Lab 15. The Ideal Gas Law: How Can a Value of R for the Ideal Gas Law Be Accurately Determined Inside the Laboratory?

Introduction

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 submicroscopic level, the molecules in a gas are separated by large distances and are in constant, random motion. A gas can be described using four measurable properties: pressure (*P*), defined as the force exerted by a gas per unit area; volume (*V*), defined as the quantity of space a gas occupies; temperature (*T*), defined as the average kinetic energy of the molecules that make up a gas; and the number of moles of gas (*n*). The relationships among these properties are summarized by the gas laws, as shown in Table L15.1.

TABLE L15.1

The gas laws

Gas law	Relationship	Equation
Boyle's law	$V \alpha 1/P$ (*T* and *n* are held constant). As gas pressure increases, gas volume decreases.	$P_1V_1 = P_2V_2$
Charles' law	$V \alpha T$ (*P* and *n* are held constant). As gas temperature increases, gas volume increases.	$V_1/T_1 = V_2/T_2$
Gay-Lussac's law	$P \alpha T$ (*V* and *n* are held constant). As gas pressure increases, gas temperature increases.	$P_1/T_1 = P_2/T_2$
Avogadro's law	$V \alpha n$ (*P* and *T* are held constant). As the number of moles of gas increase, gas volume increases.	$V_1/n_1 = V_2/n_2$
Combined law	$V \alpha T/P$ (*n* is held constant); obtained by combining Boyle's law, Charles' law, and Gay-Lussac's law.	$(P_1V_1)/T_1 = (P_2V_2)/T_2$

The ideal gas law combines Boyle's law, Charles' law, Gay-Lussac's law, and Avogadro's law to describe the relationship among the pressure, volume, temperature, and number of moles of gas. Émile Clapeyron is often given the credit for developing this law. The ideal gas law provides chemists with a powerful predictive tool that helps them understand how gases will react in different systems. The ideal gas law is expressed mathematically as $PV = nRT$. *P* is pressure in atmospheres (atm); *V* is volume in liters (L); n is the number of moles of gas (mol); and *T* is absolute temperature in Kelvin (K). The remaining component of the ideal gas law is *R*, which is called the ideal gas constant. The theoretical value of *R* that is often reported in textbooks and handbooks is 0.0821 L•atm/mol•K or 8.314 L•kPa/mol•K.

As chemists worked to determine an exact value for *R* in the mid-1800s, they were faced with numerous challenges. First, they had to develop a method that they could use to generate the experimental data they needed to calculate a value for *R* from the ideal gas law. Second, they needed to improve the precision of their measurements. The French chemist Henri Victor Regnault was able to overcome many of these challenges and generate some of the most precise experimental data about the properties of gases at that time. Rudolf Clausius, a German physicist, then used Regnault's data to calculate the earliest published value for *R*. This value for *R*, however, was not very precise by current standards. Fortunately, there have been numerous advancements in the methods and tools that chemists use to measure the properties of gases, and the value of *R* has become increasingly precise over time. There is, however, always room for improvement. In this investigation, you will have an opportunity to follow in the footsteps of Clapeyron, Regnault, and Clausius by designing, conducting trials of, refining, and then evaluating a method that can be used to calculate a precise value for the ideal gas constant.

Your Task

Design a method that can be used to calculate an accurate value of *R* inside the lab by generating a specific number of moles of gas at room temperature and then measuring the pressure or volume of the gas. As part of this process you will need to test, evaluate, and then refine your method. Your method should allow you to produce a consistent and accurate value for *R*.

The guiding question of this investigation is, **How can a value of *R* for the ideal gas law be accurately determined inside the laboratory?**

Materials

You may use any of the following materials during your investigation:

Consumables	Equipment
• 6 M hydrochloric acid (HCl) solution • Magnesium (Mg) ribbon	• Side-arm Erlenmeyer flask with stopper (50 ml) • Pneumatic trough • Plastic or rubber tubing (50 cm long) • Electronic or triple beam balance • Graduated cylinders (one each 50 ml, 100 ml, 250 ml, and 500 ml) • Glass test tube • Utility clamp • Ring stand • Gas pressure sensor • Temperature probe • Sensor interface

Safety Precautions

Follow all normal lab safety rules. Hydrochloric acid is corrosive to eyes, skin, and other body tissues. Your teacher will explain relevant and important information about working with the chemicals associated with this investigation. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Handle all glassware with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

In this lab, you will react magnesium metal with hydrochloric acid to produce a sample of hydrogen gas. The hydrogen gas produced by this reaction behaves mostly like an ideal gas. The equation for this chemical reaction is

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

The first step in your investigation is to design a method that will allow you to obtain the pressure, volume, temperature, and number of moles of a sample of hydrogen so you can use these data to calculate the gas constant (*R*). There are several approaches that you can use. One approach is to produce a specific amount of gas (in moles) and then measure the pressure of that gas while holding the volume and temperature constant. A second approach is to produce a specific amount of gas (in moles) and then measure its volume while holding pressure and temperature constant. It is important for you to consider how you might be able to measure the various properties of a sample of hydrogen gas using the equipment available. As you design your method, you should also think about the following questions:

- What type of measurements or observations will you need to record during your investigation?
- How often will you collect data and when will you do it?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of the data you collect and how will you organize it?
- How will you determine if there is a difference between the two methods?

- What type of calculations will you need to make?

The second step in your investigation is to test and refine your method. To do this, use your method to obtain information about a sample of hydrogen gas and then use this information to calculate a value for *R*. The value that you calculate will likely be rather imprecise due to flaws in your method or poor measurements. Use what you have learned from your initial test to refine your method. Once you have refined your method, you will need to test it again. You should continue this process of testing and refining until it functions as intended. Your method will therefore go through numerous iterations.

The last step in this investigation will be to conduct a formal evaluation of your method. As part of the evaluation of your method, you will need to determine if you can use it to produce a consistent and accurate value for *R*. You will therefore need to determine what data you need to collect and how you will analyze it as part of the evaluation to show that your method works.

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

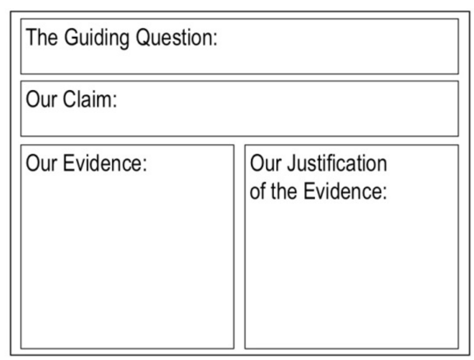
- the importance of identifying causal relationships in science,
- how scientists develop and use system models to understand complex phenomena,
- the difference between laws and theories, and
- the nature and role of experiments in science.

Initial Argument

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L15.1.

FIGURE L15.1

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might therefore need to ask the presenter one or more follow-up questions, such as:

- How did your group collect the data? Why did you use that method?
- What did your group do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- What did your group do to analyze the data, and why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?

- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer for the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. The report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!