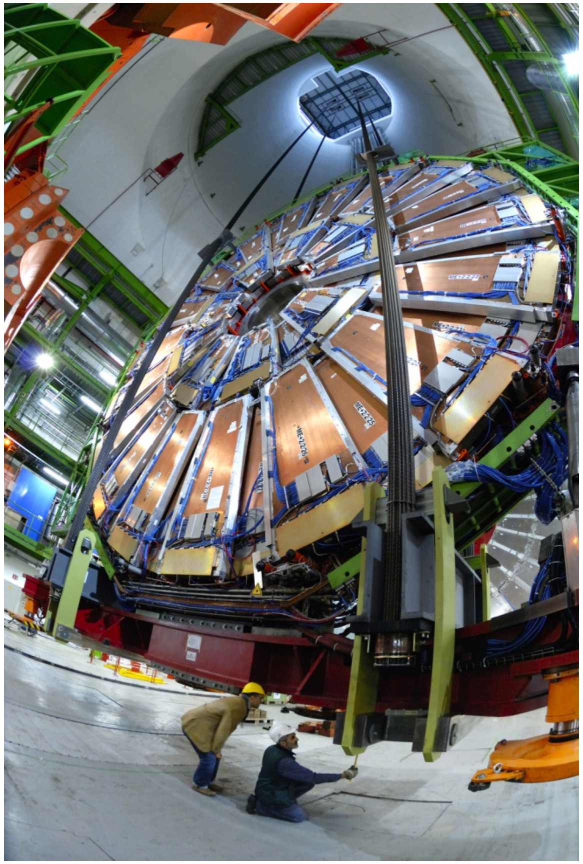
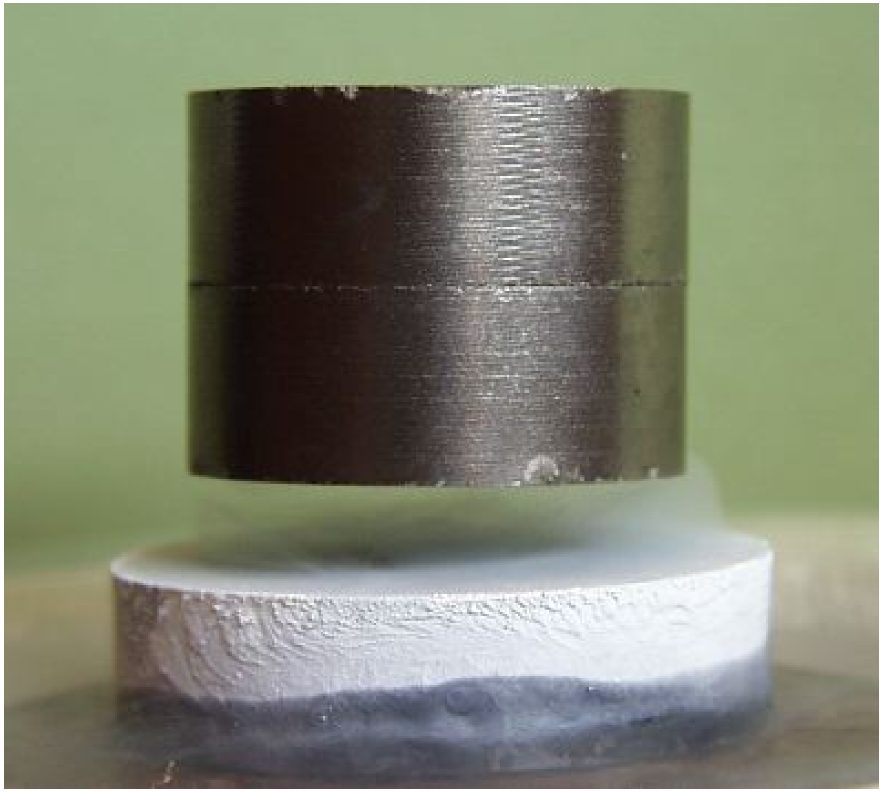
Superconductivity—a brief introduction

Reductionism vs. “more is different”

2 different paradigms for physics

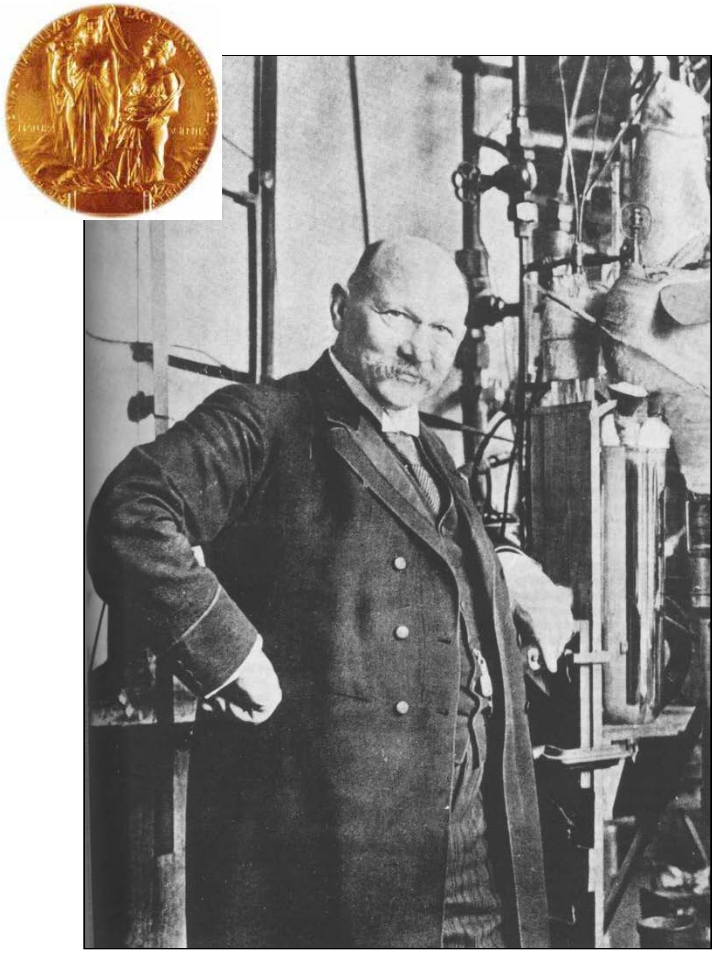


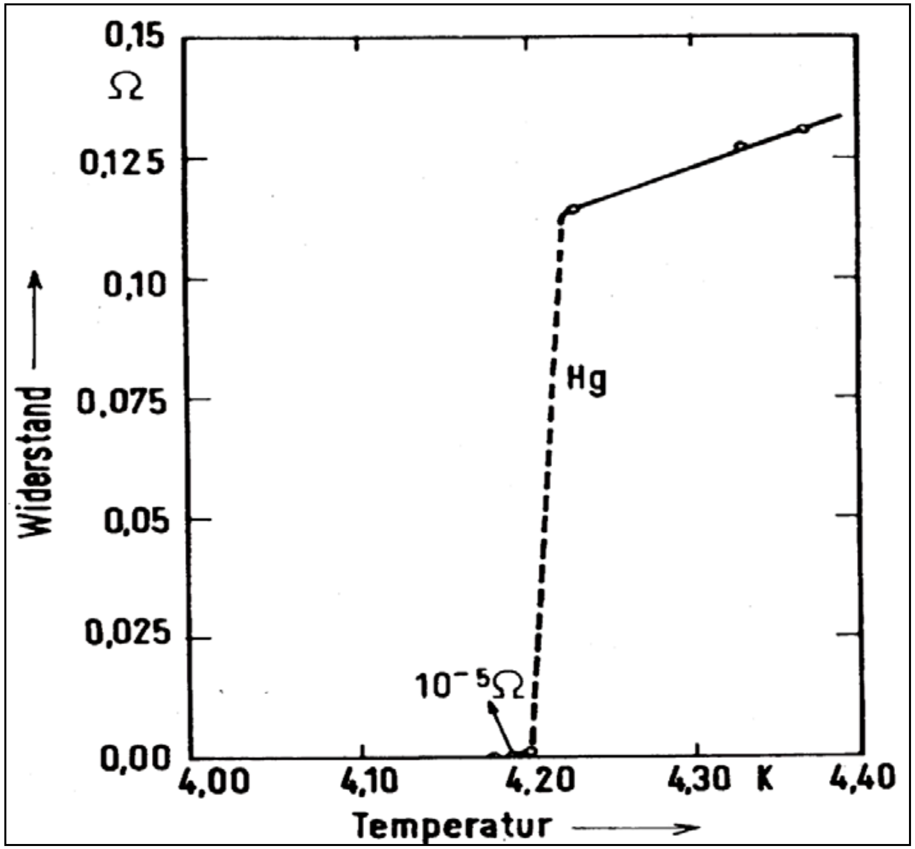


- search for smaller and smaller entities
- huge machines, 1000’s of scientists

- search for fundamentally new states of matter consisting of many particles
- tabletop experiments, small groups

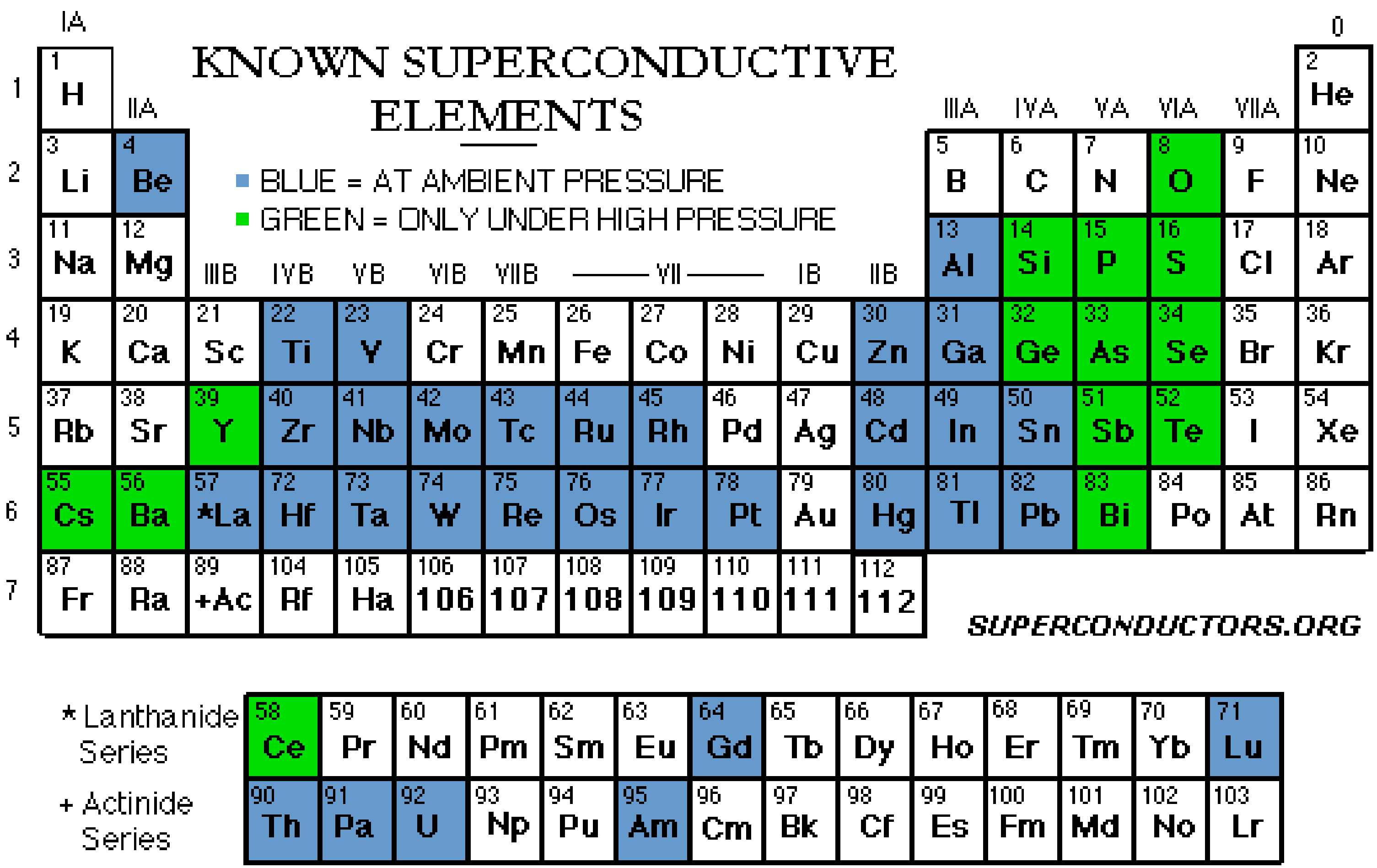
Discovery of superconductivity in Hg





Heike Kammerling Onnes (1911)

Many elements are superconductors



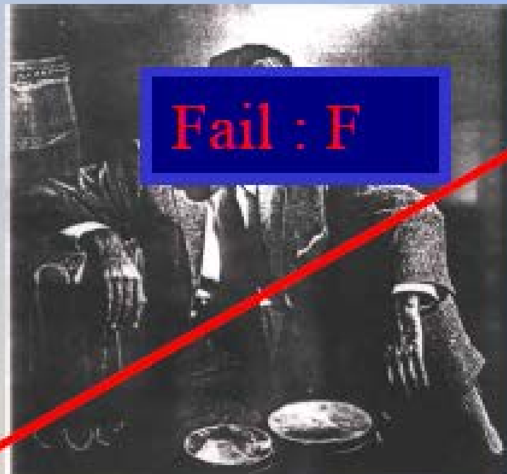
Conventional superconductors

•Search for an understanding of superconductivity: series of failures and a success

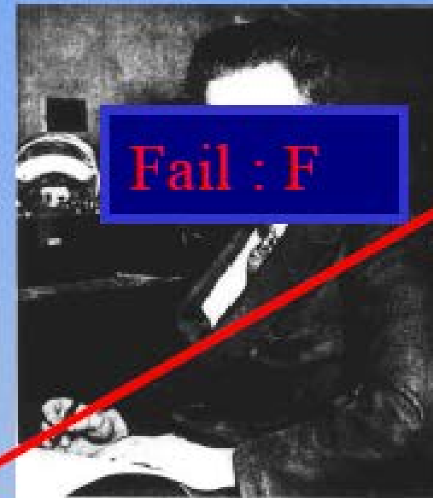
- During 46 years, from 1911 to 1957, superconductivity remains a mystery

- Around 1950 it's recognized as one of the most important problems in theoretical physics

- Richard Feynman: "No one is brilliant enough to figure it out"



Feynman



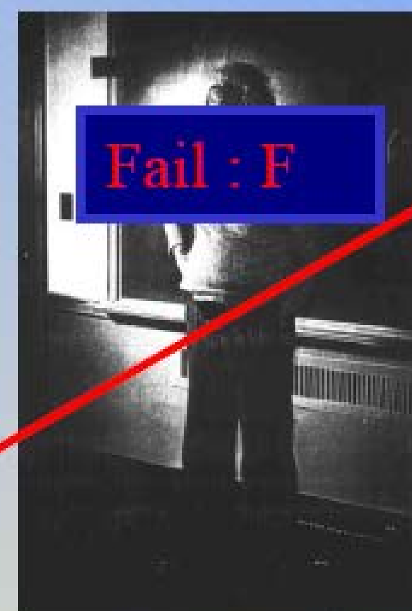
WERNER HEISENBERG (1901-) introduced matrix mechanics, which, like the Sch

Heisenberg

Bohr

NIELS BOHR (1885–1962) introduced the idea that the electro moved about the nucleus in well-defined orbits. This photograph was made in 1922, nine years after the publication of his paper

Einstein



Conventional superconductors

- BCS theory (1957)

Quantum mechanical behavior at the macroscopic scale

Leon Cooper

John Bardeen*

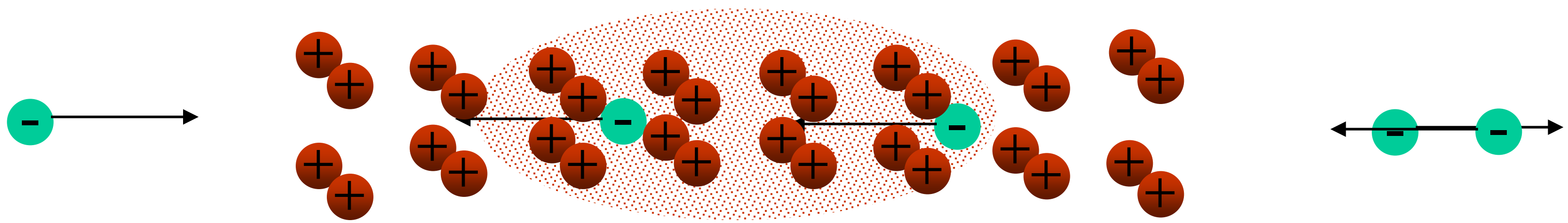
Robert Schrieffer

Nobel prize : 1972

*John Bardeen :
the only person to receive two Nobel prizes in physics!

Understanding the BCS idea:
Ingredient #1
Attraction & formation of Cooper pairs

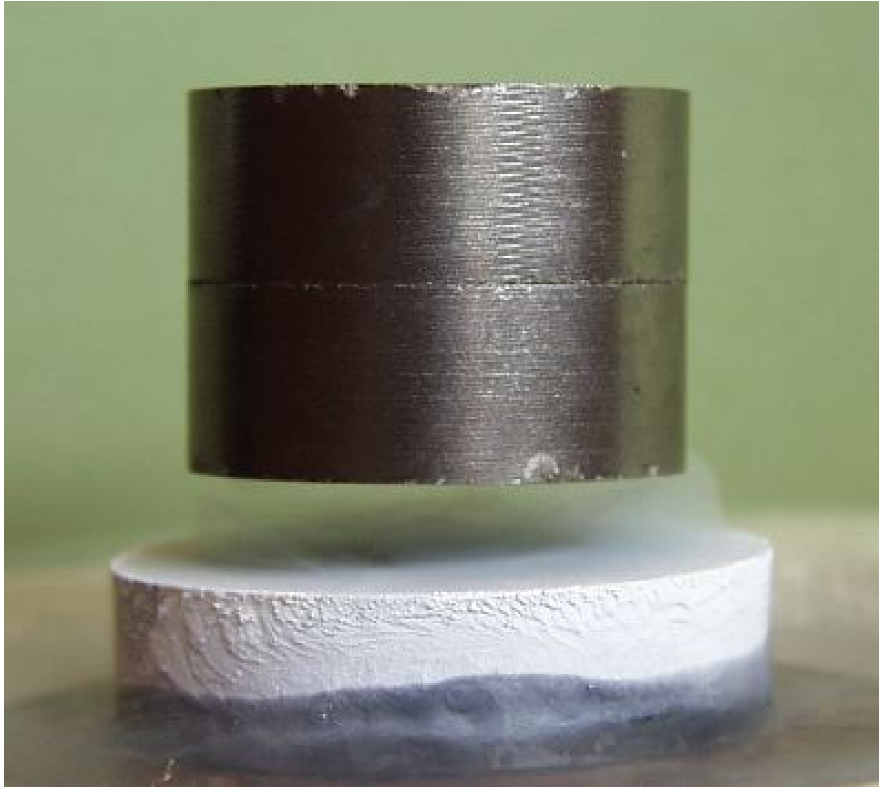
How Cooper pairs form
Prelude to superconductivity

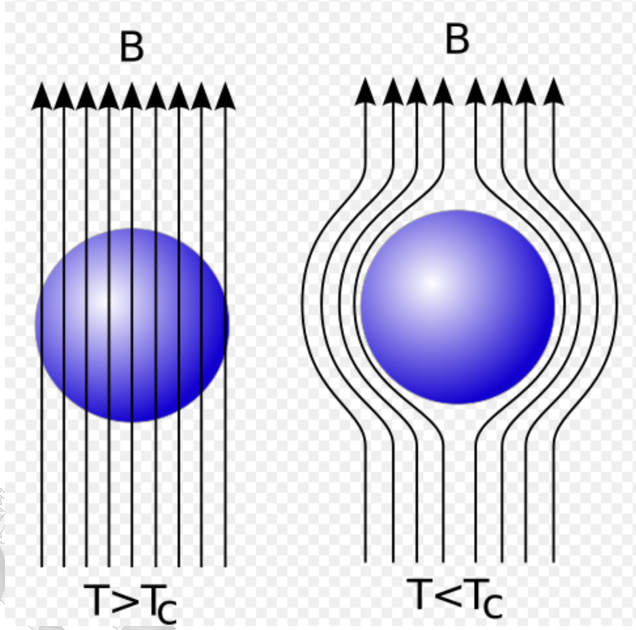


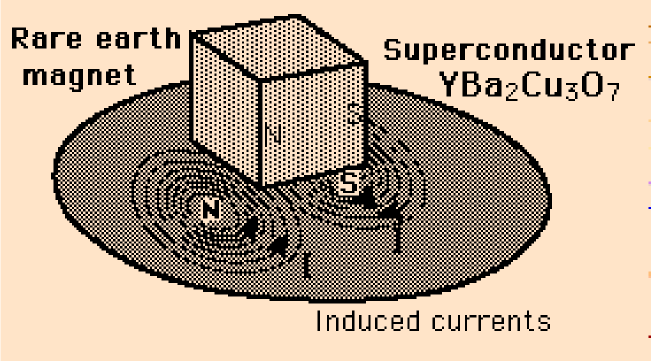
χ = -1

Perfect screening

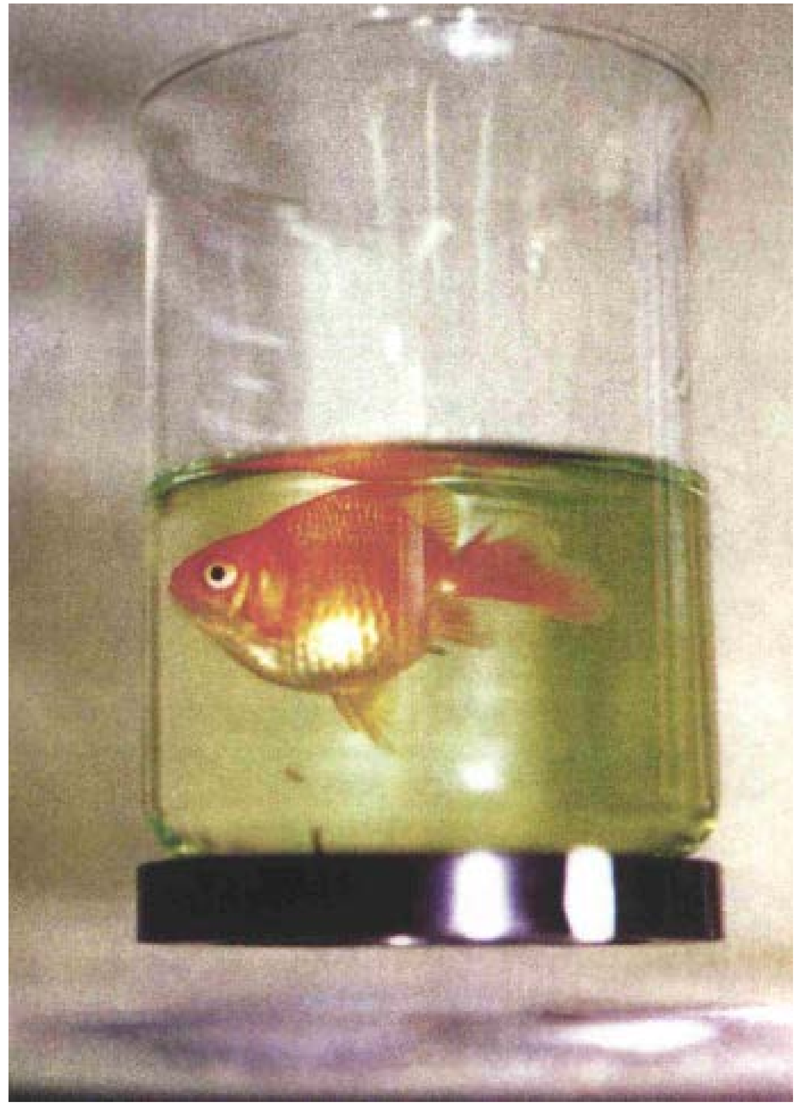
(Meissner effect)







No animals were harmed during this experiment!



More practical application: sumo wrestler levitation

http://www.youtube.com/watch?v=Ws6AAhTw7RA

Levitation, the movie

High temperature superconductivity

Possible High T_c Superconductivity in the Ba – La – Cu – O System

J.G. Bednorz and K.A. Müller
IBM Zürich Research Laboratory, Rüschlikon, Switzerland

Received April 17, 1986

Z. Physik, June 1986

Alex Müller and Georg Bednorz

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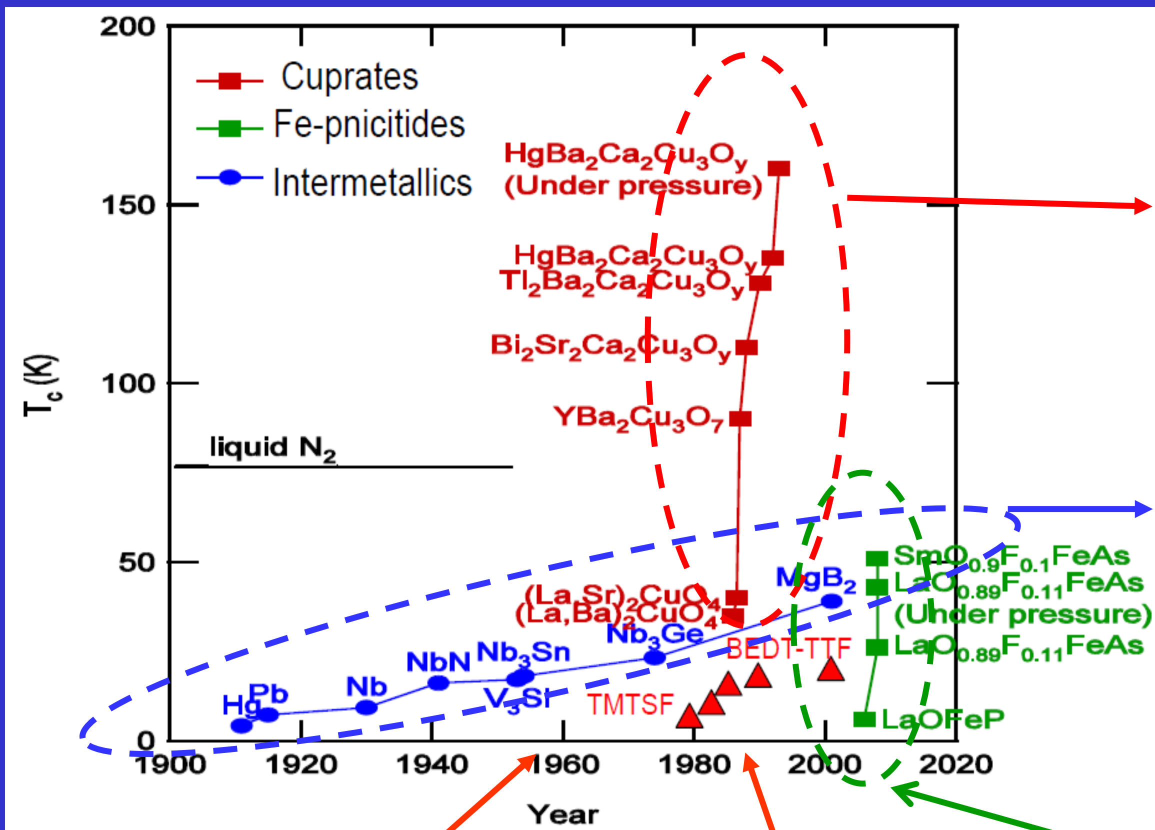
☐	Grüneisen parameter coupling in heavy fermion systems		169-174
	DOI	10.1007/BF01303699	
	Authors	M. Yoshizawa, B. Lüthi and K. D. Schotte	
	Text	PDF (494 kb)	
☐	Anomalous temperature dependence of the magnetic field penetration depth in superconducting UBe_{13}		175-188
	DOI	10.1007/BF01303700	
	Authors	F. Gross, B. S. Chandrasekhar, D. Einzel, K. Andres, P. J. Hirschfeld, H. R. Ott, J. Beuers, Z. Fisk and J. L. Smith	
	Text	PDF (1,206 kb)	
☐	Possible high T_c superconductivity in the Ba–La–Cu–O system		
	DOI	10.1007/BF01303701	
	Authors	J. G. Bednorz and K. A. Müller	
	Text	PDF (396 kb)	

20 Articles First | 1-10 | 11-20 | Next

Superconductivity timeline



Cuprates
non-BCS

Low temperature
BCS

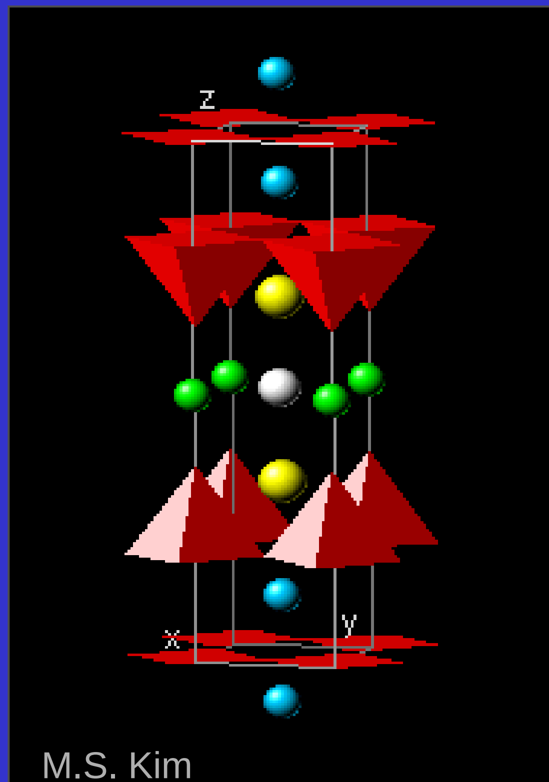
Fe-based
?

BCS Theory

Bednorz and Müller

Cuprate high-T_c superconductors

$Hg_1Ba_2Ca_2Cu_3O_8$



T_c = 135 K

under pressure: 153 K

Hg

Ba

Ca

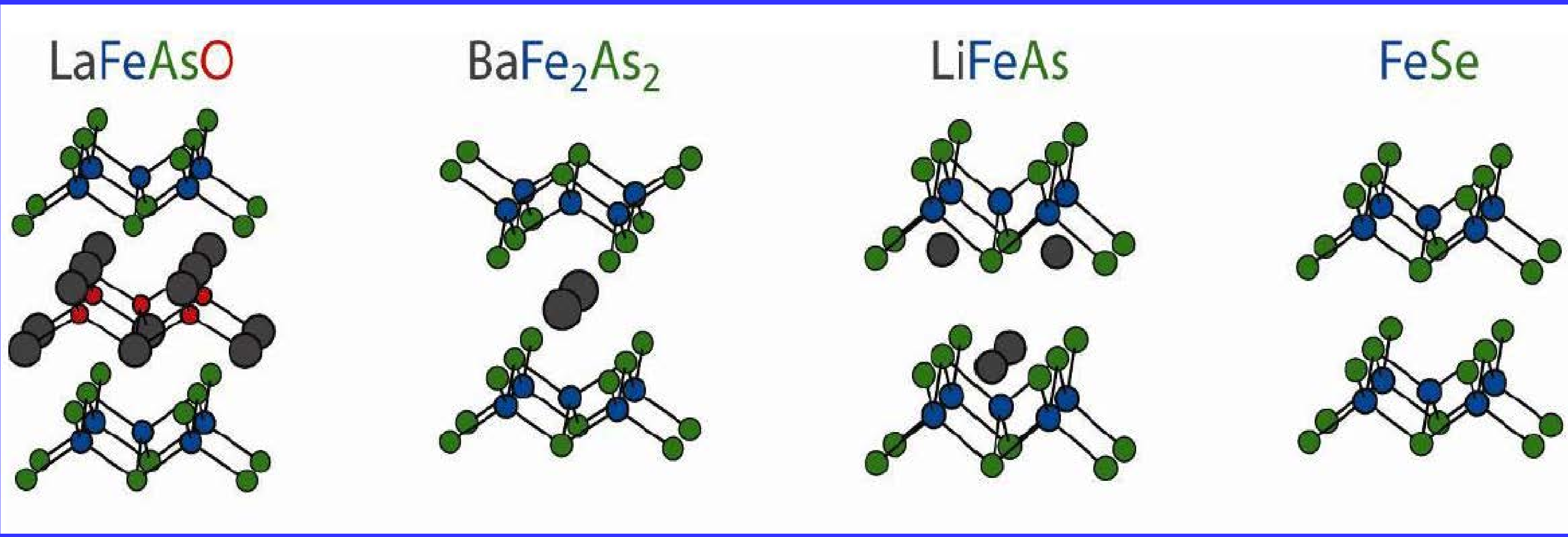
interstitial O

Cu/O

A. Schilling, M. Cantoni, J. Guo, H.R. Ott, Nature 363, 56 (1993)

Iron-based superconductors

Iron-based superconductors



Tc=28K

(55K for Sm)

• Kamihara et al JACS (2008)

• Ren et al Chin. Phys. Lett. (2008)

Tc=38K

• Rotter et al. arXiv: PRL (2008)

• Ni et al Phys. Rev. B 2008 (single xtals)

Tc=18K

Wang et al

Sol. St. Comm. 2008

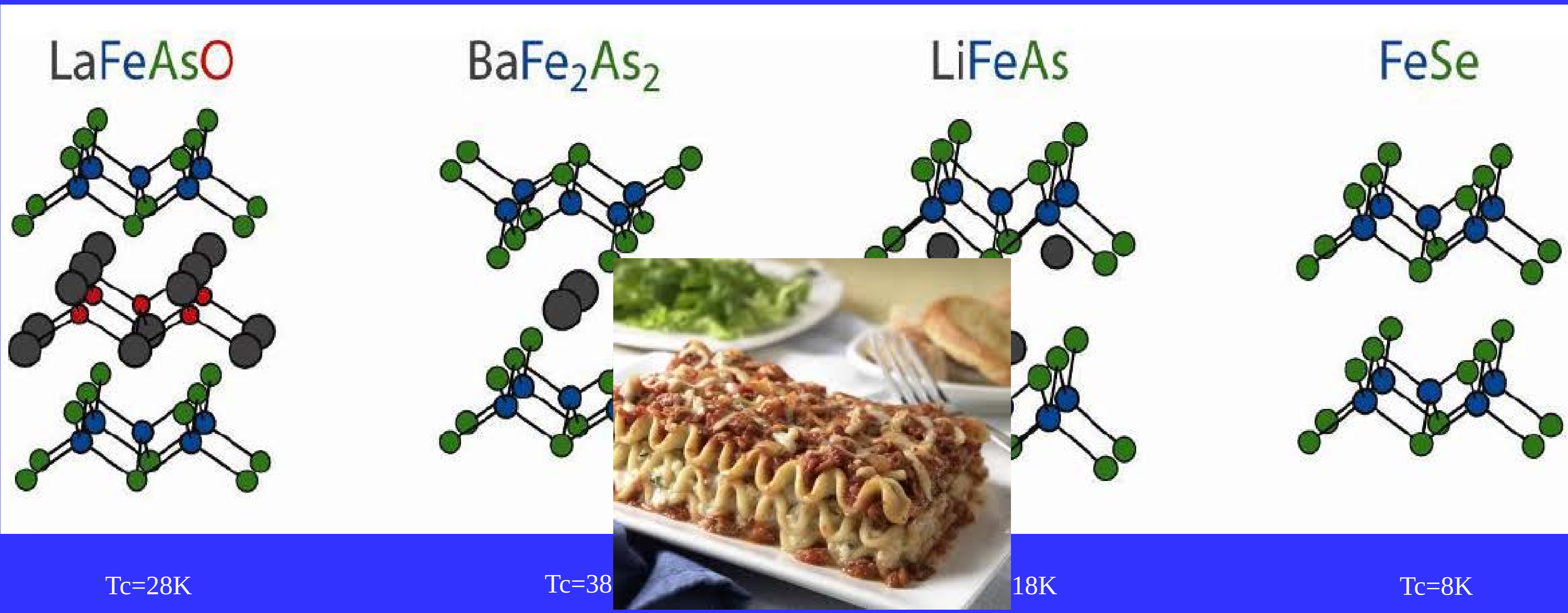
Tc=8K

Hsu et al

PNAS 2008

No arsenic ☺!

Iron-based superconductors



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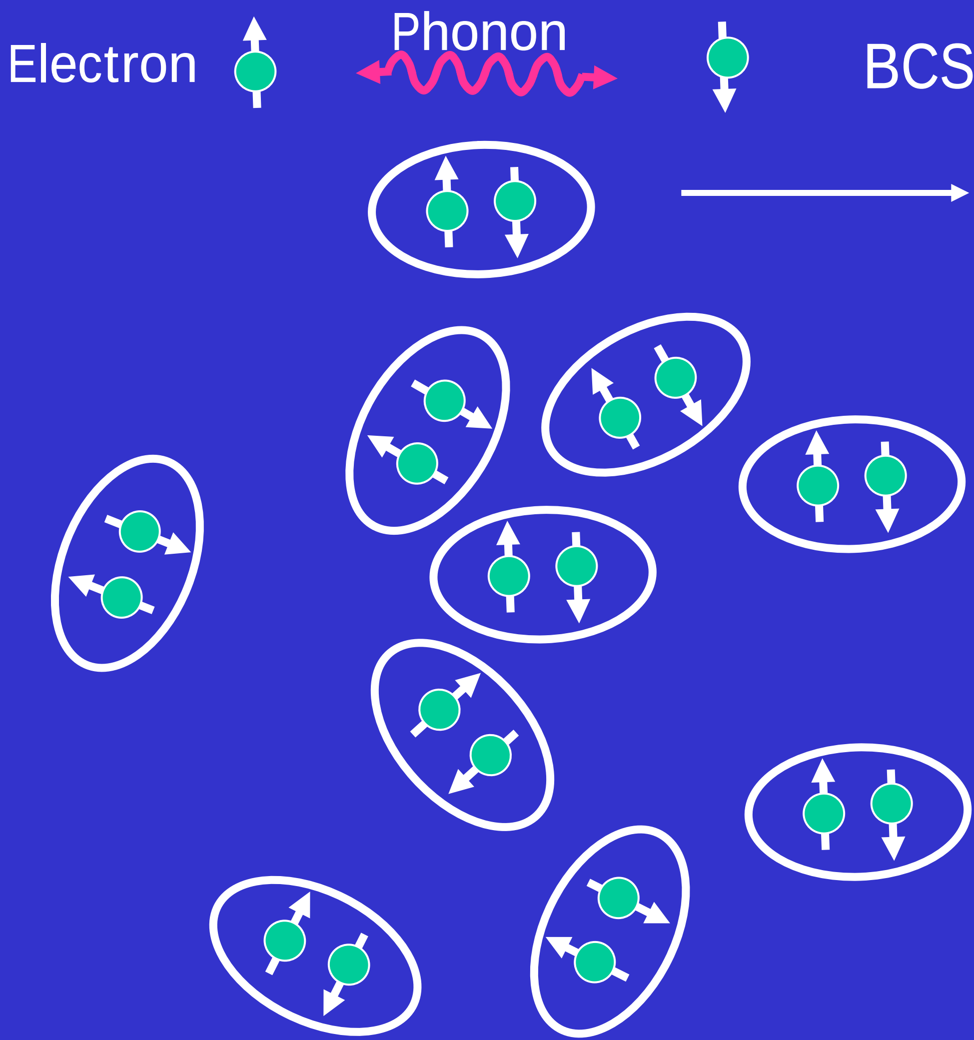
Hsu et al
PNAS 2008

No arsenic ☺!

Superconductivity: Theory



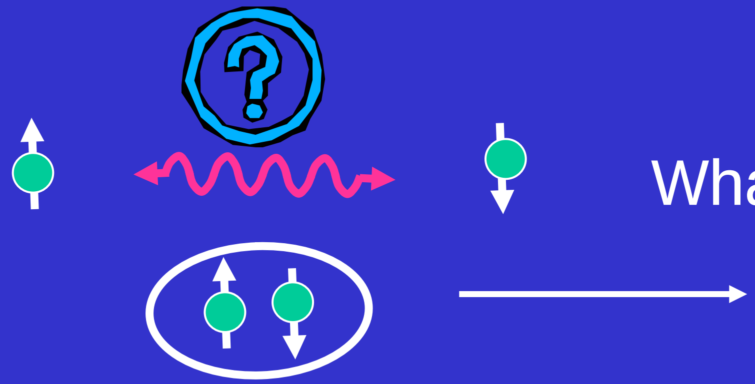
BCS: Phonon mediated pairing

Cooper pair

Ground state of a superconductor

Superconductivity: High T_c

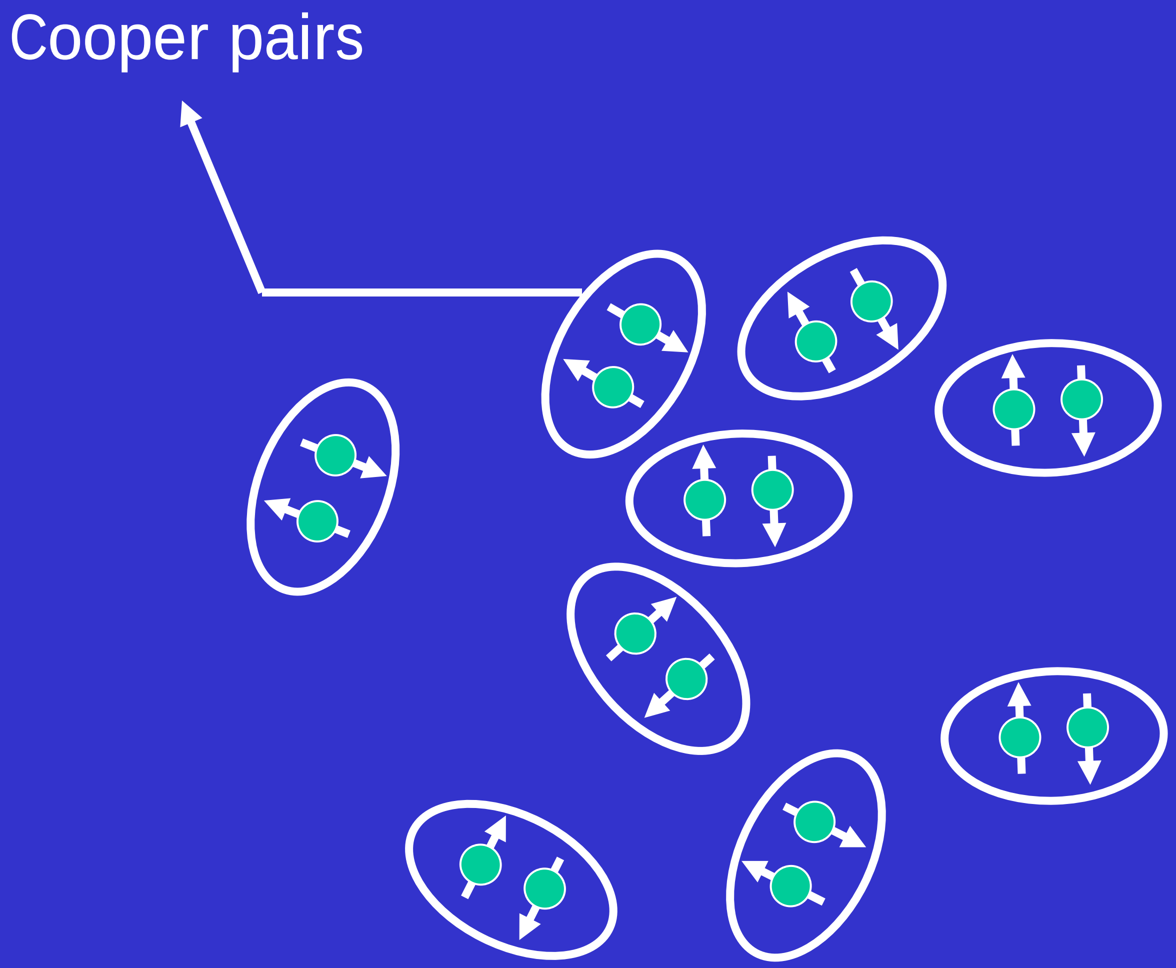
Electron



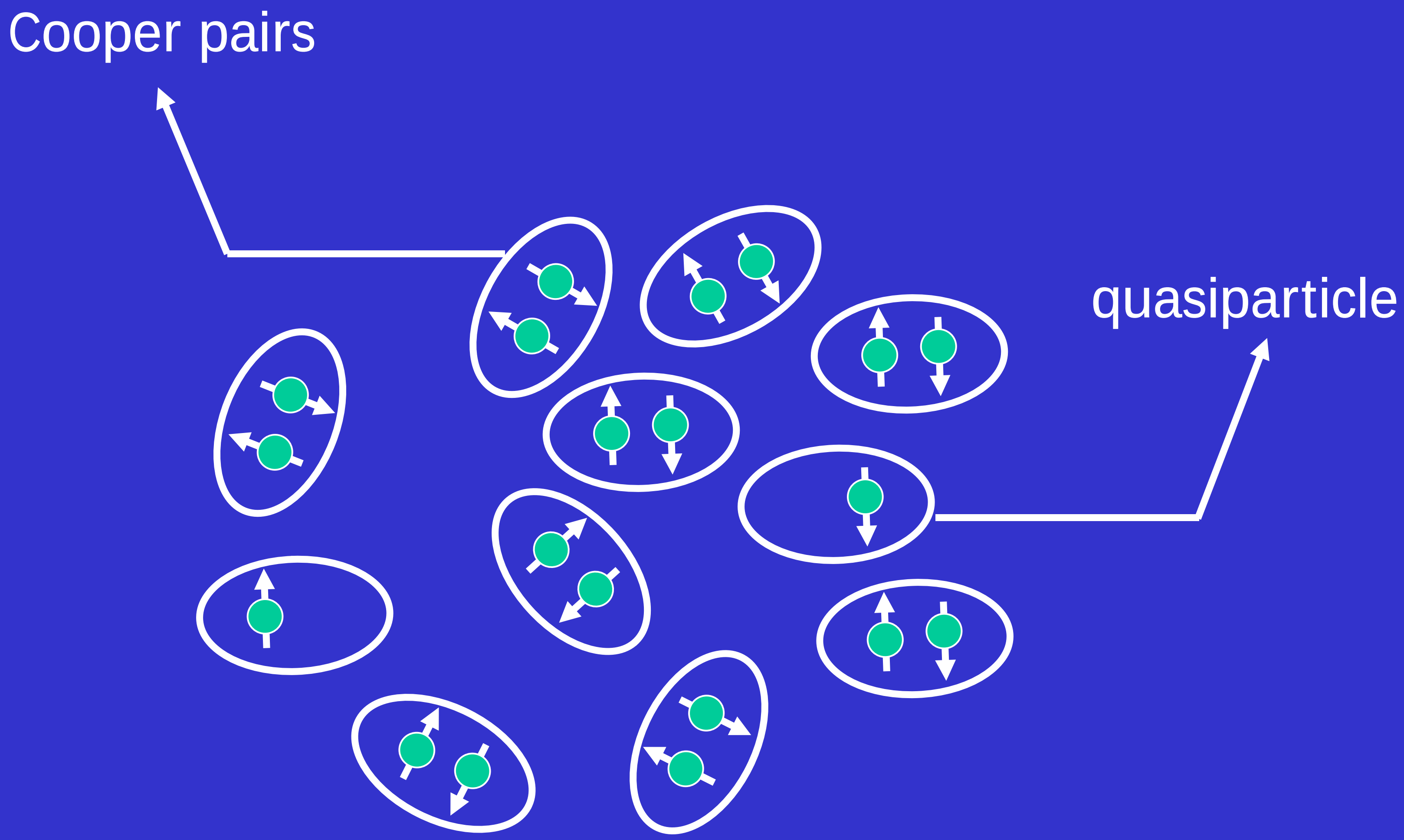
What is the "glue"?

Cooper pair

Superconductivity: Ground state

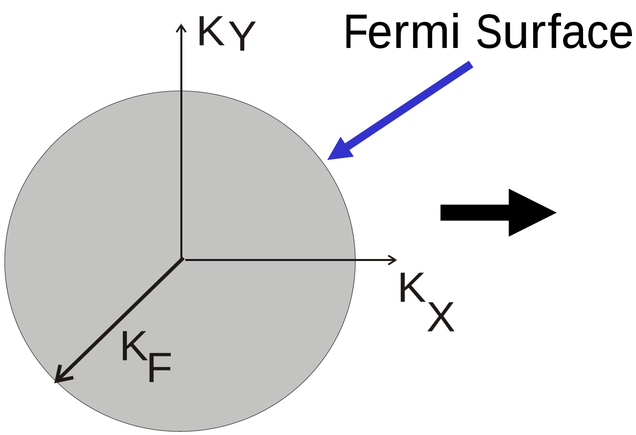


Superconductivity: excited state



Normal State

Normal State (Metal)

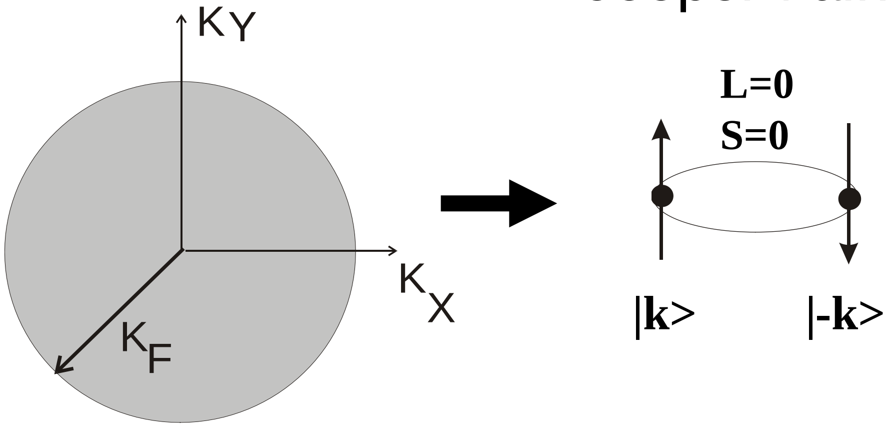


Degenerate ~free electron gas

SC Ground State

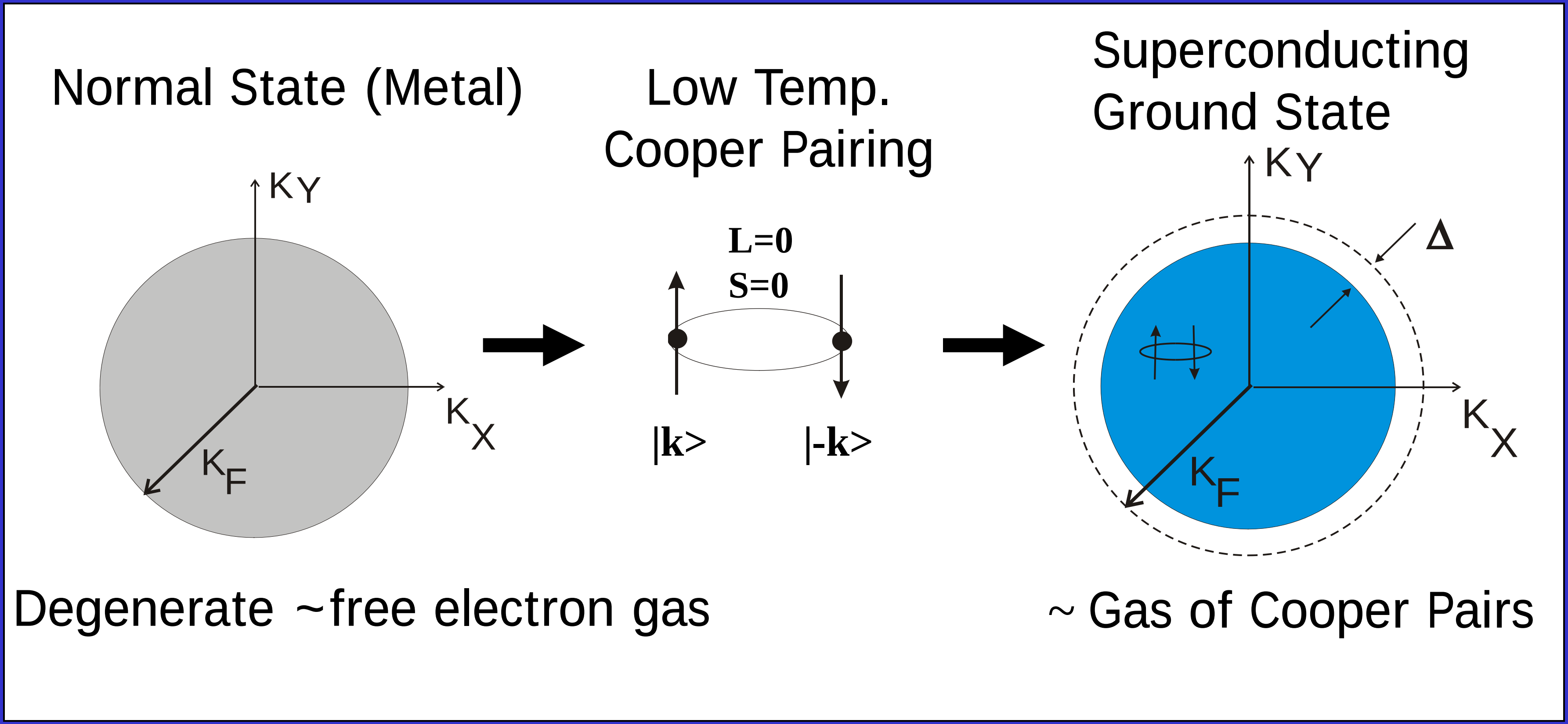
Normal State (Metal)

Low Temp.
Cooper Pairing

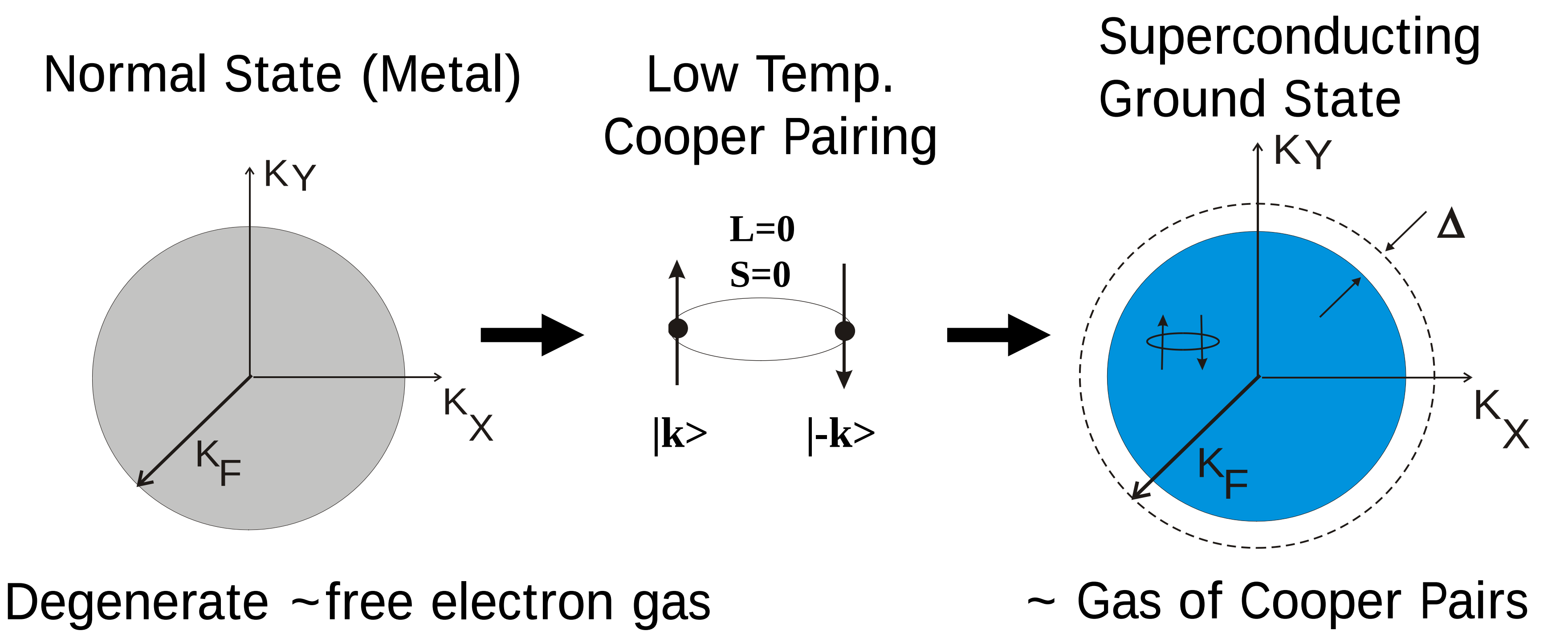


Degenerate ~free electron gas

SC Ground State



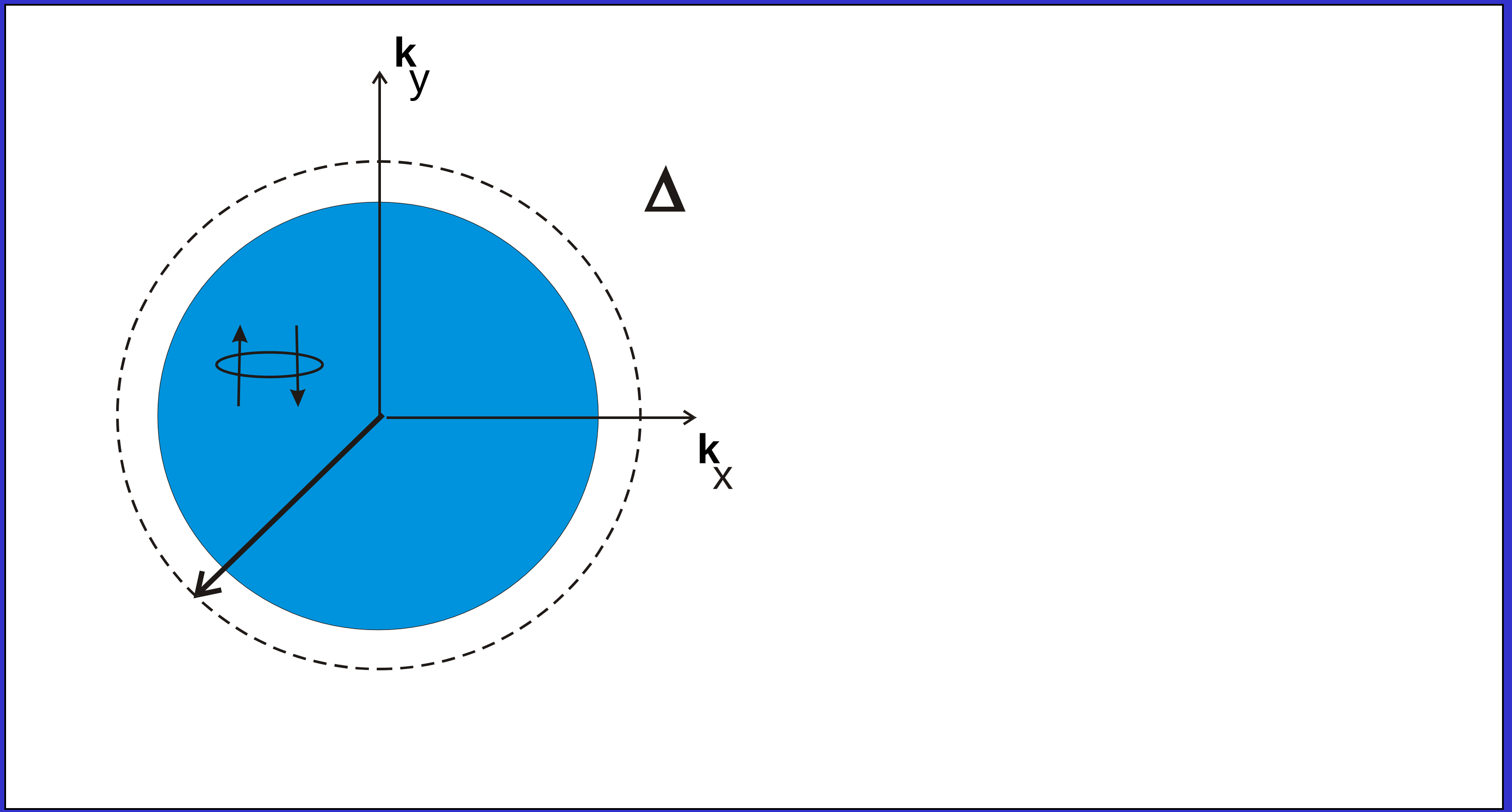
SC Ground State



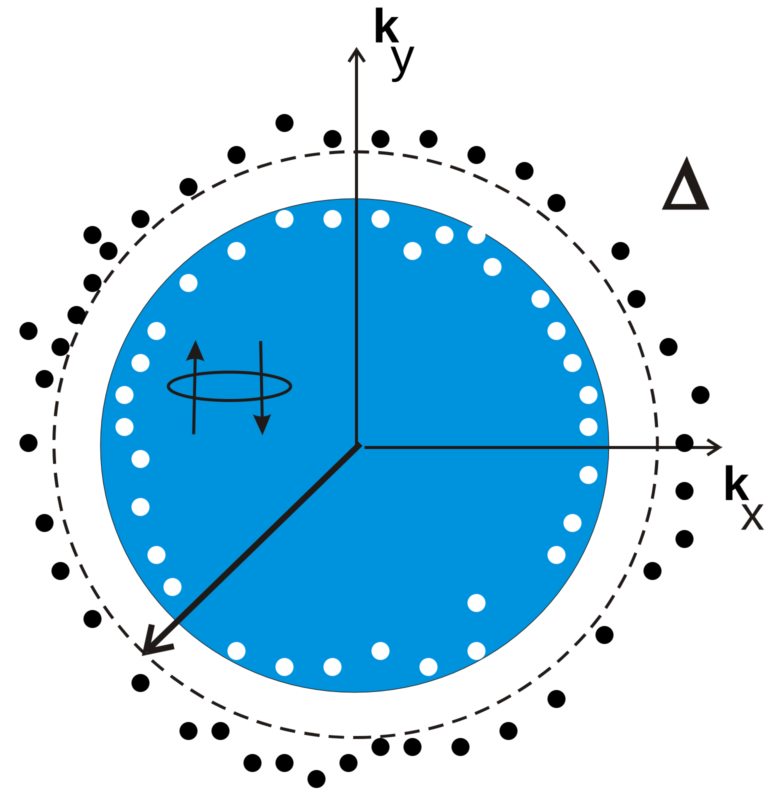
Macro. Quantum State $\Psi_{BCS} = \prod_k \left(u_k + v_k c^*_{k\uparrow} c^*_{-k\downarrow} \right) | 0 >$

s-wave Ψ symmetry $\Psi \sim \Delta_0 e^{i\phi}$

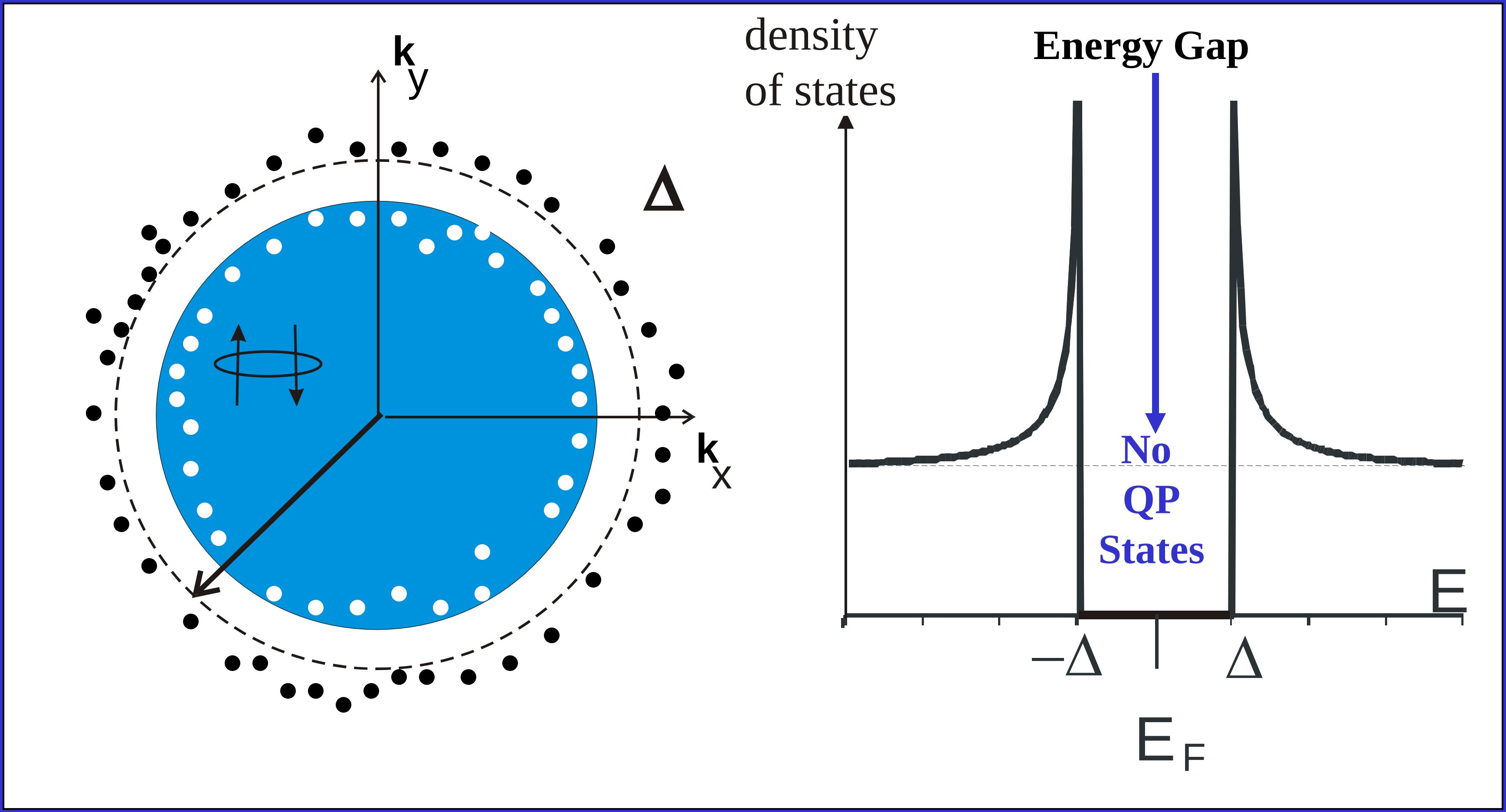
SC Ground State: Cooper Pairs



SC Excited States: Bogoliubov Quasiparticles

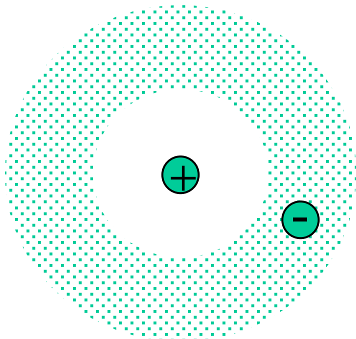


SC Excited States: Quasiparticles

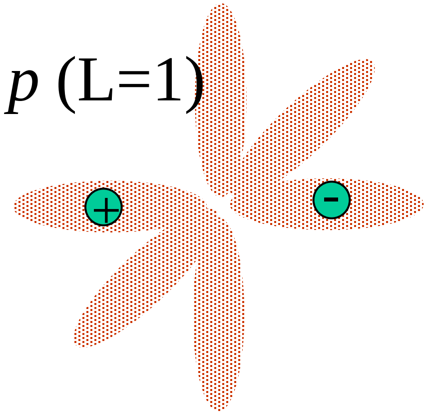


Study with quantum tunneling!

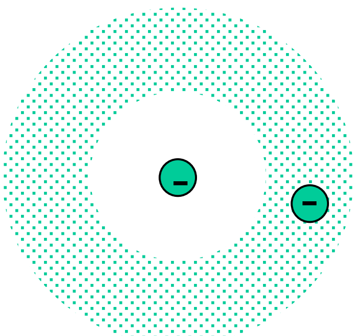
Types of 2-electron Cooper pair wavefunctions

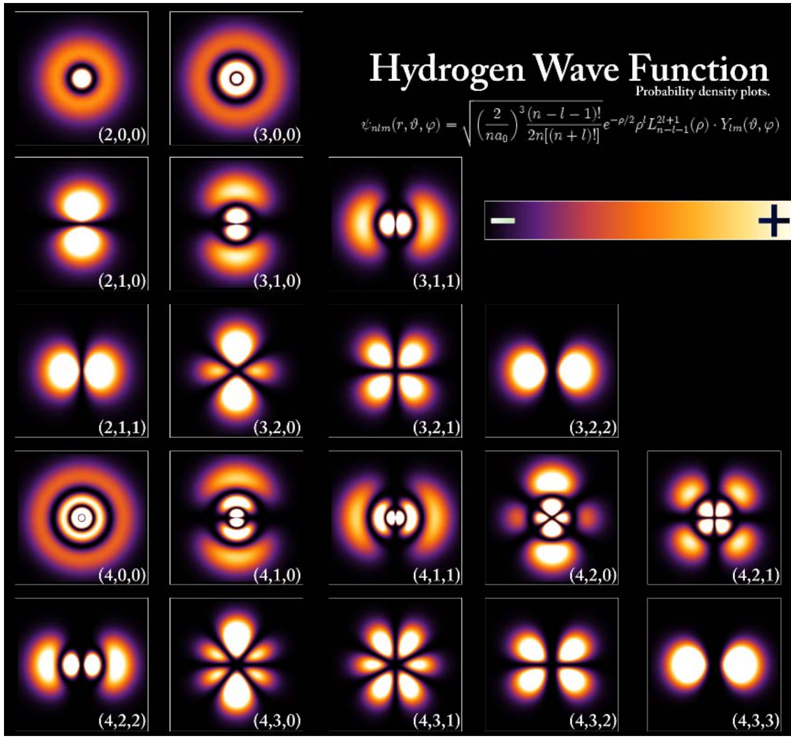


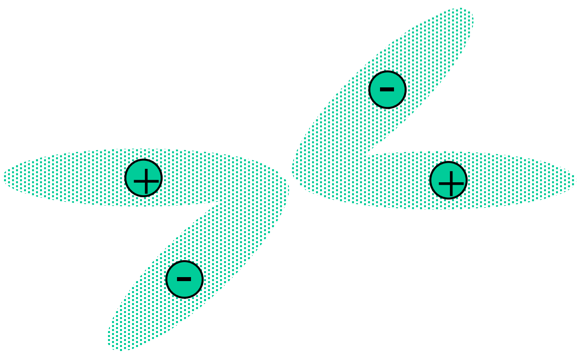
Type *p* (L=1)



Type *s* (L=0)



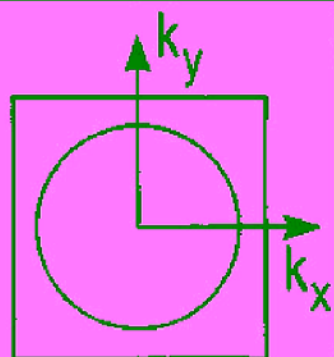
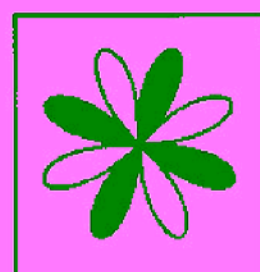
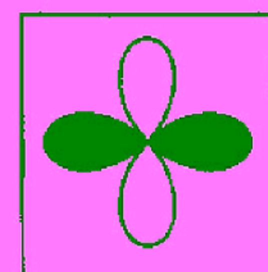
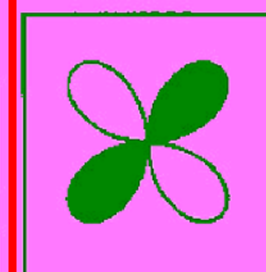




Type *d* (L=2)

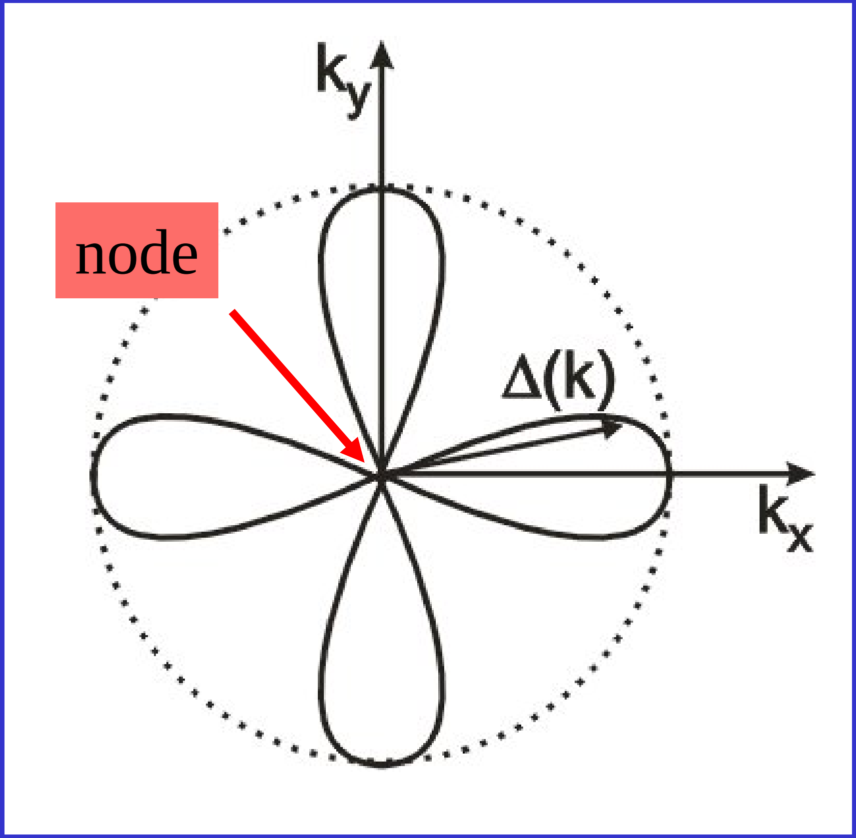
These wave functions for 2 electrons have shapes similar to atomic 1-electron wavefunctions (see Hydrogen atom)

Unconventional Superconductors

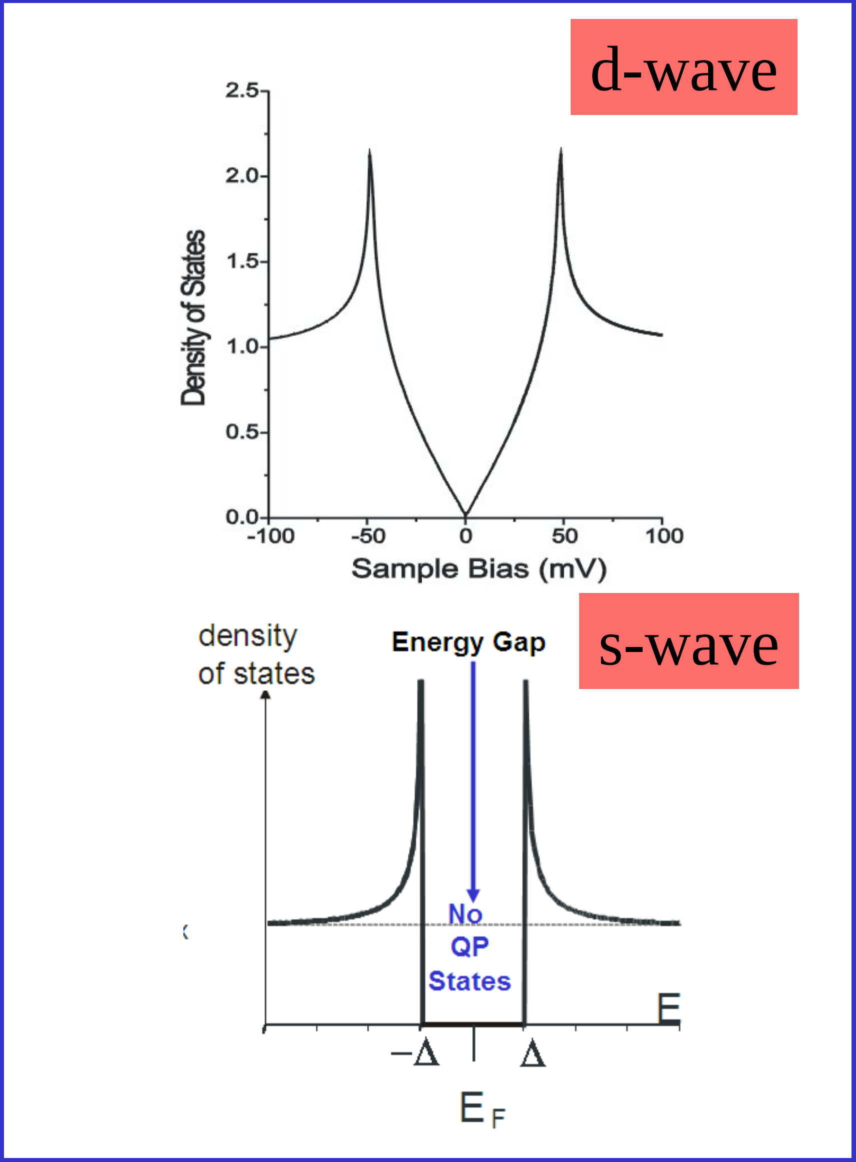
Group-theoretic notation	A_{1g}	A_{2g}	B_{1g}	B_{2g}
Order parameter basis function	constant	$xy(x^2-y^2)$	x^2-y^2	xy
Wave function name	s-wave	g	$d_{x^2-y^2}$	d_{xy}
Schematic representation of $\Delta(k)$ in B.Z.				

Cuprates

density of states for a $d_{x^2-y^2}$ Superconductor



Gap magnitude vs. k



Potential applications of HTS: power transmission

US:

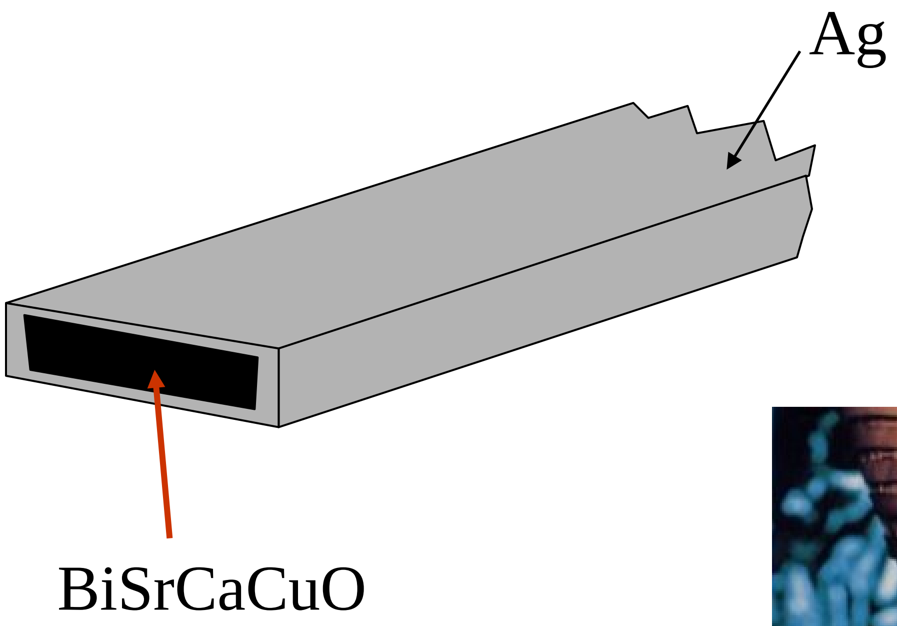
Energy transported in powerlines per year: ~ $3*10^{12}$ kWh

Use of high-T_c cables and transformers:

- reduction of transmission and distribution losses: ~ $6*10^{10}$ kWh / year
- emissions avoided: 100 000 t NO_x
  200 000 t SO_x
  30 000 000 t CO_2

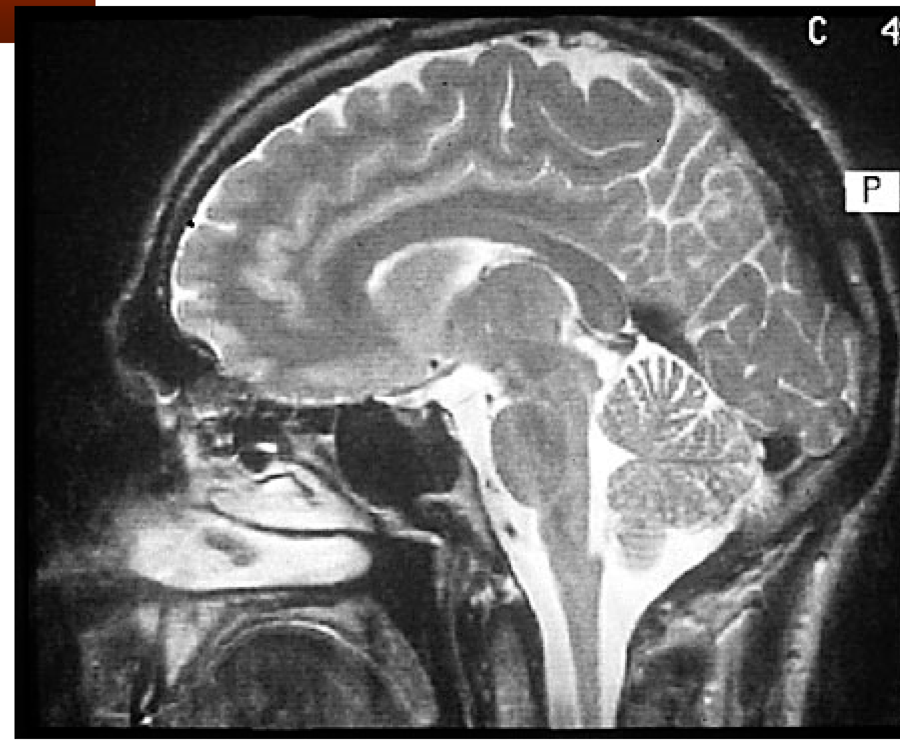
R. D. Blaughter, Research and Innovation, Siemens, Vol. 1/ 98, March 1998

transmission lines



MAGLEV

Magnetic resonance imaging (MRI)



Research:

1) higher fields
2) detection of weak fields (SQUID)

Conclusions

Challenges for superconductivity physics:

- find materials with T_c>200K, then room T!
- make devices, wires for power transmission and magnets
- Hirschfeld group:

understand how the #$!@%$! things work!

Superconductivity in the popular imagination c. 1987

Television show, “MacGyver”