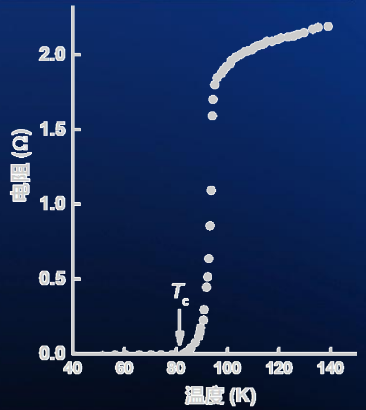
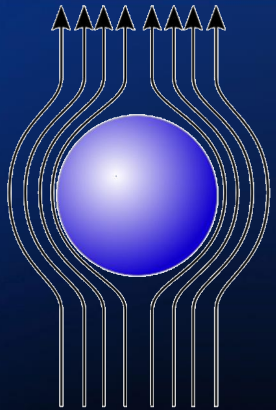
“物理学家与物理学史”
2025春季研讨会

“非凡一念与传奇一生”

“高温超导”第 0 人

马蒂亚斯





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中国科学院物理研究所

2025.04.25 北京

本次报告的主要参考资料

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② https://nap.nationalacademies.org/read/5406/chapter/14
③ https://m2s-2026.org/prizes-awards/heike-kamerlingh-onnes-prize
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⑦ 刘兵, 章立源.超导物理学发展简史 .陕西科学技术出版社, 1988
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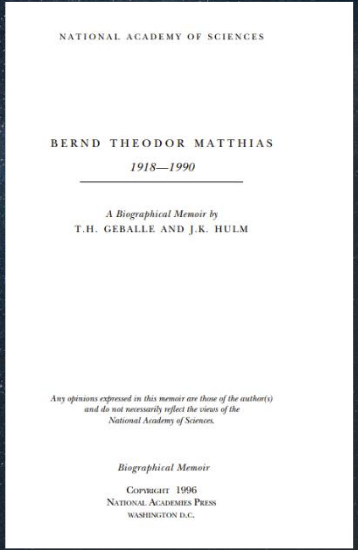

NATIONAL ACADEMY OF SCIENCES

BERND THEODOR MATTHIAS

1918—1990

A Biographical Memoir by
T.H. GEBALLE AND J.K. HULM

Any opinions expressed in this memoir are those of the author(s) and do not necessarily reflect the views of the National Academy of Sciences.

Biographical Memoir

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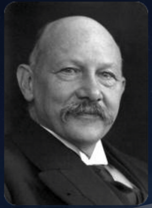
马蒂亚斯的传奇一生

超导研究获得的物理诺奖

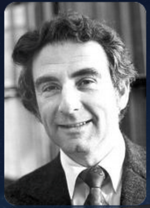
1913



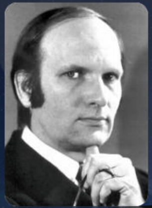
H. K. Onnes

1972

J. Bardeen

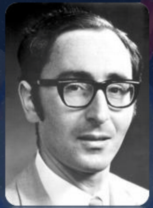


L. N. Cooper

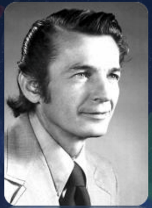


J. R. Schrieffer

1973

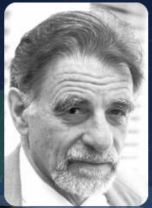


B.D. Josephson

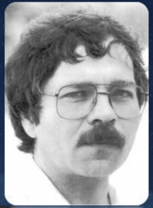


I. Giaever

1987

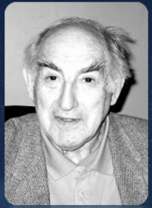


K.A. Müller

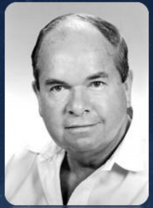


J. G. Bednorz

2003



V. L. Ginzburg

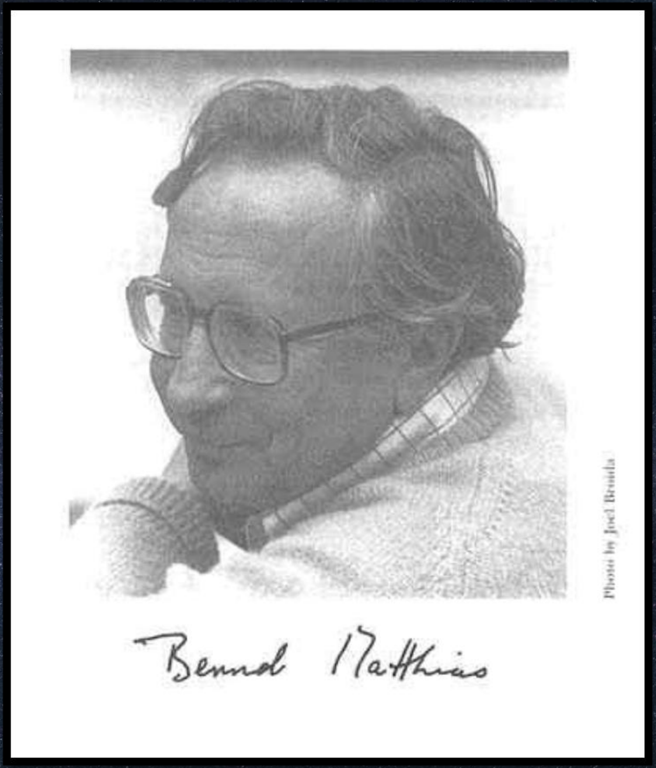


A. A. Abrikosov

从1913-2003年，超导研究一共有

10 人　5 次

获诺贝尔物理学奖



BERND THEODOR MATTHIAS

1918.6.8 – 1980.10.27

第零定律

◆ **热力学第0定律：温度的定义**

如果两个热力学系统中的每一个都与第三个热力学系统处于热平衡(温度相同)，则它们彼此也必定处于热平衡

◆ **牛顿第0定律：平衡的定义**

如果两个系统各自与第三个系统各自处于力学平衡状态，那么这两个系统之间也将达到力学平衡

◆ **热力学第1定律：能量守恒定律**

◆ **热力学第2定律：熵增原理**

◆ **热力学第3定律：绝对零度不可达**

◆ **牛顿第1定律：惯性定律**

◆ **牛顿第2定律：力与加速度**

◆ **牛顿第3定律：作用力与反作用力**

高温超导第0人
马蒂亚斯

- 1972年：马蒂亚斯提出了“高温超导”概念（T_c > 10 K 后改为 T_c > 20 K）
- 1955年：马蒂亚斯提出了探索超导体“五原则”，预测了可能的高温超导体
- 1986年： La-Ba-Cu-O高温超导被柏诺兹和缪勒发现（T_c = 35 K）
- 1987年： Y-Ba-Cu-O液氮温区高温超导被赵忠贤和朱经武等发现（T_c = 93 K）

铜氧化物高温超导的发现，证明马蒂亚斯的“五原则”全是错的！

发现YBCO高温超导的朱经武，是马蒂亚斯的博士研究生！

1989年，马蒂亚斯奖设立，是超导材料研究的最高奖项！

马蒂亚斯生平简介

Bernd Matthias
1918 – 1980

1918. 6. 8: 出生于德国法兰克福

1942 – 1947: 在瑞士苏黎世联邦理工学院学习
1943:在瑞士苏黎世联邦理工学院获得博士学位

1947 – 1948: 在麻省理工学院找到第一份教职
1948 – 1980: 在贝尔实验室担任工程师
1949 – 1951: 在芝加哥大学担任助理教授
1961 – 1980: 在加州大学圣地亚哥分校担任教授
Director, Institute for the Study of Matter (1962-1966)
Associate Director, Institute for Pure and Applied Physical Sciences (1966-1971)
Director, Institute for Pure and Applied Physical Sciences (1971-1980)

1965: 美国艺术与科学学院 院士
1965: 美国国家科学院 院士
1970: 获得凝聚态物理最高奖——巴克利奖
1979: 获美国物理学会“国际新材料奖”
1980.10.27 在圣地亚哥拉荷亚去世

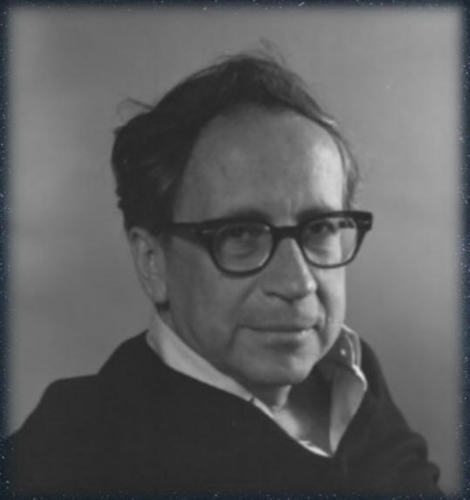
马蒂亚斯的家庭成员及早年经历

Bernd Matthias
1918 – 1980

父亲：犹太商人，在他幼年时去世
母亲：犹太人，1938年在他20岁时自杀身亡
妹妹：Judith Matthias
妻子：Joan Trapp Matthias 牧师女儿
马蒂亚斯一生无子嗣
姐姐回忆：smoke rising from the corner of his room in which he was experimenting

1924年，6岁时从法兰克福搬到科尼斯施泰因(Koenigstein)小镇，就读小学和中学，14岁时搬到瑞士(Knabeninstitute auf dem Rosenberg)就读大学，从此离开了德国。
1936年（18岁）在Institute Montana, Zug毕业后到ETH学习物理，老师是G. Wentzel, Karrer 和 Pauli。后成为Paul Scherrer的研究生，研究压电和铁电效应，于1943年获得博士学位。
1947年（29岁）受Arthur von Hippel邀请到美国工作，在贝尔实验室和加州圣地亚哥工作，结识了W. Shockley(诺奖得主)，Joe Remeika（合作研究$BaTiO_3$），John Hulm（学习低温测量技术），得到E. Fermi、Willy. Zachariasen等人的指导。

马蒂亚斯主要合作伙伴



Bernd Matthias
1918 – 1980

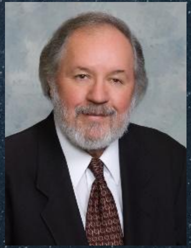
1971-1980 在洛斯阿拉莫斯实验室
R. D. Fowler, A. L. Giorgi, H. Hunter Hill
N. Krikorian, C. E. Olsen, S. J. Lawrence
G. R. Stewart, E. G. Szklarz
他们为超导材料特别是重费米子超导体的研究做出了重要贡献
在贝尔实验室：V. Compton, G. Hull, L. Longinotti….

G. R. Stewart

在ETH的导师：Paul Scherrer (导师：Debye)
保罗谢勒研究所是瑞士最大的基础科研机构

1890-1969

第一个博士生： M. Brian Maple 加州大学圣地亚哥分校
Bernd T. Matthias Prof. of Physics
The Bernd T. Matthias Prize for 2000
"Superconductivity and magnetism of lanthanum-rare earth dialuminides “
在高温超导和重费米超导方面做出了杰出贡献



1939-

马蒂亚斯的“朋友圈”

Bell Telephone Laboratories:

Guṅter Ahlers (发现混沌流体)

P. W. Anderson (凝聚态物理理论 1977诺奖)

John Bardeen (半导体和超导理论，1956和1972双料诺奖)

Robert J. Birgeneau (中子散射 加州伯克利校长)

Arthur Ashkin (光镊技术 2018诺奖)

Oliver E. Buckley (凝聚态物理最高奖以他命名)

朱经武 (发现YBCO高温超导体)

Robert J. Cava (超导新材料探索)

John J. Hopfield (人工神经网络 2024诺奖)

....

University of California, San Diego:

Maria Goeppert Mayer (女物理学家 1963诺奖)

Hannes Alfvén (等离子体物理 1970诺奖)

Marshall Rosenbluth (发展蒙特卡洛方法 1985费米奖)

Norman Rostoker (等离子体物理 1988麦克斯韦奖)

Walter Kohn(建立密度泛函理论 1998诺奖)

Richard Webb (纳米科学家 1992巴克利奖)

Zachary Fisk (发现重费米子超导体)

Herbert York (核物理学家 2000费米奖)

....

你跟牛人之间差的不是距离，而是“朋友圈”！

马蒂亚斯发现了近1000个超导体

REVIEWS OF

MODERN PHYSICS

VOLUME 35, NUMBER 1 JANUARY 1963

Superconductivity

B. T. MATTHIAS,* T. H. GEBALLE, AND V. B. COMPTON

Bell Telephone Laboratories, Murray Hill, New Jersey

TABLE I. Transition temperatures and crystal-structure data of superconducting elements.

	Superconductivity data		Crystal-structure data					
Element	Transition temperature[a] °K	References	Structure type	System	Lattice a, Å	Constants b, Å	c, Å	References
Al	1.171-1.196	33, 34, 35, 36	*A1*–Cu	Cubic	4.0496			37
β-La	5.4-*6.3*	38, 39, 40, 41, c	*A1*–Cu	Cubic	5.296			38
Ir	0.14	42	*A1*–Cu	Cubic	3.8389			37
Pb	7.175-*7.193*-7.23	33, 43, 44	*A1*–Cu	Cubic	4.9502			37
α-Th	1.37	45, 46	*A1*–Cu	Cubic	5.0843			37
V	*5.03*-5.13	33, 47	*A2*–W	Cubic	3.0282			37
Nb	*9.09*-9.465	33, 48, 49	*A2*–W	Cubic	3.3007			37
Mo	0.92	25, 50	*A2*–W	Cubic	3.1468			37
Ta	4.39-*4.482*	33, 51, 52, 53, 54	*A2*–W	Cubic	3.298			37
					3.8389			
Ti	*0.387*-0.49	55, 56, 57	*A3*–Mg	Hexagonal	2.9504		4.6833	37
Zn	0.825-*0.855*-0.875	8, 33, 58, 59	*A3*–Mg	Hexagonal	2.6649		4.9468	37
Zr	0.546-0.565	57	*A3*–Mg	Hexagonal	3.2312		5.1477	37
Tc	8.22-9.3-11.2	60, 61, b	*A3*–Mg	Hexagonal	2.735		4.388	37
Ru	0.47-*0.493*	21, 62, 63, 64	*A3*–Mg	Hexagonal	2.7058		4.2816	37
Cd	*0.52*-0.602	33, 57, 65	*A3*–Mg	Hexagonal	2.9788		5.6167	37
Hf	0.165	78	*A3*–Mg	Hexagonal	3.1946		5.0511	37
Re	*1.699*-2.42	63, 66, 67	*A3*–Mg	Hexagonal	2.760		4.458	37
Os	0.58-*0.655*-0.71	8, 62, 63, 64	*A3*–Mg	Hexagonal	2.7353		4.3191	37
Tl	2.36-2.39	33, 68	*A3*–Mg	Hexagonal	3.4566		5.5248	37
α-La	4.8-*4.9*-5.0	39, 40, 41, c	*A3'*–La	Hexagonal	3.770		12.159	37
Sn	3.701-*3.722*	33, 52, 69	*A5*–White Sn	Tetragonal	5.8314		3.1814	37
In	3.396-*3.408*	33, 52, 70, 71	*A6*–In	Tetragonal	4.5979		4.9467	37
α-Hg	4.153	68, 72, 73	*A10*–Hg	Rhombohedral	2.9863	α = 70°44.6′		37
Ga	*1.087*-1.103	33, 58	*A11*–Ga	Orthorhombic	4.5198	7.6602	4.5258	37
α-U	0.68-0.7	74, 75	*A20*–α–U	Orthorhombic	2.8536	5.8698	4.9555	76
β-Hg	3.949	72, 73		Tetragonal	3.995		2.825	77

TABLE IV. Superconductivity and crystal-structure data for compounds with *A*15-type structure.

	Superconductivity data			Crystal-structure data	
Compound	T_c °K	T_n °K	References	Lattice constants a, Å	References
Ti_3Sb	5.8		140	5.217	140
Ti_3Ir	5.4		140	5.009	140
Ti_3Pt	0.58		82	5.032	82,150
Ti_3Au		1.20	149		149
V_3Si	17.1		149	4.722	149
V_3Co		0.35	82	4.684	82,151
V_3Ga	16.5		112,152	4.816	152
V_3Ge	6.01		149		149
V_3As		1.02	112	4.74	112
V_3Rh	0.38		82	4.784	82,153
V_3Sn	7.0		154	4.94	154
	3.8		144	4.96	144
V_3Sb	0.80		82	4.941	82,136,152
V_3Ir		0.35	82	4.786	82,136,163
$(V_{2.67}Ir_{0.33})Ir$	1.39		140	4.794	140
V_3Pt	2.83		140	4.814	140
V_3Au	0.74		82	4.883	82,155
Cr_3Si		1.20	149		149
Cr_3Ga		0.35	82	4.645	82,152
Cr_3Ge		1.20	149		149
Cr_3Ru	3.3		111		111
Cr_3Rh		0.30	111		111
$Cr_{0.85}Ir_{0.15}$	0.77		111		111
Cr_3Pt		0.30	111		111
Zr_3Au	0.92		82	5.483	82,136,137
Zr_3Pb	0.76		82	5.656	82
Nb_3Al	17.5		152	5.187	152
	16.8–18.0		156, a		156, a
Nb_3Ga	14.5		152	5.171	152
Nb_3Ge	6.90		82	5.166	82,136,157
Nb_3Rh	2.50		112	5.115	112
Nb_3In	9.2		158	5.303	158
Nb_3Sn	18.05		159,160	5.289	154
Nb_3Sb		1.02	112,152	5.262	152
Nb_3Os	1.05		112	5.121	154
Nb_3Pt	9.2		154	5.153	154
Nb_3Ir	1.7		154	5.131	154
Nb_3Au	11.5		155	5.21	155
Mo_3Al	0.58		82	4.950	82,152
Mo_3Si	1.30		149		149
Mo_3Ga	0.76		82	4.943	82,152
Mo_3Ge	1.43		149		149
Mo_3Os	7.2		27		27
Mo_3Ir	8.35; 8.8		25; 27	4.974	82,161,162
$Mo_{0.74}Ir_{0.26}$	9.05		141	4.972	141
Ta_3Sn	6.0		154,159	5.276	154
	6.4		144	5.278	144

TABLE III. Superconductivity and crystal-structure data for compounds with *A* 12-type structure.

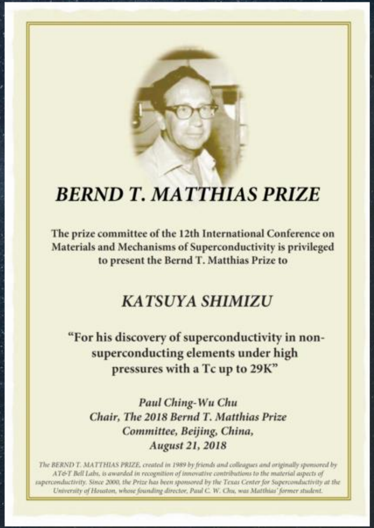
	Superconductivity data			Crystal-structure data	
Compound	T_c °K	T_n °K	References	Lattice constants a, Å	References
Mg_3Al_2		0.35	82	10.55	82,139
Ti_5Re_{24}	6.6		140	9.587	140
$Ti_{0.17}Re_{0.83}$	5.1		141	9.595	141
$V_3Fe_3Si_2$		0.37	82	8.851	82,142
$V_{2.8}Co_{3.2}Si_2$		1.02	82	8.774	82,142
$V_3Ni_3Ge_2$		0.35	82	8.928	82,142
$ZrTc_6$	9.7		60	9.636	60
$ZrRe_6$	7.4		140	9.698	140
$NbTc_3$	10.5		60	9.625	60
$Nb_{0.60}Pd_{0.40}$	2.04-2.47		141	9.77	141
$Nb_{0.40}Re_{0.60}$	2.36		141	9.781	141
$Nb_{0.18}Re_{0.82}$	9.7; 8.89		140; 143	9.641	140; 143
$NbOs$	2.86		141	9.760	141
$NbOs_2$	2.52		140	9.655	140
$MoRe_3$	9.26		143		143
$Hf_{0.50}Re_{0.50}$		1.02	113		113
$Hf_{0.14}Re_{0.86}$	5.86		113		113
$Ta_{0.36}Re_{0.64}$	1.46		140	9.765	140
$Ta_{0.34}Re_{0.66}$	1.58		141	9.762	141
$TaRe_3$	6.78		143		143
$TaOs$	1.95		140	9.773	140
WRe_3	9.00		143		143

	Superconductivity data			Crystal-structure data			
Compound	T_c °K	T_n °K	References	Lattice constants a, Å	c, Å	Lattice type[a]	References
V_5Si_3		0.30	82	9.429[b]	4.757[b]	bc	82,279
Cr_3Ge_2		1.20	149			bc	149
$CuGa_2$		1.27	82	2.836[b]	5.847[b]	p	82,280
Nb–N	8.90/11.8		165,278			fc	165,278
Nb_5Si_3		1.02	82	10.018[b]	5.072[b]	bc	82,279
Nb_5Ge_3		1.02	82	10.148[b]	5.152[b]	bc	82,281
Nb_3Sn_2	16.6		c	6.90	9.53		c
$RhIn_3$		1.02	82	7.01[b]	7.15[b]	p	82,282
β-$PdBi_2$	4.25		133	3.362	12.983	bc	132,133
$BaBi_3$	5.69		168	5.188	5.157		216
$HgCd$	1.77		82	3.940[b]	2.916[b]	bc	82,283,284
Th_3Si_2		1.20	149			p	149
U_3Si		1.10	114			bc	114

马蒂亚斯奖 (1989-2022) $6,000 USD

- ◆2022 Mikhail Eremets 高压富氢化物超导体
- ◆2018 Katsuya Shimizu 高压元素超导体
- ◆2015 陈仙辉, Zachary Fisk, 赵忠贤 铁基超导体和重费米子超导体
- ◆2012 Dirk Johrendt, Ivan Bozovic, James Eckstein 铁基超导体及新超导材料技术
- ◆2009 Yoshiteru Maeno, Hideo Hosono 钌氧化物超导及铁砷化物超导体
- ◆2006 Frank Steglich 重费米子超导体
- ◆2003 Jun Akimitsu 二硼化镁及铜氧化物超导体
- ◆2000 Brian M. Maple 磁性与超导关系的理解
- ◆1997 Bertram Batlogg, Robert J. Cava 超导新材料探索的化学和物理
- ◆1994 朱经武, Bernard Raveau, 吴茂昆 铜氧化物超导体的机理及材料探索
- ◆1991 Hiroshi Maeda, Yoshinori Tokura 铜氧化物高温超导的关键结构确立
- ◆1989 Theodore H. Geballe 新超导材料探索

M²S-2018



BERND T. MATTHIAS PRIZE

The prize committee of the 12th International Conference on Materials and Mechanisms of Superconductivity is privileged to present the Bernd T. Matthias Prize to

KATSUYA SHIMIZU

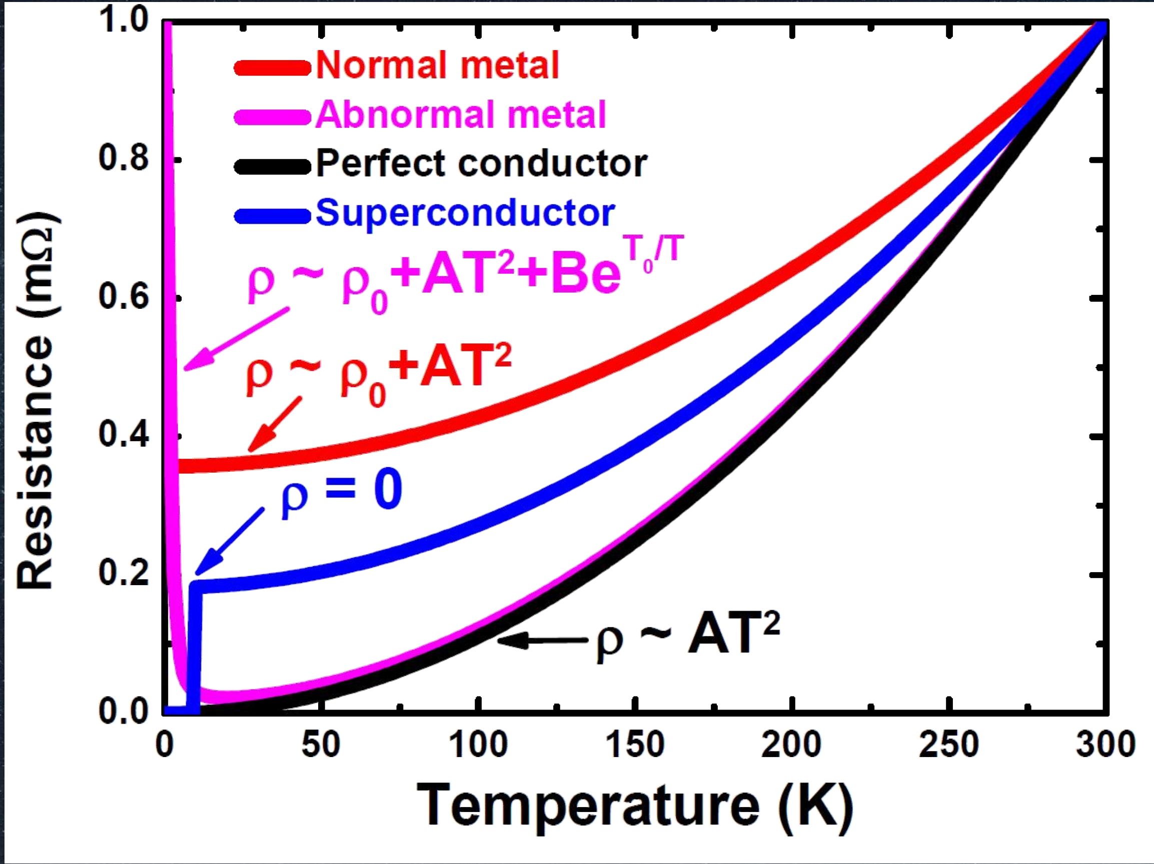
"For his discovery of superconductivity in non-superconducting elements under high pressures with a Tc up to 29K"

Paul Ching-Wu Chu
Chair, The 2018 Bernd T. Matthias Prize Committee, Beijing, China,
August 21, 2018

The BERND T. MATTHIAS PRIZE, created in 1989 by friends and colleagues and originally sponsored by AT&T Bell Labs, is awarded in recognition of innovative contributions to the material aspects of superconductivity. Since 2000, the Prize has been sponsored by the Texas Center for Superconductivity at the University of Houston, whose founding director, Paul C. W. Chu, was Matthias' former student.

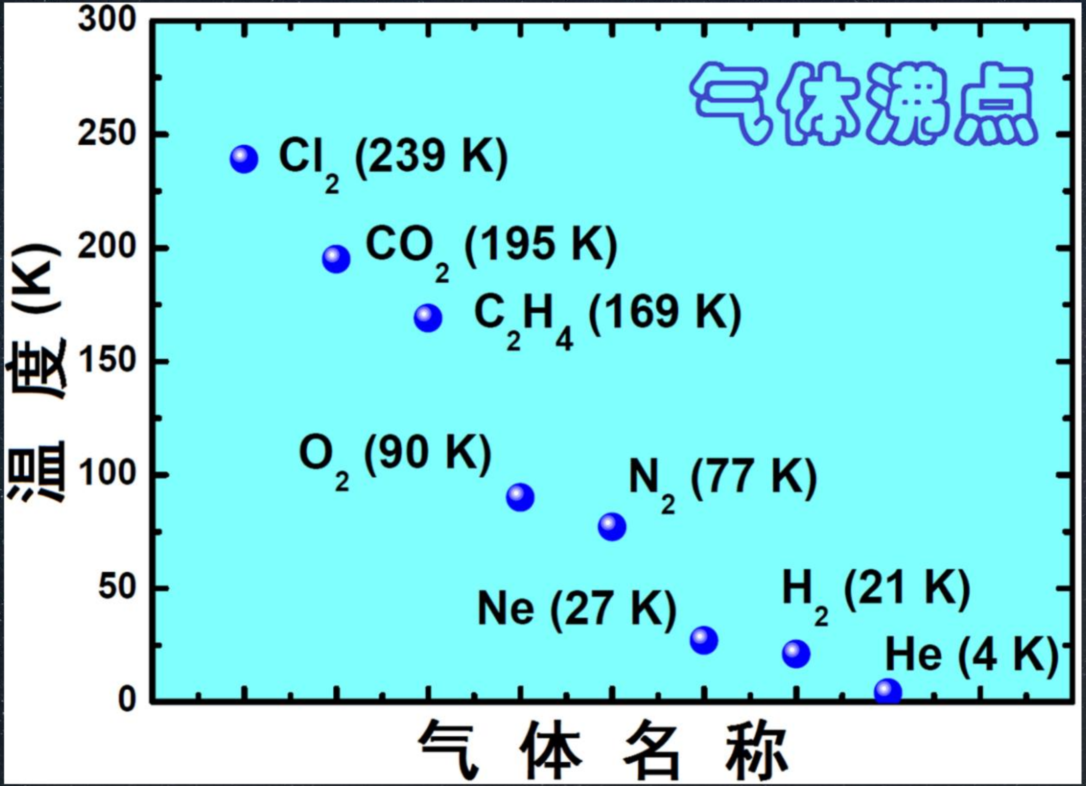
超导研究简史(八卦)

超导发现的“前夜”



Normal metal
Abnormal metal
Perfect conductor
Superconductor
ρ ~ ρ0+AT2+BeT0/T
ρ ~ ρ0+AT2
ρ = 0
ρ ~ AT2
Resistance (mΩ)
Temperature (K)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300

一场“液化气”的竞赛

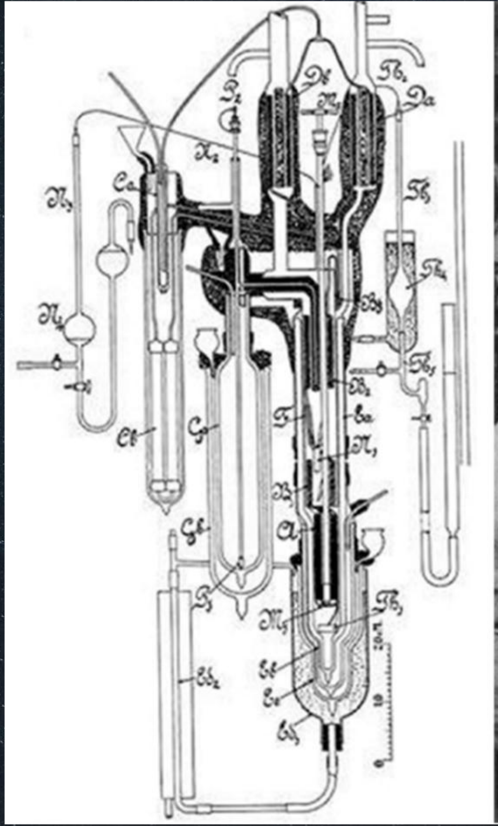


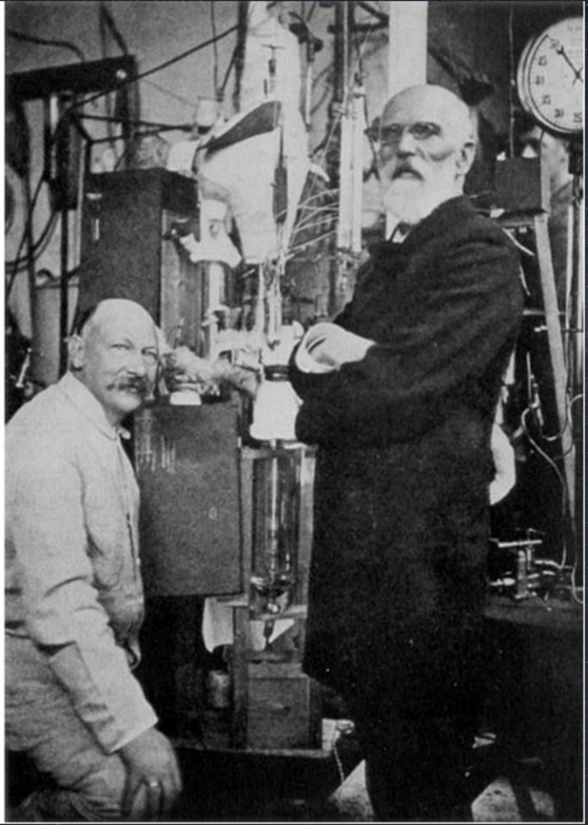
$$\left(P+\frac{am^2}{V^2}\right)(V-mb)=mRT$$

1873 年 荷兰
范德瓦尔斯提出气体状态方程

1910年
诺贝尔奖

“最后一个气体” 被液化



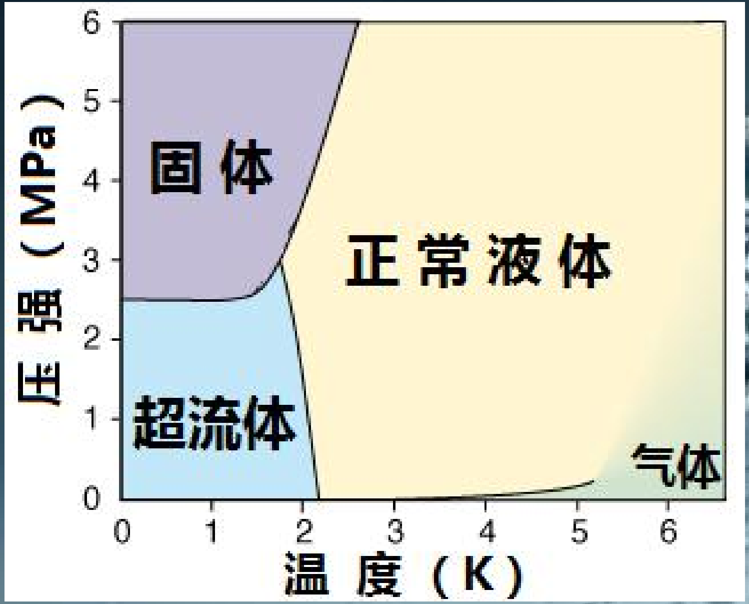


1908 年 荷兰

卡默林-昂尼斯实现氦气液化

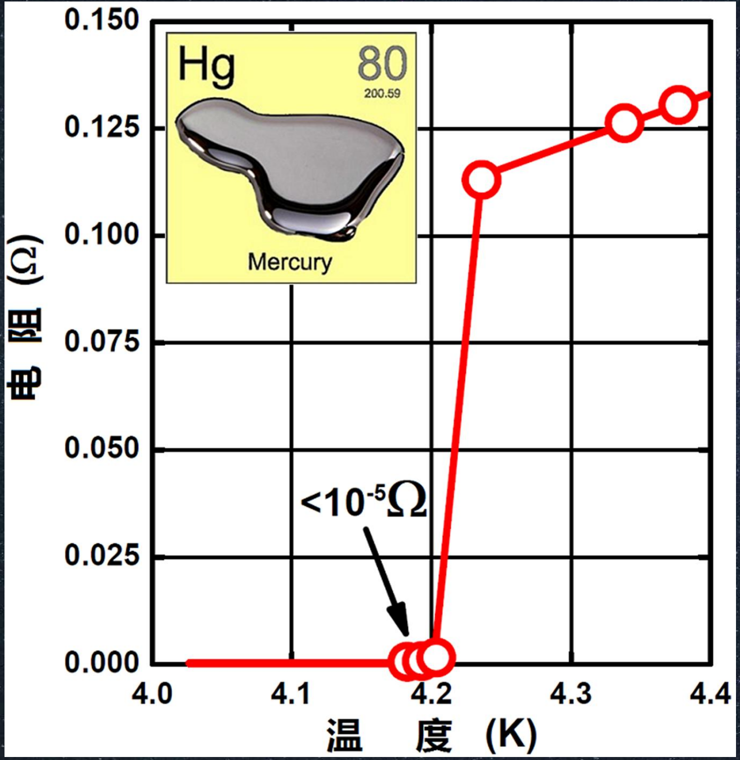
1913年
诺贝尔奖

4.2 K及更低温下会发生什么？

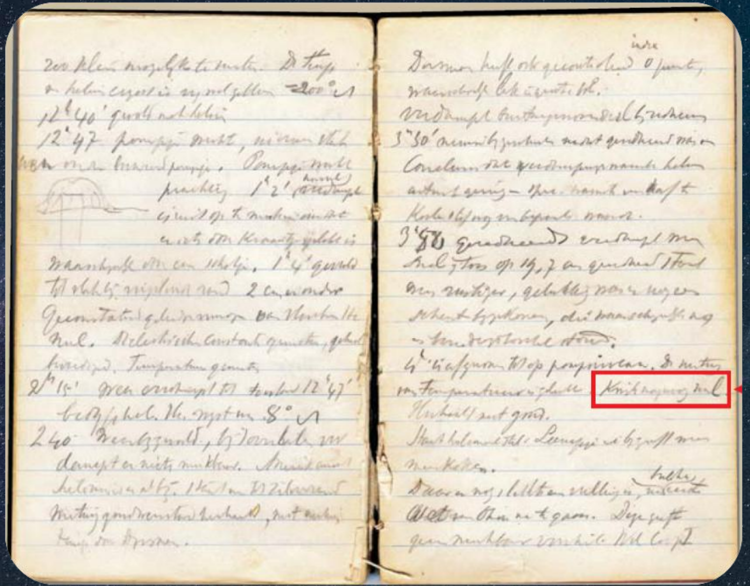


超流“液氦喷泉”

超导现象的发现



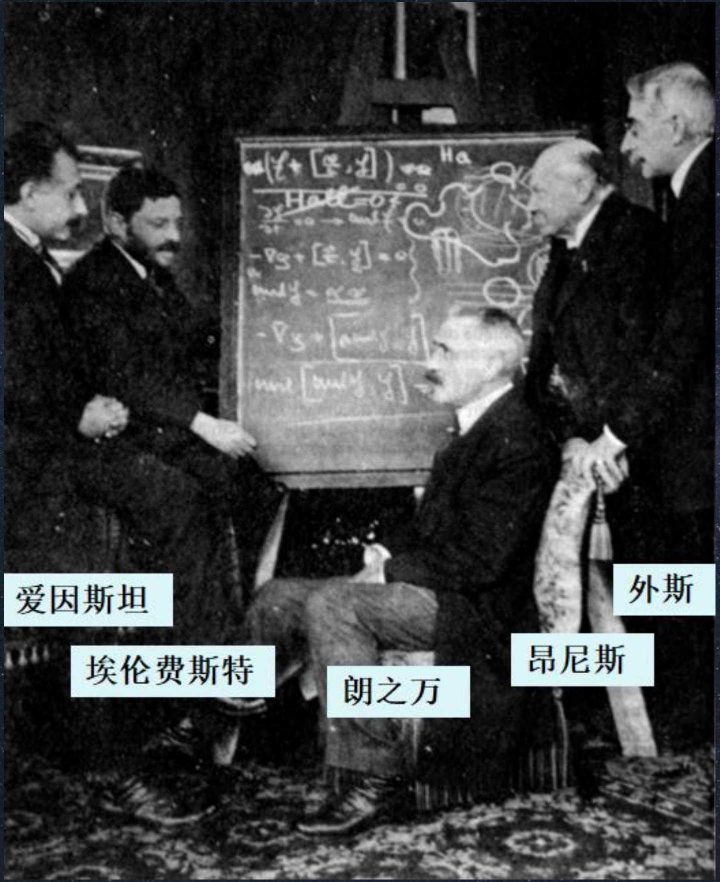
卡默林·昂尼斯

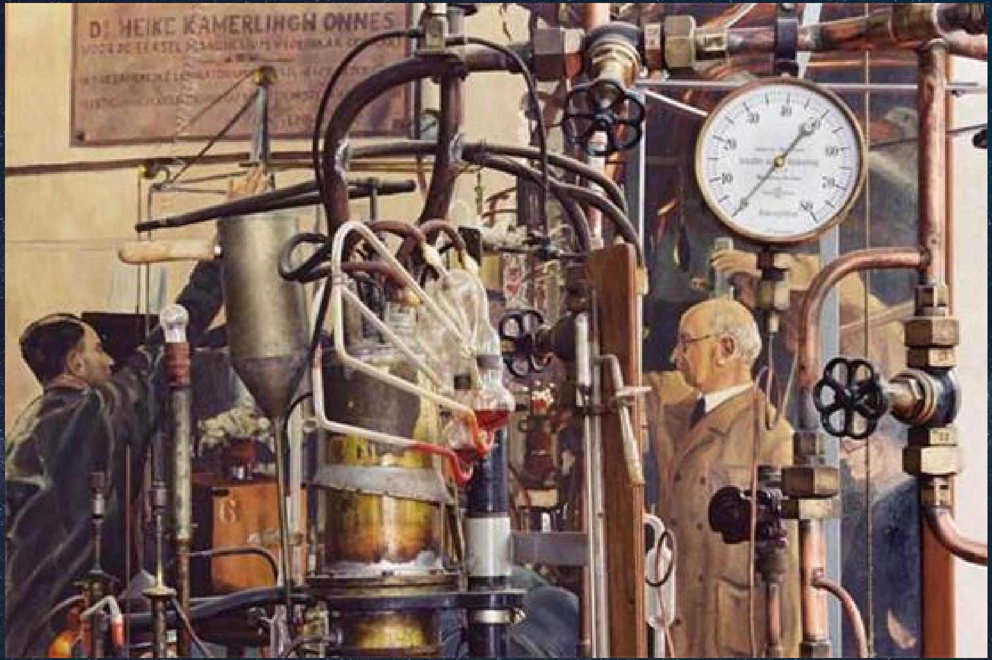


1913年
诺贝尔奖

"Mercury['s resistance] practically zero [at 3 K]."

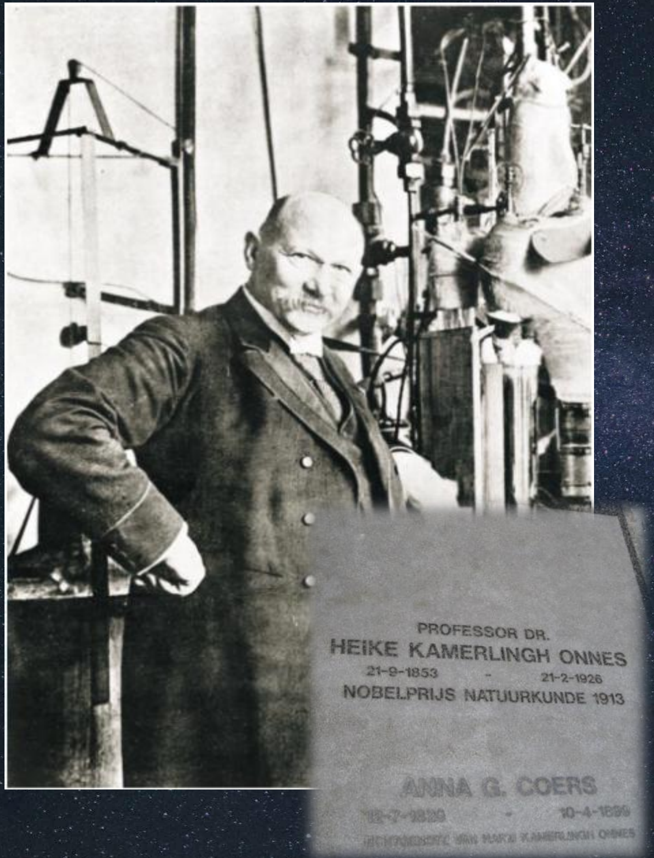
为什么是昂尼斯?





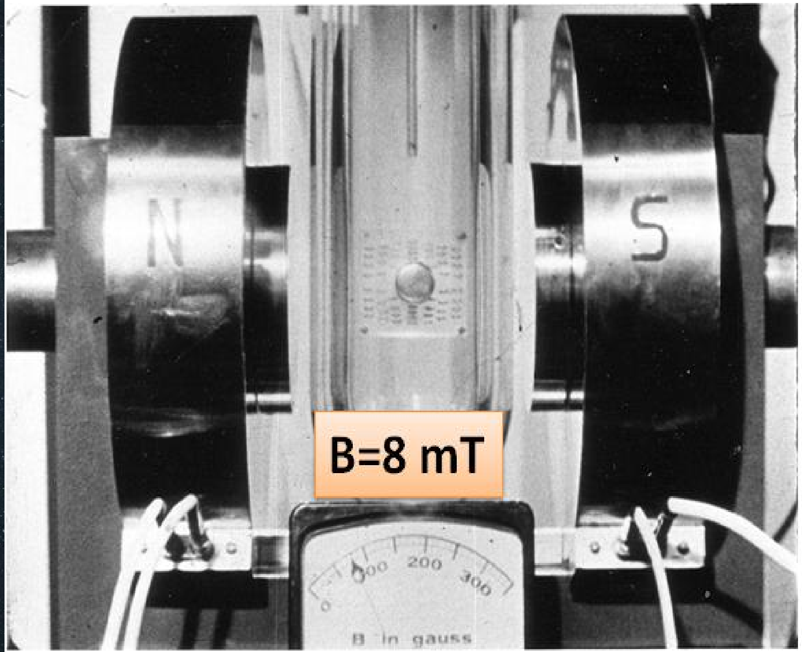
工程师： Gerrit Flim
玻璃工：Oskar Kesselring
测温员：Cornelis Dorsman
学生： Gilles Holst

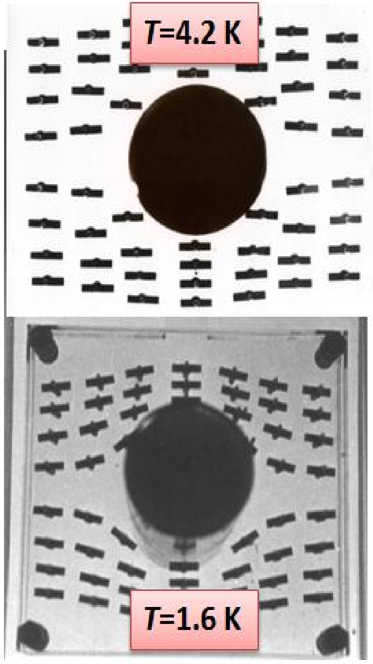
超导发现背后的“大环境”



1911年，昂尼斯发现超导现象，正值首届索尔维会议召开，超导作为首个发现的宏观量子现象，刺激了物理学的发展。

超导现象的磁效应





迈斯纳效应

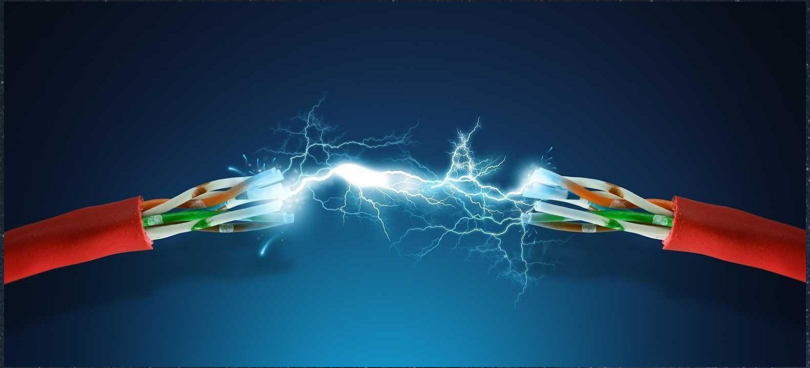
1933 年 德国

迈斯纳发现超导的完全抗磁性

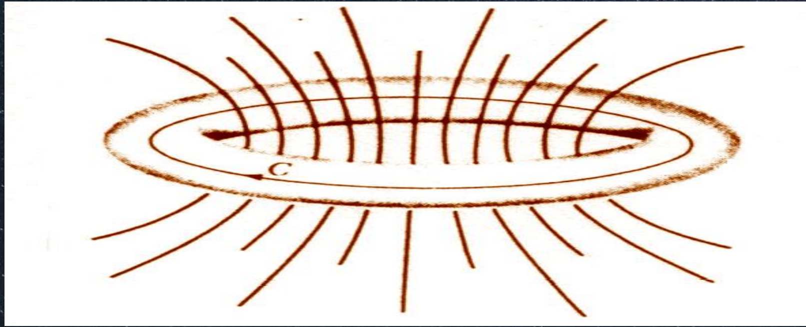
Schließlich sei noch auf die Analogie zum Ferromagnetismus hingewiesen, den schon früher GERLACH[1] in Parallele zur Supraleitfähigkeit gestellt hatte.

Berlin, Physikalisch-Technische Reichsanstalt, den 16. Oktober 1933. W. MEISSNER. R. OCHSENFELD.

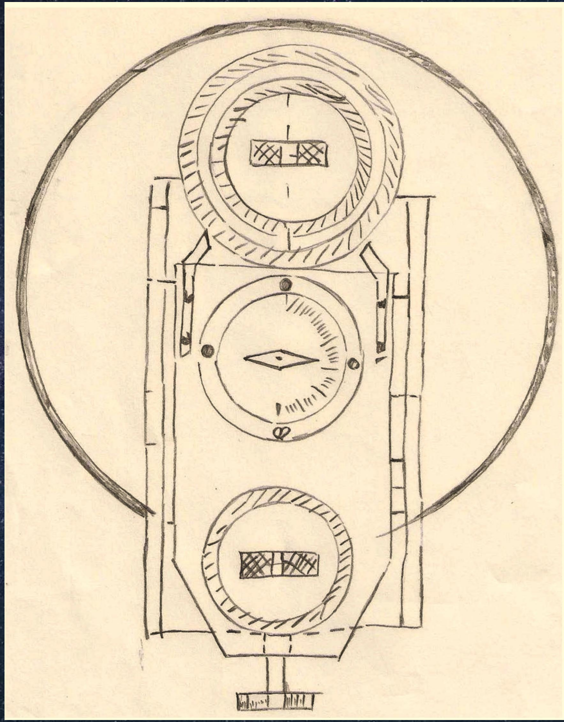
超导为什么特别：绝对零电阻



金属良导体电阻率： $10^{-10} \sim 10^{-8}\ \Omega\cdot m$

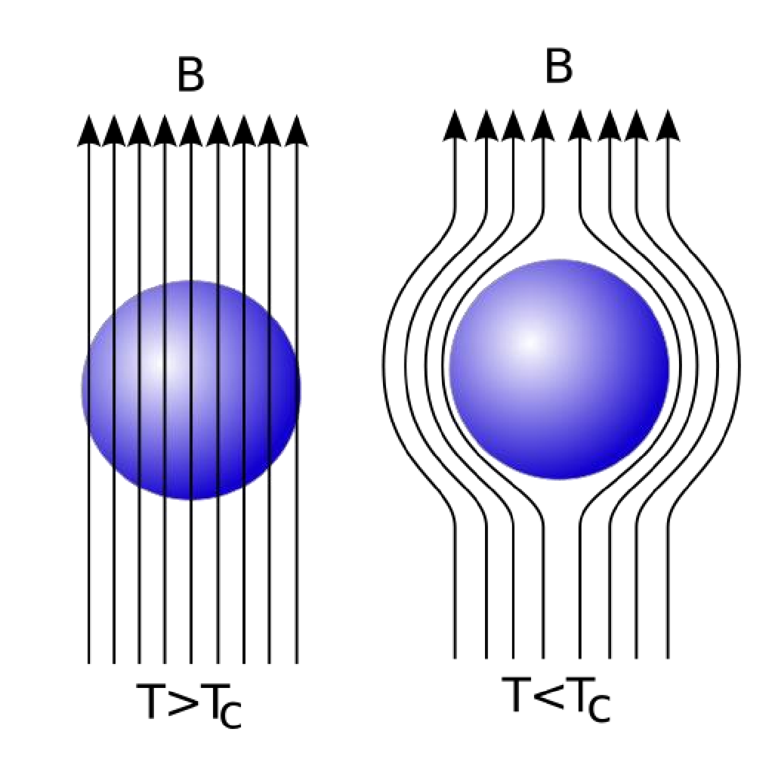


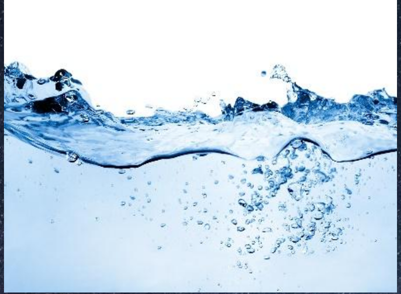
超导体电阻率：< $10^{-24} \sim 10^{-21}\ \Omega\cdot m$



超导体的电阻是绝对的零，目前最精确的实验，仍然看不到电流衰减！

超导为什么特别：完全抗磁性





水的抗磁: 0.0009%

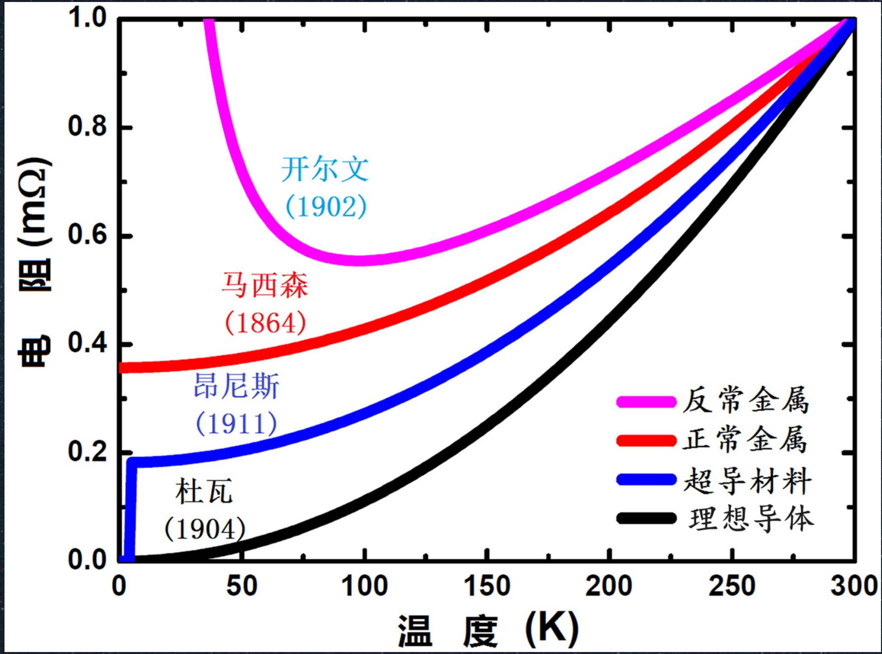
银的抗磁： 0.0026%

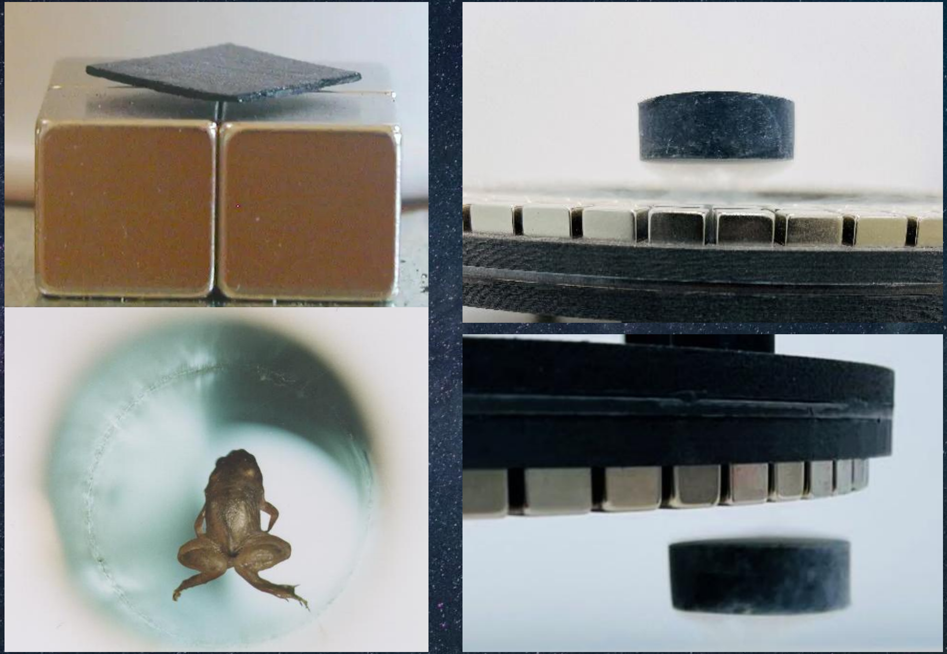
金刚石的抗磁: 0.0021%

石墨的抗磁: 0.041%

超导体的抗磁体积可达100%，远远大于其他抗磁材料（< 1%）！

超导现象的“双判据”

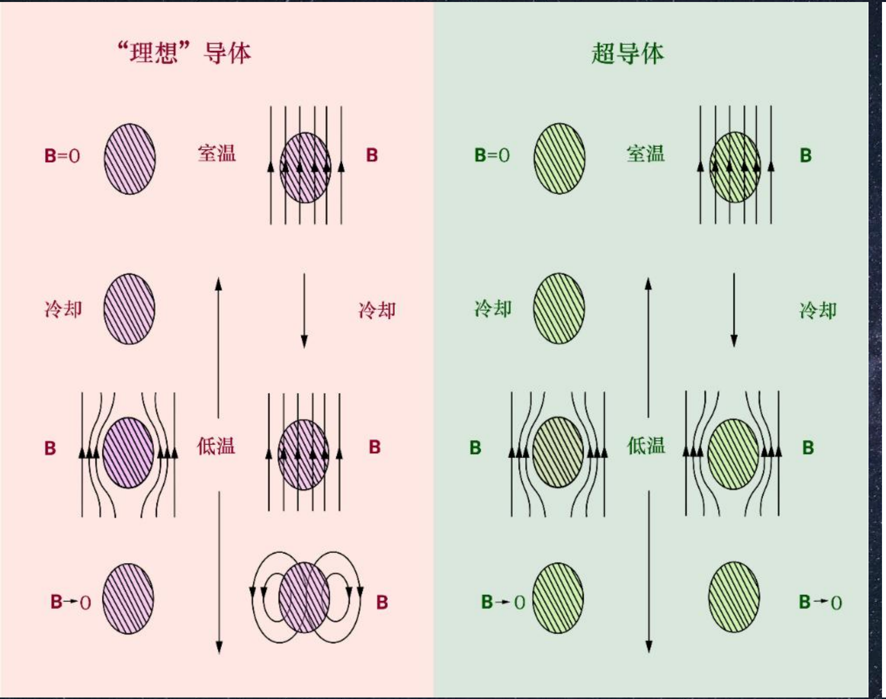


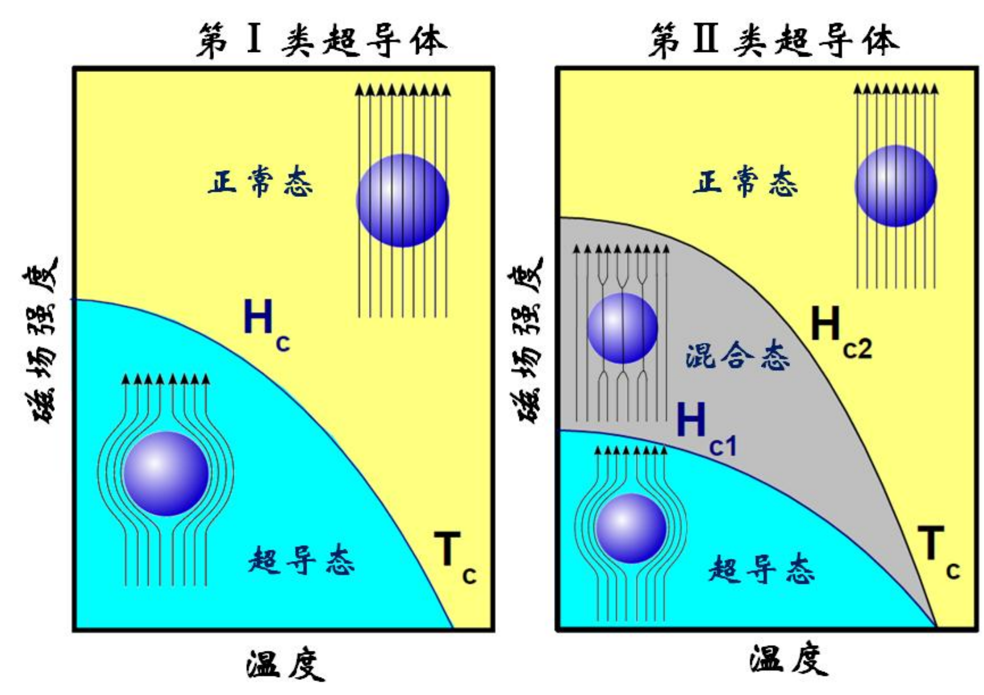


零电阻效应 ≠ 超导电性，还可能是“理想导体”

磁悬浮 ≠ 超导电性，还可能是“弱抗磁性”

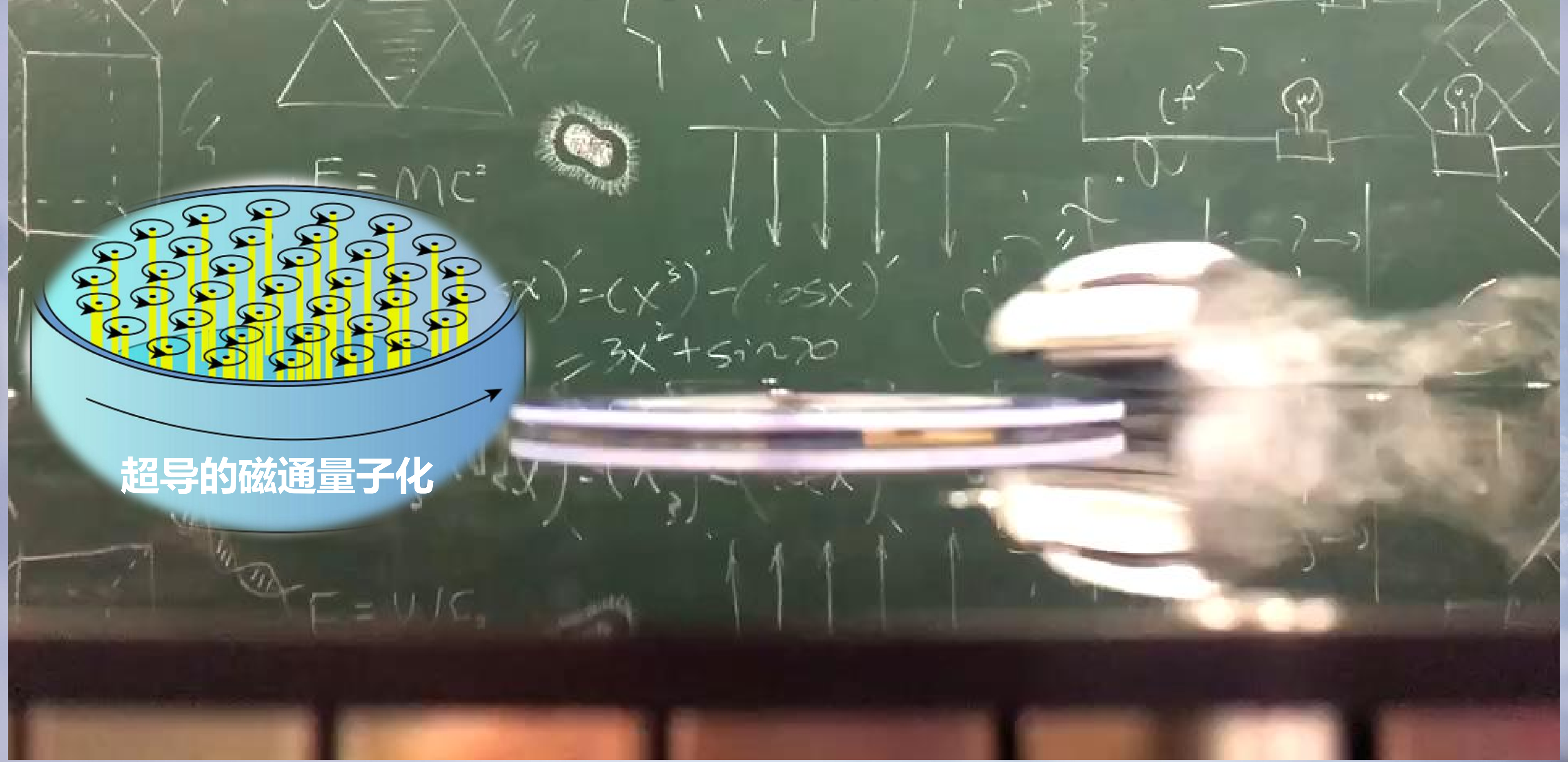
磁场下的超导体 vs 理想导体





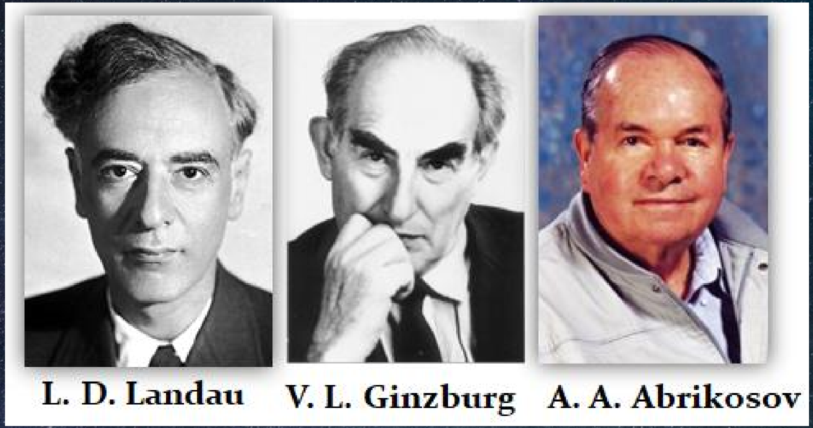
超导体和理想导体在磁场下的响应有本质区别，超导体分为I类和II类。

超导磁悬浮不是因为完全抗磁性



试图挑战过超导理论的物理学家

超导现象的本质：热力学二级相变



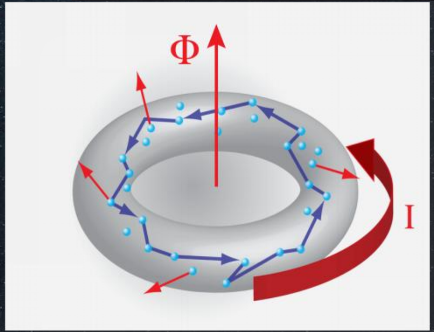
1950-1957 年

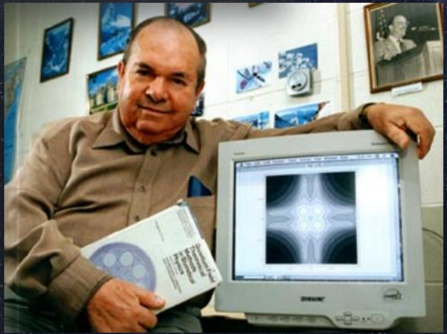
超导唯象理论的建立

1962年
诺贝尔奖

2003年
诺贝尔奖

阿布里科索夫的“非凡一念”

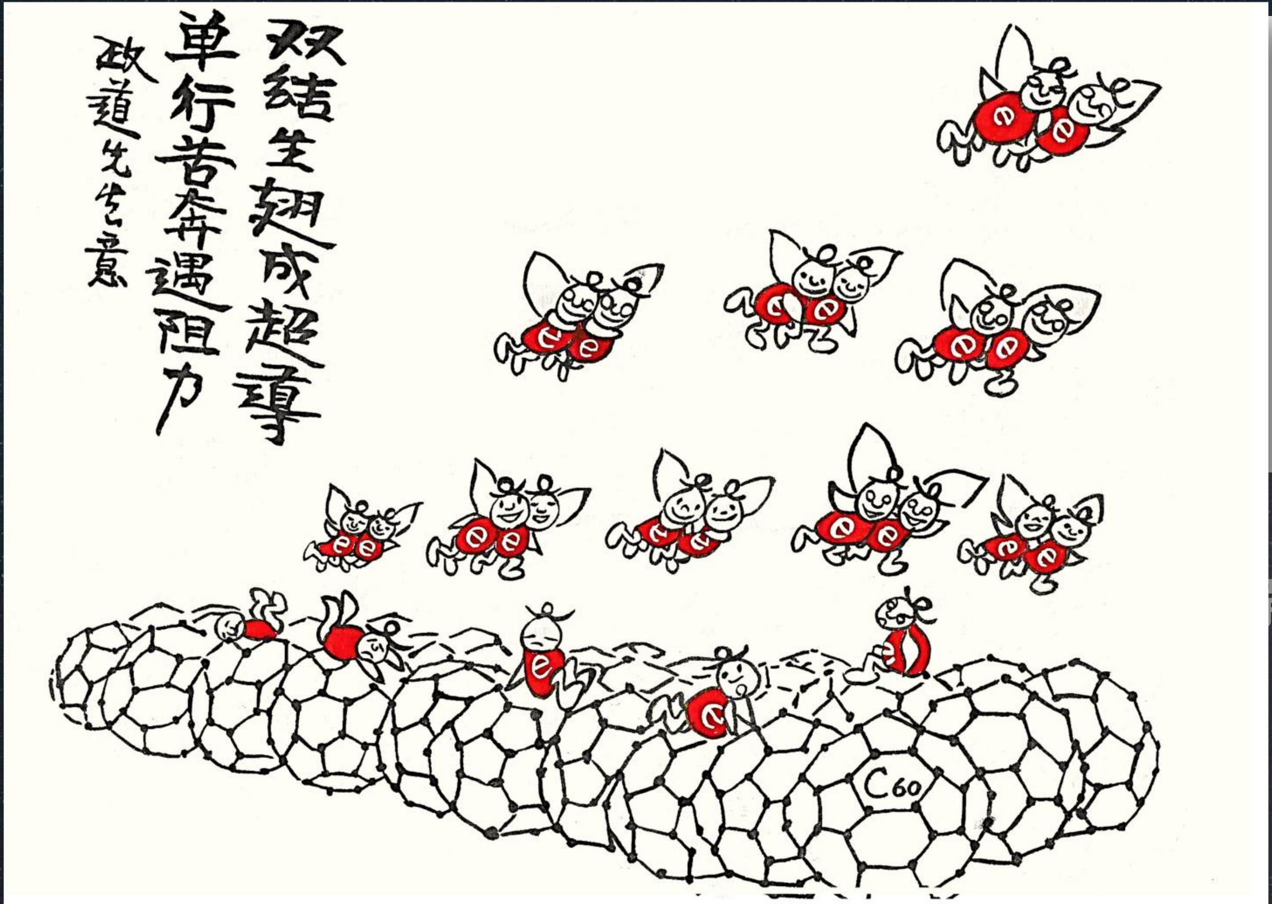


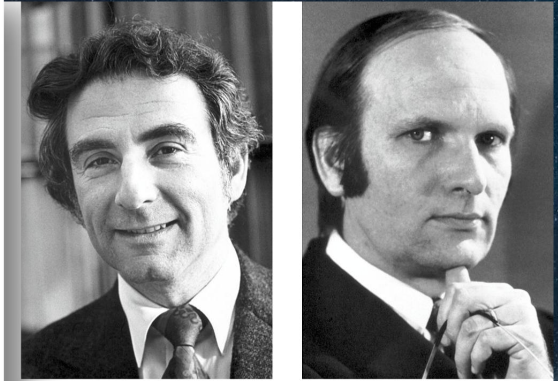


A. A. Abrikosov
获奖时75 岁
1928-2017

论一名理论物理学家的取名

超导现象的本质：电子配对相干凝聚





Leon Cooper
1930-

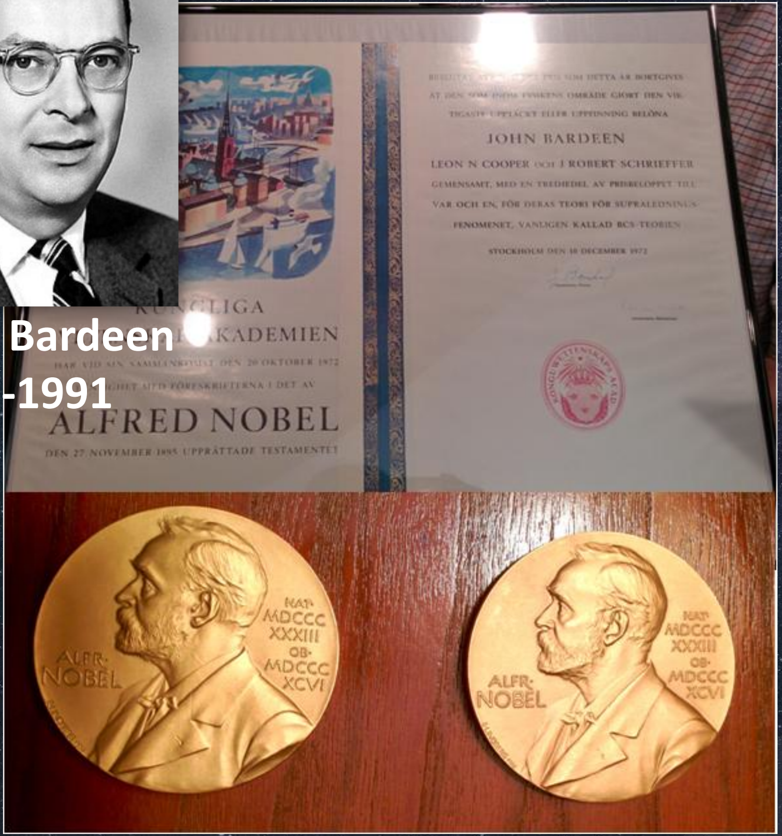
John Schrieffer
1931-2019

1957 年
微观理论的建立

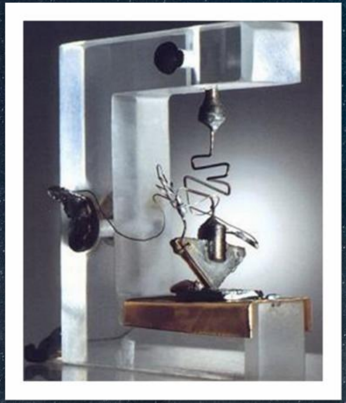
1972年
诺贝尔奖

双料物理诺奖巴丁的传奇一生

John Bardeen
1908-1991



巴丁来访中国



第一个晶体管

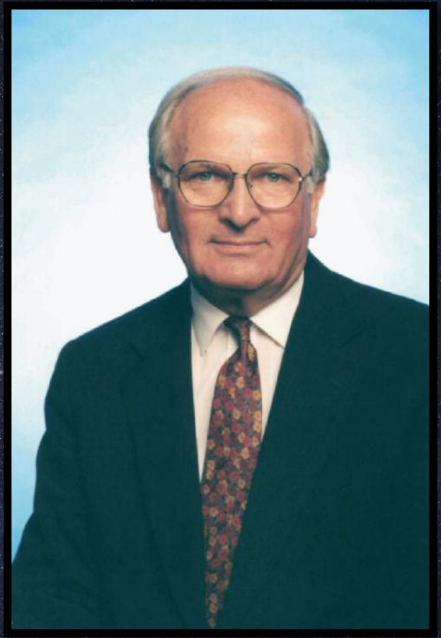
巴丁获两次物理诺奖的秘诀：
努力+机遇+合作

1956年
1972年
诺贝尔奖

施隶弗的传奇一生

John Bardeen Leon Cooper John Schrieffer

论研究生选取导师的重要性



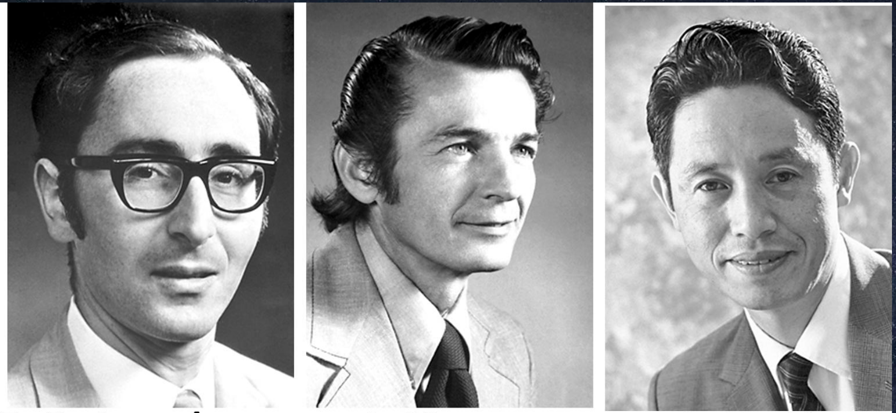
施隶弗写出超导波函数时是研究生一年级，仅26岁。

获诺奖时41岁

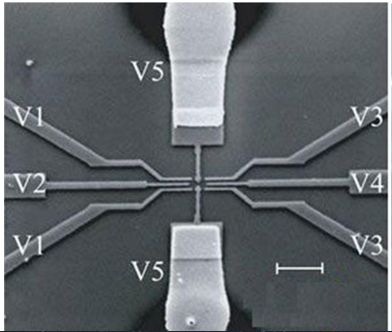
可能是唯一获诺奖后坐牢的科学家

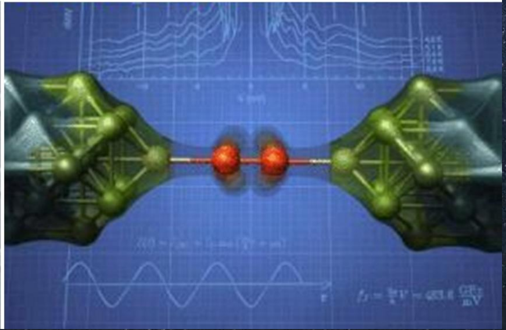
2004年因超速和交通肇事罪（1死7伤），判处监禁2年。
2019年7月27日去世。

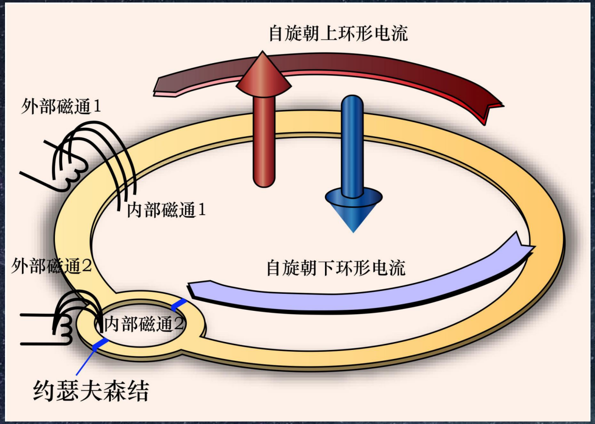
超导现象的本质：宏观量子凝聚态

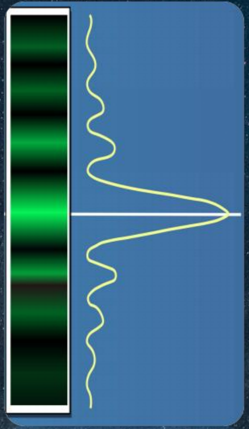


B. D. Josephson　　I. Giaever　　L. Esaki









约瑟夫森：做出工作22岁，获诺奖33岁
贾埃沃：　做出工作31岁，获诺奖44岁

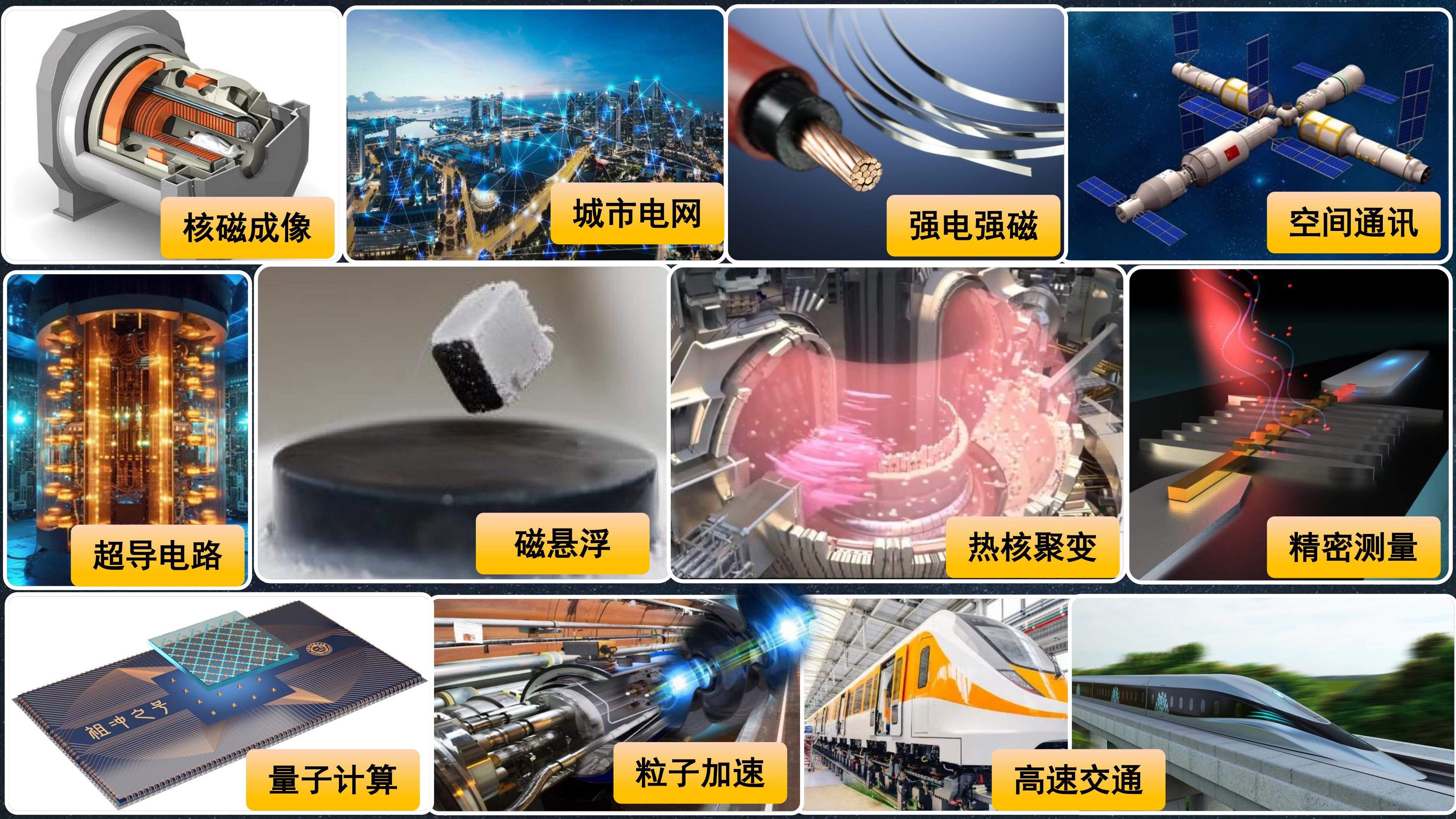
1960-1962 年
超导隧道效应的理论与实验

1973年
诺贝尔奖

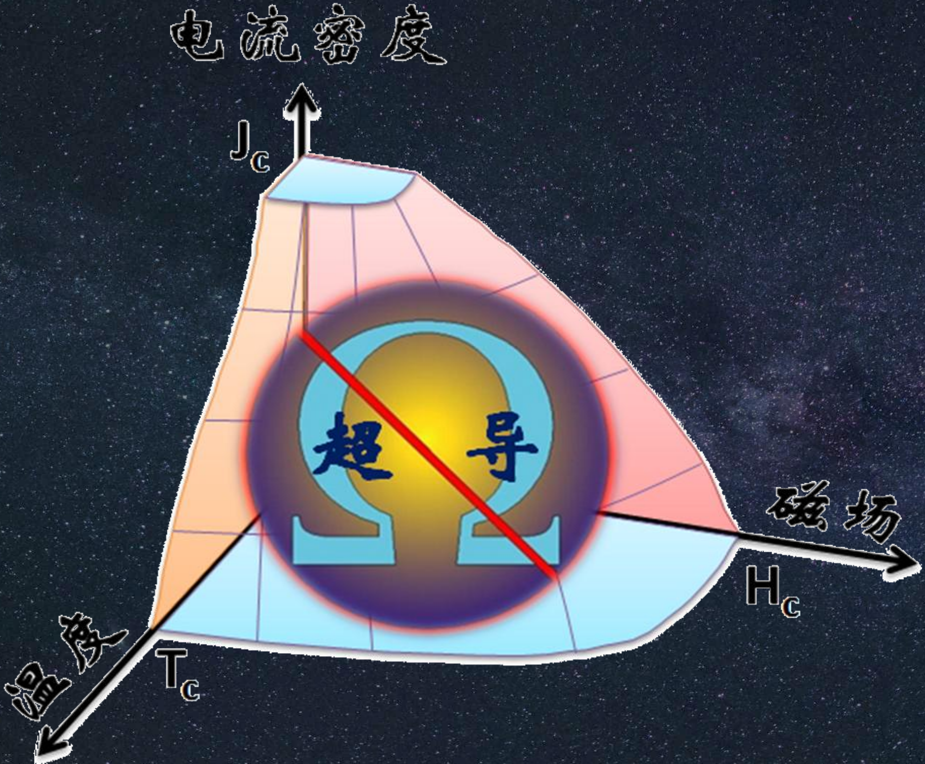
贾埃沃和约瑟夫森的传奇一生

Ivar Giaever
2008 年
中国科学院物理研究所
超导国家重点实验室

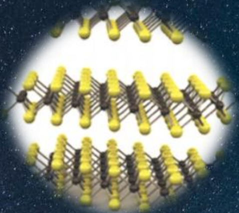
Brian Josephson
2010 年
清华大学物理系


核磁成像
城市电网
强电强磁
空间通讯
超导电路
磁悬浮
热核聚变
精密测量
祖冲之号
量子计算
粒子加速
高速交通

限制超导材料应用的因素



稳定性



机械性能

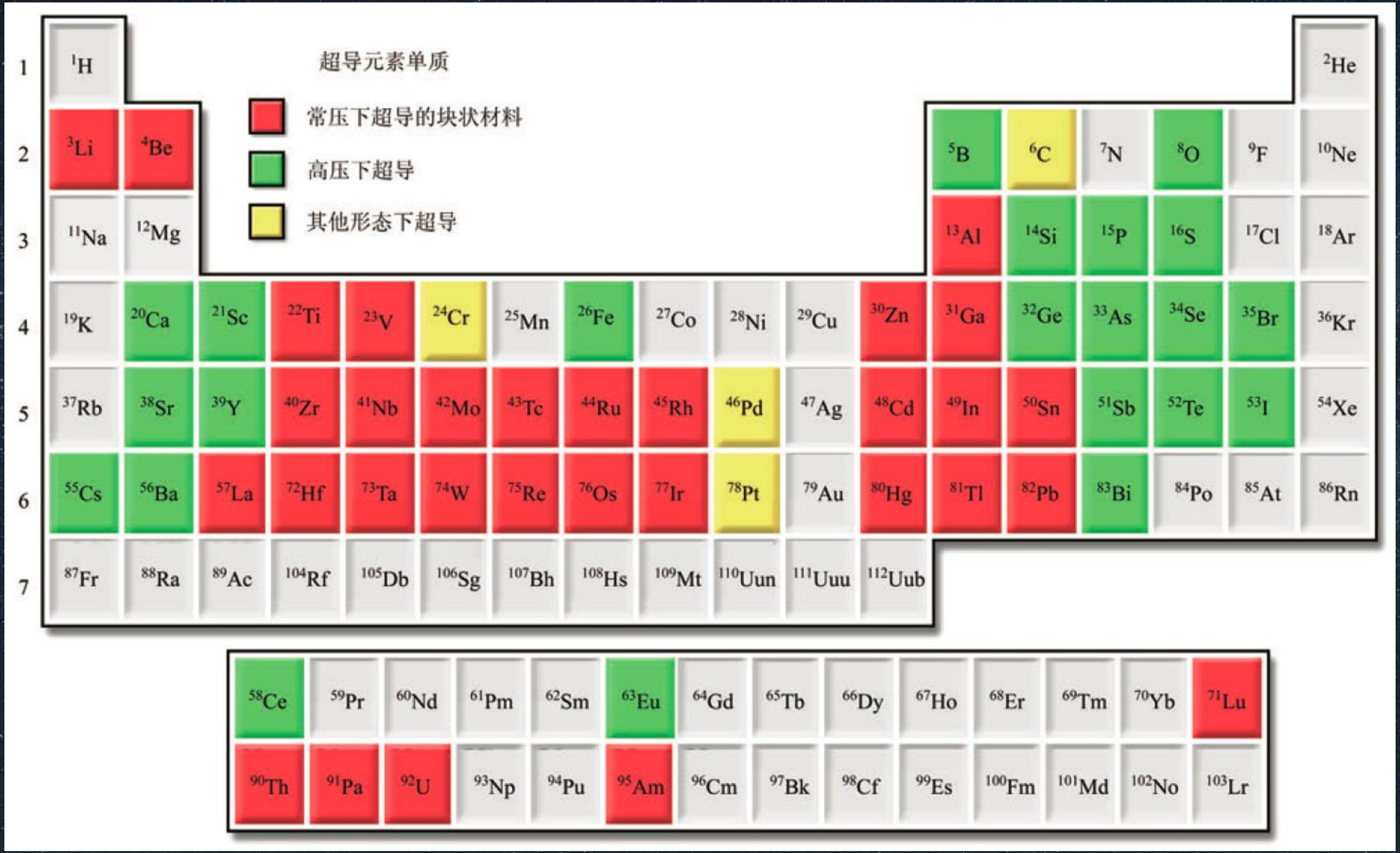
毒害性

性价比

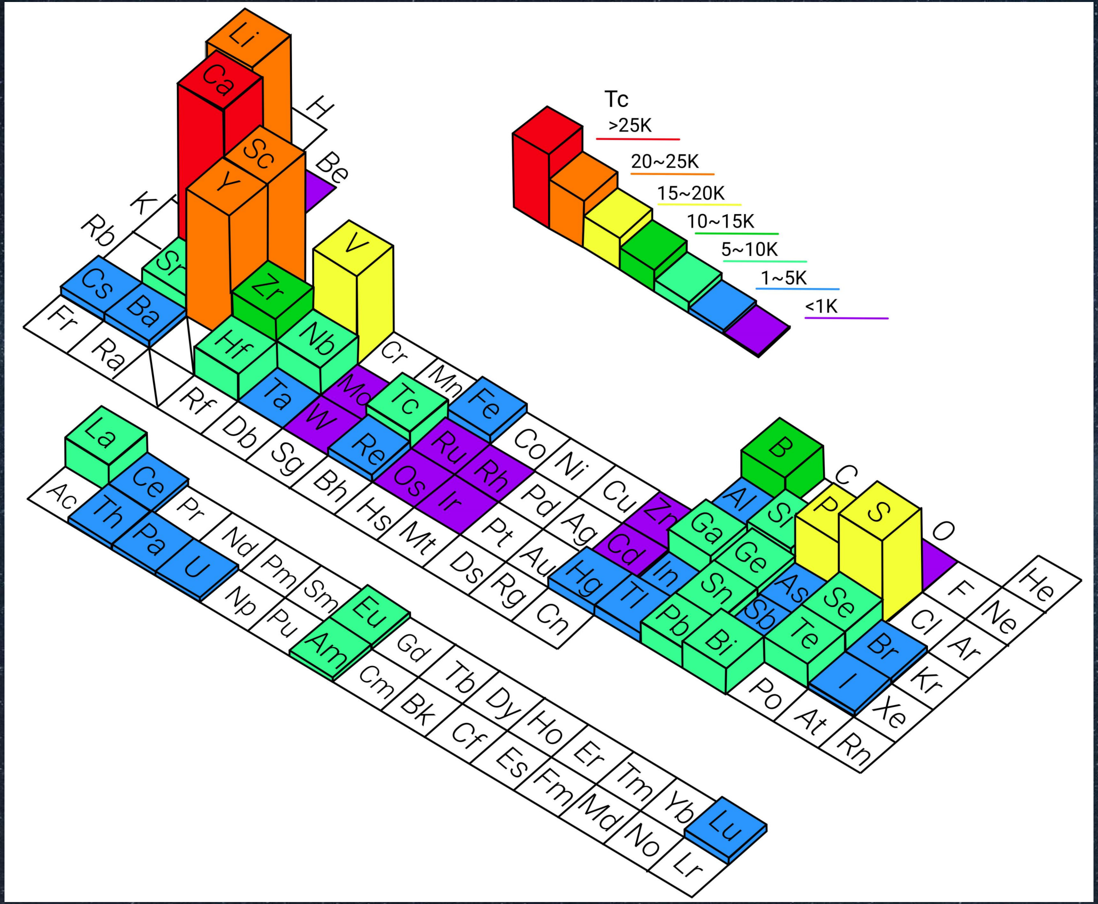
“好的”超导材料必须“三高”（T_c，H_{c2}， J_c）

马蒂亚斯的非凡一念

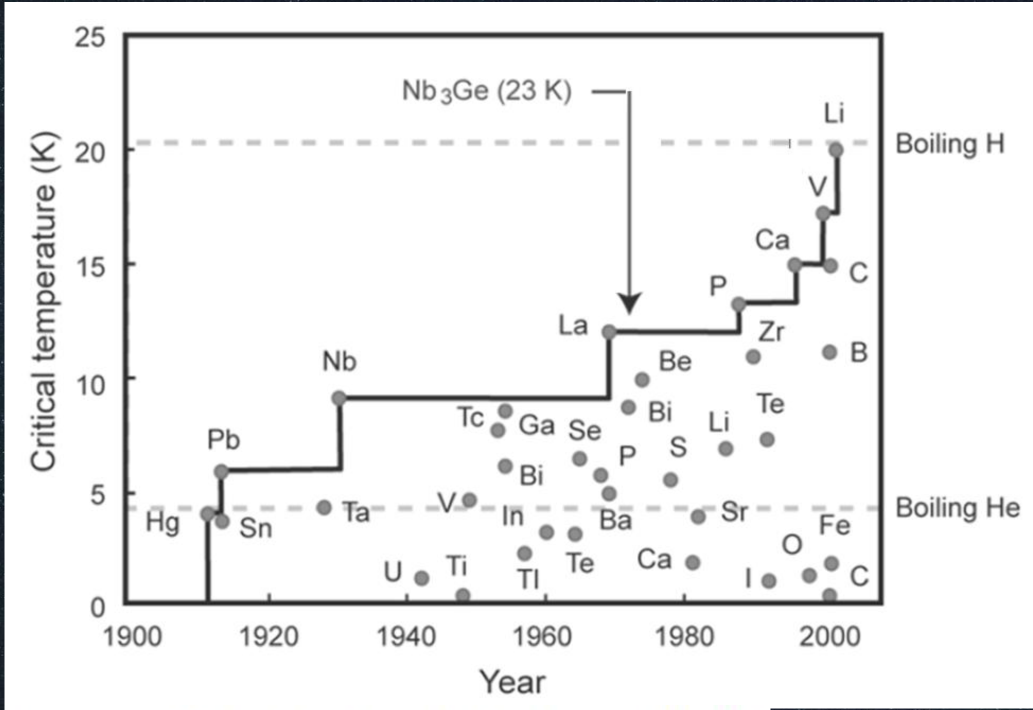
元素超导体


超导元素单质
常压下超导的块状材料
高压下超导
其他形态下超导
1 2 3 4 5 6 7
1H 2He
3Li 4Be 5B 6C 7N 8O 9F 10Ne
11Na 12Mg 13Al 14Si 15P 16S 17Cl 18Ar
19K 20Ca 21Sc 22Ti 23V 24Cr 25Mn 26Fe 27Co 28Ni 29Cu 30Zn 31Ga 32Ge 33As 34Se 35Br 36Kr
37Rb 38Sr 39Y 40Zr 41Nb 42Mo 43Tc 44Ru 45Rh 46Pd 47Ag 48Cd 49In 50Sn 51Sb 52Te 53I 54Xe
55Cs 56Ba 57La 72Hf 73Ta 74W 75Re 76Os 77Ir 78Pt 79Au 80Hg 81Tl 82Pb 83Bi 84Po 85At 86Rn
87Fr 88Ra 89Ac 104Rf 105Db 106Sg 107Bh 108Hs 109Mt 110Uun 111Uuu 112Uub
58Ce 59Pr 60Nd 61Pm 62Sm 63Eu 64Gd 65Tb 66Dy 67Ho 68Er 69Tm 70Yb 71Lu
90Th 91Pa 92U 93Np 94Pu 95Am 96Cm 97Bk 98Cf 99Es 100Fm 101Md 102No 103Lr

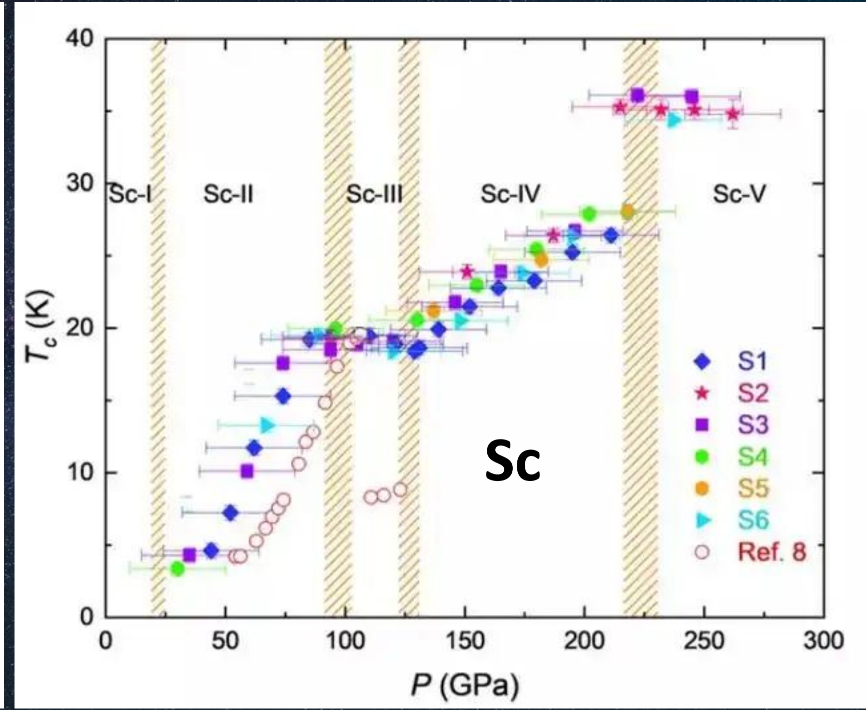
元素超导体：高压



元素超导体：高压



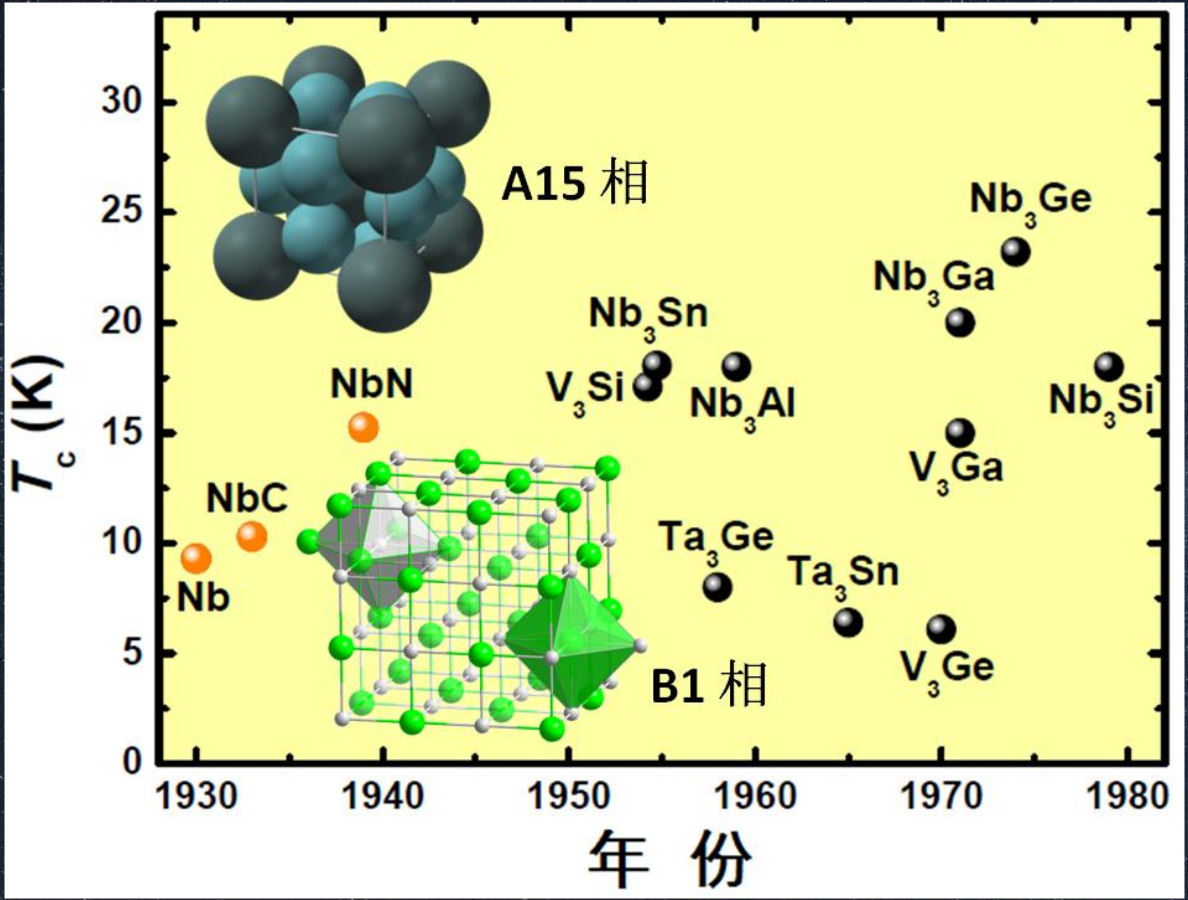
Supercond. Sci. Technol. 18 (2005) R1-R8

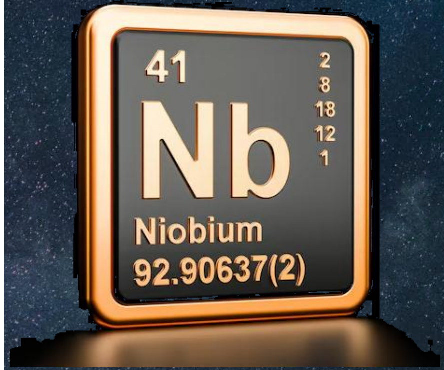


Sc

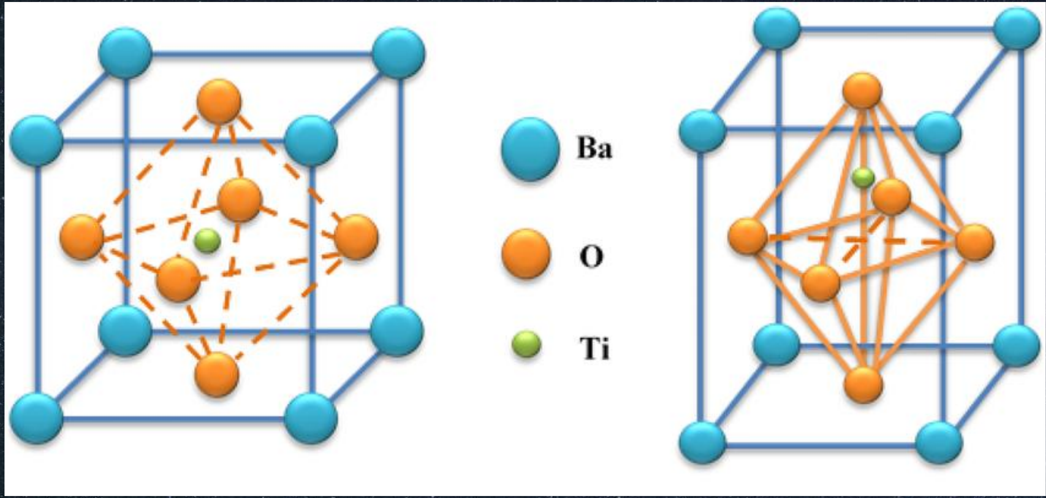
Phys. Rev. Lett. 130(25), 256002 (2023)

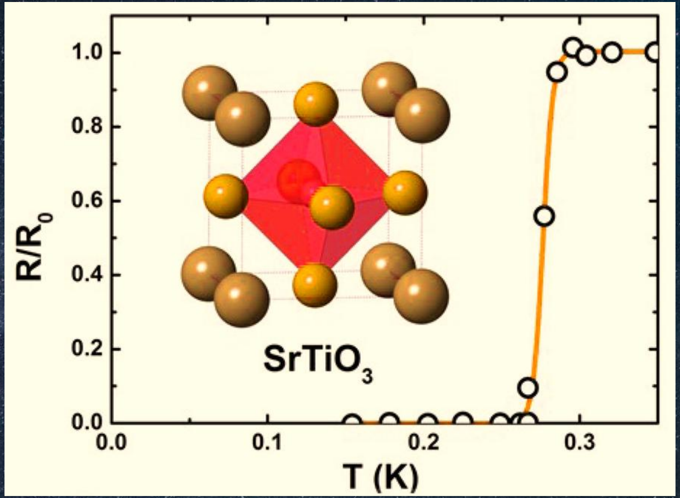
二元超导体


A15 相
B1 相
T_c (K)
年 份
30
25
20
15
10
5
0
1930
1940
1950
1960
1970
1980
Nb
NbC
NbN
V_3Si
Nb_3Sn
Nb_3Al
Ta_3Ge
Ta_3Sn
V_3Ge
V_3Ga
Nb_3Ga
Nb_3Ge
Nb_3Si


41
Nb
2
8
18
12
1
Niobium
92.90637(2)

马蒂亚斯的“投名状”

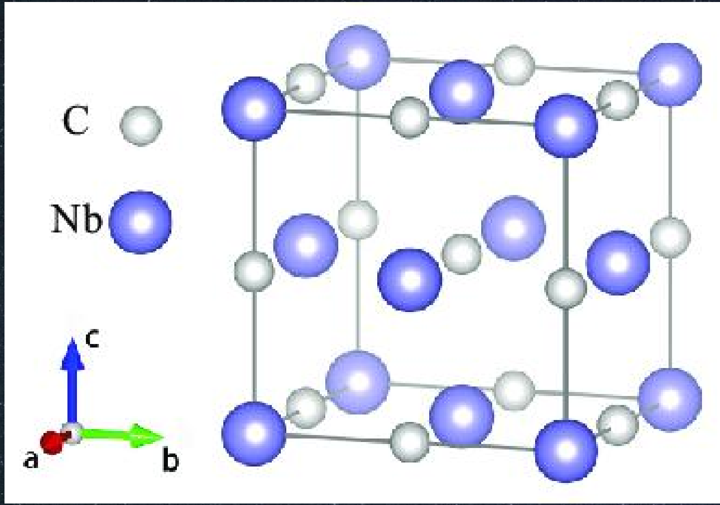




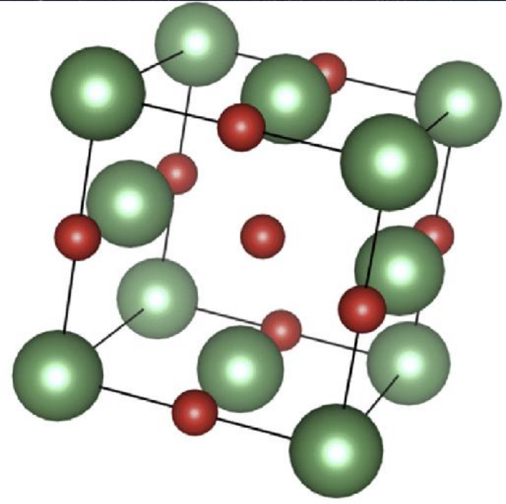
1949-1951年，马蒂亚斯与Joe Remeika合作，在芝加哥大学研究$BaTiO_3$铁电体，后来发现$LiNbO_3$ 。（此时仅发现三个铁电材料，都是氧化物：KH_2PO_4，KH_2AsO_4，$BaTiO_3$）

1964年，$SrTiO_3$成为第一个被发现的氧化物超导体，
T_c=0.3 K。
(J. Bendnorz 1974 硕士论文)

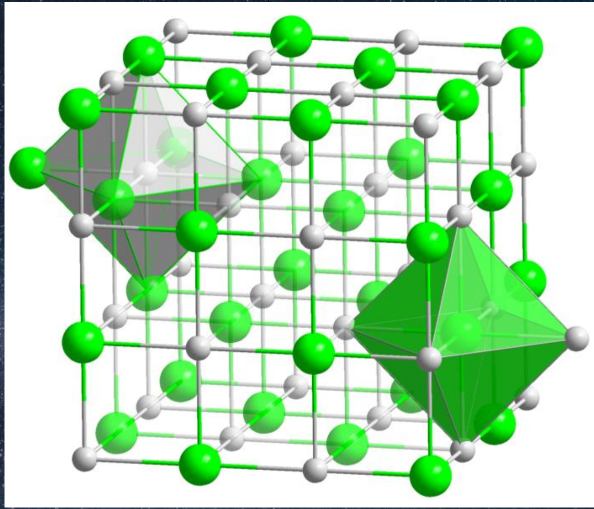
马蒂亚斯的“投名状”



NbC, T_c=10~12 K



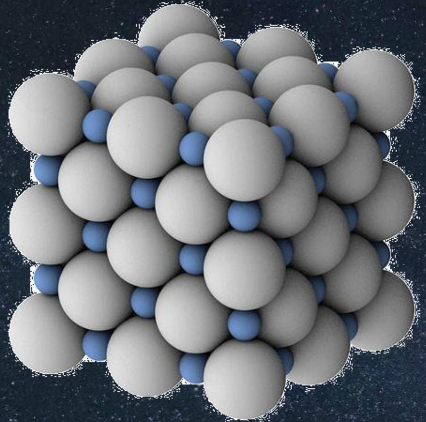
NbO, T_c=1.38 K



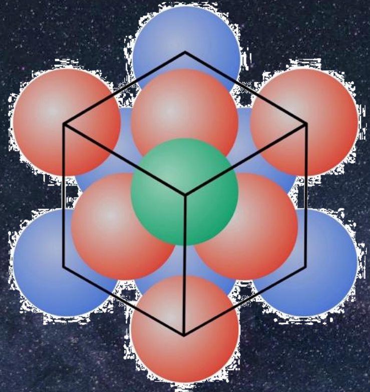
NbN, T_c=16 K

1930年代，W. Meissner在硼B、碳C、氮N等轻元素化合物中发现系列超导体（电阻测量）；马蒂亚斯和John Hulm在芝加哥大学验证了Meissner的大量工作，证明NbC（10 K）、 MoN（12 K）、NbN（16 K）等都是超导体（抗磁测量）。

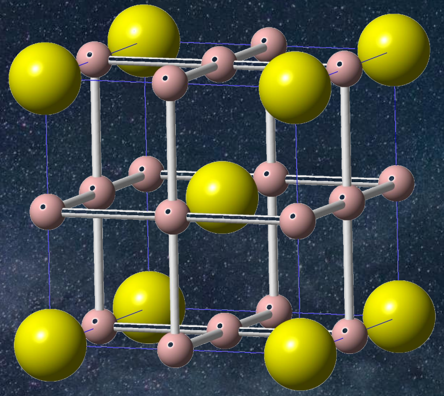
马蒂亚斯的“成名作”



$CoSi_2$, T_c=1.55 K



$CeCo_2$, T_c=0.82 K



Nb_3Sn, T_c=18 K

1953年始，马蒂亚斯和合作者发现了大量的二元超导体：$CoSi_2$、$CeCo_2$ 、Nb_3Sn （1954 T_c=18 K）等。虽然Nb_3Sn是当时最高T_c的超导体，但是仍被Physics Today批评为“schmutz physiks” （垃圾物理学）。

在铜氧化物高温体出现之前， Nb_3Sn一直都是强磁场、强电流超导应用的最佳材料。

马蒂亚斯的“成名作”

Superconducting Compounds

B. T. Matthias, E. Corenzwit, and C. E. Miller
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received January 25, 1954)

In a previous paper[1] an outline was given of the necessary though not always sufficient, conditions for the occurrence of superconductivity in compounds. Following the hypothesis of an …

(a) *Phosphides.*—Until now, no superconducting phosph… have been known. Recently we have found that Mo_3P beco… superconducting near 7°K and Rh_5P_4 at 1.22°K. We are not q… certain yet whether these compositions correspond to a si…

(b) *The* NiAs *Structure.*—As mentioned before,[1] several in… metallic compounds with this type structure have been reportec… superconductors. However, no superconducting arsenides l… previously been found. NiAs by itself does not show superc… ductivity above 1.28°K.[4,5] Assuming now that the transition ter… erature, if present, could be raised by enlarging the crystal lat… (as pointed out before[1]), we substituted the larger Pd partially… the Ni. This, however, cannot go all the way to PdAs, as this al… is not isomorphous with NiAs, nor does PdAs become superc…

(c) *The* Rh-X *System.* X=S, Se, Te.—From our previous considerations it had seemed likely that compounds of Rh with S, Se, or Te should also become superconducting.

We have found that Rh_9S_8, which is a well-defined compound,[6] becomes superconducting at 5.8°K.

NiAs, RhSe

The following compounds became superconducting at the temperatures given in parenthesis: V_3Si (17.0°K), V_3Ge (6.0°K), Mo_3Si (1.30°K), Mo_3Ge (1.43°K), $MoSi_{0.7}$ (1.34°K), $MoGe_{0.7}$ (1.20°K), $WSi_{0.7}$ (2.84°K), $ThSi_2$ (3.16°K). On the other hand, compounds which did not show superconductivity at temperatures just below 1.2°K were Ti_5Si_3, Ti_5Ge_3, TiSi, $TiSi_2$, $TiGe_2$, Zr_4Si, Zr_2Si, Zr_3Si_2, Zr_4Si_3, Zr_6Si_5, ZrSi, $ZrSi_2$, VSi_2, $NbSi_{0.6}$, $NbSi_2$, $TaSi_2$, Cr_3Si, Cr_3Si_2, CrSi, $CrSi_2$, WSi_2, $MoSi_2$. It will be noted that in the isomorphous series V_3Si, V_3Ge, Mo_3Si, Mo_3Ge, and Cr_3Si, which have a cubic structure with atomic positions similar to those in β-tungsten, only the chromium compound remained normal down to 1.2°K.

Matthias et.al. Phys. Rev.89 (4): 884 （1953）

马蒂亚斯钟情于二元超导体，其中不少在后来被认定为重费米子超导体、铁基超导体、磁性拓扑材料....

他认为：二元化物超导体非常之多，以至于“瞎鸡也能食把米”。

“the ternary materials area is so fertile that even a blind chicken can find a grain.”

马蒂亚斯的“成名作”

Superconductivity at 20 Degrees Kelvin

We have found a superconductor with a transition temperature at 20°K. The substance is a solid solution between Nb_3Al and Nb_3Ge.

During the past decade no substantial increase in superconducting transition temperature has been achieved. For the last 13 years, ever since the discovery of Nb_3Sn in 1954 (*1*), the limit of all superconducting transition temperatures has remained in the vicinity of 18°K. All attempts, through the formation of mixed phases with Nb_3Sn or other compounds crystallizing in the same β-W structure, to raise the transition temperatures over the values of both of its end points have been unsuccessful. The first attempt to do so was made by Hardy and Hulm (*2*) right after their discovery of the superconductivity of V_3Si at 17°K. Many other efforts have been made since. However, the number of negative results are so great we shall not list them. An excellent compilation can be found in Roberts' article on superconducting compounds (*3*).

The increase of superconducting transition temperature to 20°K was accomplished through the formation of a solid solution between Nb_3Al and Nb_3Ge, crystallizing in the β-W structure.

In the β-W structure, Nb_3Sn and

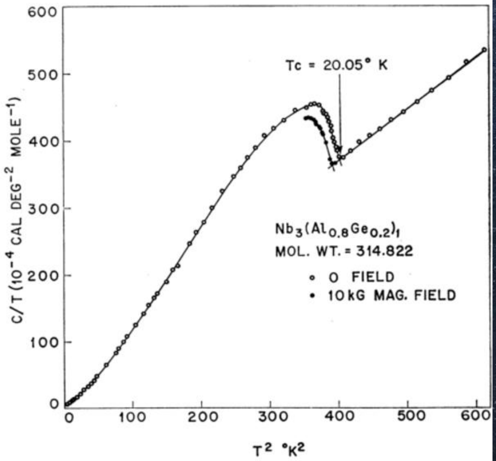
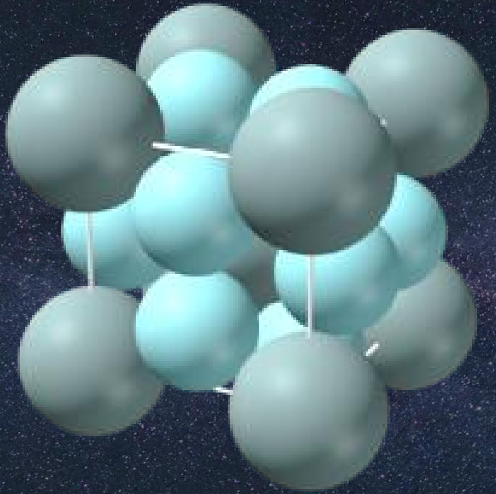


Fig. 1. Specific heat of $Nb_3Al_{0.8}Ge_{0.2}$ without magnetic field and with 10 kG.

645



Transition temperature, K				
T_{c1}	T_{c2}	T_{c3}	T_{c4}	Other phases present
19.9	19.7	19.3	18.3	T-Nb_5Ge_3 ($a = 10.17_3$, $c = 5.14_3$); NbO_2; NbO; H-Nb_5Ge_3
19.7	19.4	18.1	17.2	T-Nb_5Ge_3; NbO_2; NbO
19.7	19.3	17.9	17.2	—
19.7	19.3	17.3	15.9	T-Nb_5Ge_3; NbO; NbO_2
19.5	19.1	17.3	15.9	T-Nb_5Ge_3; NbO
19.6	19.3	18.3	17.1	T-Nb_5Ge_3; NbO
19.2	17.5	14.8	12.9	T-Nb_5Ge_3; NbO
18.7	17.5	15.0	14.2	Not measured
19.5	17.1	13.3	11.2	T-Nb_5Ge_3 ($a = 10.16_5$, $c = 5.13_5$); NbO
18.1	14.9	11.3	10.3	T-Nb_5Ge_3; NbO
15.0	9.6	7.5	6.7	T-Nb_5Ge_3 ($a = 10.16_0$, $c = 5.14_2$) NbO ($a = 4.210$)
8.2	7.5	6.1	5.8	T-Nb_5Ge_3; NbO
5.9	5.8	5.6	6.4	T-Nb_5Ge_3; NbO
5.9	5.8	5.5	5.3	T-Nb_5Ge_3 ($a = 10.16_5$, $c = 5.13_5$); NbO ($a = 4.210$)
6.2	6.1	5.7	5.5	T-Nb_5Ge_3 ($a = 10.17_1$, $c = 5.14_2$) NbO ($a = 4.216$)
5.9	5.8	5.5	5.4	T-Nb_5Ge_3 ($a = 10.16_3$, $c = 5.13_7$) NbO ($a = 4.210$)
7.3	7.2	5.7	5.6	T-Nb_5Ge_3; NbO
5.8	5.8	5.5	5.3	T-Nb_5Ge_3 ($a = 10.16_3$, $c = 5.13_3$) NbO ($a = 4.210$)

1967年，马蒂亚斯和合作者发现首个突破液氢温区（T_c >20 K）超导体$Nb_3(Al_{1-x}Ge_x)$。

后来Nb_3Ge超导体T_c达到了23.2 K，保持最高记录近20年！

Superconductivity at 20° K. Science 156, 645 (1967).

马蒂亚斯提出“高温超导”概念

Ternary transition metal phosphides: High-temperature superconductors

(superconductivity)

H. BARZ*, H. C. KU†, G. P. MEISNER†, Z. FISK†, AND B. T. MATTHIAS*†

*Bell Laboratories, Murray Hill, New Jersey 07974; and †Institute for Pure and Applied Physical Sciences, University of California at San Diego, La Jolla, California 92093

Contributed by Bernd T. Matthias, March 18, 1980

High superconducting transition temperatures of new rare earth ternary borides

(ferromagnetism/superconductors)

BERND T. MATTHIAS*, E. CORENZWIT, J. M. VANDENBERG, AND H. E. BARZ

Bell Laboratories, Murray Hill, New Jersey 07974

Contributed by Bernd T. Matthias, January 14, 1977

以及：Science175,1465 (1972)

1972年，马蒂亚斯发现首个二元“高温超导体”：

$Mo_{6-x}A_xS_6$ （A=Cu, Zn, Mg, Ag, Cd, Sn, Pb）

T_c=2.5 ~ 13 K

于是，他把T_c在10 K以上的叫做“高温超导体”，

再后来“高温超导”的门槛被提升到20 K，

$Nb_3(Al_{1-x}Ge_x)$是当时唯一T_c超过20 K的超导体！

Table 1. Superconducting transition temperatures (T_c) and lattice parameters for two systems of hexagonal ternary phosphides

Compound	T_c, K	a, Å (±0.006)	c, Å (±0.004)	vol, Å^3	Heat treatment*
TiRuP	1.33 onset	6.325	3.542	122.7	am
ZrRuP	12.34–10.56	6.459	3.778	136.5	am, 900°C, a, q
HfRuP	12.70–11.08	6.414	3.753	133.7	s 1000°C, sc
TiOsP	†	6.285	3.625	124.0	s 1000°C, sc
ZrOsP	7.44–5.70	6.460	3.842	138.8	s 1000°C, sc
HfOsP	6.10–4.96	6.417	3.792	135.1	s 1000°C, sc

* am, Arc-melted; s, sintered; sc, slow cooled; q, quenched; a, annealed. All heat treatments specified are the last step only.
† No transition observed above 1.2 K.

从二元到三元

Compound*	T_c range, K
YRh_4B_4	11.34–11.26
$NdRh_4B_4$	5.36–5.26
$SmRh_4B_4$	2.51–2.45
$ErRh_4B_4$	8.55–8.49
$TmRh_4B_4$	9.86–9.73
$LuRh_4B_4$	11.76–11.54
$Lu_{0.75}Th_{0.25}Rh_4B_4$	11.93–11.3
$Sc_{0.75}Th_{0.25}Rh_4B_4$	8.74–8.49
$ThRh_4B_4$	4.34–4.29

马蒂亚斯关于超导探索的思考

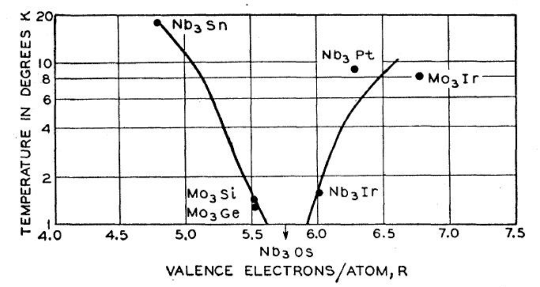
PHYSICAL REVIEW VOLUME 97, NUMBER 1 JANUARY 1, 1955

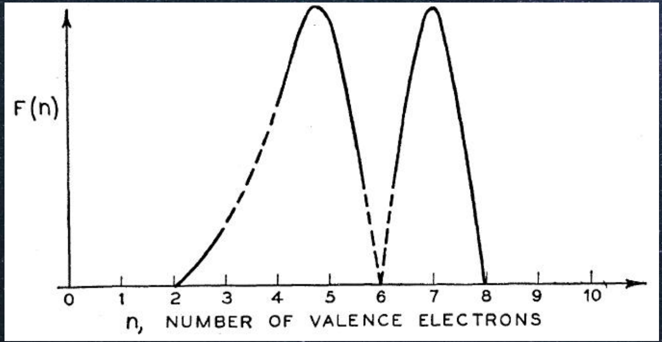
Empirical Relation between Superconductivity and the Number of Valence Electrons per Atom

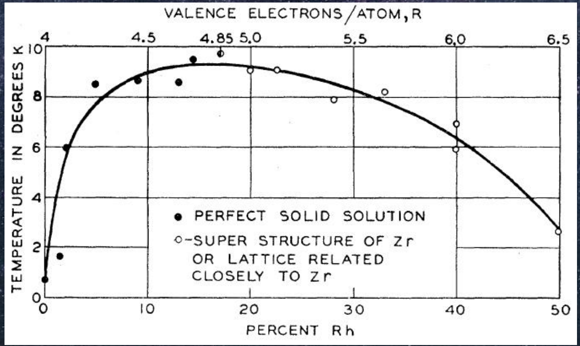
B. T. Matthias
Bell Telephone Laboratories, Inc., Murray Hill, New Jersey
(Received September 28, 1954)

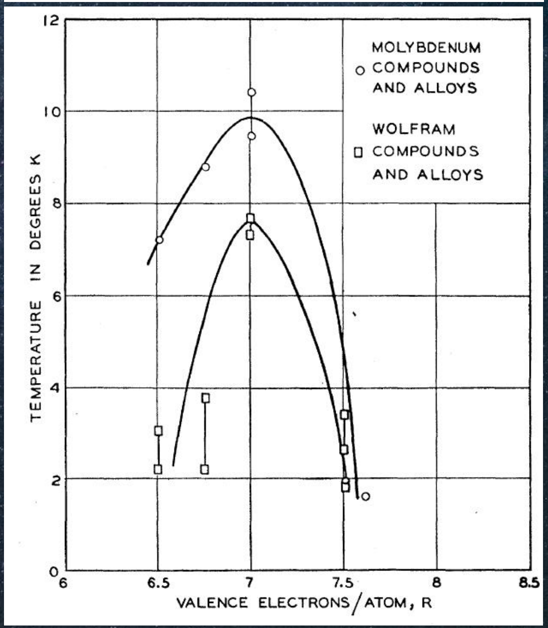
The relation between the transition temperature of a superconductor and its number of valence electrons/atom has been investigated. Optimum conditions for the occurrence of superconductivity seem to exist for 5 and 7 valence electrons/atom.

马蒂亚斯的“第一原则”









1955年，马蒂亚斯认为合金超导体的T_c与“平均”价态似乎有一定的规律，在5价和7价时T_c达到“极值”，但6价时T_c最低。

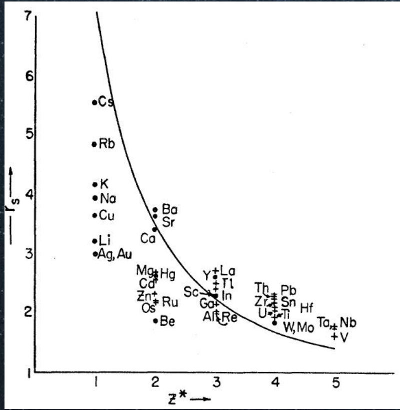
马蒂亚斯关于超导探索的思考

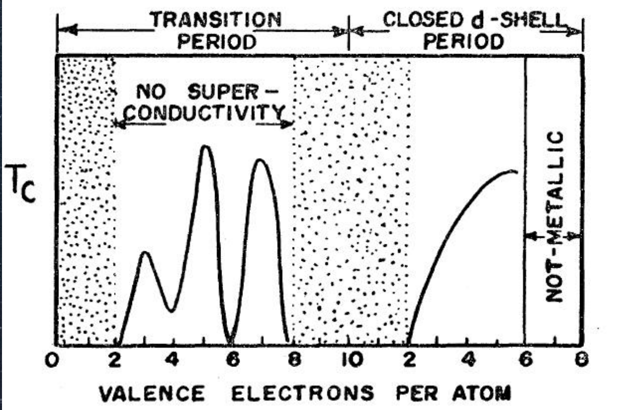
PHYSICAL REVIEW VOLUME 109, NUMBER 2 JANUARY 15, 1958

Superconductivity in the Periodic System

DAVID PINES
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received May 27, 1957)

The empirical regularities in the appearance of superconductivity in the periodic system discussed by Matthias are considered in the light of the microscopic theory of superconductivity proposed by Bardeen, Cooper, and Schrieffer. A simple model of electrons and ions interacting via screened Coulomb forces is used to describe the electron-lattice interaction. With the aid of this model, it is shown how the theory of Bardeen, Cooper, and Schrieffer provides both a satisfactory criterion for the appearance of superconductivity and a good qualitative account of the variation in transition temperature from one metal to another.





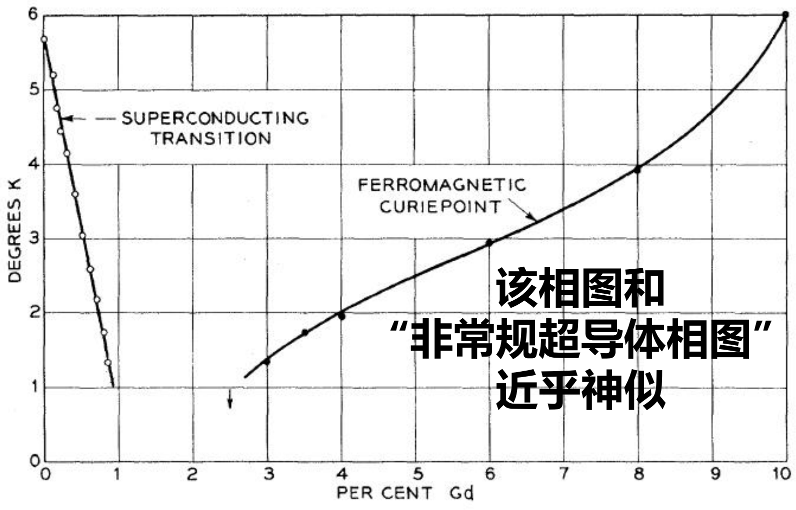
Metal	Z^*	r_s	T_c	θ_d	$N(0)V$
Al	3	2.06	1.20	375	0.193
Zn	2	2.30	0.93	235	0.200
Ga	3	2.18	1.10	240	0.206
Cd	2	2.58	0.56	165	0.196
In	3	2.40	3.37	109	0.345
Sn	4	2.21	3.74	195	0.296
Hg	2	2.66	4.16	69	0.446
Tl	3	2.48	2.39	100	0.316
Pb	4	2.28	7.22	96.3	0.493
Ti	4	1.92	0.39	430	0.155
V	5	1.61	4.89	338	0.274
Zr	4	2.14	0.55	265	0.178
Nb	5	1.78	8.8	252	0.357
Tc	3	2.12*	11.0	350*	0.345
Ru	2	2.20	0.47	350*	0.165
La	3	2.70	5.0	132	0.370
Hf	4	2.08	0.35	213	0.171
Ta	5	1.79	4.4	230	0.296
Re	3	1.98	1.7	210	0.236
Os	2	2.17	0.71	280*	0.185
Th	4	2.36	1.39	168	0.236
U	4	2.04	0.8	200	0.202

1958年，D. Pines分析了大量超导体平均价态，认为马蒂亚斯“第一原则”十分符合BCS理论。并且给出了超导体平均价态的上下限为 2~8。

马蒂亚斯关于超导探索的思考

SPIN EXCHANGE IN SUPERCONDUCTORS

B. T. Matthias, H. Suhl, and E. Corenzwit
Bell Telephone Laboratories,
Murray Hill, New Jersey
(Received July 15, 1958)



PHYSICAL REVIEW VOLUME 125, NUMBER 2 JANUARY 15, 1962

Local Magnetic Moment Associated with an Iron Atom Dissolved in Various Transition Metal Alloys

A. M. Clogston, B. T. Matthias, M. Peter, H. J. Williams, E. Corenzwit, and R. C. Sherwood
Bell Telephone Laboratories, Inc., Murray Hill, New Jersey
(Received August 29, 1961)

One atomic percent of iron has been dissolved in a series of alloys of the second row transition metals. The alloys have been chosen so as to give closely spaced coverage from zirconium to beyond palladium. For each dilute iron alloy, the susceptibility χ has been measured from 1.4°K to room temperature. In some members of the series, the susceptibility is essentially temperature independent, while in others the appearance of a local moment is evidenced by a Curie-Weiss dependence of χ on T. A local moment first appears proceeding from Nb to Mo at about $(Nb_{0.6}Mo_{0.4})_{0.99}Fe_{0.01}$ and persists nearly to Re. Disappearing at this point, the moment reappears at $(Ru_{0.75}Rh_{0.25})_{0.99}Fe_{0.01}$ and continues, becoming large in the alloys near Pd. The occurrence of local moments is discussed in terms of the band structure of the alloys and the perturbation introduced by the iron atom. The giant magnetic moments observed near Pd are related to the large susceptibilities of the iron-free alloys in this region.

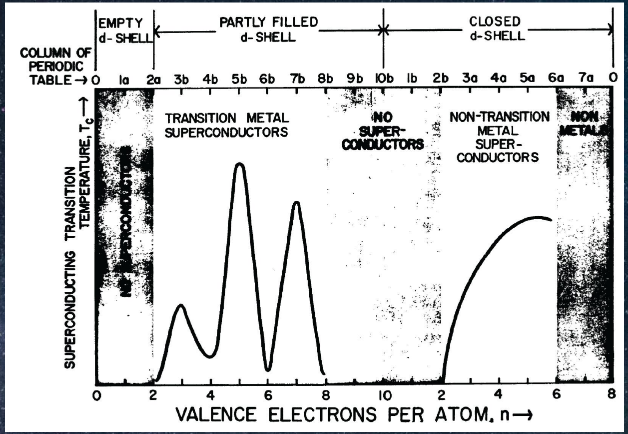
Alloy	Structure	N	μ/μ_B (Curie-Weiss)	θ (°K)
Zr	hcp	4	0.0	
Nb	bcc	5	0.0	
$Nb_{0.8}Mo_{0.2}$	bcc	5.2	0.0	
$Nb_{0.6}Mo_{0.4}$	bcc	5.4	0.0	
$Nb_{0.4}Mo_{0.6}$	bcc	5.6	0.3	-9 ± 3
$Nb_{0.3}Mo_{0.7}$	bcc	5.7	0.6	−4
$Nb_{0.2}Mo_{0.8}$	bcc	5.8	1.1	−1
$Nb_{0.1}Mo_{0.9}$	bcc	5.9	1.9	−3
Mo	bcc	6.0	2.1	−4
$Mo_{0.8}Re_{0.2}$	bcc	6.2	2.1	−6
$Mo_{0.6}Re_{0.4}$	bcc	6.4	2.2	−5
Re	hcp	7.0	0.0	
Tc	hcp	7.0	0.0	
$Re_{0.5}Ru_{0.5}$	hcp	7.5	0.0	
Ru	hcp	8.0	0.0	

Alloy	Structure	N	μ/μ_B (Curie-Weiss)	θ (°K)	μ/μ_B (Sat. mag.)	T_c (°K)
Ru	hcp	8.0	0.0			
$Ru_{0.75}Rh_{0.25}$	hcp	8.25	0.0			
$Ru_{0.63}Rh_{0.37}$	hcp	8.37	0.8	-21 ± 2		
$Ru_{0.5}Rh_{0.5}$	hcp	8.5	1.3	-13 ± 2		
$Ru_{0.25}Rh_{0.75}$	fcc	8.75	1.7	-17 ± 2		
Rh	fcc	9.0	2.2	-14 ± 2		
$Rh_{0.7}Pd_{0.3}$	fcc	9.3	4.5	−2		
$Rh_{0.55}Pd_{0.45}$	fcc	9.45	5.9(100°K)	−2		
$Rh_{0.4}Pd_{0.6}$	fcc	9.6	7.1(100°K)	1		
$Rh_{0.2}Pd_{0.8}$	fcc	9.8	9.6(100°K)	14	7.1	11
$Rh_{0.1}Pd_{0.9}$	fcc	9.9	11.4(100°K)	33 ± 2	9.5	27
$Rh_{0.05}Pd_{0.95}$	fcc	9.95	12.7(100°K)	49 ± 6	10.8	39
Pd	fcc	10.0	11.3(100°K)	55 ± 3	9.7	39
$Pd_{0.75}Ag_{0.25}$	fcc	10.25	8.3(100°K)	12	6.3	11

1958年，马蒂亚斯认为(铁)磁性可与超导共存或竞争，并探讨了过渡金属f电子和d电子体系“非声子配对”的超导电性，他发现“相比于铁磁，铁电才是与超导不兼容的性质”。

马蒂亚斯提出超导探索“五原则”v1

1955年，马蒂亚斯提出了“超导材料探索五原则”。



对元素超导体，满足5条规律：

1. 元素价态必须满足：$2 \le n \le 8$;
2. 不能是铁磁、反铁磁、非金属、半导体或半金属;
3. 过渡金属T_c在平均价态n为奇最高，为偶最低，而非过渡金属则T_c与n正相关;
4. T_c与原子体积V和质量M满足关系：$T_c \sim V^x/M^{0.5}$ $(4<x<5)$；
5. 晶体结构会对T_c造成20~30 %的影响，故以上公式还有个系数修正c，六度对称性超导T_c最佳;

马蒂亚斯提出超导探索“五原则”v2

1955年，马蒂亚斯提出了“超导材料探索五原则”。

对合金和化合物超导体，满足5条规律：

$$kT_c \sim \hbar\omega \exp\left[-\frac{1}{N(0)V}\right]$$

1. 元素价态必须满足：$2 \le n \le 8$；
2. 不能是非金属、半导体或半金属，反铁磁材料也不行，部分铁磁材料可以；
3. T_c与平均价态n的关系与元素超导体类似，但略有差异；
4. T_c与原子体积V满足关系：$T_c \sim V^x$ （$5<x<10$），不再与原子质量相关；
5. 立方或六角结构的材料T_c最高，但是应力、缺陷、杂质会进一步降低T_c；

Matthias’ words, “Most theories of superconductivity, in my opinion, are merely descriptions. They become theories only when they are able to predict.

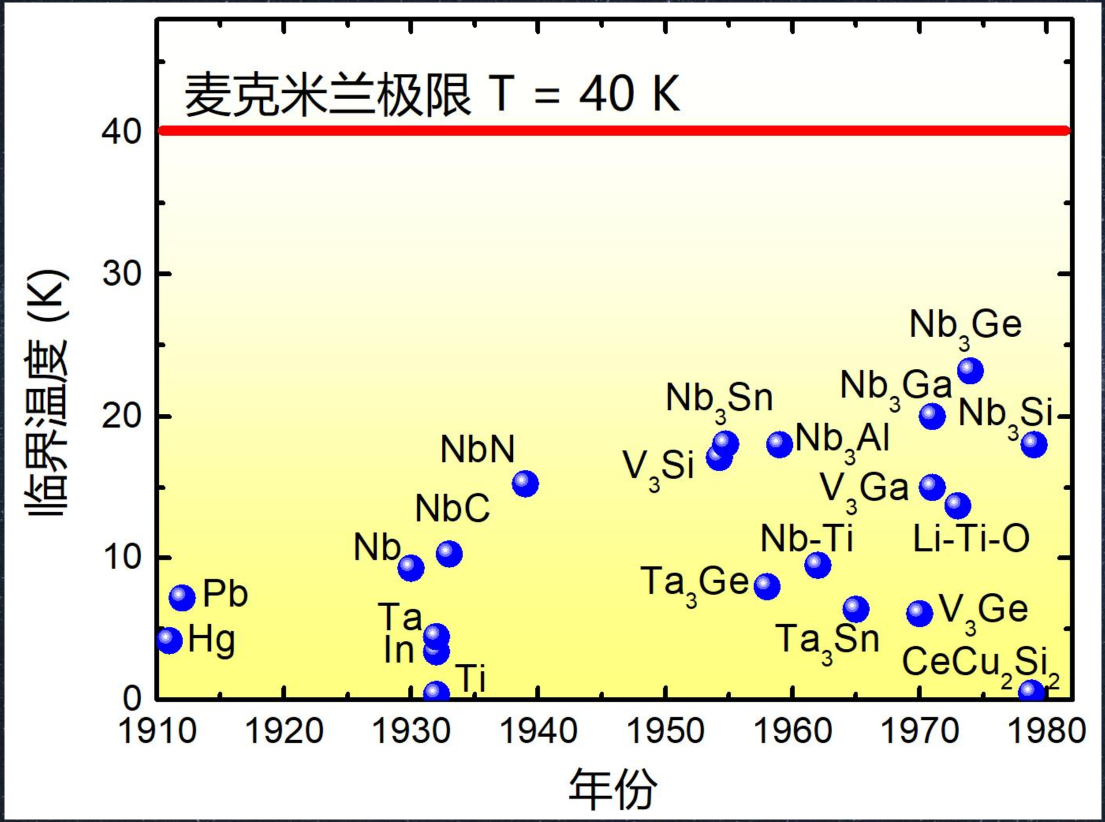
马蒂亚斯的“高温超导黄金六则”

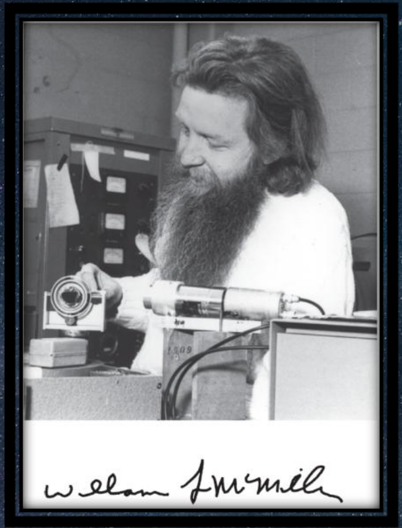
探索新超导体黄金六则：

1. 高对称性、最好立方结构；
2. 高电子态密度（浓度）；
3. 不含氧元素；
4. 没有磁性；
5. 非绝缘体；
6. 不要信理论学家；

超导研究形势“一片大好”

传统超导体的“结界”：麦克米兰极限





William L. McMillan
(1936-1984, 48岁)

1965 年
麦克米兰和安德森
指出超导T_c存在上限

传统超导体的“结界”：Why 40 K？

BCS方程

$$k_B T_c = 1.14\hbar\omega \exp\left[\frac{-1}{N(E_F)V}\right]$$

McMillan方程

$$T_c = \frac{\Theta_D}{1.45}\exp\left[-\frac{1.04(1+\lambda)}{\lambda-\mu^*(1+0.62\lambda)}\right]$$

修正的McMillan方程

$$T_c = \frac{f_1 f_2 \omega_{\log}}{1.2}\exp\left[-\frac{1.04(1+\lambda)}{\lambda-\mu^*(1+0.62\lambda)}\right]$$

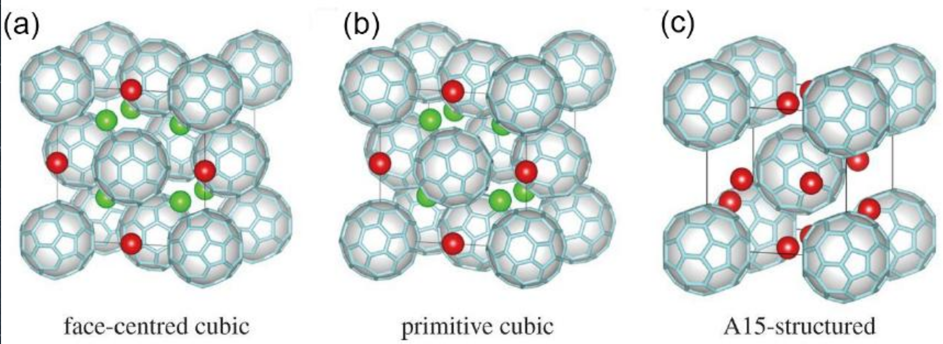
Migdal-Éliashberg 方程

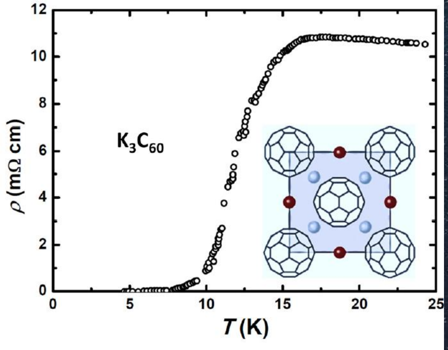
$$Z(\mathbf{k}, i\omega_n) = 1 + \frac{\pi T}{\omega_n}\sum_{\mathbf{k}'n'} W_{\mathbf{k}'}\frac{\omega_{n'}}{\sqrt{R(\mathbf{k}', i\omega_{n'})}}\lambda(\mathbf{k}, \mathbf{k}', n-n'),$$

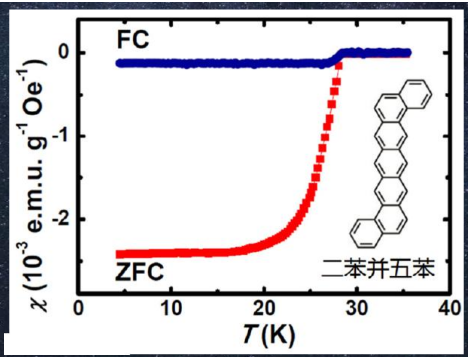
$$Z(\mathbf{k}, i\omega_n)\Delta(\mathbf{k}, i\omega_n) = \pi T\sum_{\mathbf{k}'n'} W_{\mathbf{k}'}\frac{\Delta(\mathbf{k}', i\omega_{n'})}{\sqrt{R(\mathbf{k}', i\omega_{n'})}} \times\left[\lambda(\mathbf{k}, \mathbf{k}', n-n') - N(E_F)V(\mathbf{k}-\mathbf{k}')\right].$$

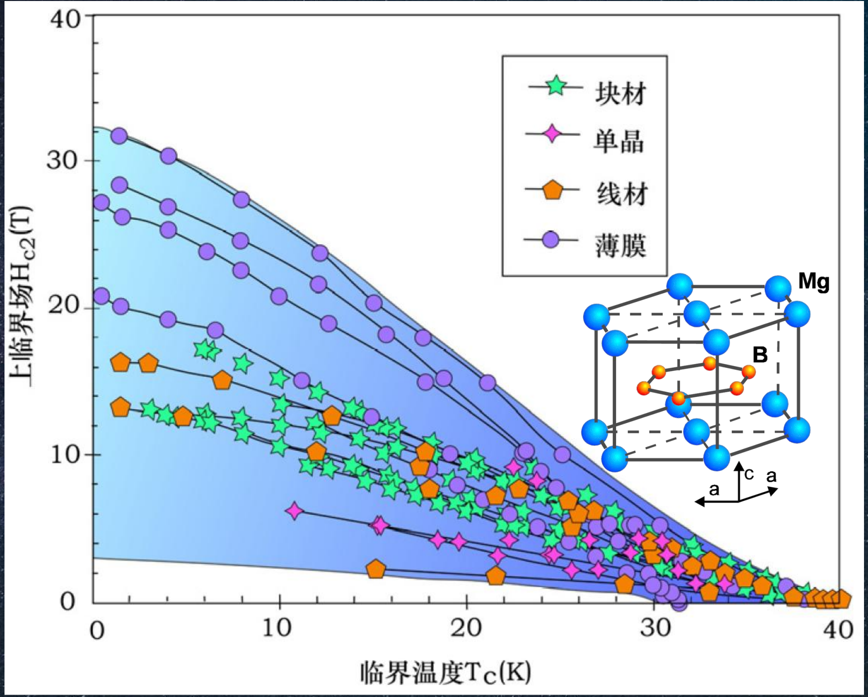
麦克米兰方程是强耦合BCS理论的一种粗糙近似，在严格求解情况下T_c完全可以超过40 K！

传统超导体T_c被“封印”了吗？







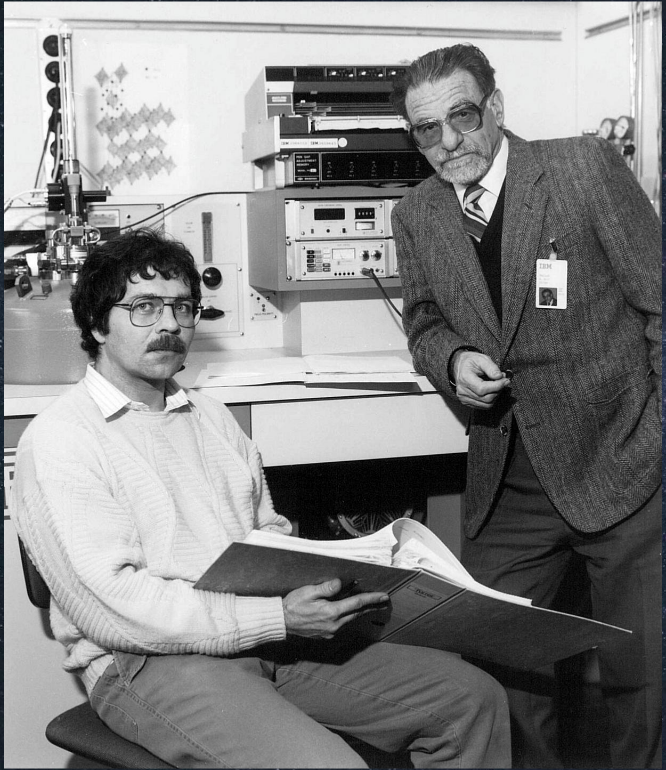


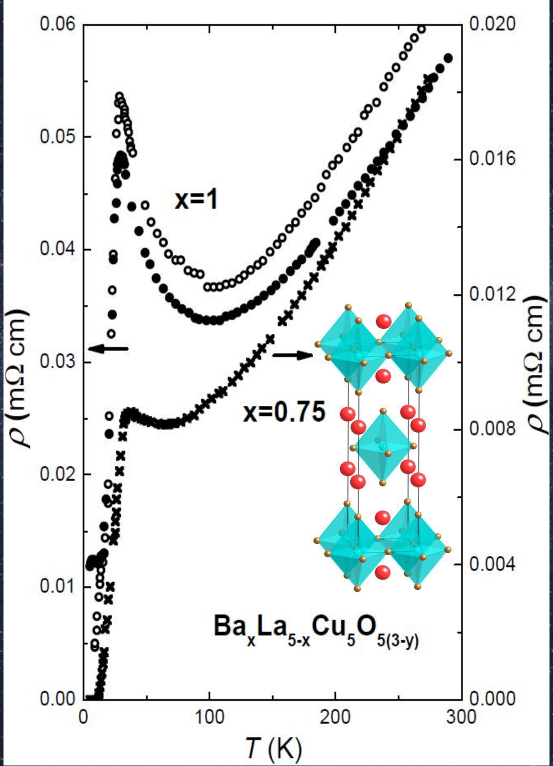
Rb_3C_{60} (T_c=29 K)、$RbCs_2C_{60}$ (T_c=33 K)、$(NH_3)_4Na_2CsC_{60}$(T_c=29.6 K)、Cs_3C_{60} (T_c=38 K)...

2001年发现的MgB_2超导体无论掺杂、加压、块材、单晶、薄膜，T_c都无法超越40 K。

马蒂亚斯之后的“高温超导”

第一个高温超导体 La-Ba-Cu-O





Z. Phys. B 64, 189 (1986)

1. 高对称性、最好立方结构； X
2. 高电子态密度（浓度）； X
3. 不含氧元素； X
4. 没有磁性； X
5. 非绝缘体； X
6. 不要信理论学家； ?

1986 年

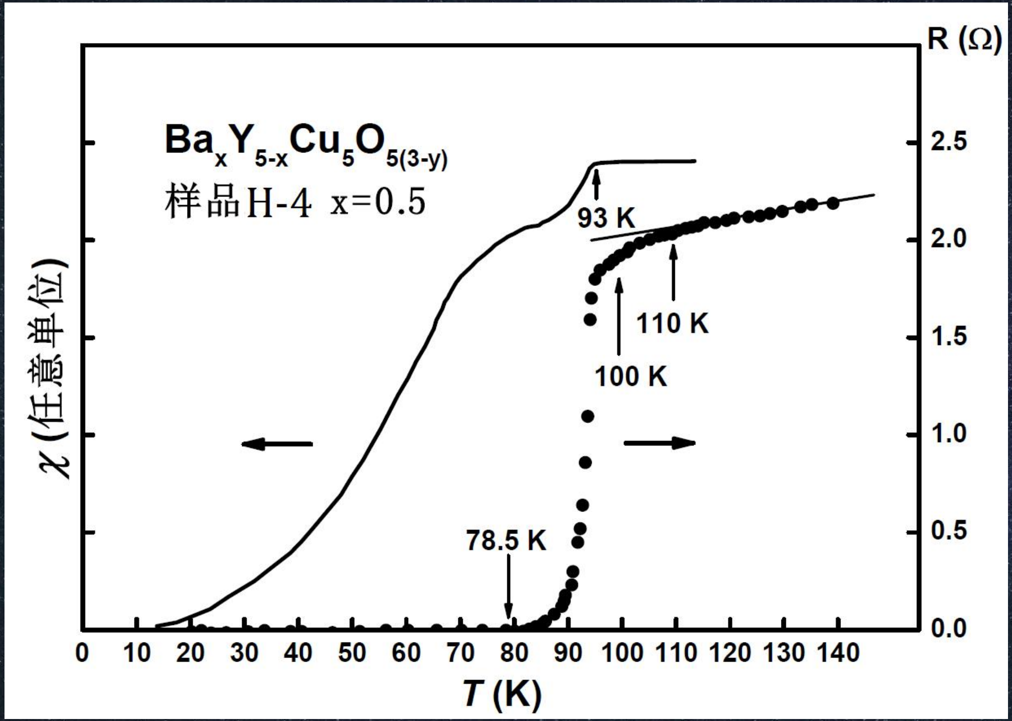
柏诺兹和缪勒

发现Ba-La-Cu-O高温超导

T_c= 35 K

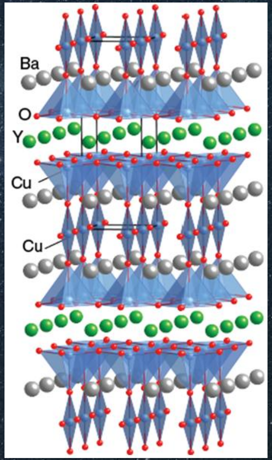
1987年
诺贝尔奖

第一个高温超导体 Y-Ba-Cu-O



科学通报 32, 412 (1987)

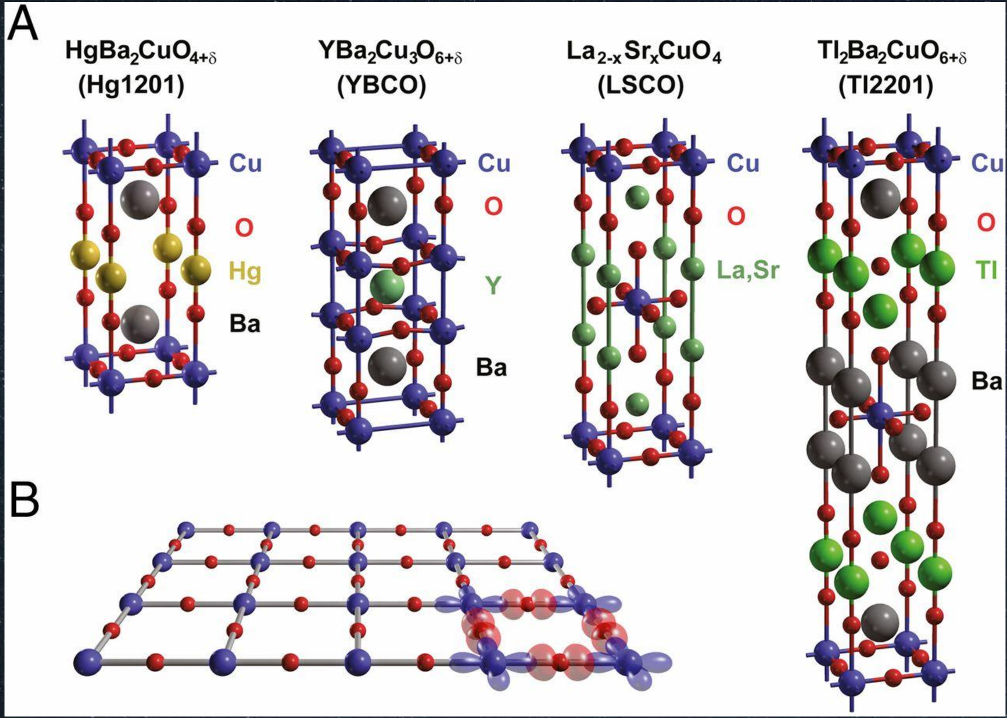
1987 年
赵忠贤、吴茂昆、朱经武等
发现Y-Ba-Cu-O高温超导
T_c= 93 K

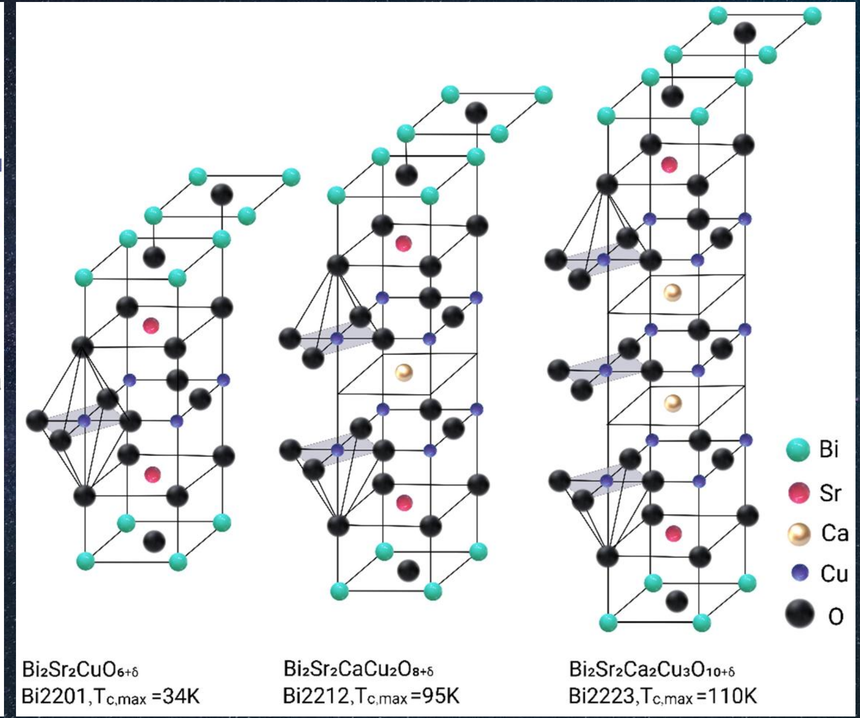


$YBa_2Cu_3O_{7-\delta}$

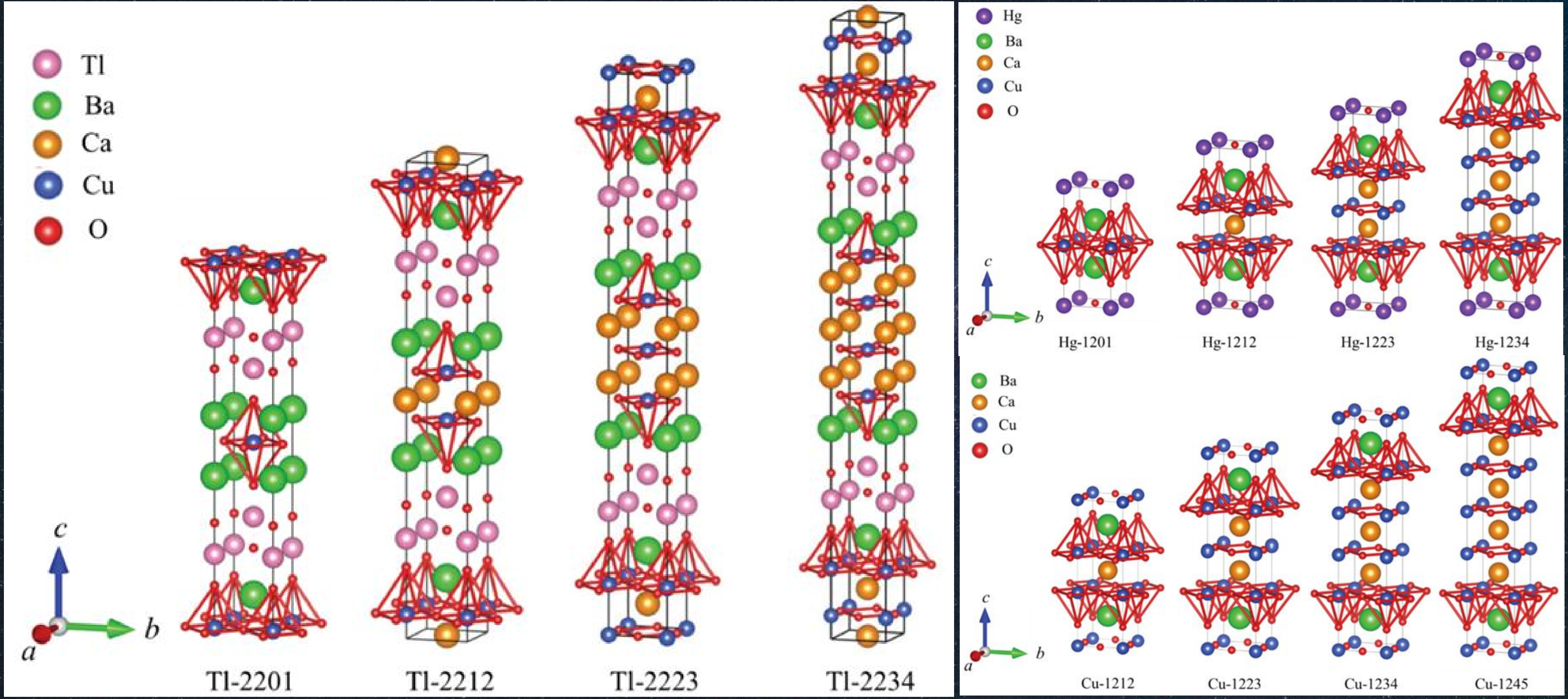
高温超导研究的峥嵘岁月

高温超导体：铜氧化物

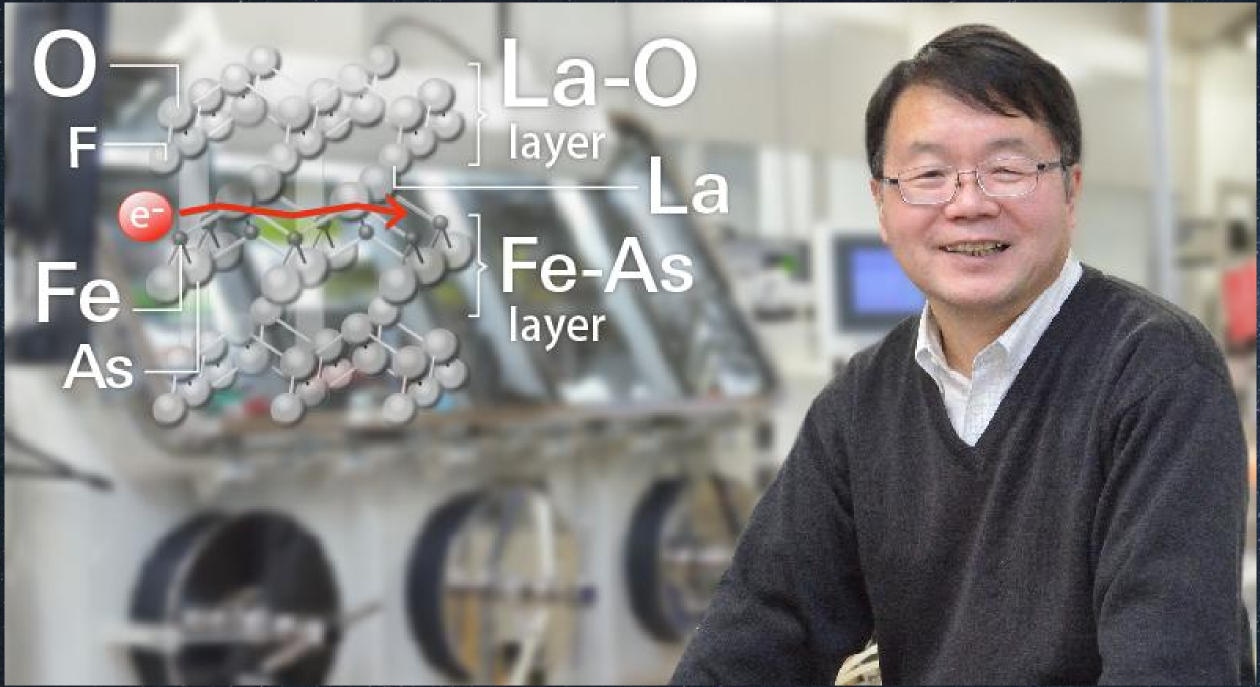

A
$HgBa_2CuO_{4+\delta}$
(Hg1201)
$YBa_2Cu_3O_{6+\delta}$
(YBCO)
$La_{2-x}Sr_xCuO_4$
(LSCO)
$Tl_2Ba_2CuO_{6+\delta}$
(Tl2201)
Cu
O
Hg
Ba
Y
La,Sr
Tl
B


Bi
Sr
Ca
Cu
O
$Bi_2Sr_2CuO_{6+\delta}$
Bi2201, $T_{c,max}$ =34K
$Bi_2Sr_2CaCu_2O_{8+\delta}$
Bi2212, $T_{c,max}$ =95K
$Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$
Bi2223, $T_{c,max}$ =110K

100 K 以上的铜氧化物高温超导体



铁基超导体 La-Fe-As-O-F



2008 年

细野秀雄等

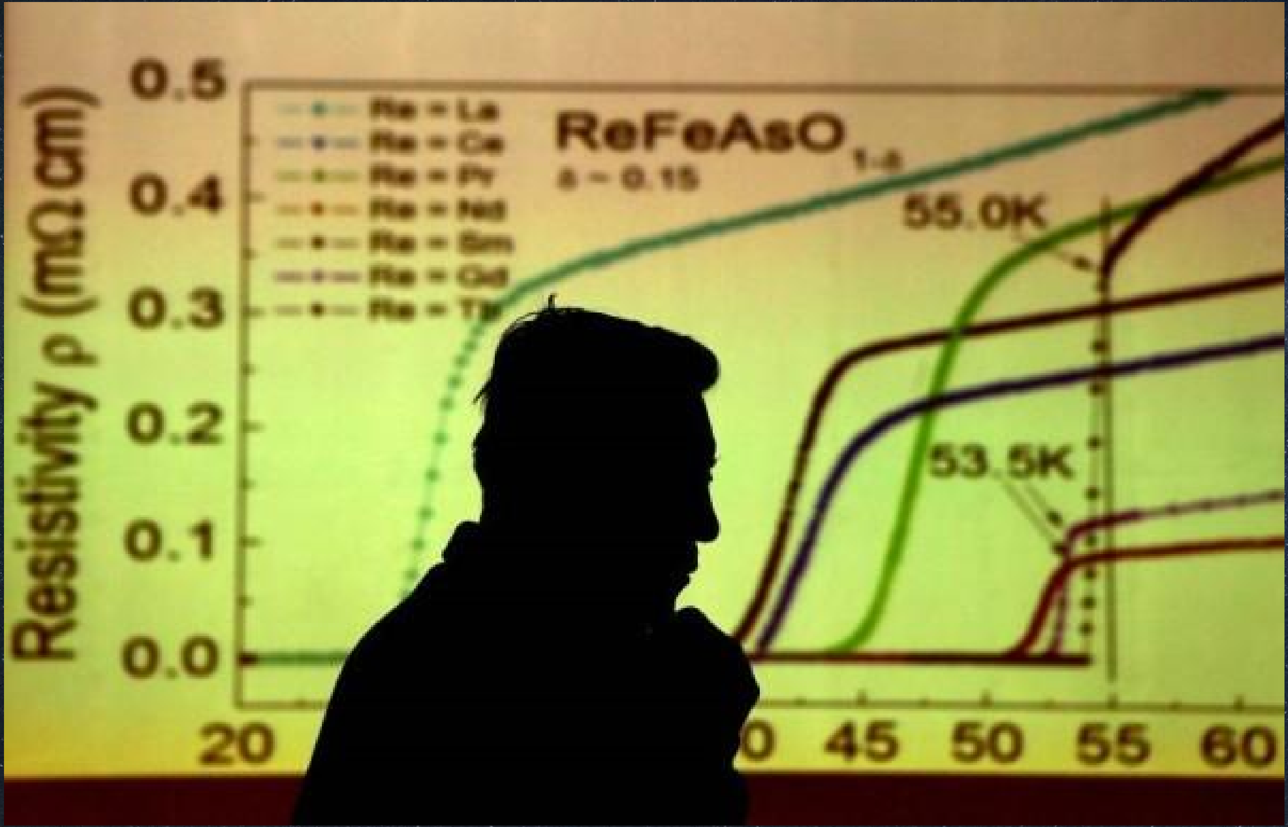
发现$LaFeAsO_{1-x}F_x$超导

T_c= 26 K

T_c ＞ 20 K 不多见

LaCuOS (1997) → LaCuOSe (2004) → LaOFeP T_c=5 K (2006) → LaONiP T_c=3 K (2007) → LaOFeAs T_c=26 K (2008)

铁基高温超导体的突破



2008 年

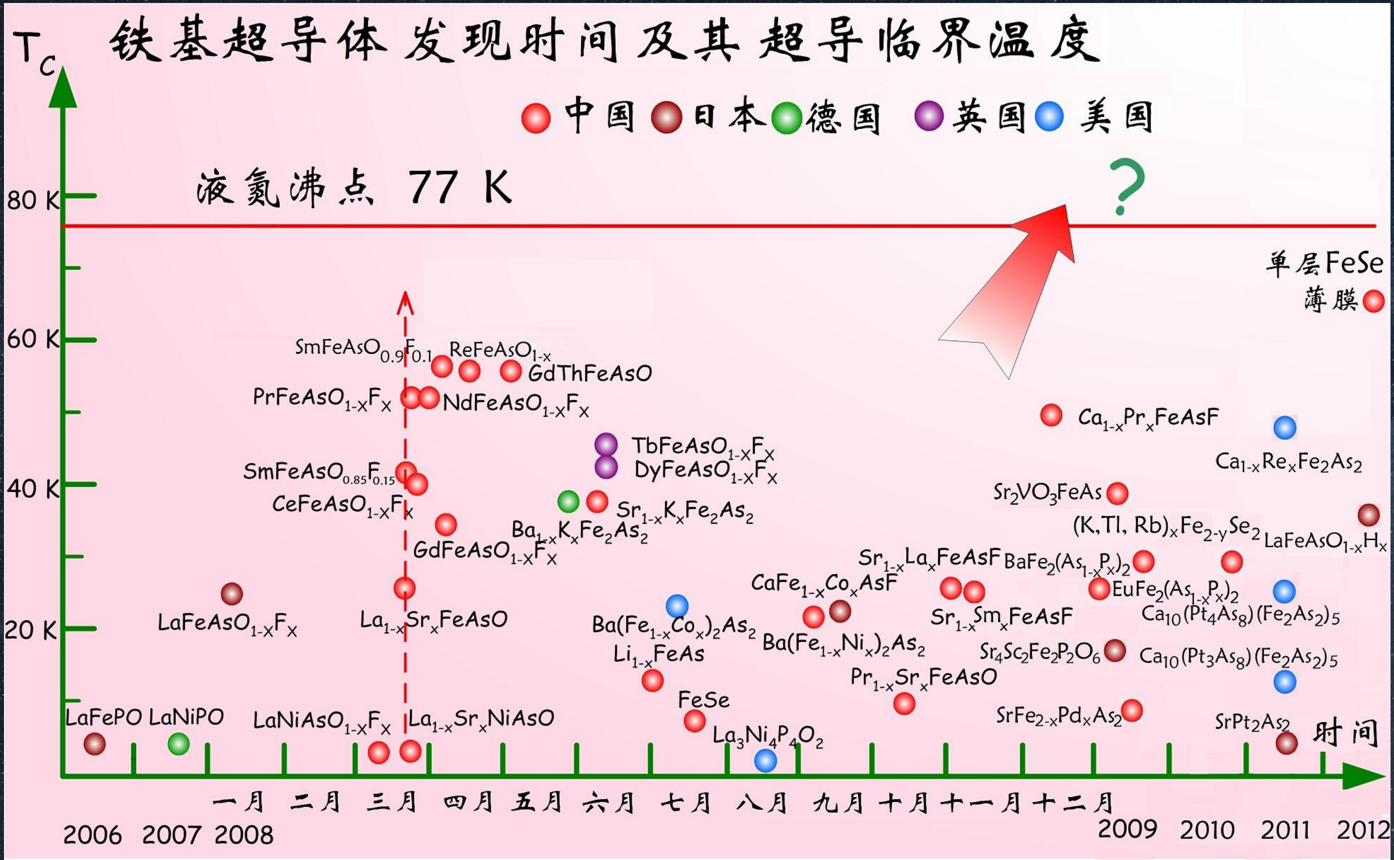
中国科学家

发现$ReFeAsO_{1-x}F_x$超导

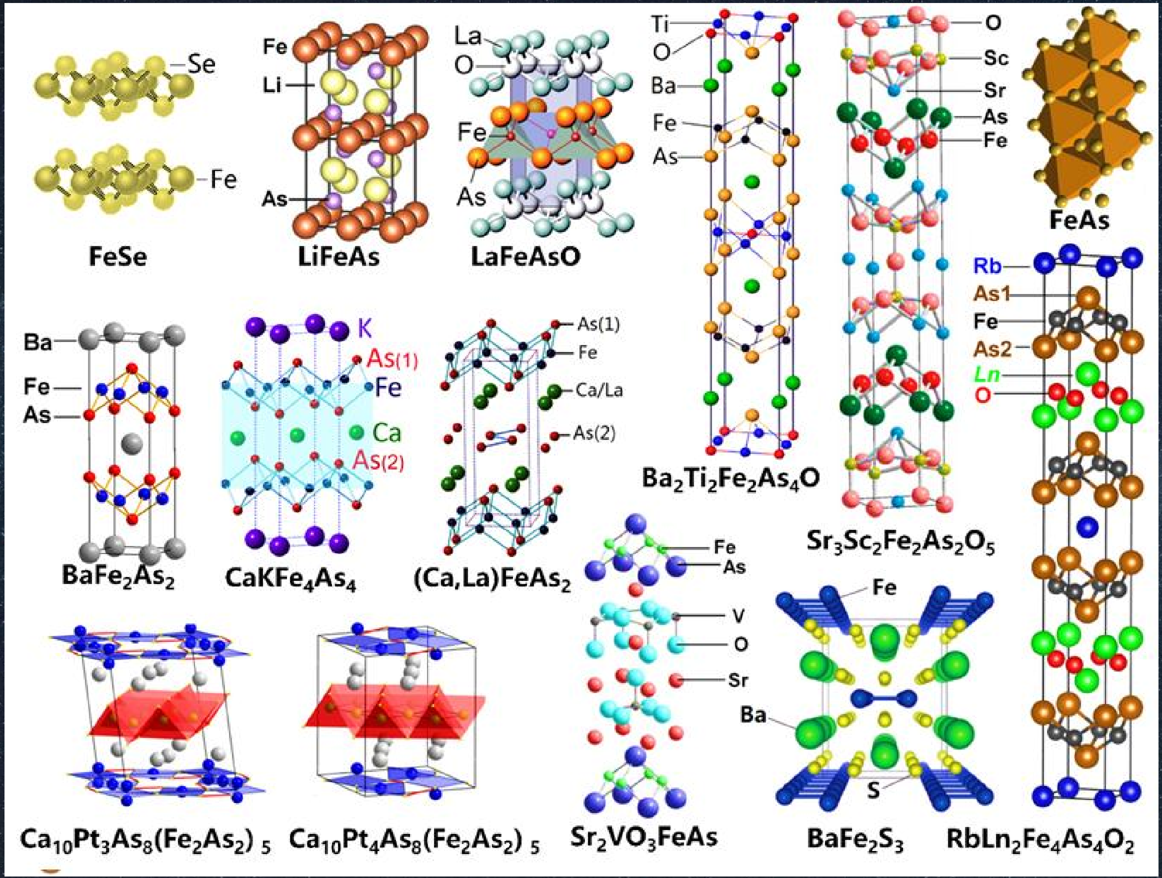
T_c= 40 ~ 55 K

发现第二个高温家族！

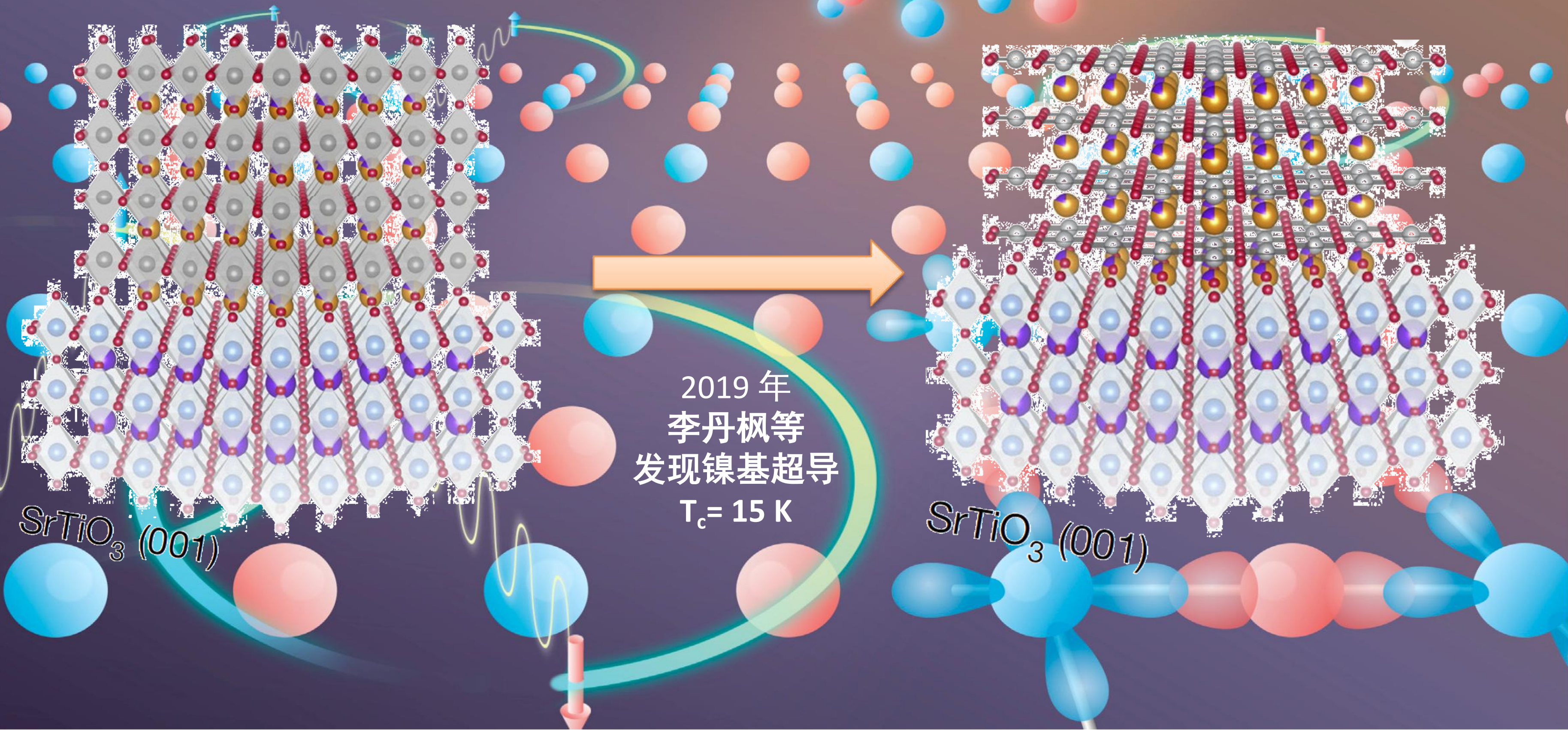
铁基超导材料探索的中国力量



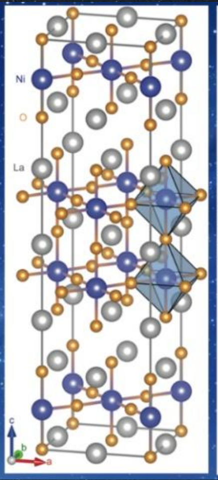
高温超导体：铁砷/铁硒化物

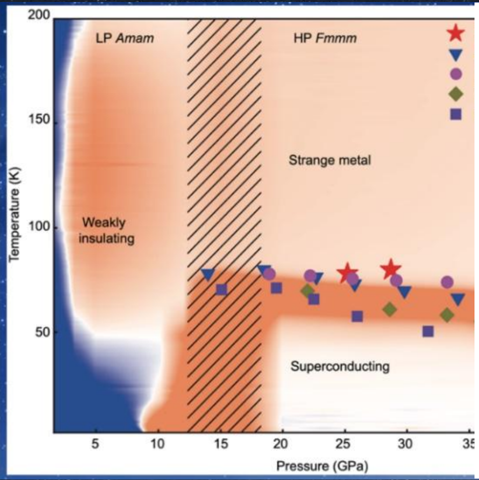


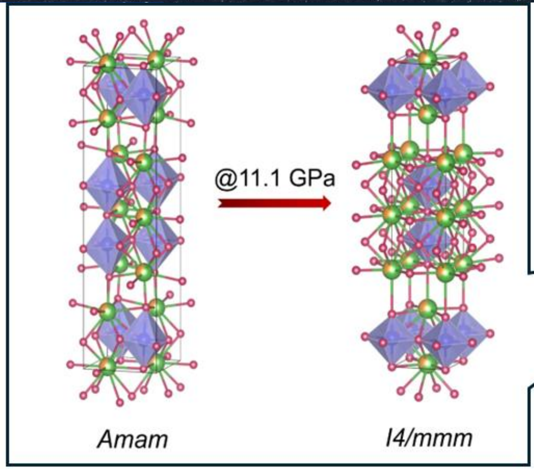
高温超导体：镍氧化物

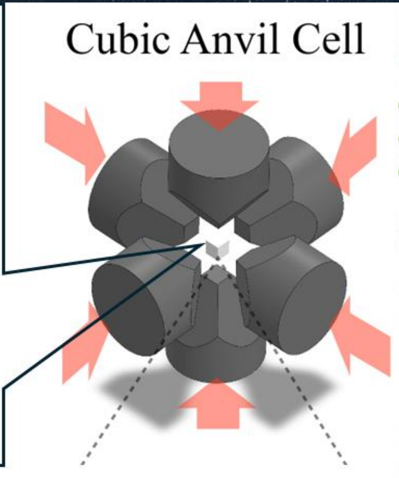


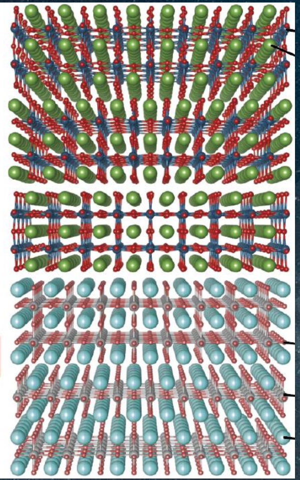
高温超导体：镍氧化物











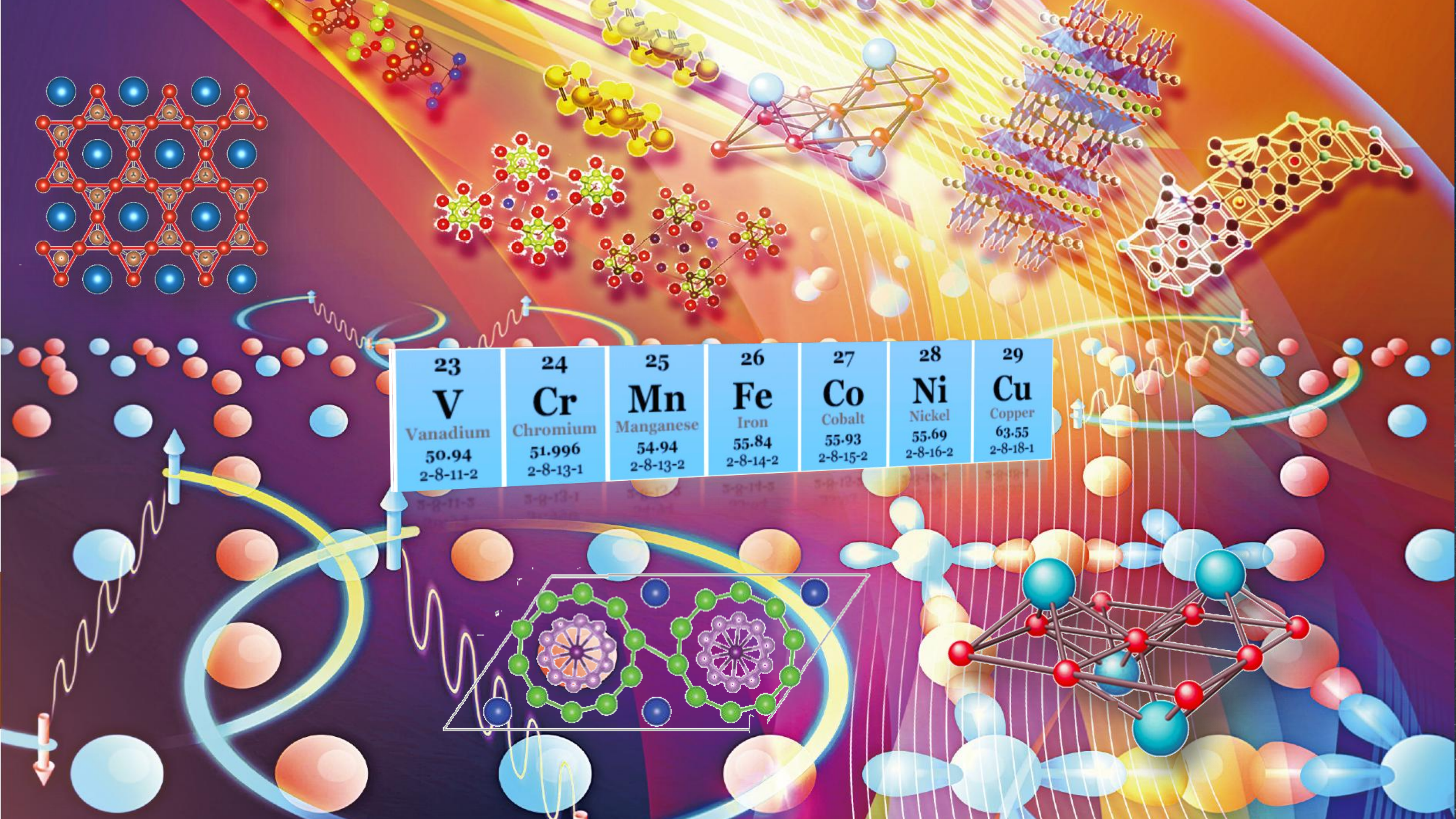
2023年5月
中山大学王猛等人
在$La_3Ni_2O_7$中实现
液氮温区超导T_c=80 K

2024年4月
浙江大学袁辉球等人
在$La_3Ni_2O_7$中实现
零电阻效应

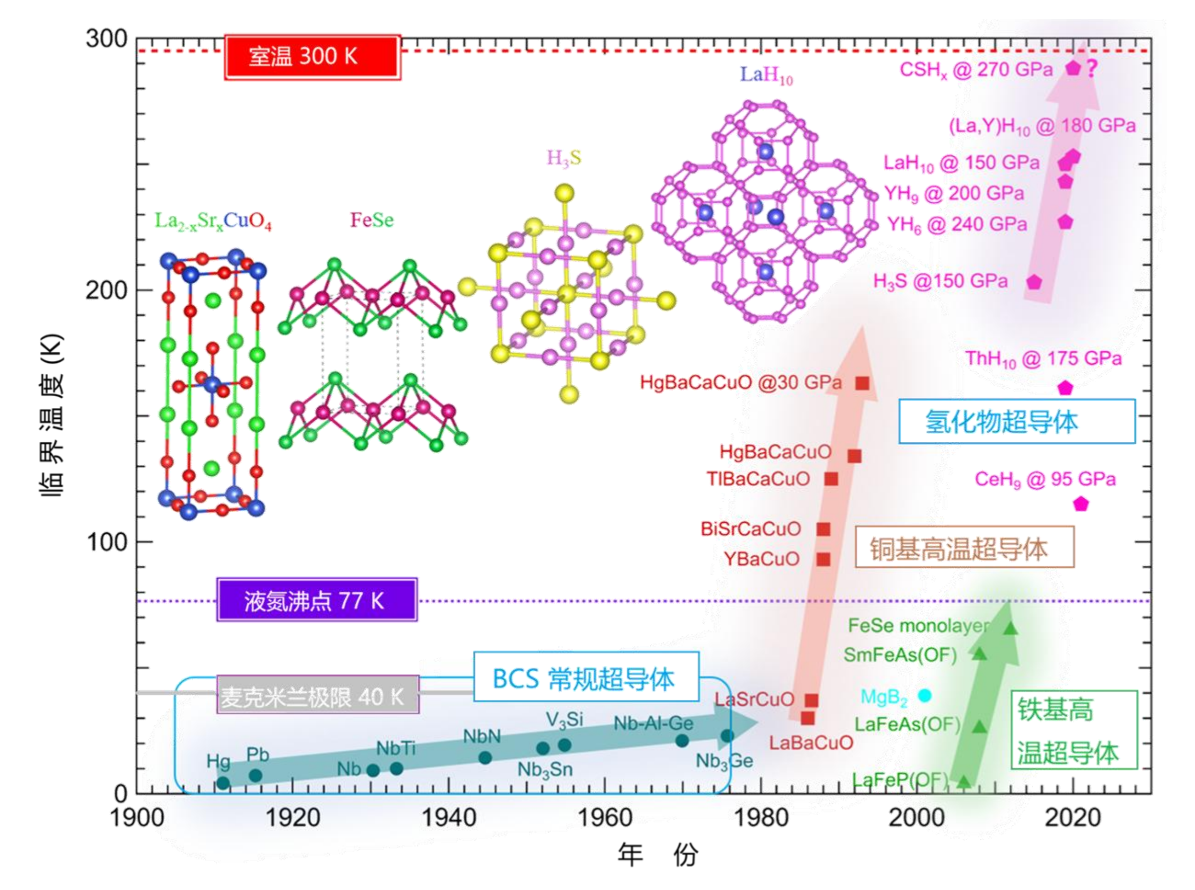
2024年7月
复旦大学赵俊等人
在$La_4Ni_3O_{10}$中实现
块体超导T_c=30 K

2024年10月
中科院物理所程金光等人
在$La_2PrNi_2O_7$中实现
60~82.5K 体超导

2025年2月
南方科大薛其坤等人
在$La_2PrNi_2O_7$薄膜中实现
40K 体超导

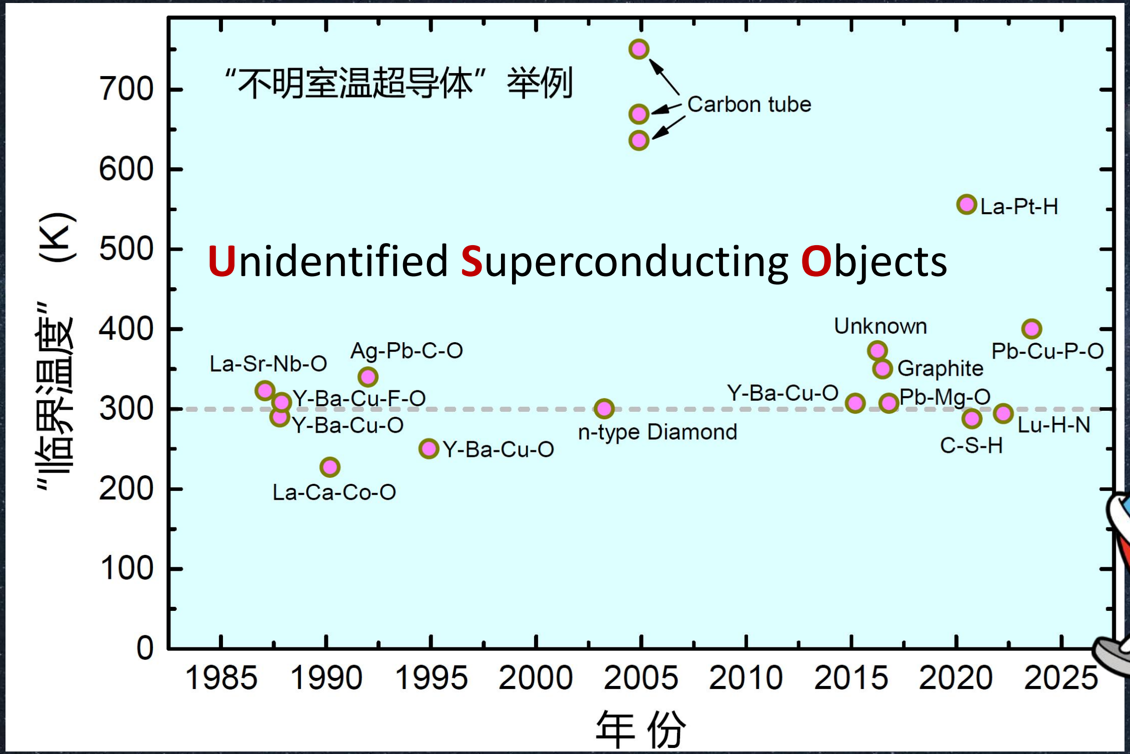

23
V
Vanadium
50.94
2-8-11-2
24
Cr
Chromium
51.996
2-8-13-1
25
Mn
Manganese
54.94
2-8-13-2
26
Fe
Iron
55.84
2-8-14-2
27
Co
Cobalt
55.93
2-8-15-2
28
Ni
Nickel
55.69
2-8-16-2
29
Cu
Copper
63.55
2-8-18-1

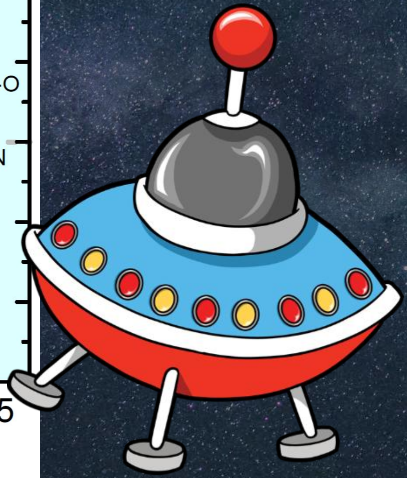
三重“天花板”：40 K, 77 K, 300 K

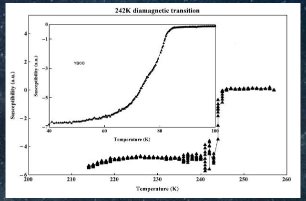


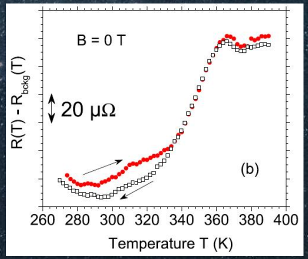
寻找“室温超导”第0人

“室温超导” 层出不穷，但都不靠谱！



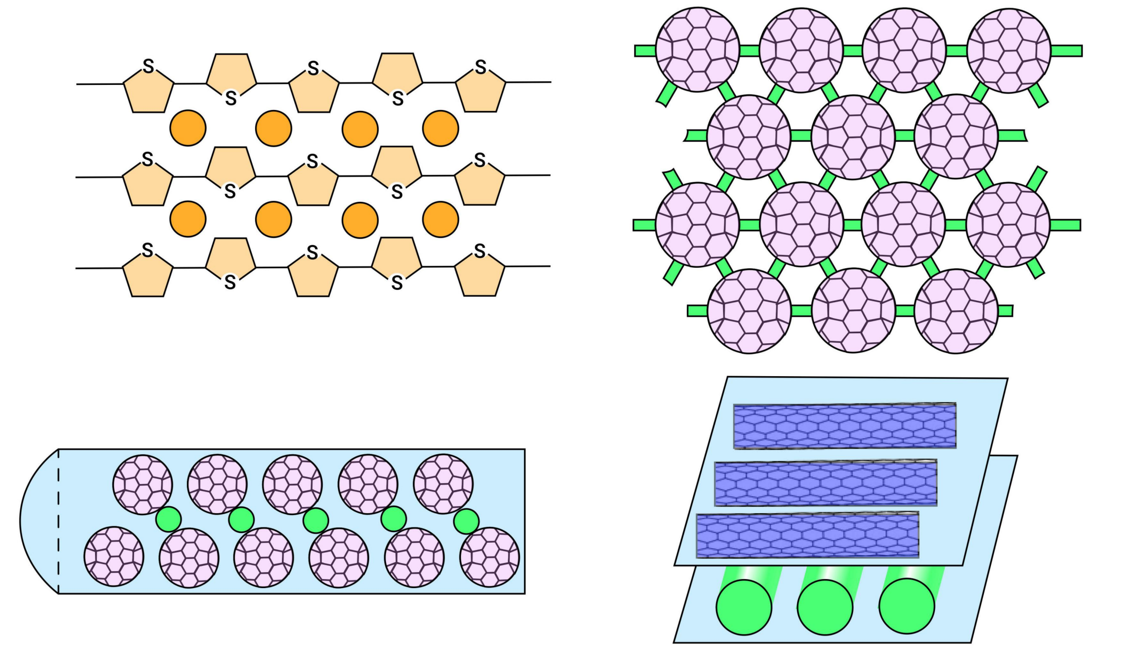




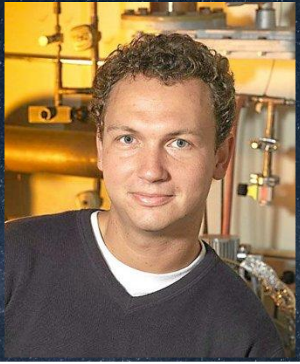


“不明超导体（USO）” 甚至“室温超导体”常有新闻，但从未确证！

“室温超导”的预言与丑闻



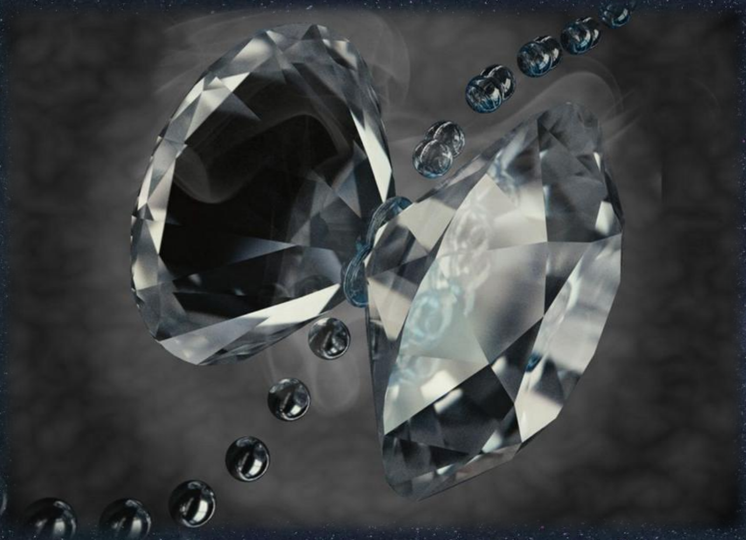
“室温”超导体，科学家的异想天开？



Jan Hendrik Schön

“物理学史上50年一遇的大骗子”
最快平均8天出一篇论文！
2002年10月， Science 撤稿8篇
2003 年3月， Nature 撤稿7篇
2004-2011 年， University of Konstanz 撤销其博士学位

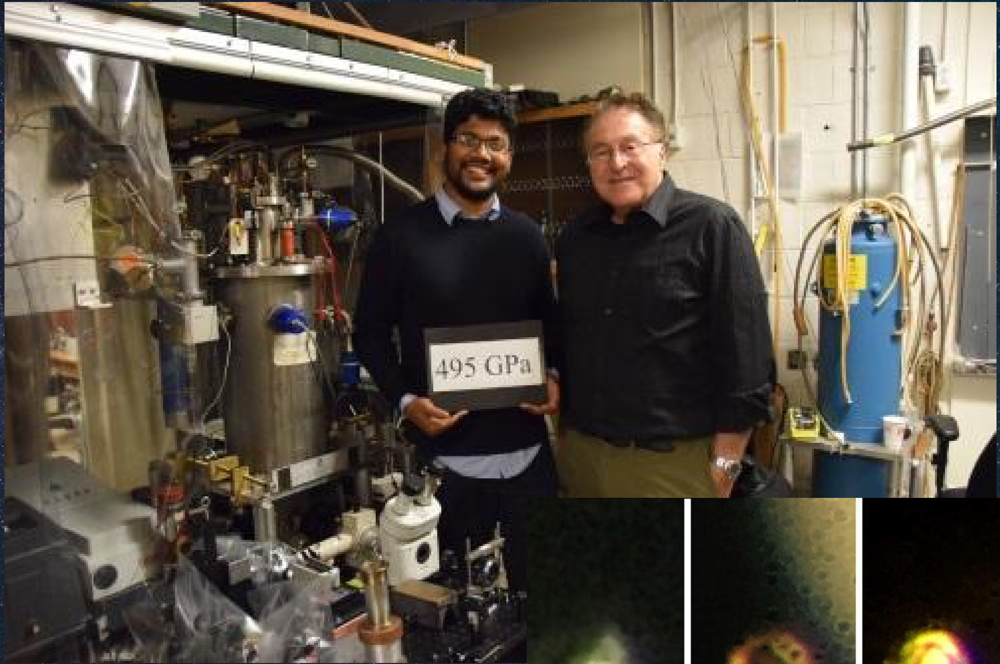
“金属氢” 乌龙事件

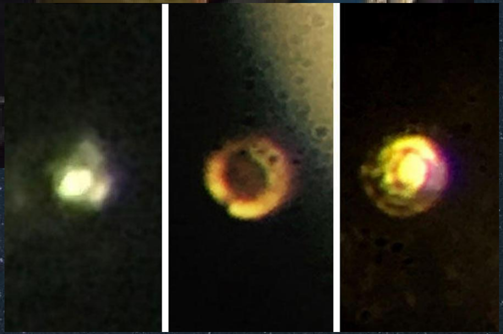


理论预言金属氢是室温超导体

但科学家努力了近90年

均未能成功！



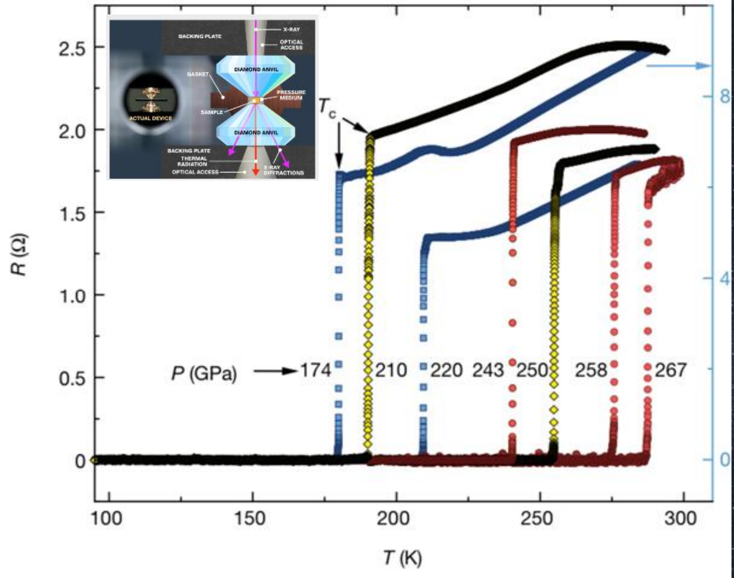


2017年

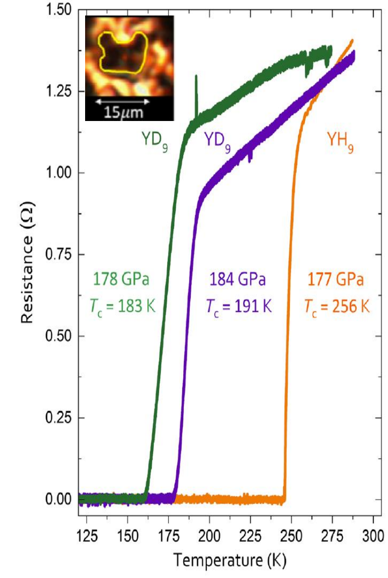
美国*Ranga Dias*和*Isaac Silvera*

宣称在495 GPa下发现金属氢

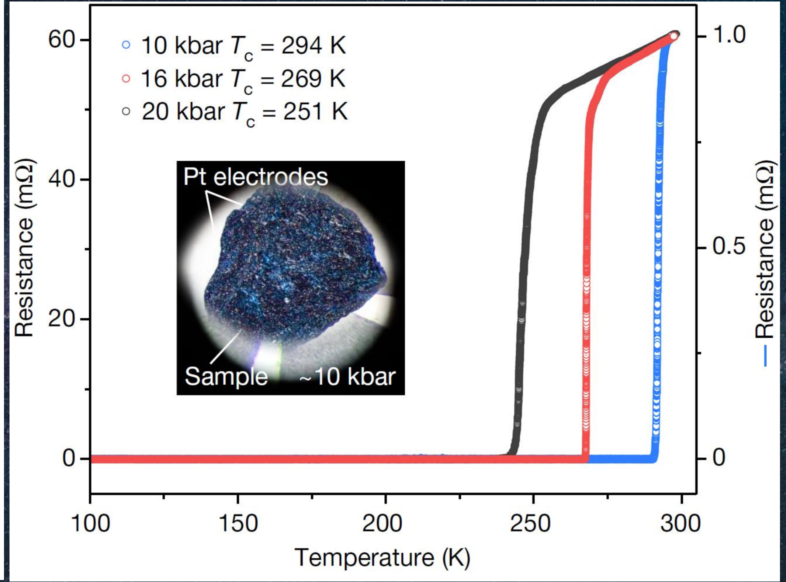
频繁打脸的Dias版“室温超导”！



C-S-H, T_c = 288 K @ 267 GPa
Nature 586, 373 (2020)



Y-H, T_c = 262 K @ 182 GPa
PRL 126, 117003 (2021)



Lu-N-H, T_c = 294 K @ 1 GPa
Nature 615, 244 (2023)

2020-2023年发现的“高压氢化物室温超导体”，无法重复验证！

“室温超导”的第N次撤稿

nature

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nature > articles > article

Article | Published: 08 March 2023

RETRACTED ARTICLE: Evidence of near-ambient superconductivity in a N-doped lutetium hydride

Nathan Dasenbrock-Gammon, Elliot Snider, Raymond McBride, Hiranya Pasan, Dylan Durkee, Nugzari Khalvashi-Sutter, Sasanka Munasinghe, Sachith E. Dissanayake, Keith V. Lawler, Ashkan Salamat & Ranga P. Dias

Nature **615**, 244–250 (2023) | Cite this article

107k Accesses | **57** Citations | **2245** Altmetric | Metrics

This article was retracted on 07 November 2023

This article has been updated

Abstract

The absence of electrical resistance exhibited by superconducting materials would have enormous potential for applications if it existed at ambient temperature and pressure conditions. Despite decades of intense research efforts, such a state has yet to be realized[1,2]. At ambient pressures, cuprates are the material class exhibiting superconductivity to the

nature

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nature > news & views > article

NEWS AND VIEWS | 08 March 2023

Hopes raised for room-temperature superconductivity, but doubts remain

A hydrogen-rich compound has taken the lead in the race for a material that can conduct electricity with zero resistance at room temperature and ambient pressure – the conditions required for many technological applications.

ChangQing Jin & David Ceperley

nature

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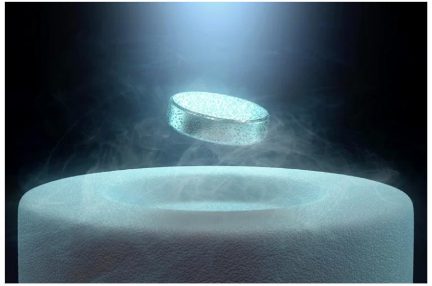
NEWS | 27 September 2022

Stunning room-temperature-superconductor claim is retracted

Retraction undermines the bold claim by physicists who said their material conducted electricity without resistance at 15 °C.

Davide Castelvecchi



A magnet levitating over a cryogenically cooled superconductor (artist's concept). Credit: KTSDesign/Science Photo Library

COVID-19 Science

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HOME > NEWS > ALL NEWS > 'REVOLUTIONARY' BLUE CRYSTAL RESURRECTS HOPE OF ROOM TEMPERATURE SUPERCONDUCTIVITY

NEWS | PHYSICS

‘Revolutionary’ blue crystal resurrects hope of room temperature superconductivity

Controversial group's material could lead to hyperefficient electricity grids and computer chips

nature

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nature > news > article

NEWS | 07 November 2023

Nature retracts controversial superconductivity paper by embattled physicist

This is the third high-profile retraction for Ranga Dias. Researchers worry the controversy is damaging the field's reputation.

Davide Castelvecchi

Physicist Ranga Dias is under investigation by his institution, the University of Rochester in New York. Credit: Lauren Petracca/New York Times/Redux/eyevine

高温超导先驱朱经武：过度关注“顶刊”迷失了科研本身

原创 韩扬眉 科学网 2023-03-22 20:04 发表于北京

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NEWS | 25 July 2023 | Update 25 July 2023 | Update 15 August 2023

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Ranga Dias will have a second paper revoked. A journal's investigation found apparent data fabrication.

Dan Garisto

Ranga Dias, a physicist at the University of Rochester in New York, is at the centre of a controversy over

室温超导引爆全网？！科学家：淡定！

中科院物理所 2023年03月10日 11:08 北京

室温超导第0人会是谁?

《物理》 2025年 第4期

实现室温超导的可行性路径探讨

罗会仟[†]
(中国科学院物理研究所 北京凝聚态物理国家研究中心 北京 100190)

Possible paths to room temperature superconductivity

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CSTR: 32040.14.wl20250401

摘 要 室温超导作为物理学皇冠上的明珠之一，吸引了众多科学家的持续关注和不懈努力。近年来，关于室温超导的报道既屡见不鲜亦充满争议，反映了人们对实现室温超导的热切期待。文章介绍了超导现象的基本特征、判定方法和典型材料，总结了“室温超导”相关的多起乌龙事件背后的经验教训。作者依据个人经验，提出了实现室温超导的10条可行性科学路径；最后表达了对室温超导的一些理性思考。作者认为，随着各类超导材料的不断涌现，室温超导的时代必将加速到来。但面对室温超导要保持谨慎乐观的态度，认真审视每一个科学判据，发掘可能的实用化价值，实现科学意义上的重大突破。

关键词 室温超导，超导电性，超导材料，高温超导体

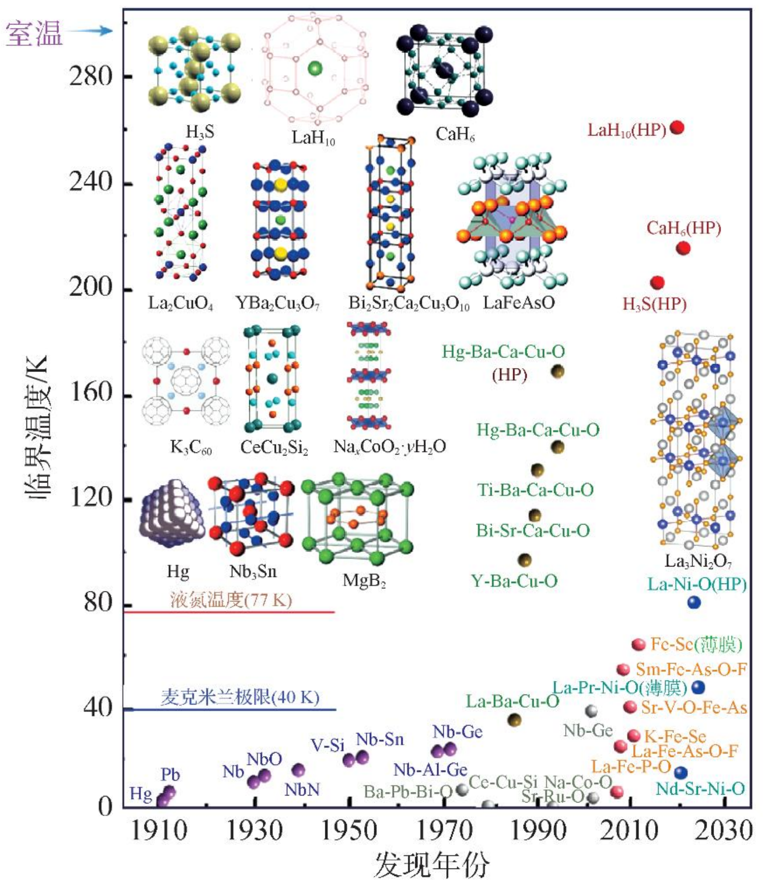
Abstract Room temperature superconductivity (RTS), as one of the jewels on the crown of physics, has attracted continuous attention and unremitting investigations from numerous scientists. In recent years, countless reports on room temperature superconductivity have led to great expectations, but their results are controversial. In this paper, we review the characteristics, assessment, and typical ingredients of superconductivity phenomena, summarize the lessons learnt from previous RTS reports, and propose 10 feasible paths to achieve RTS in the future, based on the author's personal experiences. The author also expresses some rational opinions on RTS. With the continuous emergence of various new materials in recent years, research progress is bound to accelerate. Even so, we still have to maintain a cautious optimism, carefully examine every piece of scientific evidence, explore all possible practical applications, and aim to achieve greater scientific breakthroughs.

Keywords room temperature superconductivity, superconductivity, superconducting materials, high-T_c superconductors

1 超导现象简介

超导是凝聚态物质在低温下呈现的一种宏观量子现象[1]。超导材料具有绝对零电阻、完全抗

磁性和磁通量子化等特性(图1)，可以突破传统金
属材料的电磁极限或量子极限，实现低损耗输电
高密度储能、高速磁悬浮、高场磁体、高频率谐
振腔、高灵敏光电探测和高性能量子计算等[2]



实现室温超导的可行性路径探讨

原创 罗会仟 中国物理学会期刊网 2025年04月16日 10:01 北京

物理 轻松阅读 享受物理 权威物理类中文科普期刊

作者：罗会仟

(中国科学院物理研究所 北京凝聚态物理国家研究中心)

本文选自《物理》2025年第4期

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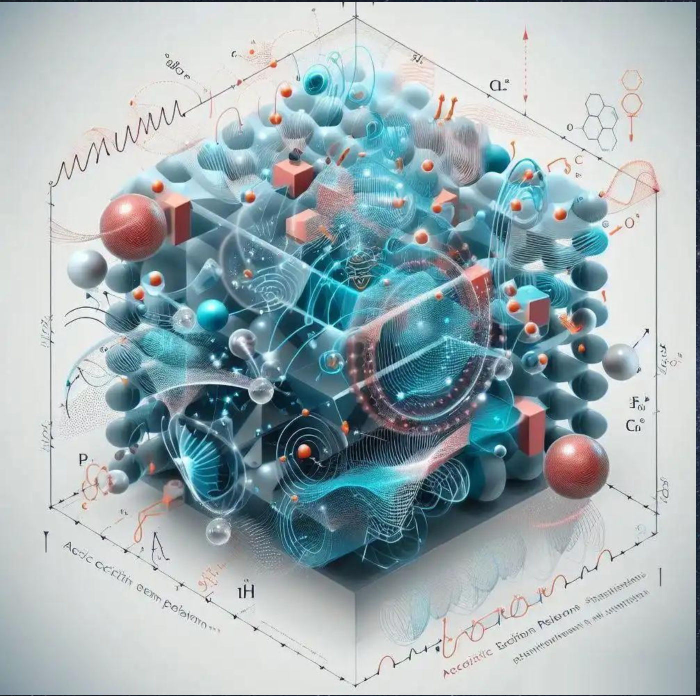
关键词 室温超导，超导电性，超导材料，高温超导体

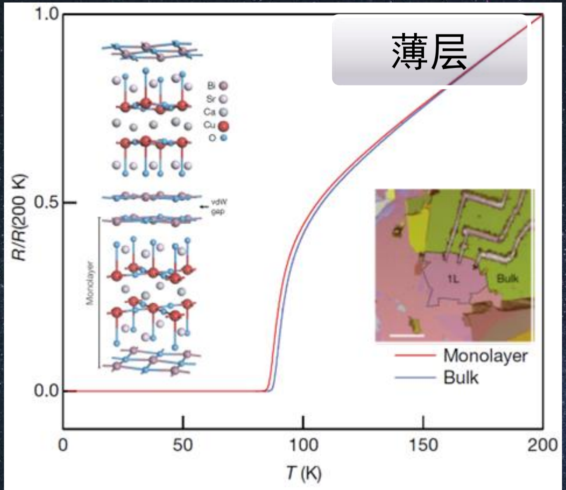
室温超导如何实现？



大数据+材料基因：

人工智能+机器学习

室温超导如何实现?



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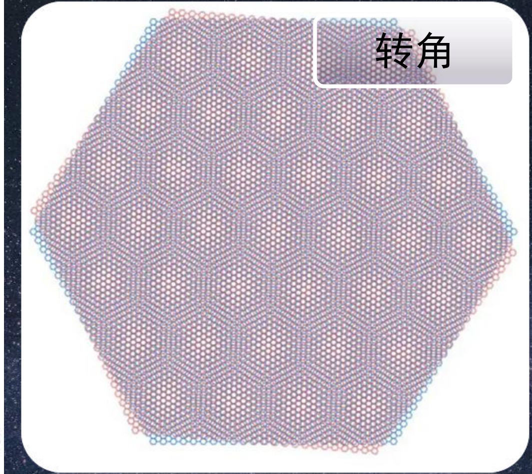
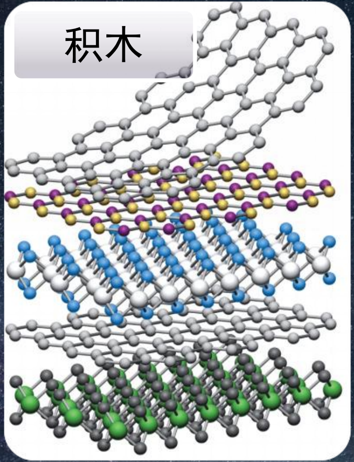
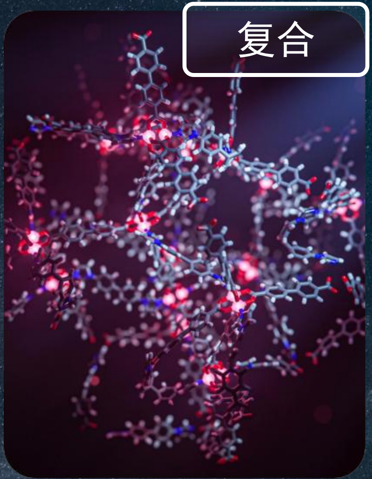


转角



积木



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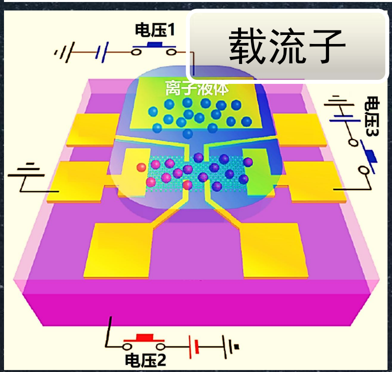
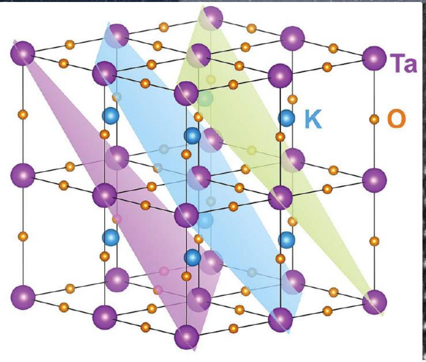


载流子
电压1
离子液体
电压3
电压2



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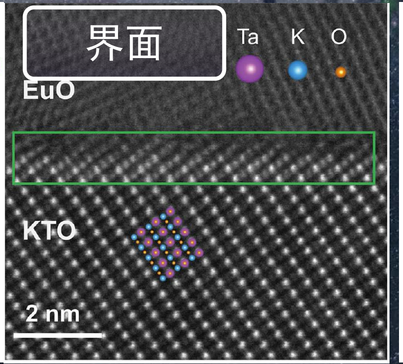

界面
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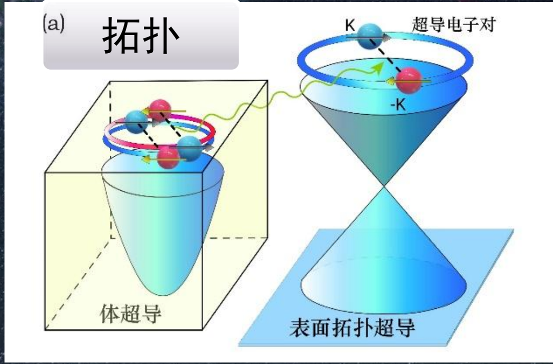
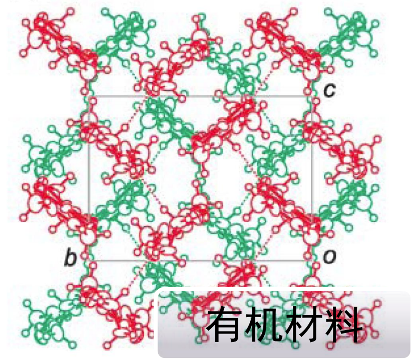
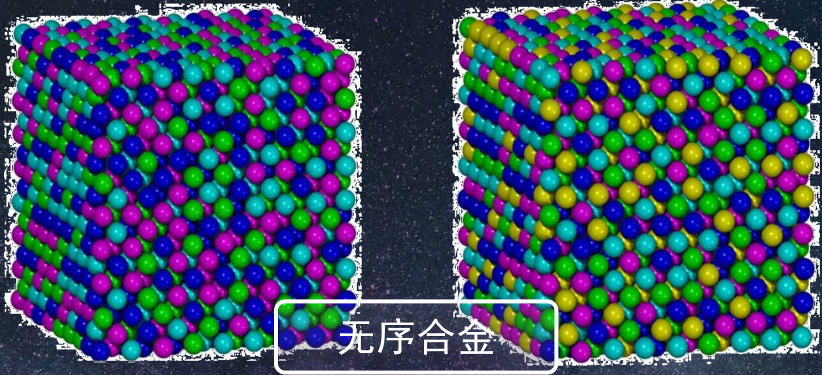
2 nm

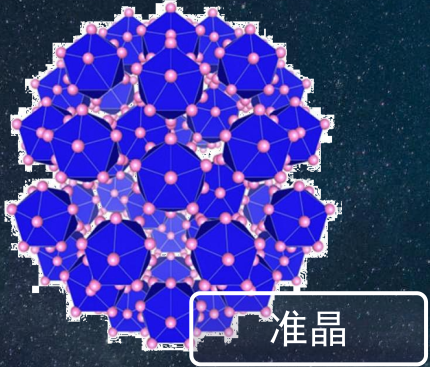


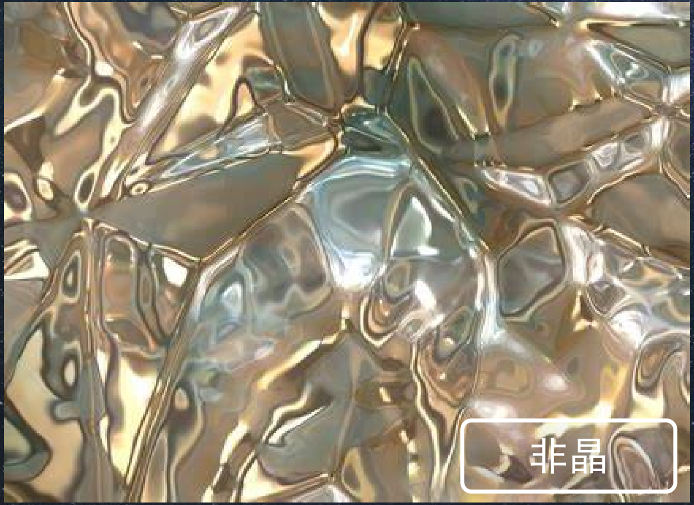
(a)
拓扑
K
超导电子对
-K
体超导
表面拓扑超导

室温超导如何实现?

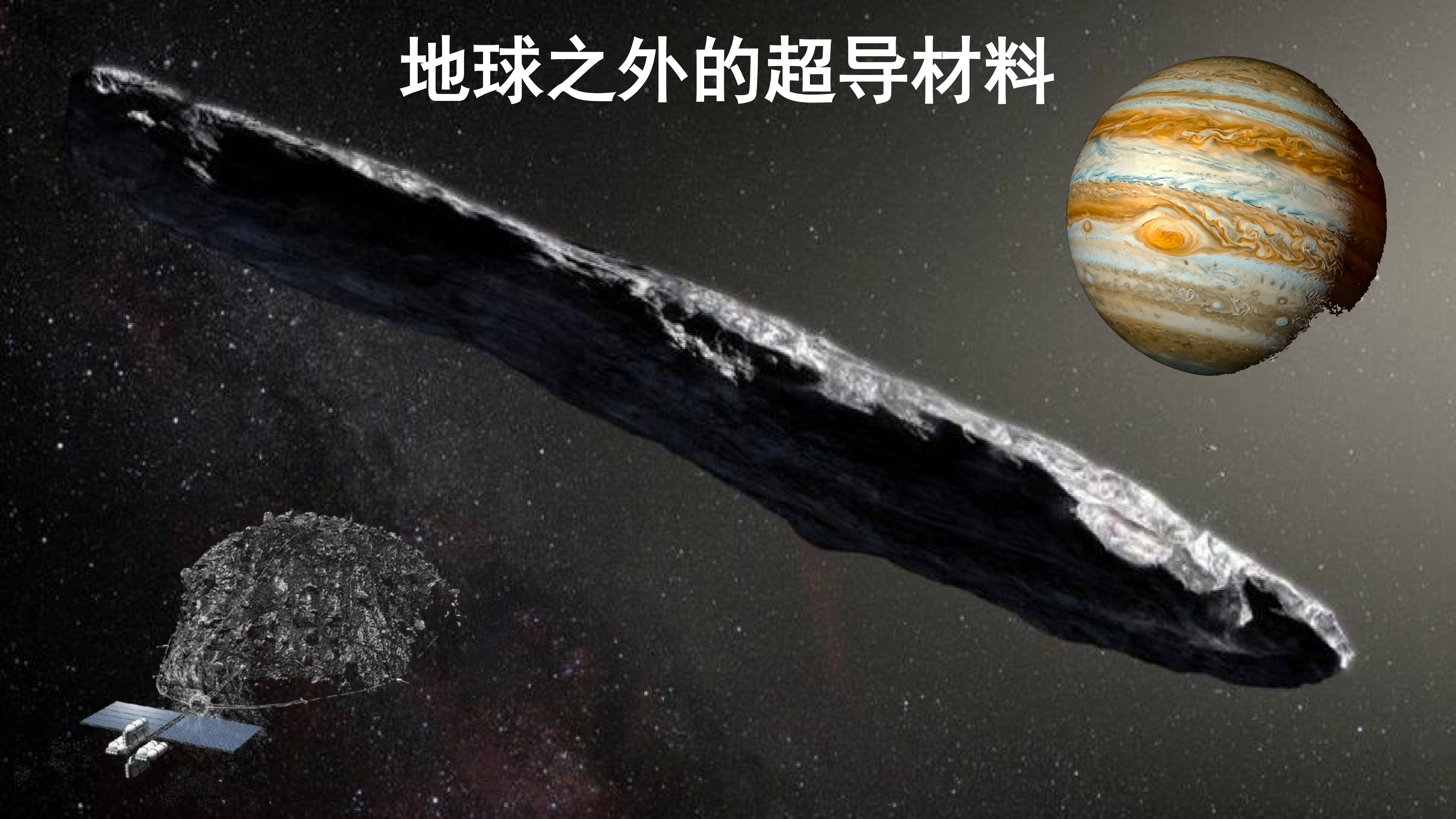








地球之外的超导材料



“高温超导”第零人 —— 马蒂亚斯

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