PHYS 18L: Investigation of Superconductivity

Amelia Konomos

Professor: Huan Huang

Lab 1A

April 19, 2022

Abstract

In this lab, we explored the phenomenon of superconductivity and the principles surrounding the Meissner effect. We used the myDAQ data acquisition system to measure two voltages and one current. Our two voltage measurements were the voltage across the thermocouple and the voltage across the superconductor. We measured the current across the wire to be 267.5 +/- 0.5mA. We used the current measurement combined with the voltage across the superconductor to calculate the resistance as 3.738E-3 +/- 0.001E-3 Ohms. Finally, we calculated the critical temperature to be 109+/- 1K.

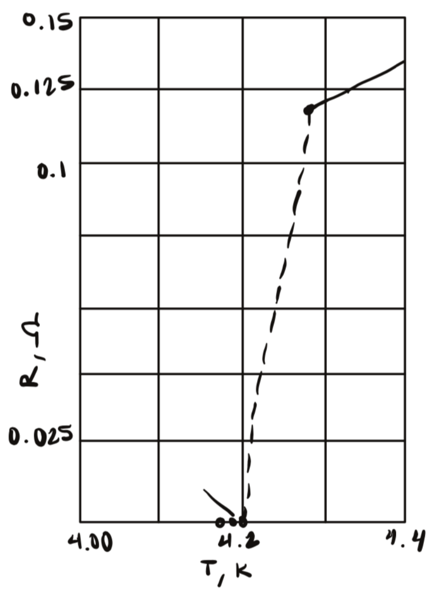

Figure 1: Graph showing the temperature dependence of the resistance of mercury

1 Experimental Theory and Objective

1.1 Superconductivity

The phenomenon of superconductivity was discovered in the early twentieth century by H. Kamerlingh Onnes at the Low Temperature Laboratory of the University of Leiden in the Netherlands. Onnes later won the 1913 Nobel Prize in Physics for this discovery. Superconductivity occurs when the electrical resistivity of a material vanishes at the critical temperature. This anomaly defies any classical explanation. In other words, superconductive materials will conduct direct current electricity while maintaining their energy at the critical temperature. The investigation of superconductivity at significantly high temperatures has become a prosperous field of research.

In this lab, understanding the mechanisms of critical temperature is integral to our data collection and analysis.

1.2 Objective

For this experiment, we tested two ceramic materials known as YBCO and BSCCO.

$$YBCO = YB_{a2}C_{u3}O_7 \tag{1}$$

$$BISCOO = Bi_2Sr_2Ca_2Cu_3O_{10} \tag{2}$$

The samples we used were provided by the Colorado Superconductor. With this experiment, we also explored the Meissner effect, discovered by Meissner and Ochsenfeld in the early twentieth century. This manifestation of superconductivity is characterized by the expulsion of a magnetic field from a material that is transitioning to a superconductive state. A cooled sample is superconducting when it agrees with equation 3.

$$T < T_c \tag{3}$$

Classically, we would expect a for a magnetic field in a superconductor to remain constant in agreement with Faraday's law. Surprisingly, this is not what is observed but rather we see the magnetic field is expelled from the superconductor. The Meissner effect has important implications for magnetic levitation.

$$T_c > 77K \tag{4}$$

Both YBCO and BSCCO agree with equation 4.

$$R = \frac{V}{I} \tag{5}$$

Finally, we will use Ohm's Law to calculate resistance values, as shown by equation 5.

2 Experimental Setup

2.1 Safety

In this laboratory, safety precautions were a priority because liquid nitrogen is a hazardous substance. This is because liquid nitrogen can cause cryogenic burns, asphyxiation, and high-velocity projectiles. We made sure to work in well-ventilated areas and avoid spilling amounts of liquid nitrogen. We wore safety glasses to avoid any high-velocity projectiles.

2.2 Equipment

Our laboratory equipment included two superconducting probes, YBCO and BSCOCO. We used one magnetic levitation kit that included rare earth magnets to explore the implications of the Meissner effect. Our electronic instruments included a myDAQ, an adjustable current and voltage power supply, and a digital multimeter. The DAQ refers to the data acquisition system which measured voltage and current. Our mechanical instruments included an adjustable stand, a clamp, rod, labjack, Styrofoam cryostat, screwdrivers, tape, and low-thermal-conductivity tweezers. Our laboratory cables included banana-to-banana cables, banana-to-clip lead cables, a wire stripper, a current-limiting resistor, and an insulated copper hook-up wire. Finally, we used a sample of liquid nitrogen.

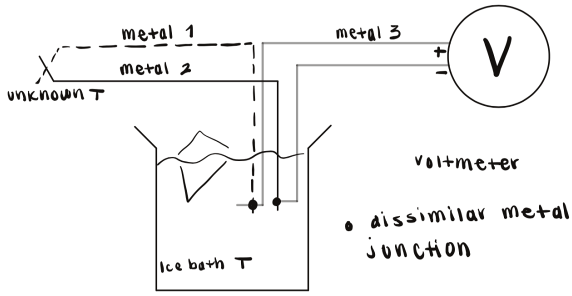

Figure 2: Standard thermocouple depiction

The superconducting probes includes a T-type thermocouple with dissimilar metals of copper and constantan.

3 Experimental Methods

3.1 Pre-Experiment

To begin the experiment, we used the NI ELVISmx digital multimeter to check the lead resistances. We used the NI ELVISmx data logger to set up the myDAQ to measure the room temperature for the thermocouple.

3.2 Constructing our Data Acquisition System

Our DAQ system took measurements of two voltages but only one current. It is typical for voltage signals to be noisy so we made sure to take multiple measurements and then the average of those measurements to get the most accurate data point. The current through our superconductor was large and significantly less noisy, and we measured it to be 267.5 mA. We configured the two myDAQ analog input channels together since they share internal timing resources.

3.3 Main Experiment

The main objective for the experiment was to connect the probe to the myDAQ unit to perform automated data acquisition. The myDAQ instrument is powered by a USB bus and has a minimum of 100 mW available for the outputs. Our probes had two wires for T-type thermocouple, and four wire resistance measurements. We used the stand, clamp, rod, and tape to set up the CS superconducting probe so that it hung vertically below the wires. Next, we connected the probe wires to the myDAQ to ensure that the current was sourced and we could collect accurate measurements. We used a labjack to carefully raise the Styrofoam cyrostat and place it into the liquid nitrogen and thus cool the cyrostat. In order to warm the probe, we lowered the cyrostat. We tried to minimize the translations of the cryostat relative to the prob in order to obtain the most accurate data. We set a voltage limit of no more than 5V and made sure to cool and warm slowly when taking measurements.

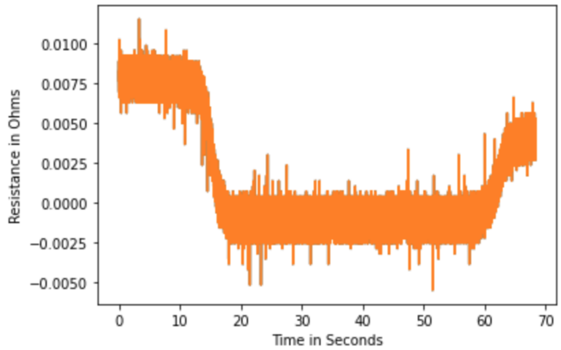

Figure 4: Resistance over time.

4 Experimental Results and Conclusions

We constructed a txt file using the myDAQ system, consisting of time, myDAQ1, and (myDAQ)/ ai 0 and ai 1. Here, ai 0 and ai 1 refer to the audio input channels. In our data set, we took two measurements for the voltage. One was for the voltage across the thermocouple and the other was for the voltage across the superconductor. This second voltage measurement can be used to calculate the resistance. For the voltage across the superconductor, we used Ohm's Law to take the average voltage over the current and found the resistance to be 3.738E-3 Ohms. We estimate this resistance value has an error of 0.001E-3 Ohms. This data comprises our main measurements and analysis for the superconductivity lab. Our error as a function of the experiment for the current measurement is 267.5. +/-0.5 mA. This error estimate does not account for systematic or random error in the experiment. With the myDAQ voltage measurements, we are able to construct a graph of the voltage over time, as seen in figure 5. Here, we observe a upward trend in the voltage as time increases.

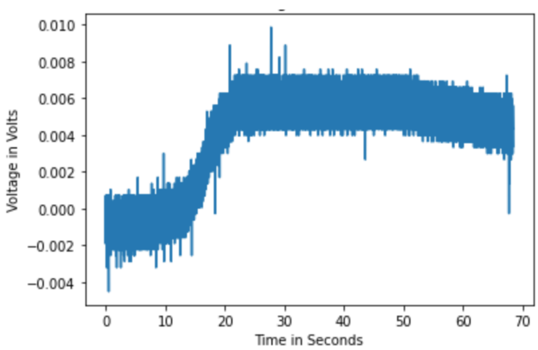

Figure 3: Voltage over time.

Likewise, we are able to graph the resistance over time, as seen in figure 6.

Conversely, we observe a downward trend for the resistance as time increases. Finally, we found the superconducting or critical temperature of the BSCCO wire which is found where the resistance of the sample equals zero. We calculated this to be 109K. We used the lowest temperature segment of the data to find where the resistance changes to above zero, which is at 88K. Since voltage is linearly related to temperature, we constructed a resistance vs temperature plot.

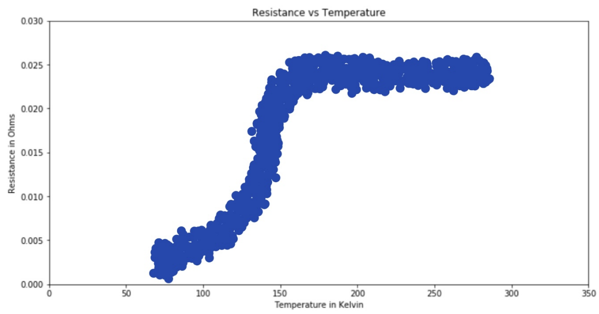

Figure 5: Resistance vs Temperature plot.

We were able to extract the resistance and temperature from the raw data to make this plot. Our error measurement for the critical temperature of 109K is +/-1K. These calculations and the graphs are the extent of our data analysis for superconductivity.

5 Further Discussion

It is possible that the probe and possibly the myDAQ moved during the experiment, causing an error in the data. Since accurate data corresponds to slower temperature changes, it is also probable that our translations of the cryostat relative to the probe were too large and thus our data was effected. Furthermore, thermocouple wires are fragile and they may have been damaged in past labs. Finally, it is known that the thermocouple leads will conduct heat away from the myDAQ contacts which in turn will change the temperature of the junction. This is a likely source of error in the experiment as a whole. In the future, we would like to explore the Meissener effect further by conducting more rigorous tests of the magnetic levitation kit.

6 References

[1] UCLA Physics 18L Manual
[2] DOE Explains...Superconductivity. Office of Science.