PHYS 403

Final Oral Presentation (120 pts)

Name: _____________ Eric Yu __________________

CRITERIA	Eugene	Alexey
Abstract is well-written and on time **(20)**	20	20
Attended both days **(6)**	6	6
First slide has appropriate title, name, affiliation, date **(4)**	4	4
Scientific background, goal and motivation were clearly and correctly presented **(20)**	19	19
Research activities were clearly and correctly presented **(20)**	20	20
Results were clearly and correctly presented **(20)**	20	20
Technical aspects: good balance of text and figures, good quality figures, appropriate citations, correct spelling, correct number of significant digits, etc. **(20)**	20	20
Time management: good balance between Introduction-Procedure-Results-Analysis, finished on time **(5)**	5	5
Spoke clearly, at a good pace, loud enough, etc. **(2)**	2	2
Answered questions clearly and correctly **(3)**	3	3
Final Totals **(120)**	119	119

119

1. You say that the results are far from the expected, yet the fits appear in excellent agreement with data.

See a few comment in text. The report is good. (ec)

O2-3

Determining the gap value of superconducting tin using electron tunneling

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The gap 2Δ of allowed energies at the Fermi level is fundamental to the superconducting state and determines many properties of a specific superconductor [1]. One way of experimentally measuring the gap value 2Δ is by measuring the tunneling current between a superconductor and a normal conductor separated by a thin insulating film. When a voltage is applied across the superconductor/insulator/normal-conductor junction, electrons will tunnel across the insulating film. However, for voltages within the energy gap electrons will not tunnel because those energies are forbidden states as shown in Fig. 1(a) [3].

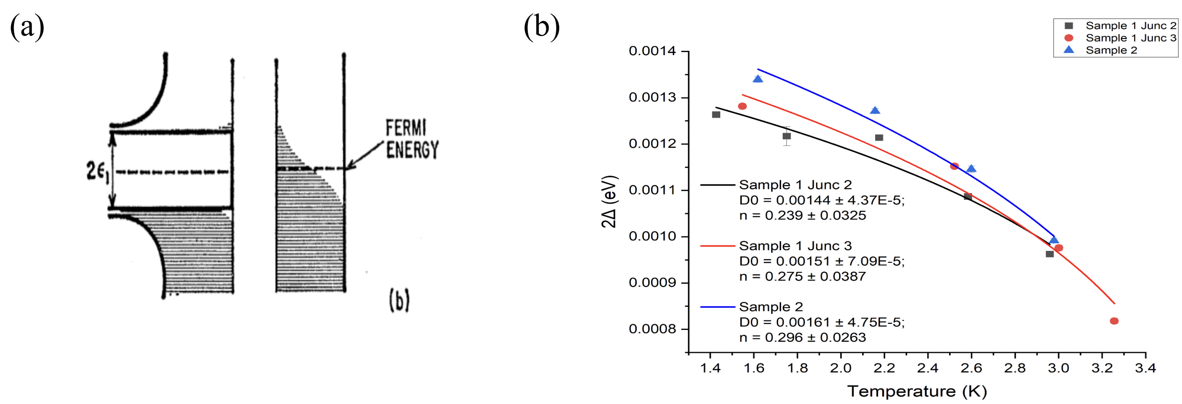
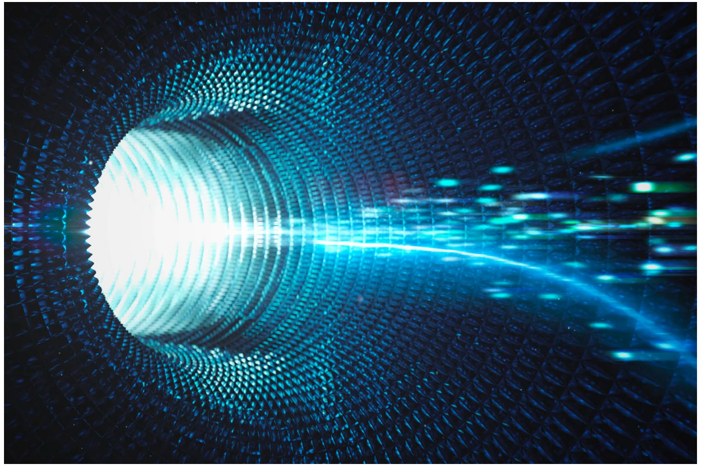


Fig. 1

We measured the gap values of superconducting tin at different temperatures below the critical temperature (3.722 K) using tin/aluminum-oxide/aluminum junctions. To determine the gap value 2Δ, recorded data is fit to an expression derived from BCS theory [2] that gives the first derivative of tunneling current with respect to applied voltage in terms of Δ and the applied voltage. The values of 2Δ for three different junctions at different temperatures are shown in Fig. 1(b). All three junctions roughly agree as they should since we are measuring 2Δ for tin. The data points are fit to a BCS relationship between Δ and temperature for temperatures near the critical temperature. The values of Δ_0 (D0) and n differ from their expected values of $\Delta_0 = 0.00103$ and n = 0.5 because the limiting case that the BCS relationship holds for does not apply to the temperature range over which we are fitting.

1. T. Kita, D. Akasako, and H. Murakami. Gap Value Determinations on the Tunneling Spectrum. *Advances in Superconductivity VII* (1995). doi:10.1007/978-4-431-68535-7_10
2. J. Bardeen, L. N. Cooper, and J. R. Schrieffer. Theory of Superconductivity. *Physical Review* ***108**, 1175* (1957). doi:10.1103/PhysRev.108.1175
3. I. Giaever and K. Megerle. Study of Superconductors by Electron Tunneling. *Physical Review Letters* (1961). doi:10.1103/PhysRev.122.1101

Determining the gap value of superconducting tin using electron tunneling



A quantum tunnel
Courtesy scientificamerican.com

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March 27, 2023

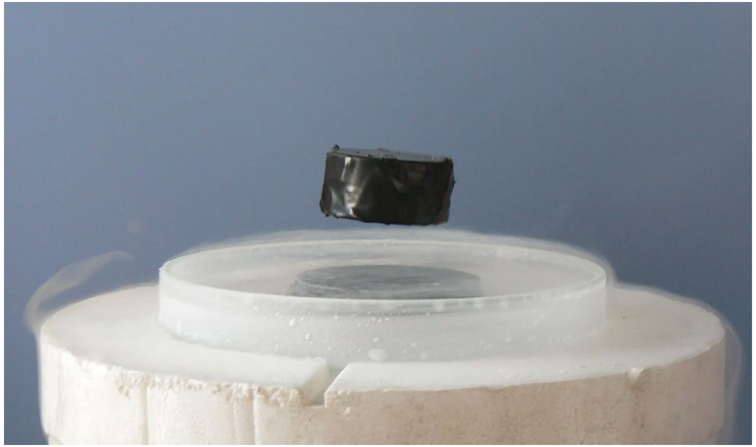
The energy gap 2Δ in superconductors

Gap 2Δ in energy distributions available to an electron.

In BCS, 2Δ is the energy required to create a Cooper pair.

2Δ is zero at T_C and reaches its maximum at 0 K.

Larger 2Δ means more energy needed to ‘break’ the superconducting state.

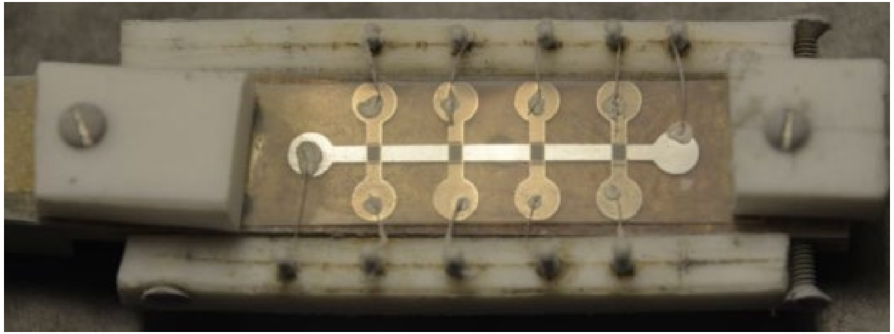


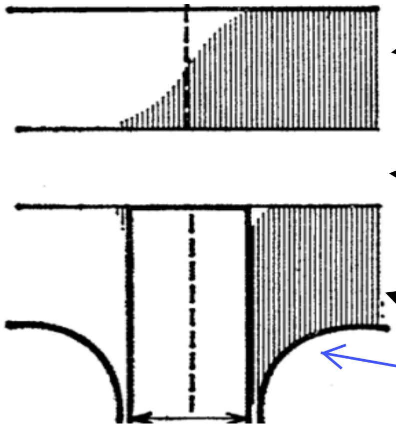
https://www.britannica.com/science/Meissner-effect

$Al/Al_2O_3/Sn$ sandwiches

<u>NIS</u> junctions:

- <u>N</u>ormal-conductor
- <u>I</u>nsulator (thin)
- <u>S</u>uperconductor





2Δ

NORMAL CONDUCTOR: Aluminum (Al) [Tc ≈ 1.2 K]

INSULATOR: Aluminum-oxide (Al_2O_3)

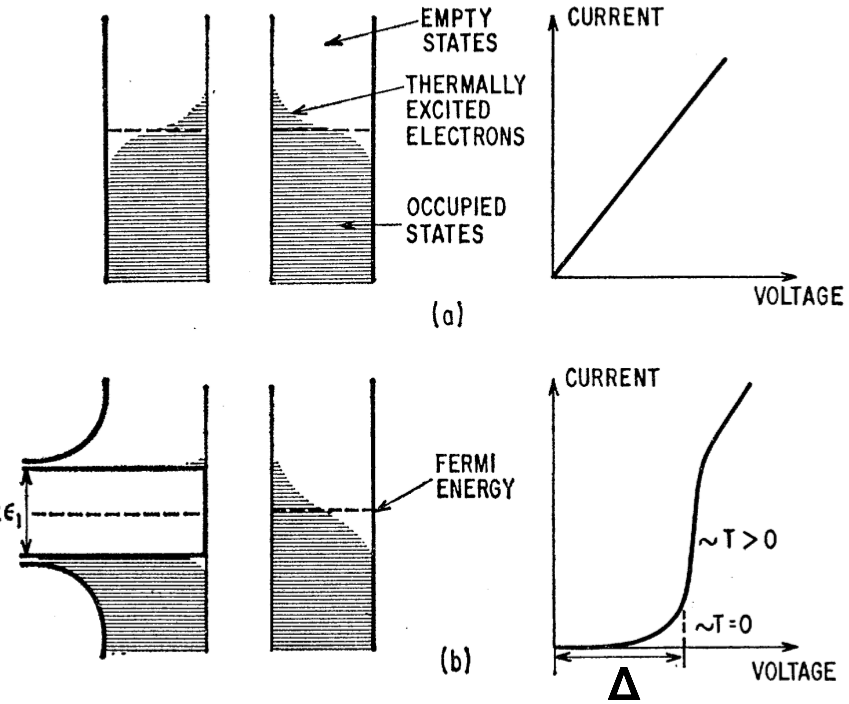
SUPERCONDUCTOR: Tin (Sn) [Tc ≈ 3.722 K]

preferable to rotate this diagram by 90^{o} cw

Tunneling current in NIS junctions

Energies **|eV| < Δ** are forbidden states in a superconductor.

Tunneling current in NIS deviates from **I = V/R** at the gap.



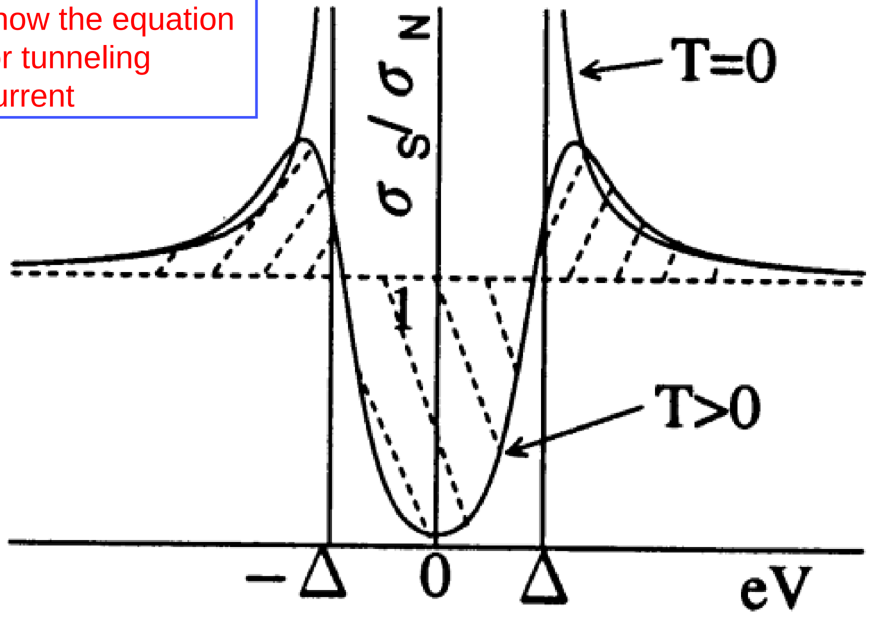
I. Giaever and K. Megerle. Study of Superconductors by Electron Tunneling. *Physical Review Letters* (1961).

According to BCS theory

The differential conductivity **dI/dV** of an NIS junction is proportional to the density of states for a superconductor, which in BCS is

would be useful to show the equation for tunneling current

$$\frac{dI}{dV} \propto \frac{|eV|}{\sqrt{(eV)^2 - \Delta^2}}$$

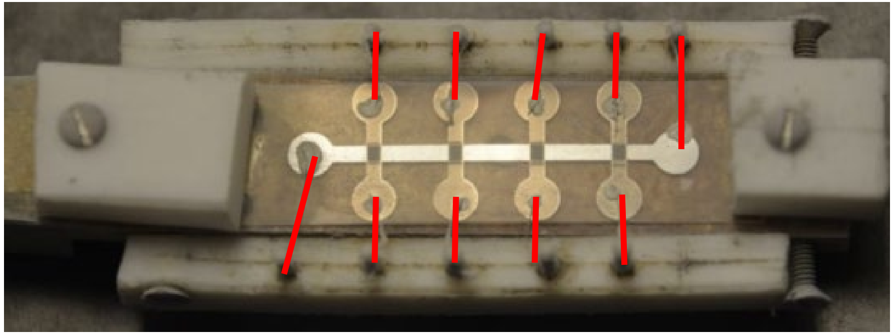


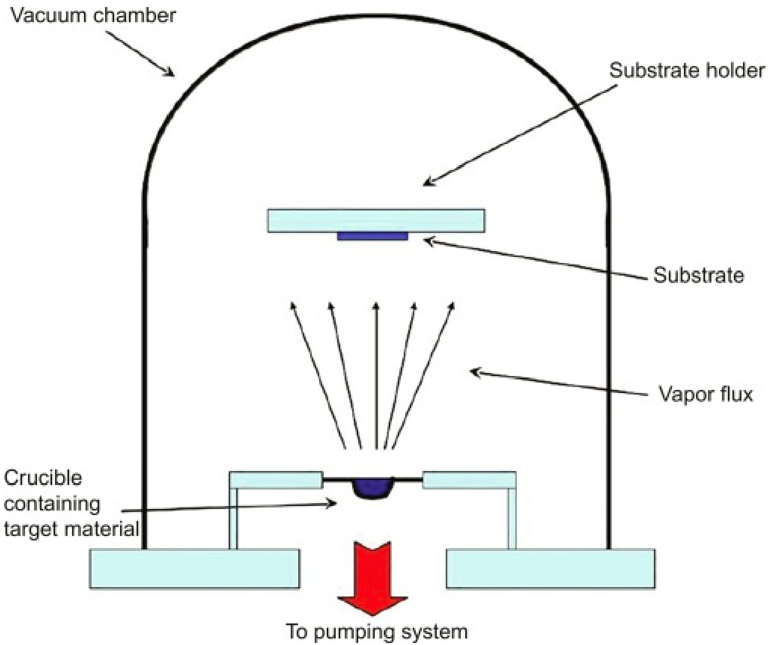
T. Kita, D. Akasako, and H. Murakami. Gap Value Determinations on the Tunneling Spectrum. Advances in Superconductivity VII (1995).

Making $Al/Al_2O_3/Sn$ sandwiches

Vacuum deposition (glass substrate)

1. Deposit aluminum: ≈ 1500 Å
2. Oxidize outer layer: ≈ 30 Å
3. Deposit tin: ≈ 3000 Å





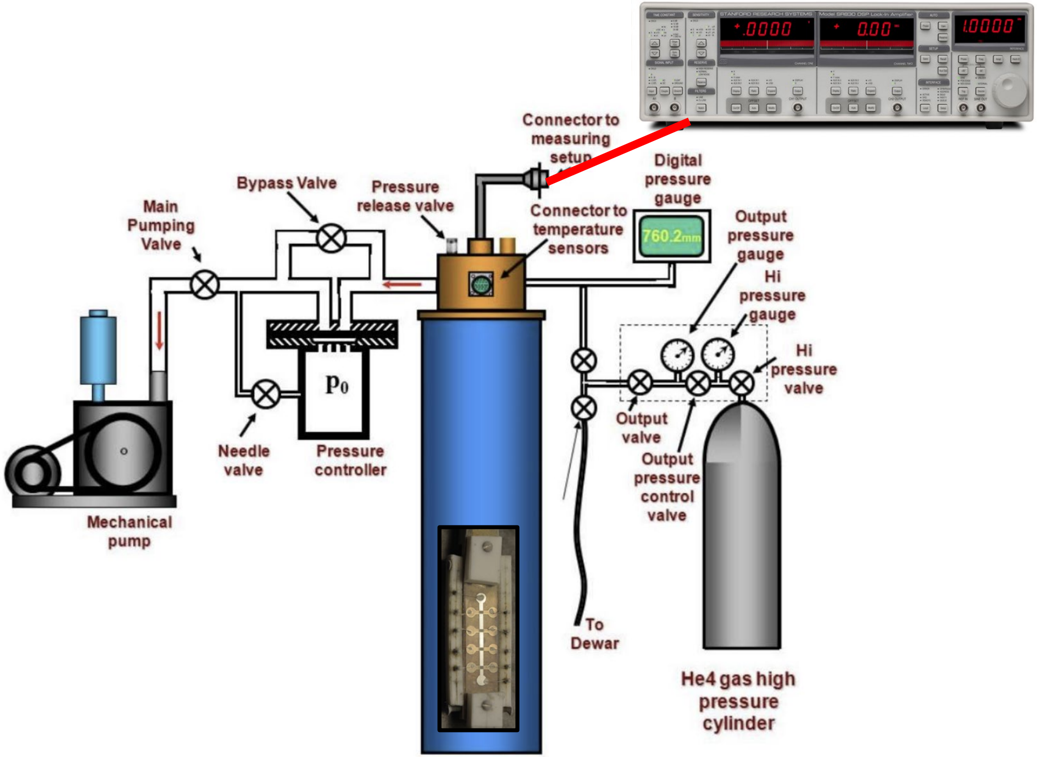
Courtesy Donald M. Mattox doi:10.1016/B978-0-8155-2037-5.00006-X

Cryogenic and measurement setup

1. Put sandwich in cryostat
2. Nitrogen: 293 K to 77 K
3. Helium: 77 K to 4 K
4. Pump: 1.5 K < T < 4 K

Lock in amplifier can measure

- Current **I**
- First harmonic **dI/dV** (differential conductivity)
- Second harmonic **d^2I/dV^2**



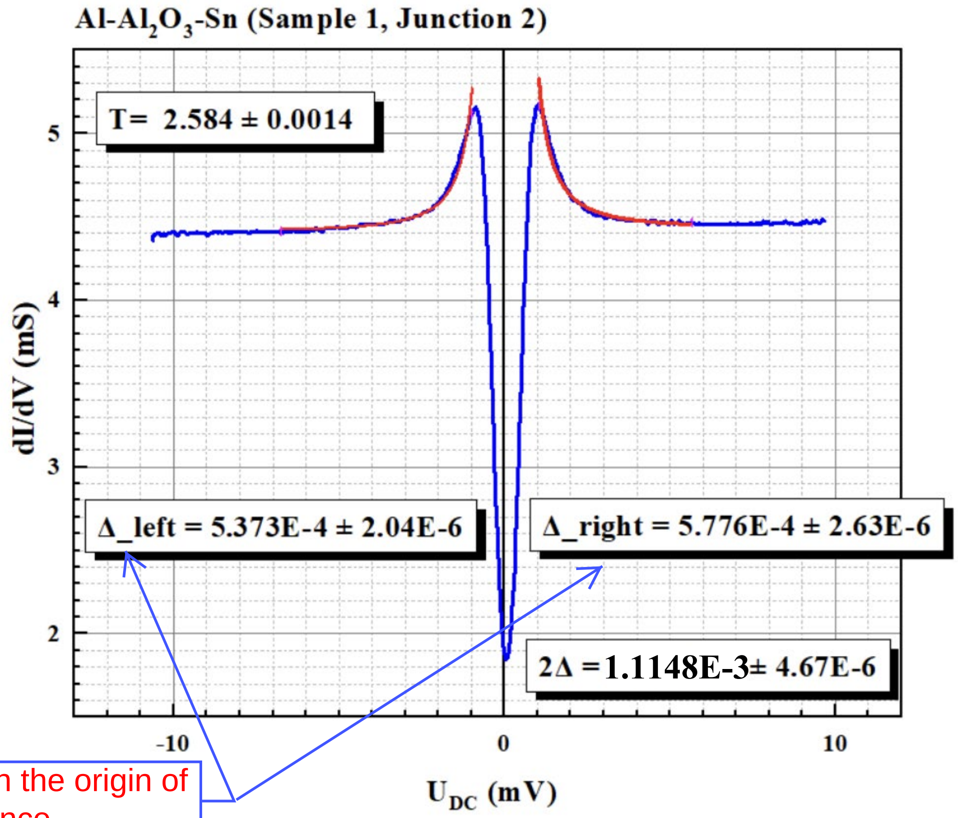
Determining Δ

Voltage U_{DC} applied to NIS junction is varied across a range and first harmonic **dI/dV** measured.

Fit to BCS equation.

Repeated at different $\mathbf{T < T_C}$.

$$\frac{dI}{dV} \propto \frac{|eV|}{\sqrt{(eV)^2 - \Delta^2}}$$



explain the origin of difference

Results

For **T** near **T_C**, BCS gives the relationship

$$\Delta(T) = 3.2k_B T_c\sqrt{1-(T/T_c)}$$

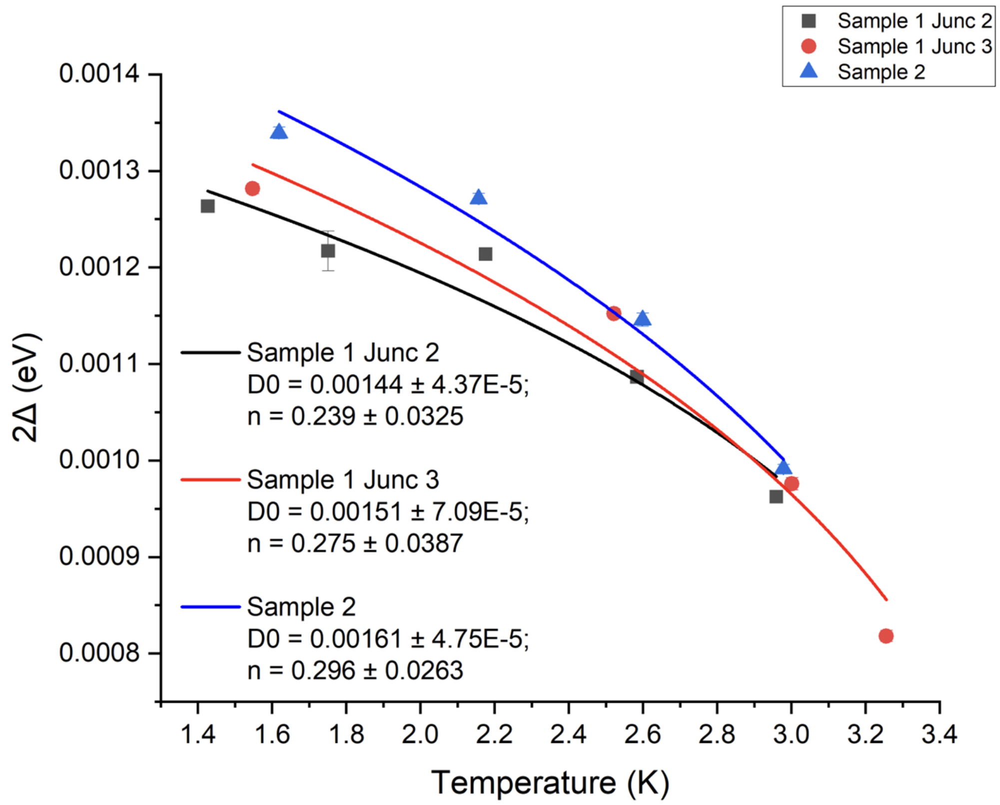
We fit to

$$\Delta(T) = \Delta_0\left(1-\frac{T}{T_c}\right)^n$$

fixing **T_C = 3.722 K.**

Expecting:

- **n = 0.5**
- **Δ_0 = 0.00103 mV**



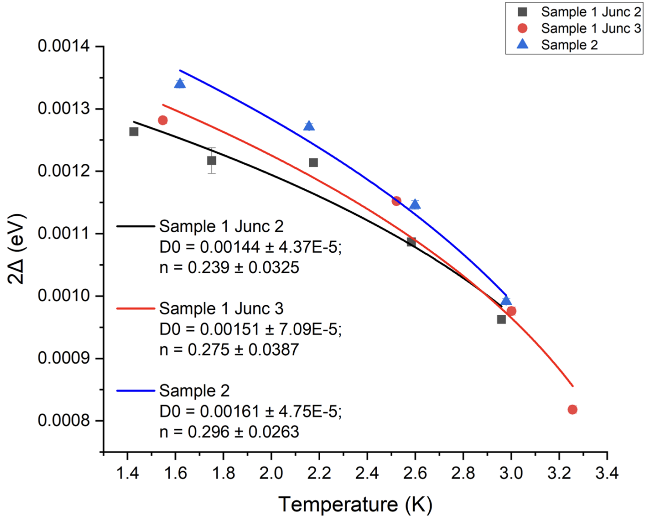
Conclusion

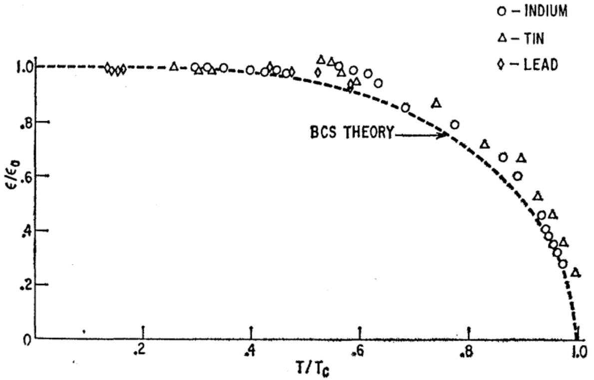
Results significantly off from expected

- Temperatures not near T_c

Improvements

- Measure at more temperatures
- Compare results to non-approximate BCS result (numerical integration)





I. Giaever and K. Megerle. Study of Superconductors by Electron Tunneling. *Physical Review Letters* (1961).

	'Theory'	Result
n	0.5	0.27
Δ_0	0.00103	0.00152