

Experiment 20. Determination of the Ideal Gas Constant (R)

INTRODUCTION

In this experiment you will determine experimentally the value of the ideal gas constant (R).

BACKGROUND

For a given gas sample, we can measure the temperature, volume, pressure, and number of moles of gas particles present. A variety of experiments by Boyle, Charles, Gay-Lussac, and Avogadro demonstrated the relationships between these properties of a gas sample. The ideal gas law ($PV=nRT$) combines all of these relationships for ideal gases. According to the Kinetic Molecular Theory, at low pressure and high temperature, most gases should behave as any other gas. Furthermore, these gases behave ideally – they behave as though there are no intermolecular forces acting between particles, and their volumes are insignificant relative to the volume of their container.

In this experiment we will use a sample of hydrogen, assuming ideal conditions. Room temperature and pressures close to one atmosphere allow gases to behave as ideal gases. We will form hydrogen gas by the single replacement reaction of magnesium metal with hydrochloric acid. The hydrogen gas produced in the reaction will be collected over water in a eudiometer tube (see figure 1). The volume of the gas may be measured directly by reading from the graduations on the eudiometer tube. The temperature of the gas will be assumed to be the same as that of the water in the apparatus. The theoretical yield in moles of hydrogen gas produced by the reaction may be calculated by stoichiometry. The most challenging property to determine will be the pressure of the hydrogen gas.

The gas inside the eudiometer tube will be at a lower pressure than atmospheric pressure. A correction factor derived from the height of the column of water in the tube must be applied to the atmospheric pressure in order to determine the pressure of the gas inside.

$$P_{\text{inside}} = P_{\text{atm}} - P_{\text{H}_2\text{O height}}$$

Furthermore, the gas in the tube will be mostly hydrogen with a small, but significant amount of water vapor. Liquids, and some solids, will have a certain number of particles escape into the gas phase. In a closed container, particles will escape into the gas phase until the equilibrium vapor pressure is reached. At that point, the rates of particles entering the gas phase and returning to the liquid phase are equal. Vapor pressures of water are well known at varying temperatures. Dalton's Law of Partial Pressures may be applied to determine the pressure of the hydrogen gas by accounting for the vapor pressure of water:

$$P_{\text{inside}} = P_{\text{H}_2} + P_{\text{H}_2\text{O vapor}}$$

Rearrange these two equations together and you get:

$$P_{\text{H}_2} = P_{\text{atm}} - P_{\text{H}_2\text{O height}} - P_{\text{H}_2\text{O vapor}}$$

$$P_{\text{H}_2\text{O height}} = \text{water height (in mm)} \times \frac{\text{density of } \text{H}_2\text{O}}{\text{density of Hg}}$$

Once the pressure, volume, temperature, and number of moles are determined, the ideal gas law can be used to calculate R, knowing that temperature must be given in Kelvin.

$$PV = nRT \quad \text{or} \quad R = PV/nT$$

PROCEDURE

1. Obtain two pieces of magnesium metal. Polish the ribbon with steel wool to remove the outer coating of magnesium oxide. Your instructor will tell you if you are using a 50-mL or a 100-mL eudiometer tube. If the eudiometer is 50 mL, use ~ 0.042 grams (not to exceed 0.045 g). If the eudiometer is 100 mL, use ~ 0.084 grams (not to exceed 0.090 grams). Mass each piece to the nearest 0.0001 g (Use analytical balance).
2. Obtain a Eudiometer tube and fill it full of tap water. Dump the water out and look to see if water drops form on the inside of the tube. If many water drops cling, wash the tube with soap and water.
3. Obtain approximately 50 mL of 3 M HCl in a beaker.
4. Record the barometric pressure.
5. Fill a large water bath half-full with tap water. Fasten a burette clamp to your ring stand.
6. Loosely roll the magnesium ribbon and tie it with thread.
7. Using a funnel, pour approximately 20 mL of the 3 M HCl into a clean eudiometer tube.
8. Carry out the reaction. The following steps must be performed quickly and SAFELY. Your apparatus should look like **Figure 1** when fully assembled. Read all of the steps carefully:
 - A. Put the coiled Mg ribbon about 5 cm into the tube, thread hanging out.
 - B. Add water carefully to completely fill the eudiometer tube, with little disturbance to the acid.
 - C. Gently push in the one-holed stopper, letting water flow out through the top.
 - D. Place your index finger over the hole and invert the tube into the water bath. Remove your finger from the hole and clamp the eudiometer tube, such that the stopper almost rests on the bottom of the water bath.
 - E. Make certain that the thread will not allow the Mg to rise up the tube.
9. When the reaction has stopped, you may tap the tube gently to cause bubbles to rise. Take the following measurements:
 - A. The volume of the gas in the tube.
 - B. The height of the water column: measure from the water level in the water bath to the bottom of the meniscus in the eudiometer tube (in mm)
 - C. Record the temperature of the water bath. We will assume this is the temperature of the gas in the column as well.
10. Empty the eudiometer tube and water baths carefully and clean them.
11. Repeat the procedure above (steps 4-9) for the second trial.
12. If the two (volumes/Mg mass) of H_2 gas differ by more than 10%, perform a third trial.

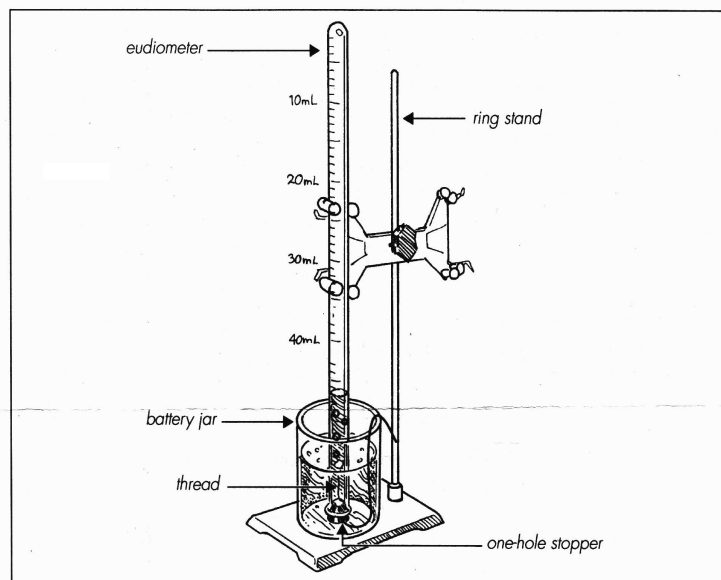


FIGURE 1 Experimental setup for determining the molar volume of a gas

Error Analysis Questions for Determination of the Universal Gas Constant, R

1. Assuming the magnesium ribbon wasn't sufficiently polished to remove a coating of magnesium oxide on the surface. How would this affect the volume of hydrogen gas produced? Would this error cause R to be overestimated, underestimated, or remain unaffected? Explain your reasoning.
2. Assume the water doesn't properly drain from the eudiometer tube thereby leaving droplets on the sides of the glass. Would this error cause R to be overestimated, underestimated, or remain unaffected? Explain your reasoning.
3. Imagine that as the magnesium reacts with the hydrochloric acid, a small portion of the hydrogen gas generated dissolves in the water. How would this affect the volume of H_2 gas measured in the eudiometer tube? Would this cause R to be overestimated, underestimated, or remain unaffected? Explain your reasoning.
4. If the temperature of the hydrogen gas was underestimated, would this error cause R to be overestimated, underestimated, or remain unaffected? Explain your reasoning.

Determination of R Experiment Assignment & Report Guidelines

READING Experiment – Lab Manual Pages

Chemistry, 6th ed. by Silberberg: Sections 5.1 & 5.2, and p. 198 or
General Chemistry 5th ed. by Olmstead and Williams: Chapter 5

PRE-LAB **ALL elements of the pre-lab MUST be completed before an experiment is started.**

Heading

- Title of experiment and number, your name, the dates of the experiment.

Purpose

- Briefly, but specifically explain the purpose of the experiment.

General Strategy

- **Summarize** the procedure of the experiment, and **explain** how you will use the data you measure to determine the quantities you want to find. Showing the important chemical reactions important formulas can be helpful.

Data Table

- On a NEW page, prepare a table for each part of the experiment that includes space for recording each quantity you will measure in the lab. (Do **not** turn in with the prelab.)

Answers to Pre-Lab Questions

- None Assigned.

LAB REPORT **The discussion and conclusion sections should be word-processed.** Other parts of the report - calculations, etc. may be typed or written in the lab notebook.

Heading

- Title of experiment and number, your name, the dates of the experiment.

Data / Observations / Results

- ORIGINAL QUANTITATIVE DATA (signed data pages from your lab notebook).
- Qualitative data (observations) –describe the unknown appearance in your lab notebook. Visually compare to your standard solutions.

Calculations / Results

Show calculations for the following quantities. Use proper format for labeling and showing calculations in a formal report. Include UNITS at all steps.

1. Calculate the pressure of the hydrogen gas in the tube.

- A. Use the density of mercury and the density of water (at the measured temperature for the experiment) to correct the height of the water column in the tube from mmH_2O to mmHg .
Hint: The heights of columns of these liquids are inversely proportional to the densities.
 - B. The total pressure inside the eudiometer tube is the barometric pressure minus the height of the column (adjusted to mmHg).
 - C. Find the vapor pressure of water at the measured temperature.
 - D. Use Dalton's law to calculate the pressure of the hydrogen gas inside the eudiometer tube.
2. Using the mass of the magnesium and the complete, balanced equation for the reaction of magnesium metal with hydrochloric acid, calculate the number of moles of H_2 produced in the reaction.
 3. Calculate the value of the ideal gas constant "R" at your experimental conditions using the ideal gas equation. Your measured and calculated values should have the following units: volume in L, pressure in mmHg , moles of hydrogen, and temperature in Kelvin. *Express R with the appropriate units.*
 4. Obtain the class values for R. For the following calculations, omit any significant outliers in the values of R (you may or may not have any to omit).
 - Find the average value of the class trials.
 - Calculate the class relative range.
 - Calculate the % error based on the literature value of R.

Discussion – Theory / Results / Error Analysis

*In this section, you will explain the experiment, evaluate and discuss your results, and analyze error. This section **REPLACES** the Discussion questions in the lab manual.*

1. Briefly summarize the experiment & your findings.
2. Discuss the accuracy and precision of the class data.
3. Assuming that you took proper measurements, discuss at least two errors that could have lead to the observed percent error (take into consideration whether the class value of R is too large or too small).

Conclusions

- Make appropriate conclusions.

Answers to Post-Lab Questions

- Answer the questions from the Lab Manual.

POSTLAB QUESTIONS

Name: _____

1. You calculated the gas constant, ***R***, using hydrogen as a sample gas. Will other gases result in the same value of *R*? Explain your answer.
2. What will be the pressure (in mmHg) inside of a 50.0 L container that holds 7.00 moles of hydrogen gas at 0.0°C?
3. Oxygen gas is produced for use in a small-scale experiment by the catalytic decomposition of hydrogen peroxide:
$$2 \text{H}_2\text{O}_{2(\text{aq})} \rightarrow 2 \text{H}_2\text{O}_{(\text{l})} + \text{O}_{2(\text{g})}$$

If 50.0 mL of a 1.00 *M* solution of H₂O₂ completely decomposes and what volume of dry oxygen gas can be collected at 21.5°C and 742.2 mmHg?