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Forensic Chemistry: Avogadro's Law and Order

Experiments

Avogadro's Law and Order: Investigating a Rocket Launch Failure

- Go Direct Gas Pressure Sensor
- Go Direct Temperature Probe

Workshop Presenter

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Avogadro's Law and Order: Investigating a Rocket Launch Failure

Avogadro's theory states that equal volumes of different gasses at the same temperature and pressure contain equal numbers of particles. In chemistry, small particles in large numbers are typically counted using the mole concept. Just as 1 dozen of anything contains 12 items, 1 mole of any substance is equal to 6.022×10^{23} particles.

The pressure limit for a plastic 2 L soda bottle is 150 psi. Your lab has been asked to safely determine how many compressions of the bicycle pump were actually performed to reach a pressure of 150 psi in a plastic bottle.

You will use an Erlenmeyer flask and syringe system as a scale model of the 2 L bottle and bicycle pump system. You will plot the pressure as you successively add equal volumes of air to the flask. You will scale up these data to determine the pressure exerted on the 2 L soda bottle from the same number of pumps.

Then you will repeat this experiment with carbon dioxide gas to see if changing to a different gas would make a difference.

OBJECTIVES

- Use a scale model to investigate the changes in gas pressure as fixed volumes of gas are added.
- Analyze data to develop a mathematical model that can predict the volume of gas needed to reach the pressure limit of a 2 L bottle.
- Use mathematical representations to compare the rates of change in pressure for air and carbon dioxide as fixed volumes of gas are added.
- Communicate scientific and technical information and ideas about how to determine the cause of the 2 L bottle explosion.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis Pro app
Go Direct Gas Pressure
Go Direct Temperature
Stir Station
10 mL graduated cylinder
20 mL gas syringe
plastic tubing with two Luer-lock connectors
2-hole rubber stopper assembly with two-way valve and stopper stem
#5 one-hole stopper (for gas generator) with stopper stem and two-way valve installed
two 125 mL Erlenmeyer flasks
distilled water
Alka Seltzer® tablets (to generate CO_2 gas)

PRE-LAB ACTIVITY

Two-liter plastic bottles can withstand pressure up to 150 psi (pounds per square inch).

Convert this pressure from psi to units of atmospheres (atm), mmHg, torr, and kPa.

PROCEDURE

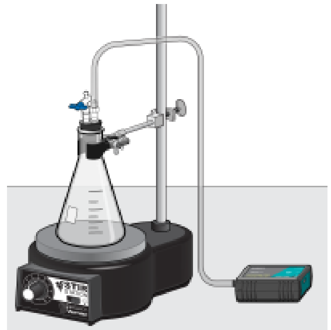

Figure 1

Part I Air

1. Launch Graphical Analysis. Connect the Go Direct Temperature Probe to your Chromebook, computer, or mobile device. Record the temperature of the room in the Evidence Record. Disconnect the temperature probe.

2. Click or tap File, , and choose New Experiment. Connect the Go Direct Gas Pressure Sensor to your Chromebook, computer, or mobile device.

3. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Enter **Total Volume Added** as the Event Name and **mL** as the Units. Click or tap Done.
   c. Click or tap View Options, , and turn on Meters. Then, turn off the View Options menu.

4. You are now ready to collect pressure data for various volumes of air added to the flask.

   a. Click or tap Collect to start data collection.
   b. Close the valve on the flask.
   c. When the pressure reading stabilizes, click or tap Keep.
   d. Enter **0** for the Total Volume Added. Click or tap Keep Point.
   e. Draw 5 mL of air into the syringe. Connect the syringe to the valve on the flask. Open the valve and inject the air into the flask. Close the valve.
   f. When the pressure reading stabilizes, click or tap Keep.
   g. Enter **5** for the Total Volume Added. Click or tap Keep Point.
   h. Repeat e–g of this step at 5 mL increments until you have added a total volume of 20 mL of air to the flask. When asked for total volume, remember to add 5 mL to the last value you entered. You can see the data in the table.
   i. Click or tap Stop to stop data collection when you have finished collecting data.
   j. Click or tap File, , and choose Save to save your data file.

Prediction

5. Air is 78% nitrogen gas, about 21% oxygen gas, and less than 1% other gasses. The average molecular mass of air is 28.9 g/mol. The molecular mass of carbon dioxide, CO_2, is 44.0 g/mol. You are about to repeat this experiment using CO_2 gas. On your graph you will make a prediction about what the graph will look like when you use CO_2 instead of air.

   a. With the data for Air displayed on the graph, click or tap Graph Options, , and select Add Prediction.
   b. Draw your prediction on the graph when CO_2 is used instead of air. When you are satisfied with your prediction click or tap Save.

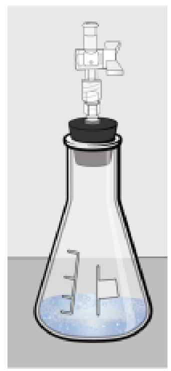

Figure 2

Part II CO_2 Gas

6. You will repeat the experiment using carbon dioxide gas, CO_2.

   a. Set up the CO_2 gas *generator* as shown in Figure 2.
   b. Place 1/4 of an Alka Seltzer tablet into the flask.
   c. Add 10 mL of distilled water to the flask.
   d. Place the one-hole stopper with the valve on the generator. Make sure the valve is open.
   e. Allow the reaction to continue for about 20 seconds to flush the air out of the generator. CO_2 gas is more dense than air and will force the air out the open valve. After 20 seconds, close the valve.

7. Open the valve on the *experiment* flask (see Figure 1) to make sure the pressure returns to room pressure.

8. You are now ready to collect pressure data for volumes of CO_2 gas added to the flask.

   a. Click or tap Collect to start data collection.
   b. Close the valve on the experiment flask.
   c. When the pressure reading stabilizes, click or tap Keep.
   d. Enter **0** for the Total Volume Added. Click or tap Keep Point.
   e. Completely depress the syringe piston to empty it and connect the syringe to the CO_2 generator bottle (see Figure 2). Open the valve and draw 5 mL of CO_2 gas into the syringe. Close the valve on the generator. Connect the syringe to the valve on the *experiment* flask. Open the valve and slowly inject the CO_2 into the flask. Close the valve.

f. When the pressure stabilizes, click or tap Keep.
g. Enter **5** for the Total Volume Added. Click or tap Keep Point.
h. Repeat e–g of this step at 5 mL increments until you've added a total volume of 20 mL of CO_2 gas to the experiment flask. When asked for total volume, remember to add 5 mL to the last value you entered. Verify that the correct data is in the table.
i. Click or tap Stop to stop data collection when you have finished collecting data.
j. Click or tap the Dataset Options, ⊡, next to Data Set 1. Choose Rename and label the Data set **Air**.
k. Click or tap Dataset Options, ⊡, next to Data Set 2. Choose Rename and label the Data set **CO_2**.

9. Save the data file as instructed. Continue to Case Analysis before closing the data file.

EVIDENCE RECORD

Room Temperature ____________________________

Table 1		
Gas	Slope (kPa/mL)	y-intercept (kPa)
Air		
CO_2		

CASE ANALYSIS

1. Click or tap the y-axis label, Pressure, and display only Run 1, Air.
   a. Click or tap Graph Options, 📈, and choose Apply Curve Fit.
   b. Choose Linear as the curve fit. Click or tap Apply.
   c. Record the slope in the Evidence Record.
   d. Repeat this step for CO_2.
   e. How do the graphs and slopes compare?
2. For each gas, calculate the change in pressure each time you injected 5 mL of gas. Record the values in Table 2.

Table 2				
	Change in pressure after 1st injection (kPa)	Change in pressure after 2nd injection (kPa)	Change in pressure after 3rd injection (kPa)	Change in pressure after 4th injection (kPa)
Air				
CO_2				

3. Click or tap the y-axis label, Pressure, and display only Run 1, Air. Use the slope and y-intercept to determine the volume air that needs to be added to change the pressure to 150 psi. **Note**: Refer to your answers to the Pre-Lab.

4. How many compressions of the bicycle pump would be required to add this much volume of air to the 2 L bottle?

5. Is this a reasonable number of pumps for the 2 L bottle? Consider that the 5 mL of gas you injected, and the flask you used are about 20 times smaller than the 2 L bottle and volume of gas per pump.

6. Pressure of a confined gas results when molecules strike the wall of the container. Judging from the graphs for both gasses and the changes in pressure, when you injected 5 mL of each gas into the experimental flask, how does the number of molecules injected compare in each case? **Note**: Due to experimental error, there may be some small deviations.

7. Since molecules are hard to count, in chemistry the number of moles is frequently used to represent large numbers of molecules. A mole contains a fixed number of particles. One mole is defined as 6.022×10^{23} particles. This is the same idea as one dozen is defined as twelve particles. The symbol for the number of moles is "*n*".

   How are the pressure and number of moles of a gas related for constant volume and temperature? Are they directly or inversely proportional? Write an expression for this. How did you determine this?

CASE REPORT

When you write your case report, make sure to include graphs, supporting data, and

- How did you collect data in this experiment?
- How did you determine the volume of air needed to burst the 2 L bottle at 150 psi?
- Are the parents justified in their concerns?
- What errors may have occurred during the analysis?