Lab: Determination of the Ideal Gas Law Constant (R)

FOR THE TEACHER

Summary
In this lab, students will collect a gas sample over water and use multiple scientific principles including stoichiometry and gas laws to experimentally determine the Ideal Gas Law Constant (R).

Grade Level
High School

NGSS Alignment
This lab will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-2**: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- **Scientific and Engineering Practices**:
  - Using Mathematics and Computational Thinking
  - Analyzing and Interpreting Data

Objectives
By the end of this lab, students should be able to

- Perform a reaction where a gas is generated and collected over water.
- Use a single replacement reaction to identify a product.
- Use stoichiometric concepts to determine that amount of gas in moles should be generated.
- Apply appropriate gas laws to a situation to determine the Ideal Gas Law Constant.

Chemistry Topics
This lab supports students’ understanding of

- Chemical Reactions
- Stoichiometry
- Gas Laws
- Dalton’s Law of Partial Pressure
- Ideal Gas Law
- Vapor Pressure

Time
**Teacher Preparation**: 20 minutes
**Lesson**: 45 minutes

Materials (per lab group)

- 2.0 -3.0 cm piece of magnesium ribbon (depending on the thickness of the Mg, it could be longer. Note: The amount of hydrogen generated must stay on the scale of the eudiometer.)
- 20 mL of 3.0 M HCl
- 50 mL Eudiometer
- Rubber stopper with at least 1 hope that fits the eudiometer
- String
- Ring stand
- Single Buret Clamp
- 600 mL beaker

Submitted by
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Thanks to:
Dow Chemistry Teacher Summit
- Deionized water/distilled water
- 1000 mL graduated cylinder (this can be shared by multiple groups. It is needed to equalize the pressure in the eudiometer to measure the volume, so it does not need graduations)
- Analytical balance (if a balance with at least 3 places after the decimal place is unavailable, measure the mass of 1.00 m of Mg ribbon and have students use the length measurement to convert to grams of Mg)

**Safety**
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- When working with acids, if any solution gets on students’ skin, they should immediately alert you and thoroughly flush their skin with water.
- Neutralize any acid spills with baking soda.
- Wear protective gloves when working with strong acids.
- Review the SDS for 3M Hydrochloric Acid.

**Teacher Notes**
- Room pressure can be measured with a barometer in the classroom, but if your room does not have one, students can find the local pressure at the time of the lab on a website, such as weather.com by entering the zip code of the school. This value is recorded in inches of mercury, which is why the data table has (in Hg) as the units.
- The experimental set-up is shown below, on the left.
- The string, magnesium ribbon and stopper are shown tied together as described in student procedure steps 2 & 3.
FOR THE STUDENT

Lesson

Determination of the Ideal Gas Law Constant (R)

Background
The Kinetic molecular theory of gases assumes that gas particles are in constant motion, have elastic collisions and no forces of attraction between particles. This theory allows us to treat gases under normal laboratory conditions as ideal gases. The Ideal gas law constant, R, relates the four variables that describe gases under normal laboratory conditions. The variables that describe gases include the pressure, volume, amount, and absolute temperature. These variables are related in the ideal gas law:

\[ PV = nRT \]

where 
\( P \) is pressure in atmospheres (atm)
\( V \) is volume in Liters (L)
\( n \) is moles of gas (mol)
\( T \) is Temperature in Kelvin (K)
\( R \) is the ideal gas law constant \( \left( 0.08206 \frac{L \cdot atm}{mol \cdot K} \right) \)

When insoluble gases are collected over water in a contained system, the total pressure of the gas collected is a sum of the partial pressure of the gas collected, and the vapor pressure of the water at that temperature. The pressure of the individual gas can be determined using Dalton’s Law of Partial Pressure:

\[ P_{total} = P_{gas} + P_{water} \]

Pressure must be measured in the same units

Using both of these concepts along with reaction stoichiometry, the value of the ideal gas law constant can be determined experimentally.

Prelab Questions
1. Convert the following measurements:
   a. 735 mm Hg to atmospheres
   b. 23.5 mL to Liters
   c. 30.0°C to Kelvin
2. What is the total pressure of a mixture of helium and hydrogen gas if the \( P_{Helium} \) is 225 mm Hg and the \( P_{Hydrogen} \) is 513 mmHg?
3. Write balanced single replacement reaction between aqueous hydrochloric acid and magnesium metal.
4. Determine the moles of hydrogen produced when 13.5g of magnesium reacts with excess hydrochloric acid.

Objective
• To learn how to collect a gas over water.
• To understand the meaning of a dry gas.
• To experimentally determine the value for the ideal gas law constant (R).
Materials
- 1 Piece of magnesium metal (2.0 – 3.0 cm)
- 20 mL of 3.0 M HCl
- 50 mL eudiometer
- Ring Stand with single buret clamp
- 1000 mL Graduated Cylinder
- Rubber stopper with hole(s)
- 10 cm String
- 600 mL Beaker
- Analytical balance
- Deionized water/distilled water

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow the teacher’s instructions for cleanup of materials and disposal of chemicals.
- When working with acids and bases, if any solution gets on your skin immediately rinse the area with water.
- Neutralize any acid spills with baking soda.
- Wear protective gloves when working with strong acids.

Procedure
1. Obtain a piece of magnesium ribbon between 2.0 and 3.0 cm long. Measure the mass of the magnesium using an analytical balance. Record in the data table.
2. Fold the piece of magnesium ribbon in half and tie one end of the string around it.
3. Tie the other end of the string through the hole in the rubber stopper.
4. Set up a ring stand and a utility clamp in position to hold a 50mL eudiometer. Place a 600 mL beaker 2/3 filled with tap water near the ring stand.
5. Tilt the eudiometer slightly and pour approximately 15-20 mL of 3.0 M HCl into it.
6. With the eudiometer still tilted, completely fill the eudiometer with deionized water. There should be no space left in the tube.
7. Place the magnesium ribbon into the eudiometer, add more deionized water if necessary and place seal the tube with the rubber stopper.
8. While wearing gloves, cover the hole(s) of the rubber stopper with your finger and invert the eudiometer into the 600mL beaker of water. Remove your finger after the stopper is below the surface of the water. Clamp the eudiometer in place so that it is not touching the bottom of the beaker. The denser acid will flow down the eudiometer and react with the magnesium.
9. Once the reaction stops (all of the magnesium should react), allow the eudiometer to sit 5 to 10 minutes so that it will return to room temperature.
10. Measure and record the temperature and pressure of the room in the data table.
11. Fill the large graduated cylinder with tap water.
12. While wearing gloves, transfer the eudiometer to the large graduated cylinder. Be sure to cover the hole(s) in the rubber stopper when transferring. Raise or lower the eudiometer until the level of water inside the eudiometer is even with the surface of water in the graduated cylinder. Record the volume of gas in the eudiometer. (This process ensures the pressure of the contained gas is equal to the pressure of the atmosphere).
13. Remove the eudiometer from the graduated cylinder and clean up.
### Data

<table>
<thead>
<tr>
<th>Mass of magnesium (g)</th>
<th>Room Temperature (°C)</th>
<th>Pressure of the room (inches Hg)</th>
<th>Volume of Gas Produced (mL)</th>
<th>Vapor Pressure of Water at Room T (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

### Reference Table: Vapor Pressure of Water at Various Temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Pressure (mm Hg)</th>
<th>Temperature (°C)</th>
<th>Pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
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<td>23</td>
<td>21.0</td>
</tr>
<tr>
<td>16</td>
<td>13.6</td>
<td>24</td>
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<td>25</td>
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<tr>
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<tr>
<td>22</td>
<td>19.8</td>
<td>30</td>
<td>31.8</td>
</tr>
</tbody>
</table>

### Calculations

1. Using the mass of magnesium measured, determine the number of moles of magnesium.
2. Convert the volume of gas collected from milliliters to liters.
3. Convert the atmospheric pressure of the room from inches Hg to mm Hg. Remember there are 2.54 cm in 1.00 inch.
5. Convert the pressure of dry hydrogen gas from mm Hg to atmospheres.
6. Using the stoichiometry and the balanced chemical equation for the reaction, determine the moles of hydrogen gas produced in the reaction.
7. Using the Ideal gas law, calculate the value of ideal gas law constant, R.
8. Calculate the % error of the experimental value of the ideal gas law constant.

### Analysis

1. Why should students wait 5 -10 minutes after the reaction is completed before measuring the volume of the gas?
2. What is the effect on the volume of gas measurement if bubbles were still in the eudiometer?
3. What effect on the ideal gas law constant would those bubbles have caused?
4. List two additional sources of error besides bubbles in the eudiometer.
Extension

1. The ideal gas law constant was calculated in this experiment, but real gases do not always behave ideally. What conditions cause the greatest deviations from the ideal gas law?

2. The Earth’s atmosphere is made up of many gases. What are the 4 most common gases of the atmosphere that a student breathes in with every breath?

3. Marcellus shale in Pennsylvania and West Virginia is a top source of what commercial gas mined in the United States? What is the name of the process used to mine the gas?