THERMOMETRY AND LEAST SQUARES FITTING

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Abstract

The effects of temperature on the resistance of a copper coil, a carbon resistor and a superconductor were investigated, and the following trends were found. The copper coil showed that its resistance decreased with decreasing temperature in a linear trend, which follows what was expected. The resistance of the carbon resistor increased with decreasing temperature in a polynomial fashion in the expected way. Finally, the superconductors resistance followed a similar trend as the copper coil up until a point where the superconductor starts superconducting, and the resistance drops suddenly.

Introduction

Resistance is a measure of the opposition to current flow in an electrical circuit (fluke, 2019). The resistance in a circuit can be compared to water flowing in a pipe. The resistance to the flow of charge in an electric circuit is similar to the effects between water and the pipe surfaces as well as the resistance offered by obstacles that are in its path. In terms of in an electrical circuit, the obstacles blocking the flow of the electrons are the atoms of the molecules in the wire. The resistance in a circuit is affected by multiple factors including the length and width of the wire and the material the wire is made from. Not all materials are the same in terms of their conductive ability. Some materials are better conductors than others and offer less resistance to the flow of charge. The conducting ability of a material is often indicated by its resistivity. The resistivity of a material is dependent upon the material's electronic structure and its temperature. For most materials, resistivity increases with increasing temperature (physicsclassroom, 2019). In terms of a generic conductor the resistance of the material increases with temperature as there is an increase in thermal vibrations. Thermal vibrations in a material are caused by a swarm of phonons which impede the organised flow of electrons leading to an increase in effective resistance (Elert, 2019). There are some exceptions to this rule with a primary example being superconductors. A superconductor is a material that can conduct electricity or transport electrons from one atom to another with no resistance. This means no heat, sound or any other form of energy would be released from the material when it has reached critical temperature, or the temperature at which the material becomes superconductive (ffden-2.phys, 2019).

Experimental Methods

The electrical resistance of a superconductor, a copper coil and a carbon-based resistor was investigated over varying temperatures. A cryostat system was used to reduce the temperature below room temperature and create a range of temperatures down to below 77 K. The cryostat system is shown in **figure 1**, showing the resistors and the coil placed in the liquid nitrogen in the inner chamber.

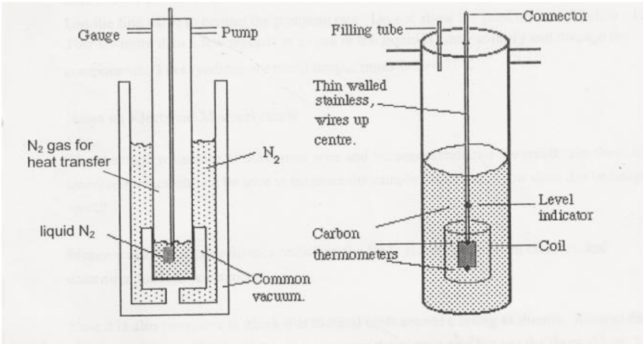

Figure 1: Cryostat system with detailed view of the inner chamber on the right (Script, 2019)

The temperature of the system was measured using an MJE 340 NPN transistor that was calibrated over a range of temperatures. The voltage over the transistor was measured and compared against a table similar to **figure 2**, which allowed the effective temperature to be determined.

Temperature (K)	Forward Voltage at 9.70 μA	Temperature (K)	Forward Voltage at 9.70 μA
294.5	0.4061	164.5	0.7387
260.7	0.4967	134.5	0.8093
257.6	0.5051	128	0.8244
249.3	0.5269	112.1	0.8618
240.3	0.5502	95.6	0.9005
216.3	0.612	83.9	0.9286
203.7	0.6434	77.5	0.9448
184.4	0.6908	76.5	0.9473

Figure 2: Temperature calibration for MJE 340 NPN transistor (Script, 2019)

The process of reducing the temperature involved closing the vacuum pump connected to the cryostat and leaking in nitrogen gas to get the system to atmospheric pressure before adding liquid nitrogen to decreased the temperature to 77 K. At this point to continue decreasing the temperature the nitrogen gas supply is cut off and the vacuum pump is turned on to reduce the pressure of the nitrogen, which lowers the temperature even further.

Results and Analysis

A plot of the transistor temperature calibration is shown in **figure 3**, the plot allows for temperature values to be determined even if the voltage value is not one of the specific points.

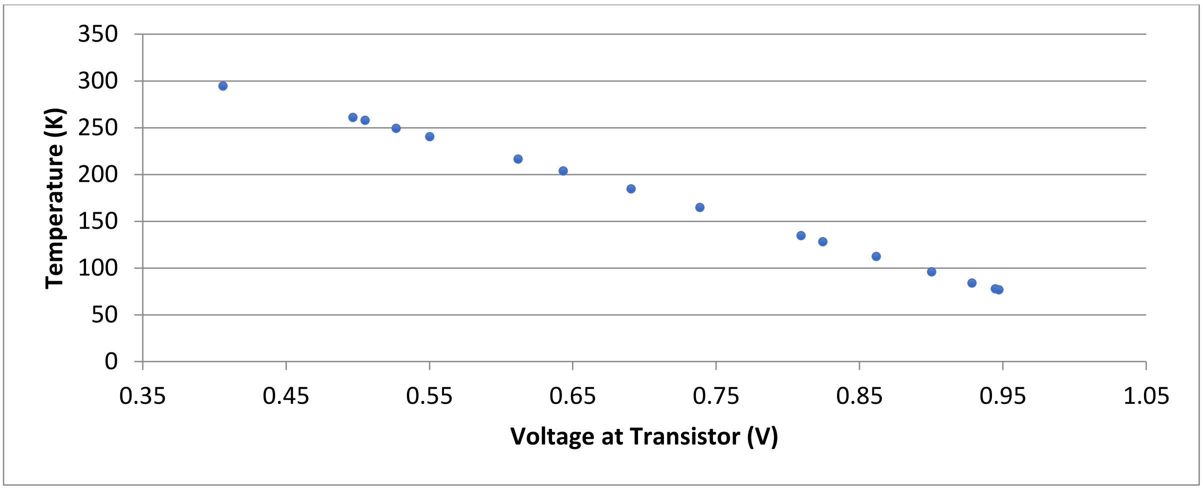

Figure 3: NPN transistor temperature calibration

The voltage and therefore resistance, according to ohms law, for the copper coil, the carbon resistor and the superconductor over a range of temperatures is shown in **figure 4**, **5** and **6** respectively.

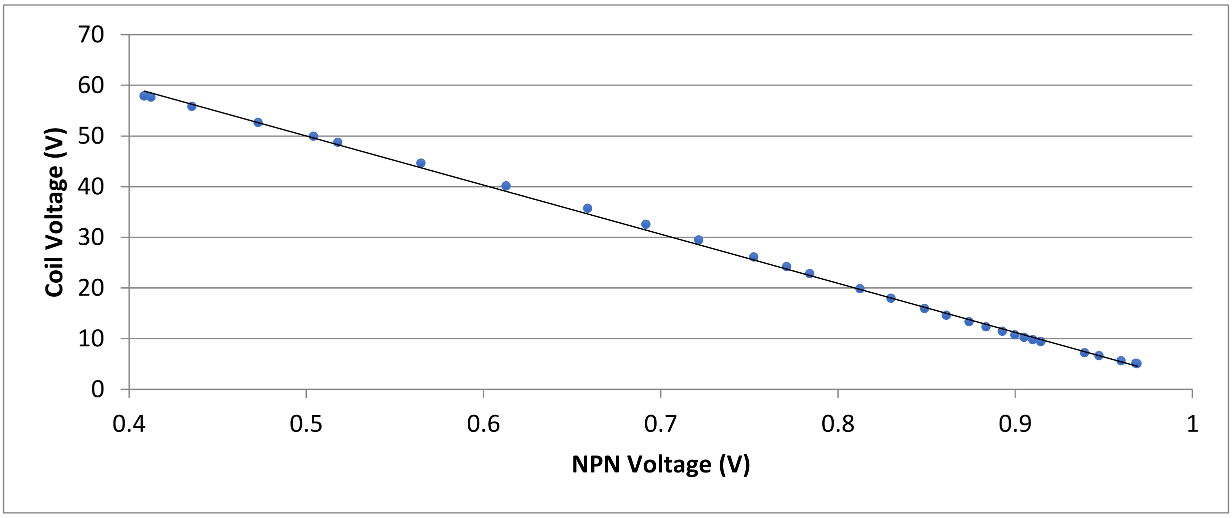

Figure 4: Resistance change of copper coil over varying temperatures

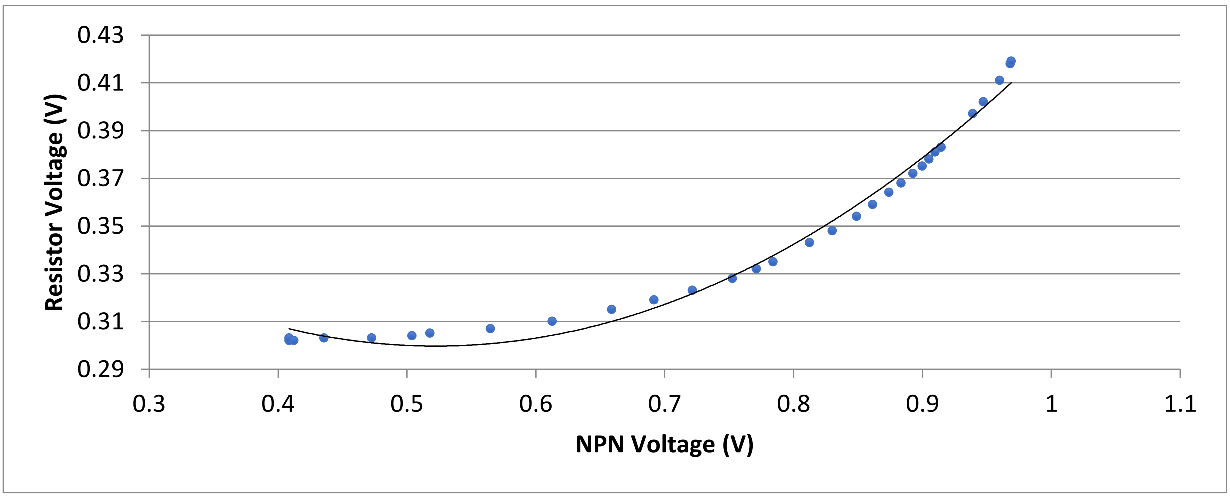

Figure 5: Resistance change of carbon resistor over varying temperatures

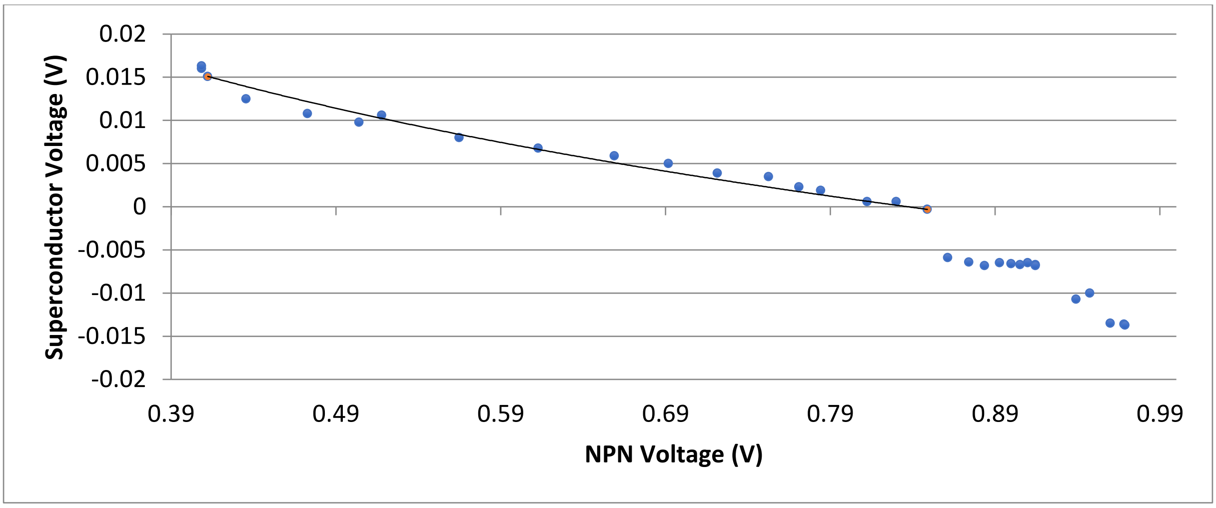

Figure 6: Resistance change of superconductor over varying temperatures, critical temperature at 116 K

The plot for the resistance change of the copper coil follows the expected trend for metals where the resistance decreases with decreasing temperature (increasing NPN voltage). The plot shows this to be a linear relationship.

The resistance of the carbon resistor does not show the same trend as for metals and instead the resistance increases in a polynomial fashion with decreasing temperature similar to that of an insulator.

The resistance of the superconductor shows a third trend where the resistance decreases with decreasing temperature similar to the copper coil up until a critical temperature around 116 K where there is a significant drop in resistance as the superconductor starts superconducting.

Figure 7 shows the presence of thermal emfs in the circuit and how the superconductor effects these. The plot shows the difference in the voltage through the superconductor as the polarity of the voltage in the circuit was switched. The plot shows how the difference in superconductor voltage decreases as temperature decreases, it also shows how the difference is completely mitigated at the point where the superconductor starts superconducting.

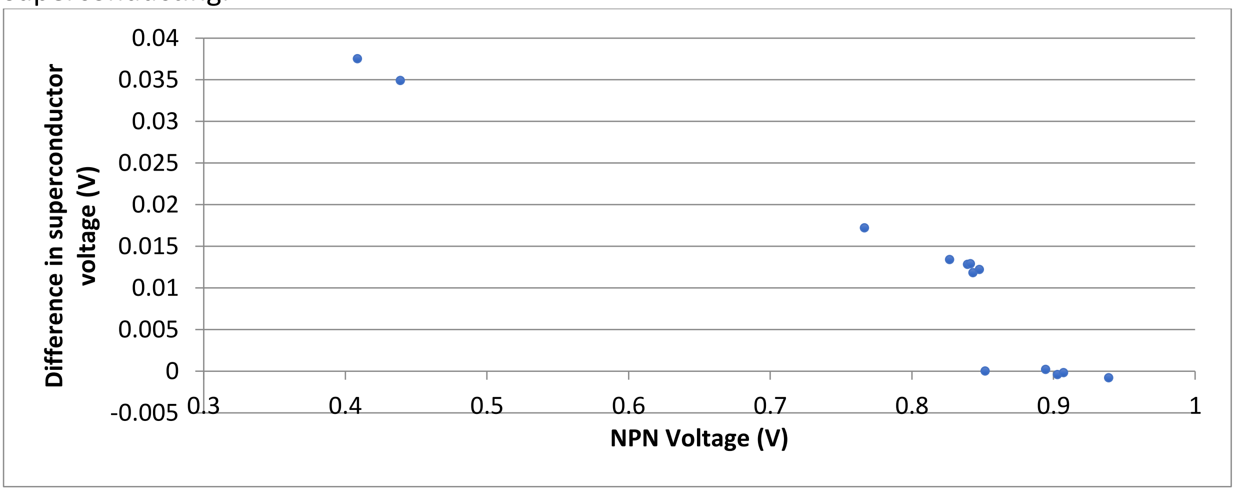

Figure 7: Thermal emfs in the circuit illustrated by the voltage difference of the superconductor when the voltage polarity was switched.

Discussion

Figures 8, **9** and **10** show the expected trends of resistivity/resistance against temperature for a copper coil, a carbon resistor and a superconductor.

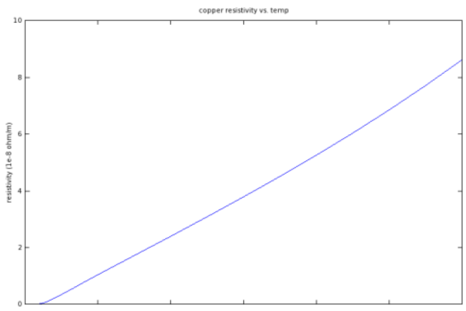

Figure 8: Resistance over temperature for a carbon coil (electronics.stackexchange, 2019)

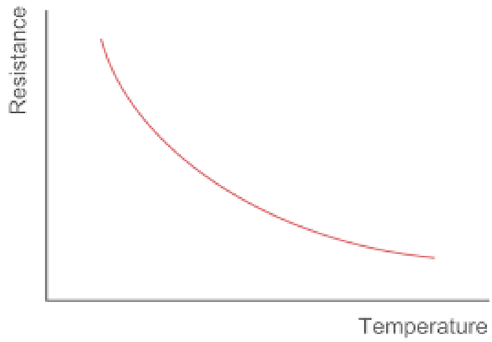

Figure 9: Resistance over temperature for a carbon resistor (electronics-notes, 2019)

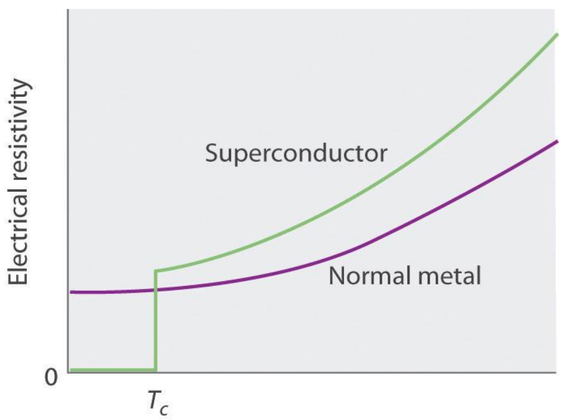

Figure 10: Resistance over temperature for a superconductor (saylordotorg, 2019)

All three plots that were experimentally found match the expected trends as shown in the prior figures (axes reversed). The copper coil showed a proportional relationship between temperature and resistance. The reason for this is because of the increased vibrations of the atoms in the metal with increasing temperature, which deflects the sea of electrons flowing through the coil and results in a higher resistance. The carbon resistor showed the opposite trend with its resistance increasing with decreasing temperature. This is a similar trend to that of an insulator where there are so few free electrons in the atoms that hardly any current can flow. Heating an insulating material vibrates the atoms, and if heated sufficiently, the atoms vibrate enough that some of their captive electrons are released, creating free electrons to carry current. Therefore at high temperatures the resistance decreases (Coates, 2019). The superconductor showed similar results to the copper coil until the critical temperature was reached and it started superconducting and the resistance dropped to zero.

The experimental setup functioned well with all the desired results achieved. Videoing the output of the NPN voltage and the voltage of all three materials lead to increased accuracy and precision as the only source of error would come from the measurement devices. The only questionable result was the fact that the superconductor voltage went below zero insinuating negative resistance however the expected trend was still observed so the equipment must be producing some scaling factor.

Conclusion

The resistance of the copper coil followed the expected trend and decreased with decreasing temperature illustrating the high temperature coefficient of the metal. The carbon resistor did the opposite in a polynomial fashion showing the resistance gradually increase with decreasing temperature. The superconductors resistance follows that of the copper coil until the critical temperature is reached where the resistance suddenly drops.

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