Using LabVIEW to Study High-Temperature Superconductors

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Abstract. This study investigated the critical temperature of the high-temperature superconductor $YBa_2Cu_3O_7$ using an experimental setup designed to measure temperature, voltage, and current. The setup included a four-point probe, LabVIEW programming for data acquisition, and liquid nitrogen for cooling. Resistance versus temperature data was collected as the sample warmed, revealing evidence of superconductivity. The critical temperature was determined using two methods: the temperature at which resistance became zero, determined as 90.4 K, and an extrapolated linear fit method, determined as 100.0 K. The two values deviated from the accepted critical temperature of 93 K. Future improvements are proposed to enhance the reliability of the results. Despite discrepancies, the experiment successfully demonstrated superconducting behavior in $YBa_2Cu_3O_7$.

INTRODUCTION

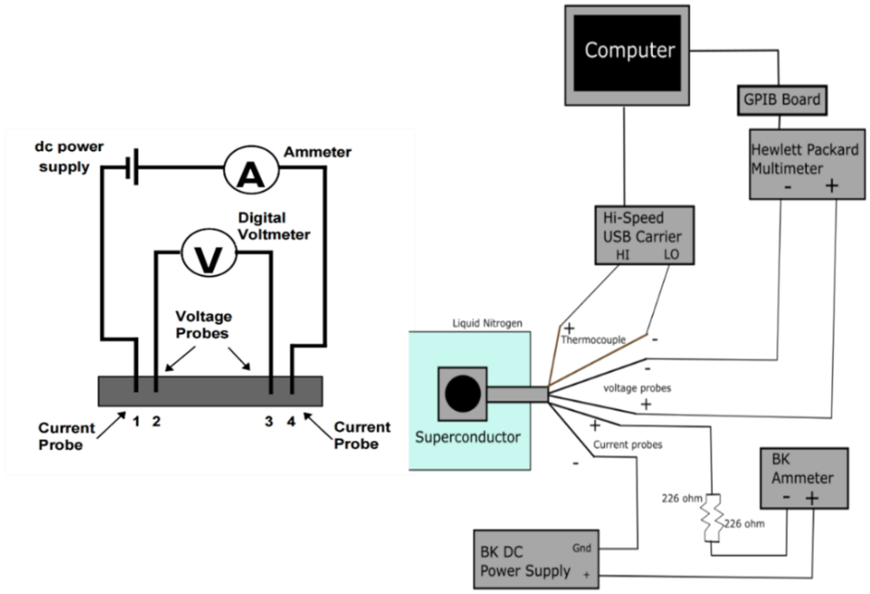
Superconductors are valuable because they can conduct electricity without resistance under specific conditions. Generally, in metals, resistance decreases as temperature decreases.[1] In the case of superconductors, once they are cooled below a temperature known as the "critical temperature," the resistance decreases to zero. The Bardeen-Cooper-Schrieffer (BCS) theory describes how superconductivity works, attributing the lack of resistance to the presence of "electron pairs."[2] All the electron pairs move coherently within the superconducting material, creating zero resistance. Superconductors also possess interesting magnetic properties, such as repelling magnets through the Meissner effect: when a material transitions from the normal to superconducting state, it undergoes the expulsion of a magnetic field from its interior.[3]

The presence of zero resistance allows superconductors to carry electric current very easily, as well as power electromagnets. Practical applications span from MRI machines and maglev trains to computer chips and particle accelerators.[4] The critical temperature is an important factor for the practical use of superconductors, as they need to be kept below that temperature to access superconducting properties.[4] High-temperature superconductors are classified as those whose critical temperatures are above the 77-K boiling point of nitrogen[4] and are of great interest because liquid nitrogen is an abundant and cheap refrigerant. For this experiment, we studied $YBa_2Cu_3O_7$, the first material discovered with a critical temperature above the boiling point of nitrogen. In this paper, we review how our research team created a setup to collect data on and determine the critical temperature of our superconductor.

THE EXPERIMENT

We utilized a $YBa_2Cu_3O_7$ superconductor from the Superconductivity Complete Exploration Kit from Colorado Superconductor Inc.,[5] which is manufactured to connect with two wires to act as a voltage probe, two wires to act as a thermocouple, and two wires to act as a current probe, as seen in Fig. 1. This sample was measured once.

A B&K Precision DC regulated power supply was utilized as the power source. In series with it, we placed two 226-Ω MEPCO resistors, the current probes of our sample, and a B&K Precision Tool Kit ammeter. The resistors were used to limit and keep constant the current through the superconductor. The current was assumed to be constant and measured by the ammeter. The voltage probes for our sample were connected to a Hewlett Packard 3478A multimeter, which, in turn, was connected with a GPIB board to a desktop computer. The GPIB board used a LabVIEW program to log the data. The thermocouple leads on our sample were wired to a high-speed USB carrier NI USB-9219 to collect temperature measurements and send them to the desktop computer and the LabVIEW program. The overall wiring configuration is shown in Fig. 1.



(a) (b)

Figure 1. (a) Schematic of the four-point measuring system. (b) Sample and devices connected through the high-speed USB carrier and the GPIB board to the computer.

A four-wire measurement system with the configuration shown in Fig. 1 was used to determine the voltage and current. If a two-wire measurement were used, the calculated resistance would have been inaccurate because the multimeter would record the resistance of the sample plus the resistance of the wires leading to the sample, which was not zero. We utilized LabVIEW programming to control our instruments. The front panel (not shown) of our LabVIEW program displayed the voltage and temperature of the sample, as well as any errors that might be displayed by our instruments.

The block diagram we wrote is shown in Fig. 2. We used the DAQ Assistant block to measure the temperature of the sample. It was wired to Dev1, which corresponded to the NI USB-9612 we used with our thermocouple. The data output from the DAQ Assistant block was in the form of dynamic data, so we converted it to double and unbundled it to isolate the temperature. From here, we had a branch connect to display the data on the front panel and another to index the values.

To access data from the multimeter, we required a different series of blocks for the program. These were, in order, VISA Open, VISA Write, VISA Read, and VISA Close. Since each one was wired to the previous block, they operated sequentially. VISA Open began by inputting the name of the equipment being wired to it. In our experiment, the Hewlett Packard 3478A multimeter registered GPIB0::21::INSTR as the input. This identified the device being used, and it was wired through to each one of the VISA icons. The next icon, VISA Write, took in a command as a string. Our command was to identify the voltage at an instant of time measured by the multimeter and write, as a string, the value measured by the device. The next step, VISA Read, then read out the value written by the previous step; it read up to 100 bytes. The value was then converted from a string to a double, and it was indexed and wired to an indicator on the front panel. Finally, VISA Close finished the task for this iteration.

Both of these sequences were contained within a while loop, which was connected to a stop button to finish and a wait function to space out the data more evenly, by 100 ms. Once the while loop was closed, the data from both instruments was written into an array, which was then saved as a delimited text file. The DAQ Assistant block and the VISA programs included an error output so that we could monitor and manage any potential problems that occurred in the course of the experiment.

Once all the equipment was correctly wired and connected with the LabVIEW program, the superconductor sample was immersed in liquid nitrogen. The LabVIEW program was promptly run to collect the voltage and temperature data of the sample as it warmed up over the next few hours. The current was measured by the ammeter.

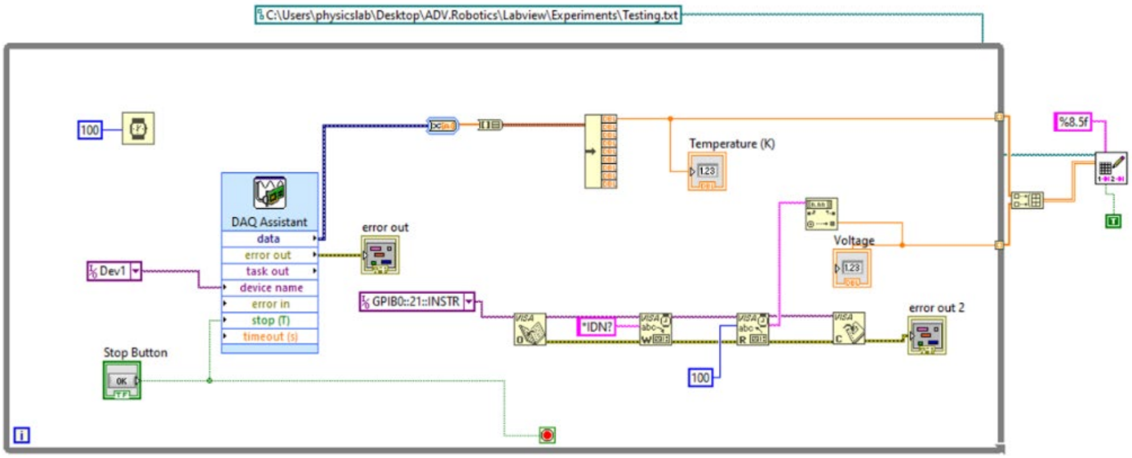


Figure 2. Block diagram of the LabVIEW program.

DATA AND RESULTS

The resistance across the sample was calculated from the measured voltage and average current using Ohm's law. We used the measured value of 77.5 mA for the current. Figure 3 shows the resistance plotted against temperature as the superconductor sample warmed up.

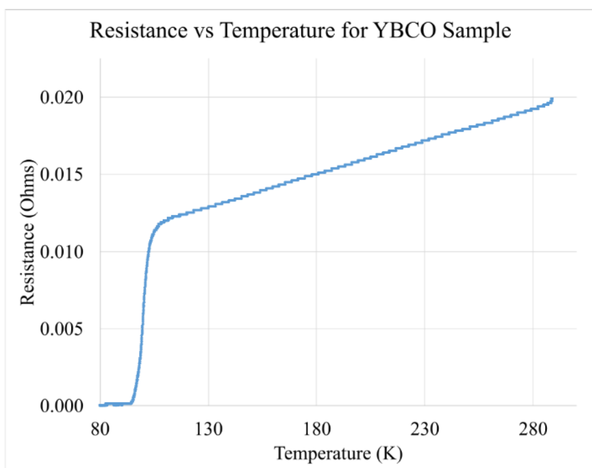


Figure 3. Resistance vs temperature data of $YBa_2Cu_3O_7$.

Previous work reports a T_{C0}, defined as the temperature at which the resistance is zero, of 91 K, with a transition width of 1.5 K.[6] The same paper shows that the midpoint T_C is 92.5 K. Other works have reported a T_{C0} of 93 K and a drop in T_{C0} when the oxygen content is different from the optimal value of 6.92. Hence, it is important to specify how we defined the transition temperature in our work. For our samples, we obtained $T_{C0} = 90.4$ K. To get the midpoint T_C, we first found a linear fit of the resistance data in the temperature range 110–288 K with an R^2 value of 0.99. This linear fit was added to the resistance versus temperature curve, shown in Fig. 4, and it was used to find the temperature where the associated resistance value was 50% of the extrapolated value. This gave a midpoint $T_C = 100.0$ K. To find the transition width, we utilized the extrapolated line and found the temperature values where the associated resistance was 10% and 90% of the extrapolated value, 96.6 K and 103.3 K, respectively. This resulted in a calculated transition width of 6.7 K.

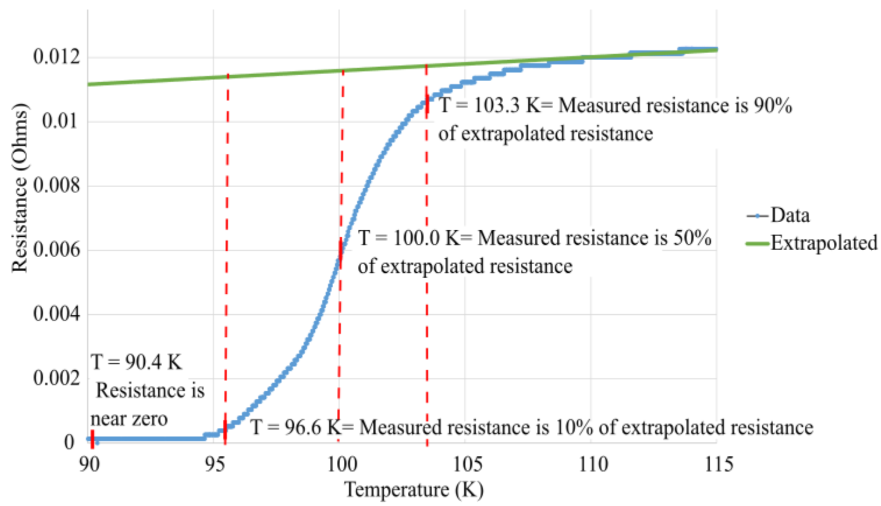


Figure 4. Resistance vs temperature for the $YBa_2Cu_3O_7$ sample with transition temperature and transition width indicated.

The zero-resistance value we obtained, T_{C0} = 90.4 K, is hence consistent with previously reported values, while the high midpoint T_C of 100.0 K and the transition width of 6.7 K are not.[6, 7] The discrepancy indicates that there is a systematic error in our experiment, due to either poor thermal contact between the thermocouple and the sample or lack of cold-junction compensation. Our sample consisted of a rather large disk of diameter d = 25 mm and height h = 3 mm. Its large size makes it prone to temperature gradients, such that parts of the sample could be at different temperatures than those recorded by the thermocouple, which was located in the middle of the bottom side of the sample. We could improve the experiment by ensuring better thermal contact between the sample and the thermocouple, as well as implementing cold-junction compensation. Cryogenic thermometers, such as silicon diodes or Cernox thermometers, could measure the temperature more accurately.

CONCLUSION

We designed an experimental setup to measure and log the temperature, voltage, and current of a $YBa_2Cu_3O_7$ superconductor sample. From this data, we calculated the resistance of the sample, which showed evidence of superconductivity once sufficiently cooled by liquid nitrogen.

REFERENCES

1. J. Tatum, *Electricity and Magnetism* (LibreTexts, 2016).
2. J. Bardeen, L. N. Cooper, and J. R. Schrieffer, “Microscopic theory superconductivity,” Phys. Rev. **106**, 162–164 (1957).
3. W. Meissner and R. Ochsenfeld, “Ein neuer effekt bei eintritt der supraleitfähigkeit,” Naturwissenshaften **21**, 787–788 (1933).
4. P. P. Urone and R. Hinrichs, 34.6: High-temperature superconductors, in *College Physics 2e* (OpenStax, Houston, TX, 2016).
5. *Experimental Guide for Superconductor Demonstrations*, 8th ed. (Colorado Superconductor Inc., 2007), https://www.physics.utoronto.ca/apl/htc/Colorado_Superconductors_Guide.pdf.
6. R. J. Cava, B. Batlogg, R. B. van Dover, D. W. Murphy, S. Sunshine, T. Siegrist, J. P. Remeika, E. A. Rietman, S. Zahurak, and G. P. Espinosa, “Bulk superconductivity at 91 K in single-phase oxygen-deficient perovskite $Ba_2YCu_30_{9-\delta}$,” Phys. Rev. Lett. **58**, 1676–1679 (1987).
7. W. E. Farneth, R. K. Bordia, E. M. McCarron, M. K. Crawford, and R. B. Flippen, “Influence of oxygen stoichiometry on the structure and superconducting transition temperature of $YBa_2Cu_3O_x$,” Solid State Commun. **66**, 953–959 (1988).