PHY324 Thermocouple Lab

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1 Introduction

The main purpose of this experiment was to find how the relation between the voltage generated by a thermocouple and the difference in temperature between both ends of the thermocouple. The thermocouple is an example of a transducer which converts a temperature difference into an electromotive force (EMF). The thermocouple consists of two wires of dissimilar metals which are joined at each end. The thermocouple in this lab was a Copper-Constantan thermocouple. When these two junctions are put into a temperature gradient, the free carriers at the hot end have more kinetic energy and tend to diffuse towards the cold end. The diffusion sets up an electric field which tends to oppose the heat flow. Thus an EMF appears along the conductor, which is proportional to the temperature difference[2]. This relation is given by the Seebeck Effect as follows:

$$V = S(T_1 - T_2) = S\Delta T \tag{1}$$

Where V is the voltage, $\Delta T = (T_1 - T_2)$ where T_1 and T_2 are the temperatures at the ends of the thermocouple such that $T_1 > T_2$, and S is the Seebeck Coefficient.

2 Materials & Methods

- Multimeter
- Thermocouple (Copper and Constantan Cables)
- Thermometer
- Alligator Clips
- Wire Cutters
- Thermos (2)
- Ice/Boiling Water (or anything to heat/cool the ends of the thermocouple)
- Electrical Wires (Banana Cables)

1. Begin by making a Copper-Constantan thermocouple. Strip about 1/2 inch from both ends of all 3 wires. Twist together each end of the Constantan wire to one end of a Copper wire. Form the twisted ends into an oval shape. Solder them. Using alligator clips and banana cables, connect the free ends of the B segments to the voltmeter. Consult Fig. 1 to verify the construction of the thermocouple.
2. Place the T_2 end of the thermocouple (see Fig. 1 below) in a thermos filled with ice and water (an ice bath). Place T_1 end of the thermocouple into a thermos with boiling water and a thermometer. Note, it is ideal if this thermos could have some sort of lid that allows for the thermometer and the T_1 end of the thermocouple to pass through as it will allow for a more steady temperature to be measured and maintained within the thermos.

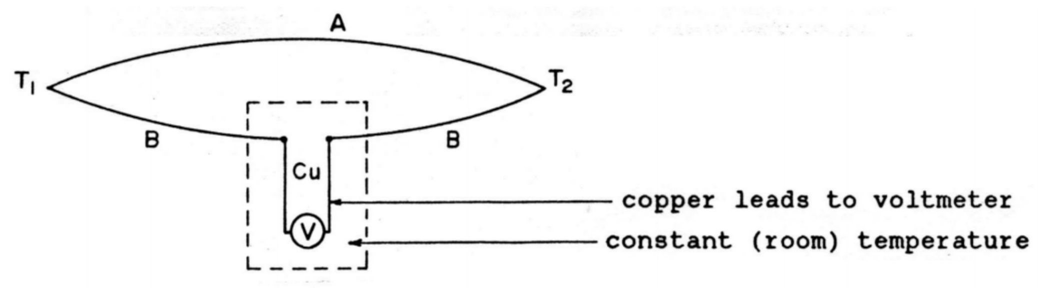

Figure 1: Diagram of Thermocouple where A is Constantan and B is Copper[2]

3. Record the temperature of T_2 at the very start and record its value. Then leave the T_2 end with the hot water in the thermos and allow a while for temperature to settle. Record this value as T_1. After doing so record the measured voltage on the voltmeter, allowing it to stabilize as the as the two ends of the thermocouple cool down/heat up.

4. The temperature of T_2 should remain constant through out so ensure to keep adding ice to the ice bath, and measure its temperature periodically to ensure it has not heated up as it tries to reach thermodynamic equilibrium with the room. Keep an eye on T_1 as the boiling water begins to cool down. Record various values of T_1 and the corresponding voltage on the voltmeter when you do so. Repeat this about 20 times to get 20 data points which should be adequate.

3 Data & Analysis

3.1 Experimental Data

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

Table 1					
Temperature 1 (°C)	Uncertainty in Temperature 1 (°C)	Temperature 2 (°C)	Uncertainty in Temperature 2 (°C)	Voltage	Uncertainty in Voltage (mV)
2	0.25	86	0.25	2.831	0.018
2	0.25	78	0.25	2.582	0.020
2	0.25	75	0.25	2.486	0.030
...	...	...	...	...	...
2	0.25	32	0.25	1.206	0.015
2	0.25	25	0.25	0.961	0.020
2	0.25	15	0.25	0.812	0.020

Table 1: Voltage of Thermocouple at Various Temperatures.

3.2 Curve Fitting

The collected data in table 1 was fitted to Eqn. 1. The `curve_fit` Python function from the `SciPy` library was used in order to fit this to the collected data. The following plot was generated:

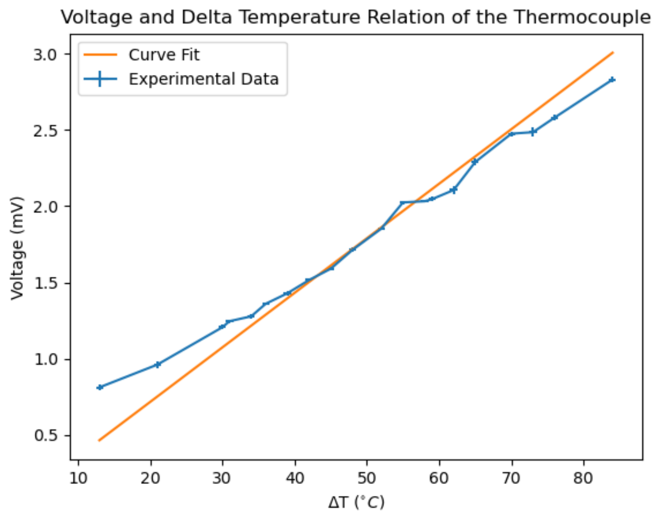

Figure 2: Caption

3.3 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 (mV/°C)	Uncertainty in Parameter (mV/°C)
S	0.03579	± 6.13852e-5

Table 2: Seebeck Constant obtained from curve fitting

The χ^2 for this fit was calculated to be 209147.7, using the formula:

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

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

4 Discussion

This experiment was conducted in order to determine the relation between a thermocouple's temperature difference between its two ends and its voltage. This was done through the method of linear fitting as shown in Fig. 2 using the experimental data in table 1 fitted to Eq.1. The returned parameter from this curve fitting and its uncertainty are shown in table 2, and the χ^2 of the fit is shown below this table.

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. 2. However, this large value arises from the fact that the uncertainties in the measurements (in table 1) are relatively small compared to the measured values. 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 quarter degree changes, but anything smaller than that was not clearly evident and thus all the uncertainties were 0.25 degrees for the recorded value. The uncertainties for the voltage 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 T_1 end of the thermistor move to thermodynamic equilibrium with the surrounding environment. The way I went about this is to record how much the voltage value fluctuated from when the thermometer hit the recorded T_1 value until it cooled or heated up by 0.25 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 Fig. 2 that the curve is only a very bad fit between 10-30 °C. 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(voltage)` which takes in V values in mV 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.

The resistance of the thermocouple was also measured during this lab using the multimeter switched into the ohm meter setting. Ideally we would measure the resistance using multiple resistors at various voltages and currents (see output resistance of a power supply lab from PHY224 for more details[1]). Since, we did not have access to extra resistors and the multimeters provided were of good quality, the resistance measurement was taken with it. The recorded value was 1.425 $\Omega \pm 0.015\ \Omega$ where the uncertainty was measured by seeing how much the value fluctuated within one minute of the recorded value. Note: the thermistor was taken out of both the ice bath and hot water long enough for it too cool to room temperature before the resistance measurement was taken.

This lab prompts an interesting idea as to whether we could connect multiple thermocouples together in series, and if this would yield any advantage. The answer is yes, and connecting multiple thermocouples together in series is called a thermopile. A thermopile works in the same way a thermocouple does, but it being made of multiple thermocouples it can hold a higher voltage than any of the individual thermocouples that make it up. This is precisely the benefit of constructing a thermopile, as it allows us to hold the combined voltage of multiple thermocouples.

5 Conclusion

In conclusion the relation between temperature difference at the ends of a thermocouple and voltage was found for the thermocouple in this lab using curve fitting. The relation is obtained by plugging in the parameter (Seebeck Coefficient) in table 2 into Eqn. 1. The Seebeck Coefficient was found to be 0.03579 mV ± 6.13852e-5 mV in this lab.

References

[1] Christopher Lee. *The Output Resistance of a Power Supply.*

[2] Ruxandra Serbanescu. *Building and calibrating a thermocouple.*