Thermometer Calibration

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Introduction:

Thermometers measure the amount of thermal energy associated with an object, also called its temperature. There are three common temperature scales: Fahrenheit, Celsius, and Kelvin. The Fahrenheit scale (°F) is most commonly used in the United States in which water freezes at 32 °F and boils at 212 °F.[1] Scientists and most other countries use the Celsius scale (°C). The freezing point of water is 0 °C and the boiling point is 100 °C. The SI unit for temperature is Kelvin (K).[2] The Kelvin scale does not use negative numbers due to assigning the coldest temperature possible as 0 K. This "absolute" zero temperature is -273 °C or -459 °F.[3]

Having reliable instruments to use for measurement in the lab is very important. Calibration is the term used to describe the comparison of measured values from a test device to the variable being measured. Given an ethanol (CH_3CH_2OH) thermometer with no markings, an experiment will be designed that will enable its use for the remainder of the semester. To do so, the thermometer must be calibrated by measuring the length of the thermometer that the ethanol fills at various temperatures, measured by a temperature probe. By plotting the approximate temperature from four sources (freezing water, room temperature water, boiling water and body temperature) versus the length the red liquid occupies in the thermometer, a best-fit line equation can be computed. The equation will allow the use of this thermometer as an accurate measuring device for the remainder of the semester.

Procedure

A blank thermometer that was filled with ethanol dyed red was obtained. The thermometer contained no markings. A Sharpie marker was used to mark a position on the thermometer that would be defined as 0 mm. This mark was made about 2 cm from the bottom of the end containing the ethanol. Approximately 250 mL of tap water was placed in a beaker and let stand at room temperature. Approximately 300 mL of tap water was placed in a second beaker and placed on a hot plate and the water was heated until boiling. A handful of ice was placed into a third beaker and approximately 200 mL of tap water was added to the ice. The ice-water mixture was stirred and allowed to sit for 5 min. The temperature of the water in each beaker (cold, hot, room temperature) was measured using the LabQuest temperature probe. Each measurement was repeated at least twice, waiting 30 seconds between measurements.

The blank thermometer was then placed in each beaker of water and allowed to equilibrate. Each position of the red liquid was marked using a Sharpie and then the length of the red liquid was measured from the previously defined zero mark to the marks determined at each temperature. These measurements were repeated at least 2 more times after removing the thermometer and letting it cool or heat in the air for a minute. A fourth temperature, body temperature, was also used as a test temperature. This was done by placing the LabQuest temperature probe under the armpit of a student and measuring the temperature. The measurement was repeated after letting the device cool a bit. Then the blank thermometer was placed under the student's armpit and the position of the red dye was marked with a Sharpie. This measurement was repeated 3 additional times after letting the device cool a bit. Finally, the distance that the ethanol moved in the blank thermometer was measured using a warm water bath with an unknown temperature. Note that the body temperature readings were taken in the armpit, with a cotton shirt still on. It is assumed that the shirt and body are at the same temperature if they are allowed to be in close contact for a minute or two.

Results:

Table 1:. Temperature from the temperature probe and length of dyed ethanol at various known temperatures. A single measurement of the water bath of unknown temperature is also included.

	Temperature (°C)			Length of Ethanol (mm)			
	Trial 1	*Trial 2*		*Trial 1*	*Trial 2*	*Trial 3*	*Trial 4*
Ice Water	-0.36	-0.36		40.6	40.8	40.9	
Room Temperature	22.71	22.72		59.5	60.1	59.6	59.4
Body Temperature	36.40	36.82		73.1	74.0	72.5	72.7
Boiling Water	99.98	99.98		128.0	127.7	127.7	
Warm Water Bath				*84.9*			

Table 2. :Average temperature and length from Table 1 experimental data

	Temperature (°C)	Length (mm)
Ice Water	-0.36	40.1
Room Temperature	22.72	59.6
Body Temperature	36.61	73.0
Boiling Point	99.98	127.8

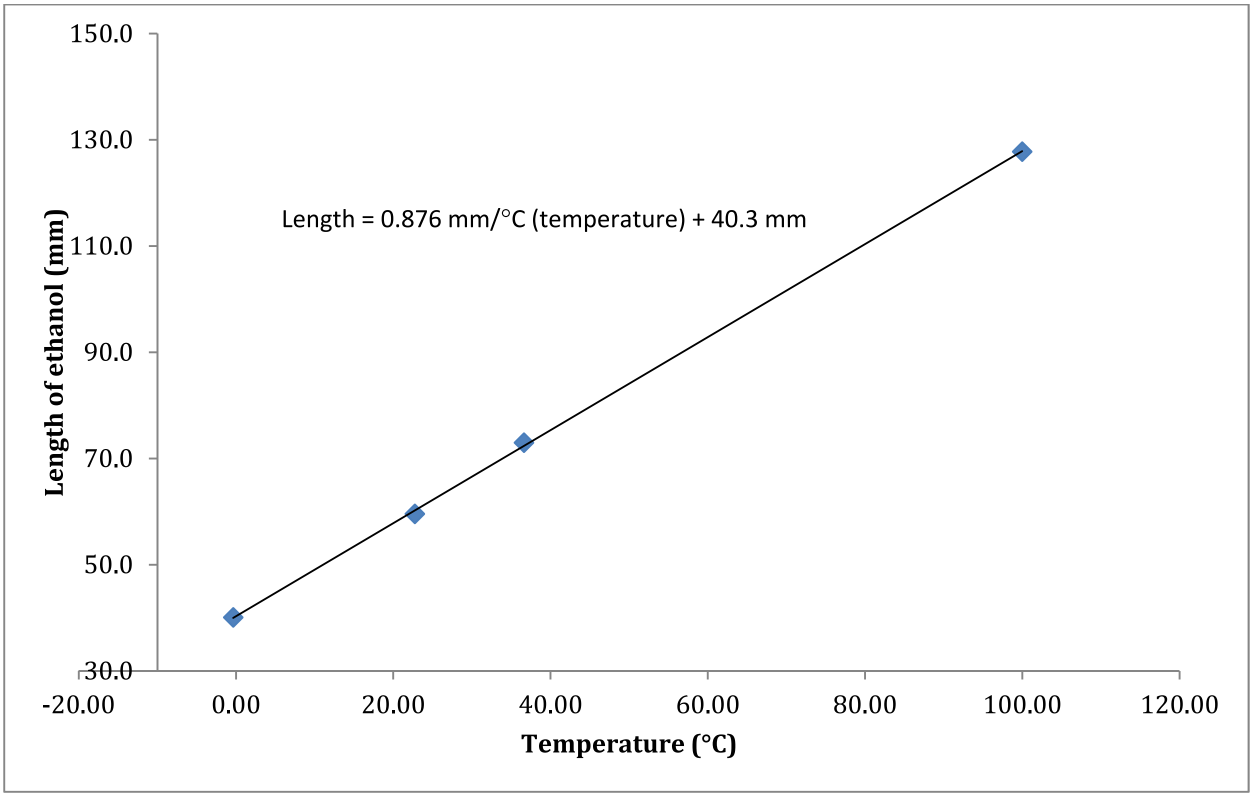

Figure 1:. Plot of length of ethanol (mm) along thermometer vs. temperatureCalibration [SM1]of an ethanol thermometer, measured with a LabQuest temperature probe. The relationship between the length of ethanol and the temperature is linear and is described by the equation: Length = 0.876 mm/°C (temperature) + 40.3 mm.

Using the equation from Figure 1, the temperature of the warm water bath can be calculated based on the length of the ethanol measured using our thermometer. To do so, the equation must first be rearranged to solve for T.

$$L = \left(0.876\ \frac{mm}{°C}\right) T + 40.3\ mm$$

$$L - 40.3\ mm = \left(0.876\ \frac{mm}{°C}\right) T$$

$$\frac{(L - 40.3\ mm)}{\left(0.876\ \frac{mm}{°C}\right)} = T$$

Solving for T for water bath: $T = \frac{(84.9\ mm - 40.3\ mm)}{\left(0.876\ \frac{mm}{°C}\right)} = 50.8\ °C$

Conclusion

As the temperature changes, the length of the ethanol in a tube changes. The relationship between the temperature and the length of ethanol in the tube is linear and can be used to calibrate a thermometer by using known temperatures and measuring the length of the tube that the ethanol fills.

Using the freezing point and boiling point of water, water at room temperature and body temperature, a plot of the average length that ethanol takes versus the average temperature yielded linear data with an equation for the best fit line of $L = (0.868\ mm/^{o}C)\ T + 40.8\ mm$. The known equation for the unmarked thermometer was used to measure the temperature of a water bath of unknown temperature. The result was 50.8 ^{o}C.

According to Figure 1, the data were precise as all the data points essentially fell on the line of best-fit. Multiple trials of each measurement were averaged in order to reduce random errors in the devices and this likely contributed to the high level of precision. It was obvious that the body temperature readings had the most error, as making contact with the armpit (where the data was taken) was not extremely repeatable. Taking more data below freezing, by adding salt, and in the 60-80^{o}C region would help make the equation more reliable. Since the exact temperature of the warm water bath was not known, it is not possible to evaluate the accuracy of the calibrated thermometer.

References

1. Tro, N. *Chemistry A Molecular Approach*; Jaworski, A., Ed.; Pearson: Boston, 2014; p 15.

2. National Institutes of Standards and Technology homepage. http://physics.nist.gov/cuu/index.html (accessed Nov. 14, 2016).

3. Strange, R.; Lang, F. A Precise Determination of Absolute Zero. *J. Chem. Ed.* **1989**, *66*, 1054.