Experiment 2

Fun with Gas Laws

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PURPOSE

The purpose of this laboratory experience is to explore the gas law relationships between pressure and volume and between pressure and temperature.

GASES

Gases are substances that we should be very familiar with from our everyday experiences. When we blow up a balloon or let the air out of a tire, we are dealing with gases. The term gas applies to a state of matter where the substance has no fixed volume or shape. In a gas, the individual molecules are far apart and there is a lot of empty space between them. So a gas can be compressed into a smaller volume or it can expand to fill a large container. Gases appear to be weightless and unaffected by gravity. But this is untrue, because otherwise the gases in the atmosphere around Earth would soon disappear. It is simply a combination of their small size and high rate of motion that gives this perception.

IDEAL GASES

Real gas molecules interact with each other, although to a lesser extent than molecules of solids or liquids. Real gas particles also occupy volume, albeit only a small fraction of the available space in which they move. An ideal gas is a hypothetical gas where there are no interactions between the gas particles and the volume of the individual particles is negligible. At moderate temperatures and low pressures, real gases (such as those found in the atmosphere) behave very much like ideal gases.

GAS LAWS

There are several quantitative relationships between the observed physical properties of gases. These relationships have been consistently observed for real gases (at sufficiently high temperatures and low pressures, such that the gas is behaving as an ideal gas). A scientific relationship that is always observed to be true, with no exceptions, is called a law. Therefore, these relationships are considered to be gas laws. While real gases can act like ideal gases, often they do not and corrections terms must be applied to the gas laws to accommodate real gas behavior. For the purpose of this lab, we will assume that the real gases are behaving as ideal gases (a very good assumption under typical laboratory conditions).

There are a number of gas laws that specify relationships between some combination of pressure, volume, temperature, and moles. We will see two of them in this lab and you will learn about several of these laws in lecture.

IN THIS EXPERIMENT

In this experiment, you will collect gas pressure vs. gas volume data and deduce the relationship known as Boyle’s law. Then you will collect a new set of data for gas pressure vs. gas temperature to determine Gay-Lussac’s law.
PRE-LABORATORY PREPARATION

1. Read the procedure and data analysis sections of the experiment.
2. There is no prelab assignment for this experiment.

EXPERIMENTAL SECTION

REAGENTS PROVIDED

Air, the stuff we breathe.

WASTE DISPOSAL

There is no waste generated in this experiment.

SPECIAL EQUIPMENT

Gas pressure sensors and stainless steel temperature probes should be available.

PROCEDURE

This experiment could be done individually, but due to equipment limitations you will do the experiment with a partner (or two, if necessary).

Data will be collected by computer-interfacing, so work at a station adjacent to a computer.

COMPUTER, GAS PRESSURE PROBE, AND TEMPERATURE PROBE SETUP

1. Start up LoggerPro.

2. Attach a gas pressure sensor to Ch 1 (channel 1) of the interface box.

   The interface should automatically detect the probe and a box containing the live reading should appear in the lower left corner of the screen. The Y column of the Data Table should change to Pressure (kPa).

   If the live reading does not appear, choose Experiment from the Top menu and then click on Live Readouts.

3. Change the pressure units to atm by double clicking on the Pressure column heading in the Data Table. Then click on the unit box and select atm and then click on Done.

   Check that the sensor is operating correctly by observing the current value listed for the room pressure. This should be near 1.00 atm (although most days it is a bit lower than 1). If it is not, your instructor needs to check your setup.

   Actually, this experiment works using any units we want for pressure. We choose atm simply because it is the unit most of us relate to the best.

PRESSURE VS. VOLUME - BOYLE’S LAW

4. Set up the syringe for readings.

   Take the plastic syringe from the box and pull the plunger out until the bottom of the inside portion of the plunger (black in color) lines up with the black ring marking 10.0 mL on the outside of the syringe. (If you are not sure which black ring to read, push the syringe all the way in and see which ring lines up with the zero line.)

   Next, carefully connect the syringe to the white stem on the end of the gas pressure sensor using a gentle ½ turn clockwise (this tightens the seal). Note; it is easiest for one partner to operate the syringe and the other partner to operate the computer.
5. **Set up the computer to collect data.**
   (a) Choose **Experiment** from the top menu.
   (b) Select **Data Collection**.
   (c) Click on **Mode** and change it to **Events with Entry**.
   (d) For the column name, enter **Volume**.
   (e) Leave the short label as is.
   (f) For the units enter **mL**.
   (g) Click on **Done**.
   (h) Double-click on the graph and select **autoscale** for both axes under the Axis Options tab.
   (i) Click on **Done**.
   (j) Click on the **Collect** button.

6. **Collect pressure-volume data.**
   Move the plunger on the plastic syringe to the first volume reading, 4.0 mL. Allow a few seconds for the pressure reading to stabilize. Click on the **Keep** box to record the pressure and then enter the volume reading, 4.0 in this case, in the box that appears in place of the **Keep** box. Press the ENTER key (or click OK) to record the volume.
   Without disconnecting the syringe from the pressure probe, move the plunger to the next volume (6.0 mL), click **keep** and enter the volume, as described above. Repeat this process to obtain pressure and volume data for all the following volumes (in mL): 4.0, 6.0, 8.0, 10, 12, 14, 16, 18 and 20.

IF YOU ENTER THE WRONG VOLUME OR CLICK ON KEEP AT THE WRONG TIME:
Numbers you enter can be changed by clicking on them on the data table and then typing the correct value. Data read by the sensor cannot be edited, but points can be deleted after you finish data collection and hit the STOP button. So you don’t need to panic or start over.

7. **Click on the STOP button when the data collection is finished.**

8. **Delete any extra (incorrect) data points.**
   To do this, click on the row number in the data table and then select **Edit – Strikethrough Data Cells** from the menus.

9. **Decide if you want to redo any points.**
   The data should generate a fairly smooth curve. If any points look out of place, you might want to delete them (as described in step 8) and redo them. IMPORTANT: you can only redo a point if you have not removed the syringe from the pressure sensor. If you have removed the syringe, then you would need to start over. Consult an instructor if unsure of what to do.

TO COLLECT ADDITIONAL DATA POINTS:
   click on the **Collect** button and then choose **Append to Latest**. You are now ready to collect additional data points, as before.
   If you remeasure some data points, your data may be out of order in the table. Once you finish collecting data and click **STOP**, you could select **Data – Sort Data** and then choose to reorder the points (e.g., **Volume ascending**).

10. **Print a copy of the data Table.**
    Choose **File** and then **Print Data Table…** from the top menu. This printout is just a backup, so that you will not need to repeat the experiment if the computer were to crash.

11. **Perform linear regression on the graph:**
   (a) Click on the linear regression icon (the button near the top of the screen containing a curve with a line going through it and the partial equation R=).
   A box should now appear containing the slope, m, and y-intercept, b, of the best-fit line drawn through the points.
   (b) If the regression box blocks your view of the plotted curve, click anywhere in the box, hold the mouse button down, and drag it to a part of the graph where it does not hide anything of interest.
   (c) Record the correlation coefficient.

12. **Examine the graph and note its appearance on your data sheet.**
    In particular, record how close the graph is to being linear.
13. Follow steps (a)-(d) below to create six calculated columns in your data table containing these six functions of volume:

1) "Volume"^2
2) log("Volume")
3) 1/"Volume"
4) 1/("Volume"^2)
5) exp("Volume")
6) sqrt("Volume")

(a) Click on Data — New Calculated Column.
(b) Enter the function as the long name (e.g., Volume^2), but leave the short name and units blank. Enter the appropriate formula into the equation box (e.g., "Volume"^2). Notice that Volume appears in quotation marks in all of the formulas that go into the equation boxes. This tells Logger Pro that Volume is a column in the data table. [It can be quicker to enter formulas by choosing the math function (log, exp, sqrt) from the Functions menu and choosing Volume from the Variables menu. If you do this, Logger Pro puts in the quotation marks for you.]
(c) Click on the Options tab and specify that 3 significant figures will be displayed.
(d) Click on Done to close the window.

Repeat steps (a) – (d) for all six functions.

14. Graph pressure (on the y-axis) vs. each one of the six columns you just created (on the x-axis) and determine which one yields the most linear relationship.
(a) Click on the x-axis label on the bottom of the graph and then select one of the columns you just created.
(a) Click on the regression icon (R=) to draw the best-fit line through your points. Record the correlation coefficient, and a brief description of the linearity of the graph of the function, on your data sheet.

Repeat steps (a) – (b) for all six functions.

The best function is the one whose plot appears most linear and be the one where the absolute value of the correlation coefficient is closest to 1.

15. Add units and a title and then print out a copy of the graph determined to be most linear. Include the regression analysis box and best-fit line on this graph.

The program automatically labels the axes, including the units on the y-axis, but you need to enter units for the variable on the x-axis (since it was a calculated column) and a title. You can write them in by hand or have Logger Pro do it.

To add units to the x-axis: Double-click on the column heading in the data table and then type the units into the appropriate box. To add a title: double-click on the title on the graph to open the Graph Options window and enter a good title, which tells what is actually plotted. For example, an appropriate title would be: Pressure vs. Volume^2 (or whatever function is made the linear graph).

If you choose “Print Graph...” instead of just “Print...”, you get a printout that looks better and is easier to read.

16. Print out your complete data table (containing the original data and all of the created columns for the six functions) by choosing File – Print Data Table...

Have your instructor check your graph before continuing, as you will be clearing your data in the next step.

17. Delete the 6 columns that you just created.

A column may be deleted by selecting Data – Delete Column – Column Name. These columns will not be needed in the next part and they just clutter the screen.

18. Clear your pressure-volume data.

From the top menu, select Data and scroll down to select Clear All Data. Now there should not be any data in the data table.

If the linear regression box is still on the screen, click on the little gray x in the upper left corner of the box to remove it.
PRESSURE VS. TEMPERATURE – THE LAW OF GAY-LUSSAC

19. Attach a temperature probe to CH 2 of the serial interface box.
   Logger Pro should automatically recognize it and set it up for you.

20. Create a new Calculated Column of 1/Temp (using the same steps as above).

21. There should be two graphs displayed. By clicking on the axis labels, change them so that the top graph shows Pressure (y) vs. Temperature (x) and the bottom graph shows Pressure (y) vs. 1/Temp (x).
   If there is still only one graph, select Insert – Graph and then click and drag to resize and move the two graphs so they don’t overlap.

22. Prepare a boiling water bath.
   Fill a 400 mL beaker to approximately the 200 mL mark with hot tap water. Place the beaker on a tripod ring stand (with wire gauze) and put a Bunsen burner under it. Heat the water until it just begins to boil. While waiting for it to boil, you can continue with next few steps.
   Tripod stands are in the cabinets under the sinks in the front and rear of the room. Bunsen burners are in a cabinet adjacent to the tripods.

23. Prepare a hot tap-water bath.
   Take a second 400 mL beaker and fill it to the 200 mL mark with hot tap-water directly from the hot water faucet. [This water can still get very hot – so handle with care.]

24. Setup the pressure vessel.
   Take the one-hole rubber-stopper from the Gas pressure sensor box and insert it firmly into a 125 mL Erlenmeyer flask. (If the opening is too large for the stopper, try a different flask.) Important: To ensure a tight fit, twist the stopper slightly as you are inserting it into the neck of the flask. The rubber-stopper has a single fitting on the top which should be attached to a length of plastic tubing (by gently turning clockwise about one-half a turn).

Remove the syringe from the pressure sensor by turning counter clockwise. Later you will attach the free end of the tubing to the pressure sensor.

25. Setup the data collection routine.
   (a) Choose Experiment from the top menu.
   (b) Select Data Collection.
   (c) Change the Mode to Selected Events.
   (d) Click on Done.
   (e) A column labeled Event should now appear in the Data Table.
   (f) Click on the Collect button.

26. Turn off the gas to the Bunsen burner and wait until the water stops boiling. Leave the beaker on the tripod, and insert the Erlenmeyer flask into the near-boiling water, submerging it as much as possible. Then insert the temperature probe into the bath.
   The air in the flask will make it float, so you should hold it with crucible tongs. Be careful not to burn your hand in the hot water! The hot ring stand will also burn through the plastic tubing, so hold it away from the stand.
   The whole temperature probe does not need to be immersed. It is more important that the flask be immersed as much as possible.
   We turned off the Bunsen burner so that boiling water will not splash out of the bath when the flask is immersed.

27. Collect your first data point, as follows:
   After the flask has been in the bath for about 1 minute, attach the free end of the plastic tubing to the pressure sensor. Wait about 15 seconds for the fluctuations to minimize and click on the KEEP button.
   We waited to attach the plastic tubing so that the air in the flask could expand. Otherwise, sometimes when the flask is put in the boiling water the pressure increase will pop the stopper.

   Leave the stopper in the flask with the tubing attached to the pressure sensor until the experiment is ended.
28. Let the boiling water bath sit until the end of the experiment so that (1) it cools before handling it; and (2) it won’t take long to reheat if you need to repeat the data point.

29. Collect your second data point using the hot tap-water bath.
   Immerse the flask and temperature probe into the hot water bath. Wait about 30 seconds or so for the pressure and temperature readings to roughly stabilize, then click on the KEEP button. If the pressure does not decrease significantly (more than .03 atm) you have a leak.

   If the data pairs are not showing up on the graphs, click on the Autoscale icon in the top row (shows an “A” and has little axes on two sides).

30. Empty the hot tap-water bath (leave the boiling water bath alone) and add 200 mL of water from the cold water tap. Immerse the flask (and temperature probe) into this bath and collect your third data point.

31. Empty the cold water bath and fill the bottom half of the beaker with ice. Add cold tap water to the ice and fill to the 200 mL mark. Immerse the flask (and temperature probe) into this bath and collect your final data point.

32. Check to be sure that your data is good and that you do not need to redo any points.
   The pressures should significantly decrease (somewhere between 0.03 and 0.1 atm) each time the temperature is lowered.

   **Once you remove the stopper from the flask OR remove the hose from the pressure sensor, air will enter the flask and no additional data can be combined with the data you have collected.** You either have to use the data you have or erase all of your data and go back to step 25.

33. If necessary, repeat any points that look suspicious. Get an instructor’s opinion if you are not sure.

   You can delete data points (once you have clicked on the STOP button to end data collection), by click on the row number in the data table and then select **Edit – Strikethrough Data Cells** from the menus.
   If you have already clicked on STOP, you can click on Collect and then **Append to Latest** to collect additional data points.

34. Click on the STOP button when the data collection is finished.
   Remove the temperature probe and Erlenmeyer flask from the bath and dry them with a paper towel.

34. By visually examining your two graphs, determine the linear relationship.
   It will be either “pressure” vs. “temperature” or “pressure” vs. “1/temperature”. Perform linear regression on the more linear graph (first click on the graph to select it, and then hit the linear regression icon) or on both graphs if it is not obvious which is more linear. **Enter a title** and then **Print out the more linear graph**, and also record the slope, intercept and correlation coefficient on the data sheet.
   Finally, also print out your data table.

35. In an ideal (gas) world.
   Switching the axes on the more linear graph (from the preceding step) provides additional information. Re-plot the graph as “temperature” (or 1/temperature”) vs. “pressure” and **record the intercept to at least 3 significant figures** on your data sheet as the answer to data analysis question 5. This will be the temperature (or 1/temperature) where the pressure is exactly zero. You do NOT need to print this graph.

RETURN EVERYTHING TO WHERE IT WAS AT THE START OF LAB. HAVE AN INSTRUCTOR CHECK YOUR STATION BEFORE LEAVING THE LAB.

    It’s always a good idea to wash your hands before leaving the laboratory.

Science is FUN!
DATA SHEET AND DATA ANALYSIS

PRESSURE-VOLUME RELATIONSHIP

1. Copy the relevant data into the table below for the pressure-volume relationship.

<table>
<thead>
<tr>
<th>Function of Volume</th>
<th>Correlation Coefficient</th>
<th>Appearance (how linear is it?) You may crudely sketch the graph or describe the appearance in words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vol.^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(Vol.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/Vol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/(Vol.^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exp(Vol.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sqrt(Vol.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Which function of volume gave the most linear relationship?


PRESSURE – TEMPERATURE RELATIONSHIP

3. Which graph gave the more linear function?  Pressure vs. Temp  Pressure vs. 1/Temp
4. Record the slope, intercept, and correlation coefficient of the best-fit line from question 3 (to at least 3 significant figures and with the appropriate units for both the slope and y-intercept).

\[ m = \text{________________________} \quad b = \text{________________________} \]

\[ \text{cor} = \text{________________________} \]

5. Provide the intercept (temperature) obtained from the graph with the axes exchanged. (See the final step of the procedure section.)

\[ T = \text{________________________} \]

6. It is always a good idea to confirm our results whenever possible, and here we can also solve for the answer to question 5 algebraically using the best-fit data from question 4. The y-intercept from the plot with the axes exchanged is the same as the x-intercept of the original graph. The x-intercept can be obtained by substituting \( y=0 \) into \( y=mx+b \) and solving for \( x \). Show this calculation below and confirm that you get the same answer as recorded in question 5, above. If your two values are significantly different (that is, more than the rounding error expected given the number of significant figures in your slope and y-intercept), you should try to find your error.

7. As stated in the final procedure step, this intercept corresponds to the temperature (or 1/temperature) when the pressure is zero. Pressure is defined as the amount of force exerted per unit area, and force is exerted when moving gas molecules undergo collisions with the container walls or other gas molecules (changing their velocities). Therefore, when the pressure is zero, for a gas sample in a closed container, what does that say about the velocity of the gas molecules?

TURN IN your DATA SHEET AND DATA ANALYSIS pages, your two data tables, and your best-fit graphs for both parts.