Name **Period** **Date**

23. Ideal Gas Law

Driving Questions

Gases are freely moving and take up the entire volume of any container they occupy. Additionally, they can be compressed, thus forcing more matter into the same volume of space, affecting the pressure of the system. Unfortunately, the temperature of the system also affects the pressure. These characteristics make gases difficult to measure. Is there a way to relate all of the different variables that affect the existence of a substance in the gas phase? If so, how can the amount of gas produced by a chemical reaction be determined from experimental data if all of the variables interact?

Background

The ideal gas law combines the four variables that describe a gas–volume V, absolute pressure P, temperature) and number of moles n–into one equation.

$$PV = nRT$$

The universal gas constant, R, is the same for all ideal gases. The value and units of R, however, depend on the specific units for pressure used in the equation. The most common forms are: 0.0821 (atm·L)/(mol·K), when pressure is in units of atmospheres, and 8.31 (kPa·L)/(mol·K), when pressure is in units of kilopascals.

The universal gas constant is based on one mole of an ideal gas at conditions of standard temperature and pressure (STP). Standard temperature is 273.15 K (0 °C) and standard pressure is 101.325 kPa (1 atm). One mole of an ideal gas occupies 22.414 liters at STP conditions. As with the other gas laws, the ideal gas law requires that temperature values be measured in Kelvin.

Materials and Equipment

For each student or group:

- Data collection system
- Absolute pressure sensor
- Stainless steel temperature sensor
- Blue plastic tubing for the temperature sensor
- Sensor extension cable
- Balance, centigram
- Graduated cylinder or volumetric pipet, 10-mL
- Graduated cylinder, 1000-mL
- Test tube, 15-mm x 100-mm
- Plastic bottle, 300- to 500-mL
- Two-hole that fits the plastic bottle
- Quick-release connector
- Tubing, 1- to 2-cm
- Tubing connector
- 1.0 M Hydrochloric acid (HCl), 10 mL
- Sodium bicarbonate ($NaHCO_3$), 0.80 g
- Glycerin, 2 drops
- Paper towels

Safety

Add these important safety precautions to your normal laboratory procedures:

- Hydrochloric acid is a strong acid. Avoid contact with the skin and eyes.
- Be sure that all acids and bases are neutralized before disposal down the drain.
- Be aware that the gas being generated causes an increase in pressure which may expel the stopper from the bottle. Because of this, eye protection should be worn during this experiment to prevent injury due to flying objects as well as splashed chemical. Reducing the amount of the limiting reactant ($NaHCO_3$) will reduce the resulting pressure of the products. It is better to error on the side of too little of the reactants than too much.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
Tilt the bottle slightly to allow the HCl to spill out of the test tube and mix with the sodium bicarbonate.	Put the sodium bicarbonate and a test tube containing 10 mL of 1.0 M HCl into a plastic bottle and insert the stopper.	Analyze the data collected to determine the initial and final pressure inside the bottle as well as the final temperature.	Determine the mass of the sodium bicarbonate.	Begin recording temperature and pressure data.

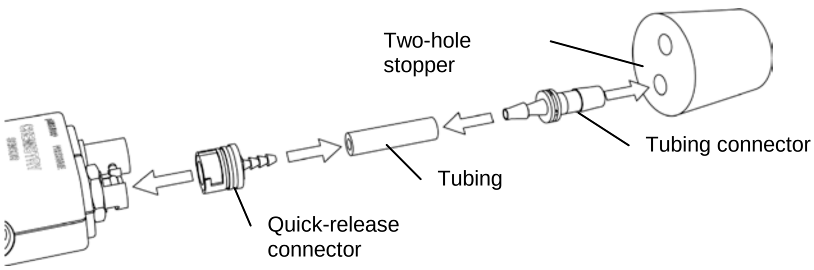
Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Connect the two-hole stopper to the absolute pressure sensor.



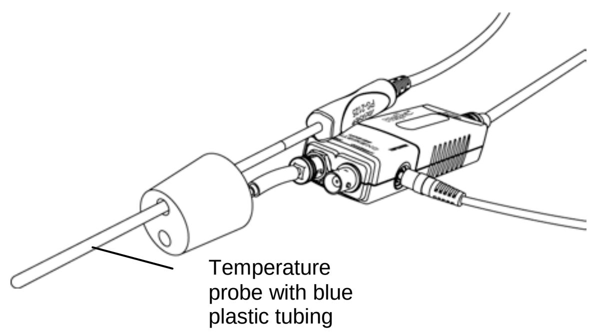
   a. Insert the thicker end of the tubing connector into one of the holes in the stopper. If this is difficult, add a drop of glycerin.

   b. Connect the 1- to 2-cm piece of tubing to the other, thinner end of the tubing connector.

   c. Insert the barbed end of the quick-release connector into the open end of the 1- to 2-cm piece of tubing. If this is difficult, add a drop of glycerin.

   d. Insert the quick-release connector into the port of the absolute pressure sensor and then turn the connector clockwise until the fitting clicks (about one-eighth turn).

2. ☐ Put a drop of glycerin into the open hole in the stopper and then insert the stainless steel temperature sensor, covered in blue plastic tubing, through the hole.



3. ☐ Remove any excess glycerin from the temperature sensor with a paper towel.

4. ☐ What are two reasons that glycerin is used in the setup above?

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5. ☐ Start a new experiment on the data collection system. �(1.2)

6. ☐ Connect the absolute pressure sensor (using an extension cable) and the stainless steel temperature sensor to the data collection system. �(2.2)

7. ☐ Display two graphs simultaneously. On one graph display Pressure (kPa) versus Time (s) and in the second graph, display Temperature (K) versus Time (s). �(7.1.11)

8. ☐ Weigh between 0.50 and 0.75 grams of sodium bicarbonate ($NaHCO_3$) and place it into an empty plastic bottle. Record the exact mass added below.

   Mass of $NaHCO_3$ (g): ________________________

9. ☐ In this experiment, the sodium bicarbonate is the limiting reactant. What is a limiting reactant?

____

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10. ☐ Fill a small test tube with 10.0 mL of 1.0 M hydrochloric acid (HCl) and place it in a test tube rack until needed later.

11. ☐ In this experiment, the hydrochloric acid is the excess reactant. What is an excess reactant?

____

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12. ☐ Tilt the plastic bottle and carefully slide the small test tube down inside so the HCl stays in the test tube and does not mix with the sodium bicarbonate.

13. ☐ Taking care not to spill the HCl from the test tube, place the stopper in the plastic bottle and *make sure it is secure*.

14. ☐ What will happen if the stopper is not secure in the plastic bottle?

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Collect Data

15. ☐ Start recording data. �(6.2)

Note: During data collection you may need to adjust the scale of the graph to see the changes taking place. �(7.1.2)

16. ☐ While holding the stopper in place, slowly rotate the bottle until the HCl spills from the test tube and mixes with the $NaHCO_3$.

17. ☐ What do you observe? Do these observations suggest that a chemical reaction is taking place? Explain.

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18. ☐ Is the chemical reaction exothermic or endothermic? How do you know?

___

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19. ☐ When the pressure and temperature have reached a maximum value and bubbles are no longer forming within the plastic bottle, stop recording data. �(6.2)

20. ☐ Dispose of the contents of the plastic bottle according to your teacher's instructions and then rinse the plastic bottle with water.

21. ☐ Determine the volume of your container by filling the bottle completely with water and then pouring it into a 1000-mL graduated cylinder. Record the volume below.

Volume of plastic bottle (g): ______________

22. ☐ Save your data file and clean up according to the teacher's instructions. �(11.1)

Data Analysis

1. ☐ Determine the measured quantities in Table 1 below from the graph of Pressure (kPa) versus Time (s) and Temperature (K) versus Time (s) that you collected. �(9.1)

   Note: The amount of $NaHCO_3$ and volume data are the values recorded during the experiment in the Procedure section, above.

Table 1: Pressure, temperature, mass, and volume data

Measured Quantity	Value
Initial Pressure (kPa)	
Final Pressure (kPa)	
Final Temperature (K)	
Amount of $NaHCO_3$ (g)	
Volume (mL)	

2. ☐ Find the change in pressure that occurred as a result of the chemical reaction.

3. ☐ Based on the units for pressure, which value for the universal gas constant will be used in the ideal gas law? Be sure to include the proper units.

4. ☐ Calculate the experimental number of moles of carbon dioxide gas generated from the reaction. Use the change in pressure for P, the final temperature in Kelvin for T, the volume of the bottle in liters for V, and the proper value for the universal gas constant, R.

   $PV = nRT$

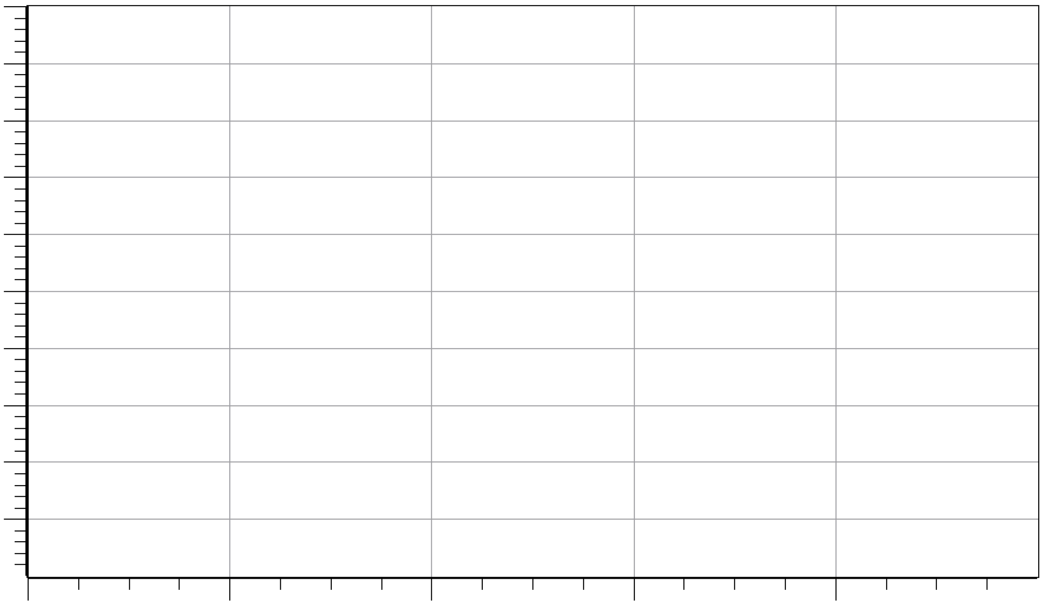
5. ☐ Write the chemical equation that represents the reaction happening in the bottle.

6. ☐ Calculate the amount of $CO_2(g)$ expected to have been generated based on the reactants used.

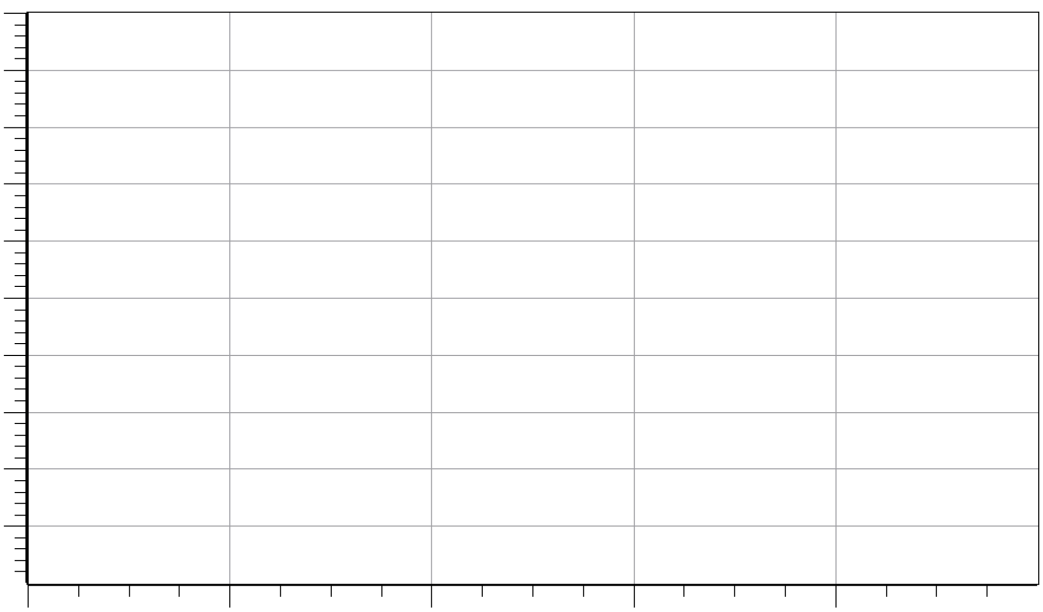
7. ☐ Calculate the percent error.

$$\text{Percent error} = \left| \frac{\text{accepted value} - \text{experimental value}}{\text{accepted value}} \right| \times 100$$

8. ☐ Sketch or print the graphs of Temperature (°C) versus Time (s). Label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



9. ☐ Sketch or print the graphs of Pressure (kPa) versus Time (s). Label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



Analysis Questions

1. **What happened to the pressure during the reaction? Why?**

2. **Why is the difference in pressure required in this experiment and not the difference in temperature?**

3. **Would the same value for moles of carbon dioxide been calculated if the temperature substituted into the ideal gas law was in degrees Celsius? Explain.**

4. **What could have contributed to your percent error?**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **What could be done to make the carbon dioxide gas behave more like an ideal gas?**

2. **How many liters would the theoretical number of moles of carbon dioxide released from the 0.60 grams of sodium bicarbonate occupy at STP?**

3. **How did the conditions in the plastic bottle compare to STP?**

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Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **At the same temperature and pressure, which sample contains the same number of moles of particles as 1 liter of O_2(g)?**

   A. 1 L Ne(g)

   B. 2 L N_2(g)

   C. 0.5 L SO_2(g)

   D. 1 L H_2O(l)

2. **A student calculated the number of moles of hydrogen gas produced from the reaction between magnesium and hydrochloric acid to be 0.142 moles. If the theoretical amount of hydrogen gas that should have been produced was 0.147 moles, what is the student's percent error for the experiment?**

   A. $\frac{0.005}{0.142} \times 100$

   B. $\frac{0.005}{0.147} \times 100$

   C. $\frac{0.147}{0.142} \times 100$

   D. $\frac{0.142}{0.147} \times 100$

3. **Which temperature change would cause the volume of a sample of an ideal gas to double when the pressure of the sample remains the same?**

   A. From 200 °C to 400 °C
   B. From 400 °C to 200 °C
   C. From 200 K to 400 K
   D. From 400 K to 200 K

4. **How much pressure exists in a 10.00 L container filled with 2.50 moles of gas at 315.0 K?**

   A. 0.000955 kPa
   B. 0.00153 kPa
   C. 654 kPa
   D. 1050 kPa

5. **A gas sample occupies a container of 25.0 mL with a pressure of 125.1 kPa at room temperature (25.0 °C). The number of moles of this gas in the container is**

   A. 0.00126 moles
   B. 0.0151 moles
   C. 1.26 moles
   D. 15.1 moles

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. The ideal gas law combines four variables that describe a gas. These variables are pressure, volume, temperature, and number of moles. The ideal gas law is ________________________. The universal gas constant, R, is equal to 8.31 (L·kPa)/(K·mol). This constant is based on ________________________ temperature and pressure (STP), where the temperature is 0.0 °C or ________________________ and the pressure is 1 atm or ________________________. When using the ideal gas law, temperature must always be measured in ________________________.

2. The ________________________ can be used to experimentally determine the number of moles generated from a chemical reaction. The reaction must take place inside a ________________________ container and the temperature, pressure, and ________________________ of the container must be recorded. The ideal gas law is most accurate for gases that behave ________________________. Real gases behave ideally at high ________________________ and low ________________________.

Key Term Challenge Word Bank

Paragraph 1

0 K

0 kPa

1 kPa

101.315 kPa

273.15 K

298.15 K

constant

degrees Celsius

Kelvin

Moles

n=PVRT

PT = nRV

PV=nRT

standard

universal gas constant

Paragraph 2

amounts

closed

densities

ideal gas law

ideally

open

pressures

temperatures

volume