Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

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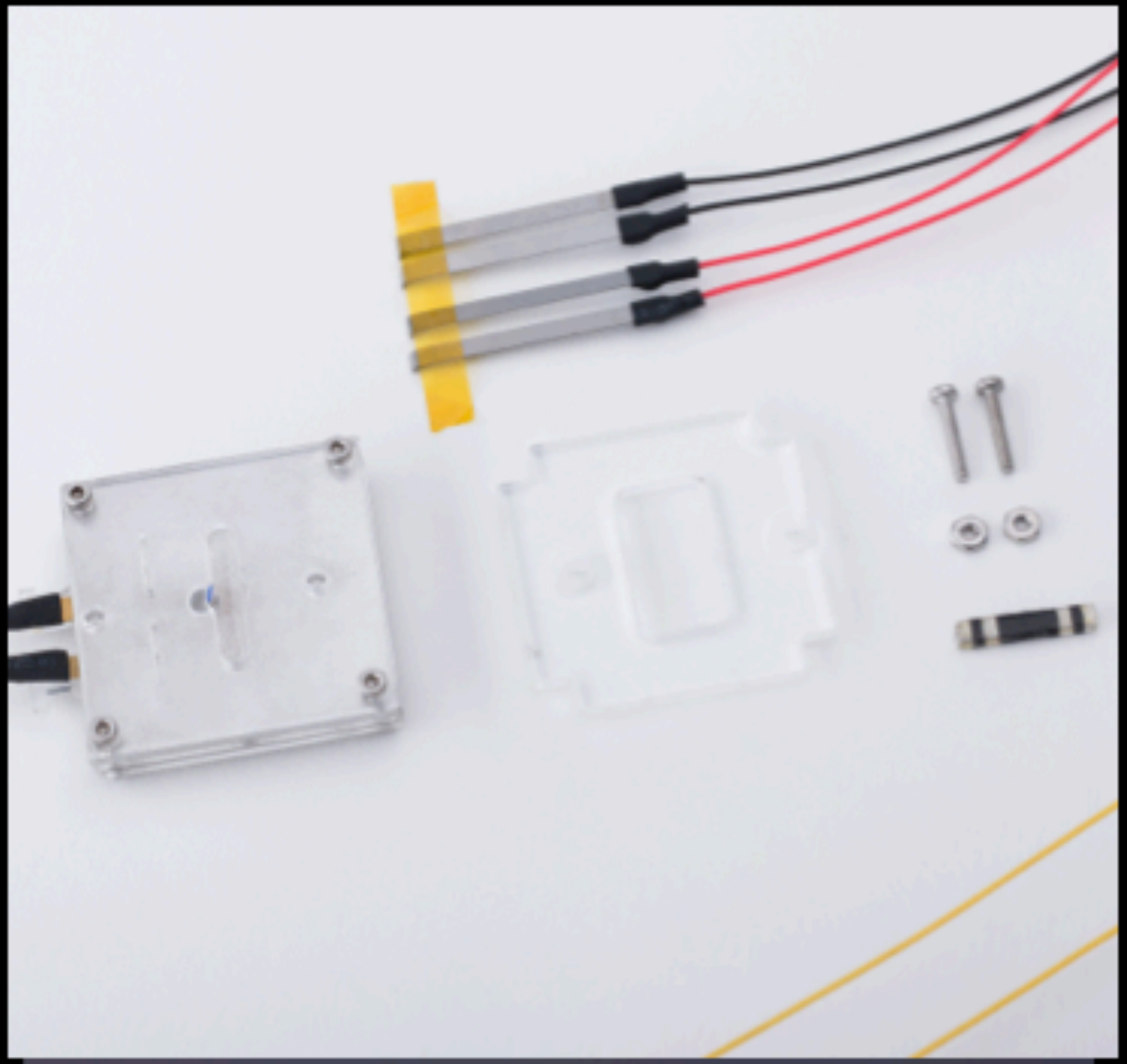
April 9th, 2025

Super conductivity

From Halliday Resnick

- The phenomena of superconductivity is of vast importance in technology: charge can flow through a superconducting conductor without losing its energy to thermal energy
- Current created in superconducting rings have persisted for several years without loss
- Electrons making up the current require a force and a source of energy at start-up time but not thereafter
- Prior to 1986, development of superconductivity was throttled by the cost of producing extremely low temperatures
    - In 1986, new ceramic materials were discovered that became superconducting at considerably higher temperatures
- Explanation:
    - electrons move in pairs
    - one of the electrons in a pair may electrically distort the molecular structure of the superconducting material as it moves through, creating nearby a short-lived concentration of positive charge
    - the other electron in the pair may then be attracted toward this positive charge
    - such coordination between electrons would prevent them from colliding with the molecules of the material and thus would eliminate electrical resistance



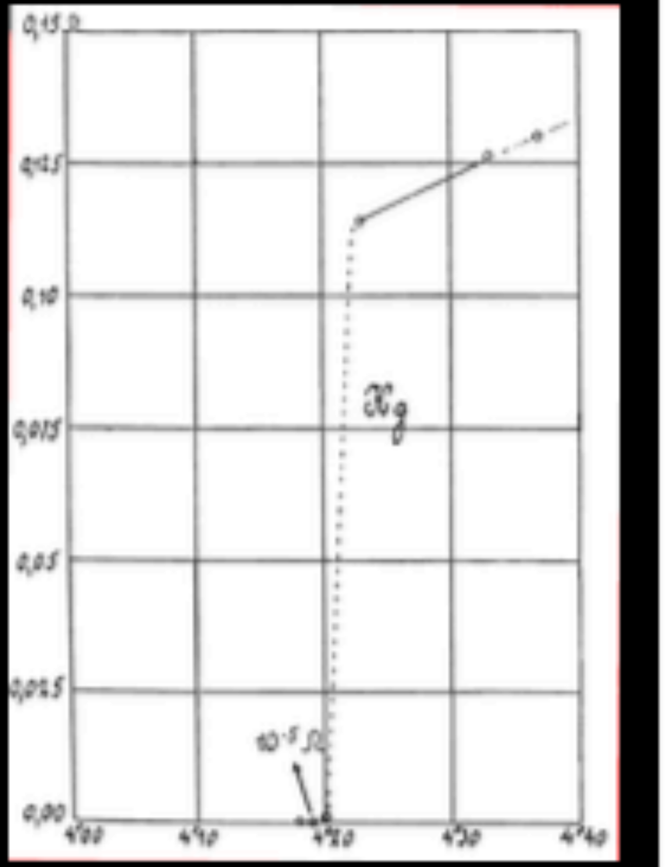
In a **4-wire measurement** the voltage probes are connected inside the current path. Current **does not** flow through the voltage probe contacts and hence the measured voltage is sensitive only to the voltage drop inside the material.

When is it OK to use 2-wire resistance measurement?

When the resistance of the object in question is much higher than that of the contacts (as for example in the thermometer case), we can disregard the voltage drop at the contacts and assume that the major contribution comes from the material itself.

MEASURING SUPERCONDUCTIVITY

Superconductivity introduces one of the most difficult challenges for physicists - how to sensitively measure the high resistance (measured in volts) of the normal state and the infinitesimally low & zero resistance of the superconducting state <u>at the same time</u>.



The original graph from Onnes's publication from 1911 showing the resistance of mercury as a function of its temperature. (H. K. Onnes, Comm. Leiden, 124c, 1911).

2-wire vs. 4-wire

When current passes through a material, the potential energy of the electrons changes along the current path. *Voltage* is the potential energy (per unit charge) of the conductive electrons.

In a **2-wire resistance measurement** we inject current into the material and measure the voltage difference between the current leads. The measured voltage drop includes both the **contact resistance** (which is unpredictable and usually not relevant) and the material resistance.

4-POINT Tc EXPERIMENT

HANDLING INSTRUCTIONS

The superconductor is a ceramic, brittle material that is sensitive to moisture. Its oxygen content strongly affects the superconducting properties. Oxygen atoms in water (from air moisture) react with the material and quickly degrade it, causing it to lose its superconducting properties.

Keep the superconductor in a sealed box with moisture absorbing material such as silica gel.

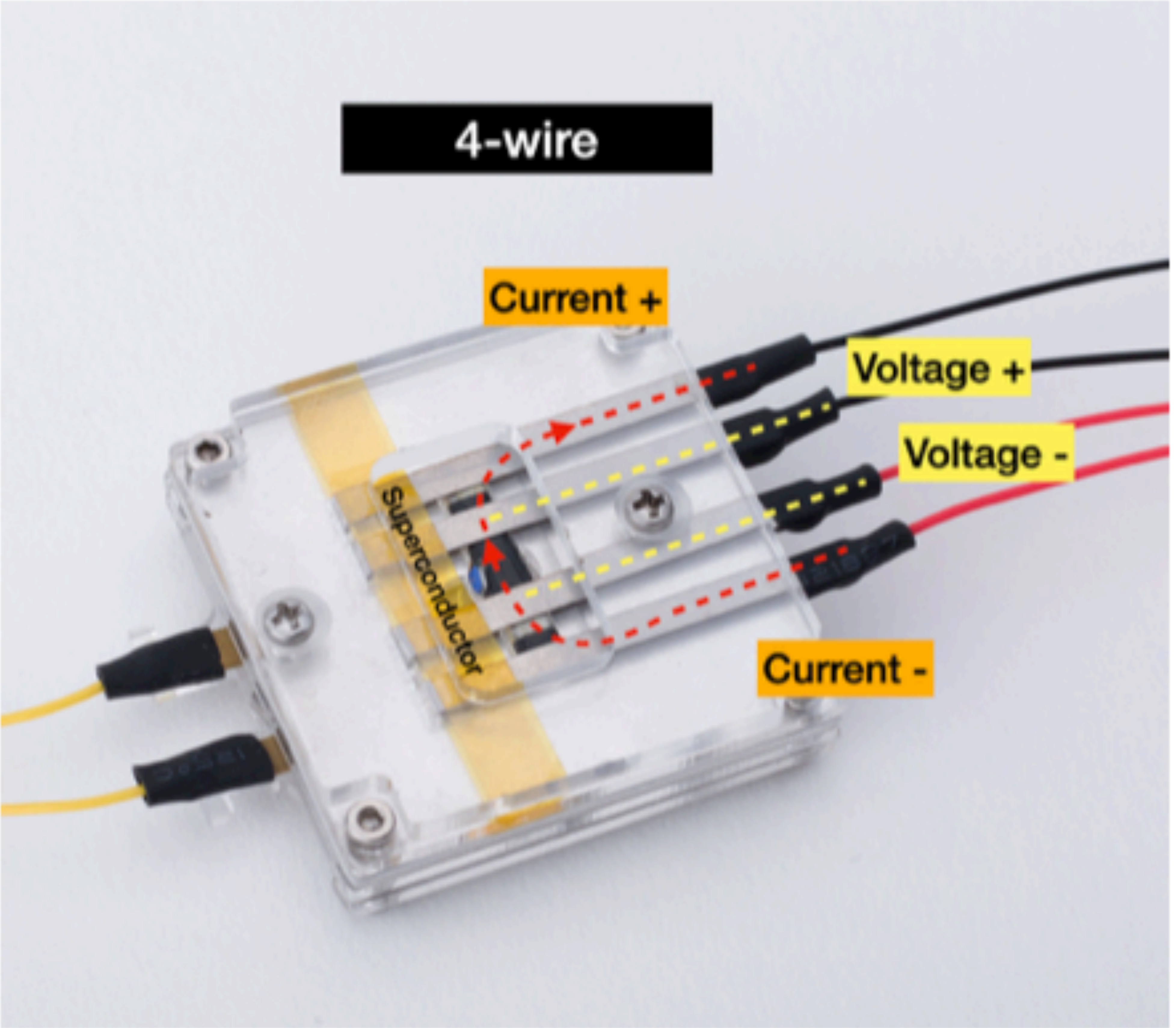
Superconductor refill

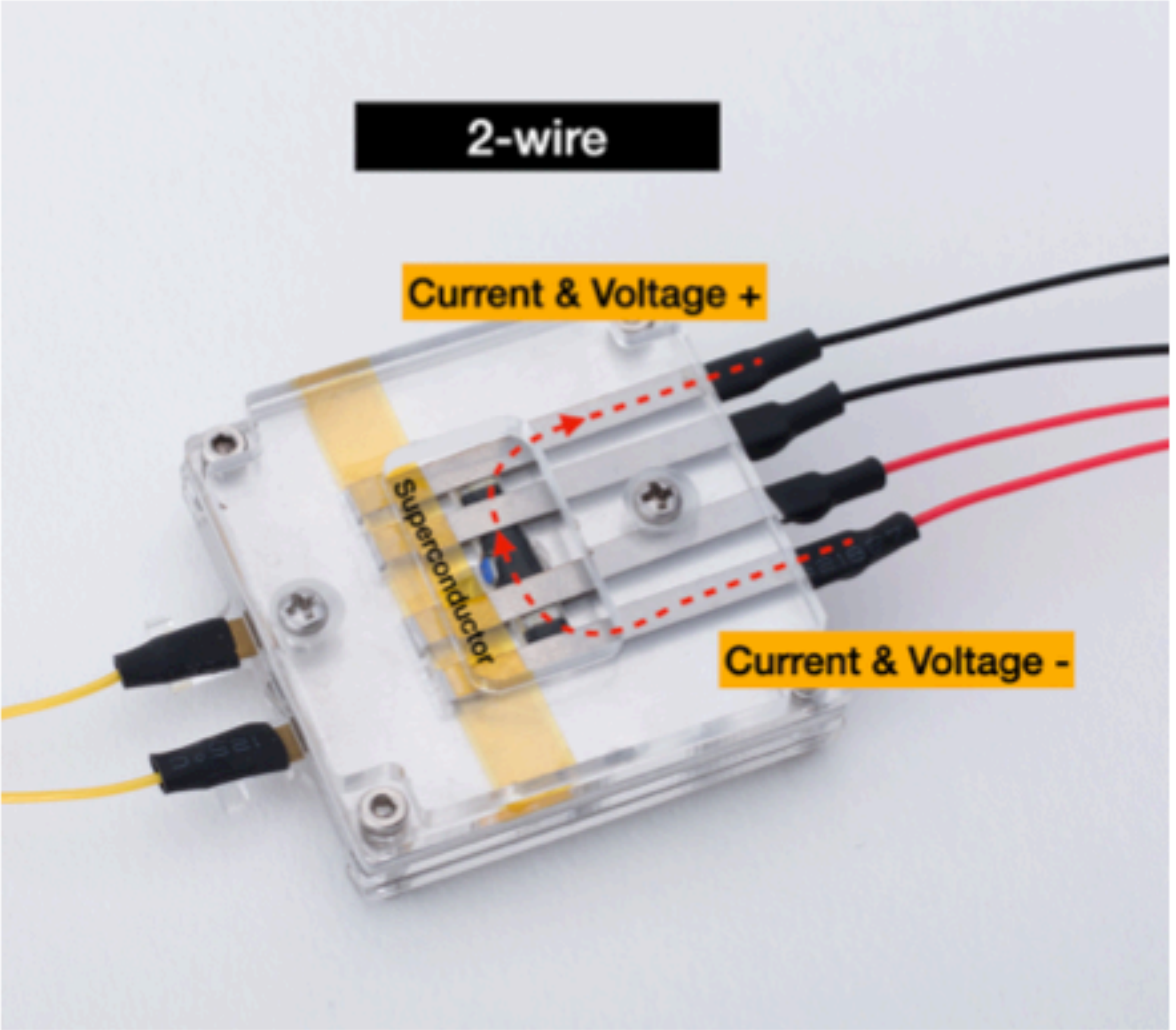
You can easily replace the superconductor if needed. Use the two screws in the center to remove the top cap. Take out the superconducting bar from its slot and replace it with a new one.

Visit our experiment website:

QuantumLevitation.xyz

Objective: understand the difference between 2-wire & 4-wire measurements. Measure the Tc of a superconductor.





Calibration

THERMOMETER CALIBRATION

Objective: Calibrate the resistance thermometer

Methods:

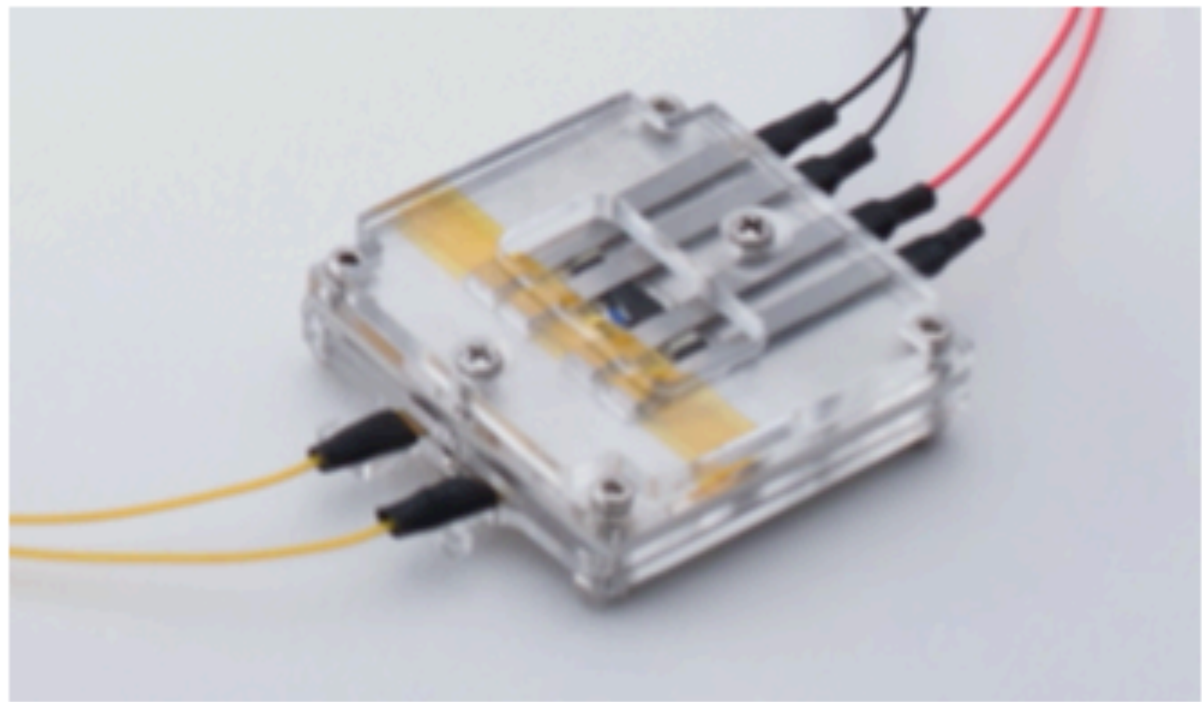
1. Connect the pt-100 thermometer to a multimeter (resistance measurement). The room temperature resistance should be ~110**Ω**.
2. Measure the resistance at 3 different temperatures (at least):
   - room temperature (~296K)
   - iced water* (~273K)
   - liquid nitrogen (~77K)

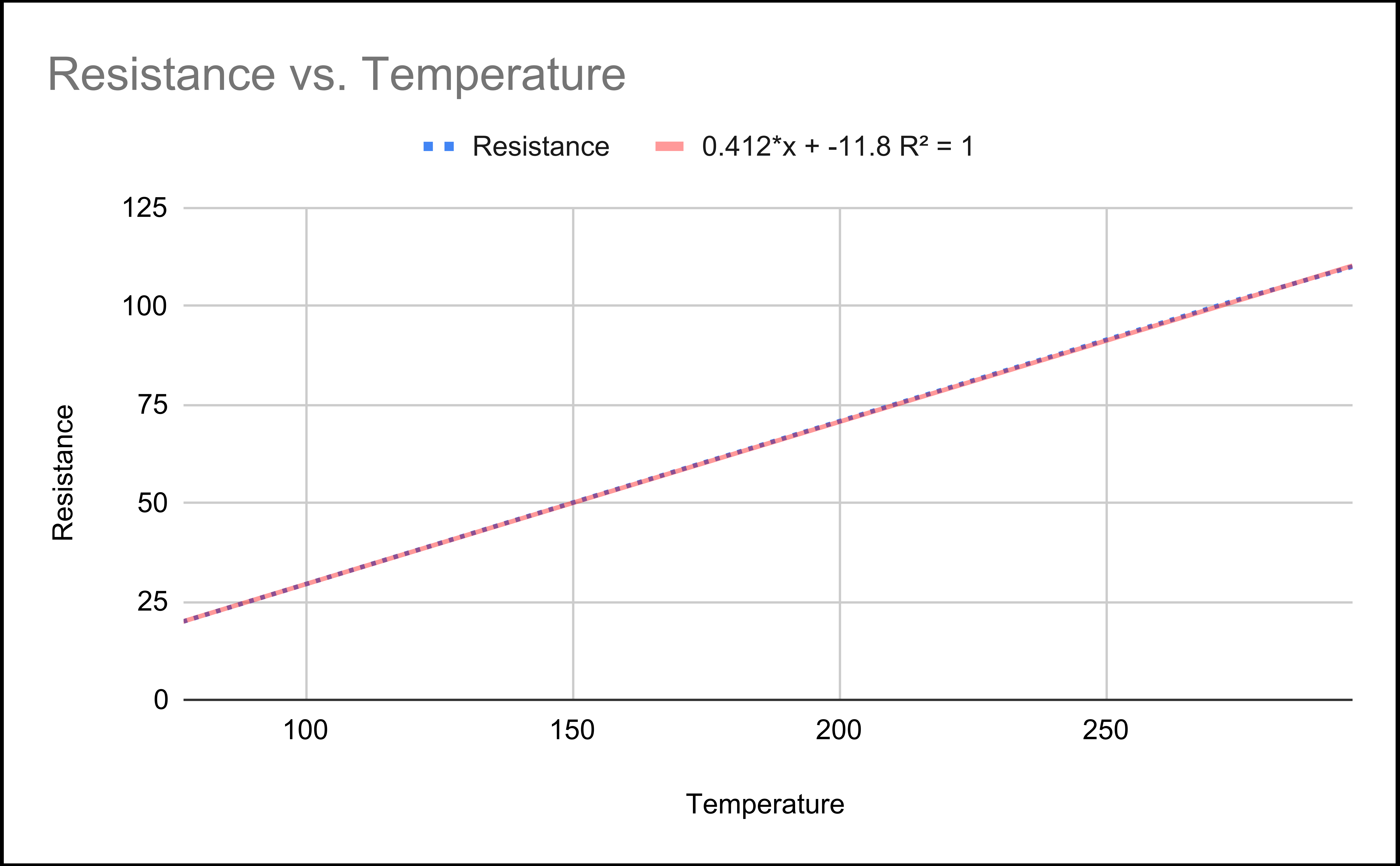
Data analysis:

1. Plot the temperature [K] vs. resistance [**Ω**].
2. Find the curve equation :

$$Temp\ \ [K] = aR[\Omega] + b$$

* place the entire setup in a plastic bag before dipping it in iced water.

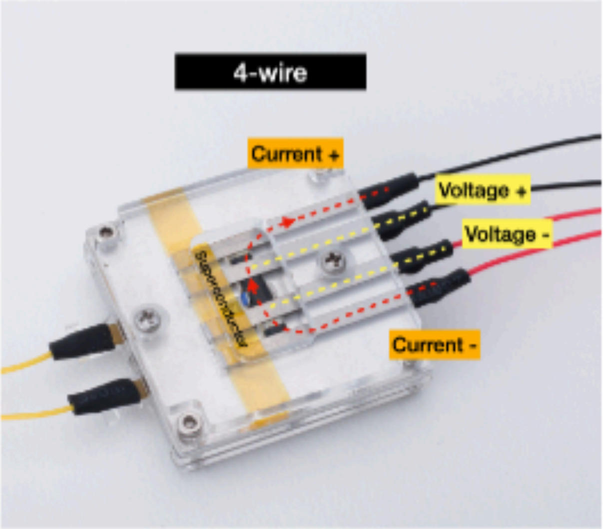


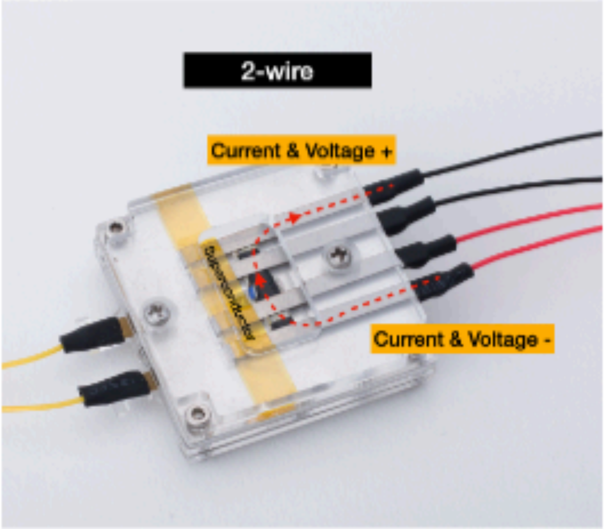


The experiment

SUPERCONDUCTOR TC, 2-WIRE VS. 4-WIRE

Objective: understand the difference between 2-wire & 4-wire measurements. Measure the Tc of a superconductor.





Methods:

1. Make a **2-wire** connection according to the drawing above.
2. Configure the current supply to a desired current. Do not exceed 1 Ampere to avoid heating.
3. Carefully dip the entire setup in liquid nitrogen. Let it cool until the bubbling subsides.
4. Take the setup out of the liquid nitrogen. Record the voltage and temperature while heating.

Tip If the heating is too fast, place the setup above the liquid in the cold vapor.

5. Repeat the measurement in a **4-wire** connection.

Analyze:

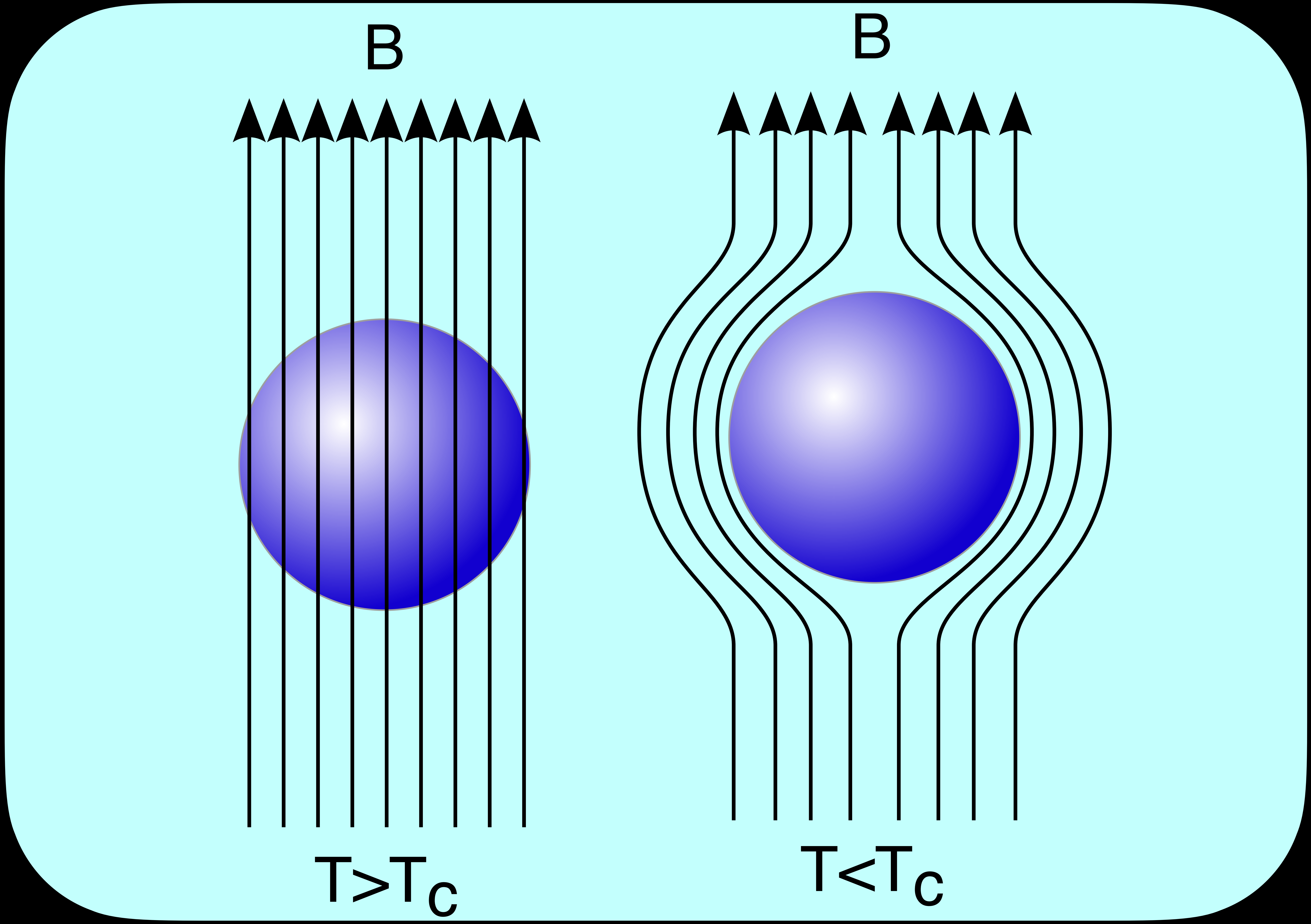
1. Plot the superconductor resistance (R=V/I) vs. the temperature. Use the thermometer formula you calculated in the previous experiment.
2. Compare the 2-wire data to the 4-wire data. Explain the differences.
3. Which measurement is suitable for measuring the critical temperature? Why?
4. Characterize the transition from normal to superconducting state:
   What is the width (in K) of the transition?
   Determine the critical temperature.
   Can you suggest several ways to define the Tc?
5. What are the Superconductor properties that effect the transition temperature & width?

Meissner Effect

- One phenomena that occurs in superconductors below the critical temperature is the Meissner effect, which is where a superconductor expels all magnetic field from within itself
- One of the most well known demonstrations of the Meissner effect is its ability to make a magnet levitate above a superconductor. The cause behind this phenomena is more complex than magnetic repulsion

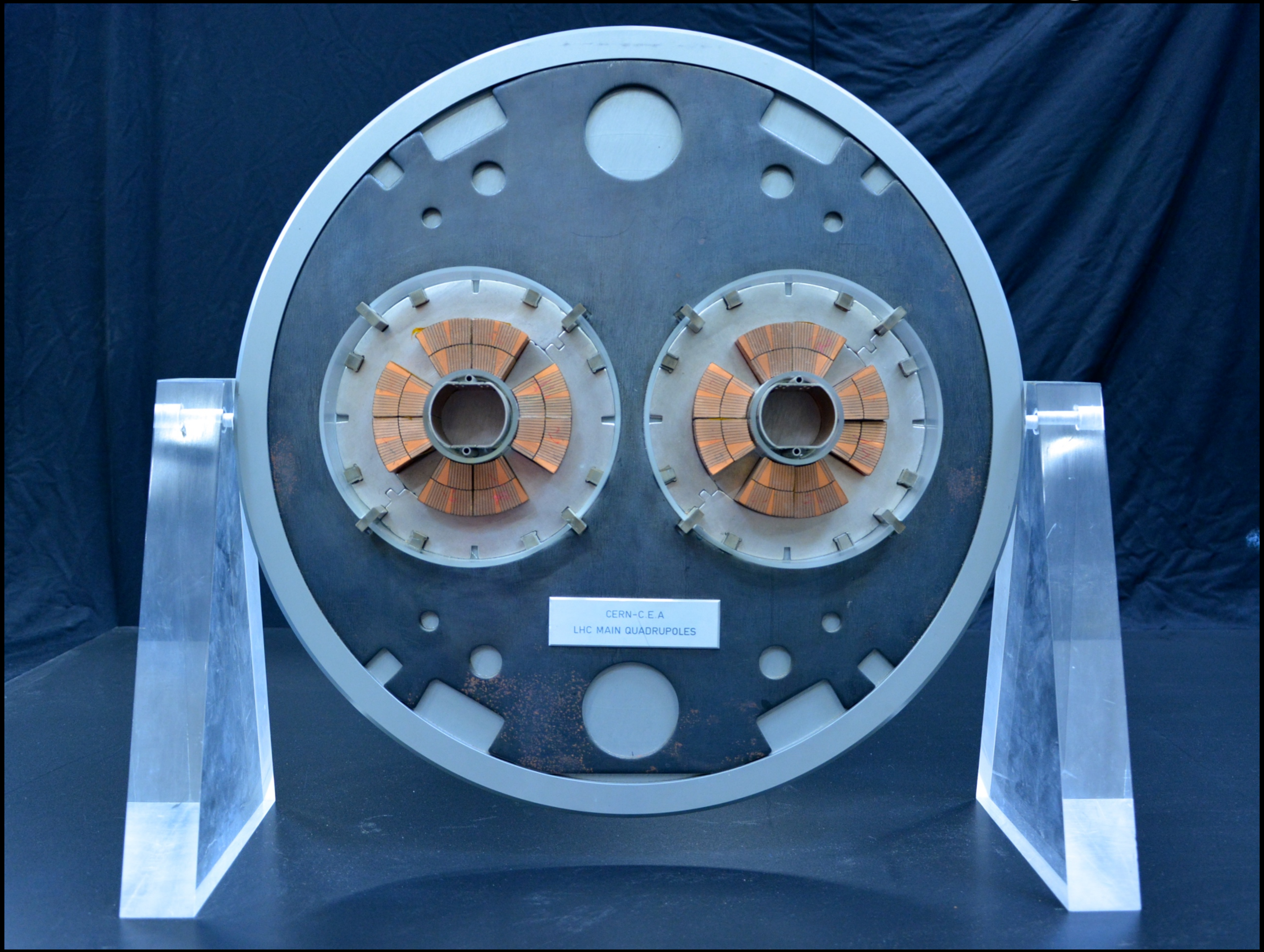
https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_%28Materials_Science%29/Magnetic_Properties/Meissner_Effect

Meissner Effect



The Large Hadron Collider (LHC)

LHC magnets



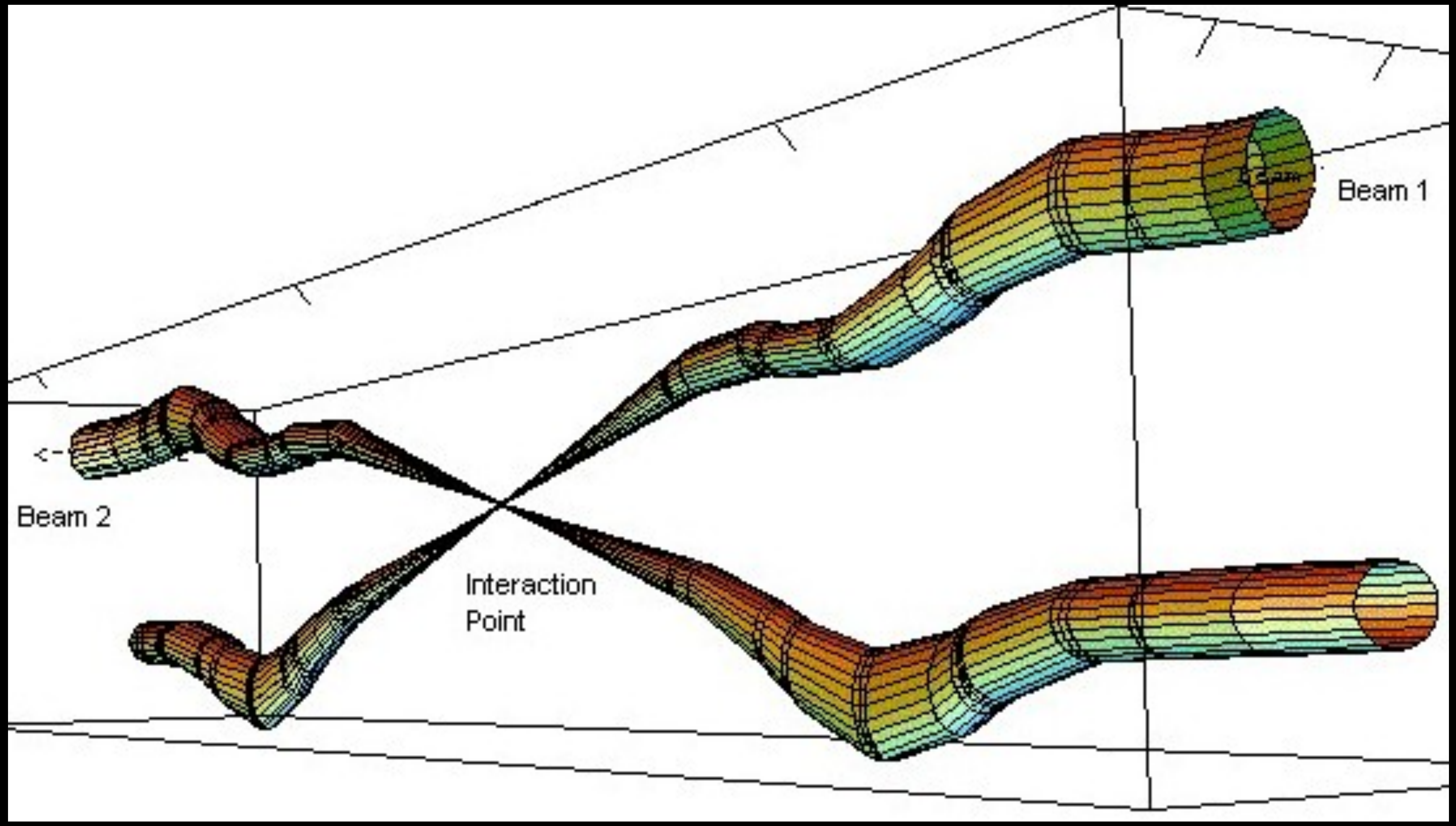
A quadrupole focusing magnet

- Use a quadrupole magnet to focus beams
- Quadrupole magnets focus the proton beams
  - Squeeze them so that more particles collide when the beams cross paths
- Precision needed analogous to colliding two knitting needles launched from either side of the Atlantic Ocean

To recapitulate…

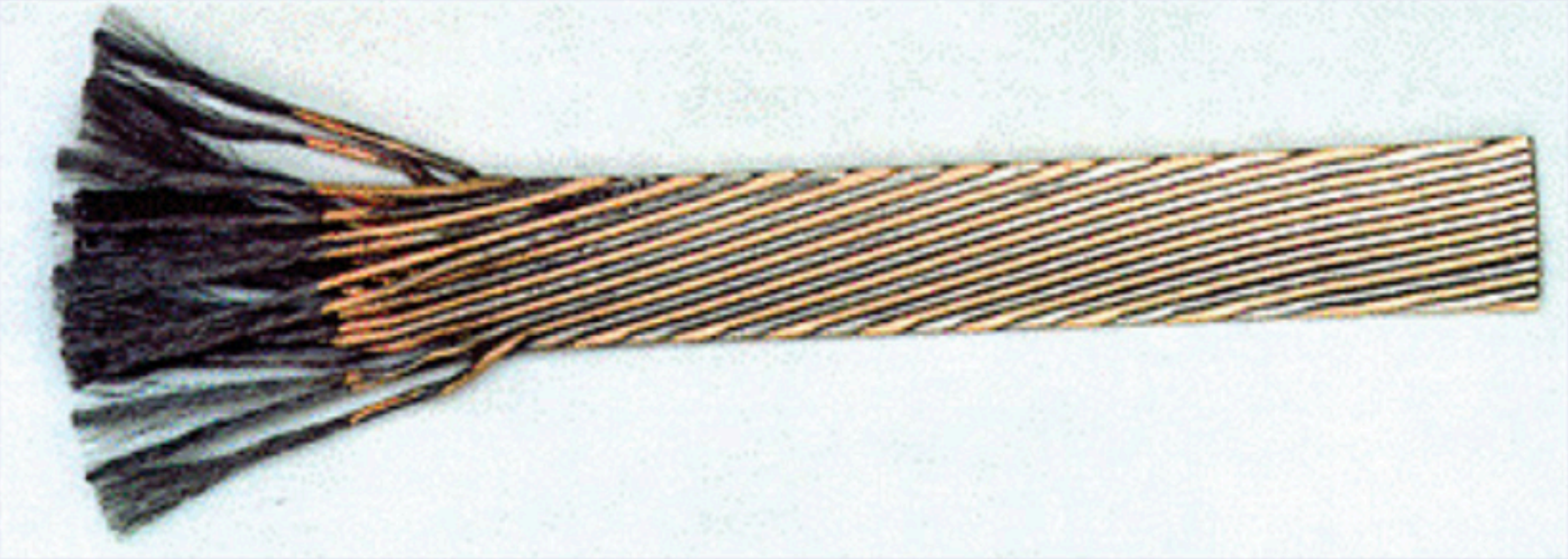
- Two kinds of magnets needed

1. Dipole magnets to bend the beams of protons
2. Quadrupole magnets to focus the proton beams at the detectors



The super conducting cables

- Super conducting filament made with niobium-titanium alloy (Nb-Ti)
  - Workhorse of superconductivity
  - Other alloys were being tested simultaneously (niobium-tin Nb_3Sn)
  - Practical choice won but simultaneous tests of other materials crucial for future projects

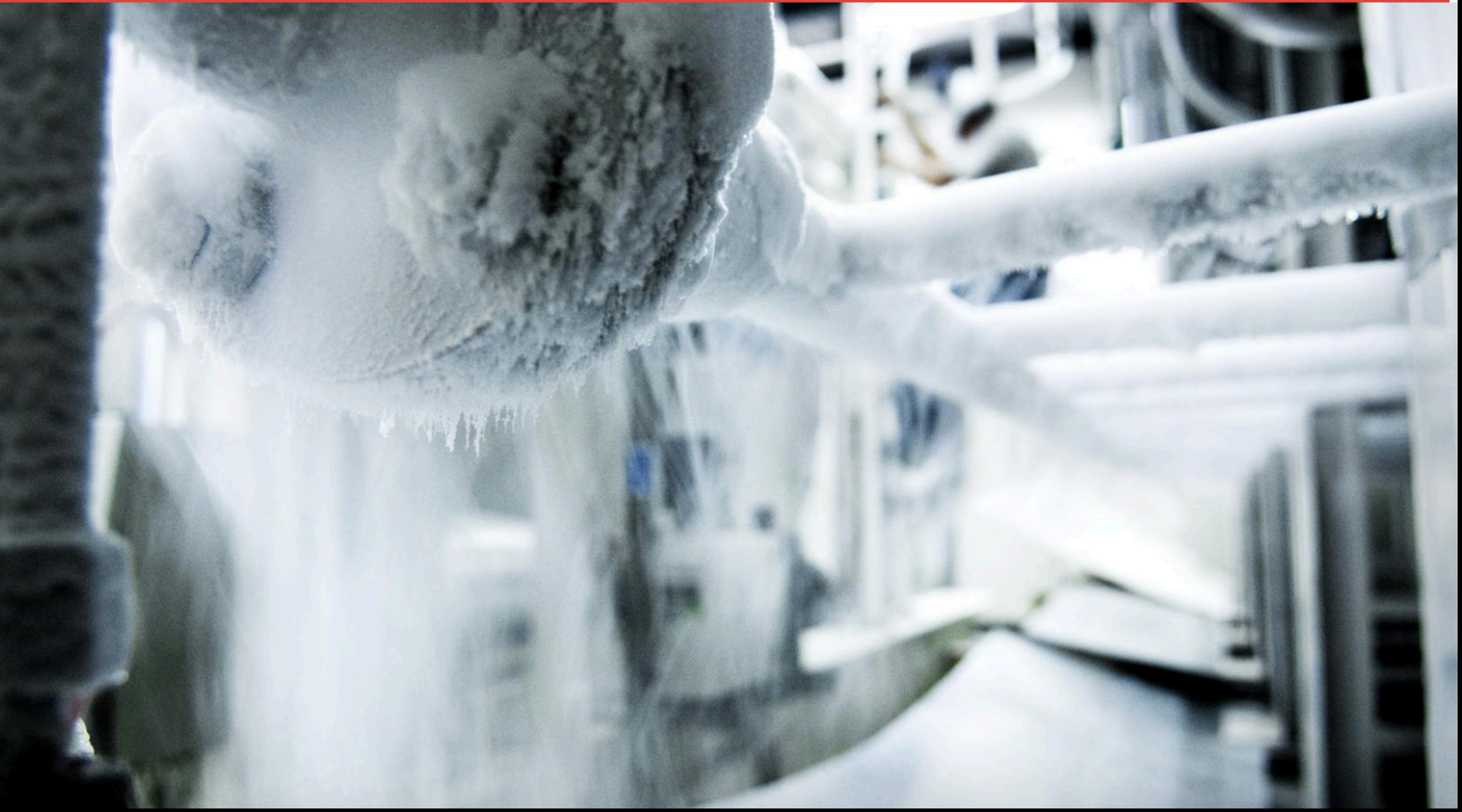


View of the flat side, with one end etched to show the Nb-Ti filaments

LHC filled with liquid helium

12/17/14 | By Sarah Charley

The Large Hadron Collider is now cooled to nearly its operational temperature.



“The Large Hadron Collider isn’t just a cool particle accelerator. It's the coldest.”

Cooling with liquid Helium

- Task:
  - Get 27 km of LHC magnets cooled down from room temperature
- Achieved by:
  - Injecting liquid He into a special cryogenic system surrounding the magnets
  - Gradually reduce temperature over several months as the He approaches liquid state
  - He becomes a liquid below 5 K
  - Naturally inert: no 

“*Filling the entire accelerator requires 130 metric tons of helium, which we received from our supplier at a rate of around one truckload every week*” — Laurent Tavian, the group leader of the CERN cryogenics team

Filling the first liquid-helium truck for external storage