Experiment 10

Ideal Gas Law and Absolute Zero

I. Purpose

The purpose of this lab is to examine the relationship between the pressure, volume and temperature of air in a closed chamber. To do this, you will test the Ideal Gas Law when the temperature is held constant (Boyle's Law) and when the volume is held constant (Charles' Law). You will also do an experiment to find Absolute Zero, the temperature at which the pressure of an ideal gas would be zero.

II. Preparing for the Lab

You need to prepare before doing this lab. Start by reading through this lab write-up. If you need a review the Ideal Gas Law, read Chapter 12 in *College Physics a Strategic Approach* by Knight, Jones and Field. Finally, don't forget to do the Pre-Lab questions and turn them in to Expert TA before your lab starts.

III. Pre-lab Questions ***(Submit answers to Expert TA before your lab section meets)***

Questions and multiple choice answers on Expert TA may vary from those given below. Be sure to read questions and choices carefully before submitting your answers on Expert TA.

#1. Suppose there are 200 cm^3 of oxygen at a temperature of 0^o C and a pressure of 1.50×10^5 Pa. How many moles of nitrogen are there?

#2. Consider the Boyle's Law Apparatus. Suppose that the volume of the gas is 30 cc and the pressure is 30 lbs/in^2. If the plunger is depressed so that the volume is decreased to 12 cc, what will the pressure be?

#3. What is room temperature on the Celsius temperature scale, approximately?

IV. References

Chapter 12 in College Physics: A Strategic Approach by Knight, Jones and Field.

IV. Equipment:

Boyle's Law Apparatus	temperature sensor	classroom Barometer
Charles' Law apparatus	pressure sensor	
Logger Pro	Spreadsheet template for Lab 10	

Safety Warning: The apparatus used in Part B to test Charles Law uses a low-voltage nichrome coil to heat a closed copper cylinder to temperatures as high as 130 ^oC. The heater coil and copper cylinder are surrounded by a metal wire screen to prevent you from contacting the coil or other hot surfaces. Do not remove this screen and do not push anything into or through the screen as this can damage the apparatus. Before using the Charles Law apparatus, make sure that it is stable, not at the edge of the bench, and the electrical cord is out of the way so that it cannot be snagged and cause the apparatus to be knocked over. Be sure to turn the power off when you are finished collecting data.

V. Introduction

The **Ideal Gas Law** says that the pressure P, volume V and temperature T of an ideal gas are related by:

$$PV = nRT \quad (1)$$

where n is the number of moles of the gas and R is the ideal gas constant. The ideal gas law is obeyed fairly well by many real gases, including air, provided the temperature does not get so low or the pressure so high that the gas starts to condense into a liquid.

In Part A of this lab, you will keep the temperature fixed and see what happens to the pressure when you change the volume of air in a closed container. Since the container is closed, the number of moles n will be fixed. Note that if the temperature is also kept constant, all the factors on the right hand side of Equation (1) are constant and we can write:

$$PV = C_B \quad (2)$$

where we have defined a constant C_B = nRT. Equation (2) is **Boyle's law** and it should hold for an ideal gas when the temperature T and number of moles n are held constant.

In Part B of this lab you will keep the gas volume constant. For this situation, Equation (1) can be rewritten as:

$$P = \left(\frac{nR}{V}\right)T \quad (3)$$

Note that if the volume V and number of moles n are kept constant, then all the factors in the parentheses on the right hand side of the equation are constant and we can write simply:

$$P = C_c T \quad (4)$$

where we have defined the constant factor C_c = nR/V. Equation (4) is **Charles' law** and it should hold for an ideal gas when the volume V and number of moles n are held fixed. Note that the Charles' Law constant C_c is not equal to the Boyles Law constant C_B.

From Equation (4) you can see that, if the temperature increases, the pressure should increase proportionally. Similarly, if the pressure decreases to zero, then the temperature must also decrease to zero and this would be the lowest possible temperature, or **absolute zero**. It is important to realize that Equation (4) is only valid if you use an absolute temperature scale, such as the **Kelvin scale**, in which the lowest possible temperature is zero. However, in this lab you will not be using a thermometer that measures using an absolute scale. Instead you will use a thermometer that uses the Celsius scale, and so you will find the Celsius temperature T_o that corresponds to **absolute zero (**lowest possible temperature) on the Celsius scale.

VII. Experiment

Part A: Check Boyle's Law: PV=C_B

(1) On the computer desktop, open the **Templates** folder and open the Excel spreadsheet named:
Phys 121 Experiment 10 Ideal Gas Law and Absolute Zero

(2) Fill in your name, your lab partner's name and the lab section number. If you do not have a lab partner, just enter "no one" in the cell for the lab partner. You can't save or exit this template unless this information has been filled in, so do so now. To save the file you must use the large gray button in the main body of the spreadsheet (the standard Save button in the menu has been disabled) and the template will automatically save a suitably named copy for you and another suitably named copy for your lab partner in the My Documents folder.

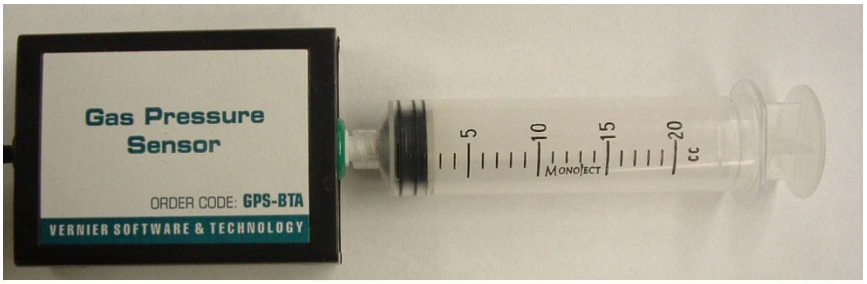

Figure 1. Boyle's Law Apparatus.

The main goal of this part is to collect some data showing how the pressure of air changes when the volume changes. This data will be used to test whether Boyle's Law is obeyed.

(3) You will need to calibrate the gas pressure sensor. To do this, start by unscrewing the plastic syringe from the gas pressure sensor box (see Figure 1).

(4) Go back to the "**Templates**" folder and now open the LoggerPro template named "**Boyle's Law**". You will use this program to automatically collect pressure data as you change the volume. In the "Experiment" drop down menu, click on "Calibrate" and choose "Gas Pressure Sensor". Go to the wall of the lab room with the windows in it, locate the barometer and read the atmospheric pressure in kPa (these units are kilo-Pascal or 10^3 Pa). Click on "Calibrate Now" and type the pressure reading from the barometer into the designated place in the open window. Click on "Keep" and then "Done" to finish the calibration.

(5) Push the plunger so that the top of the seal, which is a readily identifiable on the plunger, is at the volume V'= 12 cc mark on the barrel. Then screw the syringe onto the sensor.

(6) With the plunger at the V'= 12 cc mark on the barrel, start collecting data by clicking on the **Collect** button. Wait about 20 s. Then push the plunger in until the top of the seal is at volume V'=11 cc **and hold it there**. Wait about 20 s. Do not let go of the plunger until you are finished taking data. Then continue this sequence until the top of the seal, or your chosen marker, is at the 8 cc mark. After reaching the 8 cc mark, start pulling the plunger out in similar sized steps with pauses of 20 s until the 16 cc mark is reached and finish there by collecting data for 20 s.

(7) Select all the data, copy it, and then paste it into your spreadsheet it the designated area. The template will do its best to determine the flat sections of your data, but you may have to use some judgment.

(8) Use EXCEL to plot the pressure versus time. Your data should look like something like Figure 2. Be sure to add a chart title, axes titles and units.

(9) Examine the scale on the plunger barrel and estimate how precisely you can read the location of the top of the seal, or your chosen marker. Estimate the uncertainty ΔV' in your volume readings and record in the designated column in your spreadsheet. It will be the same for every cell in the column.

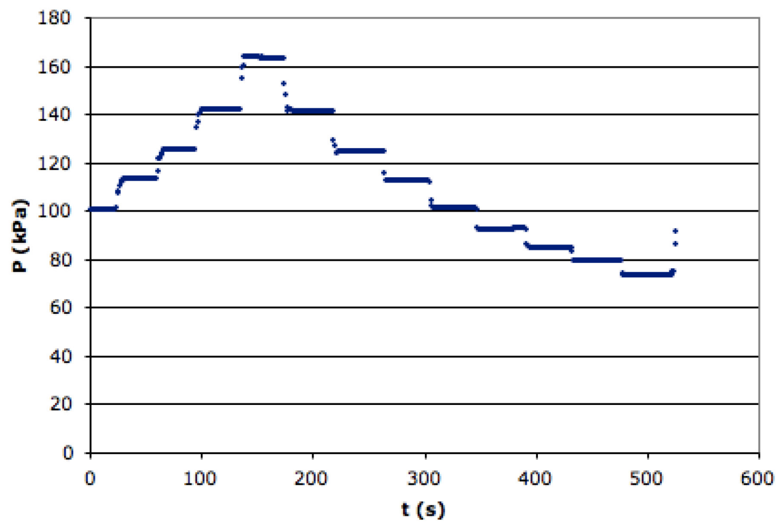

Figure 2. Sample plot showing pressure as a function of time during Part A of the experiment.

Part B: Check Charles' Law: $P/T = C_c$

The Charles Law apparatus uses a nichrome wire ribbon wrapped around a cylindrical copper vessel to heat the air contained within the vessel (see Figure 3). This apparatus allows you to measure the pressure in the vessel as the temperature varies from room temperature (in the range of 20 °C to 25 °C) up to about 130 °C, the maximum temperature the apparatus can reach. Do not remove the wire mesh screen and do not push anything into or through the screen as this can damage the apparatus.

(1) Set the toggle switch on the base of the Charles Law apparatus to the center (OFF) position (see Figure 3).

(2) You will use the same Vernier pressure sensor box that you used in the Boyles Law apparatus. Carefully unscrew the plastic syringe from the pressure sensor box and reconnect the box to the long plastic tube that goes to the copper cylinder (see Figure 3).

(3) Close the “Boyle’s Law” LoggerPro template. Go to your computer desktop, open the “**Templates**” folder and open the LoggerPro template named “Charles’ Law”. If the pressure reading seems off, follow the procedure used above to calibrate the pressure sensor.

(4) The Charles Law apparatus uses a small temperature sensor fastened to the side of the copper cylinder and insulated from the ambient air with a small piece of foam rubber. The sensor connects to the computer using the standard LabPro interface. Be sure that the temperature sensor is plugged into #3 position on the LabPro interface box.

(5) After starting the Charles Law LoggerPro template, check that the temperature is below 30ºC. If not, turn on the fan to cool the cylinder by setting the toggle switch to FAN. Once the cylinder is at or below 30ºC turn off the fan and allow the apparatus to equilibrate for ~2 minutes.

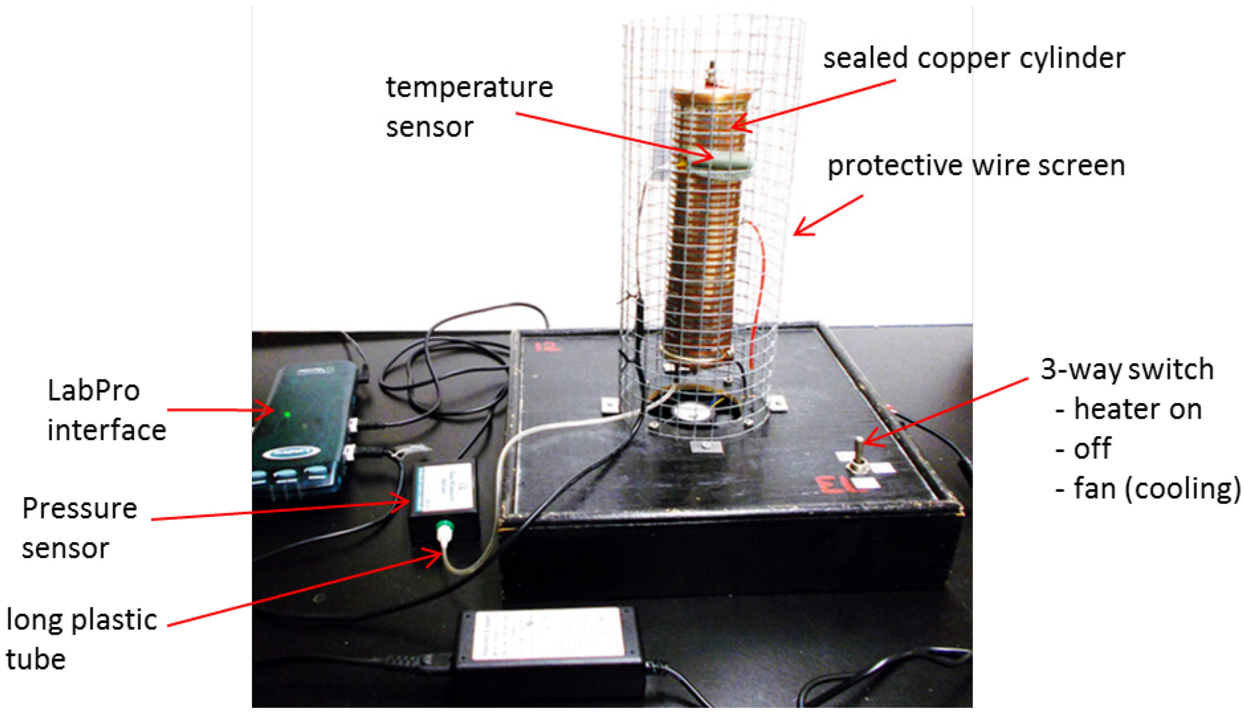

Figure 3. Photo showing Charles' Law apparatus.

(6) You are now ready to gather data. Click on the Collect button in LoggerPro. After verifying that data collection has started, move the toggle switch to the HEAT position. This will energize the nichrome coil and begin heating the copper cylinder and the gas (air) that it contains. You should see the pressure and temperature rise steadily. After about 15 or 20 minutes, the temperature should reach ~125 ºC, at which point you should stop collecting data.

(7) Turn off the heater (and blower) by returning the toggle switch to the center (OFF) position.

(8) Select the temperature data and paste it into the “T” column in Part B in your template. Select the pressure data and paste it into the “P” column in Part B in your template.

(9) Use EXCEL to plot the pressure versus temperature. Be sure to add a chart title, axes titles and units.

VIII. Analysis

Part A: Data Analysis for Boyle’s Law ($PV=C_B$)

In this part you will analyze your data to test whether Boyles Law is obeyed.

(1) Examine your pressure versus time data that you collected in Part A. For each 20 s interval during which you were supposed to be holding the plunger fixed, the pressure should be nearly constant. The template will do its best to highlight the flat sections, but you may have to use some judgment. Calculate the average pressure P_{avg} during these periods, by typing

"**=AVERAGE(**" without quotes into a cell, selecting the range of cells with the pressure values you want to average, and then close with "**)**". Enter this average pressure in the same row as its associated volume reading V' in the table in your spreadsheet.

(2) The manufacturer of the pressure sensor says that the uncertainty in the average pressure P_{avg} is $\Delta P = P_{avg} / 500$. Enter the EXCEL formula for the uncertainties into the spreadsheet.

(3) Although you have volume readings V', this is just the volume of gas in the syringe, and not the total volume V of the gas that was being expanded and compressed because there is some volume V_o in the gas pressure sensor and its connection to the syringe. That is, the total volume V is:

$$V = V' + V_0 \tag{5}$$

Unfortunately we don't know V_o and will need to find it from the data itself. If this is substituted into Equation (2), which is Boyle's Law, we get:

$$P_{avg}\left(V' + V_0\right) = C_B \tag{6}$$

Rearranging things, this becomes:

$$V' = C_B\left(\frac{1}{P_{avg}}\right) - V_0 \tag{7}$$

The idea is that if you plot V' versus $1/P_{avg,}$ it will be a straight line with a slope of C_B and a y-intercept of $-V_o$.

(4) Given that there is an uncertainty in P_{avg}, there will be an uncertainty in $1/P_{avg}$. Propagating errors in this case gives:

$$\Delta\left(\frac{1}{P_{avg}}\right) = \frac{\Delta P_{avg}}{\left(P_{avg}\right)^2} \tag{9}$$

Plug the corresponding EXCEL formula into the designated column in your spreadsheet to find the uncertainty $\Delta(1/P_{avg})$ in $1/P_{avg}$.

(5) After you have filled in the column for $\Delta(1/P_{avg})$ in your spreadsheet, click "Fit line to V' vs 1/P". This macro performs a straight-line χ^2 fit to your $1/P_{avg}$ versus V' data and extracts the best fit estimate for V_o and its uncertainty ΔV_o.

(6) Now that V_0 and ΔV_o are known, use EXCEL to calculate $V=V_o+V'$ and its uncertainty ΔV. The uncertainty in V can be found using propagation of errors and one finds:

$$\Delta V = \sqrt{\left(\Delta V'\right)^2 + \left(\Delta V_o\right)^2} \tag{10}$$

Plug the corresponding EXCEL formula into the designated column in your spreadsheet.

(7) After you have filled in the column for ΔV in your spreadsheet, click the button labelled "Fit power law to P vs V". This macro performs a χ^2 fit of your P_{avg} versus V results to an equation of the form:

$$P_{avg} = C_B V^n \tag{11}$$

For your data to be consistent with Boyle's Law, you should expect to find a good fit and a value of n near -1. Notice that the macro also gives the best fit estimate for C_B, the uncertainty Δn in n, and the "reduced χ^2 value" which is just χ^2/ν where ν is the number of data points minus the number of fitting parameters (2 in this case).

Part B: Analysis of the Charles' Law Data and Determination of Absolute Zero

In this part you will analyze your data to test whether Charles Law is obeyed.

(1) In the designated areas in part B of your spreadsheet, calculate the uncertainties ΔT in T and the uncertainty ΔP in the pressure P. The manufacturer of the temperature sensor says that the uncertainty ΔT is given by $\Delta T = 0.003T + 0.2$ (°C), and the uncertainty in the pressure is given by $\Delta P = P/500$.

(2) After you have the uncertainties ΔT and ΔP added to your spreadsheet, click "Fit line to P vs T". This macro performs a χ^2 fit of your P versus T data to the function:

$$P = C_c(T - T_o) \quad (12)$$

and extracts the best fit estimate for T_o and its uncertainty ΔT_o. The macro also gives the best fit estimate for C_c, and the reduced χ^2.

(3) Calculate the P_{fit} column in the template using:

$$P_{fit} = C_c(T - T_o) \quad (13)$$

where C_c and T_o are the fitting parameters found in the previous step. Add P_{fit} vs T to your Charles' Law plot and format the points to be a line.

(4) Notice that Equation (13) is not exactly the same as Charles Law Equation (4) because it has a term T_o. This is because Charles Law $P = C_cT$ is only true if you are measuring temperature using the Kelvin temperature scale. On the Kelvin scale, zero temperature occurs when the pressure of an ideal gas decreases to zero. On the other hand, your temperature measurements were made using the Celsius temperature scale, which goes to zero at the melting/freezing point of water. So you have to include T_o in Equation (13) and it is just the temperature on the Celsius scale that corresponds to zero on the Kelvin scale. T_o is called the absolute zero of temperature on the Celsius scale. It is the lowest temperature that is possible and is the temperature at which the gas in the sphere would have zero pressure.

(5) Save your Excel file by using the large gray button in the main body of the spreadsheet (the standard Save button in the menu has been disabled). The template will automatically save a copy for you (with your name embedded in the file name) and another suitably named copy for your lab partner in the My Documents folder. Note: You can't save or exit this template unless your name and your lab partners name and your section number have been entered into the spreadsheet in the appropriate cells.

IX. Final Questions

(1) From Part A of the experiment, does your data agree with Boyle's Law?

(2) The technique we had you use to analyze your Boyle's Law data was a bit strange because in order to find V_o, we had to use Boyle's Law (see Equation 6). To make physical sense, the correction V_o that was added to all your V' readings had to be the same value and it should have been relatively small. With this single value constraint, and its small value, this was a relatively minor tweak of the theory that we had to make to get a good correspondence between the actual set-up and the theory. What is the ratio V_o/V' for your smallest volume V'?

(3) Given the uncertainty ΔT_o in your value for T_o from part A, is your value for T_0 consistent with the expected value of -273.15 ºC?

(4) From Part B of the experiment, does your data agree with Charles' Law?

X. Finishing Up Before Leaving the Lab

- Make sure you get your lab partner's name and his or her contact information.

- Make sure you save a copy of your spreadsheets on a memory stick or e-mail yourself a copy.

- In addition, don't forget that you need to prepare a Lab Report for this Experiment and it must be submitted before it is due (see the syllabus). Also, make sure to review the Guidelines for Writing a Lab Report, right after the main introduction in this Lab Manual.

- **Finally, this is the last regularly scheduled lab for the course. If you have missed a lab during the semester and need to make it up, check the syllabus for when make-up labs are scheduled. Then make sure you contact your instructor and your teaching assistant to let them know that you still need to make up a lab during the make-up week.**