The Molar Volume of a Gas – Background

The ideal gas law, PV = nRT, gives an accurate description of the behavior of real gases at low pressures and relatively high temperatures. The ideal gas law is based on the assumption that the gas molecules experience no intermolecular forces and that the molecules occupy no volume. These assumptions are valid at low pressure and high temperature since under these conditions the molecular density is low. The molecules are too far apart to "feel" attractive forces exerted by other molecules. Furthermore, since the molecules are far apart, the volume occupied by the molecules is negligible compared to the total volume occupied by the gas. In reality, intermolecular forces do exist and molecules do occupy space. The extent to which these factors cause a gas to deviate from the ideal gas law at a particular temperature and pressure will depend on its molecular structure.

The volume occupied by one mole of a gas is its molar volume, V_{molar}. This volume can be calculated by solving the ideal gas law for volume and plugging in 1 mole for the amount of gas atoms or molecules, and STP ("standard temperature and pressure" of 273.15 K and 1 atm).

$$V_{molar} = \frac{nRT}{P} = \frac{(1\,\text{mole})\left(0.08206\,\frac{\text{L}\cdot\text{atm}}{\text{mole}\cdot\text{K}}\right)(273.15\,\text{K})}{1\,\text{atm}} = 22.41\,\text{L} \qquad (1)$$

Part 1. *Determination of the Molar Volume of Hydrogen Gas*

The hydrogen gas produced in the reaction between solid magnesium and hydrochloric acid displaces water from the 1 L Erlenmeyer flask into the graduated cylinder (Figure 1).

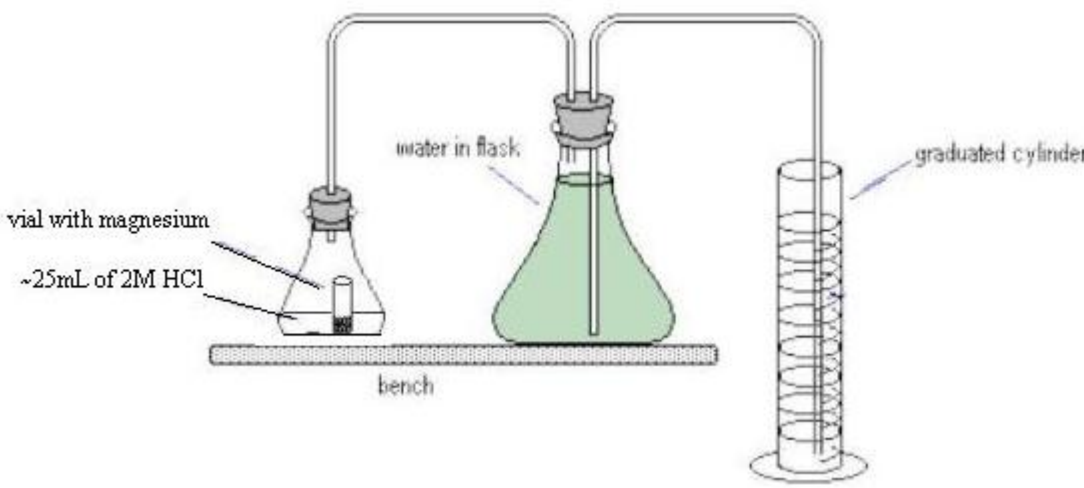


Figure 1. The apparatus for this experiment.

Once the pressure inside the siphon apparatus has equilibrated with the atmospheric pressure, the total pressure inside the flask is equal to the sum of the partial pressures of hydrogen gas and water vapor, according to Dalton's Law of partial pressures,

$$P_{lab} = P_{H_2} + P_{H_2O} \qquad (2)$$

where P_{lab} is the atmospheric pressure in the laboratory obtained from a barometer, P_{H_2} is the partial pressure of hydrogen and P_{H_2O} is the vapor pressure of water at the laboratory temperature. The value of this vapor pressure can be obtained from the *Handbook of Chemistry and Physics*, (published by the Chemical Rubber Co). Equation 2 can be easily rearranged to solve for the partial pressure of hydrogen gas:

$$P_{H_2} = P_{lab} - P_{H_2O} \tag{3}$$

The volume of the water displaced from the 1 L Erlenmeyer flask into the graduated cylinder is equal to the volume of hydrogen produced. Assuming that Boyle's and Charles' laws apply, the volume of hydrogen at STP is calculated using equation 4,

$$V_{STP} = V_{H_2}\left(\frac{273.15\,K}{T_{lab}}\right)\left(\frac{P_{H_2}}{1\,atm}\right) \tag{4}$$

where V_{H_2} is the measured volume of hydrogen gas produced and T_{lab} is the lab temperature in kelvin.

Assuming magnesium is the limiting reagent, the moles of H_2(g) produced can be calculated from the mass of magnesium weighed.

$$\text{moles } H_2 = \text{grams Mg} \times \left(\frac{1\text{ mole Mg}}{24.305\text{ g}}\right)\left(\frac{1\text{ mole } H_2}{1\text{ mole Mg}}\right) \tag{5}$$

The molar volume at STP can then be calculated by equation 6.

$$V_{molar} = \frac{V_{STP}}{\text{moles } H_2} \tag{6}$$

From your data for each of the two trials, calculate the molar volume of hydrogen at STP. Show all calculations and, as always, pay special attention to the significant figures which result from your measurements. Calculate the average molar volume of hydrogen at STP and the percent error in your average.

Part 2. *Determination of Na_2CO_3 Mass Percent in an Unknown Mixture*

The mass percent of Na_2CO_3 in the unknown can be calculated from the moles of carbon dioxide produced and the stoichiometry of the reaction below.

$$Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g) \tag{7}$$

The carbon dioxide gas produced in the reaction displaces water from the 1 L Erlenmeyer flask into the graduated cylinder. Once the pressure inside the siphon apparatus has equilibrated with the atmospheric pressure, the total pressure inside the flask is equal to the sum of the partial pressures of carbon dioxide gas and water vapor, according to Dalton's Law of partial pressures.

$$P_{lab} = P_{CO_2} + P_{H_2O} \tag{8}$$

Equation 8 can be easily rearranged to solve for P_{CO_2}:

$$P_{CO_2} = P_{lab} - P_{H_2O} \tag{9}$$

and notice that $P_{CO_2} = P_{H_2}$ from equation 3.

Once the partial pressure of CO_2 is known, it can be related to the moles of $CO_2(g)$ produced via the ideal gas law.

$$n_{CO_2} = \frac{P_{CO_2} \times V_{CO_2}}{R \times T_{lab}} \tag{10}$$

The moles of CO_2 produced can then be converted to the grams of sodium carbonate in the unknown.

$$\text{mass } Na_2CO_3 = n_{CO_2} \times \left(\frac{1 \text{ mole } Na_2CO_3}{1 \text{ mole } CO_2}\right)\left(\frac{105.97 \text{ g}}{1 \text{ mole } Na_2CO_3}\right) \tag{11}$$

The mass percent of Na_2CO_3 in your unknown can then be calculated with equation 12.

$$\text{mass \% } Na_2CO_3 = \left(\frac{\text{mass } Na_2CO_3}{\text{total unknown mass}}\right) \times 100 \tag{12}$$

From your data for each of the two trials performed, calculate the mass percent of Na_2CO_3 in your unknown. Show all calculations and, as always, pay special attention to the significant figures which result from your measurements. Calculate the average mass percent of Na_2CO_3 in your unknown.

The Molar Volume of a Gas – Procedure

Purpose:

The purpose of this experiment is to measure the molar volume of hydrogen gas, and to compare the measured value to the value predicted by the ideal gas law. Additionally you will determine the mass percent of Na_2CO_3 in an unknown sample.

Procedure:

Part 1. ***Determination of the Molar Volume of Hydrogen Gas***

To measure the molar volume of hydrogen gas, you need to generate a known number of moles of hydrogen gas, measure its temperature, volume and pressure. This data will then be used to calculate the molar volume of hydrogen gas with the ideal gas law at STP. Hydrogen gas will be generated by the reaction of magnesium metal with 2M hydrochloric acid according to the following reaction.

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \quad (1)$$

The reaction is carried out in the apparatus shown in Figure 1.

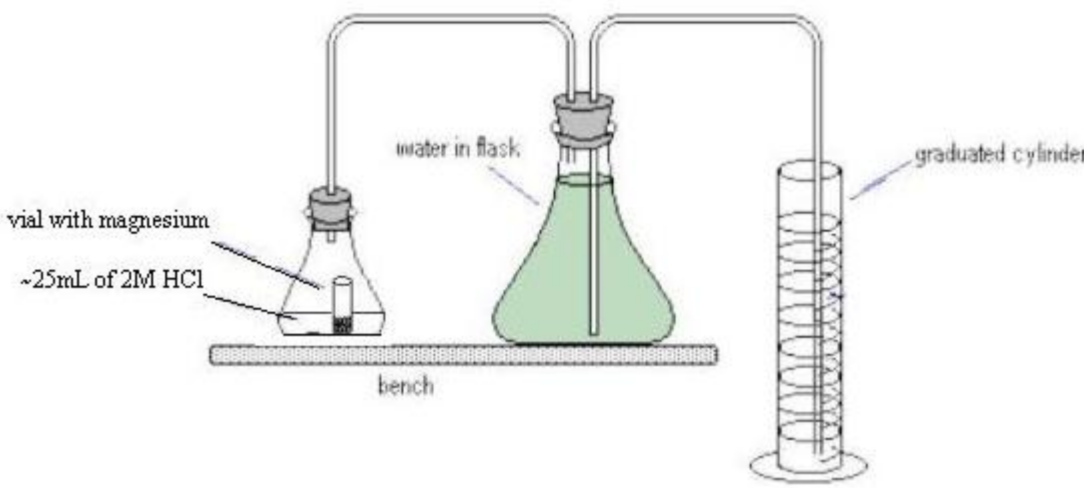


Figure 1. The apparatus for this experiment.

Fill the 1 L Erlenmeyer flask with water and fill the graduated cylinder with ~200 mL of water. Attach the stopper to the 1 L Erlenmeyer flask as shown below in Figure 1, leaving the 250 mL Erlenmeyer flask's stopper unattached. Place the other hose into the graduated cylinder so that the opening remains below the surface of the 200 mL of water.

Using a pipet bulb, create a siphon by blowing air into the free stopper tube to force water from the large Erlenmeyer flask into the graduated cylinder. There should be no air in the hose that goes from the 1 L Erlenmeyer flask to the graduated cylinder. If a siphon is successfully established, the water level inside the 1 L flask can be raised or lowered by moving the graduated cylinder above or below the level of the 1 L flask. Check to be sure your set-up is siphoning. Set the height of the graduated cylinder to keep the large Erlenmeyer flask nearly full.

Accurately weigh out a solid sample of magnesium (~0.2 grams) and place it in the small plastic vial. In your notebook, record the exact mass of the magnesium. Fill the 250 mL

Erlenmeyer flask with ~25 mL of 2 M HCl. Be careful with this concentrated strong acid! Carefully insert the plastic test tube into the 250 mL Erlenmeyer flask and seal the flask with the rubber stopper that is connected to the siphon apparatus. Measure and record the initial volume of water in the graduated cylinder, which should be around 200 mL. Gently shake the 250 mL Erlenmeyer flask to tip over the plastic vial that contains the magnesium. Once the reaction has stopped, record the final volume of water in the graduated cylinder. Remove the rubber stopper from the 250mL Erlenmeyer flask to release the pressure from the H_2 gas. Keep the rubber stopper in the 1L Erlenmeyer flask so you can reuse the apparatus to perform one more trial for a total of 2 trials. In your notebook, use a table like the following to guide your data collection for Part 1.

Part 2. ***Determination of Na_2CO_3 Mass Percent in an Unknown Mixture***

Carbonate containing compounds will react under acidic conditions to produce carbonic acid, which is in equilibrium with water and carbon dioxide.

$$Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g) \qquad (2)$$

Using the same setup as in Part 1, accurately weigh out ~1 gram of your sodium carbonate unknown into the small plastic vial. In your notebook, record the exact mass of the sample used. Fill the 250mL Erlenmeyer flask with ~25 mL of 2M HCl. Be careful with this concentrated strong acid! Carefully insert the plastic test tube into the 250 mL Erlenmeyer flask and seal the flask with the rubber stopper that is connected to the siphon apparatus. Measure and record the initial volume of water in the graduated cylinder, which should be around 200 mL. Gently shake the 250 mL Erlenmeyer flask to tip over the plastic vial that contains the sodium carbonate unknown to initiate the reaction. After the reaction is over, record the final volume achieved in the graduated cylinder. Remove the rubber stopper from the 250 mL Erlenmeyer flask to release the pressure from the CO_2 gas. Keep the rubber stopper in the 1 L Erlenmeyer flask so you can reuse the apparatus to perform one more trial for a total of 2 trials. In your notebook, use a table like that on the next page to guide your data collection for Part 2.

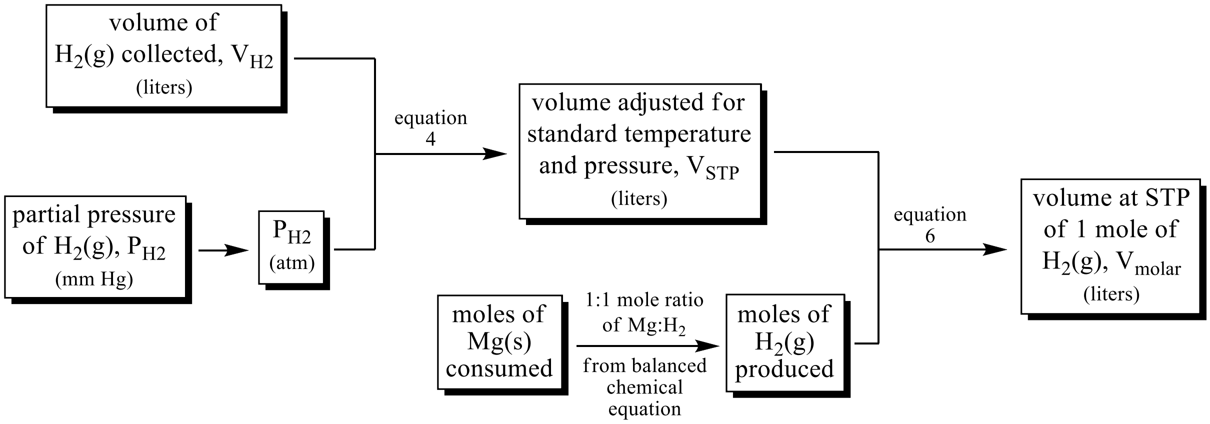
Waste Disposal:

- Dispose of all of the aqueous reaction products, from the 250 mL Erlenmeyer flask, into the appropriate waste container. Clean water can be poured down the drain.

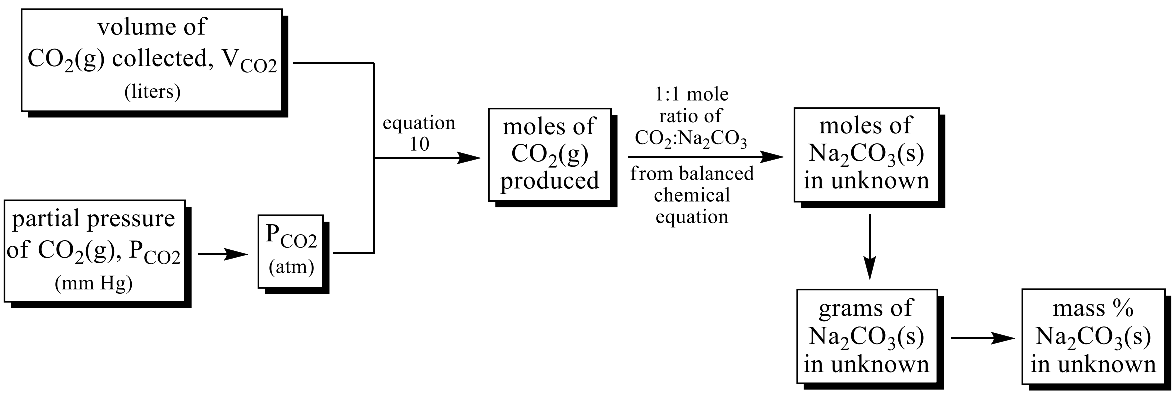
Calculations:

Use the following flow charts and refer to the Background to help with the calculations of the molar volume of $H_2(g)$ and the mass percent of Na_2CO_3 in your unknown.

Part 1: Molar volume of $H_2(g)$



Part 2: Mass percent of Na_2CO_3



Conclusion:

Report the average molar volume of hydrogen at STP based on your experimental results. What is the percent deviation from the molar volume of an ideal gas? Report the average mass percent of Na_2CO_3 in your unknown sample. Discuss potential sources of error encountered during this experiment.