PHY324 Thermistor/Diode Lab

Juan Pablo Alfonzo
juanpablo.alfonzo@mail.utoronto.ca

January 18 2021

Abstract

This experiment had two main objectives. The first being measuring the relation temperature of a thermistor had on its electrical resistance, and secondly exploring the relation of current and voltage of a silicon diode. Both where done by taking experimental measurements, plotting them, and comparing the curves to theoretical ones. Curve fitting was done to solve for various parameters allowing for a relation to be found of the measured quantities.

1 Introduction

There were two main purposes for this experiment. The first being to find the temperature of a thermistor as a function of its electrical resistance. The second was to find how voltage and current were related in a silicon diode. The thermistor data was collected by heating/cooling the thermistor to various temperatures and recording its electrical resistance using an ohm meter at these various temperatures. The data was then fitted to the Steinhart-Hart equation (Eqn 1 in lab handout[1]) in order to find temperature as function of electrical resistance.

The diode was wired into a circuit in which the current flowing through the circuit and the voltage of the diode were measured using an ammeter and voltmeter respectively. An I-V plot was then constructed with the data and curved fitted to the Shockley diode equation (Eqn 5 in the lab handout[1]).

2 Methods & Materials

2.1 Thermistor

- Multimeter
- Thermistor
- Thermometer
- Ice/Boiling Water (or any heating and cooling material)
- Electrical Wires (Banana Cables)

1. Connect the thermistor to the multimeter, and ensure the multimeter is set to the ohm/resistance setting
2. Put ice or hot water in the cup in which the thermistor and thermometer will be placed into. Insure that its position in such a way to ensure thermal insulation (like putting it in a thermos), and that you can read the thermometer while doing so. It is recommended you start with the boiling water as this will cool faster than the ice will take to heat up. This will allow you to sample a wider variety of temperatures in a short period of time.
3. Record the temperature and resistance at various intervals. Every 10 degrees should be adequate.

2.2 Diode

- Power Supply with variable voltage
- Multimeter (2)
- Silicon Diode
- Circuit Switch
- Electrical Wires (Banana Cables)

1. Connect the diode, ammeter, switch, and power supply in series. Add the voltmeter across the diode.
2. Record current and voltage as you slowly vary the voltage from the power supply. Ensure the switch is in the correct position to close the circuit.
3. 10-15 collected data point should be sufficient

3 Results

3.1 Thermistor

3.1.1 Experimental Data

The following measurements were obtained from the ohm meter and thermistor respectively.

Table 1			
Temperature (°C)	Uncertainty in Temperature(°C)	Resistance ($k\Omega$)	Uncertainty in Resistance ($k\Omega$)
87	0.5	8.125	0.30
84	0.5	8.883	0.20
82	0.5	9.646	0.15
76	0.5	14.336	0.10
66	0.5	18.321	0.16
...	...	...	...
10	0.5	157.20	0.05
5	0.5	175.20	0.05
0	0.5	253.99	0.10

Table 1: Electrical Resistance of Thermistor at Various Temperatures.

3.1.2 Curve Fitting

The collected data was fitted to the following equation (inverse of Steinhart-Hart Equation):

$$\frac{1}{T} = a_1 + a_2 ln(R) + a_3 ln(R)^2 + a_4 ln(R)^3 \tag{1}$$

Where T is temperature in Kelvin, R is resistance in kΩ, and a_1,a_2, $a_3$and a_4 are parameters to be determined for each thermistor.

The `curve_fit` python library was used in order to fit this to the collected data. However, it was done in the form

$$y = a_1 + a_2 x + a_3 x^2 + a_4 x^3 \tag{2}$$

Where $y = \frac{1}{T}$ and $x = ln(R)$ in terms of Eqn. 1

This generated the following plot using a Python script that utilizes the `curve_fit` module:

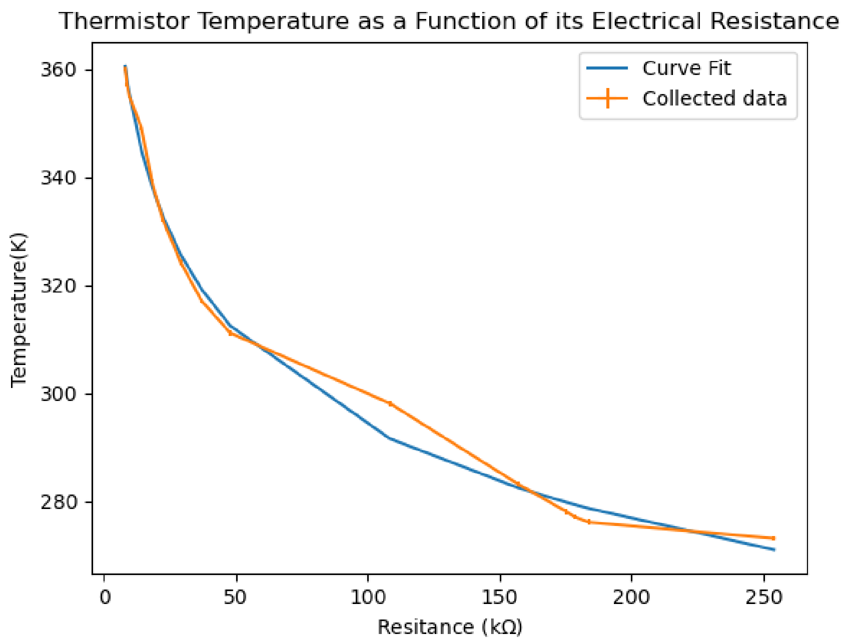

Figure 1: Thermistor Data Graphed along with Curve Fit

3.1.3 Calculated Parameters

The returned parameters from `curve_fit` along with their uncertainties can be found in the table below:

Table 2		
Parameter	Value of Parameter $(\frac{K}{k\Omega})$	Uncertainty in Parameter $(\frac{K}{k\Omega})$
a_1	0.0024114	$\pm$ 6.9348191
a_2	0.00013415	$\pm$ 6.1430384
a_3	1.918495e-05	$\pm$ 1.7273212
a_4	-3.1353440e-07	$\pm$ 0.1545717

Table 2: Electrical Resistance of Thermistor at Various Temperatures.

The χ^2 for this fit was calculated to be 362.54, using the formula:

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{c_i - c(x_i)}{\sigma_i} \right)^2 \tag{3}$$

where c_i is the array containing the experimental resistance measurements, $c(x_i)$ are the points plotted by the curve generated by `curve_fit`, and σ_i are the uncertainties in the resistance measurements. This algorithm was performed using a `Python` programming function and can be found in the code along side this lab report.

3.2 Silicon Diode

3.2.1 Experimental Data

The following measurements were obtained from the ammeter and voltmeter respectively.

Table 3			
Voltage (V)	Uncertainty in Voltage(V)	Current (miliAmps)	Uncertainty in Current (miliAmps)
0.3607	0.0001	0.004	0.001
0.4912	0.0001	0.229	0.001
0.5321	0.0001	0.639	0.001
...	...	...	...
0.8295	0.0001	219.6	0.001
0.8340	0.0001	225.7	0.001
0.8362	0.0001	239.5	0.001

Table 3: Voltage and Current Measured for the Diode

3.2.2 Curve Fitting

The collected data was fitted to the following equation (Shockley Diode Equation):

$$I = I_o(e^{\frac{qV}{kT}} - 1) \tag{4}$$

Where I is the current, I_o is the saturation current, q is the electronic charge $q = 1.6 \times 10^{-19}C$, T is temperature and k is Boltzmann's (in SI units).

The following plot was generated using a Python script that utilizes the `curve_fit` module:

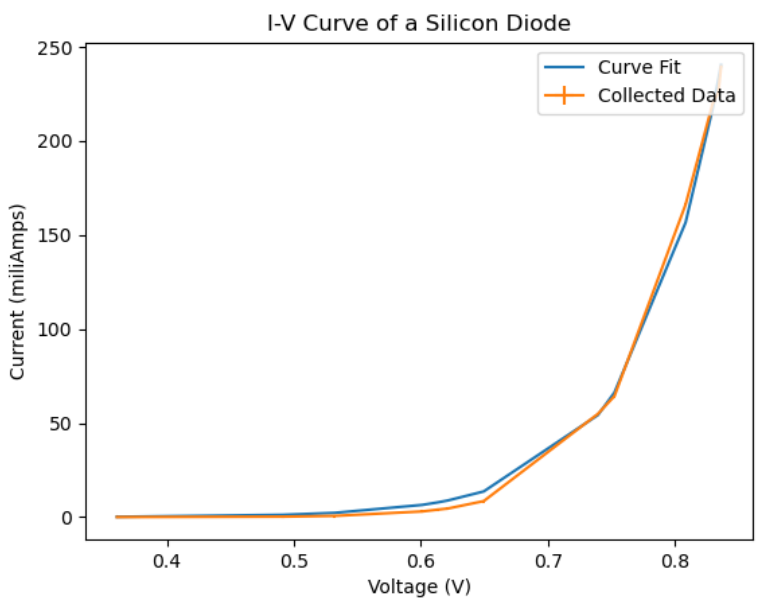

Figure 2: I-V Plot Generated from the Diode and Curve Fit generated

3.2.3 Calculated Parameters

The returned parameters from `curve_fit` along with their uncertainties can be found in the table below:

Table 4		
Parameter	Value of Parameter	Uncertainty in Parameter
I_0 (in miliAmps)	0.0006335	± 5.9226005e-08
k (in SI Units)	3.4930128e-16	± 2.5708735e-21

Table 4: Electrical Resistance of Thermistor at Various Temperatures.

The χ^2 for this fit was calculated to be 224624403.54 and was calculated as outlined by Eqn 3, but we use measured current and the appropriate fitted curve here.

4 Discussion

4.1 Thermistor

This experiment was conducted in order to determine the relation between a thermistor's temperature and electrical resistance. This was done through the method of non-linear fitting as shown in Fig. 1 using the experimental data in table 1 fitted to Eq.2. The returned parameters from this curve fitting and their uncertainties are shown in table 2, and the χ^2 of the fit is shown below this table. These parameters could then be inputted back into the inverse of Eq. 1 in order to find the temperature as a function of resistance for this thermistor.

The χ^2 of the fit is rather large which is odd considering the fitted curve does not appear too far off the experimental data in Fig. 1. However, this large value arises from the fact that the uncertainties in the measurements (in table 1) are relatively small, and thus any small difference in the curve fitting will cause χ^2 to blow up. I will now then explain how these uncertainties were measured and why the fitted curve is still a good approximation of the experimental data despite the size of the χ^2. The uncertainties in the temperature were determined by how well I could clearly make out temperature differences using the simple thermometer that was provided. I could clearly see half degree changes, but anything smaller than that was not clearly evident and thus all the uncertainties were 0.5 degrees for the recorded value. The uncertainties for the resistance readings were more complicated as I had to account for not only the normal variance of the value from the multimeter, but also ensure the change was not coming from the temperature change as the thermistor move to thermodynamic equilibrium with the surrounding environment. The way I went about this is to record how much the resistance value fluctuated from when the thermometer hit the recorded temperature value until it cooled or heated up by 0.5 degrees. The difference of the resistance value at these two temperature points then gave me the uncertainties seen in table 1. As we can see the uncertainties became smaller at lower temperatures, most likely due to the fact that the temperature was not chaining as quickly as this temperature range was closest to the the thermodynamic equilibrium temperature of the environment.

From these outlined methods I was satisfied with the accuracy of my uncertainty range. The curve was far from perfect and the uncertainties were relatively small leading to the large χ^2 value. Additionally, we can see from figure 1 that the curve is only a very bad fit between 50-150 $k\Omega$. Taking this into account the fitted curve generated is more accurate of a fit than the χ^2 would indicate. This is additionally verified using the function in the code `Temp(R)` which takes in R values in $k\Omega$ and returns temperature in degrees Celsius. Trying this out for a variety of values it matches experimental results pretty closely, while maintaining the form dictated by Eq. 1.

4.2 Silicon Diode

This experiment was conducted in order to determine the relation between current and voltage in a circuit containing a silicon diode. This was done through the method of non-linear fitting as shown in Fig. 2 using the experimental data in table 2 fitted to Eq. 4. The returned parameters from this curve fitting and their uncertainties are shown in table 4, and the χ^2 of the fit is shown below this table. These parameters could then be inputted back into Eq. 4 in order to find the current of the circuit as a function of the voltage. Note that curve fitting module uses Eq.4 in SI units, where T is set as 298.15K as this was the recorded temperature inside the lab when the measurements were taken.

The uncertainties in this experiment were taken in a similar fashion to those outlined in the previous section. In this case, voltage was set by turning the knob on the power supply and letting the voltmeter value stabilize. The current was then recorded at the same time using the ammeter. To allow proper stabilization of values the uncertainties reflect how much the readings of both voltage and current varied within a minute. The value at the start of the minute was taken as the measurement, and the uncertainty was recorded as the difference of that measurement versus the highest/lowest value that was observed on the multimeters during that minute.

For this curve fit, as above, we find a misleading χ^2 value. Visually looking at Fig. 2 we see that the fit is fairly close, but we see a large χ^2 value due to the size of the errors. The errors in this lab were very small relative to the measured values, as such we see the denominator of the χ^2 calculation will cause it to blow up for any small deviation between the experimental data and the fitted curve. The error then must lie in either: the actual calibration/set up of the multimeters that they were able to provide such stable read backs of the current and voltage, or in not having enough spread out points to provide the fitting algorithm. Additionally, in this lab only forward current and voltage could be measured for the diode as its resistance in the backward direction was too strong for the power supply to overcome.

5 Conclusion

5.1 Thermistor

In conclusion a relation was found between temperature and electrical resistance of a thermistor. It was shown that the lower the temperature of the thermistor the lower its resistance. The exact relation for thermistor in this lab was obtained by plugging in the parameters in table 2 to the inverse of Eqn 1. Additionally, a python script was created allowing for the temperature of the Thermistor to be known given an user inputted resistance. This can be used by calling the function `Temp(R)` in the provided python script.

5.2 Silicon Diode

In conclusion the relation between current and voltage in the forward direction of the silicon diode used in this lab was found. It is obtained by plugging in the parameters in table 4 into Eqn.4 (nothing that I_o must be converted into amps).

References

[1] Ruxandra Serbanescu. *Non-linear circuit elements: thermistors and silicon diodes.*