

TEACHER NOTES

The Effect of Temperature on Electrical Resistance

Abstract:

This project allows students to experimentally discover the temperature dependence of resistance using a copper wire, a standard 1 Ω resistor, and a piece of BSCCO 2223 superconducting tape. Using liquid nitrogen as the refrigerant, students will measure electrical resistance over a temperature range from -196 °C (77 K) to room temperature, approximately 22 °C (295 K).

Introduction to Research:

In 1911, while investigating the conductivity of various metals at temperatures near the boiling point of liquid helium (-269 °C, 4 K), H. Kamerlingh Onnes found that the electrical resistance of mercury dropped to a value so small that it was indistinguishable from zero. This phenomenon was given the name superconductivity. Over the past century, scientists have discovered materials that become superconducting at higher and higher temperatures. At the present time, we have materials that are superconducting at critical temperatures, the temperature at which a superconductor becomes superconductive, as high as -145 °C (128 K). This experiment gives students the opportunity to investigate the relationship between temperature and electrical resistance and to determine the critical temperature for a superconducting material.

Learner Outcomes:

As a result of performing this experiment, the student will be able to:

- Collect and analyze data using common electronics meters.
- Understand the operation of a thermocouple for measuring temperatures.
- Develop an understanding of the relationship between temperature and electrical resistance for a wire, a resistor, and a superconductor.
- Determine the critical temperature, T_c , at which a superconductor becomes superconductive.

Research Question(s):

How does temperature affect electrical resistance?

Assessment Type:

Students will prepare a presentation in which they present their results to the question, “How does temperature affect the electrical resistance of a wire, a resistor, and a superconductor?”

Alignment with [National Science Education Standards](#):

This project demonstrates elements of the following:

- [Teaching Standards](#):
 - [A](#): Plan an inquiry-based science program.
 - [D](#): Develop communities of science learners.
 - [E](#): Participate in ongoing planning and development of science program.
- [Assessment Standards](#):
 - [B](#): Achievement and opportunity to learn science
 - [C](#): Quality of data matched to decisions and actions taken
 - [D](#): Assessment is fair.
- [Content Standards](#):
 - [A](#): Science as inquiry
 - [B](#): Physical science
 - [E](#): Science and technology
- [Program Standards](#):
 - [A](#): Consistent with other standards
 - [B](#): Developmentally appropriate, interesting, and relevant
 - [D](#): Access to appropriate and sufficient resources
 - [E](#): Equitable student access

Where might this fit into the standard physics curriculum?

This activity may fit well into a unit on electrical circuits. Students must have a basic idea of Ohm's Law and how to set up a simple circuit with an ammeter and a voltmeter. This activity may serve as a tie-in to a unit on magnetism as the fundamental concepts behind superconductivity are related to magnetism.

Materials Needed:

- Power supply (at least 1 V, 1 A)
- Meters including:
 - Two voltmeters (sensitive to 0.1 mV) and one ammeter (for currents up to at least 1 A) and a type K thermocouple¹
- OR
- Probeware with a voltage sensor, current sensor, and either a type K low temperature sensor or a second voltmeter
- BSCCO 2223 superconducting tape², resistor, wire and/or other materials to serve as resistive samples
- Wire leads for connecting components of the circuit
- 10 L Dewar with liquid nitrogen
- Styrofoam container to serve as lab Dewar for holding the liquid N₂

Teaching Tips & Sample of Data/Results:

The goal of this lab is to allow students to discover the effect that temperature has on resistance. In this experiment, students build the circuit shown in Figure 1 and use the voltmeter (V) and ammeter (A) readings to determine the resistance at different temperatures, which are measured by a second voltmeter (V_{TH}) connected to a thermocouple.³ In each trial, a constant current passes through one of three materials (a wire, a resistor, and a superconductor—all are shown as the bold line in the schematic diagram of Figure 1) while the voltage across the material is measured. Figure 2 shows a 45-cm-long sample of each material being tested. Four wire leads (A→D) are soldered to each sample. Wires A and D are connected to the power supply (with an ammeter wired in series as part of this loop (see Figure 1)); wires B and C are connected to the voltmeter which measures the voltage drop across the sample. The material and leads are supported by a dowel rod holder (see Figure 3), which is allowed to approach and finally be submerged into a container of liquid nitrogen.

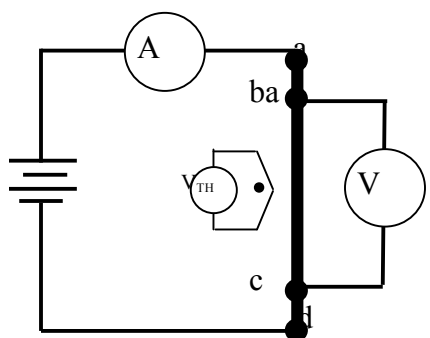


Figure 1. Schematic diagram of the circuit used to measure voltage and current (for resistance determination) and thermocouple voltage (for temperature).

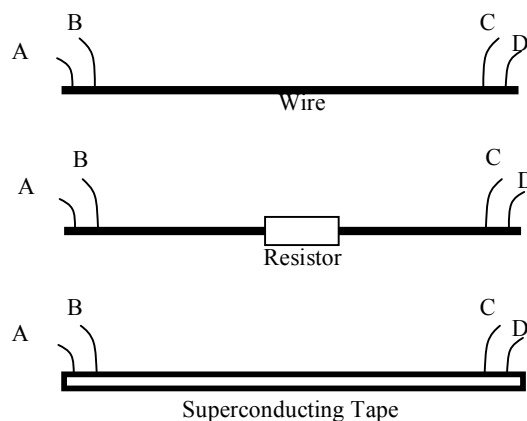


Figure 2. 45-cm-length sample of wire, resistor, and BSCCO superconducting tape to be mounted in the rod holder. Wire leads shown.

Students begin by lowering one of the samples, say a piece of copper wire, from a height of about 20 cm above a liquid nitrogen bath. Figure 4 shows a setup of this apparatus. At several heights above the liquid, the sample is held in place and the voltage and current are recorded while the temperature—which is measured using a second voltmeter attached to the thermocouple—is also recorded. If probeware is accessible, the experimenter may choose to use a voltage and current sensor to find the resistance along with a voltage sensor connected to the thermocouple. The probeware software can be used to divide voltage by current and the calibration equation for the thermocouple can be entered as an equation in the probeware software so that the computer can output resistance and temperature (see Appendix).⁴ Figure 5 shows the

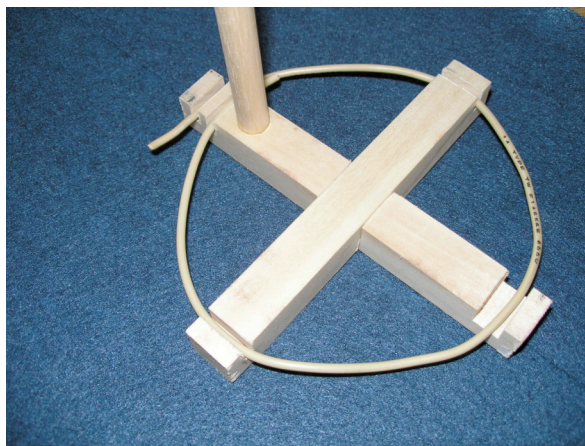


Figure 3. Frame that holds wire, resistor, and superconductor sample.

results of this experiment with: (a) a copper wire; (b) a 1 Ω resistor; and (c) a piece of barium strontium calcium copper oxide (BSCCO 2223) superconductive tape. The copper wire and resistor are readily available at local electronics stores or through most science companies. The BSCCO tape can be obtained from American Superconductors.⁵ The benefits of using this superconducting tape over a yttrium barium copper oxide (YBCO) bulk disk is that the BSCCO tape is coated in stainless steel making it very easy to solder wire leads to it.

Figure 5 illustrates that (a) the resistance of wire typically demonstrates a linear temperature dependence that nearly changed by a factor of three over the temperature range tested; (b) the resistance of a manufactured resistor is very constant—only dropping by 2 percent over the range of temperatures tested; and (c) the resistance of the BSCCO superconductor dropped with decreasing temperature linearly until the critical temperature was achieved (110 K) at which point the resistance dropped to zero.

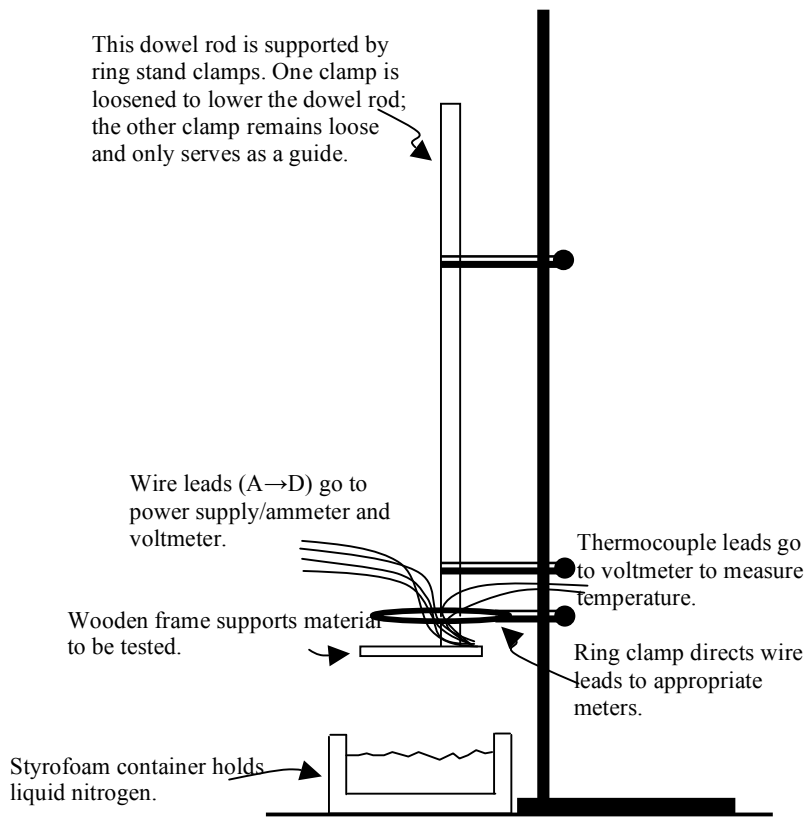


Figure 4. Equipment setup to cool sample and determine the resistance and temperature.

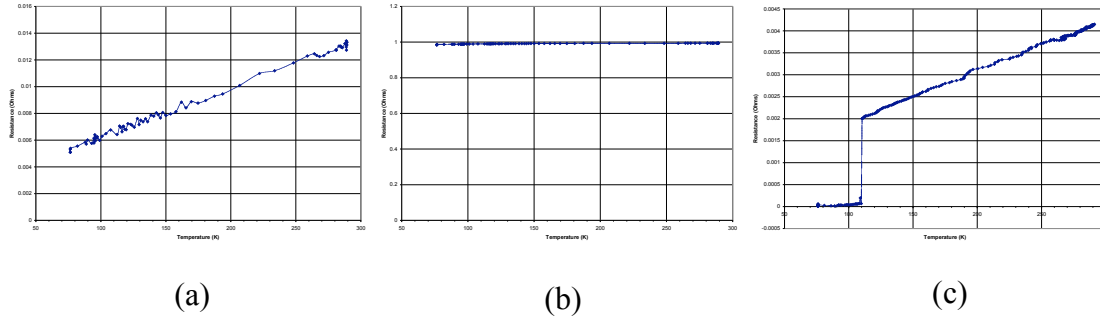


Figure 5. Resistance as a function of temperature for: (a) a wire, (b) a 1 Ω resistor, and (c) a BSCCO superconductor.

¹ We used a type K thermocouple. The cost of this was about \$10.

² A 10 m sample of the BSCCO 2223 superconducting tape may be obtained from American Superconductor Corporation. You may contact them at <http://www.amsuper.com/>

³ See note 1 above.

⁴ Tables for converting thermocouple readings (in mV) to temperature (in $^{\circ}\text{C}$) readings can be found either in the appendix or at <http://tsdown.nist.gov/srdata/its90/>

⁵ See note 2 above.