Superconductivity

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Abstract

The critical temperature of a superconductor was measured using a type T thermocouple and a four point electrical probe. The probe was submerged in liquid nitrogen, allowing it to cool to 77 K. The temperature and resistance was then measured after the probe was raised out of the liquid nitrogen and allowed to warm to room temperature. An additional set of data was taken while a magnet was placed next to the superconductor. The critical temperature measured without the magnet was found to be 103.8 ± 2.9 K. The critical temperature measured with the magnet was found to be 103.9 ± 3.1 K. No significant change in critical temperature was observed to occur by the addition of a magnet. However, the initial resistance of the superconductor was affected by the magnet; it was a small positive value, as opposed to the expected value of zero.

1 Introduction

Superconductivity was first observed by Heike Kamerlingh Onnes in 1911. While working with mercury that had been cooled by liquid helium, Onnes noticed that at the resistance through the mercury disappeared. He found not only that mercury becomes what he deemed a superconductor at 4 K, but also that lead superconducts at 7 K [1].

The purpose of this experiment was to determine the temperature at which our given superconductor is able to superconduct. Additionally, a magnet was placed near the superconductor to see if that affected the critical temperature in any way.

2 Theory

Normal conductors work because the electrons are able to move freely through the material, or flow. In superconductors, due to the cold temperatures, the electrons are able to flow without experiencing the energy consuming interactions of normal electrons. This means that though there is a current through the superconducting material, there is no resistance and thus, once a current begins to flow, it can keep going forever.

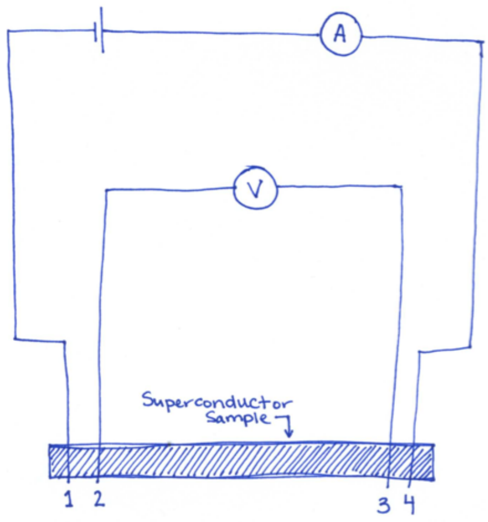


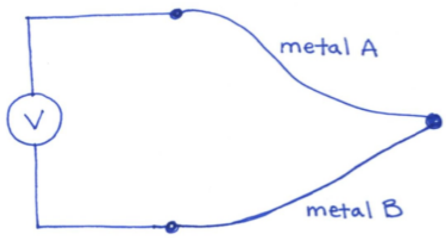
Figure 1: A four point electrical probe. The current probes are located at numbers 1 and 4 on the diagram. Through these wires, a current is produced by the power supply and is read by the ammeter after passing through the superconductor sample. The voltage probes are located at number 2 and 3 on the diagram. These serve to measure the voltage across the superconductor sample.

In order to calculate the critical temperature, resistance measurements need to be taken. For this, there is a four point electrical probe. This probe, shown in Figure 1, consists of four wires connected to the superconductor sample. Two of the wires connect to a voltmeter so the voltage across the sample can be read. The other two wires connect to an ammeter and a power supply, which both reads and produces a constant current through the superconductor. This probe is then placed in a casing to prevent damage.

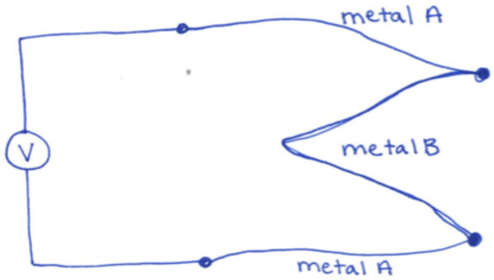
A thermocouple was used to measure the temperature of the superconductor. A thermocouple is simply comprised of two dissimilar metals attached together. When the junction between the two metals is heated or cooled, a temperature-dependent voltage is created. There are different types of thermocouples, each with different combinations of metals. Common types include T, K, J, and E.

Two designs of thermocouples are single junction and double junction, both of which can be seen in Figure 2. A single junction consists of two metals in the form of wires attached together at one end, with a voltmeter connected on the other end of both metals. A double junction has the first type of metal attached to either end of the second type, creating two places where they touch. Both of the free ends of the first type are where the voltmeter wires are attached.

Though a single junction thermocouple is simpler, a double junction is more accurate. Because the wire that attaches the thermocouple wires to the voltmeter is made of metal that is different from both types of thermo-



Single junction thermocouple



Double junction thermocouple

Figure 2: Two thermocouple designs. The single junction thermocouple has two types of metal, A and B, attached at one point. Each of those metals is then attached to a voltmeter to read the change in voltage. The double junction thermocouple has more symmetry, with type A attached to type B attached to type A again. Then only the type A metal is connected to the voltmeter.

couple metals, it means a voltage is created across those junctions as well. This usually is small enough to be neglected, but in some situations it can alter voltage readings significantly. The double junction is superior because only the type one metal is connected to the voltmeters wires. The additional voltage that is created cancels out.

3 Procedure

For this experiment, a double junction type T thermocouple was used. One of the junctions was placed inside of the superconductor probe casing, though not touching the superconductor. The other junction was placed into ice water. The ice water served as a constant reference temperature of 0°C (approximately 273 K) while the junction in the probe casing was measuring the sample temperature. The superonductor was submerged in the liquid nitrogen until it cooled to 77 K, the temperature of the nitrogen; when the liquid nitrogen stopped boiling is when the superconductor reached 77 K.

For the first two data runs, I simply started LabVIEW, the computer program measuring the temperatures and resistances, and raised the probe casing out of the nitrogen, allowing it to warm up. After each run, the probe casing was placed back into the liquid nitrogen to allow it to cool back down. Different methods were tried to make the probe warm up at a slower rate. The lid of the liquid nitrogen container was left on before and after the probe was raised, in an attempt to contain the cool air inside of the container. In addition, for the fourth through eight runs, the probe was encased in wire mesh with the idea that the cold wire would keep the probe cooler longer. Also, for runs six through eight, a small magnet was placed directly next to the probe casing to see if there were any significant changes.

Once LabVIEW collected the values for the temperature of the probe and the resistance in the superconductor, the data was then moved to Igor Pro for analysis.

4 Results and Analysis

Once the data was in Igor Pro, the resistance versus the temperature was graphed. This showed an initial steady resistance with a steep rise as the temperature passed 94 K, and a leveling off as the temperature neared 105 K. This graphical trend can be seen in Figure 3.

In theory, the resistance should jump from zero to some positive value at the critical temperature. As seen in Figure 4, the resistance meanders up over the course of almost ten degrees. The question was should it be measured where the resistance first starts to climb, at the inflection point of the curve, or where the resistance begins to level off again. I decided to measure the temperature at the inflection point. Though at that point the superconductor has stopped superconducting (because the resistance is not zero), that is theoretically where all three potential measuring spots should align.

I found the critical temperature for the probe without the magnet to be 103.8 ± 2.9

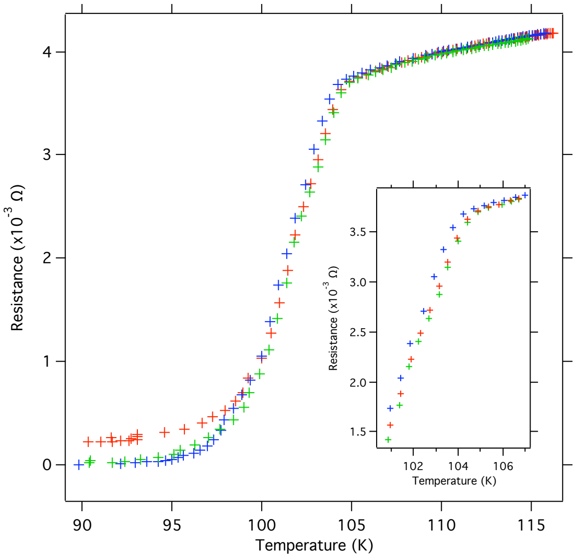


Figure 3: Resistance versus temperature of the superconductor. Three different measurements are shown within this graph. The red data is from when the magnet was placed by the superconductor; the blue and the green data is from when there was no magnet. The red points begin at a higher resistance value, meaning the magnet affected the initial resistance. Additionally, the inset graph shows a close up of the top of the curves. The blue graph has a slightly more defined change in the slope at the top of the curve.

K and the critical temperature for the probe with the magnet to be 103.9 ± 3.1 K. The addition of the magnet did not have any effect on the critical temperature.

The accepted value of the critical temperature for this given superconductor is 94 K. The measured value was about 6 K above that, at best.

As can be seen in Figure 3, there is a distinct difference in the starting resistance of one of the runs. It appears that by placing the magnet in a close proximity of the probe, I was able to create a resistance within the superconductor below its critical temperature. Once the superconductor warmed above its critical temperature, the magnet had no apparent effect on resistance.

5 Conclusion

The critical temperature of a superconductor was measured with and without a magnet present. The values of the critical temperature do not seem to be affected by the introduction of a magnet. The measurements for critical temperature without and with the magnet were 103.8 ± 2.9 K and 103.9 ± 3.1 K, respectively.

The magnet did, however, seem to affect the starting resistance of the superconductor. Where there should have been no resistance, a slight resistance was present. This difference disappeared once the critical temperature had been surpassed.

References

[1] The Naked Scientists, http://www.thenakedscientists.com/ HTML/articles/article/ ahistoryofsuperconduc ivity1160050756/. Accessed 2 March 2010.

[2] Dave Ansell, A History of Superconductors," http://www.superconductors.org/ History.htm. Accessed 2 March 2010.