Molar Volume of a Gas

Strand Molar Relationships

Topic Investigating molar volume of a gas

Primary SOL CH.4 The student will investigate and understand that chemical quantities are based on molar relationships. Key concepts include
- a) Avogadro's principle and molar volume;
- b) stoichiometric relationships.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include
- a) designated laboratory techniques;
- b) safe use of chemicals and equipment;
- f) mathematical and procedural error analysis;
- g) mathematical manipulations including SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, and dimensional analysis.

CH.2 The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of
- h) chemical and physical properties.

CH.3 The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include
- b) balancing chemical equations.

CH.5 The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include
- a) pressure, temperature, and volume;
- b) partial pressure and gas laws;
- c) vapor pressure.

Background Information

Avogadro's law says that the volume of one mole of any gas at standard temperature and pressure is 22.4 liters. This is a necessary concept for the completion of stoichiometric problems that involve the use of gases as reactants or products. Often, the difficulty students have with molar volume problems is the conversion of the temperature and pressure to STP (Standard Temperature and Pressure).

Materials

- Electronic balances
- Large graduated cylinders (100 mL or larger)
- Calculators

- 250 mL Erlenmeyer flasks
- Two-hole stoppers to fit flasks
- 10 mL graduated cylinders
- Cold-water baths to contain inverted graduated cylinders
- Magnesium ribbon
- Thistle tubes
- Ring stands
- Apparatus clamps
- Rubber tubing

Vocabulary

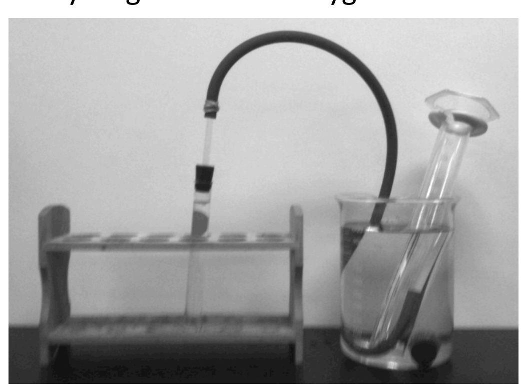
Avogadro's law, combined gas law, Dalton's law of partial pressures, deliquescent, molar volume, moles, stoichiometric, stoichiometry, vapor pressure

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

In this activity, students react magnesium with hydrochloric acid to produce hydrogen gas. The gas is collected by water displacement, so students will need to adjust the volume for the vapor pressure of water. The amount of magnesium used in this activity can be too great for the measurement of the gas collected. If too large a piece of magnesium is used, the amount of gas produced will be greater than the volume of the graduated cylinder.

Ask students how they might be able to determine the correct amount of magnesium needed for this investigation. Accept students' answers, and allow those whose answers are viable to proceed. A potential solution would be to mass a larger piece of magnesium ribbon and then calculate the mass per square centimeter. Once this is done, each student may then cut a small piece of magnesium ribbon, find its size in square centimeters, and determine its mass, using the previously determined mass per square centimeter. From this, they can determine the number of moles.

Students need a background in stoichiometry before attempting to do the calculations. You might ask students to come up with a method of reacting the magnesium and the hydrochloric acid in a way that makes it possible to collect and measure the volume of hydrogen produced. Some students may not be aware that they are collecting hydrogen. A simple test for the hydrogen is to hold the graduated cylinder upside down and place a glowing wood splint under the cylinder. The ignition of the hydrogen results in a sudden combustion of the hydrogen with the oxygen of the air.



Although this particular activity uses a graduated cylinder to collect the gas, it would be possible to use a gas collection bottle. In that case, students would need to mark the level after completing the experiment and then use a graduated cylinder to measure the volume of gas that was in the gas collection bottle.

Use the picture at right for lab setup. Have students complete the lab individually or in groups.

1. Obtain 125 mL Erlenmeyer flask, 2-hole stopper to fit flask, and cold-water bath. Obtain thistle tube, and adjust it to fit near the bottom of flask through one of the two stopper holes. Insert small glass tube in the other stopper hole, and attach rubber hose to glass tube. Obtain large graduated cylinder, fill it completely with water, and invert it in cold-water bath. Support the graduated cylinder in the inverted position in the water bath. Place rubber tube from stopper into opening of the graduated cylinder.
2. Obtain small piece of magnesium ribbon (approximately 2.5 cm). Measure length to .01 cm and record. (Alternatively, have students mass the piece of magnesium ribbon.) Use sandpaper to remove any excess oxide coating.
3. Place piece of magnesium ribbon in the Erlenmeyer flask, and replace the stopper. Make sure the stopper is well-sealed.
4. Using a small, 10 mL graduated cylinder, obtain about 5 mL of 3 M hydrochloric acid.
5. Pour hydrochloric acid through the thistle tube into Erlenmeyer flask. Make sure that the bottom end of the thistle tube is covered by liquid so that the gas produced is forced through the rubber tube into the graduated cylinder.
6. Observe the reaction, and record observations.
7. When the reaction is complete, remove the rubber hose and the clamp from the graduated cylinder. Adjust the water level in the graduated cylinder with the water level in the water bath, and record the volume of gas collected.
8. Record all information in a data table like the one below. The vapor pressure of the water vapor can be obtained from a table of water vapor pressures.

Mass of Mg ribbon before reaction	
Volume of hydrogen gas	
Room temperature	
Room barometric pressure	
Water vapor pressure at room temperature	

9. Calculate the molar volume of the gas produced in the reaction.

Assessment

- **Questions**

  Consider the chemical reaction $Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$.
  - What is the number of moles of Mg used?
  - Theoretically, how many moles of hydrogen gas were produced?
  - What is the pressure of the dry hydrogen gas (pressure exerted by H_2 alone)?
  - What is the volume of the hydrogen gas at STP? (Hint: Use the combined gas law.)
  - What is the volume of one mole of hydrogen gas at STP? (Hint: Remember you have calculated the number of moles of hydrogen produced and the volume of those moles.)
  - The accepted value for the molar volume of a gas at STP is 22.4 L. What is your percent error?
  - What is the volume of 80 g O_2 at STP?
  - How many liters would 0.25 mol of any gas occupy at STP?

- **Journal/Writing Prompts**
  - Calcium chloride is deliquescent. Explain why that makes it unsuitable for use in the experiment.
  - State the direction each of the following possible errors would cause your results to deviate from the accepted value of 22.4 L/mol at STP. Explain your answers.
    - Air bubbles were introduced when the graduated cylinder was inverted.
    - Not all the Mg ribbon reacted.
    - Not all the MgO coating was removed from the Mg ribbon before beginning the experiment.
    - You read the volume when the water level in the graduated cylinder was higher than the water level outside the graduated cylinder.
- **Other**
  - Have students answer the following: If 3.7 moles of propane are at a temperature of 28^{o}C and are under 154.2 kPa of pressure, what volume does the propane sample occupy?
  - Tell students that a sample of carbon monoxide at 57^{o}C and under 0.67 atm of pressure takes up 85.3 L of space. Have them determine the mass of carbon monoxide present in the sample.

Extensions and Connections (for all students)

- Respiration in animals brings in oxygen from the air, and the oxygen reacts with sugar within the cells, producing energy for the organism. Have students explain what else produces energy in the cells and what the energy is used for.

Strategies for Differentiation

- Have students use colored pencils, markers, or highlighters to color-code safety procedures and safety questions.
- Provide students with barometric pressures and vapor pressures, as needed, to further understanding.
- Challenge students by having them read barometric pressures and water temperatures to determine vapor pressures from sources.