**AP Chemistry Lab #15: Experimental Determination of the Gas Constant**

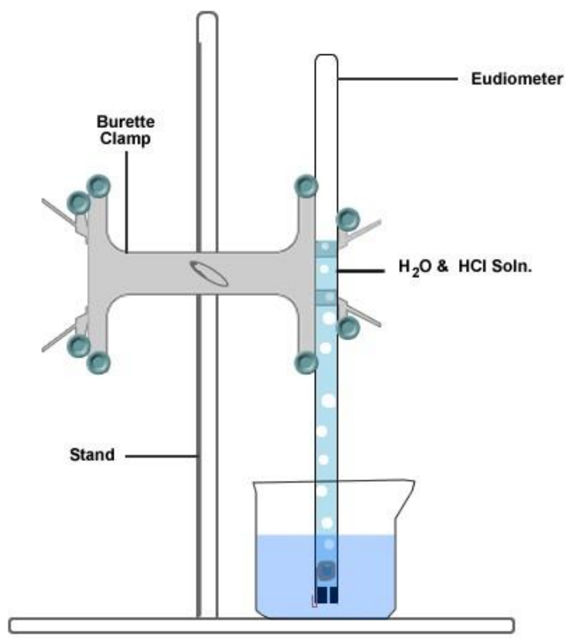
**Purpose:** The objectives of this lab are to experimentally determine the value of the Gas Constant, *R*, and to practice using the Gas Laws to solve a variety of problems.

**2.A.2:** The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.

**1.A.3:** The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.

**Background** : A gas is the state of matter that is characterized by having neither a fixed shape nor a fixed volume. Gases exert pressure, are compressible, have low densities and diffuse rapidly when mixed with other gases. On a microscopic level, the molecules (or atoms) in a gas are separated by large distances and are in constant, random motion. Please view the instructional video prior to conducting the investigation (CLICK HERE). Four measurable properties can be used to describe a gas quantitatively: pressure (*P*), volume (*V*), temperature (*T*) and mole quantity (*n*).

A closer look at the Combined Law reveals that the volume of a gas depends on both the pressure and temperature. Thus, if the volumes of two gases are to be compared, they must be under the same *P* and *T*. A commonly used set of *P* and *T* reference conditions is known as Standard Temperature and Pressure, or STP. Standard temperature is defined as exactly 0 °C (273 K) and standard pressure is defined as exactly1 atm (760 mm Hg). The Ideal Gas Law is obtained by combining Boyle's Law, Charles's Law and Avogadro's Law together: $PV = nRT$. Here, *P* represents as the gas pressure (in atmospheres); *V* is the gas volume (in Liters); *n* is the number of moles of gas in the sample; *T* is the gas temperature (in Kelvins). *R* is a proportionality constant called the Gas Constant, and has a theoretical value of 0.08206 L.atm/K.mol. Note that the units of *R* will allow the units of *P*, *V*, *n* and *T* in the Ideal Gas Law to cancel correctly.




In this lab, students will measure various properties of a sample of hydrogen gas in order to experimentally determine the value of the Gas Constant, *R*. The single replacement reaction between magnesium metal and hydrochloric acid will be used to generate the hydrogen gas:

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

The hydrogen gas will be collected in a eudiometer, a tube closed at one end and marked in milliliter volume units. The gas will be collected in the closed end of the tube over a water bath via the technique of water displacement as shown in the diagram to the right. Students will then obtain the following values for the collected sample of hydrogen gas: (1) Volume, (2) Temperature, (3) Moles, and (4) Pressure. The hydrogen volume will be directly measured from the eudiometer scale. The hydrogen temperature will also be directly measured using a thermometer. However, the mole quantity and pressure of the hydrogen gas must be determined indirectly. The mole quantity of the collected hydrogen can be easily calculated from the measured mass of the magnesium reactant using stoichiometry. But the hydrogen pressure is a little more difficult to obtain. Since hydrogen is collected over a water bath, a small amount of water vapor is mixed with the hydrogen in the eudiometer. The combined pressure of the $H_2$ and $H_2O$ gases will be equal (after adjustments) to the external atmospheric pressure: *Patm = Phydrogen + Pwater vapor*

$P_{atm}$ (atmospheric pressure) will be measured using a barometer. $P_{water\ vapor}$ (the partial pressure of water vapor) depends on the temperature of the water bath, and can be obtained from the table on the next page. By substituting these values in the above equation, the pressure of hydrogen ($P_{hydrogen}$) will be determined.

Finally, to determine the value of the Gas Constant (*R*), the quantities *V*, *T*, *n* and *P* obtained for the hydrogen gas must simply be substituted into the Ideal Gas Equation. Students can then evaluate their accuracy in this experiment by comparing their experimental result to the true theoretical value of *R*, and by calculating their percent error.

| Temperature (°C) | $P_{water\ vapor}$ (mm Hg) |
|---|---|
| 16 | 13.5 |
| 17 | 14.5 |
| 18 | 15.5 |
| 19 | 16.5 |
| 20 | 17.5 |
| 21 | 18.7 |
| 22 | 19.3 |
| 23 | 21.1 |
| 24 | 22.4 |
| 25 | 23.8 |
| 26 | 25.2 |
| 27 | 26.7 |
| 28 | 28.3 |
| 29 | 30.0 |

**P1**. Explain what makes a gas "ideal". Using the ideal gas law equation and mathematical reasoning, explain what factors could result in a very large volume, which is a condition that is favorable for an ideal gas.

**P2**. If 60.0 L of nitrogen is collected over water at 29.0 °C when the atmospheric pressure is 760.0 mm Hg, what is the partial pressure of the nitrogen?

**P3**. A container holds three gases: oxygen, carbon dioxide, and helium. The partial pressures of the three gases are 2.00 atm, 3.00 atm, and 4.00 atm, respectively. What is the total pressure inside the container?

**P4**. A 256 mL sample of an unknown gas was collected over water at 23˚C and 750 mmHg. The gas has a mass of 0.80 grams. What is the molar mass of the gas?

**Safety**: Concentrated HCl is dangerous. Handle it with extreme care as demonstrated by your instructor. If any spills occur, inform your instructor immediately. Wash under running water (sink or shower) and use the neutralizing sodium bicarbonate solution supplied at the sinks if necessary. Also note that hydrogen gas is flammable, so be sure to have no open flames nearby when you perform this experiment.

**Materials and Equipment**: 4.0-cm ribbon of magnesium, length of copper wire (reusable), 6M HCl (*aq*), 50-mL eudiometer, eudiometer stopper (size 00) with hole, burette stand, large beaker, thermometer, small funnel, small graduated cylinder, barometer, large tub of water, electronic balance, and sandpaper.

**Procedures:**

1. Obtain a 4.0-cm ribbon of magnesium (Mg), a piece of sandpaper, and a length of copper wire.

2. Carefully sand the outside of the Mg ribbon to remove any oxide coating. Place the Mg ribbon on a paper towel while sanding. Weigh the cleaned Mg ribbon and record this mass on your report form. Note that this mass should be less than 0.040 grams. If it is heavier, your Mg ribbon will have to be "trimmed" or you will displace all of the solution in the eudiometer and have to start over.

3. Wrap the Mg around the end of the copper wire. Do this in a tight ball with only a small gap between layers. Then wrap the copper wire to form a cage around the Mg ball. The cage must be tight enough to keep the Mg inside, but loose enough to allow water to easily flow around the wire. Roughly 3-cm of copper wire should be left over as a "handle" (see Figure).

4. Obtain a eudiometer tube and stopper size 00 (with holes). Use the burette clamp to hold it in place, open end up.

5. Add ~10-mL of 6M HCl (*aq*) to the eudiometer tube using a small funnel. Then add blue tap water to the eudiometer carefully and slowly until it is filled to the brim (see Figure on the last page).

6. Hang the Mg ball inside the open end of the eudiometer, ~2-cm down from the top. Then insert the stopper into this end, and, while holding it in place, quickly invert the entire tube into your largest beaker ¾ filled with water. Clamp the tube in the water in the upside down position or simply hold the tube.

7. The reaction will occur as soon as the acid diffuses down the tube and reaches the Mg ribbon. As hydrogen gas is generated it will fill the eudiometer by forcing the water out of the tube and into the beaker via water displacement. Allow the reaction to proceed until no Mg is left and no further gas is formed. This should take 3-5 minutes.

8. To ensure that the pressure of hydrogen (and water vapor) in the eudiometer is equal to atmospheric pressure, the level of the water inside the tube must be the same as the level of water outside the tube. To achieve this, transfer both the tube and the beaker of water into the large bucket of water in the sink. Then raise or lower the tube until the internal and external water levels are equal. This step may not always be necessary, depending on the volume of gas collected.

**Q1**. After equalizing the water levels (if necessary), record the following measurements in a data table. You will need to conduct a second trial, so plan accordingly on your data table.

The volume of hydrogen gas collected (read directly from the eudiometer scale), in mL

The temperature of the hydrogen gas collected, in °C. This can be measured by first removing the stopper then placing the thermometer directly in the eudiometer (keep the tube inverted so the gas does not readily escape). It is also acceptable to assume that the temperature of the hydrogen gas is the same as the temperature of the water bath, especially if you wait a while before making your measurements.

The atmospheric pressure (use the lab barometer), in mm Hg

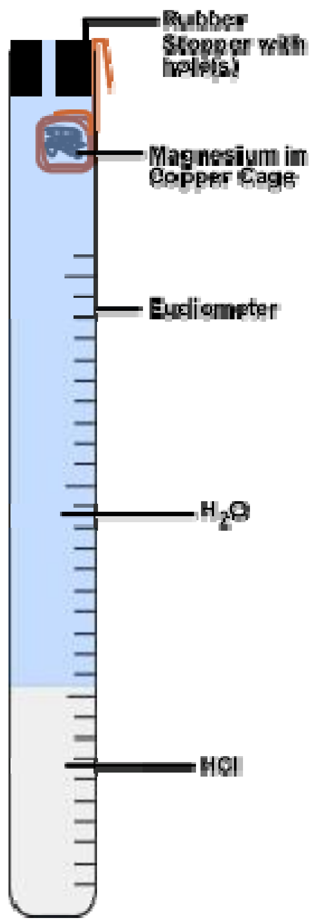
The temperature of the water in the plastic tub (use the thermometer), in °C

The vapor pressure of water at the above temperature (obtain from Table on page 2), in mm Hg

**Q2**. Calculate the experimental value for the ideal gas law constant. Show your work.

**Q3**. Calculate the percentage error for the ideal gas law constant.

**Q4**. List at least four factors that could have led to any systematic or random errors.

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**Self-assess your lab report using the checklist/rubric**