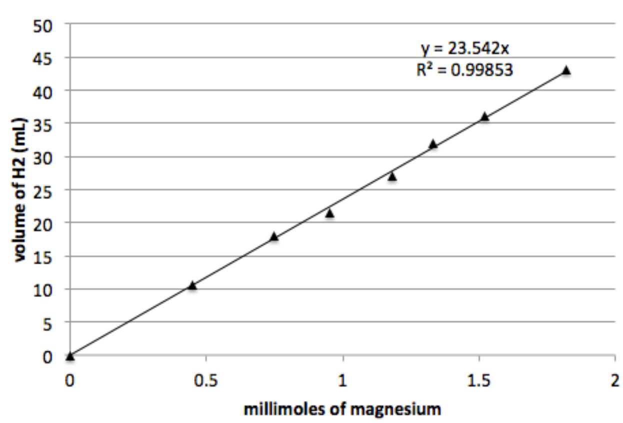
CHAPTER 11 | DETERMINING THE BAROMETRIC PRESSURE WITHOUT A BAROMETER

THIS CLASSROOM GROUP LABORATORY EXPERIMENT utilizes everyone's data to give an overall group result that demonstrates how the ideal gas law can be used to determine the barometric pressure. The experiment is useful because schools often do not have an accurate barometer. The barometric pressure given by the weather service is not immediately useful either because it is not the absolute pressure, but rather a value that has been adjusted for the local elevation above sea level.

Students prepare hydrogen using an excess 2 M HCl(aq) with varying amounts of solid magnesium, Mg. The reaction is:

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

The quantity of magnesium used will generate a proportional amount of $H_2(g)$. The exact volume depends on the temperature and atmospheric pressure. All of the collected data are plotted producing a group graph that should look similar to the figure at right.



Quantity of magnesium used (millimoles) vs volume of hydrogen generated at 275 K

This graph allows one to determine the atmospheric pressure from the ideal gas law:

$$PV = nRT$$

This equation can be rearranged to take the form of the equation for a straight line, $y = mx + b$:

$$V = \frac{nRT}{P}$$

Gathering R, T and P together gives:

$$V = (\frac{RT}{P})n$$

where V is the same as y and n is the same as x in $y = mx + b$. Thus, m, the slope of the line is:

$$m = \frac{RT}{P}$$

In the example shown with the graph, in which the volumes were determined at 275 K, the slope of the line has a numerical value of 23.529 mL/mmol. Knowing the temperature of the ice bath (which should be measured) and given R, the ideal gas law constant, one could calculate a value for the barometric pressure.

Ignoring the vapor pressure of water makes for a simple calculation that gives fairly accurate results — within 3 – 4% of the actual barometric pressure.

$$P = \frac{RT}{m}$$

Taking into account the vapor pressure of water gives better results ($\pm$ 2% of actual) with a slightly more difficult calculation. The slope of the line, m, is equivalent to the molar volume of a gas (L/mol) and is too large due to the vapor pressure of water. To compensate for the vapor pressure of water, we multiply the molar volume, m, by the fraction $(P_{total} - P_{H_2O}) / P_{total}$. (This fraction has a value very close to 1.) The equation above is thus modified:

$$P_{total} = \frac{RT}{m(P_{total} - P_{H_2O}) / P_{total}}$$

Rearranging and solving for P_{total} ultimately gives a simple equation.

$$P_{total}(P_{total} - P_{H_2O}) / P_{total} = \frac{RT}{m}$$

$$P_{total} - P_{H_2O} = \frac{RT}{m}$$

$$P_{total} = \frac{RT}{m} + P_{H_2O}$$

BAROMETRIC PRESSURE WITHOUT A BAROMETER.

INFORMATION FOR THE TEACHER.

Suitability

For use by high school and university-level chemistry students. This experiment can be conducted at about the time that the ideal gas law is being introduced.

Background skills required

Students should be able to:

- generate a gas as learned in Chapter 1
- measure quantities of liquid reagents
- use a balance
- accurately read the volume gradations on the syringe (including estimating between two marks)
- graph data (on graph paper or by using a computer)
- know how to read a graph and calculate the slope of a line

Time required

Students should be able to perform this experiment in a single 45 minute laboratory period.

Equipment

Microscale Gas Chemistry Kit (Chapter 1)
analytical balance
ice bath

Chemicals

0.05 g magnesium (turnings)
5 mL 2 M HCl(aq)

Before students arrive

Each experiment will consume 5 - 7 mL 5 mL 2 M HCl(aq), but we suggest that the volume estimation be based on 8 – 10 mL per experiment. Determine the number of pieces of magnesium each pair of students will use in their experiment. Pieces of magnesium vary considerably in size and mass. We do not want to use more than 0.045 g per experiment because that will generate more hydrogen than can be contained in the syringe. This maximum mass corresponds to 1 - 2 large magnesium turnings or 3 – 4 small pieces. If you have only one analytical balance, you may wish to measure out samples of magnesium for the students to use before they arrive. Use masses that range from as low as 0.0100 g to as high as 0.0450 g.

Ice bath

One or more ice baths will be needed. We recommend a container such as a 4 L (gallon) wide-mouth tall plastic jar, filled to the top with ice. Add water to fill the jar completely. This forms an ice bath with a temperature very close to 0 ^{o}C. Check the exact temperature. The syringes will have to be held in the bath for 20 minutes. We place a basket over the top of the syringes in order to hold them under the surface. A small weight on top of the basket holds the syringes under water.

Accurately reading the volume gradations on the syringe

The volume of the liquid level inside the syringe is generally easy to read because water does not exhibit a meniscus with plastic as it does with glass. Nevertheless, two common sources of error must be avoided. The syringe must be perfectly vertical in order for an accurate reading to take place. We set the syringe balancing on its syringe cap on a flat surface. Read the syringe with eyes at the same level as the liquid. It is possible to estimate the volume to within $\pm$ 0.2 mL. The vial cap will cause erroneous readings if it is floating near the calibration marks.

To read the volume near the black rubber seal, we recommend reading the position where the seal first comes in contact with the barrel from the perspective of inside the syringe. It is possible to estimate the volume to within $\pm$ 0.3 mL.

Website

This chapter is available at our gas website:

http://mattson.creighton.edu/Microscale_Gas_Chemistry.html

Instructions for your students

Content for this chapter first appeared as “Microscale Gas Chemistry, Part 27. Barometric Pressure without a Barometer”, Mattson, B.; and Snipp, R.; Eskestrand. S.: ***Chem13 News***, **326**, 12 - 14, Jan, 2005.

BAROMETRIC PRESSURE WITHOUT A BAROMETER.
INSTRUCTIONS FOR STUDENTS.

General Safety Precautions

Always wear safety glasses. Gases in syringes may be under pressure and could spray liquid chemicals. Follow the instructions and only use the quantities suggested.

Toxicity

Hydrogen is relatively non-toxic; but it is a simple asphyxiant if inhaled in very large quantities. We will not be generating large quantities of hydrogen.

Instructions

1. Make sure the plunger slides smoothly within the plunger. You may need to try a different plunger/barrel combination.

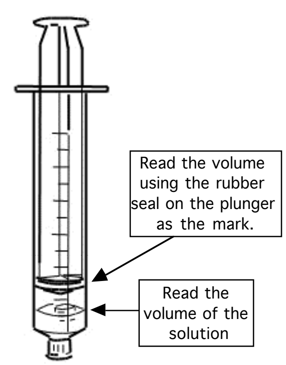
2. Your teacher may give you samples of magnesium with masses that have been previously measured. If so, record the mass in your laboratory notebook. If not, your teacher should have given you an approximate mass to use. Place an empty vial cap on the *analytical balance* and tare the balance to read 0.0000 g. Remove the vial cap and carefully transfer one or more pieces of magnesium turnings into the vial cap. Return the vial cap to the analytical balance and determine its exact mass. You may need to add one or two additional pieces in order to get close to your assigned mass. Record the exact mass in your laboratory notebook.

3. Lower the cap containing the magnesium into the syringe by flotation.

4. Fill a weighing dish with 2 M HCl(aq).

5. Draw up 5 mL of the HCl solution into the syringe. Push the syringe fitting into the syringe cap. Use caution so that the reagents do not mix until Step 7.

6. Read the initial volume of the syringe using the bottom of the rubber seal as the mark as shown in the figure. Also read the level of the acid solution. The difference between these two readings is the volume of air in the syringe. This volume will be subtracted later. Record your data. Also record the room temperature.



7. Perform the reaction by shaking the syringe. The reaction is rather fast. Assist the plunger from time to time by pulling it outward by a few mL. The reaction is done within a few seconds — when no more bubbles are being produced in the solution.

8. This experiment uses the volume of a gas to determine the barometric pressure. According to the ideal gas law, the volume is temperature-dependent, so we must measure the volume of hydrogen collected at a specific temperature. For this purpose, we will use a large ice bath with a temperature typically between 0 - 3 ^{o}C. Check the exact temperature. Submerge the gas-filled syringe(s) into the ice bath so that all of the region containing the hydrogen and the rubber seal are below the surface. Your instructor may have some suggestions for holding the syringe under water for this long.

9. You are now ready to measure the final volume. You'll get your hands wet doing it. First, pull the plunger outward until it feels like you pulling against a force. Let go of the plunger and it will return to an "equilibrium" position where the pressure inside the syringe is fairly close to the outside pressure. Remove the syringe cap under the surface of the ice water while holding the plunger outward creating a reduced pressure. Open the syringe deep enough under enough water so that only water — no air — enters the syringe. Water will rush into the syringe to equalize the pressure. Recap the syringe underwater. The gas pressure inside the syringe is now very close to the atmospheric pressure outside the syringe. Be careful to not move the plunger inward or outward after it has been recapped. Take the final volume readings for both gas and solution as previously done in Step 6 — and do so quickly before the hydrogen warms up and causes the plunger to move. The difference in volumes this time is the volume of hydrogen + air initially present. The volume of hydrogen only is obtained by subtracting the volume of air (Step 6) from the volume of hydrogen + air just determined. Record all results.

10. You instructor will provide you with instructions for sharing the data with your classmates (such as plotting your results on a group graph).

11. Record the temperature and pressure.

Disposal of hydrogen samples

Unwanted hydrogen samples can be safely discharged into the room.

Clean-up and storage

At the end of the experiments, clean all syringe parts (including the diaphragm), caps and tubing with soap and water. Rinse all parts with water. Be careful with the small parts because they can easily be lost down the drain. Store plunger out of barrel.

Laboratory Report:

Part 1. Class Graphical Data

Mass of pure magnesium used:

Volume of hydrogen calculation:

Initial syringe readings:

Room temperature:

Rubber seal (mL): Solution (mL):

Volume air at room temperature (mL):

Volume of air, adjusted for the temperature of the ice bath:

Final syringe readings:

Ice bath temperature:

Rubber seal (mL): Solution (mL):

Volume air + H_2 (mL):

Volume of H_2 collected = Volume air + H_2 (mL) (measured in the ice bath) – Volume of air, adjusted for the temperature of the ice bath.

Questions

Part 1. Class graphical data

1. Add your data points to the graph being prepared on the chalkboard (or follow the data collection procedures given by your teacher). Do your data agree with the general trend?

Part 2. Determine the pressure

2. Review the discussion on pages 133 and 134. On you own paper, rearrange the ideal gas law, $PV = nRT$, to solve for V. Then, gather R, T and P together as shown on pages 133 and 134. Explain how this equation has the general form of $y = mx + b$. How does y relate to P, V, n, R, or T? How does x? How does m? (Note: When relating $PV = nRT$ to $y = mx + b$, the value of b is 0.)

3. What is the value of m determined from the graphed data? Did you determine the slope by estimating Δx and Δy or did you use the equation of a line as determined by a computer? Which value of m would give better results?

4. Using the value of m, the measured temperature of the ice bath, and the given value of R, determine a numerical value for the pressure. Be sure to use the correct units for T — must be in kelvins.

SUMMARY OF MATERIALS AND CHEMICALS NEEDED FOR CHAPTER 11. DETERMINING THE BAROMETRIC PRESSURE WITHOUT A BAROMETER.

Equipment required

Item	For 5 pairs	For 10 pairs
Microscale Gas Chemistry Kit (Chapter 1)	5	10
analytical balance	2 - 3	3 - 5

Materials required

Item	For 5 pairs	For 10 pairs
large container for ice bath	1	2
plastic basket	1	5

Chemicals required

Item	For 5 pairs	For 10 pairs
2 M HCl(aq)	40 mL	80 mL
magnesium(s)	2 g	4 g
ice	5 L	10 L

