Name Reganne Date 1/12/16 Period 6

Molar Volume of a Gas - Lab

Introduction

Chemists have noticed that equal volumes of all gases, when measured at the same temperature and pressure, contain the same number of moles. This assumption was proposed in 1811, by Amadeo Avogadro, an Italian chemist. Another Italian chemist, Stanislao Cannizzaro, came upon Avogadro's hypothesis nearly 50 years later and recognized that equal volumes of gases contain equal numbers of particles at the same temperature and pressure. Therefore, the volume of exactly **one mole** of any gas should be constant under standard conditions.

The volume of gas chosen for comparison was the volume occupied by one mole of a substance. However, because the volume occupied by a gas depends on its temperature and pressure, a standard temperature and pressure were chosen so that valid comparisons could be made. The standard temperature and pressure (STP) are 273 K and 101.3 kPa (760 mmHg). At STP, the volume occupied by one mole of a gas is called the **standard molar volume**.

This investigation will result in the determination of the standard molar volume of hydrogen gas. You will begin by reacting a known amount of magnesium metal with an excess of hydrochloric acid. The hydrogen gas produced will be collected by displacing water in a gas collection tube. Because a gas collected over water is a mixture of the collected gas and water vapor, Dalton's law of partial pressures must be used to correct the pressure. It states that the total pressure of any gas mixture is equal to the sum of the component pressure of each of the gases.

$P_{total} = P_x + P_y + \ldots$ for any number of gases.

For this experiment, the statement becomes

$P_{total} = P_{hydrogen} + P_{water\ vapor}$

The gas collection tube can be adjusted so that the pressure of the gas inside the tube is the same as the air pressure outside, that is $P_{total} = P_{room}$. The vapor pressure of water can be obtained from a reference table.

In this experiment, you will use Mg metal to produce hydrogen gas and then you will measure the volume of the gas at the temperature and pressure in the lab. The volume of hydrogen gas collected in this experiment is dependent on the mass of Mg reacted. After the volume of hydrogen is measured, the volume at lab temperature and pressure will be converted to a ***molar volume*** at STP and compared to the accepted ***standard molar volume*** of a gas.

PRELAB QUESTIONS

1. Write a balanced equation for the reaction of magnesium and hydrochloric acid that produces hydrogen gas and magnesium chloride.

   $Mg + 2HCl \rightarrow H_2 + MgCl_2$

2. What is the ratio of moles of magnesium to moles of hydrogen gas in the above equation? 1 mole to 1 mole

3. What is meant by STP? (include numbers) Standard Temperature and Pressure (273 K) (1 atm)

4. What two gases will be collected in the gas collection tube? H_2 and $H_2O_{(g)}$

5. What value from a reference table will you need in order to complete the calculations in this experiment? Explain why you need this information and what gas law it incorporates.

   The calculations in this experiment require a water vapor pressure from a reference table because there is water vapor mixed in with the H_2 gas. This incorporates Dalton's law of Partial Pressures.

5/5

6. 35.0 mL of nitrogen gas was collected in a lab by water displacement to a total final pressure of 99.1 kPa at 24°C. The vapor pressure of water at this temperature is 2.99 kPa.

a. Using Dalton's Law of partial pressures, calculate the pressure of the nitrogen gas alone. SHOW WORK!

$$P(N_2) = 99.1 - 2.99$$

$$\boxed{P(N_2) = 96.1 \text{ kPa}}$$

b. Assume that the temperature and pressure of the nitrogen gas are changed to STP. Use the combined gas law to determine the new volume of this gas. SHOW WORK!

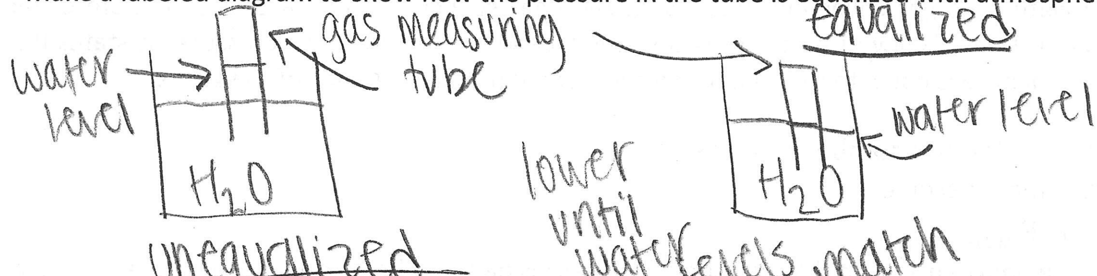
$$\frac{(96.1\text{ kPa})(0.035\text{ L})}{(297\text{K})} = \frac{(101.3\text{ kPa})(X\text{ L})}{273\text{ K}}$$

$$\boxed{V_2 = 0.031\text{ L}}$$

$$\frac{35.0\text{ mL}}{1000} = 0.035\text{ L}$$

$$24°C + 273 = 297\text{ K}$$

7. Make a labeled diagram to show how the pressure in the tube is equalized with atmospheric pressure.



Problem Statement: Read the lab and use your EDR to write a problem statement for this lab.

The purpose of this experiment is to determine the standard molar volume of hydrogen gas. The independent variable is the amount of magnesium reacted and the dependent variable is the gas pressure of the water vapor and produced volume of H_2 gas. The pressure for only H_2 gas will be determined in calculations. Values that are held constant are room temperature, water vapor pressure, and pressure of the room.

Materials and Equipment

Goggles	Gas measuring tube	Beaker, 400 mL	Deionized water
Two-hole stopper, #00	Thermometer	Large glass cylinder	3.0 M HCl
Cu wire	10 mL graduated cylinder	Ring stand	Mg strip
Buret clamp			

Safety

Wear goggles and aprons during the entire investigation.

Do not let the hydrochloric acid come in contact with your eyes, skin, or clothing. If this happens, tell your instructor and rinse the exposed skin with water.

Procedure

1. Record the barometric pressure of the room, room temperature, and the precise mass of 1.000 meter of magnesium ribbon.
2. Get a 250 mL beaker and fill it about 2/3 full of tap water. Rinse the gas measuring tube with D.I. water.
3. Cut a piece of magnesium ribbon, Mg, about 2 cm long. Make sure you cut the ends of the ribbon squarely. Carefully measure the length of your sample of ribbon to the nearest 0.01 cm. Record the length on your data sheet.
4. Obtain a piece of copper wire about 15 cm long and wrap it around the magnesium ribbon which has been folded to a size that will fit inside the gas measuring tube. (See Figure B)
5. Thread the copper wire through a hole in the rubber stopper so that the copper-wrapped Mg is below the bottom of the stopper. Bend the copper wire over the top of the stopper.
6. Prepare a ring stand to support the gas measuring tube.
7. Slowly pour about 10 mL of 3.0 M HCl into the gas tube. CAUTION: Dilute HCl will stain, cause mild burns, and irritate the lungs and eyes. Avoid contact and inhalation. Rinse spills with plenty of water.
8. Incline the tube slightly so the air may escape and slowly fill it with D.I. water from the wash bottle. Pour the water slowly down the sides of the tube so the water and acid mix as little as possible. Fill the tube completely.
9. With the tube completely full of water, insert the stopper, with the Cu-wrapped Mg ribbon, into the tube. The stopper should force water and all air bubbles out of the tube and should hold the wire wrapping the Mg in place.
10. With your finger over the hole in the stopper (make sure there is no air in the hole of the stopper), invert the stoppered end of the tube into the beaker of water. Clamp the tube in place so that the bottom of the rubber stopper is slightly above the bottom of the beaker. The reaction will not start immediately because it takes time for the acid to diffuse down through the column of water to the metal (Figure A).
11. When the magnesium has reacted completely and production of hydrogen gas has stopped, tap the tube with your finger to dislodge any bubbles you see attached to the side of the tube or the copper wire.
12. Place your finger over the hole in the stopper and remove the tube from the beaker. Lower the tube into a large cylinder of water and remove your finger. Raise or lower the tube until the level of the water inside the tube is the same as the level of the water outside the tube. This equalizes the pressure. Read the volume on the tube as accurately as possible (to the nearest 0.1 mL). This reading will give the volume of the gases (hydrogen and water vapor) in the tube. Record the volume.
13. Record the vapor pressure of water at room temperature. (Figure C)
14. Empty the contents of the tube and beaker into the sink and rinse both with tap water.

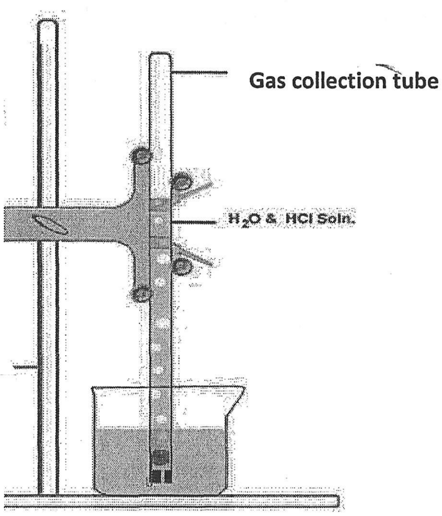


Figure A

Figure B

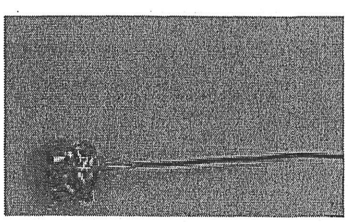


Figure C

Temperature	Vapor Pressure (mmHg)
20	17.5
21	18.7
22	19.8
23	21.1
24	22.4
25	23.8
26	25.2
27	26.7
28	28.3
29	30.0

Data: Length of Magnesium and Volume, Temperature, and Pressure for H_2 Gas

Object Measured	Value of Measurement
Length of Mg Ribbon (cm) +/- 0.01cm	2.35 cm
Volume of H_2 Gas (mL) +/- 0.01mL	28.09 mL
Room Temperature (°C)+/- 0.1 °C	23.8 °C
Vapor Pressure of Water (mmHg) from Figure C	22.4 mmHg
Atmospheric Pressure (mmHg) +/- 0.5 mmHg	626.5 mmHg
Mass of 1m Mg Ribbon (g) +/- 0.0005	0.865g

CALCULATIONS:
Use the **EDR** to present the following calculations.

1. Calculate the mass of the magnesium strip by converting cm to m and using the g/m given.

2. Determine the moles of magnesium used. (Convert g → mol of Mg

3. Determine the moles of hydrogen gas produced in this reaction, based on the moles of Mg reacted. Use the mole ratio in the balanced equation.

4. Record the vapor pressure (in mmHg) of water under the conditions of this experiment. (Figure C)

5. Determine the pressure of ***just*** the hydrogen gas in mmHg? (Use Dalton's law)

6. Determine the STP volume of the H_2 gas that was produced.(Use $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$)

7. Convert the volume of H_2 gas from mL to liters.

8. Use a volume to mole ratio to determine the volume of <u>one</u> mole of hydrogen gas at STP (Standard molar volume). The answer is in L/mol.

9. *The theoretical value for the volume of 1 mole of any gas at STP is 22.4 liters.* Determine the percent error of your experimental value.

$$\% \text{ error} = \frac{|\text{theorectical value} - \text{experimental value}|}{\text{theoretical}} \times 100$$

ANALYSIS, CONCLUSIONS AND EVALUATION: Type a 2 paragraph, double-spaced, conclusion using your EDR and the prompts below.

CONCLUSION

- Restate the purpose (NOT problem statement) of the lab
- Identify relationship between variables (length of Mg used and volume of H_2 produced) using experimental data. Suggest how the volume of H_2 would change if the length of Mg was increased and explain how moles of H_2 can be determined. Include numbers.
- State the results of your experiment (what you were trying to determine). Include ONLY the important results, do not recite all of the data and calculations. Provide numbers.
- Use scientific laws, theories, and/ or principles to explain how the standard molar volume of a gas could be determined from the volume of H_2 produced at room temperature and pressure. Include a quote from a reliable source to support your explanation and a parenthetic reference(s).
- Compare your results with published/ accepted values. Include a parenthetic reference.

EVALUATION OF EXPERIMENT

- Suggest a logical source of error. Exclude "measuring wrong" and/or miscalculation.
- Explain the effect of the error on the experimental results (standard molar volume) and INCLUDE numbers.
- State the validity of the experimental results based on your percent error.

IMPROVING THE EXPERIMENT

- Suggest at least 1 improvement that could be made to reduce the identified error.
- Suggest a different way to investigate molar volume.

REFERENCE

- Cite source(s) in complete APA format

Molar Volume of a Gas - Lab Calculations

① Mass of the Magnesium Strip

x grams of Mg = length Mg $\times \frac{m}{cm} \times \frac{\text{mass of 1m Mg}}{m}$

x g Mg = 2.35 cm $\times \frac{1\ m}{100\ cm} \times \frac{0.865 g}{1\ m}$ = 0.0203 g

$\boxed{x \text{ g Mg} = 0.0203 \text{ g Mg}}$

② Moles of Magnesium Used

moles of Mg = grams Mg $\times \frac{1 \text{ mole Mg}}{\text{molar mass Mg}}$

x mol Mg = 0.0203 g Mg $\times \frac{1 \text{ mol Mg}}{24.31 g} = 8.35 \times 10^{-4}$ moles

$\boxed{x \text{ mol Mg} = 8.35 \times 10^{-4} \text{ moles Mg}}$

③ Moles of Hydrogen Gas Produced

moles H_2 = moles Mg $\times \frac{\text{mol ratio } H_2}{\text{mol ratio Mg}}$

x mol H_2 = 8.35×10^{-4} mol Mg $\times \frac{1 \text{ mol } H_2}{1 \text{ mol Mg}} = 8.35 \times 10^{-4}$ mol H_2

$\boxed{x \text{ mol } H_2 = 8.35 \times 10^{-4} \text{ mol } H_2}$

④ Vapor Pressure of Water

vapor pressure based on temperature of experiment

28.3°C → 22.4 mmHg

$\boxed{x \text{ pressure} = 22.4 \text{ mmHg } H_2O}$

(5) Pressure of Hydrogen Gas

pressure of hydrogen gas = air pressure − water vapor pressure

x pressure H_2 = 626.5 mmHg − 22.4 mmHg = 604.1 mmHg

$\boxed{x \text{ pressure } H_2 = 604.1 \text{ mmHg } H_2}$

(6) Volume of H_2 Gas at Standard Temperature + Pressure

$$\frac{(\text{pressure}_1)(\text{volume}_1)}{(\text{temperature}_1)} = \frac{(\text{pressure}_2)(\text{volume}_2)}{(\text{temperature}_2)}$$

°C
+273
K

$$\frac{(604.1)(28.09)}{(296.8)} = \frac{(760)(V_2)}{(273)}$$

23.8 °C
+273
296.8 K

H_2 volume at STP = $\boxed{20.54 \text{ mL } H_2}$

(7) Volume of H_2 gas from mL to L

$$H_2 \text{ gas (L)} = H_2 \text{ gas (mL)} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$H_2 \text{ gas volume} = 20.54 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.02054 \text{ L}$$

$\boxed{H_2 \text{ gas volume} = 0.02054 \text{ L}}$

8) Volume of One Mole of H_2 at STP

$$\frac{\text{calc. amount of L}}{\text{calc. amount of moles}} = \frac{\text{amount of L}}{\text{one mole}}$$

$$1 \text{ mol } H_2 \cdot \frac{0.02054 \text{ L}}{8.35 \times 10^{-4} \text{ mol } H_2} = \frac{x \text{ L}}{1 \text{ mol } H_2} \cdot 1 \text{ mol } H_2$$

$$\boxed{1 \text{ mol } H_2 = 24.6 \text{ L } H_2}$$

9) Percent Error of Experimental Value

$$\% \text{ error} = \frac{(\text{theoretical value} - \text{experimental value})}{\text{theoretical value}} \times 100$$

$$\% \text{ error} = \frac{(22.4 - 24.6)}{22.4} \times 100 = 9.82\%$$

$$\boxed{\% \text{ error} = 9.82\%}$$

+3

Reganne

- The purpose of this investigation is to determine the molar volume of hydrogen gas.
- The amount of hydrogen gas (H_2) produced is dependent on the amount of magnesium (Mg) that is reacted. In the experiment, 2.35 cm, or 0.0203 g, of Mg reacted and it produced 28.09 mL of hydrogen gas (H_2). If the length of the magnesium increased, the amount of hydrogen gas produced would also increase. The volume of hydrogen gas produced is dependent on the amount of the magnesium that is reacted, because the moles of reactants and products must be equal in a chemical reaction. Using the chemical formula, the amount of H_2 can be calculated using the mole ratio of 1 mole Mg to 1 mole H_2.
- In the investigation, the molar volume of hydrogen gas was calculated to be 24.6 L at STP, or standard temperature and pressure of 101.3 kPa and 273 K.
- In order to calculate the molar volume, the pressure of the H_2 was determined using Dalton's law of partial pressures. The pressure of the water vapor was subtracted from the pressure in the room to find the pressure of H_2, 604.1 mmHg. Then, the volume of the gas produced was converted from the experimental temperature and pressure to STP using the combined gas law. The value at STP is 0.02054 L H_2. Finally, that value and the amount of moles of H_2 produced, 8.35×10^{-4} moles H_2, was used in Avogadro's law to calculate the amount of liters for every mole, or the molar volume. "1 mole of any gas at STP occupies 22.4 liters of volume. Using this information, the volume occupied by any number of moles (or grams) can be determined" (Science Geek, 2014). In the experiment, the formula was used with the volume to determine the molar volume of hydrogen.
- The result of the experiment was a molar volume of 24.6 L, and the accepted value is 22.4 L. "1 mole of any gas at STP occupies 22.4 liters of volume" (Science Geek, 2014).
- In the investigation, a logical source of error may have occurred when the gas collecting tube was turned over and placed in the beaker. When this happened, the hole at the top of the stopper was supposed to be fully covered so that no air escaped, and no air entered the gas collecting tube. If the hole was uncovered at all, some air may have entered the gas collecting tube causing there to be an extra volume of gas that wasn't H_2.
- If air entered the gas collecting tube, the measured volume would be higher, and the converted volume of gas at STP would also be greater. Then, the ratio of H_2 gas volume to H_2 gas moles would be increased, causing the molar volume of hydrogen to be incorrect. In the experiment, the calculated molar volume was 24.6 L, and the accepted value is 22.4 L. The calculated molar volume was greater than the accepted value by 9.82%.
- Based on this error percentage, the experiment is valid. If the percent error was over 10%, the experiment would be invalid.
- In order for the investigation to be improved, the hole in the stopper could be covered with tape until it is submerged in the beaker. By adding tape, no air could escape and no air could enter the gas collecting tube. In turn, the calculated molar volume would be closer to the accepted value, and the error percentage would be smaller.
- Another possible investigation to determine molar volume could be .... helium balloon with dry ice?

Name Reganne ________ Editor Malela ________

Score each bullet below using the **0 – 1 – 2** scale. Provide feedback if a score of "1" is given.

CONCLUSION:

2 ❖ Restate <u>purpose</u> (NOT problem statement) of the lab

1 ❖ Identify relationship between variables (length of Mg used and volume of H_2 produced) Include numbers. don't need depend't + independent

2 ❖ State the ***results*** of your experiment. Include numbers. (volume of 1 mole at STP)

2 ❖ Use scientific laws, theories, and/ or principles (such as Avogadro's Law or Combined Gas Law) to explain how the standard molar volume of a gas could be determined from the volume of H_2 produced at room temperature and pressure. Support your explanation by citing a source and include parenthetic reference(s) and APA citation. 2 sources

1 ❖ Compare results with published/ accepted values. Cite source

EVALUATION OF EXPERIMENT

0 ❖ Suggest a ***logical*** source of error.

1 ❖ Explain the effect of the error on the experimental results (standard molar volume). Use words such as higher/lower/greater/less **AND** INCLUDE numbers.

2 ❖ State the validity of the experimental results based on your percent error.

IMPROVING THE EXPERIMENT

1 ❖ Suggest at least 1 improvement based on the identified error.

1 ❖ Suggest a different way to investigate molar volume. change metals or dry ice in balloon

WORKS CITED

0 Cite source(s) in complete APA format

Conclusion - Molar Volume of a Gas
Lab Reganne

The purpose of this investigation is to determine the molar volume of hydrogen gas. The amount of hydrogen gas (H_2) produced is dependent on the amount of magnesium (Mg) that is reacted. In the experiment, 2.35 cm, or 0.0203 g, of Mg reacted and it produced 28.09 mL of hydrogen gas (H_2). If the length of the magnesium increased, the amount of hydrogen gas produced would also increase because the moles of reactants and products must be equal in a chemical reaction. Using the chemical formula, the amount of H_2 can be calculated, based on the mole ratio of 1 mole Mg to 1 mole H_2. In the investigation, the molar volume of hydrogen gas was calculated to be 24.6 L at STP, the standard temperature and pressure of 101.3 kPa and 273 K. In order to calculate the molar volume, the pressure of the H_2 was determined using Dalton's law of partial pressures. The pressure of the water vapor was subtracted from the pressure in the room to find the pressure of H_2, 604.1 mmHg. Then, the volume of the gas produced was converted from the experimental temperature and pressure to STP using the combined gas law. The value at STP is 0.02054 L H_2. Finally, that value and the amount of moles of H_2 produced, 8.35×10^{-4} moles H_2, was used with Avogadro's law to calculate the amount of liters for every mole, or the molar volume. "1 mole of any gas at STP occupies 22.4 liters of volume. Using this information, the volume occupied by any number of moles (or grams) can be determined" (Science Geek, 2014). In the experiment the opposite strategy was used: the volume was entered into the formula to determine the standard molar volume of hydrogen. The result of the experiment was a molar volume of 24.6 L, and the accepted value is 22.4 L. "1 mole of any gas at STP occupies 22.4 liters of volume" (Science Geek, 2014). The experimental value was 9.82% above the accepted value.

A logical source of error may have occurred when the gas collecting tube was turned over and placed in the beaker. When this happened, the hole at the top of the stopper was supposed to be fully covered so that no air escaped, and no air entered the gas collecting tube. If the hole was uncovered at all, some air may have entered the gas collecting tube causing there to be an extra volume of gas that wasn't H_2. If air entered the gas collecting tube, the measured volume would be higher, and the converted volume of gas at STP would also be greater. Then, the ratio of H_2 gas volume to H_2 gas moles would be increased, causing the molar volume of hydrogen to be incorrect. In the experiment, the calculated molar volume was 24.6 L, and the accepted value is 22.4 L. The calculated molar volume was greater than the accepted value by 9.82%, making it logical that some air entered the gas collecting tube during the experiment. Based on this error percentage, the experiment is valid. If the percent error was over 10%, the experiment would be invalid. In order for the investigation to be improved, the hole in the stopper should be covered with tape until it is submerged in the beaker. By adding tape, no air could escape and no air could enter the gas collecting tube. In turn, the calculated molar volume would be closer to the accepted value, and the error percentage would be smaller. Another possible investigation to determine molar volume could be placing dry ice inside a balloon in order to measure the amount of CO_2 produced. The mass and moles of the dry ice could be measured before the phase change as well as the temperature of the room. Then after the investigation, the volume and pressure of the balloon could be measured. Next, the volume could be changed to STP using the combined gas law. Finally, a ratio of moles to volume could be calculated, determining the standard molar volume of the CO_2.

Science Geek. (2014). Science Geek.net. Retrieved on January 16th, 2016, from
http://www.sciencegeek.net/Chemistry/taters/Unit7MolarVolume.htm