Meteo 440W - Lab 2 – Thermocouple Calibration

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1. Introduction

Temperature is a quantity involved in many thermodynamic equations. Having a cheap and efficient way to measure this quantity is required. A thermocouple is one such instrument which can measure temperature in an efficient manner. The instrument consists of two metal wires of different compositions that are soldered together to form a junction. As temperature changes, the voltage across the two metals differs due to the difference in the heat capacities of the two metals. Several types of thermocouples exist, all functioning for different temperature ranges and environments. For this experiment, a type T thermocouple was used, which contains a copper wire and a constantan (copper-nickel alloy) wire.

The thermocouple in this experiment has two junctions. These include a reference junction, held at some constant reference temperature and the measuring junction which is used to measure the temperature. In this case, the reference junction is held at 0°C using a bath of iced water. If a temperature difference exists between the measuring junction and the reference junction, a small voltage is induced in the thermocouple. This analog signal can be converted to a digital signal by use of an analog-to-digital board and this digital information can be read by a computer.

For this experiment, a personal computer was used to record the voltages for objects of known temperature. These voltages were compared to the actual temperature of these objects, and a formula for converting between the two measures was created.

2. Data and Methods

A. Calibration Experiment

Several sets of supplies were distributed to groups of students performing the experiment. For this particular instance of the experiment, a hot plate, 3 beakers, a bulb thermometer, and the thermocouple labeled number 5, were gathered.

Next, the thermocouple instrument was prepared. This involved filling the control thermos with an iced water bath. The thermos was filled with ice and then water was added to fill the thermos completely. The thermos was closed and sealed, ensuring that the junction of the instrument was completely submerged in the water. The reason for this iced water bath is to have an easily replicated control temperature fluid which can be used for subsequent utilizations of this particular instrument. This ensures that the conversion factors created through this calibration experiment will work consistently on objects of varying temperature. The instrument was equipped with a Universal Serial Bus (USB) connector which allowed it to be easily linked to the personal computer at the workstation. This computer was used to digitally record the measurements taken by the instrument. In order to ensure that the instruments were working, the temperature of the room was measured with the bulb thermometer and the voltage measured on the thermocouple were recorded. This temperature was not part of the calibration experiment, merely a test to ensure the equipment was functioning.

Three additional water baths were created as the next step of the calibration experiment. One bath was created using cold tap water and some ice. A warm water bath was created using warm tap water. Finally, a boiling water bath was created using tap water of arbitrary temperature heated to a rapid boil using the hot plate. For each of the baths, the temperature measured by the bulb thermometer and the voltage measured by the thermocouple were recorded.

The program TracerDAQ was used on the personal computer to actively record the data stream from the thermocouple instrument. These data were written to Comma Separated Value (CSV) files which were opened in Microsoft Excel for analysis. Measuring the voltages required waiting for the instrument to reach an equilibrium value. The plotting tools in TracerDAQ were utilized to determine when a stable value was reached and only after values stabilized were the readings written to file. Typically, values were seen to stabilize after about 10 seconds of time had elapsed. At the same time as the voltage readings were being recorded, the temperature of the bath was also measured by using the bulb thermometer. A total of four files were created with voltage measurements, one for each of the three baths and a fourth for the atmosphere, measured earlier.

These data were indexed by the bath they were measured in so that thermocouple voltages could be appropriately matched with their corresponding values of temperature in degrees Celsius. Once these measurements were complete, the equipment was appropriately disassembled, dried, and returned to storage.

B. Data and Analysis

Data were tabulated in Microsoft Excel spreadsheets for analysis. Separate tables were imported from the CSV files generated by TracerDAQ. The imported files contained only data after the instrument reached equilibrium. The mean voltage reading for each measurement was calculated by averaging across each data point from the corresponding file. A summary of this data can be seen in Table 1.

Figure 1 shows data from the iced water bath measurement as an example. This plot is completely horizontal because data was only recorded after the instrument reached equilibrium. With the data available it is not possible to compute either the time constant or the voltage difference. The data relevant to these calculations were omitted from the record as they did not seem necessary during the experiment and were not explicitly requested. The state of the measurement was actively observed and measurements were recorded only after it was reasonably certain that equilibrium had been reached.

Figure 2 shows data from both the iced water bath and the boiling water bath. A linear trend and the R^2 value were computed using Excel and are also displayed. The formula for this trend can theoretically be used to convert from voltage readings measured by the thermocouple into temperature readings in degrees Celsius. Instructions were clear that the end points should use the theoretical values of temperature for both control baths (iced at 0^oC and boiling at 100^oC) in order to more accurately represent the linear trend when comparing the temperature to voltage readings. This produced the following formula:

$$Y = (25.253 * X) – 2.2727$$

Where Y is the temperature in degrees Celsius and X is the voltage reading in millivolts. This equation may be used to convert voltage readings from the number 5 thermocouple to temperature readings, thus enabling the instrument to be used to measure temperatures. Summary data using this formula is presented in Table 1.

Results

A. Hypothesis 1

This particular thermocouple produces values within 0.1mV of reference values only at high temperatures. For low temperatures, the measured values differ from the reference values by as much as 0.3mV. This hypothesis is plausible. Further testing should involve using more controlled water baths, since there was an observed-to-theoretical value mismatch.

B. Hypothesis 2

Data suggest that the thermocouple, calibrated with a linear fit to iced and boiling water standards, yields a temperature measurement with a difference of 2-3 K from actual. Thus, data suggest that this hypothesis is incorrect.

C. Hypothesis 3

This hypothesis cannot be tested due to experimental oversight. Data are not available to calculate this quantity. No assumptions can be made about the validity of this hypothesis.

4. Tables and Figures

Object	Mean Voltage (mV)	Calculated T (^oC)	Reference T (^oC)	Actual T (^oC)	Actual T Reference Voltage (mV)
Air	0.96	15.2	18	23.9	0.95
Iced Water	0.09	0.0	2.5	6.1	0.23
Tap Water	1.20	28.0	30	33.5	1.36
Boiling Water	4.05	100.0	95	92.5	3.95

Table 1: Final data gathered from the experiment. From the left, column 1 shows the object which was measured, column 2 shows the mean voltage measured by the thermocouple, column 3 shows the temperature as calculated by the formula, column 4 shows the temperature as referenced by the standard thermocouple voltage measurements, column 5 shows the actual temperature as measured by the bulb thermometer and column 6 shows the corresponding voltage for the actual temperature as shown by the standard thermocouple voltage measurements. Return to text.

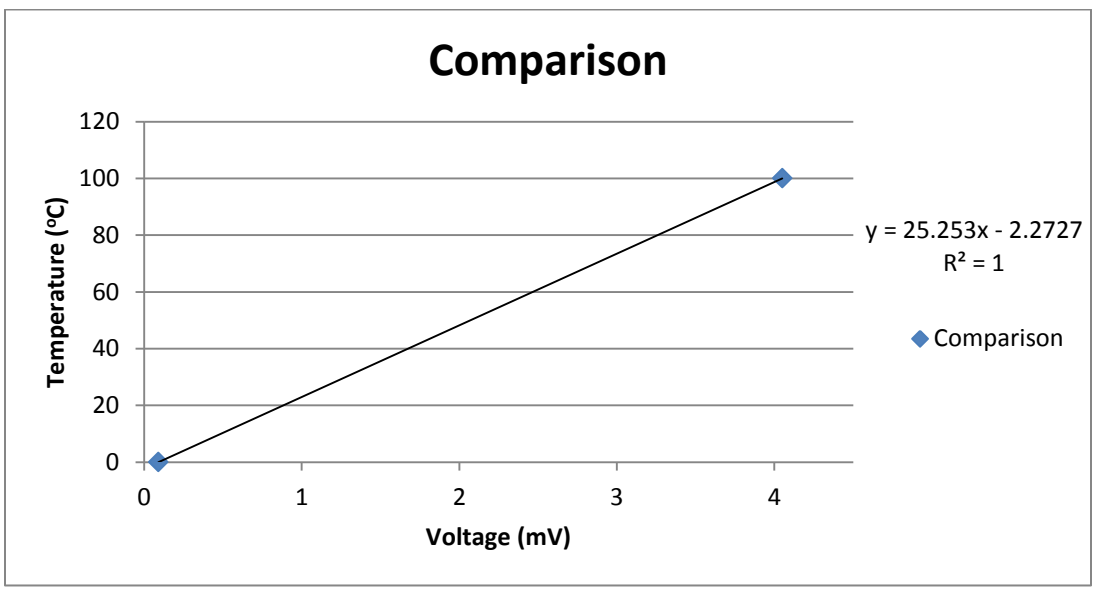

Figure 1: Voltage readings from the number 5 thermocouple as compared to standard temperature values from an iced water bath and a boiling water bath. A linear trend has been drawn (gray slanted line) and the formula of this trend can be seen on the right margin along with the R^2 value. Return to text.

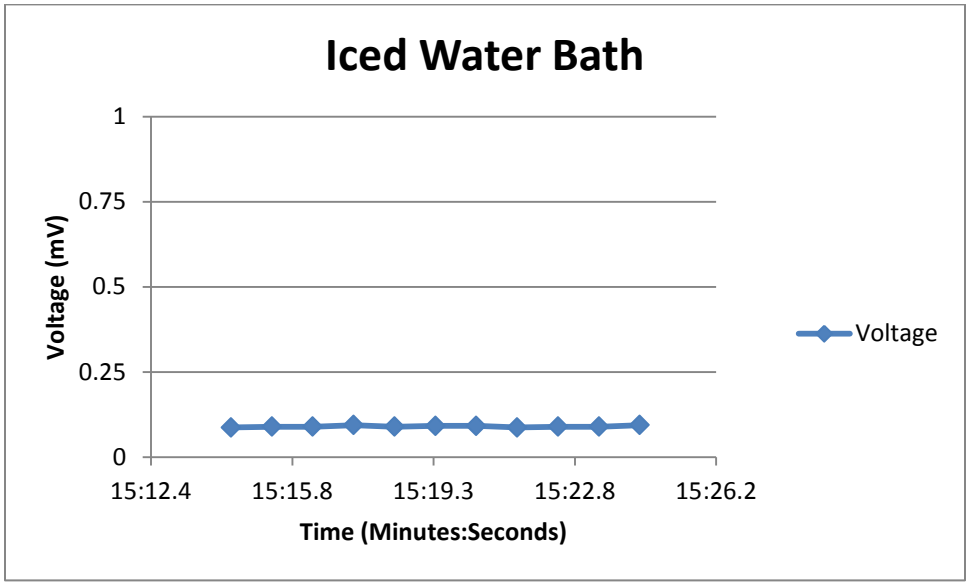

Figure 2: Data from the iced water bath which includes voltage (y-axis) over a period of time (x-axis) spanning approximately 10 seconds. Return to text.