

Superconductors Lab: Measuring Resistance versus Temperature and Critical Temperature

Equipment: Superconductor kit; 2 Voltmeters, Alligator clips; lots of liquid N₂

The measurement of electrical resistance as a function of the superconductor's temperature yields fundamental insights into its properties. The **Critical Temperature**, **Critical Current Density**, and the **Critical Magnetic Field**, can all be obtained through variations of this basic experiment.

This experiment requires the following pieces of equipment:

1. A constant current source, or a power supply operating in the current limited mode. The output should not exceed 0.5 Amp. This is connected between the black current probes (probes 1 and 4). An ammeter placed in series with this circuit will measure the current. This current will be referred to as I_{14} . **When connecting and disconnecting probes, make sure the power supply is turned all the way down. If the probes are disconnected or connected to an active power supply, they will be damaged.**
2. A digital voltmeter with a 0.01 millivolt resolution to measure the voltage drop across the yellow voltage probes (probes 2 and 3). This voltage will be referred to as V_{23} .
3. A container of liquid nitrogen deep enough to completely immerse the four point probe device.

The voltmeters should be connected as shown in [figure 2](#). Alternatively, a strip chart recorder with a 10 millivolt full-scale range and a resolution of 10 microvolt may be connected between probes 2 & 3. This will provide a continuous record of the voltage drop. If a two-channel recorder or x-y plotter is used, then the thermocouple reading can also be measured simultaneously. The output from the voltmeters connected to probes 2 & 3, and to the thermocouple, may be sent directly to a computer to store and further analyze the data.

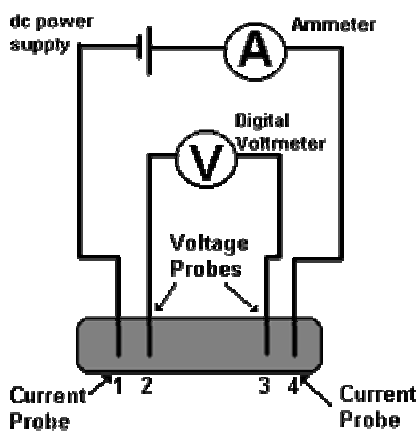


Figure 2: Schematic of Four-Point Probe

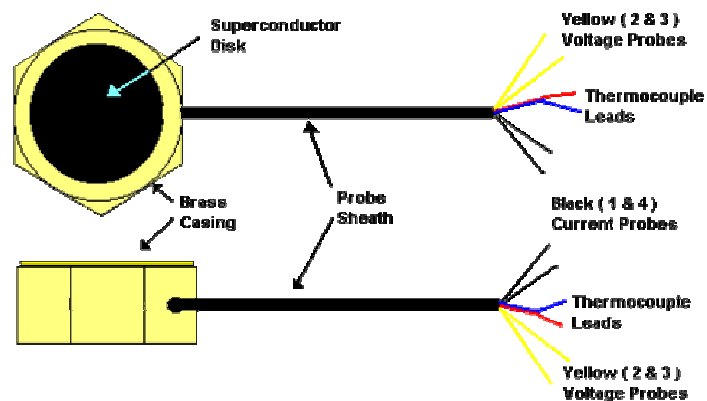


Figure 3: The Superconducting Four-Point Probe

The following is a step by step guide for measuring the device Resistance versus its Temperature:

Procedure.

1. **ACTION:** Set up the equipment as described above, but do not as yet immerse the device (four point probe) in liquid nitrogen.

RESULT: The voltage across probes 2 & 3 (V_{23}) should measure between 2 and 5 mV.

2. **ACTION:** Carefully immerse the device in liquid nitrogen. Use the white, sheathed wire bundle to suspend the device in the liquid. Ensure that the current (I_{14}) remains constant at 0.5 A.

RESULT: The nitrogen boils furiously. Wait until the boiling subsides.

3. **ACTION:** Record the voltage V_{23} , and across the thermocouple junction.

RESULT: V_{23} should equal zero. The thermocouple temperature reading should be 77 K.

4. **ACTION:** Remove the device from the liquid nitrogen. As it warms, continuously monitor the value of V_{23} . Record the thermocouple reading each time V_{23} is recorded.

RESULT: Initially, V_{23} remains constant even as the thermocouple reading increases. Then, V_{23} , the voltage between the probes, abruptly increases, the thermocouple reading corresponding to this jump in voltage is the Critical Temperature, or T_c of the superconductor. The ratio of the voltage between probes 2 & 3 (V_{23}) to current flowing between probes 1 & 4 (I_{14}) is the instantaneous resistance of the superconductor between probes 2 & 3. The probe voltage, and the thermocouple reading could be input directly into a computer or chart recorder for more accurate results. This latter approach also provides a permanent record of the data. This result is shown in figure 4 below.

Precautions.

1. When pouring liquid nitrogen be careful to prevent any splashing.
2. Be careful not to touch the device or wires when they are cold. Follow the safety directions.
3. No more than 0.5 Amp of current should pass through the device at any time.
4. Use a hair dryer to carefully dry the Four Point Probe device after use. Store it with a desiccant.
5. The probe and thermocouple wires are very brittle when cold. Please handle them with care.

Some Questions.

1. What effect would one expect if the Critical Temperature is measured with the device placed inside a functioning electromagnet?
 2. Why is the transition in resistance gradual at the Critical Temperature?
 3. A simple two-probe measurement of device resistance below its Critical Temperature exhibits a non-zero value. Why?
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Determination of the Critical Temperature

The Critical Temperature (T_c) is obtained during the measurement of the electrical resistance as function of the Temperature of the superconductor above. The Critical Temperature of the $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ superconductor is about 108 Kelvin versus about 95 Kelvin for the $\text{YBa}_2\text{Cu}_3\text{O}_7$ material. These results are shown below in figure 4.

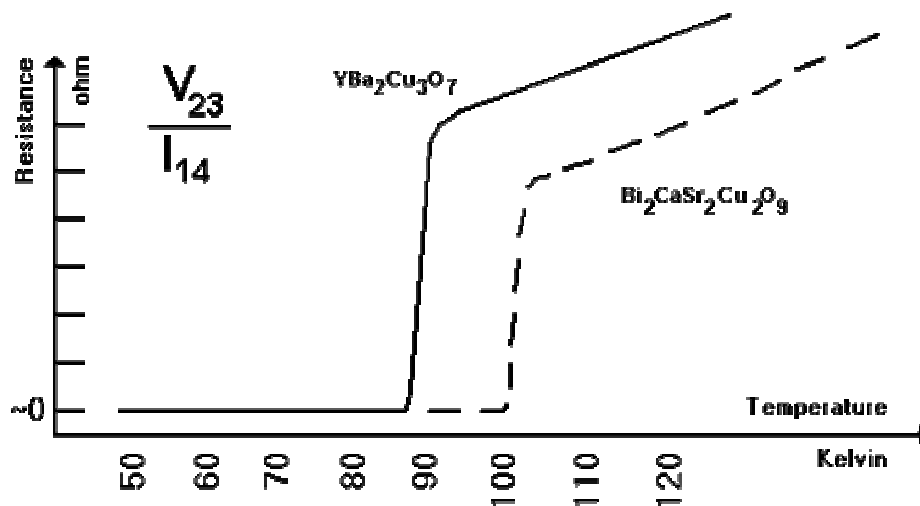


Figure 4: Resistance versus Temperature