Physics 238 Intermediate Physics Laboratory
Superconductivity
Due Wednesday, May 13, 2026, 5:00 p.m.
Please submit your report via Moodle.

Safety

Liquid Nitrogen

You will use liquid nitrogen in this experiment. You can **seriously** injure yourself with liquid nitrogen. Here are a few specific cautions, but more generally, you should follow good safety practices, pay attention to your surroundings, and use common sense.

- Wear insulating gloves at all times when handling liquid nitrogen.
- Wear safety glasses at all times while near containers with liquid nitrogen.
- Do not let the liquid nitrogen, or objects that have recently been in liquid nitrogen, touch your skin or clothing.
- Be careful not to splash the liquid nitrogen when pouring. Pour it very slowly.
- Do not store liquid nitrogen in a container with a tight-fitting lid.
- Do not pour the liquid nitrogen on any surfaces except those designed for it. Most surfaces will be damaged by the extreme cold.
- Do not touch the sample holder with your bare skin. It can stay dangerously cold for a long time even after you pull it out of the liquid nitrogen.

Chemical Safety

The superconducting rods are made from materials that are toxic if ingested. You should not need to touch the rods at all, but if you do, you should wash your hands.

Logistics

- Plan on taking your data by Friday, May 8, 2026.
- There are only two setups for this experiment, so you will have to take turns. I will post a sign-up sheet.
- Because this experiment involves liquid nitrogen, you can only do it during the day when I am around. There ought to be enough time during our scheduled lab sessions.
- A successful run typically takes about half an hour, but if you add too much liquid nitrogen at the beginning, it can take much longer.
- The actual analysis and write-up can be rather brief.
- The final report is due at 5:00 pm on Wednesday, May 13, 2026. Turn in your report via the link on our Moodle page.

1 Introduction

High T_C superconductors, with transition temperatures above the liquid nitrogen liquification point of 77 K, have opened the door to accessible demonstrations of superconducting phenomena. We will observe the transition to the superconducting state in two cuprous oxide ceramics, $YBa_2Cu_3O_7$ (YBCO) and $Bi_2Sr_2Ca_{n-1}Cu_nO_9$ (BSCCO). (n is typically 2 or 3, depending on the manner in which the material is made. A typical polycrystalline sample will contain a mixture of both types.) More information about the chemistry and fabrication of these materials is in Colorado Superconductor's "Experiment Guide for Superconductor Demonstrations," available both in the lab and on our Moodle site.

2 Experiment

2.1 The Four Point Probe

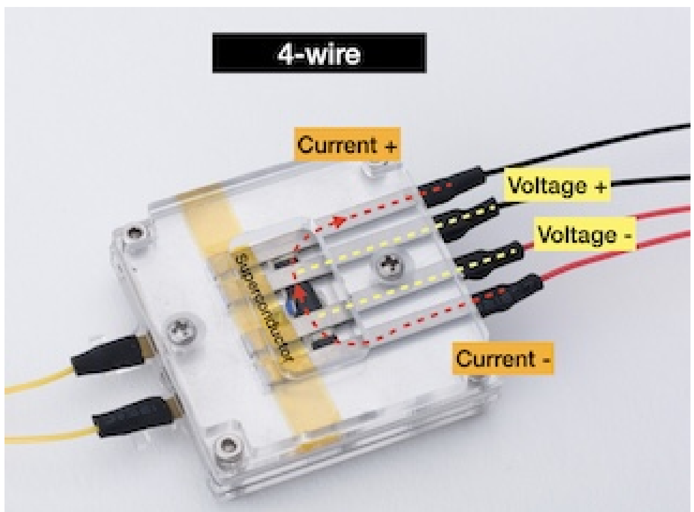

Figure 1: Quantum Levitation sample holder with 4-point probe. The two yellow wires on the left are for the platinum RTD temperature sensor.

The superconducting samples have been outfitted with a four point current probe which eliminates the effects of contact resistance in measurements of the resistance of the superconducting sample. The probe is shown in Fig. 1. A DC power supply causes a constant current to flow the length of the sample through probes labeled `Current +` and `Current -` in the figure. The voltage drop across the sample is read from the `Voltage +` and `Voltage -` wires. Typically, the two positive connections are as close as possible without touching, and the two negative connections are similarly close. The high impedance of the voltmeter prevents any significant current from flowng through the voltage leads so that their resistance does not contaminate the measurement.

The yellow wires connect to a platinum RTD for measuring temperature.

2.2 Measuring Temperature With a Platinum RTD

A Platinum RTD is a "Resistance Temperature Detector" made with platinum wire, and then encased in a suitable housing. The resistance of the device varies nearly linearly with temperature over a very wide range of temperature, and is also stable over long times. This makes a platinum RTD an excellent thermometer for many applications.

Before use, however, the RTD must be calibrated. Since each device can varyy slightly in its manufacture, each RTD must individually be calibrated. However once calibrated, we can assume that the calibration will not change over the course of our experiments.

2.2.1 Connect Voltge and Current Leads

Connect the voltage leads to one of the digital multi-meters (DMM) and set it to measure DC Voltage. Connect the current leads to a power supply. Do not turn on the power supply yet.

2.2.2 RTD Calibration Procedure

For this experiment, we will assume that the resistance of the thermometer varies linearly with temperature, or

$$T = a_0 + a_1 R \tag{1}$$

where the resistance R is measured in Ohms, and the temperature is given in Kelvin.

We will use a simple 3-point calibration. For more exacting work, many more reference points would be used, and a higher order polynomial would be used in place of Eq. 1. Specifically, we can measure the resistance at three well-controlled temperatures (room temperature, an ice-water bath at 273.15 K, and liquid nitrogen at 77 K.

1. Record the resistance of the RTD at room temperature. Also record room temperature.

2. An ideal well-mixed ice-water bath will have a temperature of 273.15 K. Unfortunately, the sample is very sensitive to water. Put the sample in a small plastic bag to keep it dry. If it gets wet, the sample may be destroyed. Please be very careful not to get the sample wet.

   It may take a minute or two to stabilize. Once it is stable, record the resistance of the RTD in the ice-water bath.

3. *Wear safety glasses and gloves whenever handling liquid nitrogen.* Remove the sample from the plastic bag and place it in the dewar. Keep all the wires attached. Place the dewar inside a larger container (to contain spills).

   Slowly and carefully pour a small amount of nitrogen into the dewar. It will boil vigorously. That's ok, but add the liquid *slowly and carefully* to try to avoid splashing. Do *not* cover the sample with liquid nitrogen—it will take too long to all boil off! Cover the dewar lightly with a piece of foam. Do *not* seal the dewar! Attempting to confine liquid nitrogen to a fixed volume can lead to a dangerous build-up of pressure.

   An ideal well-mixed liquid nitrogen bath at its boiling point will have a temperture of 77 K. Once the liquid is calm, record the resistance of the RTD. It should be in the range of about 19 Ω. It may take a minute or two to stabilize.

4. Fit your measured values to Eq. 1 to find the a_0 and a_1 values necessary to convert resistance to temperature.

2.3 Superconducting Critical Temperature

The critical temperature can be measured by observing the point at which the sample resistance becomes immeasurably small while cooling, or, equivalently, by measuring the temperature at which the resistance suddenly jumps upon warming. As a practical matter, it is much easier to warm slowly in a controlled manner, so that is the transition we will use.

Much of the equipment may already be set up from a previous run.

2.3.1 Connections

1. Record the label from your superconductor. Include that information in your description of the results.

2. Gently place the device in a small dewar. Place the dewar inside a larger container (to contain spills).

3. Connect a constant-current power supply to the current leads. Any supply with a current-limiting mode ought to work fine. The maximum safe current is 0.5 A, but a value of half that is plenty for this experiment. Set the current knob to zero and turn the voltage knob about 1/4 of the way up. *Slowly* increase the current knob until a current of about 0.25 A flows. The value will fluctuate a little as the power supply warms up, but ought to settle down.

4. Connect the voltage leads to a Keithley 2000 DMM. Set this to read DC Volts. If you get a negative voltage, swap the leads. In order to read the values on the computer, you may need to use the front panel to enter the GPIB menu (use the `Shift` key),

set the address to 14, and the `Lang` to `SCPI`. (Move within a menu entry with the left and right arrow keys, change values with the up and down arrow keys, and press `Enter` to enter a value.)

5. Connect the RTD leads to a second Keithley 2000 DMM. Set the DMM to read resistance. In order to read the values on the computer, you may need to use the front panel to enter the GPIB menu (use the `Shift` key), set the address to 15, and the `Lang` to `SCPI`.

2.3.2 Data Collection

1. On the computer, launch the `superconductivity` LabView program. Enter the current in the input current box.
2. Enter your RTD calibration values for a_0 and a_1. (Do not assume the default values are correct.)
3. The computer will record the resistance and temperature repeatedly. You can change the delay between data points by changing the `delay` box. A value of 0.5 s works well.
4. Select a `.txt` file name to store the final data.
5. Wear safety glasses and gloves whenever handling liquid nitrogen. *Slowly and carefully* pour nitrogen into the dewar. It will boil vigorously. That's ok, but add the liquid *slowly and carefully* to try to avoid splashing. Do *not* cover the sample with liquid nitrogen—it will take too long to all boil off!

   Watch the resistance and wait for it to stabilize. Once the temperature gets below about 85 K, the sample is sufficiently cold.
6. Check that the current I is still constant and that the value entered into the computer program is still correct. Wait until the boiling subsides. There should still be a small amount of liquid at the bottom of the dewar.
7. While still wearing the gloves, add some foam insulation to the top of the dewar and press it down gently. Do not seal off the dewar; just cover it gently.
8. Start the computer program to record the temperature and resistance. You start the program by pressing the small arrow on the top toolbar. The program will run as long as the big green button is green. When you press the green button, the program will stop and prompt you for a place to store the output file, unless you have already entered the filename above. To start the program again, you have to press the big button so that it turns green and then press the small "run" arrow on the top toolbar.

9. The temperature should intially read 77 K, but likely will be slightly off due to our imperfect calibration. If it is significantly off, you may need to re-do the calibration.

10. There will be a fairly sharp jump in resistance when the sample warms above the transition temperature. Since the sample is not a single uniform crystal, there actually will be a small range of transition temperatures. In addition if there are any temperature gradients in the sample, not all parts will go through the transition temperature at the same time. In this experiment, the transition typically takes place over a range of about 5 K. Depending on how much liquid nitrogen you added, it might take up to half an hour to warm sufficiently.

11. Once the sample is warm enough that it no longer is superconducting, you should stop the program by pressing the big green button. Copy the data to a safe place so that it isn't accidentally overwritten.

3 Analysis

1. Plot resistance *vs.* temperature for the warming portion of your data. Delete any extraneous data before making your final plot.

2. In this experiment, the transition typically takes place over a range of about 5 K. Make your best estimate for the transition temperatures for your sample. How does it compare with published value?

   (a) You can sometimes improve your estimate of T_c by fitting a straight line to the data shortly above the transition and extrapolating back to $R = 0$.

   (b) No formal uncertainty analysis is required, but you should give an estimate of your uncertainty in the critical temperature, and discuss the observations that support your estimate.

   (c) Note that the value for $Bi_2Sr_2Ca_{n-1}Cu_nO_9$ depends on the n value. The samples supplied by QuantumLevitation have an unspecified composition. They likely contain both $n = 3$ and $n = 2$ components. This will likely lead to a much broader transition. Is that consistent with your observations?

   (d) Though you can search for published values through the "Web of Science" through the Lafayette library home page, you may find it difficult to wade through all the citations. The Wikipedia references for "BSCCO" and "YBCO" are pretty helpful. A relatively recent *CRC Handbook of Chemistry and Physics* (available in room HSC-042) also has tabulated values for many superconducting compounds. Finally, the "Experiment Guide" posted on Moodle has many more details.

   (e) Initially, the sample warmed very slowly. However, as soon as it reached the transition temperature, the temperature rose more rapidly. Why do you think that is?