Experiment 8

Temperature & Thermometers

⚠️ Warning: Liquid nitrogen may be used. University regulations require students to have splash proof safety goggles, long pants, and closed toe shoes.

In this experiment you “build” a thermometer by calibrating the output of a thermometric system. The system is a sealed container of air at fixed volume. The output is the pressure of the gas in the container. The calibration is achieved by relating the pressure to temperature in units of degrees Celsius. Once you have a working thermometer, you use it to determine some temperatures.

Preliminaries.

Temperature scales are based on convenient and accessible points, usually the freezing and boiling points of water. The Celsius scale assigns 0 °C to the freezing point and 100 °C to the boiling point, evenly splitting these points with 100 divisions. Once the degree size is determined, the Celsius scale is extended above 100 °C and below 0 °C.

Physical systems cannot be cooled beyond a certain limit, called absolute zero. This observation underlies the Kelvin scale, which is the most useful in physics. The Kelvin scale has units of Kelvins (K). A Kelvin is the same size as a Celsius degree. Absolute zero is, by definition, at 0 K.

You use a constant volume gas thermometer in this experiment. This is an air-filled spherical container with a pressure gauge attached to it. The Ideal Gas Law relates the volume $V$, the pressure $p$ and the temperature $T$ of an ideal gas as

$$pV = nRT \quad \text{(eq. 1)}$$

where $n$ is the amount of gas measured in moles and $R$ is the ideal gas constant. The pressure and temperature are linearly related. An important thing about this Law is that the temperature must be expressed in Kelvins. Eq. 1 states that the pressure of a gas extrapolates to zero as the temperature approaches absolute zero. This never actually happens because gases liquefy as they are cooled.

Figure 1 shows a graph of gas pressure vs temperature for two different containers of gas. The horizontal temperature axis is in degrees Celsius. The Ideal Gas Law says that the horizontal intercept (zero pressure) corresponds to 0 K, or "absolute zero." The horizontal intercept in Figure 1, therefore, gives the value of absolute zero in degrees Celsius. The accepted value is $T_0 = -273 \degree C$.

All of the thermometers have a pressure release valve on the rod connecting the sphere and gauge. The valve may be opened to allow passage of air into or out of the sphere. It is important to realize that, if the valve is opened and the amount of air in the sphere is changed, a totally new and different thermometer is created (and the old thermometer destroyed!). This new thermometer exhibits a different relation between pressure and temperature, or calibration.

In this experiment you calibrate a thermometer, destroy it, then calibrate another. The second thermometer is used for temperature measurements. The reason for calibrating two thermometers is to display both calibration curves together as in Figure 1, allowing for a more accurate determination of the Celsius value of absolute zero.

The gauge on your constant volume thermometers reads absolute pressure in pounds per square inch (psi). You may notice that, on some gauges, the interval from 0 to 5 psi is subdivided into only four divisions, not five. In fact, 1 psi is
not included on the gauge. To read the gauge properly for pressures less than 5 psi, read down from 5 rather than up from zero.

**Procedure.**

- Fill the metal container with enough water so that it can completely cover the ball of your thermometer. Put the water on the hotplate and bring to boil. Do not put the thermometer in the warm water yet.

- Open the valve of the thermometer (at room temperature) for a few seconds to atmospheric pressure. It should read about 14.7 psi. If it does not, you need to correct for the gauge error in all pressure readings.

- Now place the thermometer in an ice-water bath. Hold the valve open and allow the pressure to settle to a constant value (of atmospheric pressure. Why? Sometimes the gauges stick, so tap the gauge to make sure of an accurate reading. You have just calibrated your first thermometer to 0 °C at atmospheric pressure.

- Close the valve and transfer the thermometer to the boiling water. Allow the pressure to reach a constant value as the system comes to equilibrium. Sometimes the gauges stick, so tap the gauge to make sure of an accurate reading. Record the pressure. You have just calibrated your first thermometer to 100 °C at atmospheric pressure.

- With the ball of the thermometer still in the boiling water, hold the valve open and allow the pressure to come to settle to atmospheric pressure. Sometimes the gauges stick, so tap the gauge to make sure of an accurate reading. When equilibrium is established, close the valve and DO NOT OPEN IT AGAIN for the rest of the experiment. You have just destroyed your first thermometer, created your second thermometer and calibrated it to 100 °C at atmospheric pressure.

- Transfer the thermometer to the ice water. Allow the pressure to come to equilibrium. Sometimes the gauges stick, so tap the gauge to make sure of an accurate reading. Record the pressure. You have just calibrated your second thermometer to 0 °C at this pressure.

- Submerge your thermometer in the carbon dioxide / alcohol solution. Sometimes the gauges stick, so tap the gauge to make sure of an accurate reading. Record the pressure. You have just used your "second thermometer" to determine the temperature of this solution.

- Use the digital thermometer to determine and record the “accepted” value for the carbon dioxide / alcohol solution.

- You now have pressure data for two temperatures (0 °C and 100 °C) for two thermometers (before and after the open valve). Graph the data as two separate sets with the pressure on the vertical axis and the Celsius temperature on the horizontal axis. Distinguish the data for different thermometers by using different shaped point indicators. Draw a straight line through each of the data sets. Construct the graph so that you can see and graphically determine the temperature intercept. When you are done, you should have something like Figure 1.

- Determine the Celsius value of absolute zero for each data set from the intercept. Although these values should be the same, experimental error makes it unlikely for your data. Take the average of the two values as your final determination.

- Graphically determine the temperature of the carbon dioxide / alcohol solution. Find the measured pressure on the pressure (vertical) axis of your graph. Go horizontally until you hit the line on the graph corresponding to the thermometer you are using. (Which one was it?) Go vertically down from the line until you hit the temperature (horizontal) axis. Read the temperature value where you hit the axis.

**Questions** (Answer clearly and completely).

1. Water boils at a temperature lower than 100 °C at higher altitudes. How would your experimental determination of the Celsius value of absolute zero
be affected if you were to do this experiment on top of a mountain?

2. What value do you determine for the Celsius value of absolute zero? What is the percent difference from the accepted value?

3. What value do you determine for the temperature of the carbon dioxide / alcohol solution? What is the percent difference from the accepted value?

4. Why should straight lines be drawn through the data sets graphed. You should refer to eq. 1.

5. Estimate how many moles of air, molecules of air, and grams of air escape when you open the valve in the boiling water. (Note: 1 mole of air has a mass of 29 grams.)

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