Protocol | Exploring Gas Laws

Bring a USB drive with you to lab this week.

Download the **pdf here (https://gatech.instructure.com/courses/334258/files/42101053?wrap=1)**.

Learning Objectives

1. Students will be able to construct a model that explains gas behavior using experimental results.
2. Students will be able to summarize gas behavior by generating a formula to represent each variable considered.

Introduction

Theoretical Background

Gases are the simplest phase of matter because they lack forces between their molecules (intermolecular forces). Gases are simple enough that their behavior can be predicted from first principles; simple measurements of gases very early in the history of chemistry confirmed these predictions. Ideal gases behave in a very predictable manner and can be inferred based on several simple relationships between variables: pressure, temperature, moles, and volume. When some of these variables are controlled or kept constant, ideal gas behavior can be reduced to a simpler set of laws called *empirical gas laws*, implying that they can be experimentally determined!

In this experiment, we will be performing tests analogous to those carried out by early chemists to understand relationships between variables relevant to gases. The goal is to generate our own empirical gas laws and combine them to create a more complex model of gas behavior. As part of this exploration, you will generate a particle-level model of gas behavior and a theoretical equation for ideal gas behavior. Deviations from model behavior, such as nonlinearity or nonzero y-intercepts can be explained as deviations of a specific gas from ideal behavior or experimental errors.

Chemical Systems Under Study

This experiment will have multiple gas evolution reactions to choose from, but we will also work with air. Capturing air is straightforward (simply enclose it in a sealed container), but keeping air contained while measuring pressure, temperature, and volume can be somewhat trickier. Watch your stopcocks and seals carefully throughout this experiment to avoid leaks or open valves.

To determine the relationship between moles and gas volume, it is essential to generate a known number of moles (n) of gas. We can also measure the pressure exerted by a gas (P) with a pressure probe, its temperature (T) with a thermometer, and the volume it occupies (V) using glassware.

These measurements will be used to deduce the following relationships: n with V, V with P, P with T, and T with V. Note: Each individual relationship must be tested separately to determine the simple relationship while holding all other variables constant. (e.g., to determine the relationship of V with P, T and n must be constant!)

We will generate hydrogen (H_2) gas, carbon dioxide (CO_2) gas, and a mixture of hydrogen and oxygen (O_2) gases. This way we will be able to compare results with different gases to determine if the chemical makeup (identity) and/or purity of the gas dictates behavior. The reactions we will use for this purpose are: 1) the oxidation of magnesium metal in excess hydrochloric acid, 2) the decomposition of hydrogen peroxide in the presence of an iron (**III**) catalyst, and 3) the decomposition of sodium bicarbonate in the presence of excess hydrochloric acid.

- Mg (*s*) + 2 HCl (*aq*) → $MgCl_2$ (*aq*) + $\mathbf{H_2}$ **(*g*)**
- 2 H_2O_2 (*aq*) → 2 H_2O (l) + $\mathbf{O_2}$ **(g)**
- $NaHCO_3$ (*s*) + HCl (*aq*) → $\mathbf{CO_2}$ **(g)** + NaCl (aq) + H_2O (l)

These are slightly exothermic reactions that take some time to complete. Monitor your temperature and pressure measurements carefully to ensure that they reach a maximum before recording final measurements. Confirm visually that the reaction has completed.

Class-wide Goals

1. Combine results for all tests with each gas to generate models and formulae.
2. Considering all experimental results, develop group models that explain gas behavior and compare with other groups to refine model.
3. Considering all experimental relationships between variables, integrate all variables into a single formula to describe ideal gas behavior.

Research Questions

1. What is the volume to mole relationship for a gas at room conditions when pressure and temperature are held constant?
2. What is the pressure to volume relationship for a gas when temperature and moles are held constant?
3. What is the temperature to pressure relationship for a gas when volume and moles are held constant?
4. What is the volume to temperature relationship for a gas when pressure and moles are held constant?

5. What is the effect of the identity of a gas on behavior (V, T, and P) with the same number of moles?

Safety and Materials

Working with systems under high pressure poses mechanical hazards. Avoid pressures in excess of 2 atmospheres. Only heat a closed system when you are carefully monitoring the pressure inside it; do not leave closed systems at elevated temperatures unattended.

Hydrogen and oxygen gases are both flammable and the hydrochloric acid used in this experiment is corrosive. Handle the hydrochloric acid with care and vent the apparatus slowly after generating hydrogen gas. The hydrochloric acid used in this experiment is corrosive; handle it with care. Exercise caution when using hot plates: ensure that plastic does not contact the hot surface and leave hot plates plugged in to cool. The aqueous products of these reactions can be rinsed down the drain with water.

The following reagents will be available:

- **2.0 M hydrochloric acid solution (https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/education/regulatory-documents/sds/chemicals/chemicals-h/S25358.pdf)**
- **Magnesium metal (ribbon) (https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/education/regulatory-documents/sds/gsc-magnesium-ribbon-safety-data-sheet.pdf)**
- Sodium bicarbonate ($NaHCO_3$) solid
- Hydrogen peroxide (3%) solution
- Iron (III) nitrate solution (0.5 M)

Procedures

Planning Investigation (~15 min)

1. Your TA will help to organize groups of 4 **based on the selected reaction** from the prelab quiz (written in notebook).

2. Groups will **determine which procedure** aligns with each research question and **determine a plan** to carry out 2-3 of these procedures as a team. (See recommended combinations for time-efficient suggestions).

3. The group's plan must be briefly written in the lab notebook along with any data tables needed for the investigation. Consider each of the following when writing out the plan: What amounts will be used? Who will do what? How will you collect and organize data in your notebooks?

Carrying out Investigation (~60 min)

Recommended procedure combinations:

- A + C + E
- A + B
- C + D
- B + C
- D + E

A. Measuring Pressure and Volume

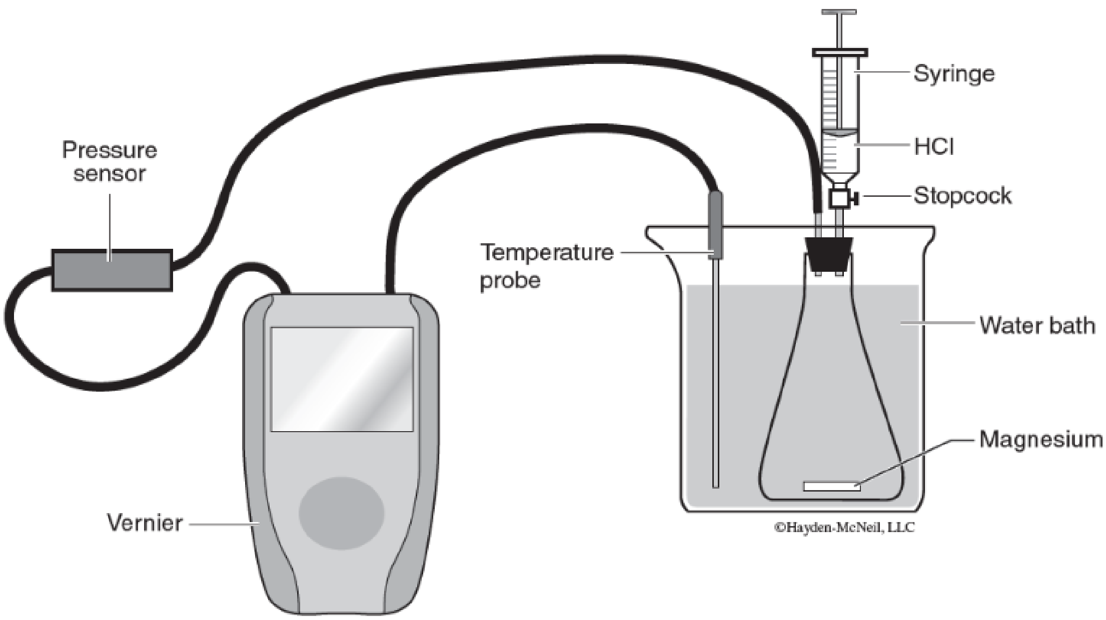
1. Obtain a 20 mL syringe, open the Graphical Analysis app, and get out a pressure probe. Carefully take apart the syringe, rinse with deionized water, and dry to remove any residual acid.
2. Connect the pressure probe via Bluetooth to the app. Ensure that the pressure is displayed in atmospheres and that the reading is approximately 1.0 atm (it is likely to be slightly lower).
3. Open the syringe so that the plunger seal is at a desired mL mark and connect it to the Luer lock fitting on the pressure probe. Seal with a gentle twist.
4. Record the initial pressure and volume of air inside the syringe.
5. Move the plunger to seven other locations and manually record the pressure and volume of gas at these locations (use at most two significant figures in recorded volumes). Do ***not*** compress the gas to a pressure greater than 2 atm, as the pressure sensor may break.

B. Measuring P, V, T, by identity of gas

1. Connect a pressure probe to the Graphical Analysis app. Ensure that the pressure is in atmospheres.
2. Fill a large beaker with water so that a 125 mL Erlenmeyer flask can sit in it as a bath.
3. Calculate the amount of limiting reagent (sodium bicarbonate, magnesium, and hydrogen peroxide) needed to produce 0.0015 moles *total* of gas for each reaction. Measure this approximate mass or volume and record the exact value used. Place the reagent inside a 125 mL Erlenmeyer flask; this will be used as your reaction chamber.
4. Connect two conical adapters to the open holes of the tan gas stopper. After you have added the reagent to the Erlenmeyer flask, insert the stopper into the opening of the flask and push to seal. To one of the adapters, connect a piece of Luer lock tubing connected to the pressure probe. To the other, connect a stopcock. Close the stopcock so that the inside of the flask is now sealed.
5. Calculate the volume of **2.0 M hydrochloric acid** needed to completely consume the magnesium or sodium bicarbonate. Multiply the volume by 3 to ensure sufficient excess. For the hydrogen peroxide reaction, collect ~1 mL of iron (III) nitrate solution. Obtain the necessary volume in a syringe from a small beaker.
6. ***Before delivering the hydrochloric acid, ensure that you are wearing eye protection and are a safe distance from the apparatus. The risk of acid exposure is high!*** Connect the

syringe to the stopcock. The apparatus should resemble the image below (without the LabQuest device due to the use of Bluetooth).

7. Record the initial temperature using either a digital or analog thermometer.
8. Set up the app for time-based data acquisition and press the Collect button *before* adding HCl or iron (III) nitrate.
9. When you're ready to add the second reactant, open the stopcock first and then, if necessary, depress the syringe plunger. Close the stopcock after adding the liquid and observe the reaction. Ensure that the reaction has completed before halting data collection.
10. **Repeat until data has been collected for <u>all reactions</u>.**

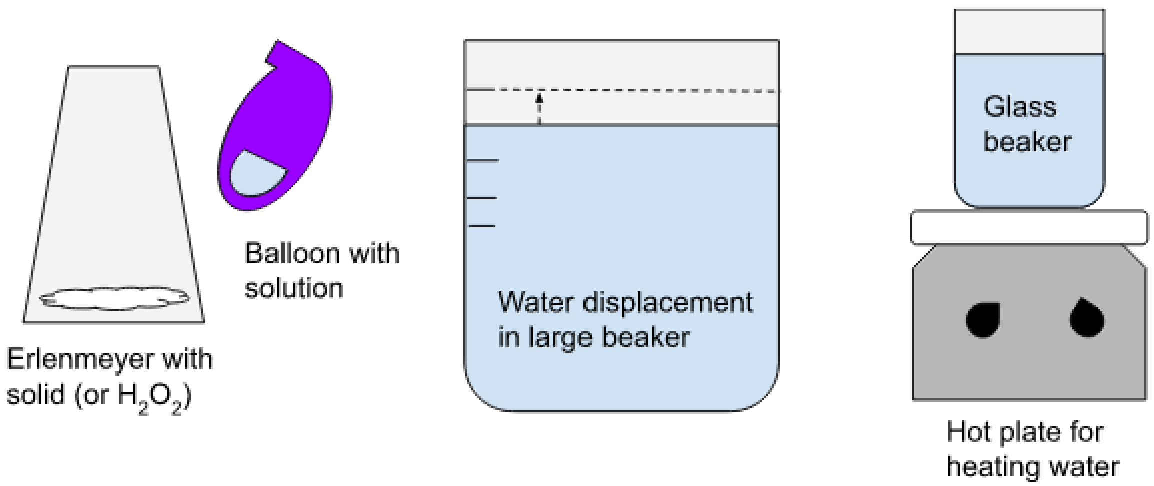


C. Measuring Volume and Temperature

1. Calculate the amount of limiting reagent (sodium bicarbonate, magnesium, or hydrogen peroxide) needed to produce 0.025 moles *total* of gas for each reaction. Measure this approximate mass or volume and record the exact value used. Place the reagent inside a small Erlenmeyer flask (50 ml).
2. Calculate the volume of 2**.0 M hydrochloric acid** needed to completely consume the magnesium or sodium bicarbonate. Multiply the volume by 2 to ensure sufficient excess. For the hydrogen peroxide reaction, collect ~5 mL of iron (III) nitrate solution.
3. Pour the second reactant into the balloon and stretch the top of the balloon over the mouth of the Erlenmeyer flask **without tipping the solution into the flask!** Once securely attached, raise the balloon so that the solution falls into the flask to begin reacting. The balloon should expand until the reaction has completed.
4. To measure the temperature and volume relationship, you will use a series of water baths at various temperatures. ***Do not heat large plastic beakers on hot plates! Heat water in a glass beaker and pour into the plastic beaker!*** Water displacement can be used to determine volume by inverting the flask and submerging the balloon portion. Wait until the final volume is reached

for each temperature condition. Record all relevant data. *Note: Greater than 10 degree differences in bath temperature may be needed to observe changes - the precision and accuracy of the volume measurements will be low!*

5. Dispose of the balloon and flask contents in the sink and flush down the drain with excess water.



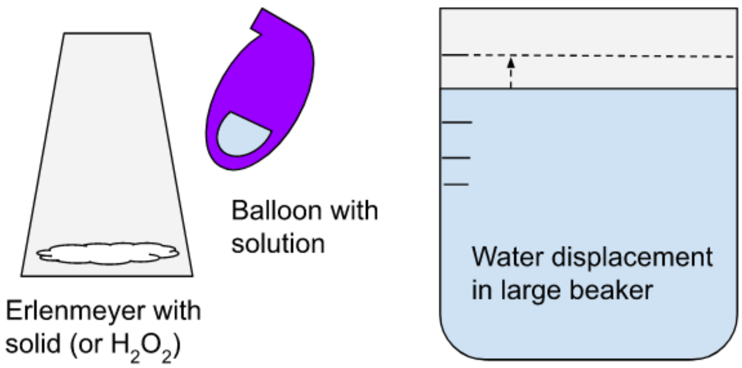
D. Measuring Pressure and Temperature

1. Using an Erlenmeyer flask, a stopper, a pressure probe, a water bath, and a hot plate, design an experiment that measures the relation between pressure and temperature for air with all else constant. Your apparatus must ensure that volume and amount of gas do not change as the pressure and temperature vary.
2. **Collect at least ten data points over a range of at least 15 ºC.** Before beginning data collection, check your apparatus and procedure with your teaching assistant.

E. Measuring Volume and Moles

1. Calculate the amount of limiting reagent (sodium bicarbonate, magnesium, or hydrogen peroxide) needed to produce a specific number of moles *total* of gas for each reaction. Your goal is to produce varying moles of gas in separate reactions, so you must calculate the amount needed for 4 separate reactions ranging between 0.005 and 0.05 moles of gas.
2. Measure this approximate mass or volume and record the exact value used. Place the reagent inside an Erlenmeyer flask (50 mL).
3. For the magnesium or sodium bicarbonate reactions, calculate the volume of **2.0 M hydrochloric acid** needed to completely react with the limiting reagent. Multiply the volume by 2 to ensure sufficient excess. For the hydrogen peroxide reaction, use ~5 mL of iron (III) nitrate solution. Obtain the necessary volume of liquid.
4. Pour the second reactant into the balloon and stretch the top of the balloon over the mouth of the Erlenmeyer flask **without tipping the solution into the flask!** Once securely attached, raise the balloon so that the solution falls into the flask to begin reacting. The balloon should expand until the reaction has completed.

5. To measure the volume, water displacement can be used by inverting the flask and submerging the balloon portion below the level of the water. Wait until the reaction has completed to measure volume. Record all relevant data.
6. **Repeat with other calculated amounts to <u>vary the number of gas moles</u>.**
7. Dispose of the balloon and flask contents in the sink and flush down the drain with excess water.



Group Analysis and Modeling (~30 min)

1. Groups will **return to the research questions** addressed by the three completed procedures then discuss and analyze their data with that in mind.

2. Groups will decide how to present their results **visually**.

3. Groups will **generate (draw) an explanatory model** to describe how gases behave on a particle-level based on their combined macroscopic observational evidence. They will debate amongst themselves **alternative models** as applicable.

Class Presentations of Findings (~30 min)

Groups will **submit their conclusions and evidence** to the class results spreadsheet. Groups will also **share their model and explain** why they developed it in this way, providing evidence from their experiments.

Model Revision and Expansion (~30 min)

Each group will **revise their previous model to account for class-wide findings**. Groups will then **develop a tentative formula describing gas behavior that accounts for all the variables**. (TA's can assist in this process) *See below.

*One approach to follow:

- Consider there to be an unknown constant (call it Z) involved.
- Consider the proportionality relationships observed to determine how to relate everything to Z.
- Set Z equal to a fraction.
- Place variables in the numerator or denominator of the fraction based on their proportionality relationships.