IDEAL GAS LAW

(Equipment: water containers, paper towels, blocks of wood with string, scale, force probe, pressure sensor, temperature sensor, tubing, ice, hot plate, boiling flask & stopper, syringe, computer, LabPro, 100-g mass, Pasco Heat Engine Apparatus, motion detector.)

OBJECTIVES

1. To experimentally verify some aspects of the Ideal-Gas Law.
2. To experimentally determine absolute zero.

PRE-LAB (to be completed before coming to lab)

Prior to coming to lab, read through this write-up and perform all the exercises labeled Pre-Lab”. During the first 5 minutes of lab, I will check that you have done them. During the course of the lab, you may find that some pre-labs were incorrect – correct them, for I will grade the final versions (provided you’d done respectably before lab).

OVERVIEW

The Ideal-Gas Law is

\[ PV = nRT = NkT, \]

where \( n \) is the number of moles of gas and \( N \) is the number of gas atoms or molecules. The relation between number of moles and number of molecules is

\[ N = nN_A, \]

where \( N_A = 6.02 \times 10^{23} \). The number of moles is the mass divided by the atomic or molecular mass. \( R=8314 \text{ J/kmol}\cdot\text{K} \) is the gas constant and \( k=1.38 \times 10^{-23} \text{ J/K} \) is Boltzmann’s constant. This law describes the approximate behavior of gases that are far from condensation. The temperature used in it must always be expressed in kelvins. The temperature in kelvins is never negative because neither pressure nor volume can be negative. The lowest possible temperature is zero kelvin, which is known as absolute zero. The relation between the temperature in kelvins \( (T) \) and the temperature in degrees Celsius \( (T_C) \) is

\[ T = T_C + 273. \]

The pressure in the law is the absolute pressure, not the gauge pressure \( (P_G = P - P_a) \). Recall that a pressure is a force divided by an area. Also, the relations between some common pressure units are:

\[ 1 \text{ atm} = 1.01 \times 10^5 \text{ Pa} = 76 \text{ cmHg} \quad 1 \text{ Pa} = 1 \text{ N/m}^2 \]

PART ONE: Calibration of the Pressure Sensor

Before you can use the pressure sensor and temperature probe, you must calibrate them by entering readings for two known situations.
0. Unplug the force probe.
1. Plug the pressure sensor into Channel 1 and the thermometer into Channel 2.
2. Open Physics Experiments / Phys 344/ Ideal Gas / “Pressure-Temperature.”
2. You’ll need to calibrate the pressure sensor. Under the Experiment menu, select “Calibrate” and select just the pressure sensor. Hit “Calibrate Now.” With the syringe completely pressed in, attach it to the pressure sensor (they screw together.) Hit “Calibrate Now.” For the first calibration point, attach the larger of your two syringes and pull back on the plunger until the sensor reads 0 (or as close as you can get it). Then enter 0 kPa and hit “Keep.” For the second calibration point, remove the syringe and allow the sensor to be exposed to atmospheric pressure; enter 101 kPa and hit “Keep.” Finally, hit “Done.”
PART THREE: Constant Temperature

For this part, you will work with air at room temperature. All changes in the volume of the syringe should be made slowly so that the temperature of the gas inside can readjust if necessary.

1. Un-attach the syringe from the gauge and pull it back to 20 cm³. Then re-attach the syringe to the gauge. Do not squeeze the syringe so hard that the pressure goes above 6 times atmospheric pressure or you may damage the sensor. Gas is also likely to leak out of the syringe at very large pressures and you will be assuming the quantity of gas is constant.

2. Record the room temperature.

   \[ T_C = \quad ^\circ C \quad T_K = \quad K \]

3. Slowly compress the air in the syringe and take readings of the pressure for five volumes, two smaller than 20 cm³ and two larger. Note: without hitting “collect”, you can just monitor the pressure reading in the bottom left of the program window. Also, calculate the inverse of the volume for each measurement.

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<thead>
<tr>
<th>Volume (cm³)</th>
<th>1/Volume (cm⁻³)</th>
<th>Pressure (kPa)</th>
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4. **Pre-Lab:** According to the Ideal Gas Law, sketch what you’d expect a plot of $P$ vs. $1/V$ to look like.

```
  | P
---+---
   | 1/V
```

5. **Pre-Lab:** In terms of $N$, $k$, and $T$, what does the Ideal Gas Law say the slope should be (no numbers required)?

6. Plot the pressure vs. (1/volume) below. (Note: you can use LoggerPro to do this if, under the “Data” menu, you define a new data column and enter your 1/V values.)

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<th>P (kPa)</th>
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<th>1/V (cm$^{-3}$)</th>
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**Question:** Does your data agree with the Ideal-Gas Law? Explain.

Calculate the Slope (you may wish to use LoggerPro or Excel).
**Question:** How many molecules are inside the syringe? Show your work. (Note: you’ll need to convert pressure, temperature, and volume into base SI units – Pa, K, and m³).

**Question:** If you assume that all of the air is nitrogen molecules (molecular mass of 4.6 ×10⁻²⁶ kg / molecule), what is the total mass of the gas inside the syringe? Show your work.

**Question:** If you very suddenly compressed a gas to half of its original volume, why could the pressure more than double?
PART FOUR: Constant Volume

You will move a can of air between boiling water and ice water, noting the pressure and temperature changes. Note: Be sure no tubing or wires touch the hot plate, for their apt to melt!

1. Attach the pressure sensor and temperature sensor to a can filled with air as shown below.

2. In the “Pressure – Temperature” program, hit “Collect.” There should now be a “Keep” button. Whenever you wish to record a data point, hit “Keep.” When you’ve taken all your data points, hit “Stop.”

3. Ice water, tap water, and boiling water are at your disposal. Take data points for the can at temperatures throughout the corresponding temperature range. You can take data points with the can submerged in these three and in mixtures of them (to give in between temperature points.)

4. Transfer the resulting Pressure vs. Temperature graph below.
Questions: According to your data, at what pressure would the temperature be zero? (There’s a “Linear Fit” button in the program.) How does your value compare to the accepted value of absolute zero?

**PART FIVE: Constant Pressure**

1. Replace the pressure sensor with the piston shown below. You’ll begin with the piston fully compressed. Because of compatibility problems, you’ll need to change the tubing as well.
2. Within the piston’s base, close the shut-off valve on the tubing from the unused port. You may also need to loosen the set-screw at the top of the piston.

3. Attach the motion detector to DIG / SONIC 1, and detach the pressure sensor from the LabPro. Inside the piston’s base should be a label giving the piston’s diameter. If it quotes 32.5 mm, then open “Volume-Temperature Large” in Physics Experiments / Phys 344 / Ideal Gas, otherwise, open “Volume-Temperature Small” in the same folder.

4. Aim the motion detector so it monitors the piston’s head. Note: the detector is far-sighted, so don’t place it within 10 cm’s of the piston’s furthest reach. Under the “Experiment” menu, Zero just the motion detector.

5. Starting with the piston fully compressed and the can at room temperature, take data points over the range of temperatures from room temperature to near boiling by submerging the can in water of different temperatures. It’s probably best to start with the piston in tap water and let the water heat on the hot plate – that gives a nice, slow temperature change. Too quickly varying the can’s temperature won’t allow the piston to come into equilibrium with it.

6. Transfer the resulting Volume vs. Temperature graph below.

Questions: According to your data, and given atmospheric pressure, how many particles are in the can – piston system?