Experiment 11 – Boyle's Law

Discussion

Robert Boyle formalized his law around 1660. This is one of the earliest instances of the use of experiment and mathematics to describe physical systems as they are rather than using pre-conceived notions of what the system should be.

In this experiment, you will measure the pressure and volume of a sample of air trapped in a tube. Afterwards, you will examine the data and discover how close your data is to the ideal gas law.

Boyle's Law is simply stated as $P \propto 1/V$. That is, the pressure and volume are inversely proportional. Another way of writing this is $PV = k$. If the gas is "ideal", its pressure and volume will follow this equation at a constant temperature.

Procedure

1. Record the temperature (using a thermometer) and pressure (using a barometer) of the air in the room.

2. Obtain a gas pressure sensor, LabQuest mini, USB cable, chemistry department laptop computer, and a syringe.

3. Connect the gas pressure sensor to any channel on the LabQuest mini, then connect the USB cable from the LabQuest mini to the laptop computer

4. With the syringe disconnected from the pressure sensor, slide the plunger of the syringe so that the first black rubber gasket (the base of the rubber "cone") rests on the 10 mL line. Connect the syringe directly to the port on the pressure sensor with a gentle twisting motion – do not over-tighten (see Figure 1). If the syringe or the pressure sensor has been damaged from overtightening (by a previous student), you may use Parafilm to form an air-tight seal between the syringe and the pressure sensor. For the remainder of the experiment, do not unscrew the syringe from the gas pressure sensor or remove the piston from the syringe. The air that is trapped inside the syringe will serve as the "gas" for your experiment.
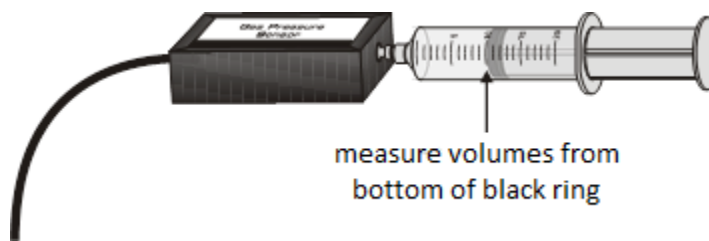

measure volumes from
bottom of black ring

Figure 1. Syringe connected to pressure sensor.

5. Open the Logger Pro software on the laptop computer. The computer monitor will display the pressure of the air that is trapped inside of the syringe, measured by the gas pressure sensor. This pressure is shown in the lower left corner of the Logger Pro window (see Figure 2). As you adjust the volume, you will record the pressure of the air inside the syringe in your data table in the column labeled "Pressure".
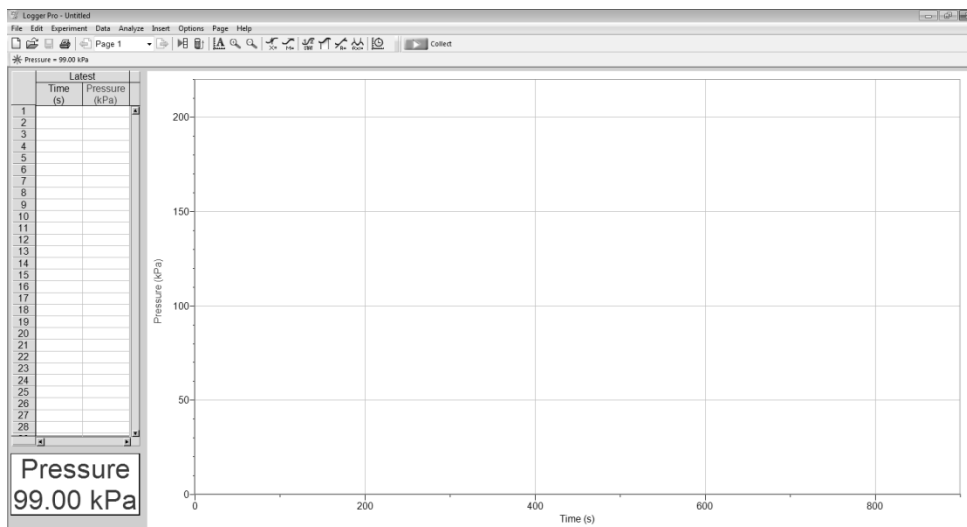

Figure 2. The Logger Pro window. In this example, the pressure is 99.00 kPa.

6. Gently depress the plunger until the first black gasket rests on the 5 mL line on the syringe. You will have to hold the plunger in. Do not push further than the 5 mL line – the maximum pressure the sensor can tolerate is 210 kPa.

7. Hold the plunger in this position for at least 15 seconds. If the pressure slowly drops during this time, then the seal between the syringe and the pressure sensor is not air-tight. Disconnect the syringe from the pressure sensor and go back to step 4! If the pressure is stable, then record the pressure in your data table.

8. Move the plunger to the 6 mL line on the syringe and hold it there. Record the pressure in the appropriate row of your data table. Repeat this procedure for each volume that is listed in your data table.

9. Open Microsoft Excel® on the laptop computer. Each of the "boxes" that you see are called "cells." In one row of cells, type the headings (in the same order) that you see at the top of your data table.

10. In the cells under the headings for "Syringe Volume (mL)" and "Pressure (kPa)," copy the numbers that you recorded in lab. Each cell should contain one number (without units).

11. Now, we are going to use Excel® to calculate the rest of our data for us. The volume printed on the side of the syringe does not account for the volume of air that is trapped in the tip of the syringe and inside of the gas pressure sensor itself. This volume has been measured to be 0.8 mL. To adjust for this volume, you will need to add 0.8 mL to each of the volumes listed in the data table. Click on the top empty cell under the "Actual Volume (mL)" heading. Type the equal sign (this tells Excel® to start a calculation), then click on the top

number in the "Plunger Position (mL)" column to use this number in your calculation. Type **+0.8** and hit enter. This cell should now display the number 5.8.

12. Repeat this process to calculate the top cell in each of the other columns. Be sure that you start each calculation by typing the equal sign and that use the actual volume (NOT the plunger position) for all of your calculations. "Click" on any number from the data table that will be a part of your calculation (do not enter any numbers by hand unless they are a part of a formula).

13. Once the first row of your data table is complete, click and drag to select the three cells that contain calculations. When these cells have been selected, a box will appear around them with a dark "dot" on the bottom-right corner (*Figure 3*). Double click on this dot and Excel® will automatically calculate all the rest of the rows in your data table.
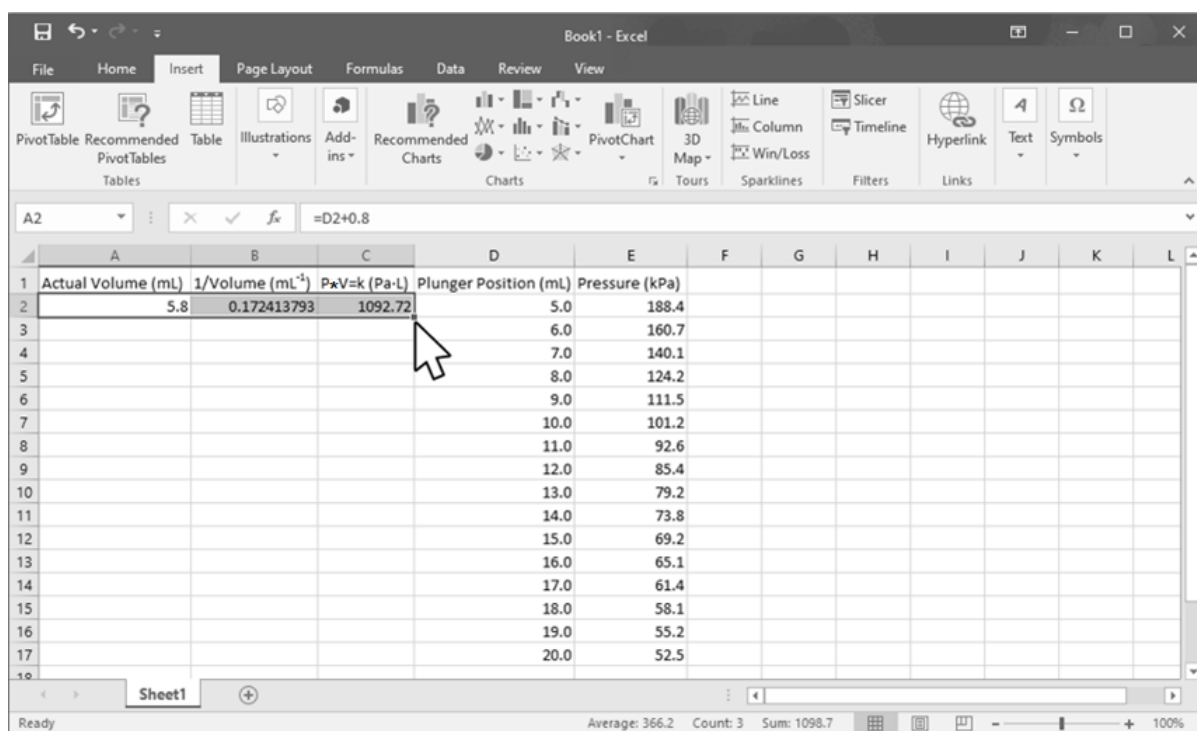

Figure 3. A partially complete Excel® data table.

14. To calculate the average value of "k", find an empty cell away from your data table and type **=AVERAGE(** and then click and drag to select all of the numeric data in the P×V=k (Pa·L) column. Press enter on the keyboard and then copy the average onto your data page.

15. Create two graphs using Excel®. On the first graph, you will need to graph Pressure vs. Actual Volume (this is Pressure on the y-axis, Volume on the x-axis). The first graph is not linear, so it should not have a trendline. On the second graph, you will need to graph Pressure vs. 1 / Volume (again Pressure on the y-axis, 1 / Volume on the x-axis). Add a linear trendline to the second graph and include the equation of the line. Be sure to save a copy of the Excel® data table and graphs to include with your report (or show them to your instructor before the end of lab).

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Excel® Graphing Procedure

Note that various versions of Excel® may function a bit differently from the directions outlined below (which work on department-owned laptop computers):

Click and drag your mouse to highlight the boxes containing the numeric data for the x-axis. Then, *while holding CTRL on the keyboard*, click and drag your mouse to highlight the boxes containing the numeric data for the y-axis. From the "Insert" tab, choose a "Scatter" plot (*Figure 4*).
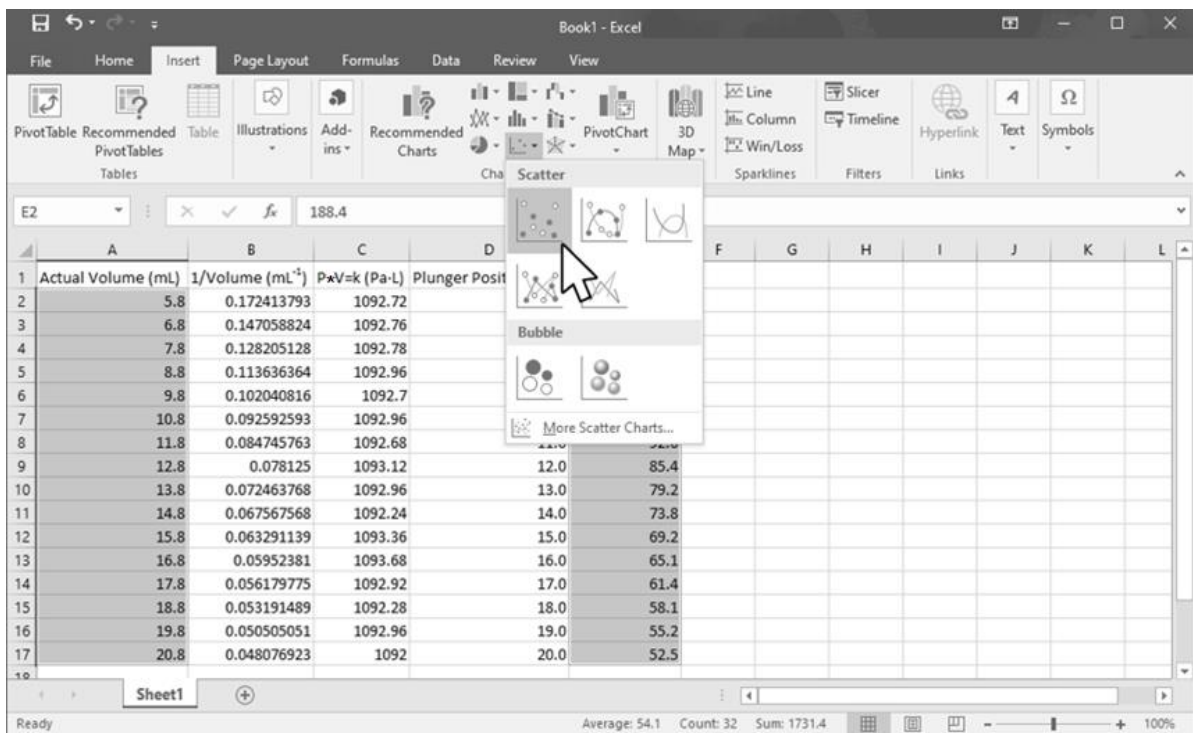

Figure 4. Creating a Scatter Plot.

Your graph must include a meaningful Chart Title and Axis Titles (with units). These Chart Elements can be added to your graph by clicking on the "+" icon in the upper right corner of your graph. Your instructor may request additional Chart Elements.

To add a Trendline, right click on any data point on your graph and choose "Display Trendline" from the menu that appears. The format trendline pane will appear on the right side of your screen. Linear should be selected by default. From this pane, you should check the box next to "Display Equation on chart." Your instructor may also ask you to check the box for "Display R-squared value on chart."

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Data and Calculations for Experiment 11

Pressure of the air in the room: _____

Temperature of the air in the room: _____

Actual Volume (mL)	1 / Volume (mL^{-1})	Pressure * Vol. = k (Pa·L)	Plunger Position	Pressure (kPa)
			5	
			6	
			7	
			8	
			9	
			10	
			11	
			12	
			13	
			14	
			15	
			16	
			17	
			18	
			19	
			20	

These will be calculated in Excel®. Submit your spreadsheet and your graphs.

Average k = _____

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Questions

1) On your <u>linear</u> graph, do any points deviate from the straight line?

2) Write down the equation of the trendline (y = mx + b) from your linear graph. How does the slope (m) compare to the average P*V=k value from the table of data?

3) Using the equation of your trendline, solve for the pressure at a volume of 2.0 mL. *Hint:* x = 1/V in your equation!

4) Why must the temperature be constant during this experiment? Use observations from your experiment and the graphs to support your answer!

5) If you repeated this experiment at a higher temperature, how would the P vs. V curve obtained differ from the curve on your 1st graph?

6) You have a 1.00 L sample of Argon gas at 700.0 mmHg. You decrease the pressure to 500.0 mmHg. What is the new volume?

7) Describe (quantitatively) what you would do to the volume of a container of gas if you wanted to double the pressure inside.