PHY102 Acitivity #4 – Friday 1/24/03
Ideal Gas Laws

Purpose: To verify the ideal gas law ($PV = NkT$) of which we make so much use in this course. Today you will work mostly on gathering data. You will analyze this data as part of HW#2 due Thursday 1/30. Be sure to hand in your data sheet (below) with HW#2. Also, be sure to have your TA or coach initial your data sheet before you leave the lab. The relevant HW questions are below in the Analysis section. If you have time after collecting your data, you should start on them here in the workshop.

Equipment List (See picture at the end of this handout)

1. Metal chamber from PASCO Gas Law Experimenter Kit
2. Electronic Pressure sensor (+ computer & software)
3. Connector with small hole.
4. Syringe
5. Two one-way flow valves
6. Tubing, T-junction, connectors, and a 3-hole stopper
7. Gas Supplies: Helium and Nitrogen. Note that Helium has atomic number 2 and forms a monatomic gas, while Nitrogen has atomic number 7 and forms a diatomic gas (N_2).
8. Thermometer
9. You will not use the balloon assembly shown in the picture. Cap off this opening (or attach a 3-way valve and turn it off).
10. Temperature sensor.
11. Plastic bucket to fill with water.
12. Tray to put under bucket to catch spills.
13. Bin for ice at the front of the room.

1 Theory and Background

We have begun to discuss the idea gas law, $PV = NkT$, in class and we will soon derive this law from the kinetic-molecular theory of heat. But, is this law really true in the real world? Today we will see that it holds to an excellent approximation, even for a relatively complicated gas such as air.

We will do this by verifying two parts of this law separately. First, note that if N and T are constant, it is useful to write the law as

$$P = \frac{NkT}{V}.$$

Since NkT is a constant, one says that P is 'inversely proportional' to V. We will verify this by holding NkT constant and plotting a graph of P vs. $1/V$. The ideal gas law *predicts* that this graph is a straight line.

Let us also consider what happens if we hold N and V constant but change T. Then it is useful to write the law as

$$P = \frac{Nk}{V}T.$$

We say that P is proportional to T and a graph of P vs. T should form a straight line.

Verifying that these two graphs form a straight line is tantamount to verifying the entire ideal gas law.

2 Preliminary Setup

If you are lucky, much of this will be already done for you. Nevertheless, you should double check to make sure that all parts are properly connected.

a) Attach the electronic pressure sensor to DIN1 of the ULI box. Be sure that the red switch on the back of the ULI box is set to 1.

b) Attach the electronic temperature sensor to DIN2 of the ULI box.

c) Wake up the computer (press enter or spacebar or turn it on) and double click on Logger Pro 2.0 to start it from the computer desktop.

d) From the Setup menu, choose ‘sensors.’ Click DIN1. You will find a pop-up screen with two menus (Sensor and Calibration) and a row of buttons marked ULI along the top. Set ‘Sensor’ to ‘Pressure-Gas’ and ‘Calibration’ to kPa_gps.

e) From the Setup menu, choose ‘sensors’ again. This time, click DIN2. Set ‘Sensor’ to ‘Temperature-Direct Connect’ and ‘Calibration’ to $Deg-C-dc$. Click OK.

f) Click on the number at the top left of the graph and type ‘105’ into the box. Similarly set the number at lower left to zero.

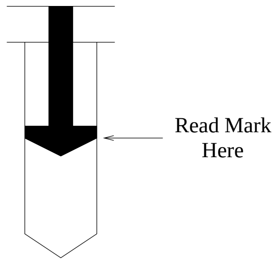
3 Part I

Setup

For the first part of this experiment, we need only a small fraction of the equipmment: the syringe, the short piece of tubing connected to the syringe, and the pressure sensor. If the syringe and its short piece of tubing are connected to the 3-way junction, pull them off. Similarly, separate the pressure sensor from the rest of the tubing. Then connect the short tube on the syringe directly to the pressure sensor. There should be only one short (about 2 inches long) piece of tubing between the syringe and the pressure sensor.

Proceedure

a) The idea is to fill the syringe with varying amounts of gas. We will do this by disconnecting the tubing from the pressure sensor, setting the syringe to a desired volume, and then reconnecting the tubing to the pressure sensor. This defines the ‘initial volume’ of the syringe. We will try this experiment for initial volumes of 20cc and 60cc. Note that you read the volume of the syringe by aligning the mark with the place where the conical tip of the plunger meets the edge of the tube as shown in the diagram below.



b) Start with an initial volume of 60cc and set up the system as just described. The pressure should read roughly one atmosphere – somewhere around 100kPa, depending on the weather. Record the inital pressure in the data table below. Now, leaving all of the tubing connected, move the syringe in turn to the 50cc, 40cc, and 30cc marks, recording the pressure at each of these the data table. For this case, we do not try to compress the gas to 20cc or 10cc because the pressure sensor only reads pressure up to slightly over 200kPa.

c) Repeat this with an initial volume of 20cc. Take data at each of 10cc, 20cc, 30cc, 40cc, 50cc, and 60cc.

4 Part II

We will now study P vs. T.

Procedure

a) The system should be set up as shown in the figure at the end of this handout, except that the balloon assembly should have been replaced with a cap. Well, OK, we seem to have drilled holes in all of our caps, but if you screw on a 3-way valve and turn the valve off, this will function as a cap. In particular, use the short transparent tube to attach the syringe to the T-junction that is connected to the green one-way flow valves. Also, attach the pressure sensor to the other plastic tube that goes into the chamber.

b) Pull the white stopper out of the metal chamber to allow it to equilibrate to atmospheric pressure. Then put the stopper back. Press it in tightly.

c) Begin by pumping the system down to about half an atmosphere. You do this by pumping the syringe. Having the chamber at less than atmospheric pressure lets the atmosphere press everything together for you so that the seals close tightly. After you have pumped it down, watch the reading on the pressure gauge for 30 seconds or so. Note that the leak rate is much lower than on the effusion experiment. In fact, it should be effectively zero.

d) Fill your tall plastic container with warm water (bath or shower temperature will do) from the tap at the back of the room. You may have to let the tap run for a bit before it heats up. Stop when the water is about an inch from the top. Take this container back to your table and place it inside the large plastic tray. The tray is to catch spills that will inevitably happen during this experiment.

e) Stir the water to make sure that it is all at the same temperatue. You can use your hand or the metal chamber for this.

f) Measure the temperature of the water with the electronic temperature probe. Try not to get the black part wet. Record this temperature on your data sheet.

g) Submerge the metal chamber in the water and watch the reading on the pressure sensor. It should reach equillibrium in a few seconds. Record this equillibrium pressure.

h) Now, get some ice from the front of the room and place it in your water container. Stir until the ice is completely melted. The goal is to lower the temperature of the water about 10^oC. Add more ice (or more hot water) until you get a temperature roughly 10^oC less than you had before. [Note: Anything between 8 and 12 degrees will do.] Again, measure and record the temperature of the water at the equillibrium pressure of the air in your chamber.

i) Continue to add ice and take data in this way until the temperature of your water bath gets close to zero C.

5 Analysis

Part I: Use the graph paper provided to make a graph of P vs. $1/V$ for each of your initial volumes from Part I. Make the axes of your graph long enough that the origin (the point $P = 0, 1/V = 0$) is actually on your graph. On each graph, draw the straight line *through the origin* that best fits the data. The easiest way to do this is to place the edge of a ruler or a piece of paper through the origin and then to rotate the paper around your origin (sweeping the paper across the page), stopping the rotation when the edge seems to best fit the data. Draw the resulting line on your graph – is this line a good fit?

Give a percentage estimate of how well the straight line through the origin fits your data by the following method: Find the data point that lies farthest from the line. Determine the difference in pressure between your data point and the point on your line at the same volume. Divide this number by the pressure at your data point and express the result as a percentage. Fill these numbers in on your data sheet. The point of this is that the straight line is compatible with your data only under the assumption that there is an error or uncertainty in your measurement of this magnitude.

Discuss possible sources of such error or uncertainty with your group and record the most likely ones on the data sheet.

Part II: Plot your data from Part II on a graph of P vs. T. Even though your data did not go this far, your axes should be labeled down to $P = 0$ and $T = -300C$ or so.

Draw the straight line that best fits your data. (This time, don't worry about whether it intersects your 'origin' or not.) Now, use the method described above to give a percentage description of the extent to which your data deviates from this line.

Again, discuss some possible sources of error or uncertainty with your group and record the most likely suggestions.

Finally, use your line to determine the absolute zero of temperature in ^{o}C. This is the temperature at which your line predicts that the pressure will become zero. You should be able to read this value off of your graph. Record this value on your data sheet.

How close is it to the accepted value? How does this compare with your uncertainty computed above?

6 Data Sheet

TA/Coach Initials:

Part I:

Initial Volume: 60cc

Volume	60cc	50cc	40cc	30cc
Pressure				

Initial Volume: 20cc

Volume	60cc	50cc	40cc	30cc	20cc	10 cc
Pressure						

Percentage Accuracy Estimates of straight line fit through origin fit to P vs. 1/V:

Initial Volume	60cc	20cc
% fit		

Suggested sources of error or uncertainty:

Part II:

Temperature	Pressure

Percentage Estimate of straight line fit to P vs. T:

Suggested sources of error or uncertainty:

Experimentally determined absolute zero:

Is this as close to the accepted value as you would expect based on your error estimated above?