Experiment 4
Measurements - Temperature

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Name:

Date:

Key Objectives

1. Deepen our understanding of accuracy and precision.
2. Use of Percent Error.
3. Determine if a measurement is accurate or precise.
4. Understand the difference between Fahrenheit ($°F$), Celsius ($℃$), and Kelvin (K) scales
5. Convert between $°F$, $℃$, and K scales.

Discussion

Temperature Measurements

Temperature is commonly measured in one of three units, degrees Fahrenheit ($°F$), degrees Celsius ($℃$) and Kelvin (K) as shown in Figure 4.1. In the United states the use of Fahrenheit is considered standard, while the rest of the world uses the metric Celsius scale. The Kelvin scale is an absolute scale which scientists frequently use and is used when discussing gas laws, thermodynamics and kinetics. For now the use of the Celsius scale will be considered our standard unit, with the introduction of the Kelvin scale discussed later.

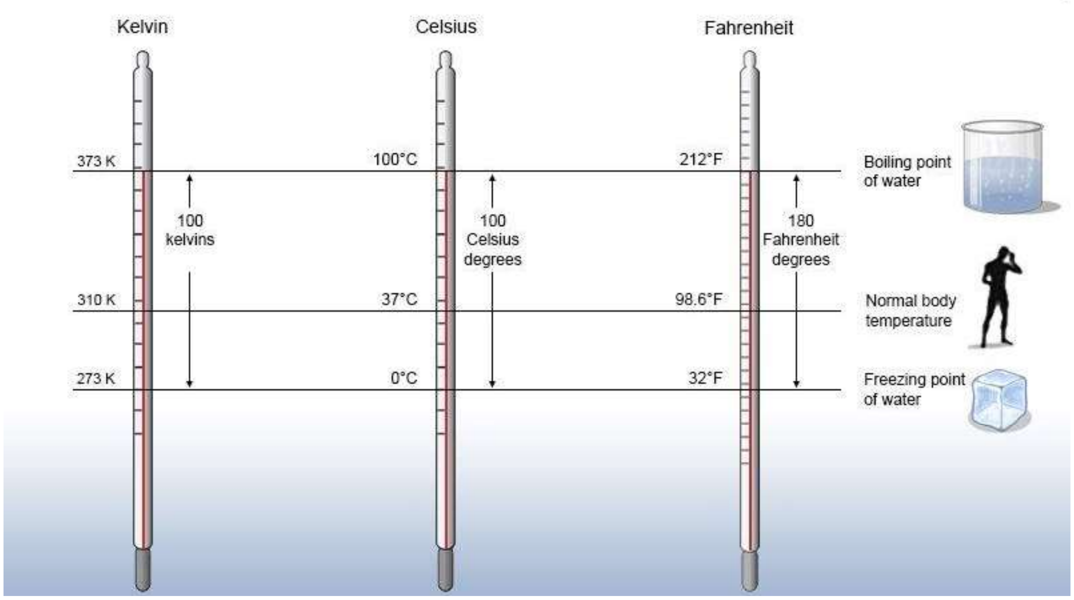

Figure 4.1: The relationship between the three most common temperature scales: degrees Fahrenheit ($°F$), degrees Celsius ($℃$) and Kelvin (K) credit: `https://commons.wikimedia.org/wiki/File:Temperature-Scale_diagram.jpg`

The main difference between the three temperature scales is the choice of standards for the freezing

$$
\begin{aligned}
{}^{\circ}\mathrm{F} &= 1.8 \times {}^{\circ}\mathrm{C} + 32 \\
{}^{\circ}\mathrm{C} &= \frac{({}^{\circ}\mathrm{F} - 32)}{1.8} \\
K &= {}^{\circ}\mathrm{C} + 273.15
\end{aligned}
$$

Figure 4.2: Equations for converting between the three most common temperature scales.

and boiling points and the size of the degree. The Fahrenheit scale was based on the freezing point of a salt water solution (0 $^{\circ}\mathrm{C}$) and the average human body temperature (originally set at 96 $^{\circ}\mathrm{F}$). The scale results in the freezing point of pure water as 32 $^{\circ}\mathrm{F}$ and boiling water as 212 $^{\circ}\mathrm{F}$. There are 180 degrees separating the two values.

The Celsius scale sets the freezing point and boiling point of pure water at 0 $^{\circ}\mathrm{C}$ and 100 $^{\circ}\mathrm{C}$ and is based on the metric system resulting in the 100 units being placed between the two standards.

The Kelvin scale is based on the motion of atoms with 0 K (also known as absolute zero) being the temperature at which no molecular motion occurs. The size of the Kelvin unit is based on the metric system, thus the same size as the Celsius degree. The freezing point of water on the Kelvin scale is 273.15 K, while the boiling point is 373.15 K.

Conversions between the three temperature scales can be done using the equations in Figure 4.2. You do not have to memorize the formula, they are given on your cheat sheet. Other mathematical representations of the formula are possible with the factor of 1.8 often being replaced with the fraction 9/5, which is the ratio of the 180 Fahrenheit degree's to the 100 Celsius degree's. The addition or subtraction of 32 (and 273.15) is to correct for the different definitions of zero for each scale.

Error's in Measurements

In statistics **error** is the difference between the computed, estimated. exerimental or measured value and the true, specified or theoretically correct value. Errors are not mistakes. All measurements however are subject to a variety of errors which can result in incorrect values. Several examples are human error (simply being human is enough to get some things wrong), incorrect procedures, broken measuring instruments, and poorly calibrated instruments. The goal of a scientist is to minimize the possible sources of error in any measurement. The list of ways to do this is large, but the most common ones used in class will be by (1) following proper procedures, (2) calibrating instruments, (3) testing versus known quantities, and (4) making multiple measurements.

Percent Error

One measure of accuracy is to calculate the Percent Error in your measurement which represents the difference between the experimental or measured value and the theoretical or correct value scaled by the theoretical/correct value. It is given by the following formula:

$$
\text{Percent Error} = \left| \frac{(\text{Experimental Value} - \text{Theoretical Value})}{\text{Theoretical Value}} \right| \times 100
$$

For example know value for the boiling point of water is 100.0 ℃, but if you measure the temperature of boiling water in lab as 94.5 ℃ then the percent error in your measurement would be 5.5%. Make sure you try to calculation yourself and get the same result.

Calibration

Calibration is the validation of specific measurement techniques and equipment. At the simplest level, calibration is a comparison between measurements of known quantities and the value obtained using the measuring instrument. Many devices come pre-calibrated, but most electronic devices and thermometers do not come calibrated. The accuracy of the device is established by measuring known quantities and correlating this with the values measured on the laboratory equipment. This process is known as calibration. In general glassware for measuring volume is purchased already calibrated, thus we will only need to calibrate thermometers and balances (scales).

Your first task will be to check the accuracy of your thermometer by calibrating it to two known values. The two temperatures you will use are transition between ice and water (melting point) which occurs at 0 ℃ and the transition from liquid to gas (boiling point) which occurs at 100 ℃ at sea level. The melting point is not affected to a noticeable degree by elevation, in contrast, the boiling point is affected by elevation. Those curious may read about this in Hein Ch. 13.5 (p. 305), Chang Ch. 11.8 (p. 466) or in McMurry Ch. 10.5 (p. 396). The boiling point is the temperature at which the vapor pressure of a liquid is equal to the external pressure (generally atmospheric pressure) above the liquid. In Rangely CO, we are at an elevation of approximately 1 mile, this will result in the lowering of the boiling point of water to approximately 94.7 ℃ .

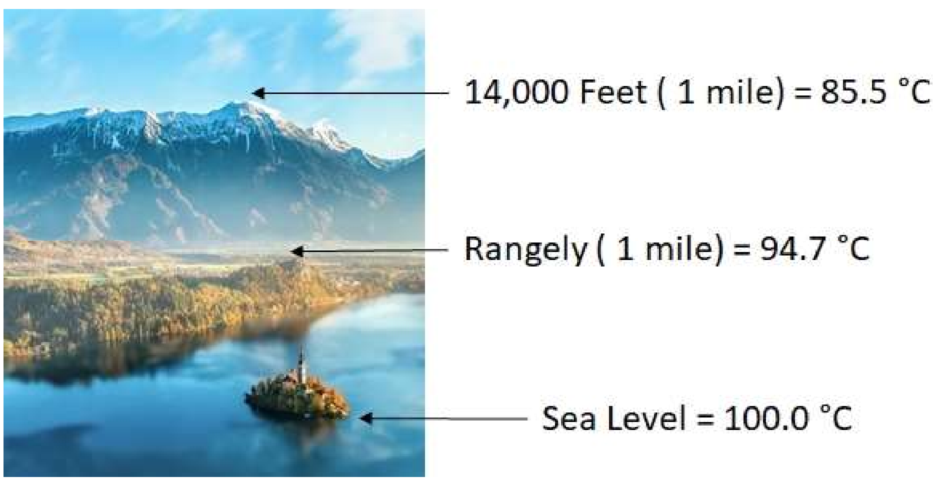

Figure 4.3: Boiling point of water at different elevations. credit: author

Thermometer Basics

The simple act of measuring temperature with a thermometer can easily involve many errors. When measuring the temperature of a liquid one can minimize error by observing the following procedures:

1. Hold the thermometer away from the walls of the container.
2. The bulb of the thermometer should be fully immersed in the water.
3. Allow sufficient time for the thermometer to reach equilibrium with the liquid.

4. Be sure the liquid is adequately mixed.
5. Always make readings at eye-level.
6. Sometimes a note card placed behind the thermometer makes the mercury easier to see.

Some additional pointers for using a thermometer:

1. Thermometers are round. Round objects on flat surfaces (lab bench tops) tend to roll. Always place your thermometer such that it will not roll off the lab bench top.
2. Thermometers are fragile, **do not** use them as stirring rods. Stirring rods should be used to stir liquids.
3. Always secure your thermometer with a clamp.
4. Many thermometers contain mercury (a toxic heavy metal), if you break a thermometer immediately inform your instructor so the proper hazardous waste procedures can be followed.

Proper use of Bunsen Burners

We will be using Bunsen burners for the first time in this experiment. Bunsen burners can be found in the tall drawer at the lab benches. Figure 4.4 below shows the proper set-up for a bunsen burner

1. Check the rubber hose attached to the Bunsen burner for cracks or splits. Report any bad hoses to your instructor so they may be replaced. Attach the hose to the stop-cock.
2. Check the turn screw at the bottom of the Bunsen burner, and leave it partially open (this controls the amount of gas burning).
3. Clear the area of flammable substances.
4. Turn the stop-cock perpendicular (90 degrees) to the pipe. Never adjust the amount of gas going to the Bunsen burner with the stop-cock, use the valve at the bottom of the burner. The stop-cock should always be either on or off, never between.
5. Adjust the flame using the screw at the bottom of the burner to adjust the gas flow, and the tube of the burner to adjust the oxygen flow. The goal is to form a small blue cone. The hottest part of the flame is the tip of the blue cone. It does not have to be large in order to provide the maximum amount of heat.
6. When done using a Bunsen burner turn it off at the stop-cock.
7. Allow the Bunsen burner to cool, then replace the Bunsen burner in the cabinet.

Procedure

A. Measure the melting point of ice

1. You will need a ring stand (in the cabinets under the lab benches), a ring clamp, wire pad, and a thermometer clamp.
2. Set up a ring stand as shown in Figure 4.5 and as can be seen at the instructor lab bench.
3. Have your instructor check your assembled apparatus before proceeding.
4. Fill a 500 mL beaker with approximately 75% ice and 25% distilled water.
5. Place the thermometer in the ice water solution and allow 3-5 minutes for the system to equilibrate.

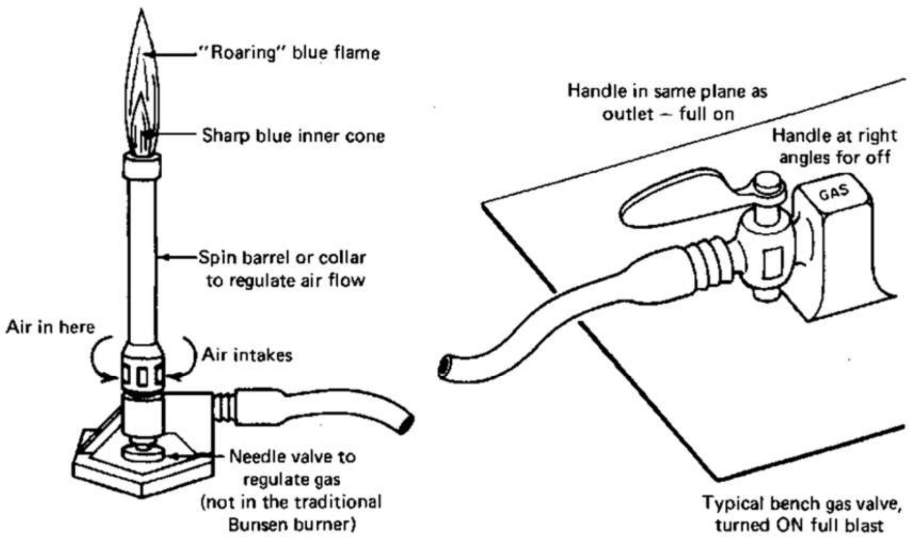

Figure 4.4: Typical bunsen burner. The flame on the bunsen burner is adjusted by changing the amount of air and gas. credit: unknown

6. Record the temperature on the results page.
7. If your results are not within 2 °C of the expected temperature, consult your laboratory instructor.

B. Measure the boiling point of water

1. Place approximately 350 mL of distilled water in a 500 mL beaker. (75% full)
2. Place 1-2 *boiling chips in the beaker.
3. Place the beaker on the ring stand as shown in Figure 4.5. Be sure to cover the ring stand with a piece of wire screening to set the beaker on.
4. Light the Bunsen burner and adjust the flame such that the blue cone is just touching the beaker.
5. Allow the water to boil for 3-5 minutes to establish a consistent temperature.
6. Obtain a small thermometer from your instructor.
7. Record the temperature of the water in the beaker.
8. If your results are not within 2 °C of the expected temperature of 96 °C consult your laboratory instructor.
9. Allow your water bath to cool before attempting to dispose of the water in the sink.

*Boiling results in the rapid formation of bubbles of air in a solution. In small containers (such as the beakers used in laboratory) or in pure liquids (such as the distilled water used in laboratory) the rapid formation of a large bubble can cause the beaker to "‘bump"’ or move abruptly causing it to be knocked off the ring stand. Boiling chips are used when boiling substances to prevent this from occurring by creating places for bubbles to form in a controlled manner.

C. Comparing Thermometers

1. Obtain a second (long) thermometer from your instructor.
2. The thermometer you received is **expensive**, take extremely good care of it to avoid the wrath of your instructor.
3. Record your observations of the thermometer in the results section.

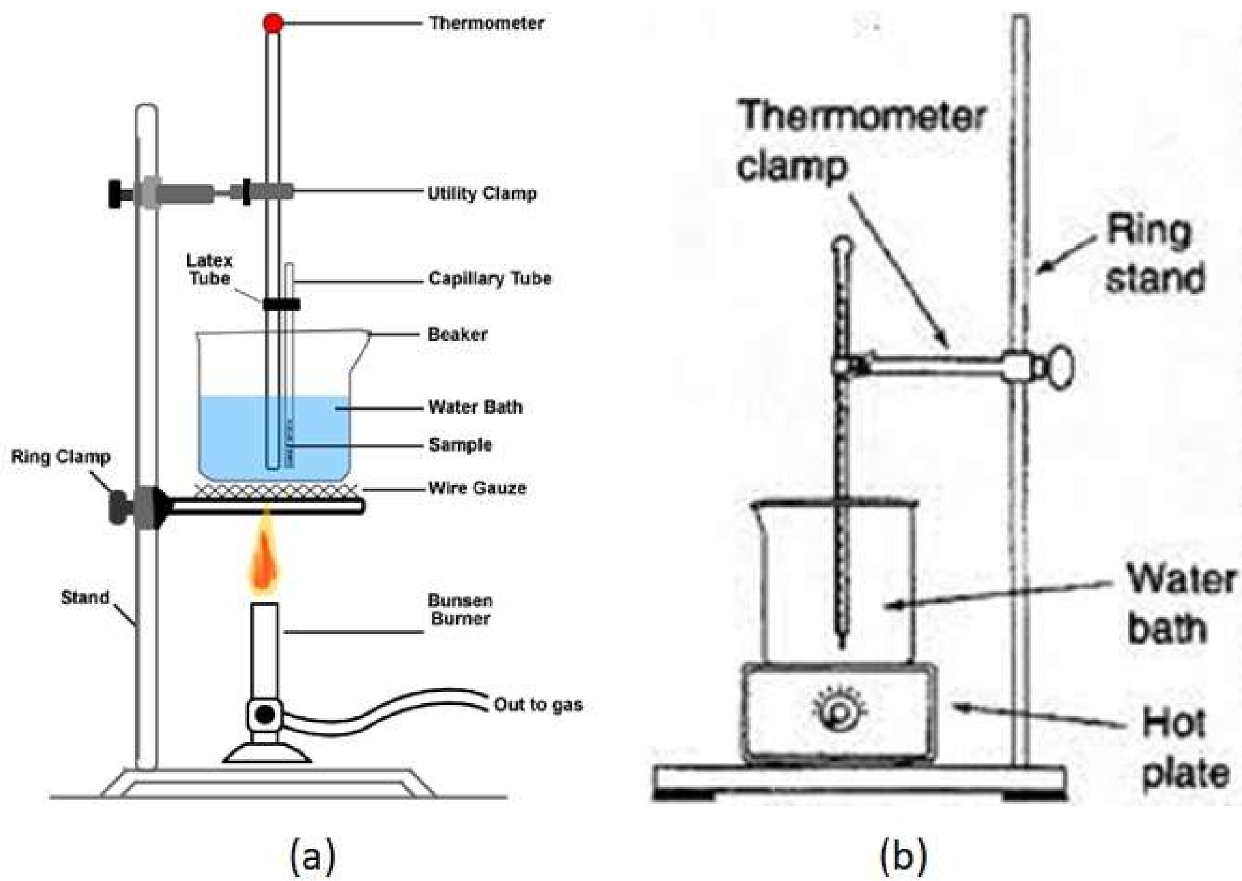

Figure 4.5: (a) Using a bunsen burner to boil water. (b) Using a hot-plate to boil water. credit: (a) `https://chem.libretexts.org/@go/page/95586` (accessed Jun 19, 2021) (b) unknown

Results

Cheap Thermometer

1. Temperature can be read with what uncertainty($\pm$) (cheap thermometer): ____________
2. Temperature of ice-water bath (cheap thermometer): ____________
3. Percent Error in Freezing Point(show calculation below): ____________
4. Temperature of boiling water bath (cheap thermometer): ____________
5. Percent Error in Boiling Point (show calculation below): ____________

Expensive Thermometer

1. Temperature can be read with what uncertainty($\pm$) (expensive thermometer) ____________
2. Temperature of ice-water bath (expensive thermometer): ____________
3. Percent Error in Freezing Point(show calculation below): ____________
4. Temperature of boiling water bath (expensive thermometer): ____________
5. Percent Error in Boiling Point (show calculation below): ____________

Questions

1. What are 4 most common ways to try to control or eliminate errors when performing experiments?

2. Are we testing the accuracy or the precision of the thermometer in this experiment? Explain.

3. Why is the second thermometer much more expensive than the first thermometer (used to measure the freezing point and boiling point of water)? Explain.

4. What should you do if you break a thermometer?

5. What basic rules should you follow when using bunsen burners?

6. Perform the following three conversions. Make sure to show your calculation, and include the correct number of Significant Figures and Units for each.

   (a) Convert 220 °C to °F. 6(a) ____________

   (b) Convert 15.4 °F to °C. 6(b) ____________

   (c) Convert 400. °F to Kelvin. 6(c) ____________

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