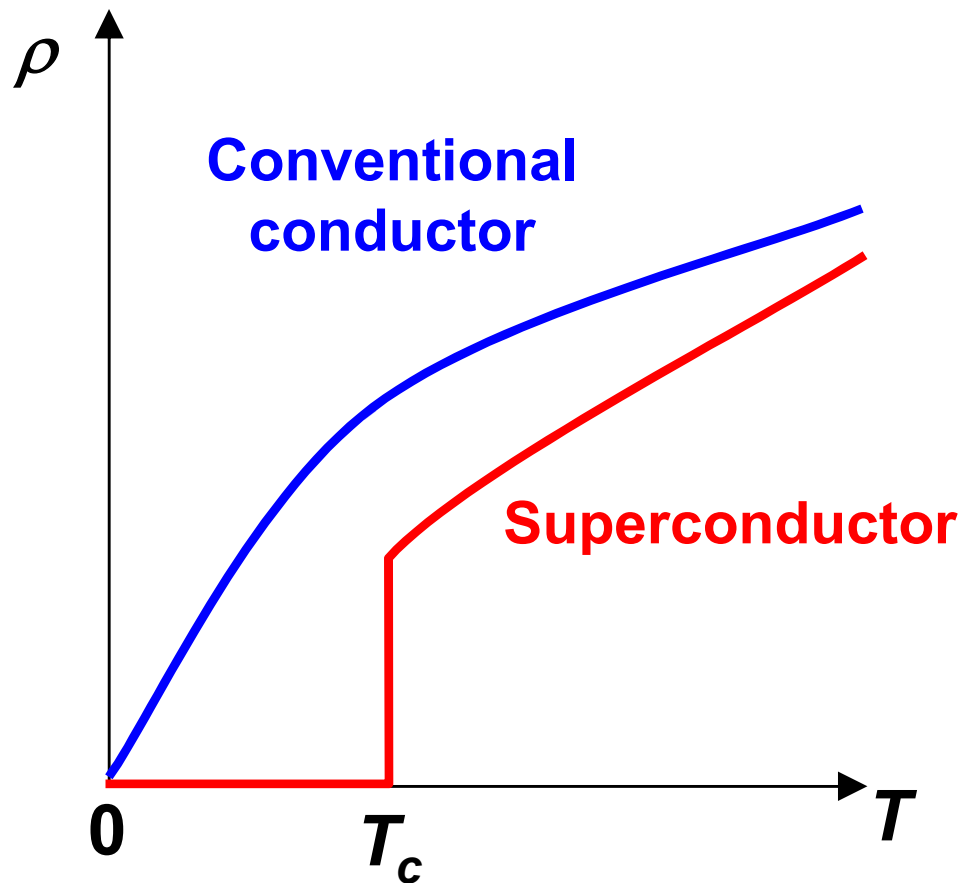
$$\rho = \frac{1}{\sigma}$$

when T decreases \rightarrow τ increases \rightarrow 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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Superconductor 超导体

KNOWN SUPERCONDUCTIVE ELEMENTS

■ BLUE = AT AMBIENT PRESSURE
■ GREEN = ONLY UNDER HIGH PRESSURE

1	IA	1	H	IIA	2	He	0																														
2		3	Li	4	Be	5	B	6	C	7	N	8	O	9	F	10	Ne																				
3		11	Na	12	Mg	III B	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																			
4		19	K	20	Ca	21	Sc	22	Ti	23	Y	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
5		37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
6		55	Cs	56	Ba	57	*La	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn
7		87	Fr	88	Ra	89	+Ac	104	Rf	105	Ha	106	106	107	107	108	108	109	109	110	110	111	111	112	112												

SUPERCONDUCTORS.ORG

* Lanthanide Series

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

+ Actinide Series

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Nobel Prizes in Superconductivity

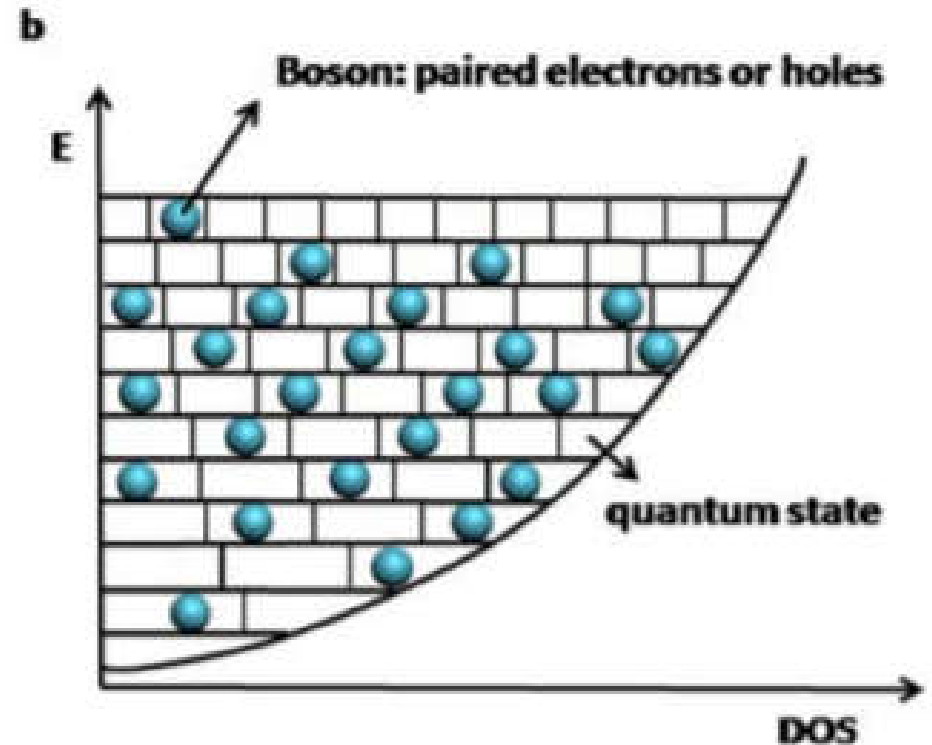
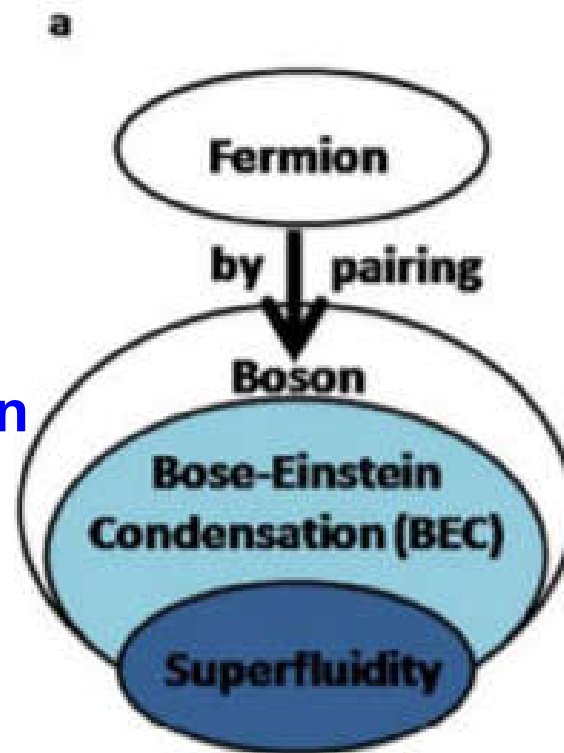
- **1913** **Low temperature physics**
- **1972** **BCS theory of superconductivity**
- **1973** **Tunneling effects in superconductors**
- **1987** **High temperature superconductors**
- **2003** **Theory of superconductors**
- ...

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



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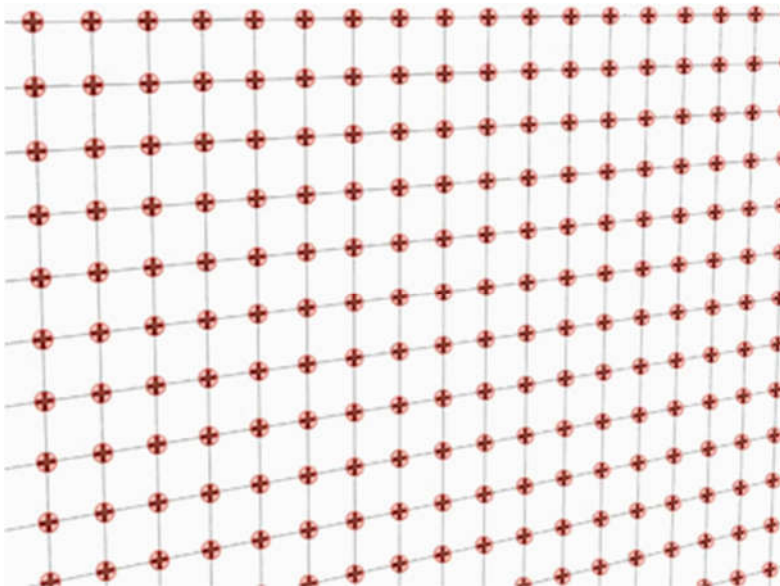
**A Cooper Pair of electrons
moving in the lattice**



**Bardeen, Cooper and Schreffer
1972 Nobel Prize in Physics**

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**A Cooper Pair of electrons
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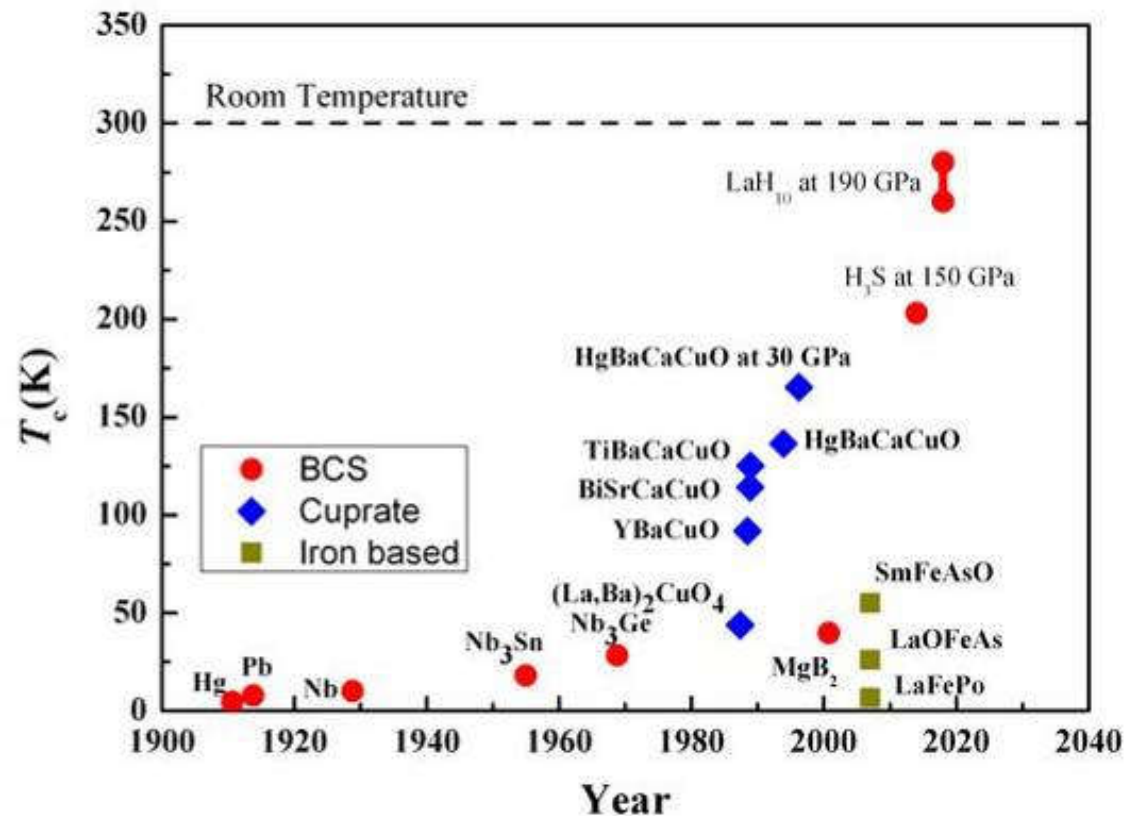
**The Physicist Who
Won the Nobel Prize
Twice!**



**Bardeen, Cooper and Schreffer
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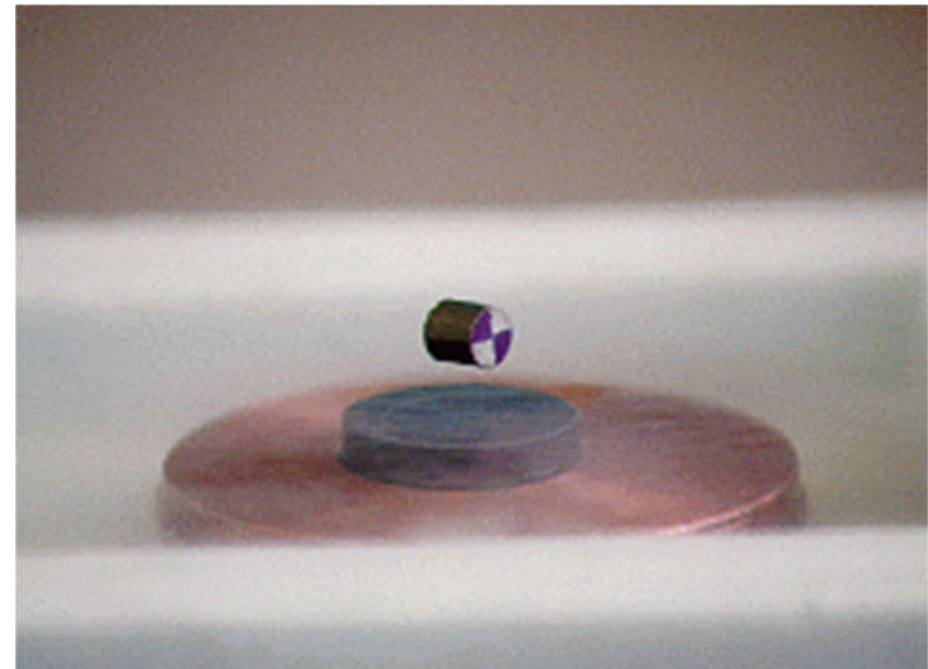
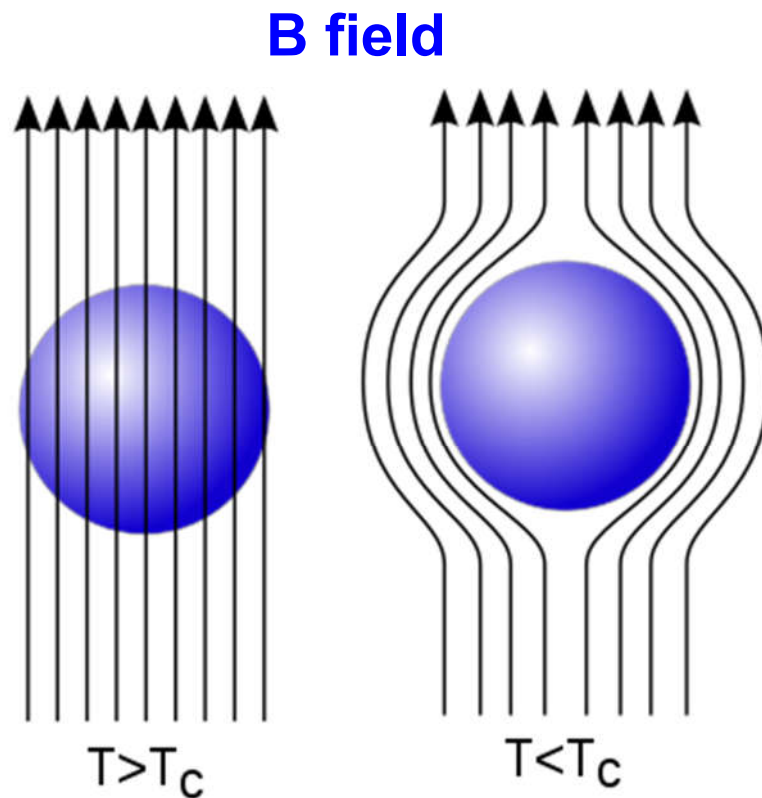
Chasing High T_c

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



Superconductor 超导体

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



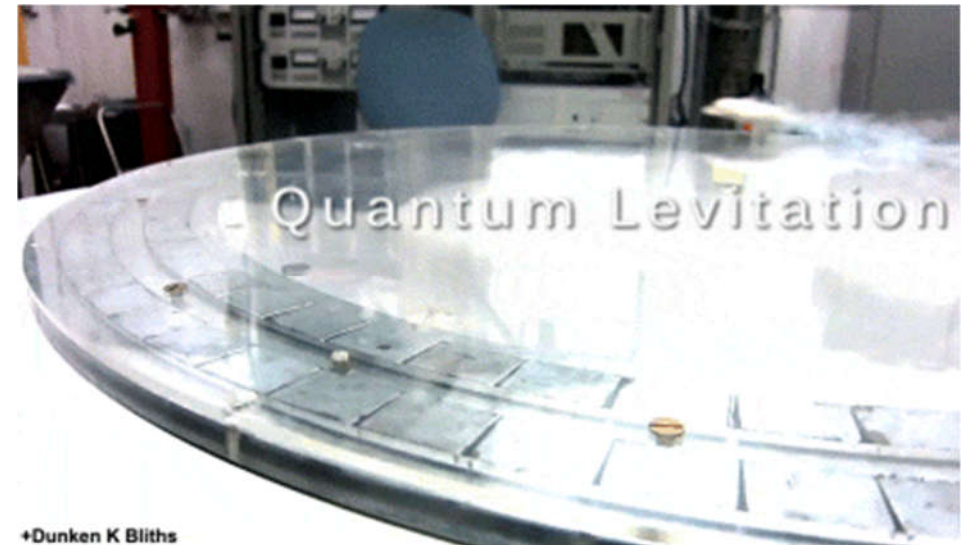
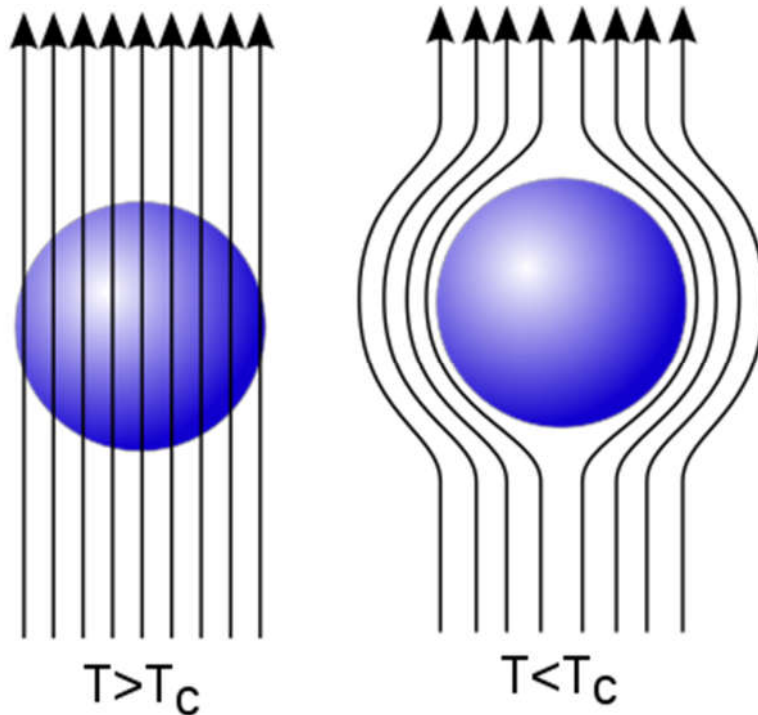
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- **A superconductor is not just a perfect conductor**
 - Meissner effect cannot be simply explained by $\rho = 0$
 - It can only be understood by quantum mechanics

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B field

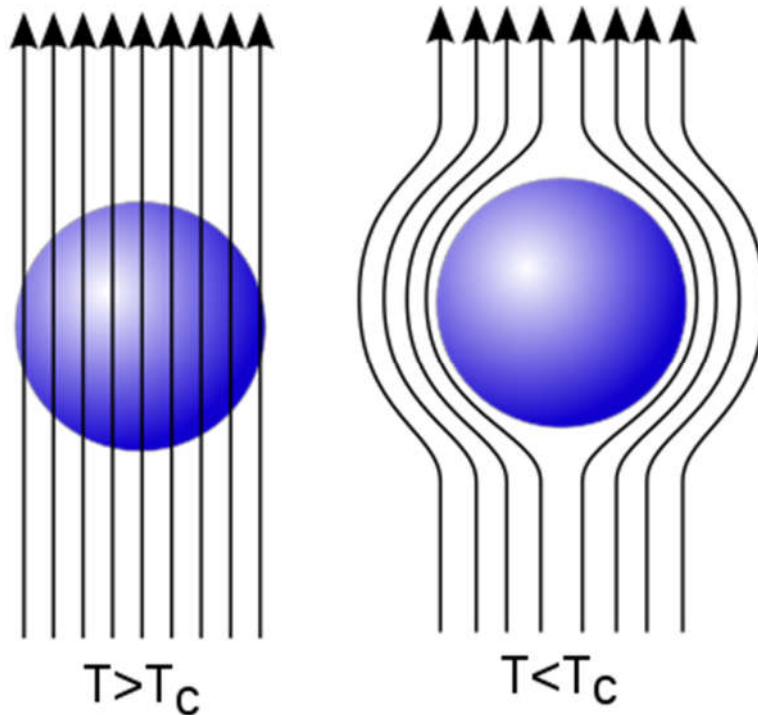


<https://wonderfuleengineering.com/these-15-magnet-gifs-will-show-you-the-power-of-magnetism/>

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B field



MagLev (磁悬浮列车)

Thank you for your attention