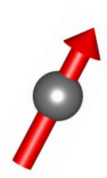
Mind the gap: microscopic theory

e-ph coupling, Cooper pairs

photoemission
and microwave spectroscopy

John Bardeen



by Alexander Tsirlin, Leipzig University

Lecture 10: June 13, 2024

- **1915, John Thompson:** fluctuating electric dipole chains
- **1921, Kammerlingh Onnes:** superconducting filaments
- **1922, Einstein:** molecular conduction chains
- **1932, Bohr and Kronig:** coherent motion of electron lattice
- **1932, Brillouin:** local maxima of band dispersion
- **1933, Bloch and Landau:** electric current as order parameter

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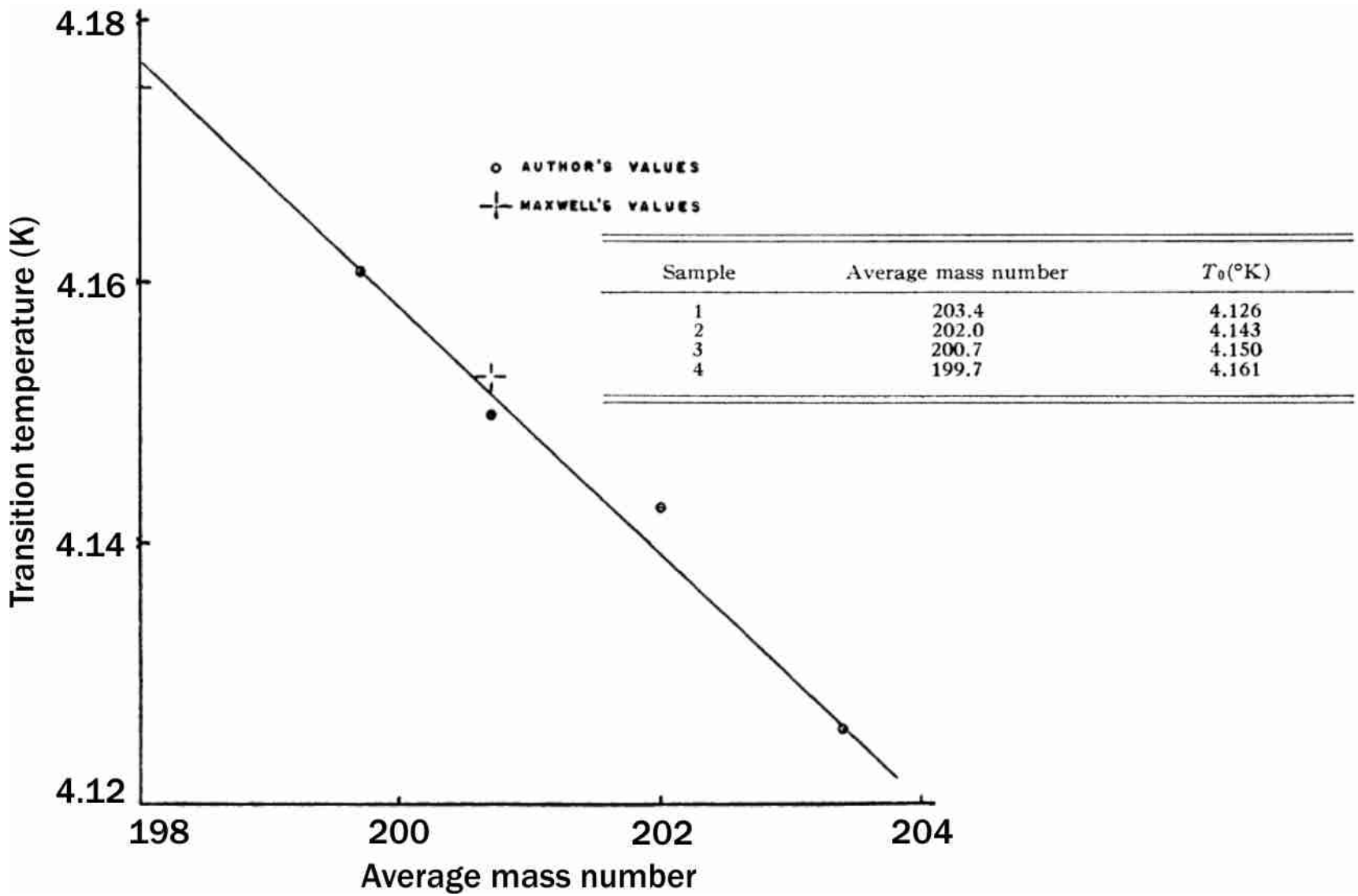
First Bloch's theorem: in the absence of a magnetic field the most stable state of an electron system is that of zero current

Second Bloch's theorem:
any theory of superconductivity can be refuted



Sample	Average mass number	T_0(°K)
1	203.4	4.126
2	202.0	4.143
3	200.7	4.150
4	199.7	4.161

Phys. Rev. 78, 487 (1950)

Herbert Fröhlich (1905–1991)

Theory of metals, theory of dielectrics,
theory of coherent excitations in biological systems

Proposed electron-phonon coupling
as the driving force of superconductivity (1950)

This article will be of interest, I hope, to the non-specialist. It addresses itself, however, also to specialists, in particular to those who excel in the use of a single technique such that their understanding has the form of a δ-function. There is hope that some of them might realize that a calculation should be preceded by an idea.

H. Fröhlich, Rep. Prog. Phys. 24, 1 (1961)

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With Fröhlich's work and the observed isotope effect, everyone (or nearly everyone) suddenly realized that here was the answer, it was like the sudden acceptance of quantum mechanics in 1925-26, when within a year papers could begin "In quantum mechanics" this or that occurs.

Sir Neville Mott

Leon Cooper
born 1930

Postdoc of John Bardeen,
1972 Nobel prize in physics

Later worked on brain networks

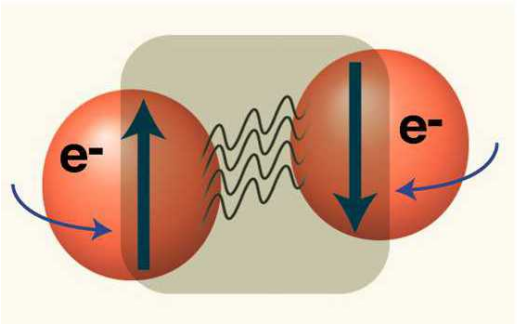
Bound Electron Pairs in a Degenerate Fermi Gas*

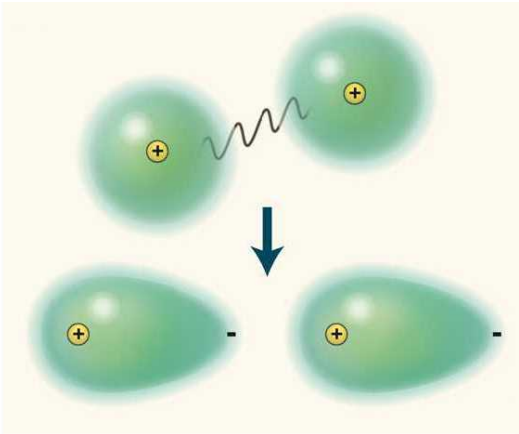
LEON N. COOPER

Physics Department, University of Illinois, Urbana, Illinois

(Received September 21, 1956)

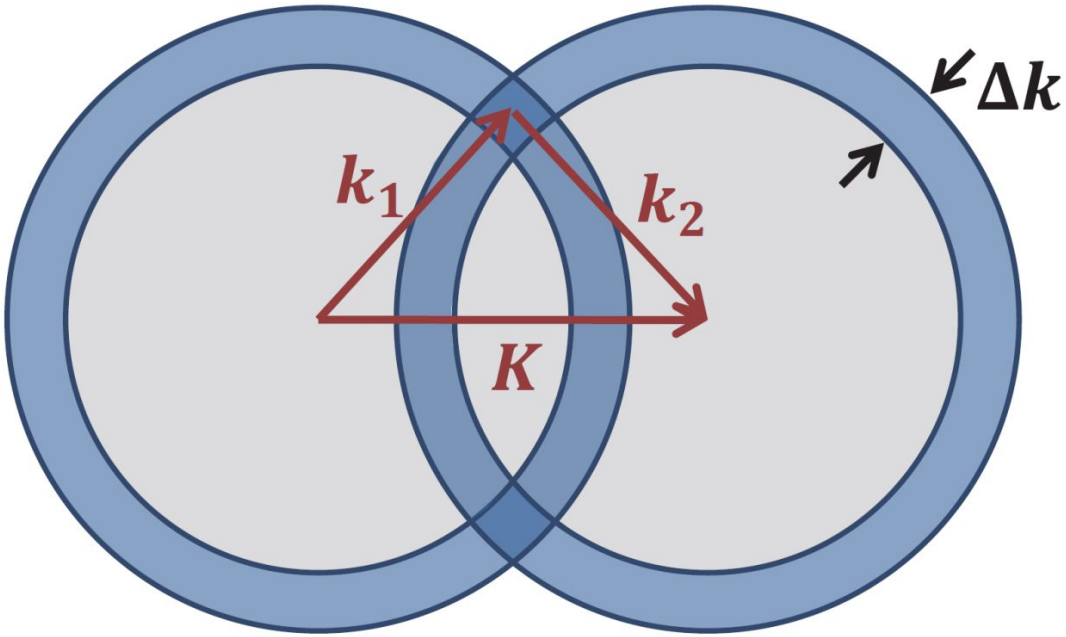
Phys. Rev. 104, 1189 (1956)



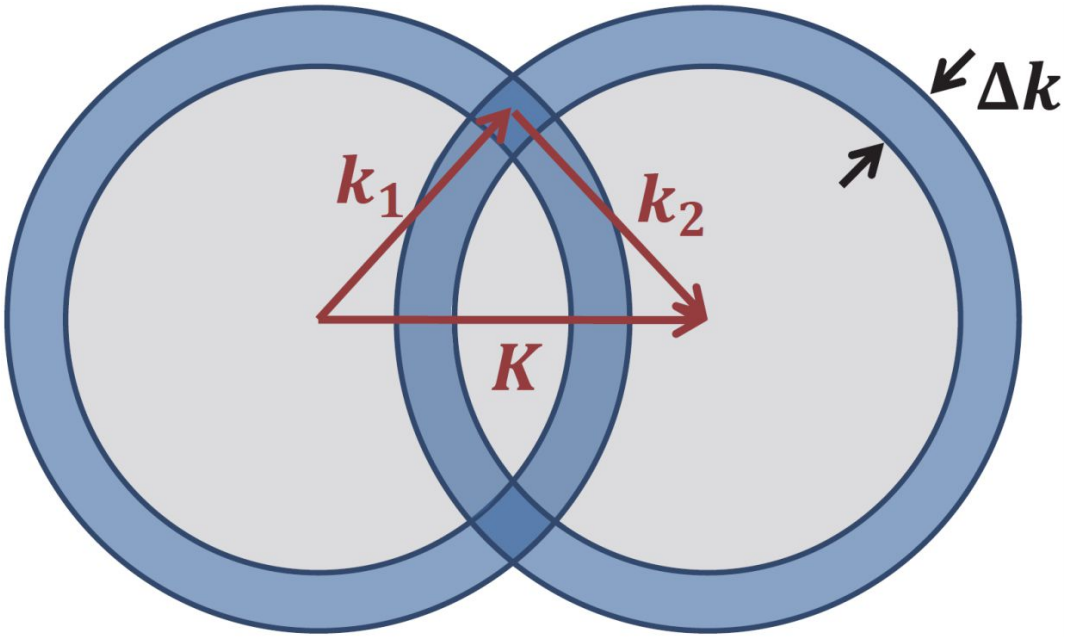


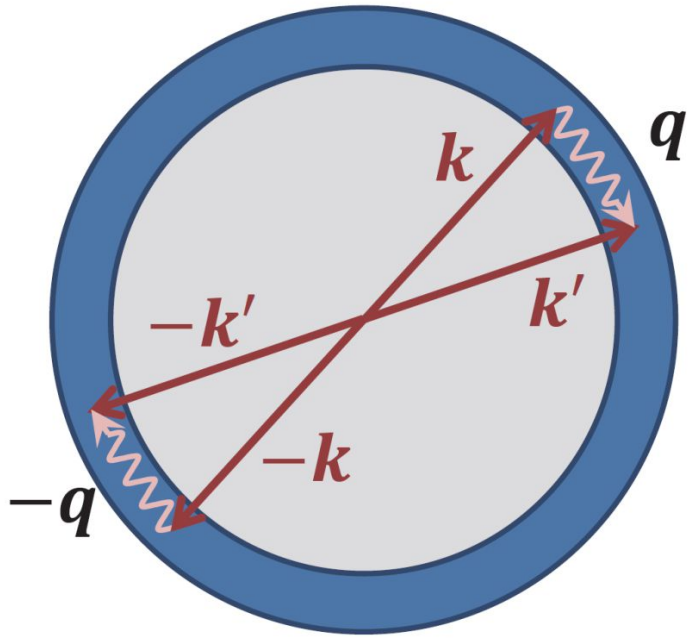
Science 332, 200 (2011)

Formation of Cooper pairs



Gross and Marx, Festkörperphysik





Best pairing is achieved when the spheres overlap: $\mathbf{K} = \mathbf{k}_1 + \mathbf{k}_2 = 0$

Gross and Marx, Festkörperphysik

Personality

John Bardeen

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1908–1991

- 1923–29: studied electrical engineering at the University of Wisconsin-Madison
- 1930–33: work for Gulf Research Laboratories
- 1933–36: PhD in mathematical physics from Princeton
- 1941–44: military work for the Naval Ordnance Lab
- 1945–51: work at Bell Labs

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1956 Nobel prize in physics
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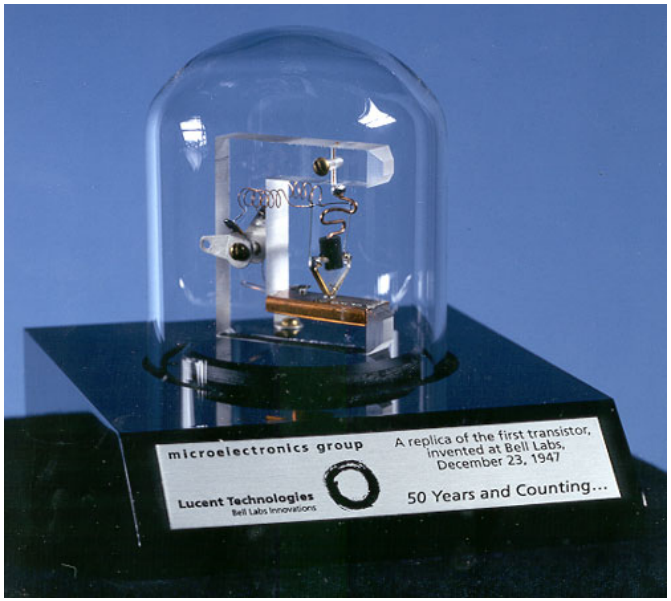

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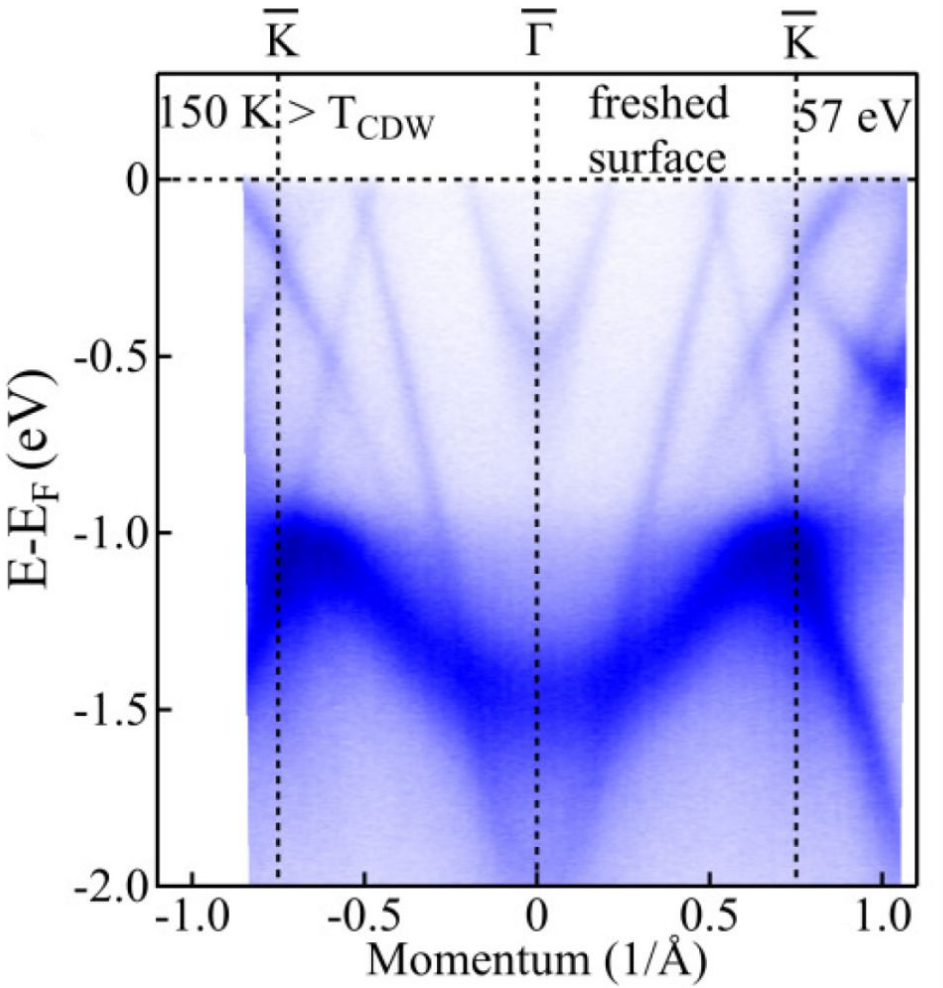
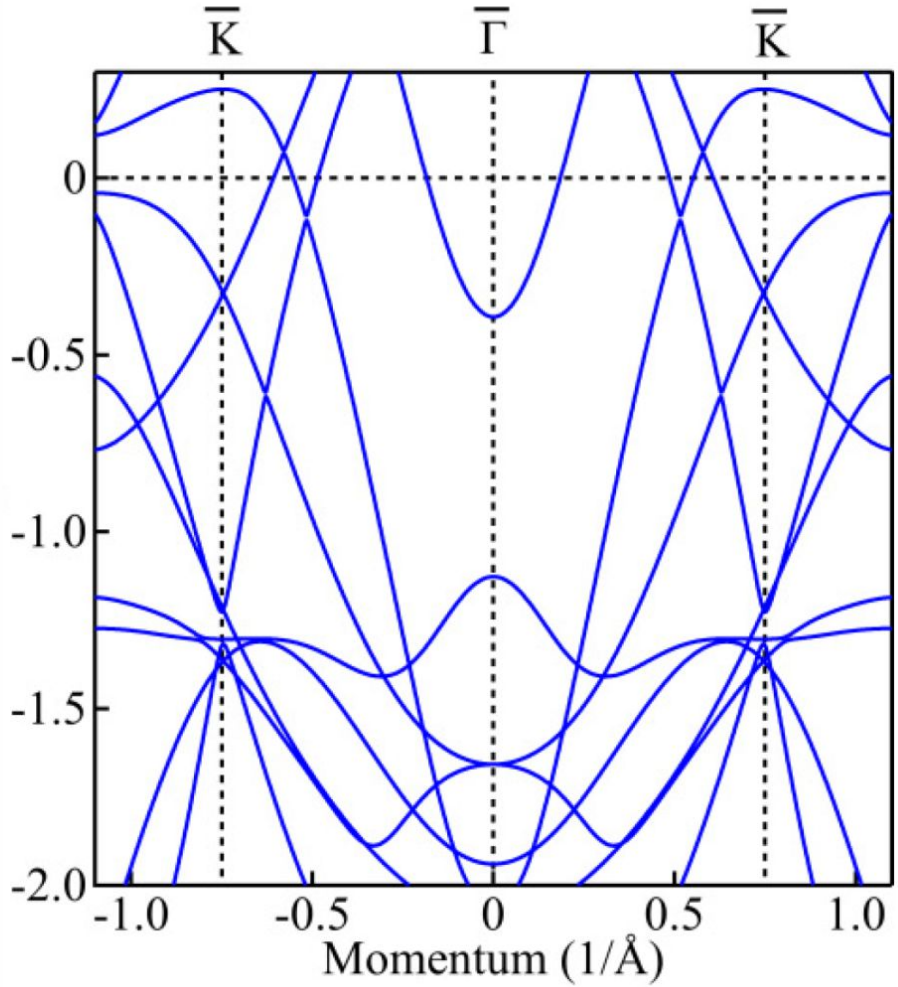
Experiment

microwave and photoemission spectroscopy

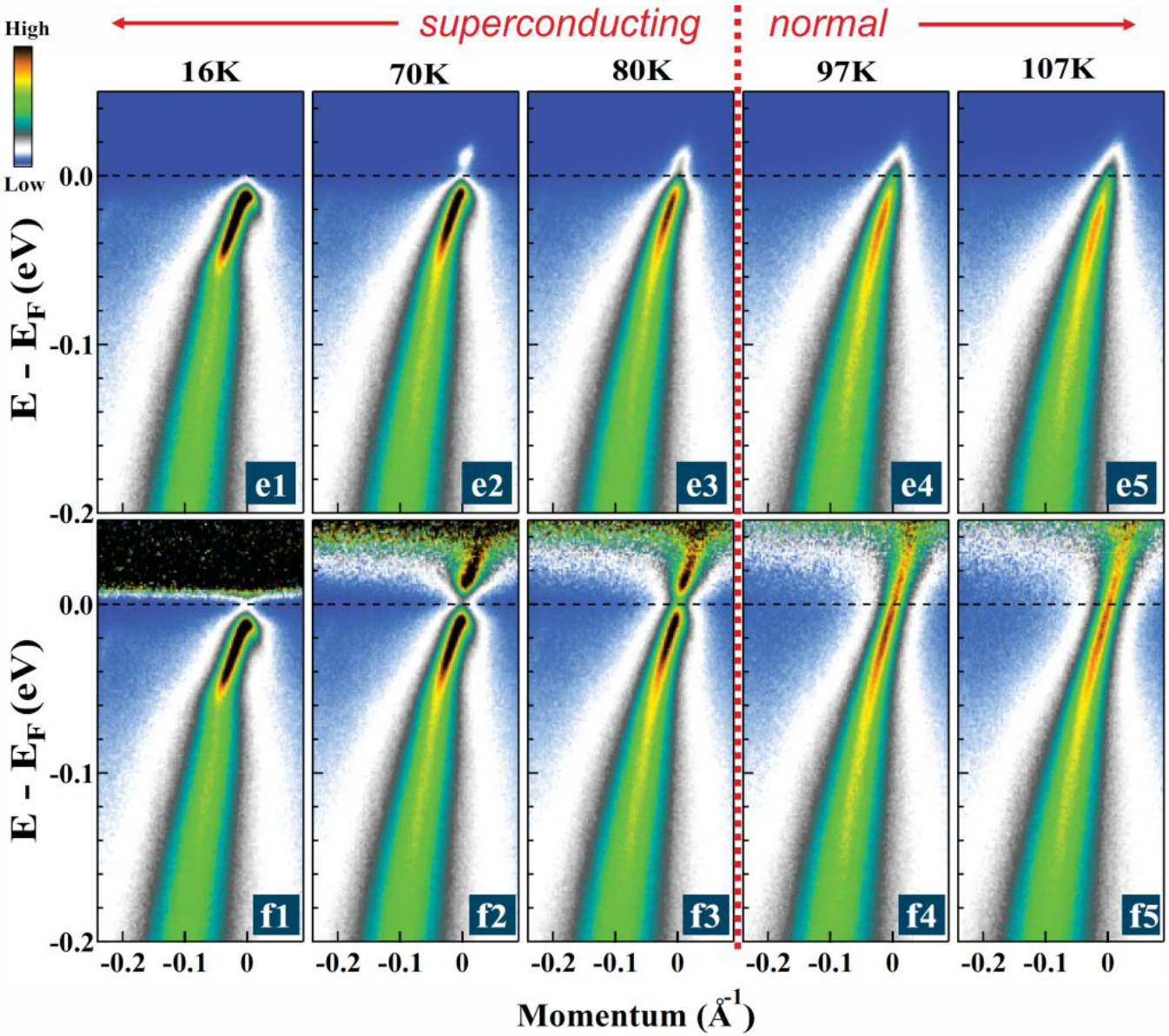
experiment

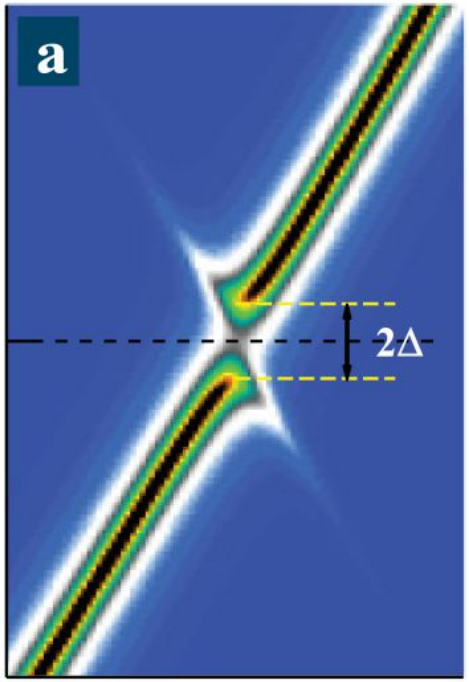


calculation



Phys. Rev. Research 4, 033072 (2022)





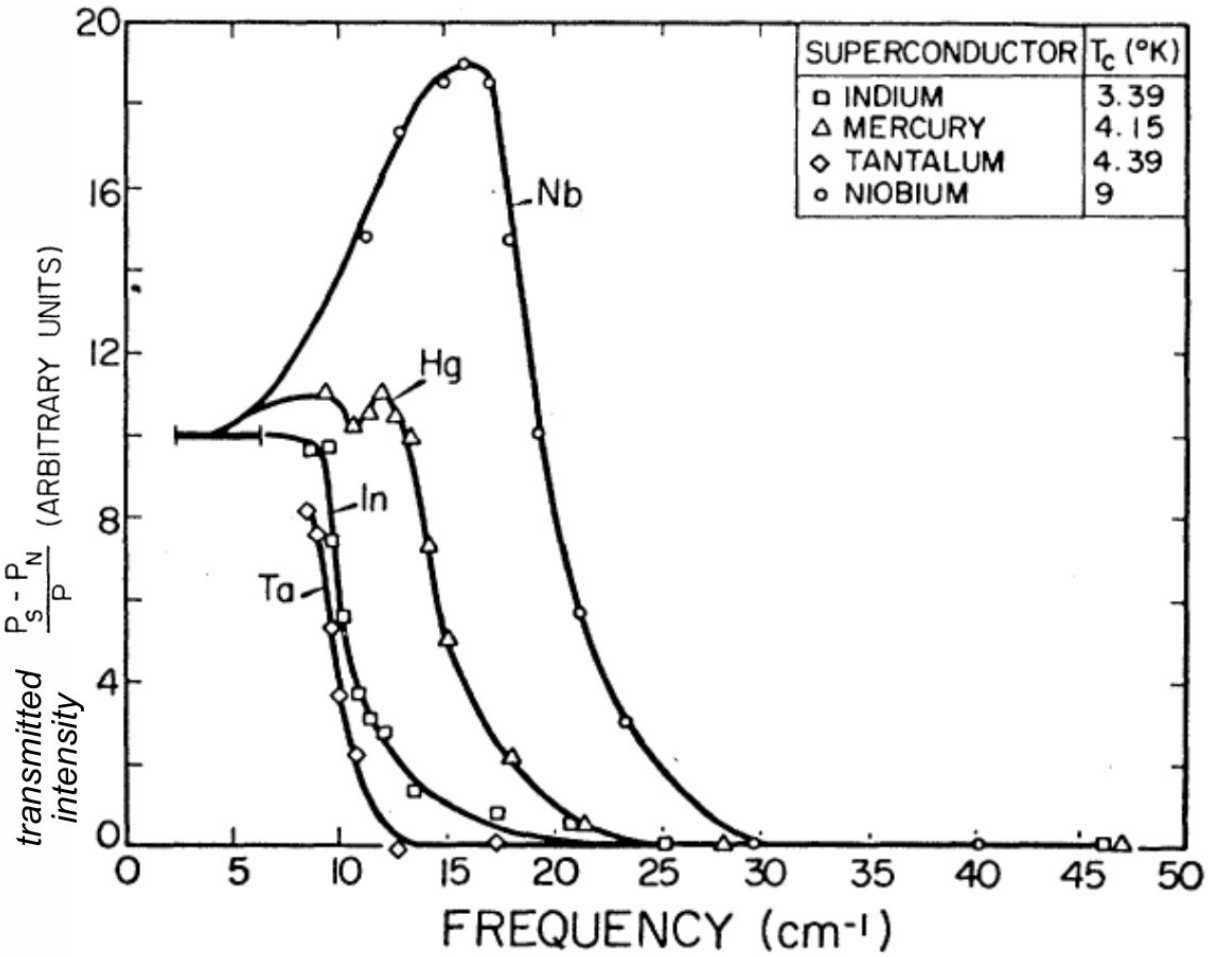
$Bi_2Sr_2CaCu_2O_8$
(BSCCO)

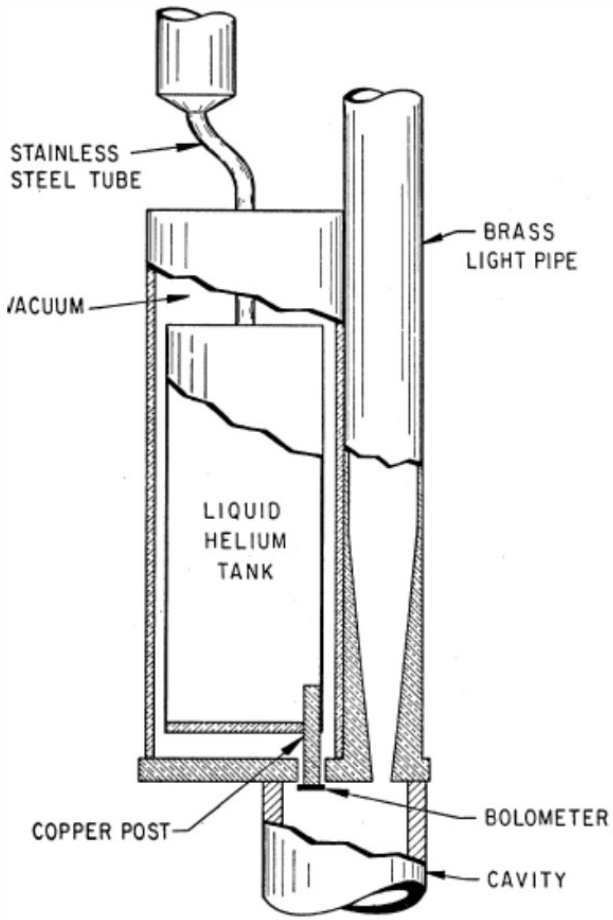
$T_c = 89\,\mathrm{K}$

Phys. Rev. B 85, 064514 (2011)

Microwave spectroscopy

Phys. Rev. 119, 575 (1960)





Gap energies: $0.1 - 10\,\mathrm{meV}$

$(10 - 1000\,\mathrm{GHz})$