SUPERCONDUCTIVITY, BCS-THEORY

Photo from the Nobel Foundation archive.

John Bardeen

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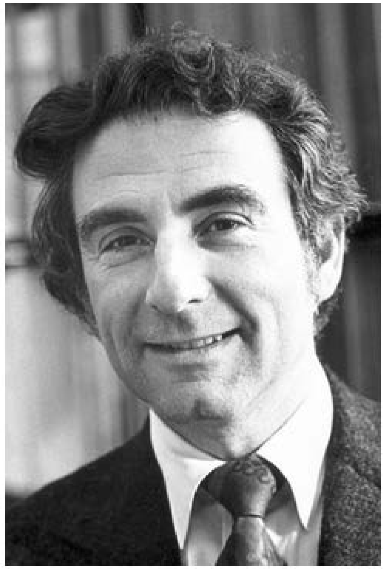

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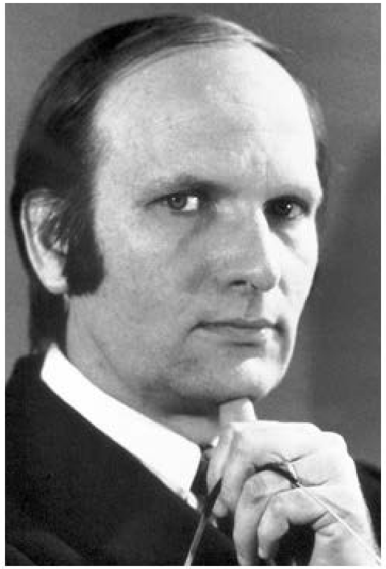

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John Robert Schrieffer

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Shablenko Volodymyr

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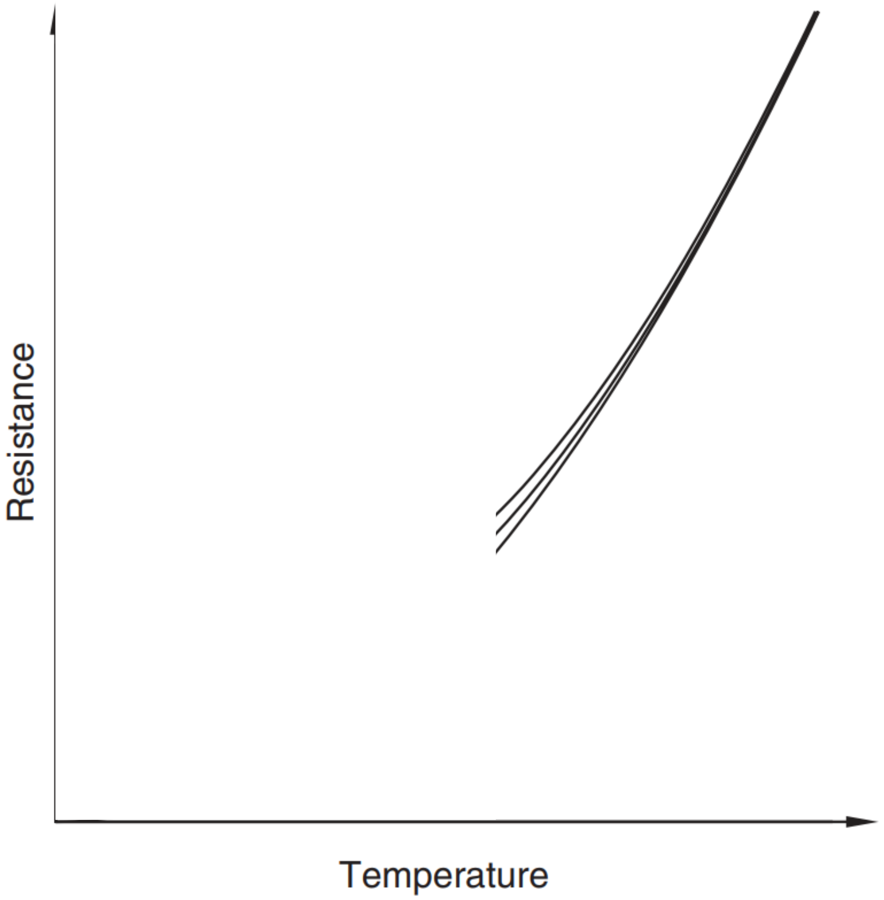
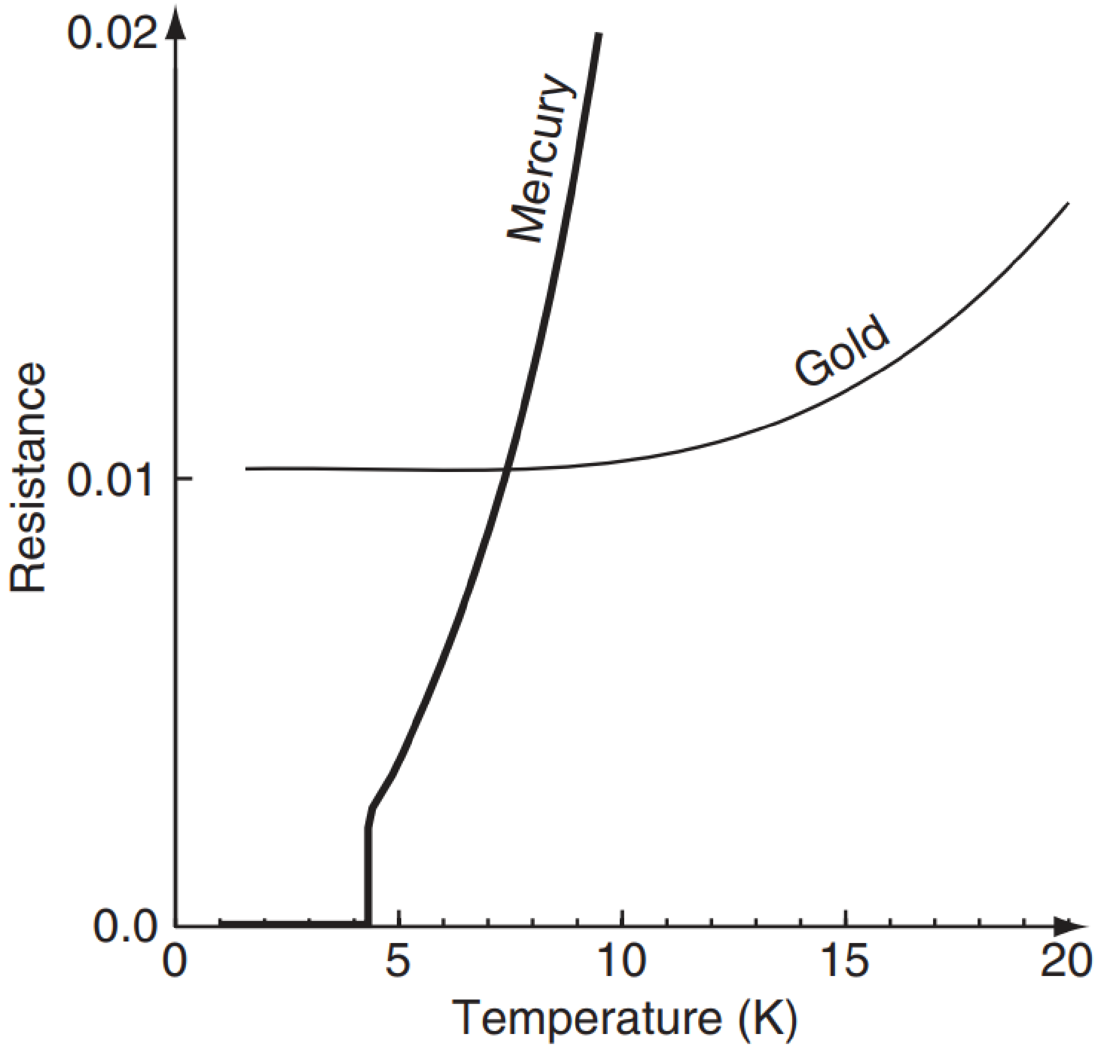
Resistance

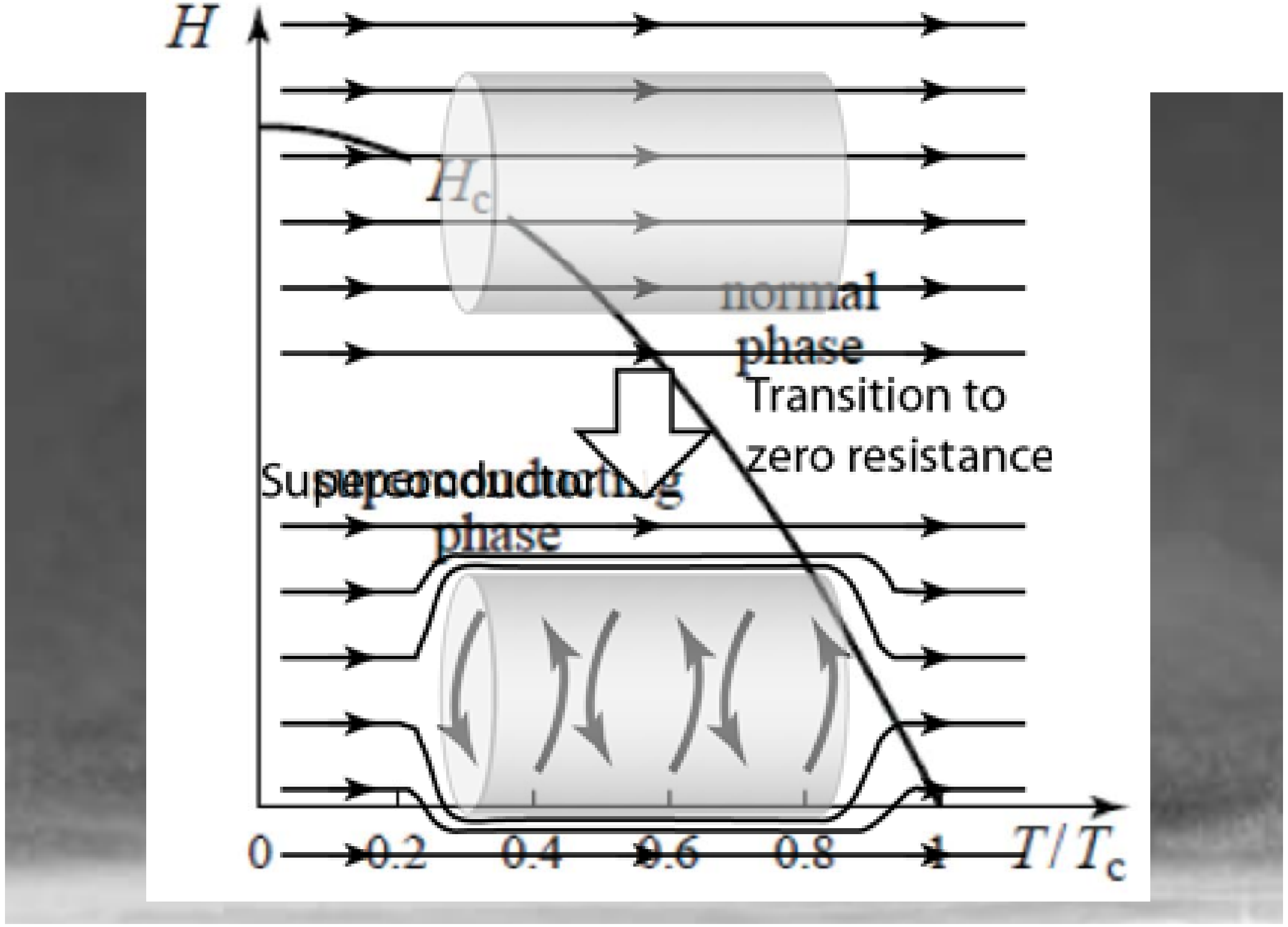


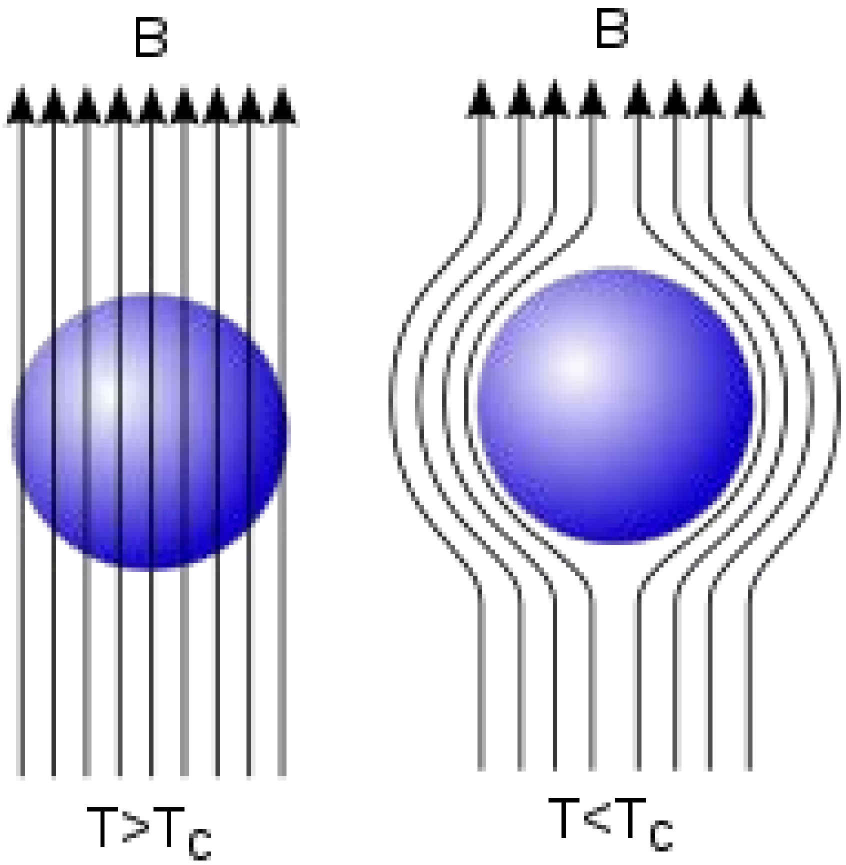
Resistance
Temperature



0.02
0.01
0.0
Resistance
Mercury
Gold
0
5
10
15
20
Temperature (K)

Magnetic Field

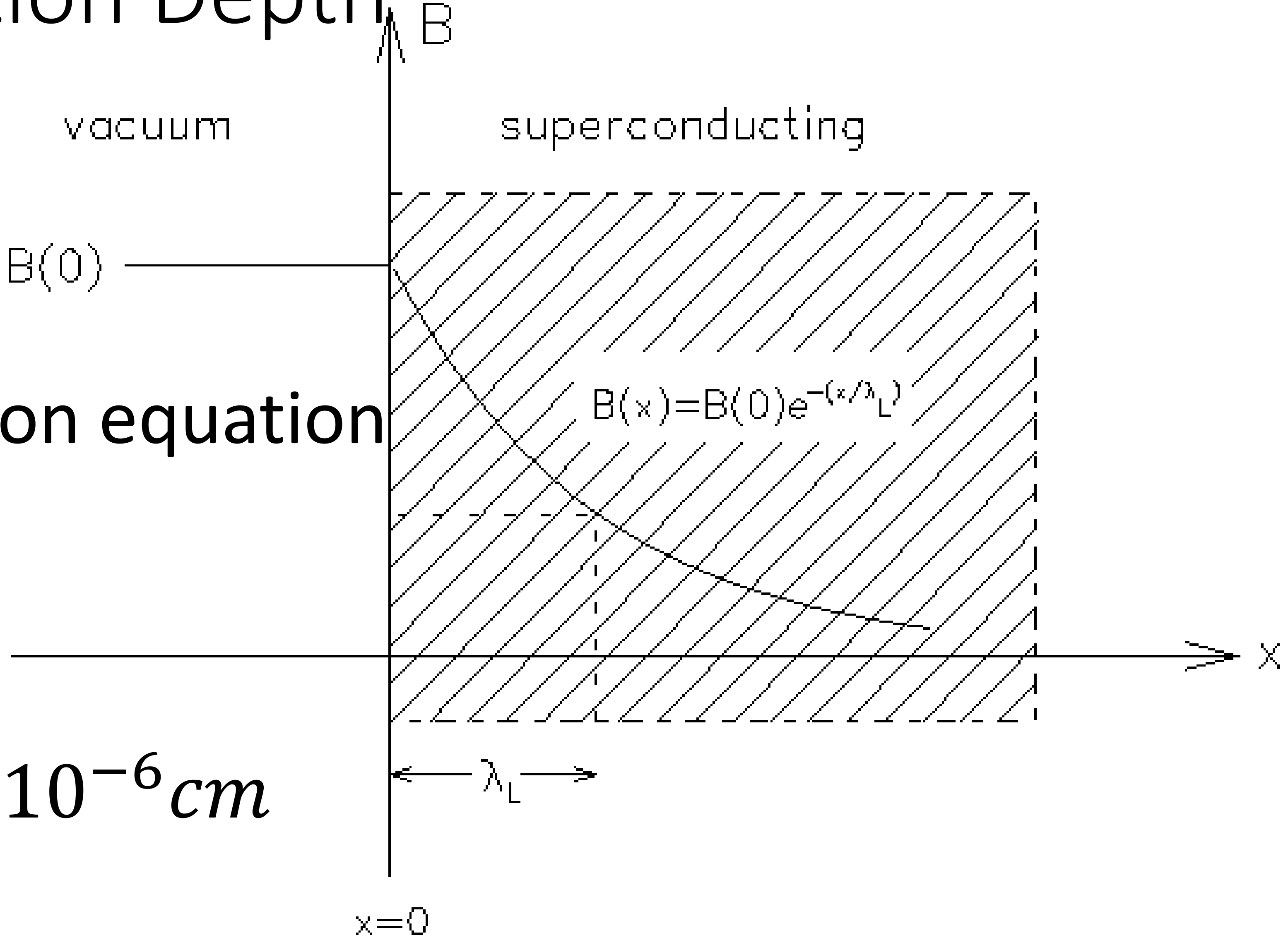




London Penetration Depth

Two fluid model:

- $q = q_s + q_n$
- $j_s = -\frac{1}{\Lambda c} A$ – London equation
- $\Lambda = {}^{m}/_{q_s e^2}$
- $\nabla \cdot A = 0$
- $\lambda_L = \sqrt{\Lambda c^2 / 4\pi} \approx 10^{-6} cm$

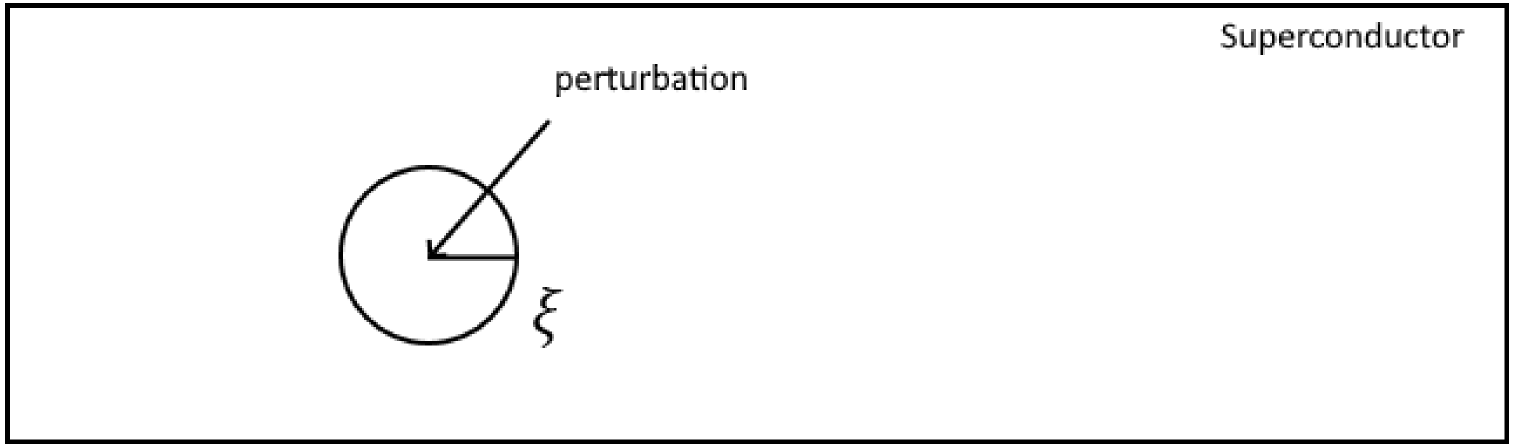


Quantum Mechanical Description

- Wavefunction of the superconducting state is unchanged by presence of an external magnetic field
- $\frac{q_s(r)}{q_n} = |\psi(r)|^2$
- ΔF – free energy difference between the superconducting and normal states
- $\Delta F = \int \left\{ \frac{\hbar^2}{2\bar{m}} \left| \left(\nabla + \frac{\bar{e}}{c} A(r) \right) \psi(r) \right|^2 - a(T)|\psi(r)|^2 + \frac{b(T)}{2} |\psi(r)|^4 \right\} d^3r$
- $a(T_c) = 0$
- $\Delta F \sim 10^{-8} eV$

Quasi-Particle Description

- Coherence length: perturbation of the superconductor at a point influences the superfluid within this length
- $\xi = a\frac{\hbar v_F}{kT_c} \sim 10^{-4} cm$



articular
ations Φ_n

The Pairing Concept

- $\Psi_0 = \sum_n a_n \Phi_n$
- $E_0 = (\Psi_0, H\psi_0) = \sum_{n,n'} a_{n'}^* a_n (\Phi_{n'}, H\Phi_n)$
- Pair binding energy:

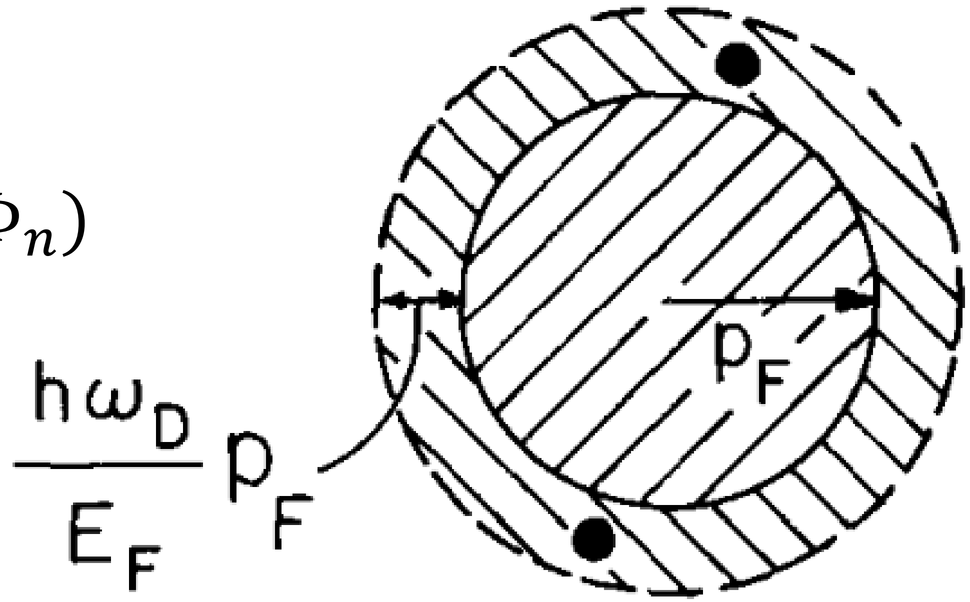
$$E_B \cong \hbar\omega_D Exp[-\frac{2}{N(0)V}]$$

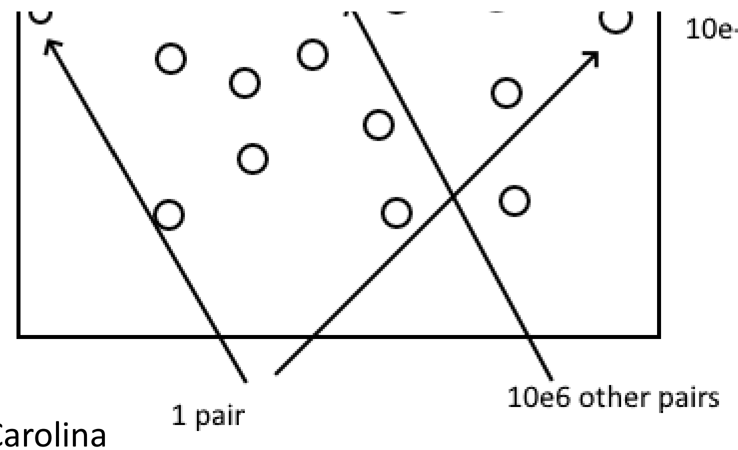
- Reduced Hamiltonian:

$$H_{red} = \sum_{ks} \varepsilon_k n_{ks} - \sum_{kk'} V_{k'k} b_{k'}^{+} b_k$$

1st term - energy of particles in pair

2nd term – pairing interaction





The Ground State

Ground state:

- $\Psi_0 = \pi(u_k + v_k b_k)|0>$, where $u_k = \sqrt{1 - v_k^2}$
- $v_k^2 = \frac{1}{2}[1 - \frac{\varepsilon_k - \mu}{E_k}]$
- $E_k = \sqrt{(\varepsilon_k - \mu)^2 + \Delta_k^2}$
- $\Delta_k = -\sum V_{k'k} \frac{\Delta_{k'}}{2E_{k'}}$ - energy gap equation
- $\Delta = \hbar\omega_D Exp[-\frac{1}{N(0)V}]$ and $\Delta F = \frac{1}{2} N(0)\Delta^2$

$$V_{k'k} = \begin{cases} V, |\varepsilon_k - \mu| < \hbar\omega_D \; and |\varepsilon_{k'} - \mu| < \hbar\omega_D \\ 0, otherwise \end{cases}$$

References

- J.R. Schrieffer. Macroscopic quantum phenomena from pairing in superconductors, Nobel Lecture, University of Pennsylvania, December 11,1972
- S. Blundell. Superconductivity: A very short introduction, Oxford, 2009
- The Nobel Prize in Physics 1972. NobelPrize.org. Nobel Media AB 2021. Wed. 17 Feb 2021. https://www.nobelprize.org/prizes/physics/1972/summary/