

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 have a fixed size, 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 compared to the volume of the space in which they move. 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 (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 Amonton's Law (also known as 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.
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EXPERIMENTAL SECTION

WASTE DISPOSAL

There is no waste generated in this experiment.

PROCEDURE

This experiment could be done individually, but due to equipment limitations you will do the experiment with a partner.

COMPUTER, GAS PRESSURE PROBE, AND TEMPERATURE PROBE SETUP

1. Turn on the LabQuest2 by pressing the red power button on the top.

It takes a minute to warm up. It then should start in Time Based Data Collection mode.

2. Attach a gas pressure sensor to CH 1 (channel 1) on the left end of the LabQuest2.

The LabQuest2 should automatically detect the probe and a box containing the live reading should appear on the screen. No calibration is necessary.

3. Change the pressure units to atm by tapping on the box containing the pressure reading. Then tap on *Change Units* and then tap on *atm*.

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.

While this experiment will work using any units for pressure, we choose to use 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 Labquest2.

5. Set up the computer to collect data.

- a. Tap on *Mode* in the upper-right corner of the screen.
- b. Tap on *Mode: Time Based* to change the mode and then tap on *Events with Entry*.
- c. Tap on the *Name box* and change the name to *Volume*.
- d. Tap on the *Units box* and change the units to *mL*.
- e. Tap *OK*. This should return you to the Meter screen (where you see the pressure reading).
- f. Tap on the *Start* button. This is the little green arrowhead in the lower left corner.

6. Collect pressure-volume data.

Move the plunger on the plastic syringe to the first volume reading, 4 mL. Allow a second for the pressure reading to stabilize. Tap on the **KEEP** box to record the pressure and then enter the volume reading, 4 in this case, in the box that appears. Tap **OK**. (Note: once you tap on KEEP, you can release the plunger.)

Without disconnecting the syringe from the pressure probe, move the plunger to the next volume (6 mL), tap **KEEP** and enter the volume, as described above. Repeat this process to obtain pressure readings for all the following volumes (in mL): 4, 6, 8, 10, 12, 14, 16, 18 & 20.

Note that there is always an extra point on the screen which shows the current pressure reading. You can see it move as you move the plunger to change the pressure. Do not be distracted by this point.

IF YOU ENTER THE WRONG VOLUME OR CLICK ON KEEP AT THE WRONG TIME: Numbers you enter can be changed or points can be deleted after you finish data collection and hit the Stop button. So you don't need to panic or start over. Data collected by the sensor cannot be edited, but it can be deleted.

7. Click on the Stop button (the red square in the lower left corner) when the data collection is finished.

8. Delete or Edit any extra/incorrect data points.

- Tap on the **Data Table icon** in the upper right corner of the screen. It is the little white icon with the X and Y at the top.
- To edit a volume, double tap on a volume (so that only the number is highlighted) and then enter the correct volume and tap on **Done**.
- To delete a data point, tap on a row, so that the entire row is highlighted. Then tap on **Table** (in the top row) and then **Strike Through Data**. There should now be a line through the erroneous data point and it will be ignored when you do the analysis. This can be undone by tapping on **Table** and **Restore Data**.

9. Tap on the Graph icon (which shows a graph and now should be located in the upper left corner of the screen). 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: tap on the **Start** button and then choose **Append**. You are now ready to collect additional data points, as before. Tap on the **Stop** button once you are finished.

If you remeasure some data points, your data may be out of order in the table. That's okay.

10. Perform linear regression on the graph:

- Tap on the Graph icon (if the graph is not showing on the screen).
- Tap **Analyze** then **Curve Fit**.
- Tap on the box saying **Pressure** that appears.
- Tap on the **Fit Equation** box and select **Linear**.
- You should now see the slope (m), y-intercept (b), correlation coefficient, and RMSE (root-mean standard error) for the best-fit line drawn through the points.
- Record the correlation coefficient.
- Tap **OK**.

*Note: To remove an incorrect or undesired linear regression fit from your graph, tap **Analyze**, then **Curve Fit**, then **Pressure** (which will uncheck the box and remove the line).*

11. Examine the graph and note its appearance on your data sheet.

In particular, record how close the graph is to being linear. You may do this in words, by roughly sketching the curve, or both.

12. Follow the steps below to create six calculated columns in your data table (and construct six graphs) in order to find a function of pressure that generates a linear graph.

- Tap on the **Data Table** icon.
- Tap on **Table** (from the top menu line).
- Tap on **New Calculated Column**.
- Tap on the **Name** box and enter the name found in Table I (e.g., P squared) and then tap **Done**.
- Tap on **Select Equation** and then choose the appropriate equation from the dropdown menu (e.g., AX^B).
- Leave **Column for X** as **Pressure**.
- Change the value of B to that listed in Table I, if required for that equation, then tap **Done**.
- Tap **OK** to close the window.
- Perform linear regression on this curve, as described in procedure step 10 and record the correlation coefficient.
- Record how close the graph is to being linear, as described in procedure step 11.

13. Repeat procedure step 12 for each of the functions of pressure listed in Table I. In all cases, the function of pressure should be on the y-axis and volume should be on the x-axis.

Table I. Functions of Pressure

#	Name	Equation	A	B
1	P squared	AX^B	1	2
2	Log P	$A\log(X)$	1	
3	Exp P	Ae^X	1	
4	1 / P	A/X	1	
5	1 / P squared	A/X^B	1	2
6	Sqrt P	AX^B	1	0.5

14. Once you have seen all of the graphs, decide which function worked the best.

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

You can review the plots from the graph screen. Tap on the y-axis label and then select the function that you would like to see plotted.

15. Prepare the graph of your best function vs. volume for printing. To do this:

- Tap on the y-axis label and then select the best function.
- Perform linear regression on the graph (as in step 10).
- Add units to the y-axis (if needed):
 - Tap the Data Table icon.
 - Tap the column heading of your best function.
 - Type the units into the appropriate box.
 - Tap **Done** then Tap **OK**.

Alternately, you can write the units, by hand, on the printed graph.
- Print out a copy of the graph. To do so:
 - Tap on the **Graph icon** (if you are not on the Graph screen).
 - Tap **File** from the top menu.
 - Tap **Print** and then **Graph**.
 - Tap on **Print Graph Title**.
 - Enter an appropriate graph title. Usually, the title tells what is graphed in the format “Y” vs “X” (e.g., Pressure vs Volume).
 - Tap **Print**.

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

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

17. Clear your pressure-volume data.

- Tap the **Data Table** icon (if you are not on the Data Table screen).
- Tap **Table**.
- Tap **Clear All Data** and then tap **OK**.
This should erase all data from the data table.

PRESSURE VS. TEMP. – AMONTON'S LAW

18. Tap the Meter icon (in the upper left corner) to return to the meter screen. Attach a temperature probe to CH 2 of the Labquest2.

You should see a second box appear containing the temperature reading.

19. Tap on the Temperature box and change the units to K.

20. Tap the Mode box (in the upper right). Change the mode from *Events with Entry to Selected Events*. Then tap *OK*.

21. Return to the Graph screen. There should be two graphs displayed. By clicking on the axis labels, change them so that Temperature is on the x-axis and the top graph shows Pressure on the y-axis and the bottom graph shows 1/Pressure on the y-axis.

If only one graph is displayed, tap on **Graph – Show Graph – All Graphs**.

If 1/Pressure is not an available axis choice, you can re-create the column in the data table, just as you created them earlier. Then you can go back to the graph screen and choose it.

22. Tap the Start button.

23. 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.

24. 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.]

25. 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.

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 tap 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, tap **Graph** then **Autoscale Once**.*

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 0.10 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 (as in step 17) and go back to step 22.*

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 tapping on the row number in the data table and then selecting **Table – Strike through Data**.

If you have already clicked on **Stop**, you can tap on the **Start** button and then tap **Append** to collect additional data points.

34. Tap the Stop button when the data collection is finished.

Remove the temperature probe and Erlenmeyer flask from the bath and dry them.

35. Print out your complete data table by tapping File – Print – Table – Print.

36. Return to the Graph screen and, by visually examining your two graphs, determine which is linear and perform linear regression on it.

Tap **Analyze – Curve Fit** – the appropriate function of pressure – **Linear – OK**. Record the slope and y-intercept on the data sheet (this is the answer to data analysis question 4).

37. Print out the more linear graph, following the same procedure as in step 15d.

Be sure to add the appropriate units to the y-axis (by hand or as in step 15c) and a title.

38. Shut down the LabQuest2 by first tapping File – Quit. Choose to Discard the data. Next, tap on the System folder and then Shut Down and, finally, tap OK.

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

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

Science is FUN!

Name _____

Station Used _____

Instructor/Day/Time _____

Partner _____

Station Checked & Approved _____

DATA SHEET AND DATA ANALYSIS

PRESSURE-VOLUME RELATIONSHIP

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

Function of Pressure	Correlation Coefficient	Appearance (how linear is it?) You may crudely sketch the graph or describe the appearance in words
P		
P squared		
Log P		
Exp P		
1 / P		
1 / P squared		
Sqrt P		

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

P P squared Log P Exp P 1 / P 1 / P squared Sqrt P

PRESSURE – TEMPERATURE RELATIONSHIP

3. Which graph gave the more linear function? P vs. Temperature 1 / P vs. Temperature

4. Record the slope and y-intercept of the best-fit line for your more linear temperature graph (to at least 3 significant figures). Include the units for both the slope and y-intercept. You should be able to determine the units for each based upon the units of the axes on your linear graph.

m = _____ b = _____

5. The x-intercept can be obtained by substituting $y=0$ into $y=mx+b$, using the slope and y-intercept from your graph (data analysis question 4), and solving for x. Show this calculation below.

6. The Temperature you obtained in question 5 is either the temperature when $P = 0$ (if P vs. T was linear) or when $P = \infty$ (if $1/P$ vs. T was linear). 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, if the pressure was zero, what would that say about the velocity of the molecules in the container?

TURN IN your DATA SHEET AND DATA ANALYSIS pages, your complete pressure-volume data table, your complete pressure-temperature data table, and your most linear graph for each part.