The Empirical Gas Laws

# Introduction

A property is an identifying characteristic of a substance. Three important properties of a gas are temperature, pressure, and volume. It turns out that the mathematical relationship between these three properties, called the *equation of state* of the gas, is mostly independent of the type of gas. For most real gasses, regardless of their chemical natures, the equation

PV = nRT

describes the relationship between these properties quite well. A gas with no deviation from this equation is called an *ideal gas* or a *perfect gas*.

The symbols P, V and T in the equation of state stand for the variables pressure, volume, and temperature, respectively. A fourth variable for a real sample is the amount of the gas, n, measured in moles. The symbol R in the equation of state is called the ideal gas law constant.

The purpose of this experiment is to confirm that the ideal gas law is an appropriate equation of state for air. To demonstrate this, we will hold two variables constant and collect data for other two. Reducing the full equation of state to simpler, more manageable forms results in the *empirical* gas laws because the relationships are the result of observation and measurement. If the data matches the expected relationships of the empirical gas laws, then we have reason to believe the ideal gas law correctly describes the behavior of air.

Since the ideal gas law has four variables, there are six empirical relationships:

P vs. V P vs. T V vs. T

P vs. n V vs. n n vs. T

For this experiment, we will always keep the amount of gas constant and only examine the three empirical gas laws in the first row above.

# Materials and Methods

LabQuest2

150 mL Erlenmeyer flask

Pressure sensor with two-holed stopper and tubing

20-mL syringe

Temperature sensor

600-mL beaker

# Procedure, Data and Results

1. **Pressure and Volume: Boyle’s Law**

Attach a pressure sensor to a LabQuest in Channel 1. Select the “pencil” icon on the monitor screen then Tap ‘File’, then ‘Open…’ and open the *PVgas.qmbl* file.

Fill a 20-mL syringe to the 10 mL mark and screw it onto the pressure sensor, as shown in the figure. Since we are not heating the air in the syringe, we are holding the temperature as well as the amount of gas constant in this experiment.



Tap the graph icon to the right of the meter icon. Tap the green arrow at the lower left corner or press the arrow button to the right of the ‘home’ button on the LabQuest to begin data collection.

Tap the ‘KEEP’ button and enter a volume of 10 mL, then tap ‘OK’. Compress the syringe to 8.0 mL, press the ‘KEEP’ button and enter a volume of 8 mL. Do this for 6 and 4 mL volumes of air as well. Next, expand the syringe to a volume of 12 mL and ‘keep’ the data point. Do this again for 14, 16, 18, and 20 mL of air in the syringe. Tap the red square to stop data collection.

Tap on the data table icon to the right of the graph icon. Record the volume, pressure, and inverse volume readings in the data table on the Report Sheet (attached to the lab handout). (You can do this in order of increasing volume.)

If the ideal gas law is accurate, then the curve should be a hyperbola: PV = constant. This can be demonstrated by two different methods: the product of pressure and volume should be approximately constant; and a plot of inverse volume on the x-axis versus pressure on the y-axis should be a straight line with a y-intercept close to (0,0).

In the data table on the Report Sheet, record the product of pressure and volume (P\*V). Is it mostly constant?

Next, tap on the graph icon on the LabQuest, then tap on ‘Volume’ on the x-axis and choose ‘Inverse Volume’ instead. Depending on your data, you may need to go to “graph options” and “autoscale once” to make this more readable. Does the data appear to be a straight line passing through the origin?

Approximate the equation of the best straight line through the data by dragging the stylus across the screen to highlight the data (You can do a better job of finding the best fit later when writing the lab up).

Tap on ‘Analyze’ (which is available only after you have “stopped” data collection) in the top menu, then tap on ‘Curve Fit’ and hit the check box for ‘Pressure’. From the ‘Choose Fit’ drop-down menu, select Linear. Record the slope, m, and the intercept, b, on the Report Sheet. Is the slope close to the average value of the product of pressure and volume from the data table? Is the y-intercept close to zero pressure? (For context – standard atmospheric pressure is about 100 kPa)

1. **Pressure and Temperature: Gay-Lussac’s law**

Attach a temperature probe to Channel 2 while keeping the pressure sensor in Channel 1 of the LabQuest in Channel 1. Tap ‘File’, then ‘Open…’ and open the *PTgas.qmbl* file.

Attach the pressure sensor to a two-holed stopper inserted in a 125-mL flask using the clear plastic tubing. Insert the valve body in the other hole on the stopper and then turn the valve is in the closed position. Add a magnetic stir-bar to your beaker and add “some” tap water to the beaker (read what comes next before asking how much). Submerge the flask up to its neck in a 600 mL beaker filled with cold water on a hot plate, and place the temperature probe in the water bath, as shown in the figure below. Use a stand or other setup to make sure to keep the probe and all wiring and tubing away from the surface of the hotplate. Also, the temperature probe should be suspended in water only and not touching the glass of the beaker, especially the bottom.



In this case, the amount of gas is fixed since it is sealed in the flask and the volume of the glass flask is also constant during data collection.

Equilibrate the temperature of the water bath by using a stirring bar, or stirring the water with the temperature probe, or bobbing the flask up and down in the water. Make sure you have a stable base-line temperature before adding heat.

Turn on the hot plate to medium-high and begin data collection by tapping on (or pressing) the green arrow. Monitor the temperature on either the meter or graph screen and tap the ‘KEEP’ button to record a data point. Collect at least 10 data points about every 5 Celsius up to a maximum temperature of 80 Celsius before stopping data collection. Record the data on the Report Sheet.

The plot of volume on the y-axis versus temperature on the x-axis should be a straight line. From the graph screen, find the equation of the best straight line through the data by following the same steps as with the Boyle’s law plot. Record the slope and intercept of the line on the Report Sheet.

The data can be used to estimate absolute zero. If y = mx +b, then the x-intercept will be –b/m. The x-intercept will be a numerical estimate of absolute zero since the gas pressure should be zero at that temperature.

1. **Volume and Temperature: Charles’ law**

Tap ‘File’, then ‘Open…’ and open the *VTgas.qmbl* file. Replace the warm water in the water bath with cool tap water. Attach the syringe with no air in it to the valve of the two-holed stopper; make sure the valve is in the open position. As with the previous two experiments, the total amount of gas in the closed system is fixed.

Data collection for this experiment is similar to Boyle’s Law. The total volume of the 125 mL flask is close to 150 mL. Record the total pressure of the gas as measured by the pressure sensor on the Report Sheet. Begin data collection by tapping on the green arrow, choose ‘KEEP’, and enter a volume of 150 mL.

Attach the syringe to the rest of the setup via the valve body with the valve still in the closed position. While it is very much an approximation, we will consider the flask to have an initial volume of 150 mL.

Open the valve and then expand the syringe to 2 mL. Because the volume is now larger, the pressure has dropped (Boyle’s law). To raise the pressure, we are going to heat the gas in the water bath (Gay-Lussac’s law).

Begin heating the water bath and *when the pressure returns to the original value* – the necessary constant pressure condition for this empirical gas law – tap the ‘KEEP’ button and record the new volume of 152 mL. The pressure can be monitored on either the meter screen of the graph screen.

Extend the plunger by 2 more mL and repeat the process by adding ‘2’ to the previous total volume and ‘keeping’ the data point when the pressure has returned to its original value. Collect at least 8 data points up to a maximum volume of 170 mL before stopping data collection. Record the data on the Report Sheet.

The plot of volume on the y-axis versus temperature on the x-axis should be a straight line. From the graph screen, follow the steps of the Analyze menu to record the slope and intercept of the best straight line through the data. This x-intercept should also be a reasonable estimate of absolute zero since an ideal gas at zero temperature has no volume, so calculate the value of –b/m from these data and record it on the Report Sheet.