Experiment 12

The Constant Volume Gas Thermometer

12.1 PURPOSE

In this lab, you will

1. Test how well the ideal gas law applies to a sample of helium kept at constant volume, and
2. Use a constant volume gas thermometer to obtain an estimate of the value of absolute zero on the Celsius scale.

12.2 INTRODUCTION

A gas of a sufficiently low density and a temperature well above the liquification point follows the relationship known as the ideal gas law (at least to a good approximation). That law, or equation of state, is often written as $pV = nRT$ where, in SI units, p is the absolute pressure (in pascals), V is the volume of the gas (in m^3), n is the number of moles of gas of the sample, R is the universal gas constant, and T is the absolute temperature (in kelvins). Physicists often prefer to write the ideal gas law in the form $pV = Nk_BT$, where N is the number of molecules and k_B is Boltzmann's constant.

On the Kelvin scale, a temperature of 0 is the temperature at which an ideal gas would exert a pressure of 0. This temperature is known as absolute zero. On the Celsius temperature scale, on the other hand, the 0 is placed at an arbitrary (but fixed and convenient) value corresponding to the freezing point of water. In terms of °C, the ideal gas law can be written

$$T_c = T_z + Cp \tag{12.1}$$

where T_c is the temperature in degrees Celsius, C is a constant that depends on V, n, and R, and T_z is absolute zero, *i.e.* the temperature in degrees Celsius when the pressure is 0.

12.3 EXPERIMENT

You will work with a closed flask that has been filled with helium gas. The flask is a hollow metal sphere with a pressure gauge attached. Record the apparatus number, which is written on a label on the back of the pressure gauge. The gauge reads **absolute** pressure, so you can use those readings without having to make a correction for atmospheric pressure. Unfortunately, the gauge is calibrated in pounds per square inch (psi), but since you will not need to calculate the numerical value of the constant C in Eq. 12.1, you may just leave your readings in psi and not worry about converting them to SI values.

Several constant temperature baths have been set up in the lab room ranging from boiling water at nearly 100°C to liquid nitrogen (also boiling slowly) at −195.8°C.

SAFETY REMINDER: You can **seriously** injure yourself with either the very hot or the very cold temperature baths in the room. Do not let the hot or cold fluids, or objects that have recently been in those fluids, touch your skin or clothing.

Slowly immerse the spherical part of the flask in each bath and wait until thermal equilibrium has been obtained. Record the equilibrium temperature and pressure for each bath.

You may be able to improve the accuracy of your data somewhat with good technique: tap the gauge lightly before reading, stir each bath gently while waiting for equilibrium, and repeat each reading at least once. After you have finished all the readings, you should go back to the bath you started with to be certain that nothing has changed in your flask.

You should also consider plotting your data as you go along so that potentially errant points can be identified and checked quickly.

12.4 ANALYSIS

You have two main goals in this experiment:

1. Test how well your helium sample is described by the ideal gas law, and
2. Obtain an estimate for absolute zero on the Celsius scale.

Make a graph of T *vs.* p. (Remember, when you make a graph of A *vs.* B, the A goes on the vertical axis and the B goes on the horizontal axis.)

What does the ideal gas law predict for the *shape* of this graph? Do your data agree? (Note we are not interested in the numerical value of C in Eq. 12.1, we are just interested in whether the data is of the same functional form.)

The temperature at which an ideal gas would have a pressure of zero is known as absolute zero. From your data, what is your best estimate of absolute zero on the Celsius scale? What is the uncertainty in your estimate? Explain.

Compare your experimental results with the expected value of $T_z = -273.15°\text{C}$, including a complete uncertainty analysis. Are the differences significant?

What effect might the thermal contraction of the metal sphere have on your results? Did that appear to have been a significant factor? Explain. Can you think of any other sources of systematic error? Discuss.

As always, discuss sources of error and ways in which the experiment or write-up could be improved.