Superconductivity and Critical Temperature

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The critical temperature, T_c, of a superconducting ceramic material was found by lowering it into a cup of liquid nitrogen. A circuit was connected to the material to measure the resistance. Once the resistance reached a minimum value after a steep descent, the critical temperature has been reached. Our best data determines this value to be $103.9 \pm 0.5K$. *This value has a* 3.80% *error from the accepted value of* $108K$. *[2]*

I. Introduction/Theory

Superconductivity is the ability of a material to have no electrical resistivity. This ability is only attained for some materials when they are cooled below a certain temperature. This temperature is known as the critical temperature T_c for that material. For most known superconducting materials, the critical temperature is around a few degrees Kelvin [1]. This makes it very impractical to use superconductivity for electrical transmission. However, a group of ceramic oxides were discovered to have critical temperatures above 77 K. The theory behind this phenomenon for the high critical temperature materials is still not completely understood.

Not only can superconductors transmit electricity with zero resistance, but also they can be used to levitate items via the Meissner effect. The Meissner effect ensures that once a material's temperature is below its critical temperature, there must be no magnetic field inside the material.

Since liquid nitrogen has a boiling point of 77 K, it can be used to cool the ceramic material to its critical temperature. However, when connected in a circuit, the resistance will not read 0 because there is a small resistance at the contact junction between the circuitry wire and the superconductor.

The critical temperature can be found by observing the relationship between temperature of the superconducting material and the resistance of the applied circuit. The resistance is calculated via Ohm's law

$$V = IR \tag{1}$$

with a known voltage V and a known current I. The critical temperature occurs when the resistance has reached a minimum as the material is cooled.

II. Experimental Arrangement and Procedure

The ceramic material used is BSCCO ($Bi_2Sr_2Ca_2Cu_3O_{10}$). The material is embedded in a probe with 6 wires made, all made by Colorado Superconductor. The probe can be seen in Fig. (1). 2 Wires are thermocouple leads that are used to measure the temperature. This is done by connecting the two thermocouple leads to a LabVIEW myDAQ to measure the voltage. However, there is an

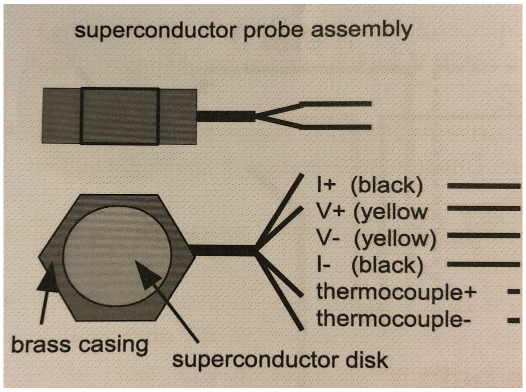

Figure 1: *The superconducting probe with the 6 different wires labeled.*

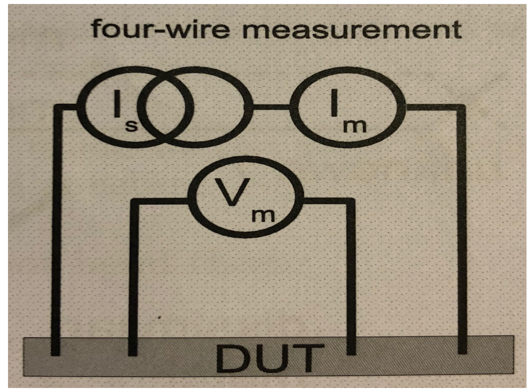

Figure 2: *The setup for the four wire circuit. I_s is the current source and I_m is an ammeter. V_m is a voltmeter.*

offset with the analog-to-digital converter that must be measured. This is done by shorting the myDAQ voltage input channel. The offset was measured to be 7mV. Once the offset is measured, the myDAQ voltage input channel is connected to the thermocouple leads of the probe. A myDAQ assistant VI built by T.A. Brian Zutter is then used to convert the measured voltage to temperature (K). The resultant temperature is checked to be close to room temperature of 293-298 K.

In order to get the probe below its critical temperature, it is slowly lowered into a Styrofoam cryostat with a labjack. However, first it is connected to a four wire circuit as seen in Fig. (2). Two different four wire circuits are made. The first uses constant voltage output of 5V using the myDAQ 5V output channel instead of a constant current source. A resistor is added to the circuit so that the myDAQ input channels don't exceed the current limit of 1.25A [1]. The second four wire circuit uses a constant current supply instead with no resistor. The second four wire setup with constant current instead of constant voltage was able to provide more accurate results due to the fact that a larger current of up to 0.5A is achieved. The larger current minimizes errors because there is no added resistance of a resistor to overshadow the resistance measurements of the superconductor.

The lowering process of the probe into the liquid nitrogen is deliberately slowed to around 5 minutes. This way the temperature of the thermocouple and superconducting material are the same.

III. Data, Analysis, and Results

The probe's temperature was measured as it was slowly lowered into the liquid nitrogen as well as when it was slowly raised out of the liquid nitrogen. The plot of its measured resistance vs temperature when being lowered can be seen in Fig. (3). The current applied was at a constant value of 0.442A during the entire process of lowering and raising the probe. Using Equation (1), the resistance can be solved for given the voltage and constant current measurements.

The resistance measurements were originally in the negative values and decreasing in value as the temperature decreased. However, this offset was just a factor of the voltage offset and was corrected by adding the offset resistance of $16 \pm 1 m\Omega$. This coordinates the minimum of resistance with 0 resistance as a superconductor should have when ignoring the offset contact voltage. Ignoring the offset contact voltage does not interfere with the critical temperature measurement because it only shifts the data up or down. The critical temperature is identified along the x-axis so only shifts/dimension

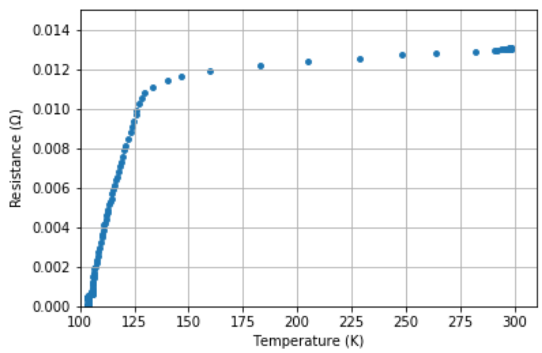

Figure 3: *The graph of the probe's temperature vs the probe's resistance at a constant current of* $0.442A$.

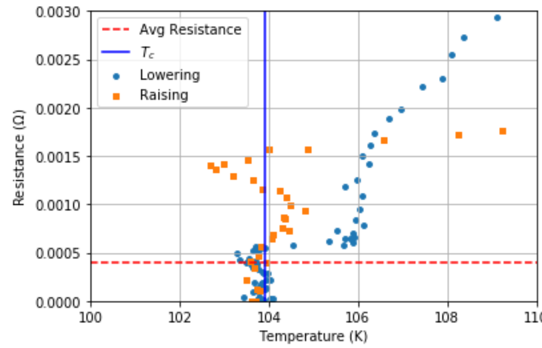

Figure 4: *A zoomed in portion of Fig. (3) of where the critical temperature is reached. The solid line is the critical temperature.*

changes in the left and right directions would interfere.

With a zoomed in view and the added data from raising the probe as well, Fig. (4) shows the critical temperature along with the average resistance when the material is superconducting. In order to calculate the critical temperature, the average temperature of the data points in an approximately vertical line was taken. The critical temperature is measured to be $103.9 \pm 0.5K$. The average resistance below that temperature is identified as $4 \pm 1m\Omega$. A possible explanation for why this value is not $0m\Omega$ is that the contact voltage does not stay constant as the temperature changes. This means that when the minimum resistance measurement is offset to $0m\Omega$, all other fluctuations in the contact voltage cause the resistance measurement to read greater than $0m\Omega$. Additionally, the raising data's line near the critical temperature is not as vertical as the lowering data's line. This is likely due to the fact that the probe was raised faster than it was lowered. This means that the temperature of the material and thermocouple were not in sync.

IV. Conclusion

The measured critical temperature for the BSCCO of 103.9 ± 0.5K has a percent error of 3.80% from the accepted value of 108K [2]. This error could be due to an incorrect thermocouple voltage offset. The offset value of 7mV is large compared to the measured voltage of the probe which can be a source of error. Changing this offset shifts the graph in Fig. (4) to the left or right. Therefore, it would change the value of the critical temperature.

The lab may improved by running more trials on the probe. Additionally the lowering and raising time can be lengthened to ensure the thermocouple and material are at the same temperature. Another way to improve the lab is to have another method of measuring the temperature of the probe when it's at room temperature. That way, instead of ensuring that the thermocouple voltage gives the temperature in the range of room temperature, 293-298K, it can be ensured that the thermocouple voltage gives the exact temperature of the probe.

The BSCCO material is a special case because not only is it superconducting at certain temperatures, but also those certain temperatures are much higher than the commonly referred to superconducting sources. A temperature of 108K is still extremely low, but clearly much more attainable than the few degrees Kelvin required for the other materials. This highlights the much improved practicality of using superconducting materials for everyday purposes such as electricity transmission or levitating trains. However, much more research is needed to where it becomes a viable option.

References

[1] G. Wang, Physics 18L Lab Manual (2018).

[2] UCSB Physics
web.physics.ucsb.edu/ lecturedemonstrations/Composer/Pages/64.27.html