

Experiment 11

The Gas Laws

Introduction: In this experiment you will (1) determine whether Boyle's Law applies to a mixture of gases (air) and (2) calculate the gas constant, R , by determining the volume of a known amount of gas (H_2) at a measured temperature and pressure.

Determination of Whether Boyle's Law Applies to Air

Boyle's Law states that for a fixed amount of gas at constant temperature, the pressure of the gas will vary inversely with the volume so that $P \propto 1/V$ or $PV = a$ constant (if n and T are constant). To determine whether this relationship holds for a mixture of gases, the pressure of a fixed amount of air (which is a mixture of gases) will be measured as the volume of the air is varied while keeping the temperature of the air constant.

Determination of the Gas Constant, R

The ideal gas law arises from several different gas laws. *Boyle's law* describes the inverse relationship between pressure and volume, $P \propto 1/V$, for a sample of gas at constant temperature. *Charles' law* describes the direct relationship between volume and temperature, $V \propto T$, for a sample of gas at a constant pressure. The *Gay-Lussac law* describes the direct relationship between pressure and temperature, $P \propto T$, for a sample of gas at constant volume. Together these lead to what's referred to as the *combined gas law*, used to relate the properties of a given sample of gas at two different sets of conditions, labeled 1 and 2.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad (1)$$

Note that all three of the gas laws are satisfied by this equation. For example, if temperature is constant, $T_1 = T_2$ so that T_1 and T_2 can be eliminated from the equation, leaving $P_1V_1 = P_2V_2$, which is Boyle's Law.

Another relationship between gas properties is *Avogadro's Principle*. It states that for the case in which the pressure and temperature of a gas are held constant, the volume of the gas is proportional to the number of moles, or $V \propto n$, or $V/n = a$ constant. Adding this relationship to the *combined gas law* gives the following:

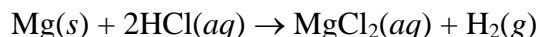
$$\frac{PV_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} = \text{Constant} \quad (2)$$

The constant in the above equation is the ideal gas law constant, or simply, **the gas constant, R** , calculated for a "near ideal gas," such as H_2 . Replacing "Constant" with R in equation (2) gives the Ideal Gas Law:

$$PV = nRT \quad (3)$$

Equation (3) describes the relationship between the properties P , V , n and T for any sample of gas behaving as an ideal gas. No matter what changes are made to any of the properties, the relationship still is true as long as the conditions are near ideal. But the equation is only useful if the value of R is known.

In this experiment you will calculate a value for R by generating a known number of moles of H_2 , under conditions in which it behaves like an ideal gas, by the reaction:



Based on the reaction stoichiometry, if the $HCl(aq)$ is in excess, the moles of H_2 produced must be equal to the moles of Mg reacted, which can be calculated from the mass of Mg used and its formula mass. If the volume, pressure and temperature of the known number of moles of H_2 produced are measured, then equation (3) can be used to calculate R . The H_2 will be generated in the Erlenmeyer shown in Figure 1 below by adding the HCl solution in the syringe to the Erlenmeyer containing the Mg ribbon.

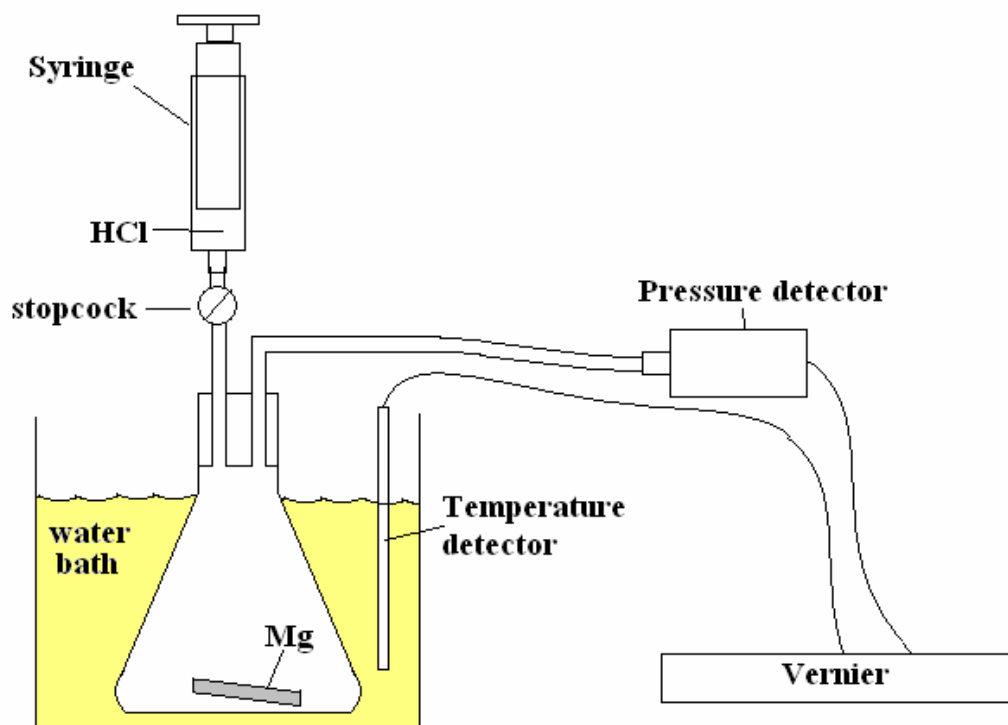


Figure 1. Apparatus for Determination of R .

Initially the pressure will be that of the air in the Erlenmeyer, designated $P(\text{air})$. Once the HCl is added, the reaction generating H_2 gas will occur, thus increasing the pressure. The total pressure measured in the Erlenmeyer after the reaction has been completed, $P(\text{total})$, will be the sum of (1) the pressure of the H_2 produced by the reaction, $P(H_2)$; (2) the measured pressure of air initially in the Erlenmeyer flask, $P(\text{air})$, and (3) the vapor pressure

of water, $P(\text{H}_2\text{O})$, present in the Erlenmeyer due to the presence of the water in the HCl solution added to the Erlenmeyer. Thus the pressure of the “dry” H_2 gas present in the Erlenmeyer will be obtained as

$$P(\text{H}_2) = P(\text{total}) - P(\text{H}_2\text{O}) - P(\text{air}) \quad (4)$$

$P(\text{H}_2\text{O})$ can be obtained from the table at the end of Part B since the temperature of the gases (including the temperature of the collected H_2) in the Erlenmeyer will be the same as that measured for the water bath.

With the pressure, temperature and number of moles of H_2 having been obtained, it is only necessary to measure the volume of the H_2 gas collected. This is the volume of the Erlenmeyer plus the volume of the tube connecting the flask to the pressure detector.

Pre-Laboratory Notebook: Provide a **title, purpose, brief summary of the procedures, and table of reagents** (HCl and Mg) in your notebook before coming to lab.

Equipment:

- Vernier computer interface
- Vernier temperature and pressure sensors (and accessories)
- TI -84 calculator
- Logger *Pro* 3.3 software (on computer in Room 242), for graphing results
- Water reservoir in plastic tub
- 125 mL Erlenmeyer flask
- 50 mL and 100 mL Beakers
- 100 mL graduated cylinder

In Lab Experimental Procedure (Note: Work in pairs)

Part A: Determination of Whether Boyle’s Law Applies to Air

1. Set up the LabPro system according to the first section of the Vernier tutorial, and connect the gas pressure sensor into channel 1 of the LabPro and the temperature probe into channel 2.
2. With the 20-mL syringe disconnected from the gas pressure sensor, move the piston of the syringe until the front edge of the inside black ring is positioned at the 10.0 mL mark, then attach (by twisting on) the syringe to the white port of the gas pressure sensor as shown in Figure 2. Do not over tighten.
3. Turn on the calculator, press APPS and scroll down to select the DATAMATE program. After pressing CLEAR to reset the program, pressure and temperature readings should appear. If the calculator displays a gas pressure set to units other than MMHG in CH 1, change the units to MMHG (same as torr). To do this, press 1:SETUP to get a display of channels. With the cursor at CH1 press ENTER and then select 2: Gas Pressure (MMHG). Select 1: OK two times to return to the main screen.

- To set up the data-collection mode for Events with Entry: Select 1:SETUP and then, by pressing \uparrow or \downarrow , move the cursor until it is to the left of MODE and press ENTER . Select 3:EVENTS WITH ENTRY from the SELECT MODE menu. Select 1:OK to return to the main screen.
- You are now ready to collect pressure and volume data. Read all of step 6 carefully to be clear on how you will proceed. **Record all data in your lab notebook!**
- Select 2:START to begin data collection. Press ENTER and the calculator will record the pressure corresponding to the 10 mL volume of air in the syringe. When the calculator displays ENTER VALUE? enter “10” for the volume and press ENTER to store this pressure-volume data pair. Record the volume and pressure values *in a table in your notebook* for this and the subsequent measurements.
- Move the piston so the front edge of the inside black ring is positioned at the 5.0-mL line on the syringe (see Figure 2). Hold the piston firmly in this position while the pressure value displayed on the calculator screen stabilizes. Press ENTER and the calculator will record the pressure. Then type in “5”, the gas volume on the calculator and press ENTER .

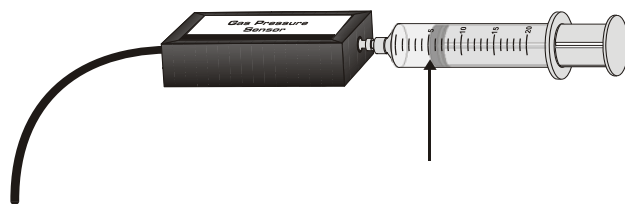


Figure 2

- Continue with this procedure using various volumes (alternating between larger and smaller volumes) until you have collected ten data points spread over the range 5 to 15 mL. Press $\text{STO} \blacktriangleright$ when you have finished collecting data.
- At the end of data collection press ENTER to view the P vs V curve on the calculator. Press ENTER again and then 1:MAIN SCREEN to go back to the main screen. Select 6:QUIT and then press ENTER to shut off the calculator. At this point **you can choose** between two approaches to the Part A Postlab Analysis on page 6-6: either (1) unplug the calculator and use Logger Pro software to retrieve your data as described in “Downloading data” section of the Vernier tutorial and save it in an Excel spreadsheet for later analysis, or (2) use the data in your lab notebook to be entered in Excel in the postlab calculations.

Part B: Determination of the Gas Constant, R (Done two times)

- Return to the main screen of the DATAMATE program and refer to Figure 1 on p. 6-2 in the experimental procedure that follows.
- Obtain a pre-cut sample of magnesium ribbon (use a 4 cm length with a mass of ~ 30 mg), weigh it in a tared weigh boat, and record its mass.

3. Fill a plastic tub with tap water to a level (see Figure 1) that will nearly submerge a 125-mL Erlenmeyer flask. Connect the temperature sensor to channel 2 of the Vernier and insert the temperature probe into the water bath.
4. Place the piece of pre-cut Mg ribbon into a **clean, dry** 125-mL Erlenmeyer flask. Connect the pressure sensor to channel 1 of the Vernier. Fit the white stopper into the flask tightly to ensure a closed system. Important: Close the valve on the white stopper by turning the white handle so it is perpendicular to the valve stem.
5. With the completely depressed syringe screwed onto the stopcock, open the stopcock and retract the plunger to the 20 mL mark to remove air from the flask and then close the stopcock. The pressure should be reduced to about 520 torr. Unscrew the stopcock and depress the plunger completely. Screw the stopcock back on to the syringe. Then **OPEN the stopcock** and withdraw another 20 ml air from the flask, and **then CLOSE the stopcock**. This should lower the pressure to ~450 torr. Repeat this process until the pressure in the flask is about 350 torr. With the stopcock remaining closed, check that the pressure is not increasing more than about 3 torr in 2 minutes, indicating reasonably secure seals.
6. Pour approximately 25 mL of 3.0 M HCl (**Caution!**) into a 50-mL beaker and draw up about 5 mL of the HCl solution into the 20-mL syringe. Read and record the volume at the front edge of the inside black ring on the piston of the syringe. Connect the syringe to the still closed stopcock on the white stopper using a twisting motion.
7. Select 1:SETUP from the main screen. To select MODE, press or until the cursor is to the left of MODE and press . Select TIME GRAPH from the SELECT MODE menu. Then select CHANGE TIME SETTINGS. Type "5" for the time between samples in seconds, and press . Type "40" for the number of samples, and press . Select 1:OK twice to return to the Main screen.
8. Partially submerge the Erlenmeyer flask in the water bath as shown in Figure 1, with the stopper held in place. Press START from the main screen on the calculator to begin data collection. After 20 seconds, the partner not holding the flask in the bath should open the stopcock directly below the syringe, allowing the plunger to smoothly and quickly add all of the HCl solution to the flask. Then immediately close the stopcock.
9. Checking that the stopper remains in place while the reaction occurs, wait for the beep from the Vernier system to signify the end of data collection. In a few seconds following the end of data collection, the screen will display the list of channels. With the cursor arrow at CH 1:Pressure, press and a plot of pressure vs. time will appear. Use the cursor arrow buttons to scan through the plot and record the pressure (y value) at the start of the plot, $P(\text{air})$. Then locate and record the maximum pressure following reaction, $P(\text{total})$. Press to get back to the list of channels and move the cursor to CH2-TEMP and press again. Scan through the plot and record the temperature at the end of the reaction. Use this temperature as the temperature of the collected gas and to determine the $P(\text{H}_2\text{O})$ from the table below.
10. Press to clear the Lab Pro and press 1-Main screen. Then repeat the process for the next strip of Mg starting at step 4, using the same Erlenmeyer.

- To determine the volume of the collected gas, fill the same 125 mL Erlenmeyer flask to the brim with water and insert the stopper into the top, displacing some of the water. Remove the stopper and record the volume of the water remaining in the flask by transferring the water, in two separate transfers, to a 100 mL graduated cylinder. The sum of the two collected volumes is the volume of the flask. *(Something to think about: One could add to that total the volume of the tubing connecting the flask to the pressure detector, which is approximately 5.0 mL. However, this increased volume is offset by the 5.0 mL of HCl solution added to the flask, which decreases the volume available to the gas.)*
- After completing the two runs, add about 50 mL of DI water to a 100 mL beaker and clean the syringe by taking up 10-20 mL volumes of the DI water three times and discarding the water by smoothly depressing the plunger. Then clean and replace all parts of the Vernier equipment into their boxes for check out by your Instructor.

Vapor Pressure of Water at Various Temperatures

$T, ^\circ\text{C}$	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0
$P(\text{H}_2\text{O}), \text{ torr}$	15.5	16.5	17.5	18.7	19.8	21.1	22.4	23.8	25.2	26.7	28.3

Part A: Postlab Analysis

- If you saved the data in an Excel spreadsheet, open it. If not, open a blank spreadsheet and transcribe the PV data into it. If the data points are out of order, sort them using the sort command in the data menu. **IMPORTANT:** Because there is a volume of 0.85 mL between the end of the syringe and the pressure detector it is necessary to correct each of your volume readings by this amount. This can be done by inserting a column (V corrected) next to the volume column in which 0.85 is added to each of the volume entries.
- Form an additional column, which gives the product PV(corrected) for each data pair. Then highlight just the P and V(corrected) columns and use the graphing tools of Excel to generate an “XY scatter” plot (“with data points connected by smooth lines”), with V(corrected) on the x-axis. The graph should have a title, axis labels, and major gridlines shown. Each point in the plot should have a marker.

Lab Report Outline for Gas Laws

Graded Sections Percent of grade

Pre Lab 10

In Lab 10

Report

Part A: Attach a copy of the Excel spreadsheet containing the P - V data collected, including the V (corrected) values, the PV (corrected) products, and the resulting plot of P vs V (corrected). See Post-Lab Analysis section. 25

Discussion: Is the product PV (corrected) constant for your set of data pairs. Do the results confirm that Boyle's Law applies to a mixture of gases? Explain your answer. 5

Part B: Restate your data **in your notebook** in a table of data and results as shown below 10

Run	1	2
Mass Mg		
Moles H ₂ (= mol Mg)		
P (air)		
Temperature, K		
P (H ₂ O)		
P (total)		
P (H ₂)		
Volume (H ₂) collected		
Gas constant, R		

Show the following calculations for Run 1 and enter the results in the table above. It is not necessary to show the calculations for Run 2, but the results must be entered in the table shown above.

1. Calculate the moles H₂ from the mass of Mg used 5
2. Calculate P (H₂) from P (total), P (air) and P (H₂O) [Eqn (4)] 5
3. Calculate the volume (H₂) collected as described in Part B, step 11. 5
4. Calculate the value of R in units of (L atm)/(mol K) using equation (3) 10
5. Calculate the average value of R for the 2 runs. 5
6. Discussion (Summarize results; sources of error? Which measurement limits the number of sig figs in your calculated value of R ? How close is your calculated value to the known value of R ? Do your results indicate that under the conditions of the experiment, H₂ behaves as an ideal gas?) 10

