Determining Absolute Zero in the Kitchen Sink

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The kitchen is a good place to prepare a meal; it is also a good place to measure absolute zero. An experiment from our science education class gave us this idea.[1] The experiment is designed to qualitatively demonstrate Charles's law, and it consists of a glass bottle, a lump of clay, a straw, and a drop of water. The drop of water is placed in the straw, the straw is placed in the glass bottle, and the clay is used to seal the top of the bottle to create a constant-pressure thermometer (Fig. 1). When one places his or her hands around the bottle, the air inside heats up, and the drop of water rises in the straw.

We decided to do this experiment quantitatively, in an average kitchen sink, to get an estimate for absolute zero. The basic physics is contained in Charles's law, which states that for an ideal gas under constant pressure, the volume is directly proportional to the temperature in kelvin:

$$\frac{T_i}{T_f} = \frac{V_i}{V_f} \tag{1}$$

where the subscripts i and f refer to the initial and final volumes and temperatures. For an ideal gas, $PV = nRT$. At constant pressure, V is directly proportional to T and so $\frac{T_i}{V_i} = \frac{\Delta T}{\Delta V}$. Equation (1) reduces to:

$$T_f = V_f \frac{T_i}{V_i} = V_f \frac{\Delta T}{\Delta V} \tag{2}$$

By measuring V_f and ΔV, we can use Eq. (2) to determine the absolute temperature T_f in units of ΔT. Thus the value of absolute zero with respect to the two reference temperatures T_i and T_f can be obtained. Even though the straw in the bottle is not an ideal constant-pressure thermometer, it does fairly well, as will be shown. The constant pressure is the sum of the atmospheric pressure, the pressure due to the weight of the waterdrop, and any pressure caused by the surface tension of the drop.

There are two points for the student to think about in doing this experiment: the units to use and the proper dimensions of the thermometer.

In deciding on the system of units, one can be creative with volume, since its units cancel out in Eq. (2). We used the unit of "strawfulls." One strawfull equals the volume of the straw being used. It is easy to measure the volume of the bottle in strawfulls by determining the number of strawfulls of water needed to fill the bottle. Also, ΔV can be directly measured with a ruler as the distance the waterdrop moves down the straw, and then expressed as a certain fraction of a strawfull. For temperature we chose units of degrees centigrade to compare with values from the literature.

It is important to have the proper dimensions for the thermometer. If the bottle is too big, the drop will fall out the end of the straw when the temperature drops. It would be nice to use the standard reference temperatures of boiling water and ice water (also, they are readily available in the kitchen). With this choice, however, $\Delta T / T_f$ is 100/273, and the volume of the bottle would need to be less than 2.73 times the volume of the straw. A very small bottle is needed if standard straws are used. A glass straw could be used, but they are usually found in labs, rather than in homes. Instead of boiling water, we used room-temperature water as a reference, since ΔT is around 20°C. With this choice, the thermometer can be constructed with a larger bottle. When using a common plastic straw from our school dining area, a nail-polish bottle worked well. The temperature of the room-temperature water was measured with a thermometer (hopefully also found in the kitchen).

The nail-polish bottle we used held about 3.3 strawfulls. Clean it first with acetone (nail-polish remover), then with soap and water. Allow it to air dry. You will need some nonhardening modeling clay (available at arts and crafts stores) to seal the gap between the straw and bottle. Let a cup of water sit a while to come to equilibrium with the room. Put the bottom tip of your straw into the water, then place your finger on the top tip to take a drop of water large enough

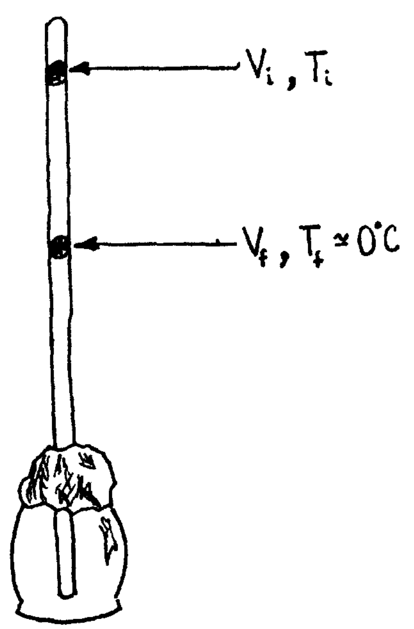
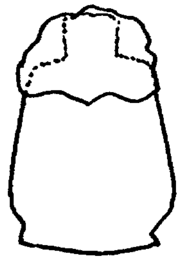


Fig. 1. The constant-pressure thermometer.



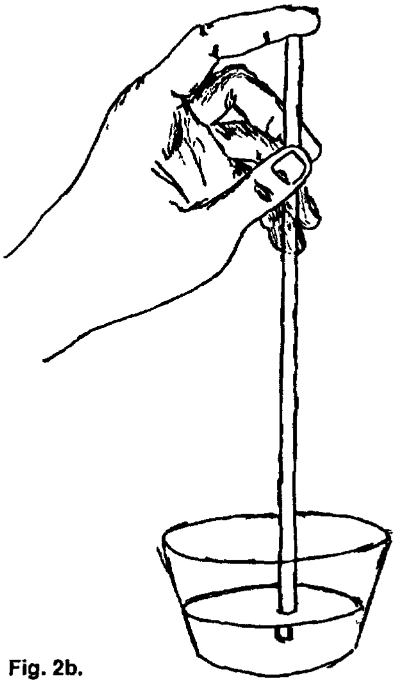


Fig. 2b.

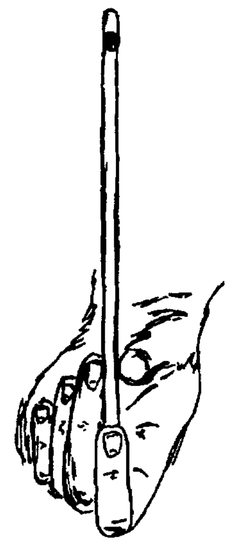


Fig. 2c.

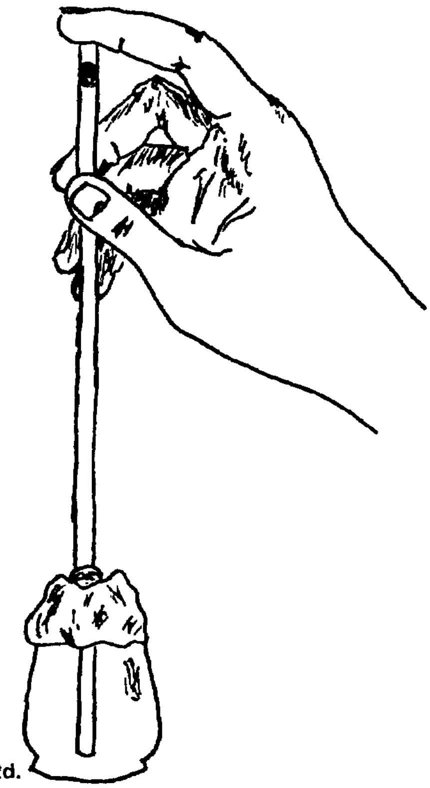


Fig. 2d.

Fig. 2. Constructing the thermometer: (a) nail-polish bottle with clay; (b) take about 3 mm of water into the transparent straw; (c) turn the straw upside down and allow the drop to slide down a bit; (d) carefully seal the tip of the straw and insert it into the bottle, and then seal the gap with clay.

to move about freely in the straw without breaking (around 3 mm). This will take some practice (see Fig. 2b).

Keep your finger on the top tip of the straw and carefully turn the straw upside down. Let the drop slide down just a little (Fig. 2c), then use the index finger of your other hand to seal the other end of the straw; you can now release your first finger from the bottom of the straw. Be sure to keep the straw vertical to prevent the drop from breaking.

Carefully insert the straw into the bottle and seal the gap with clay (Fig. 2d). Try not to push the clay into the bottle's neck. Now remove your finger from the top of the straw. Place the "thermometer" into the room-temperature water and wait for the drop to stop moving (equilibrium). Measure the temperature of the water with the standard thermometer; this is ΔT in Eq. (2). Mark where the drop is.

Now, carefully place the bottle in a cup of ice water. Make sure that nearly all of the bottle is immersed. The drop will move downward. When the drop has stopped moving, measure Δh, the distance the drop has moved. Determine ΔV and V_f in units of strawfulls. Plug your measured values into Eq. (2). Absolute zero will be $-T_f$.

Some data taken in our department chair's kitchen at our physics end-of-year party is shown in Fig. 3. There appears to be a systematic error causing the results to be lower than -273°C. This might be due to different surface tension forces at the initial and final points, causing ΔV to be smaller than it should be. We tried to check for possible systematic errors by placing the bottle back in the room-temperature water to see if the drop returned to its original height. Sometimes it came very close. The standard thermometer used to measure ΔT was actually hanging in the kitchen.

Please note that the most dangerous part of the experiment is getting in the cook's way.

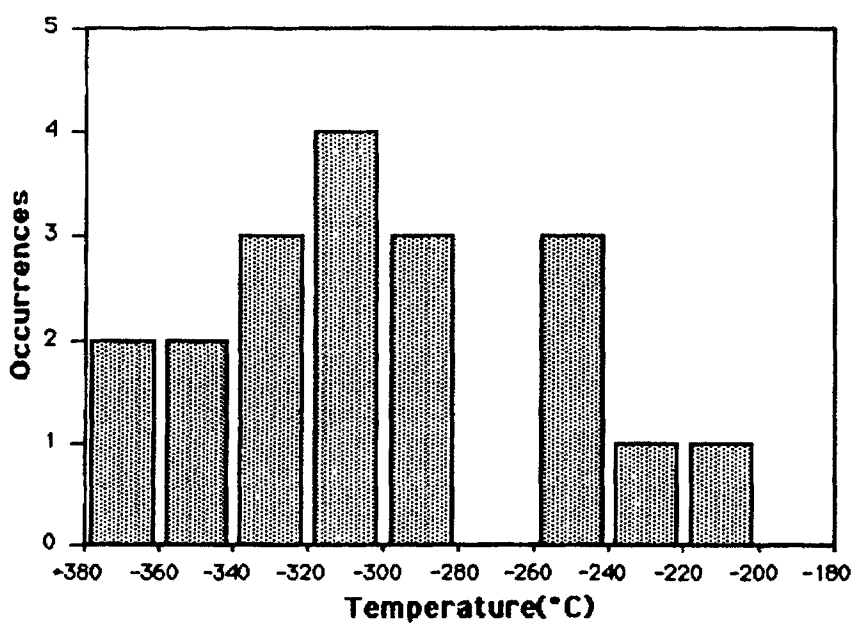


Fig. 3. Histogram showing results of data taken from 19 experimental runs.

Reference

1. J.P. Vancleave, *Teaching the Fun of Physics* (Prentice-Hall, Englewood Cliffs, NJ, 1985), pp. 22–23.