Gas Laws: Determination of Gas Constant *R*

Learning Goals:

1. Use a chemical reaction to generate and collect oxygen, $\mathbf{O_2}$, gas over water.
2. Use Dalton's Law of Partial Pressures to determine the pressure of oxygen gas collected.
3. Use the ideal gas law, **PV = n*R*T**, to calculate the Gas Constant ***R*.** (Assuming O_2 is an Ideal Gas)

Abstract:

A gas is a form of matter that consists of a collection of molecules in chaotic, random motion. Unlike a solid or liquid, the molecules of a gas are widely separated, and a gas will expand or contract to fit the container in which it is held. Since a gas is free to expand or contract (it is compressible), the behavior of a gas is susceptible to several factors. These factors are volume, quantity in moles, temperature, and pressure. Each of these variables affects the other; for example, a change in pressure will bring about a change in volume. The relationship between the volume (V), moles (n), temperature (T), and pressure (P) can be summarized as follows:

$$PV \propto nT$$

In this lab, you will experimentally determine a numerical value for the gas constant *R*, and compare your value with the accepted value. To do this you will measure an enclosed volume of oxygen gas that forms when potassium chlorate ($\mathbf{KClO_3}$) is heated in the presence of a catalyst called manganese dioxide ($\mathbf{MnO_2}$).

$$2\ KClO_3(s) \xrightarrow{MnO_2} 2\ KCl(s) + 3\ O_2(g)$$

You will also determine the **pressure** of the oxygen gas, by using **Dalton's law of partial pressures**. The total pressure is the atmospheric pressure, which is equal in this case to the pressure of the gas and the vapor pressure of water. The atmosphere pressure can easily be obtained by using a barometer and the vapor pressure of water, which is temperature dependent, is obtained by using Table 1. in the procedure.

$$P_{atm} = P_{O_2} + P_{H_2O}$$

By measuring the pressure of O_2 generated (**P**), the room temperature (**T**), the weight of O_2 generated (*mass*), the atomic weight of O_2, and the volume of O_2 generated (**V**), ***R*** can be experimentally determined.

$$R = \frac{PV}{\langle \frac{mass}{mol.wt.} \rangle T}$$

Prelab Assignment

In your lab notebook, prepare the following information.

1. A brief (2-3 sentence) introduction to the lab.

2. A table of safety information including the chemicals used in the lab and their safety handling precautions. This information can be obtained from the MSDS safety sheets.

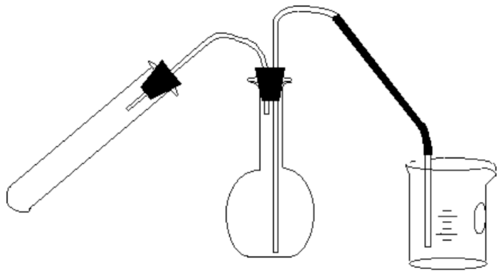
3. Given that one mole of an Ideal Gas at standard temperature and pressure (0^{o}C, 1atm) has a volume of 22.4L, calculate the value of *R* to three significant figures.

Give the information to your TA at the beginning of the lab. You will not be allowed to work in the lab without this information.

Chemicals, Equipment, and Instruments

Chemicals	Equipment	Instruments
Distilled water (H_2O)	500mL Florence Flask	Balance
Potassium chlorate ($KClO_3$)	1 100mm test tube	
Manganese dioxide (MnO_2)	1 150mm Pyrex® test tube rubber tubing	
	400mL beaker gas collecting apparatus	
	Bunsen Burner	

Lab Experiment Guidance

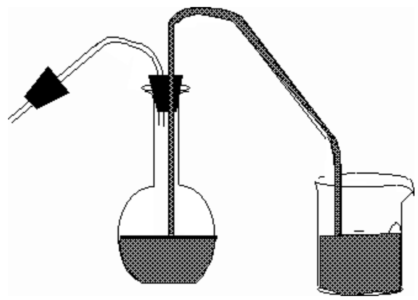


1. Obtain a gas collecting apparatus. You will need to fill the 500mL Florence flask with distilled water and allow it to come to room temperature.
2. While you are waiting for your apparatus to come to room temperature, prepare a test tube with the potassium chlorate sample. Obtain two clean, dry test tubes, one small (100 mm) and one large Pryex® or Kimex ® (150 mm). **The larger test tube must be free of cracks or chips and labeled either Pyrex®or Kimex® glass**. With a scoopula (spatula-like scoop utensil) place a 2.5 cm layer of dry potassium chlorate, $\mathbf{KClO_3}$, into the 100 mm (small) test tube. Then add a 0.5 cm layer of dry manganese dioxide, $\mathbf{MnO_2}$. Mix thoroughly and transfer to the clean, dry Pryex® or Kimex ®150 mm (larger) test tube. **Make sure that none of the mixture remains close to the mouth of the tube**.

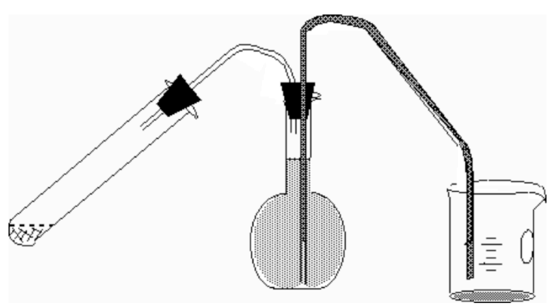
Be **very careful** when handling this mixture, because an explosion may occur if it comes in contact with rubber (a stopper, for example).

3. **Place the sample test tube into an Erlenmeyer flask and obtain the weight to the nearest 0.001 g**. Be sure to save the Erlenmeyer flask for each subsequent weighing because you will be weighing the tube and Erlenmeyer flask after each run. The Erlenmeyer flask needs to be the same one so it can be subtracted out correctly. The quantity of sample is large enough for two runs of the experiment.
4. Insert the stopper with the glass and rubber tubing attached into the Florence flask. Place the end of the rubber tubing into a clean 400-mL beaker. Now you need to remove any air from the rubber and glass tubing connecting the Florence flask and the beaker. Use a rubber bulb to push air into the flask, which will in turn force water through the rubber tubing into the beaker. Now there should be water in both the beaker and the flask and the tube connecting them should be filled with water (no air bubbles).

5. Before you attach the test tube containing the sample, the Florence flask must be at atmospheric pressure. Carefully raise the level of the water in the beaker above the level of water in the flask, until almost all of the water flows back into the flask. Then lower the beaker until the levels of water in the beaker and flask are identical (see Figure below).



6. While holding the water levels equal, attach the test tube containing the **$KClO_3/MnO_2$** mixture to the other end of the apparatus. Make sure that the test tube is placed onto the stopper tightly and that the solid mixture is at the bottom third of the test tube. Now the apparatus should be a closed system and the pressure in the flask is the same as the pressure on the water in the beaker (atmospheric pressure).
7. Now, while positioning the water in the two containers level, pinch the rubber tube closed with your fingers. Empty the excess water from the beaker and reposition the beaker under the end of the rubber tube. A small amount of water will flow out of the tube into the beaker since the water levels are not equal anymore. This is okay because the same amount of water will flow back when the levels are again equalized at the completion of the gas collection. Your set-up should look like the figure below.



8. Final checks:
   a. Make sure that the sample is spread out over the bottom third of the test tube. You can gently tap the test tube if necessary. Also make sure that the tube has a slight downward angle so that the sample does not flow toward the mouth of the test tube.
   b. Check each aspect of your setup below before you begin heating, then ask you TA to inspect your set-up: **Your instructor must inspect the apparatus before you begin heating the sample.**

☐ A Pyrex or Kimax test tube that has no cracks or chips is attached to the apparatus at an angle slightly below horizontal.

☐ The sample mixture is spread evenly over the lower half of the tube.

☐ All connections are tight.

☐ The water level in the Florence flask is within a few centimeters of the base of the stopper.

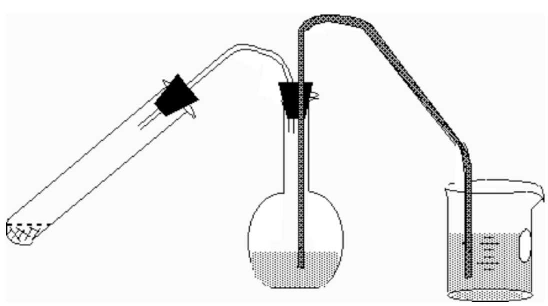
☐ Water is not flowing into the beaker.

☐ Your Bunsen burner is adjusted to a small, hot (no yellow) flame.

9. After your instructor has checked your apparatus you can begin heating the sample to liberate the oxygen. Start at the bottom of the test tube (sample) and heat only a small portion at a time. **Be sure your hands are not under the test tube.** When the tube is first heated the air will expand and force water through the tube even before any oxygen is produced. **This means you will need to allow the tube to come back to room temperature after the generation of oxygen and before any measurements are taken.** As the sample heats up and melts, oxygen gas forms and escapes into the Florence flask forcing water from the flask to flow into the beaker. Watch both the beaker and the tube to control the experiment. Stop heating after 150 to 200 mLs of water have flowed into the beaker but be sure to stop before the beaker completely becomes filled!

Do not let molten $KClO_3$ or the burner flame come into contact with the rubber stopper!

10. After a run, allow the apparatus to cool to room temperature. When the test tube is cool, equalize the pressure in the Florence flask with the outside (atmospheric) pressure by raising or lowering the beaker or flask until the two levels of water are equal. When the two water levels are equal, pinch the rubber tubing and remove it from the beaker. The volume of water in the beaker is equal to the total volume of gases (oxygen plus water vapor) produced in the test tube and Florence flask.



11. Measurements:
    a. **Measure the temperature of the water in the beaker.** This will be the temperature of the gas collected in the flask. Use Table 1 to determine the

vapor pressure of water at this temperature.

b. **Use a graduated cylinder to measure the volume of water in the beaker.** This will be equal to the volume of O_2 produced in the experiment. Be sure to return the water to the Florence flask for the second run of the experiment.

c. **Remove the test tube containing the sample and weigh it in the same Erlenmeyer flask used before**. The mass change will be equal to the material in your test tube that reacted (and equal to the mass of O_2 liberated in the reaction).

d. **Record the atmospheric pressure from a barometer.**

12. Reassemble the apparatus for a second run and have the instructor check it again before heating. Make the same measurements as before.

13. Disassemble and clean the apparatus. Dispose of all chemicals in the properly labeled containers.

Table 1. Vapor Pressure of Water 10-39 °C. Origin of data: Keyes International Critical Tables, accesses at http://www.ge-mcs.com/download/moisture-humidity/913-324A.pdf, January 4, 2015.

T (°C)	*P* (mm Hg)	*T* (°C)	*P* (mm Hg)	*T* (°C)	*P* (mm Hg)
10°	9.209	20°	17.535	30°	31.824
11°	9.844	21°	18.650	31°	33.695
12°	10.518	22°	19.827	32°	35.663
13°	11.231	23°	21.068	33°	37.729
14°	11.987	24°	22.377	34°	39.898
15°	12.788	25°	23.756	35°	42.175
16°	13.634	26°	25.209	36°	44.563
17°	14.530	27°	26.739	37°	47.067
18°	15.477	28°	28.349	38°	49.692
19°	16.477	29°	30.043	39°	52.442

Post-Experiment Analysis:

General Guidelines for Your Lab Reports

Lab reports are your own original works. **Copying another student can result in failure.** When working with a partner or group, identify your collaborators and you may share data but not written analysis or claims, which should describe your own thinking.

The purpose of lab reports is to communicate your lab findings, analysis, and claims clearly. There are no required lengths or formatting. However, we provide the following outline to suggest an organization to increase the chances that your report will be easy to construct and follow.

Summary: The purpose of the summary is to present the title of your report, the date that the lab work was done, your partners, if any, and a couple overview sentences about what the lab experiment was about. You can write this section first.

Data, Results, Evidence. Title this section with one of these words. The purpose of this section is to present information that is easy to follow concerning what was measured and observed during the experiment. Remember that observations can be important data to use in your analysis. Since patterns are often critical to understanding data, this often means presenting data in a Table as well as a Figure. An annotated lab report is provided, which includes a poor example to illustrate the difficulty of understanding data when it is not tabulated and graphed. This is followed by an excellent example that includes Tables, Figures, and additional information necessary for understanding and interpreting the data.

Reasoning: Analysis of Evidence. Title this section with these words. The purpose of this section is to provide the logic to understand your data, results, or evidence section. This is the section where you can add outside references. Data from outside sources goes here rather than in the Data section because you were not involved in obtaining the data. You can use outside data to support your analysis. The "thinking" work involved in analyzing what you did in lab belongs here and it often is the most difficult and challenging part of writing a lab report. You greatly aid your analysis by starting your thinking about your results while you are doing your experiments! This is a skill that benefits all scientists. A best practice in lab is to make notes you think are important right in your lab notebook! Examples of poor and good analysis are shown in the annotated report.

Claims, Conclusions. Title this section with one of these words. The purpose of this section is to explain what claims or conclusions you can make from the data. The logic of your claims builds from the details presented in your previous sections. The strength of your claims will be tied to what evidence you present, and what reasoning you use to make meaning of the experiments you conducted (along with outside references). A good claim will include a short summary of the major pieces of evidence and analysis. Scientific claims are submitted to the scientific community, and judged based on the evidence and analysis presented. We therefore ask you to write your claims so that your instructor and fellow students will be able to follow them, in order to assess their strengths. Examples are provided in the annotated lab.

For an annotated example of a lab report, please visit: http://umaine.edu/general-chemistry/lab-report-instructions/.

Specific Guidelines for Writing Up Determination of Gas Constant R Lab

Include the following in your lab report, which will be uploaded through your ICN account.

1. Create a Table of that includes data for each run. Give a specific title for each run so you can refer to it in your calculations (e.g. Gas Constant Run AB+RB run 01):

    a. The initial and final weights to the nearest 0.001 g of the larger test tube and Erlenmeyer flask for each run you conductted. (**Evidence**)

    b. The temperature of the water in the beaker. (**Evidence**)

    c. The atmospheric pressure from a barometer. (**Evidence**)

    d. The volume of water in the beaker. (**Evidence**)

2. Using Dalton's Law of Partial Pressure, calculate the partial pressure of O_2 (P_{O_2}) produced. (**Analysis of Evidence.**)

$$P_{atm} = P_{O_2} + P_{H_2O}$$

3. Calculate the moles of O_2 from your measurement of the mass of O_2 produced. The mass of oxygen produced is found from the difference in mass before and after heating. The mass of oxygen is then converted to moles by dividing by its molar mass. (**Analysis of Evidence.**)

4. You now have values for the pressure, the volume, the temperature and the number of moles of O_2 (n). With this information you can determine a numerical value for the ideal gas constant, *R*. Calculate an average value for the gas constant, *R*. (**Analysis of Evidence.**)

$$R = \frac{PV}{\langle \frac{mass}{mol.wt.} \rangle T}$$

Note: be sure to include the correct units.

5. Compare your experimental value of *R* with the published accepted value and

determine the percentage error for your value of *R*. Are there any improvements to your experimental procedure that you could suggest to improve your determination of *R*? **(Analysis of Evidence.)**

6. Claims: what claims can you make based on your evidence and reasoning? A good claim will include a short summary of the major pieces of evidence and analysis. Scientific claims are submitted to the scientific community, and judged based on the evidence and analysis presented.

Your lab report will be grading using the rubric on the next page. You are required to upload your lab report as a word (.doc) or pdf file into your InterChemNet account. This will also be the place that your lab instructor will post your grade and give you feedback.

Instructions for your laboratory report (due next lab meeting)

Rubric: **Section:**

Claim(s): Statement(s), derived from evidence, using scientific reasoning. **(15 pts total)**	**Summary of claims:** Clearly state any major conclusions about the experiment you've conducted. Each claim should be backed by evidence using sound scientific reasoning.
Evidence: Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim. **(30 pts total)**	**Introduction:** Provide background information to put the experiment in context. **Procedure:** In a narrative (not numbered directions) carefully describe how you developed your procedure and what you did. How did you collect evidence? Did anything go wrong? You may reference parts of this procedure by providing the title and web address. **Results:** Carefully organize and present the data you collected that supports your argument. Provide all of the spectra you collected (carefully labeled) for the food dye (overlaying multiple spectra to show a pattern might be useful).
Reasoning: Scientific explanations that use evidence and appropriate chemistry concepts to construct claims. **(35 pts total)**	**Discussion:** Explain why the evidence you presented supports your claim. What pattern is evident in your data? How did you discover this pattern? What underlying chemical explanations can you provide about your evidence? Use the lab procedure, outside sources, or talk to your instructor to gather information. Is there a way to discuss the phenomena at both the submicroscopic (molecular) level and macroscopic (visible to your eyes) level? This will, in general, strengthen your analysis.

*General instructions for completing your laboratory report are available in the course guide: http://umaine.edu/general-chemistry/lab-report-instructions/ . Be sure to look over the examples and guidelines in the course guide as well as the specific instruction above.