CHEMISTRY 206

Experiment 1: EXPLORING THE PROPERTIES OF GASES

Instructor's Informal Preamble

In your first laboratory session in Chem 206, you will be performing experiments that probe the physical behaviour of gases. This topic was covered in Chem 205, so be sure to review the appropriate chapter in your textbook.

It is important to remember that the molecules in any substance are constantly moving, and that the average kinetic energy of the molecules is proportional to the temperature. The most noteworthy feature of substances in the gas phase is that the molecules are so far apart that they do not interact with each other significantly. The result is that all substances behave more-or-less the same way in the gas phase, regardless of the chemical structures of their constituent molecules. In the 17^{th} and 18^{th} centuries, the scientists Avogadro, Boyle, Gay-Lussac and Charles made general observations of gases, which they summarized as the natural laws of gas behaviour. You will likely recall the form of these natural laws that we use most often: the ideal gas law ($PV = nRT$), which shows how the quantity (in moles, n) and temperature (T) of a gas determine the volume (V) it occupies and the pressure (P) it exerts.

Experiments involving gases are a useful starting point for the laboratory work in Chem 206 because of their quantitative nature. This week's experiments give you a good opportunity to focus on mastering your observation and measurement skills and practicing making careful and well thought-out calculations using simple, familiar concepts. The rest of the experiments in Chem 206 depend on you being able to make careful quantitative measurements and calculations involving more sophisticated concepts – so it is very important that you make a considerable effort to become comfortable with quantitative work this week.

Acknowledgement: This group of experiments is adapted from "Advanced Chemistry with Vernier", J. Randall, Vernier Software and Technology, 2006.

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Experiment 1: EXPLORING THE PROPERTIES OF GASES

Introduction

The purpose of this investigation is to conduct a series of experiments, each of which illustrates a different gas law. Four properties of gases will be investigated: pressure, volume, temperature, and number of molecules. By assembling the equipment, conducting the appropriate tests, and analyzing your data and observations, you will be able to describe the gas laws, both qualitatively and mathematically.

Objectives of the Experiment

In this experiment, you will:

- Conduct a set of four experiments, each of which illustrates a gas law.
- Gather data to identify the gas law described by each activity.
- Complete the calculations necessary to evaluate the gas law in each activity.
- From your results, derive a single mathematical relationship that relates pressure, volume, temperature, and number of molecules (moles).

Prelaboratory Assignment

Carefully read the procedure and answer the prelaboratory questions before coming to the lab. The questions include the calculation of the maximum quantity of sodium hydrogen carbonate to be used in Part IV of the experiment. ***It is essential that you verify that your answer is correct before proceeding.*** Your teaching assistant will inspect and collect your prelab before you are permitted to begin the experiment - keep a copy of it for yourself, and have the TA sign your receipt record.

Experiment Summary

In each part of the experiment, you will investigate the relationship between two of the four possible variables, the other two being constant.

Part I Pressure, P, and volume, V (temperature and number of molecules constant).
Part II Pressure, P, and absolute temperature, T (volume and number of molecules constant).
Part III Volume, V, and absolute temperature, T (pressure and number of molecules constant).
Part IV Volume, V, and number of moles, n (volume and absolute temperature constant).

Review each of the four parts of this experiment carefully before starting your work. You may wish to conduct a test run without collecting data, in order to observe how the experiment will proceed.

Materials

Apparatus

- Computer and Logger *Pro*™ Software
- Vernier™ pressure sensor and temperature probe
- 20 mL plastic syringe (Lubricate the barrel with a drop of silicone oil (if necessary for smooth operation.)
- Plastic tubing with 2 Luer-lock connectors
- Rubber stopper assembly with valve and Luer-lock connectors
- Large container (30 cm high) for use as a water bath
- 125 mL Erlenmeyer flask
- 125 mL bottle
- 5 sample vials
- 4 mL plastic graduated tube (must fit into the 125 mL flask.)

Reagents and Disposables

- sodium hydrogen carbonate
- 2.5 M acetic acid solution
- Ice and hot water supplies

Procedures

Preliminary Set-up of the Data Acquisition System

(The following may already have been done for you when you arrive in the lab.)

1. Connect the gas pressure sensor (using a Vernier Go!Link™ adaptor) and a temperature probe to the two USB ports on the front panel of the computer.
2. Turn on the monitor and printer, and start the computer.

Part I: Pressure and Volume (Boyle's Law)

In this experiment, you will observe the relationship between the volume and pressure of a small sample of air trapped in a syringe, under conditions where the temperature is kept constant.

1. Start the Logger *Pro*™ program on your computer by double-clicking the file "CHEM206 Boyle" on the desktop. This file will allow you to collect pressure data from the gas pressure sensor, and type in the corresponding volume.
2. ***Important***. Note the current lab temperature and atmospheric pressure at the beginning of the lab report form.
3. Position the piston of the 20 mL syringe so that there will be about ~ 10 mL of air trapped in the barrel of the syringe. Attach the syringe to the valve of the gas pressure sensor, as shown in Figure 1. A gentle half-turn should make a secure air-tight connection between the syringe and the sensor.

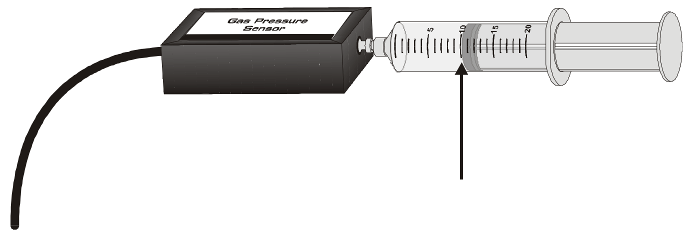

Figure 1

4. To begin collecting data, click the green “Collect” button near the top of the screen.
5. (The following operation is easier with two people.) Adjust the volume to a chosen value by withdrawing or pressing in the syringe barrel. **Note:** Read the volume at the inside edge of the black ring on the piston of the syringe, as indicated by the arrow in Figure 1. Click the Keep button. This will record the pressure, and will open a small input window. Type in the volume using the computer keyboard, and click “OK”. Each data point will be recorded in the columns to the left of the screen, and a graph of pressure plotted against 1/volume will be displayed.

   Note: At any time during data collection, in order to optimize the way the graph is displayed, right click the mouse with the cursor over the graph and select “Autoscale and then choose “Autoscale” or “Autoscale from 0”. (The first option adjusts the axes to fit the data points in the largest area, and the second does the same thing, but includes the zeros on the axes.)
6. Measure the pressure of the air in the syringe at various volumes. Satisfactory results are achieved by collecting at least six data points. Click “Stop” when you have finished collecting data points.
7. Optimize the graph axes using the “Autoscale from 0” option..
8. Click “Data” on the menu bar at the top of the screen and then select “Sort Data Set” and select “Latest”. A small window will open. Pick “Pressure”, and click “Done”.
9. Highlight all the data (in dark grey) by dragging the cursor either over the graph, or in the data table (over the Pressure and 1/Volume columns). Then on the menu bar, click “Analyse” and select “Linear Fit”. A little box will appear in the graph area giving the slope and intercept of the best straight line through your data points. (If it hides some of the graph, you can click on it and drag it aside with the cursor.)
10. Print two copies of the screen. Save your experiment in the Gas Experiment folder on the desktop using a unique name such as “Boyle_your_name”. Close Logger *Pro*.

Part II: Pressure and Temperature

In this experiment, you will study the relationship between the absolute temperature of a gas sample and the pressure it exerts. (This law does not have a scientist’s name associated with it.) You will place an Erlenmeyer flask, containing an air sample and connected to a pressure sensor, into a water bath. You will vary the temperature of the water bath, and record the resulting pressure in the flask.

1. Assemble the apparatus shown in Figure 2. Make sure the rubber stopper and flask neck are dry. With the valve open, insert the rubber stopper and twist and push firmly into the flask to ensure it will not pop out at higher temperatures. Close the valve. The flask must be immersed in the water up to the level of the stopper. Hold it down with a stand and clamp (not shown in Figure 2).
2. Restart the Logger *Pro*™ program on your computer by double clicking the file "CHEM206 P_vs_T" on the desktop. This file is set up to collect pressure and temperature data from the attached sensors. This mode allows you to collect a data pair simultaneously from the gas pressure sensor and temperature probe by clicking on the Keep button as in Part I, however in this case, no key board input is required, therefore no input window will appear.

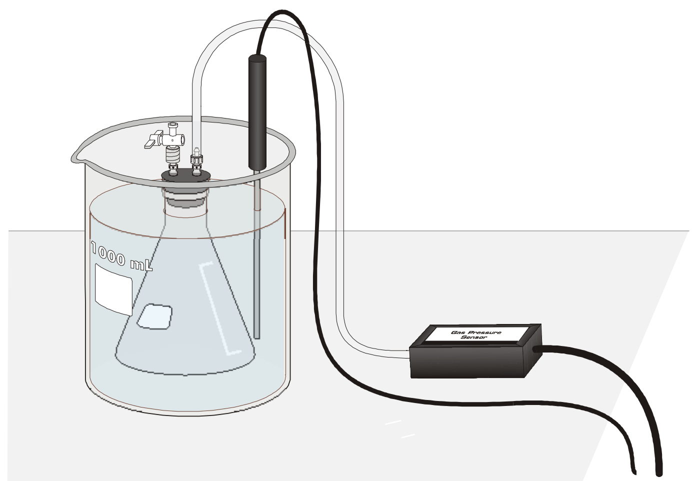

Figure 2

3. Collect data at several different temperatures by adjusting the temperature of the water in the bath with ice or hot tap water. After making a change, wait for the pressure to stabilize before recording a data point. Do not forget to click "Stop" when you have finished collecting data points.
4. Optimize the graph axes using the "Autoscale" option. (See part I).
5. Click "Data" on the menu bar at the top of the screen and then select "Sort Data Set" and select "Latest". A window will open. Pick "Temperature", and click "Done".
6. Highlight all the data (in grey) by dragging the cursor either over the graph or in the data table (over the Pressure and Temperature columns). Then on the menu bar, click "Analyse" and select "Linear Fit". A little box will appear in the graph area giving the slope and intercept of the best straight line through your data points. (If it hides some of the graph, you can click on it and drag it aside with the cursor.)
7. Print two copies of the screen. Save your experiment in the Gas Experiment folder on the desktop using a unique name such as "P_vs_T_your_name". Close Logger *Pro*.

Part III: Volume and Absolute Temperature (Charles' Law)

In this experiment, you will study the relationship between the volume of a gas sample and its absolute temperature. You will place an Erlenmeyer flask, fitted with a syringe and pressure sensor, containing an air sample into a water bath. You will vary the temperature of the water bath, and record the volume while holding the pressure constant using the syringe.

1. Assemble the apparatus shown in Figure 3. Start with an ice-water bath. Set the piston close to the 0 mL mark on the syringe, and make the connection to the pressure sensor last, so that the pressure in the system is close to atmospheric. This will allow the gas volume to increase in warmer water baths. Make sure the rubber stopper and flask neck are dry, then twist and push hard on the rubber stopper to ensure a tight fit. Be sure the water level is at least as high as the air confined in the syringe. You will need to hold the buoyant flask and syringe down with a stand and clamp (not shown in Figure 3).

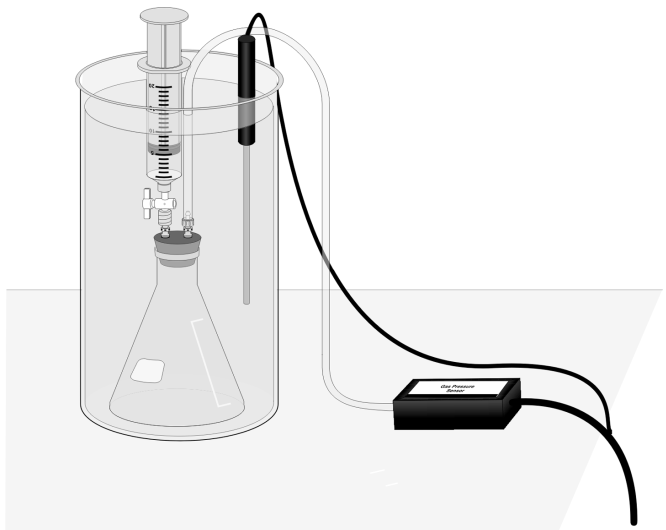

Figure 3

2. Restart the Logger *Pro*™ program on your computer by double clicking the file "CHEM206 Charles" on the desktop. In this case, when you click the Keep button, the current temperature and pressure will be captured, and you will be able to enter the volume reading off the syringe. Even though the pressure reading will not be plotted, it is important for the pressure to be monitored so that it can be kept constant with the syringe.

3. Collect volume data at several different temperatures by adjusting the temperature of the water in the bath with ice or hot tap water. Manually adjust the syringe to restore the pressure to the starting value. After making any change, wait for a minute or so to be sure the pressure has stabilized. The temperature of the water bath cannot be increased to more than ~ 50 ^{o}C (because the syringe barrel would go off the scale). Click "Stop" when you have finished collecting data points.

4. At this point, the volumes recorded and plotted will be the volumes that were in the in the syringe only. It is necessary to plot the *total* volume of air in the syringe *and* the flask.

   After recording your data using the dry flask, mark the position of the bottom of the stopper with a felt tip pen or wax pencil and remove it. Weigh the flask empty, fill it to the mark with cold water, and weigh it again to obtain the volume.

5. Double-click on the column heading "Total Volume". A window will open. Edit the equation to read: "Vol (syringe)"+n, where n is the volume of the flask (~125 mL), which

you measured in step (4), plus 4.0 mL for the estimated total volume of the valve below the bottom of the syringe and the tubing from the stopper to the gas pressure sensor box.

6. Optimize the graph axes using the “Autoscale” option.
7. Click “Data” on the menu bar at the top of the screen and then select “Sort Data Set” and select “Latest”. A window will open. Pick “Temperature”, and click “Done”.
8. Highlight all the data (in dark grey) by dragging the cursor either over the graph or in the data table (over the Temperature and Total Volume columns). Then on the menu bar, click “Analyse” and select “Linear Fit”. A little box will appear in the graph area giving the slope and intercept of the best straight line through your data points. (If it hides some of the graph, you can click on it, and drag it aside with the cursor.)
9. Print two copies of the screen. Save your experiment data in the Gas Experiment folder on the desktop using a unique name such as “Charles_your_name. Close Logger *Pro*.

Part IV: Molar Volume

In a bottle connected to the syringe and the pressure sensor, a measured quantity of sodium hydrogen carbonate will be mixed with an excess of acetic acid solution. The reaction occurs according to the following equation:

$NaHCO_3(s) + CH_3COOH(aq) \rightarrow NaCH_3COO(aq) + H_2O(l) + CO_2(g)$

This reaction can be summarized more briefly by using the net ionic equation:

$HCO_3^-(aq) + H^+(aq) \rightarrow H_2O(l) + CO_2(g)$

The carbon dioxide produced will tend to push out the syringe piston, and its volume can thereby be measured. Five runs are done using different quantities of sodium hydrogen carbonate ($NaHCO_3$), and the results plotted graphically. An average value for the molar volume of carbon dioxide (or, according to Avogadro’s Law, any other gas) can be calculated from its slope.

1. Prepare the apparatus as shown in Figure 3 above, except that the water bath will not be needed since the data will be collected at room temperature, and the bottle is used in place of the Erlenmeyer flask.
2. Zero the balance. Label and weigh the sample vials, and then add the masses of $NaHCO_3$ required for each of the five runs. The actual masses taken should be within ±10% of those you calculated in the prelab (question 4). *Write down the masses of the vials plus $NaHCO_3$ on the experiment report form to the nearest milligram.*
3. Start the Logger *Pro*™ program on your computer by double clicking the file “CHEM206 MolarV” on the desktop. In this case, you will enter a value for the quantity (moles) of $NaHCO_3$ used, and the volume of CO_2 generated in each reaction, *after doing all five runs*. The pressure and temperature will be displayed.

The following steps [(4) - (7)] will be repeated with the five samples of $NaHCO_3$. Do not forget to keep a written record of weighings and volume readings on the report form. These will be entered into the computer *after* all five runs have been completed.

4. Tip one of the $NaHCO_3$ samples into the bottle. (You will weigh the empty vials later.)

5. Place about 4.0 mL of 2.5 M acetic acid solution into the graduated tube. Make sure there is no solution on the outside: dry the vial with paper towel if necessary. Carefully slide it into the bottle, *without spilling the contents*.
6. Move the syringe piston close to the zero mark. Carefully, replace the syringe and stopper assembly. Adjust the pressure using the syringe to 1.00 atm. Note the volume reading on the syringe on the lab report form. (It should still be near zero.) Then, by carefully tilting the bottle, cause the acetic acid solution to spill and react with the $NaHCO_3$. ***Do not allow the acetic acid to enter the syringe or tube leading to the pressure sensor***. Carbon dioxide will be evolved, and the syringe piston may be driven outwards. *[If the piston comes all the way out, you have really messed up your pre-lab calculations!]* As the reaction slows, agitate the flask a few times to make sure all the $NaHCO_3$ has reacted. Move the syringe piston to restore the pressure to 1.00 atm, and note the new reading on the report form. To obtain the volume of CO_2 evolved, subtract the two volume readings.
7. Disconnect the bottle, and rinse it and the graduated tube to be ready for the next run. The spent reaction mixture can be washed down the sink. Repeat, starting at step (4) for the other starting quantities of sodium hydrogen carbonate.

Finish the experiment with the following steps:

8. Zero the balance again. Re-weigh the empty vials to determine the exact masses of $NaHCO_3$ taken (to the nearest milligram). *Record the masses of the emptied vials on the report form*. For each run, calculate mass and moles of $NaHCO_3$ and volume of CO_2.
9. Click the green “Collect” button.
10. Click the Keep button, then enter in the exact number of moles of $NaHCO_3$ that was used and the volume of carbon dioxide that was been evolved, for each of the five samples. The computer displays a graph of the volume of CO_2 evolved plotted against the number of moles of $NaHCO_3$ added.
11. Click “Stop” when you have finished entering data points.
12. Optimize the graph axes using the “Autoscale” option.
13. Click “Data” on the menu bar at the top of the screen and then select “Sort Data Set” and select “Latest”. A window will open. Pick “Moles of $NaHCO_3$”, and click “Done”.
14. Highlight all the data (in dark grey) by dragging the cursor either over the graph or in the data table (over the Volume of CO_2 and Moles of $NaHCO_3$ columns). Then on the menu bar, click “Analyse” and select “Linear Fit”. A little box will appear in the graph area giving the slope and intercept of the best straight line through your data points. (If it hides some of the graph, you can click on it, and drag it aside with the cursor.)
15. Print two copies of the graph and data. Save your experiment data in the Gas Experiment folder on the desktop using a name such as “MolarV_your_name”. Close Logger *Pro*.

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CHEMISTRY 206

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Prelaboratory Questions

1. (2 marks) Provide a one-page (maximum) summary of the experimental *procedures*. This can take the form of a flow-chart or a list of the main steps. DO NOT simply copy the procedures directly from the manual.
2. (0.5 mark) In Part I, which illustrates Boyle's Law, although the procedure does not mention it, it is probably good practice to hold the syringe at the open end of the barrel with your finger tips while moving the piston, rather holding it than in the palm of your hand. Why?

3. (0.5 mark) In Parts II and III, the procedure asks you to make sure the rubber stopper and flask neck are dry when you assemble the apparatus. From a practical point of view, why might this be important?

4. (1 mark) The maximum volume of gas that could be measured by the syringe in Part IV of this experiment is 20 mL, if the syringe starts empty. Calculate the mass of sodium hydrogen carbonate, $NaHCO_3$, required to generate 20 mL of carbon dioxide, CO_2, at 1 atm pressure and 25 ^{o}C. To do this calculation, you will, of course, need to use the gas laws which this experiment is intended to illustrate! [NOTE: In the five reaction runs you do for your experiment, you should use approximately 1/5, 2/5, 3/5, 4/5, and 5/5 of the quantity you calculate here.] ***Important: for this and any calculations which you present in this course, please show detailed calculations, including units as appropriate.***

5. (1 mark) The CRC handbook of Chemistry and Physics gives the solubility of carbon dioxide in water at 25 ^{o}C as 0.145 g in 100 mL. Assuming that the solubility of carbon dioxide is the same in the acetic acid solution as in water, how much carbon dioxide (in mL of gas at 25 ^{o}C and 1 atm) might be dissolved in the 4.0 mL used for each reaction?

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CHEMISTRY 206

Experiment 1: EXPLORING THE PROPERTIES OF GASES

Laboratory Report

Lab Temperature	^{o}C	**Atmospheric Pressure**	**atm**

Part I: Pressure and Volume (Boyle's Law)

1. (1.5 marks) Hand in the printout of your graph of pressure against 1/volume.
2. (1.5 marks) Using the information shown on your graph, write down the exact equation that describes the behaviour of your sample of gas from this part of the experiment. *Note: this is your own observed version of Boyle's Law!* Comment on how this compares to Boyle's law from your textbook.

Part II: Pressure and Temperature

3. (1.5 marks) Hand in the printout of your graph of pressure against temperature.
4. (0.5 mark) Using the information shown on your graph, write down the exact equation that describes the behaviour of your sample of gas from this part of the experiment.

Part III: Volume and Absolute Temperature (Charles' Law)

5. (1.5 marks) Hand in the printout of your graph of volume against temperature.
6. (1 mark) From the information on the printout, what is your value of absolute zero in degrees Celsius? Provide a reasonable explanation for the difference of your value from the accepted value of –273.15 ^{o}C.

7. (1.5 marks) Using the information shown on your graph, write down the exact equation that describes the behaviour of your sample of gas from this part of the experiment. *Note: this is your own observed version of Charles' Law.* Comment on how this compares to Charles' law from your textbook.

Part IV: Molar Volume (Avogadro's Law)

Run	**Vial + $NaHCO_3$ (mg)**	**Emptied vial (mg)**	**Mass $NaHCO_3$ (mg)**	**Moles $NaHCO_3$ (mol)**	**Starting volume (mL)**	**Final volume (mL)**	**CO_2 Gas generated (mL)**
1							
2							
3							
4							
5							

8. (1.5 marks) Hand in the printout of your graph of volume of CO_2 against moles of $NaHCO_3$.
9. (1.5 marks) Use the slope of the graph to determine your experimental value for the molar volume of CO_2.

10. (1.5 marks) In the pre-lab questions, you estimated how much CO_2 might be dissolved in the reaction mixture in Part IV. Qualitatively (no calculation required), what effect would this dissolved CO_2 have had on the value of the molar volume you have calculated?

11. (1.5 marks) To judge the accuracy of your determination, calculate the percent difference (*i.e.*, percent error) between your experimental value for molar volume and the expected value at the same temperature.

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