NAME: HONORS CHEMISTRY

SECTION: Lab: Molar Volume of a Gas

Equal volumes of all gases, measured at the same temperature and pressure, contain equal numbers of particles. This assumption was proposed by Amadeo Avogadro, an Italian chemist, in 1811. Stanislao Cannizzaro, another Italian chemist, came upon Avogadro's hypothesis nearly 50 years after it had been proposed. He saw that this hypothesis pointed a way to finding the molar masses of gaseous elements and compounds. If equal volumes of gases contain equal numbers of particles, then the masses of those gas volumes should be in the same ratio as the masses of their constituent particles.

The volume of gas chosen for comparison was the volume occupied by one mole of a substance. However, the volume occupied by a mole of gas depends on the temperature and pressure of the gas. Therefore, a standard temperature and pressure were chosen. Standard temperature and pressure (STP) are 273 K and 101.3 kPa. At STP, the volume occupied by one mole of a gas is the standard molar volume.

In this experiment, you will determine the standard molar volume of a gas. You will react a known mass of magnesium metal with an excess of hydrochloric acid and collect the generated hydrogen gas over water in a gas-collection tube. The evolved gas will rise to the top of the water-filled tube, displacing an equal volume of water. Since the collected hydrogen gas will be saturated with water vapor and at non-standard conditions, corrections must be made to the observed volume. The total pressure of the gas mixture is equal to the sum of the component pressures of each gas:

$$P_{tot} = P_{H2} + P_{H2O}$$

Algebraically, we can rearrange the equation to obtain:

$$P_{H2} = P_{tot} - P_{H2O}$$

The gas collection tube is adjusted so that the internal gas pressure equals the exterior atmospheric pressure: $P_{tot} = P_{atm}$. Then, given the P_{H2O}, the above equation can be solved for the actual pressure exerted by the hydrogen gas. This pressure value, the observed volume, and the ambient temperature can then be substituted into the combined gas law to obtain the volume that would be occupied by this gas sample at STP. The number of moles of hydrogen can be calculated from the amount of magnesium used to generate it. The standard molar volume can then be calculated using the number of moles of hydrogen gas and the volume that would be occupied by the gas at STP.

Objectives
- To collect a volume of hydrogen gas over water by carrying out the reaction between magnesium and hydrochloric acid
- To determine the partial pressure of hydrogen gas
- To convert the observed volume of hydrogen gas to the corresponding volume at STP
- To calculate the volume occupied by one mole of hydrogen gas at STP

Materials

Barometer (for class)
Thermometer (for class)
Ring stand
Utility clamp
50-mL eudiometer
10 mL graduated cylinder
1 hole rubber stopper to fit eudiometer
large graduated cylinder
millimeter ruler
balance
goggles
apron
magnesium ribbon
copper wire
3M hydrochloric acid

Safety
Hydrochloric acid is corrosive to skin, eyes, and clothing. When handling hydrochloric acid, wear safety goggles and a lab apron. Wash spills and splashes off your skin and clothing immediately using plenty of water. Call your teacher immediately.

Procedure
Before beginning the lab, read through the entire procedure and create an appropriate data table.
1. Put on your laboratory apron and safety goggles.
2. Record the barometric pressure and the room temperature.
3. Obtain a piece of magnesium ribbon approximately 2 cm long. Record the mass of the magnesium ribbon.
4. Obtain a piece of fine copper wire approximately 15 cm in length. Bend a hook into one end of the wire. Roll the magnesium ribbon into a small ball and encase it in a "cage" of copper wire at the other end. Be sure to leave several centimeters of the copper wire extending from the cage. This "handle" will allow the ball of magnesium to be anchored at the stoppered end of the eudiometer.
5. Assemble a ring stand and utility clamp to support the eudiometer.
6. Fill a large container or graduated cylinder with room-temperature tap water.
7. Using a graduated cylinder, carefully add 10 mL of 3M HCl into the eudiometer.
8. Put some distilled water in a beaker, and then use the beaker to completely fill the eudiometer. Avoid agitating the bottom acid layer.
9. While holding the copper handle, insert the copper wire holding the magnesium ribbon about 4 cm into the tube. Hang the hook over the edge of the tube and secure the wire by inserting a 1-hole rubber stopper into the tube end.
10. Cover the stopper hole with your finger. Invert the tube and submerge the stoppered end into the large container of water. Secure the eudiometer with a utility clamp. Position the tube so that the stoppered mouth is just above the bottom of the container. Since the acid is more dense than the water, it will diffuse through the tube and eventually react with the magnesium.
11. Once the reaction has stopped, wait about 5 minutes for the solution to cool to room temperature. Raise or lower the tube until the water level in the eudiometer is the same as that in the large container. This is necessary so that the total pressure of the gas in the tube is equal to the atmospheric pressure. Record the volume to the nearest 0.01 mL on the report sheet.
12. Discard the tube contents and rinse all apparatus with tap water.
13. Before you leave the lab, wash your hands thoroughly with soap and water.

Post-lab Discussion
The balanced equation for the single replacement reaction carried out in this experiment is

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

Since the coefficients of magnesium and hydrogen are the same, the reaction involves an equal number of moles of each substance. To obtain the number of moles of magnesium, and the number of moles of hydrogen, use the mass of magnesium ribbon that reacted and the gfm of magnesium.

To calculate the partial pressure of the hydrogen gas, the total system pressure and the partial pressure of water vapor must be known. In Step 11, the system pressure was equated with atmospheric pressure; therefore the initial barometer reading is equal to the total system pressure. The vapor pressure of water at the experimental temperature can be found by consulting a reference table.

Using the combined gas law, calculate the volume occupied by the H_2 gas at STP (273 K and 101.3 kPa). Use this volume and the number of moles of hydrogen calculated earlier to find the standard molar volume of hydrogen.

Calculations

Remember to present all of your data in an appropriate table in your final lab report. Show all your work and be careful to follow all the rules of significant figures.

1. How many moles of magnesium were used?
2. Use the moles of magnesium reacted to predict the moles of hydrogen gas produced in this reaction.
3. What is the vapor pressure of water under the conditions used in this experiment?
4. Use Dalton's Law of Partial Pressures to determine the partial pressure of the dry hydrogen gas generated in this experiment.
5. Carry out the necessary calculations to find the volume of the dry hydrogen gas at STP.
6. Use the volume of hydrogen produced at STP and the moles of hydrogen produced to calculate the volume per mole of this gas at STP. (mL of gas sample / moles hydrogen)

Analyze and Apply Questions

1. How does Avogadro's hypothesis relate to the results of this experiment?
2. What volume of hydrogen gas would have been collected if you had used 0.50 g of magnesium ribbon in your experiment? Support your answer with a calculation.
3. Suppose you had used 6.0 M HCl, rather than 3.0 M HCl. How would this affect the results of the experiment?
4. The accepted value for the volume of one mole of any gas at STP is 22,400 mL/mol. Find the percent error in your determination of the molar volume of a gas (#6 in your calculations).
5. How would each of the following situations affect your calculated molar volume? Justify your answers.
    a) The gas produced in the reaction was slightly soluble in water.
    b) During the procedure, small amounts of air entered the eudiometer.
    c) A small amount of magnesium ribbon remained at the end of the reaction.
6. A sample of solid sodium chlorate was heated in a test tube and decomposed according to the reaction: $2\ NaClO_3 \rightarrow 2\ NaCl + 3\ O_2$
   The oxygen produced was collected by water displacement at $22^{o}C$. The resulting mixture had a total pressure of 754 torr and a volume of 650. mL. Calculate the partial pressure of O_2 in the gas collected and the number of moles of oxygen present.

Remember to include an appropriate conclusion to the lab. A good conclusion includes the following the main findings/results of the lab and a discussion of plausible sources of error (NOT mistakes due to calculations).

For the introduction:

A) Explain why the measured properties of a mixture of gases depend only on the total number of moles of particles, not on the identity of the individual gas particles. How is the observation summarized as a law?

B) Explain how gases are collected over water and how to determine the pressure of the "dry" gas. You should include illustrations or diagrams.

C) State Avogadro's hypothesis.