Experiment 9 – Gas Laws

Overview

Gases have been one of the most useful types of substances for driving scientific discovery. In this experiment, we will look at A) Boyle's Law which describes the relationship between the **volume** of a gas sample and its **pressure**,

$$p_1V_1 = p_2V_2$$

and B) the Ideal Gas Law

$$pV = nRT$$

which we will use to determine a value of R, the Gas Law constant.

Boyle's Law

Boyle's Law describes the relation between pressure and volume of a gas sample at constant temperature. It states that pressure and volume are inversely proportional, such that their product must be a constant for a given sample of gas at constant temperature:

$$pV = constant$$

If we consider two pairs of pressure-volume data, the following must hold:

$$p_1V_1 = p_2V_2$$

Example: A sample of gas occupies 1.00 L at a pressure of 350 mm Hg. What volume will the gas occupy at a pressure of 570 mm Hg if the temperature is held constant?

Solution: Using Boyle's Law, we know that

$$p_1V_1 = p_2V_2$$

We can find in the problem the following values:

p_1 = 350 mm Hg	p_2 = 570 mm Hg
V_1 = 1.00 L	V_2 = ?

So, it follows that

$$(350\ mm\ Hg)(1.00\ L) = (570\ mm\ Hg)(V_2)$$

$$V_2 = 0.614\ L$$

Note: Since the new pressure was higher than the first, the volume of the gas decreased relative to the initial volume.

The Ideal Gas Law

The **Ideal Gas Law** is one of the most important relationships in science. It relates the properties of **pressure** (p), **volume** (V), **temperature** (T), and number of **moles** (n) of a sample of gas through

$$pV = nRT$$

where R is a constant which has the value 0.08206 atm L mol^{-1} K^{-1}. Note that in order to use the Ideal Gas Law, the temperature must be in absolute temperature scale units, such as Kelvin! In this experiment, you will generate a sample of gas chemically, so that you can determine the number of moles using stoichiometry. The reaction which you will use to generate the gas is

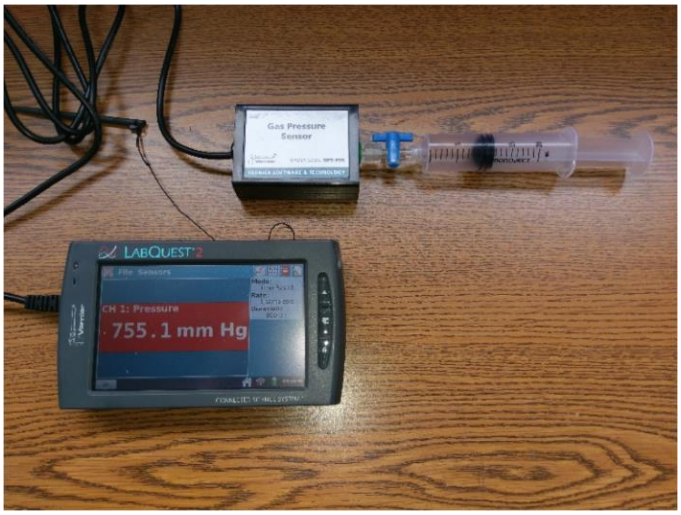
$$Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

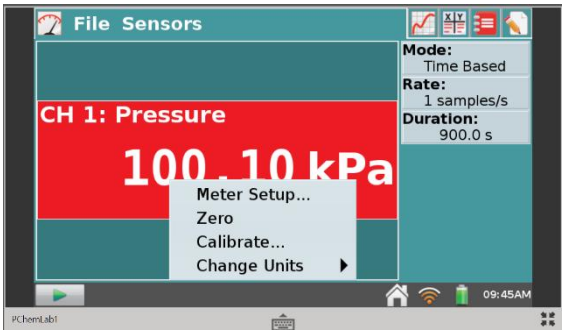
You will use measured values of pressure, temperature, and volume, along with the number of moles, in order to determine an experimental value of the Gas Law constant, R.

Experimental description

Part A – Boyle's Law

1. Construct the apparatus shown in the diagram, with the plunger on the syringe set initially at 10 mL.
2. The LabQuest can be set up to record data in whatever units you find convenient. To change the units, tap the red box on the LabQuest and choose "Change Units" as shown in the picture below:





3. Record several pairs (at least seven pairs) of volume and pressure by depressing and holding the plunger on the syringe (increasing the pressure), or pulling it back to lower the pressure.
4. Make a graph, with properly labeled and scaled axes, an appropriate title, and a clear presentation of your data.

Part B – Determination of R

1. Determine the volume of your apparatus.
    a. Construct the apparatus as shown, using a 125 mL Erlenmeyer flask and the parts in the pressure sensor kit, including the white stopper, syringe, and gas pressure sensor connected to the Tygon tubing. The initial plunger reading on the syringe should be 20 mL. Record the pressure of the air trapped under these conditions. The volume of the apparatus at this point is V + 20 mL. (The picture does not include the waterbath in which the Erlenmeyer flask is to be placed.)

    b. Depress the plunger all the way in, causing the pressure in the system to increase. The volume of the apparatus at this point is V. Record the pressure.
    c. Calculate the volume (V) of the apparatus using Boyle's Law

$$p_1(V + 20\ mL) = p_2V$$

Substituting your measured values of p_1 and p_2.

Example: A student measures the pressure of a sealed apparatus described above, with the syringe set at 20 mL to be 749.9 mm Hg. When the syringe is pushed all the way in, the pressure is measured to be 845.8 mm Hg. What is the volume of the apparatus with the syringe pushed completely in?

Solution: We can solve this problem using Boyle's Law.

$$p_1V_1 = p_2V_2$$

p_1 = 749.9 mm Hg p_2 = 845.8 mm Hg
V_1 = V + 20.0 mL V_2 = V

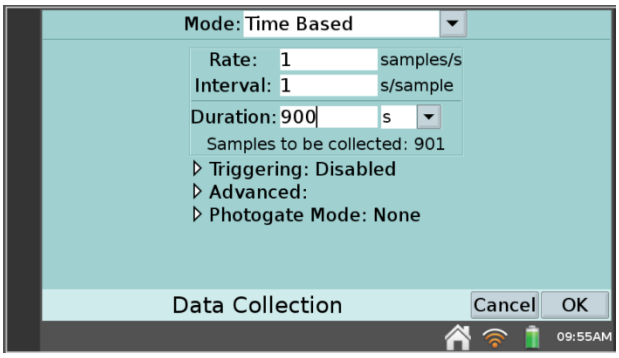
So

$$(749.9\ mmHg)(V + 20.0\ mL) = (845.8\ mmHg)(V)$$

Solving for V yields

$$V = 156.4\ mL$$

2. Generate hydrogen gas in your apparatus by reacting magnesium with hydrochloric acid.
   a. Obtain, clean with sandpaper, and weigh approximately 0.015 g of magnesium (approximately 2 cm of magnesium ribbon). Record the mass to within 0.0001 g using the analytical balance. Place your magnesium into the Erlenmeyer flask.
   b. Fill your syringe with 5 mL of 1.0 M HCl, leaving no bubbles in the syringe.
   c. Set the LabQuest (or LoggerPro software) to Time-based mode, and to collect one data point every second for 300 seconds (5 minutes.) Begin data collection by clicking the start button. The data acquisition parameters can be changed by tapping on the "Mode" box, to pull up the dialog box shown at the right.



   d. Begin acquiring data by tapping the "play" button (the green arrow.) Once the initial pressure is fairly well established (about 15 seconds), depress the syringe, deploying the HCl into the flask. *Note*: Because the acid takes up some volume, the volume inside the apparatus is now V – 5.0 mL. Collect pressure data for the remainder of 5 minutes, or until all of the magnesium has reacted. (It is possible that you will need to set the apparatus to collect data for longer than 5 minutes – especially if you use too big a piece of magnesium!)
   e. Measure and record the temperature in the water bath and the difference in pressure (this is the partial pressure of the hydrogen produced).
   f. Using the data you recorded above, in conjunction with your determined flask volume, and the number of moles of Mg (which is equal to the number of moles of H_2(g) produced), calculate the value of the gas law constant R

$$R = \frac{pV}{nT}$$

Example: Maggie records the following data in her lab notebook for this experiment:

Description	Value	Comments
Mass Mg	0.0172 g	Determination of moles
Pressure at V + 20.0 mL	0.9899 atm	Determination of volume
Pressure at V	1.1003 atm	
Initial pressure	0.9893 atm	Determination of pressure
Pressure after reaction	1.0846	
Water bath temperature	21.1 ^{o}C	Determination of temperature

Solution: Maggie's analysis of the data is as follows:

To get moles of H_2(g):

$$0.0172\ g\ Mg \cdot \frac{mol}{24.30\ g} \cdot \frac{1\ mol\ H_2}{1\ mol\ Mg} = 0.000708\ mol\ H_2$$

To get the system volume:

$$(0.9899\ atm)(V + 20.0\ mL) = (1.1003\ atm)(V)$$

$$V = 179.3\ mL = 0.1793\ L$$

Now subtract 5 mL to account for the HCl:

$$V = 0.1793\ L - 0.005\ L = 0.17\underline{4}3\ L$$

To get pressure of H_2(g):

$$p_{H_2} = 0.9893\ atm - 1.0846\ atm = 0.0953\ atm$$

To get temperature:

$$T = (21.1\ ℃ + 273.15℃) \cdot \frac{1\ K}{1℃} = 294.\underline{2}5\ K$$

To get R:

$$R = \frac{pV}{nT} = \frac{(0.0953\ atm)(0.1743\ L)}{(7.08 \cdot 10^{-4} mol)(294.25\ K)} = 0.079\underline{7}7\ \frac{atm\ L}{mol\ K}$$

Note: this value is a little low, but is certainly of the right order of magnitude!

Vocabulary and Concepts

References

Randall, Jack. 2013. *Advanced Chemistry with Vernier.* 3rd. Beaverton, OR: Vernier Software and Technology.

Pre-Laboratory Assignment – Gas Laws

Name _____ Section _____

1. A sample of gas occupies 12.5 L at a pressure of 104.2 kPa. What will the volume be at a pressure of 352 Torr? (1 atm = 760 Torr = 101.325 kPa)

2. Using the apparatus for the determination of R, the pressure with the syringe at 20.0 mL is 659.2 mm Hg. With the syringe at 0.0 mL, the pressure is 742.1 mm Hg. What is the volume of the apparatus?

3. In performing part B of the experiment, Claudia records the following data:

Description	Value	Comments
Mass Mg	0.0164 g	Determination of moles
Apparatus V	0.1920 L	Determination of volume
Initial pressure	743.2 mm Hg	Determination of pressure
Pressure after reaction	799.3 mm Hg	
Water bath temperature	20.3 ^{o}C	Determination of temperature

Calculate the experimental value of R based on Claudia's data:

Report Sheet – Gas Laws

Name _____ Date _____

Lab Partner(s) _____

Part A – Boyle's Law

Pressure (include units!)	Volume (include units!)

In the space below, write the formula of the function to which you fit your data:

Part B – Determination of R

Description	Value	Comments
Mass Mg		Determination of moles
Pressure at V + 20.0 mL		Determination of volume
Pressure at V		
Initial pressure		Determination of pressure
Pressure after reaction		
Water bath temperature		Determination of temperature

On the next page, calculate the value of R consistent with your data in the tale above.

How many mol of H_2 (g) did you produce?

n = _____ mol

What was the volume of your system in L?

V = _____ L

What was the pressure increase in your system due to the production of H_2(g) in atm?

p = _____ atm

What was the temperature of your system in K?

T = _____ K

What is the value of R that you calculate from your data?

R = _____ atm L mol^{-1} K^{-1}