# The Molar Volume of a Gas

Avogadro's hypothesis states that equal volumes of ideal gases contain equal numbers of molecules under the same conditions of temperature and pressure. At standard temperature and pressure (also known as STP), *viz.* 0°C (273.15 K) and 1 atm (101.3 kPa), the accepted value for the molar volume of an ideal gas is: 22.41 L/mol, *i.e.*, exactly one mole of any ideal gas at 273.15 K and 101.3 kPa pressure will occupy a volume of 22.41 L. This volume is called the *molar volume*. In this experiment, you will confirm that the molar volume of hydrogen gas at STP is indeed 22.41 L/mol.

In this experiment, you will conduct a chemical reaction between solid magnesium metal and a hydrochloric acid solution, as shown in the reaction equation below.

$$Mg\ (s) + 2HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2\ (g)$$
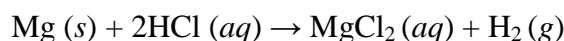
You will react a known mass of solid magnesium with an excess of hydrochloric acid, making the magnesium the limiting reagent. The reaction will be conducted in a sealed vessel, thus trapping the evolved $H_2\ (g)$ in the vessel. You will use a Gas Pressure Sensor to measure the pressure increase in the sealed vessel and a temperature probe to measure the temperature of the reaction indirectly, by measuring the temperature of the water bath in which the vessel will be placed.

You will also calculate the number of moles of hydrogen indirectly. The balanced reaction above shows that the molar ratio of magnesium reacted to H_2 produced is 1:1. Thus, by knowing the mass of magnesium, you will be able to determine the number of moles of hydrogen gas produced. To put everything together as you analyze your data to confirm Avogadro's hypothesis, you will use the Combined Ideal Gas Law to calculate the volume, at STP, of the hydrogen gas that your reaction produced at nonstandard conditions.

OBJECTIVES

In this experiment, you will:

- Measure the gas production of a chemical reaction by a pressure change.
- Determine the molar volume of the gas produced in the reaction.
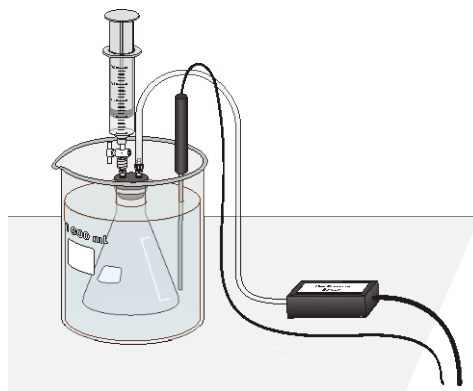- Calculate the molar volume of a gas at STP.

Figure 1

MATERIALS

Vernier computer interface	1.0 M hydrochloric acid, HCl, solution
computer	Small beaker for HCl solution
Vernier Gas Pressure Sensor	Magnesium ribbon
Temperature Probe	20 mL gas syringe
600 mL or one liter beaker	Plastic tubing with two Luer-lock connectors
10 mL graduated cylinder	Rubber stopper assembly with 2-way valve
125 mL Erlenmeyer flask	Balance, ±0.001 g precision

PROCEDURE

1. Obtain and wear gloves and goggles throughout the experiment.

2. Obtain the 125 mL Erlenmeyer flask that you will use for the experiment. Measure and record the weight of the dry, empty flask to within 0.01 g using a top loading balance. In order to determine the available volume of the flask that the hydrogen gas will occupy as it is produced from the reaction of the solid magnesium with the hydrochloric acid solution, fill the flask with distilled water to the top of its neck. Slowly insert the rubber stopper assembly into the neck of the flask and secure it tightly, which will cause some of the water to overflow and result in the flask being completely filled with water to the bottom of the rubber stopper. Remove the rubber stopper assembly; dry the outside of the flask, and weight the filled flask to within 0.01 g using a top loading balance.

3. Obtain a piece of magnesium ribbon with a mass between 0.010 g and 0.015 g. Measure and record its mass to the nearest 0.001 g. Place the piece of magnesium ribbon in the clean and dry 125 mL Erlenmeyer flask whose volume you determined in Step 2.

4. Prepare a room temperature water bath in a large beaker. The bath should be deep enough to completely cover the gas level in the Erlenmeyer flask.

5. Connect a Gas Pressure Sensor to Channel 1 of the Vernier computer interface. Connect a Temperature Probe into Channel 2 of the interface. Connect the interface to the computer with the proper cable.

6. Use the clear tubing to connect the white rubber stopper to the Gas Pressure Sensor. (About one-half turn of the fittings will secure the tubing tightly.) Twist the white stopper snugly into the neck of the Erlenmeyer flask to avoid losing any of the hydrogen gas that will be produced in the reaction (see Figure 1). **Important**: Close the valve on the white stopper by turning the handle so it is perpendicular to the valve stem.

7. Obtain a small amount of 1.0 M hydrochloric acid. **CAUTION:** *Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin*. Draw 5 mL of HCl solution into the 20 mL syringe. Thread the syringe onto the two-way valve on the white stopper (see Figure 1). Submerge the Erlenmeyer flask into the water bath. Position the Temperature Probe in the water bath so that the tip of the probe is not touching the beaker.

8. Start Logger *Pro* on your computer. Open the file "05 Molar Volume" from the *Advanced Chemistry with Vernier* folder.

9. With the flask still submerged in the water bath, click `▶ Collect` to begin data collection. After about 20 seconds, open the two-way valve directly below the syringe, press the plunger to add all of the 5 mL of HCl solution to the flask and pull the plunger back to its original position. Close the two-way valve.

10. Keep the flask immersed in the water bath as the reaction proceeds. Data collection will stop after 5 minutes. If you need more data collection time, chose Extend Data Collection from the Experiment menu. Alternately, you may click `■ Stop` to end data collection *before* 5 minutes have elapsed.

11. Carefully remove the white stopper from the flask to relieve the pressure in the flask. **<u>Important</u>**: Do not open the two-way valve to release the pressure in the flask.

12. Examine the pressure data to determine the change in pressure, ΔP, during the reaction. In addition, determine the mean temperature of the water bath during the reaction. Write down these values in your data table.

13. From the Experiment menu, choose Store Latest Run to save your data.

14. Rinse, clean, and dry the flask for a second trial. Obtain a new piece of magnesium ribbon and place it in the flask. Repeat the necessary steps to conduct the second trial.

15. Follow the same procedure to conduct a third trial.

DATA TABLE (Mg)

	Trial 1	Trial 2	Trial 3
Mass of Mg (g)			
Volume of flask (mL)			
Maximum pressure (kPa)			
Initial pressure (kPa)			
Pressure change, ΔP (kPa)			
Temperature (K)			

16.   Obtain samples of an unknown metal from your instructor, and repeat the above procedure to obtain data for three trials with the unknown.

DATA TABLE (Unknown)

	Trial 1	Trial 2	Trial 3
Mass of unknown metal (g)			
Volume of flask (mL)			
Maximum pressure (kPa)			
Initial pressure (kPa)			
Pressure change, ΔP (kPa)			
Temperature (K)			

DATA ANALYSIS

1. Using the measured weight of the empty 125 mL Erlenmeyer flask, its weight when filled with water, and the known density of water at the temperature of the measurement, calculate the "effective" volume of the 125 mL Erlenmeyer flask, *i.e.*, the volume available for occupancy by the H_2 gas. (You must also take into account the volume of the added HCl solution, which decreases the volume available to the H_2 gas.)

2. Calculate the molar amounts of each piece of magnesium and unknown metal that you used.

3. Based on the measured temperatures and pressure changes for each reaction, use the ideal gas law to calculate the molar amount of hydrogen gas that was produced in each reaction.

4. Calculate the volume occupied by one mole of hydrogen gas (molar volume) at STP.

5. Compare your calculated molar volume, at STP, with the accepted molar volume of an ideal gas at STP, *viz.*, 22.41 L/mol. If the values do not compare well, suggest possible sources of experimental error.

6. Use your calculated value for the STP molar volume to determine the atomic weight of your unknown metal. What is the likely identity of the metal?