Empirical Gas Laws (Parts 1 and 2)

Pressure-volume and pressure-temperature relationships in gases

Some of the earliest experiments in chemistry and physics involved the study of gases. The invention of the barometer and improved thermometers in the 17th century permitted the measurement of macroscopic properties such as temperature, pressure, and volume. Scientific laws were developed to describe the relationships between these properties. These laws allowed the prediction of how gases behave under certain conditions, but an explanation or model of how gases operate on a microscopic level was yet to be discovered.

After Dalton's atomic theory was proposed in the early 1800's (that matter was composed of atoms) a framework for visualizing the motion of these particles followed. The kinetic molecular theory, developed by Maxwell and Boltzmann in the mid 19th century, describes gas molecules in constant random motion. Molecules collide resulting in changes in their velocities. These collisions exert pressure against the container walls. The frequency of collisions and the speed distribution of these molecules depend on the temperature and volume of the container. Hence, the pressure of a gas is affected by changes in temperature and volume.

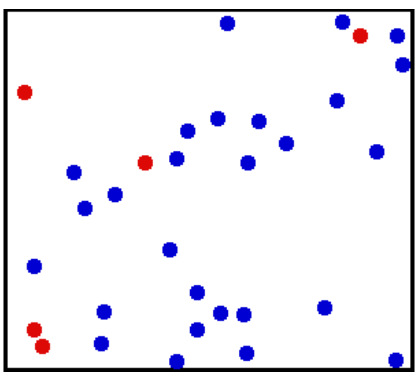

Figure 1.
The Kinetic Theory considers gas molecules as particles that collide in random motion.

You may already think that the relationships between pressure, volume, temperature, and number of gas molecules are intuitive, based on your ability to visualize molecular motion and a basic understanding of the kinetic theory. The simple experiments that follow will allow you the opportunity to confirm these relationships empirically, in a qualitative and quantitative manner. In essence, you will play the role of a 17th century scientist (with some 21st century tools!) and discover the laws for yourself—laws and constants that are still in use today.

In this experiment, you will:

- Determine the relationship between the volume of a gas and its pressure (Part 1).
- Determine the relationship between the temperature of a gas and its pressure (Part 2).

Note: If you are doing Part 3 to determine the value of the Universal Gas Constant, R in the same period as Parts 1 and 2, you should get Part 3 started first.

Part 1: Pressure-Volume Relationship of Gases

In Part 1 you will use a gas pressure sensor and a gas syringe to measure the pressure of an air sample at several different volumes to determine the relationship between the pressure and volume of air at constant temperature.

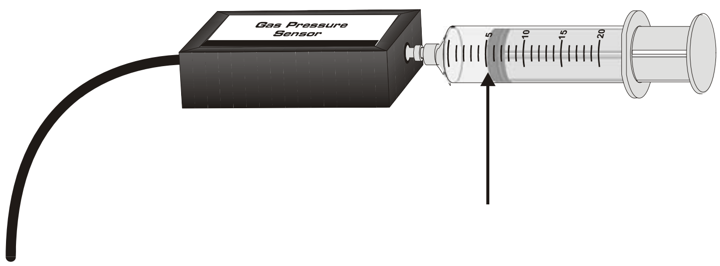

Figure 2

Procedure

1. a. Plug the gas pressure sensor into channel 1 of the computer interface.
   b. 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 (indicated by the arrow in Figure 2) is positioned at the 10.0 mL mark.
   c. Attach the 20 mL syringe to the valve of the gas pressure sensor.
2. Start Logger*Pro*. Open the file "06 Boyle's Law" from the *Chemistry with Computers* folder.
3. Click [▶ Collect]. This will allow you to collect data points in the table as you go.
4. Collect the pressure *vs.* volume data. It is best for one person to take care of the gas syringe and for another to operate the computer.
   a. Move the piston to position the front edge of the inside black ring (see *Figure 2*) at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value stabilizes.
   b. When the pressure reading has stabilized, click [Keep]. (The person holding the syringe can relax after [Keep] is clicked.) Type in the volume injected. Press the ENTER key to keep this data pair. Note: You can choose to redo a point by pressing the ESC key (after clicking [Keep] but before entering a value).
   c. Move the piston to the 7.0 mL line. When the pressure reading has stabilized, click [Keep] and type in the volume.
   d. Continue this procedure for six more syringe volumes of your choice, above and below 5 mL.
   e. Click [■ Stop] when you have finished collecting data.
5. **Record the pressure and volume data** in the data table provided on the report sheets (in case the computer crashes!). Don't forget units and significant figures. Print the graph.

6. Are there any data points that you've collected that seem strange? Explain why these points "do not fit" and what you should do with them.

7. Examine the graph of pressure *vs.* volume.

   Based on the graph, we think there is a _________________ (direct or inverse) relationship between the pressure and volume of a gas.

   To verify if your prediction is correct:

   If the relationship between *P* and *V* is a *direct* relationship, the plot of ***P*** **vs.** ***V*** should be linear and pass through (or near) your data points.

   If the relationship between *P* and *V* is an *inverse* relationship, the plot of ***P vs.*** **1/*V*** should be linear and pass through (or near) your data points. To check this using Logger *Pro*:

   a. Remove the Curve Fit box from the graph by clicking on its upper-left corner.
   b. Choose New Calculated Column from the Data menu.
   c. Enter "1/Volume" as the Name, "1/V" as the Short Name, and "1/mL" as the Unit. Enter the correct formula for the column (1/volume) into the Equation edit box. To do this, type in "1" and "/". Then select "Volume" from the Variables list. In the Equation edit box, you should now see displayed: 1/"Volume". Click Done.
   d. Click on the horizontal-axis label, select "1/Volume" to be displayed on the horizontal axis.

   Based on the analysis above, there is a __________________ relationship between the pressure and volume of a gas.

8. Once you have confirmed that the graph represents either a direct or inverse relationship, print the graph.

Part 2: Pressure-Temperature Relationship of Gases

In Part 2 you will use a gas pressure sensor and a temperature probe to measure the pressure of an air sample at several different temperatures to determine the relationship between the pressure and temperature of air.

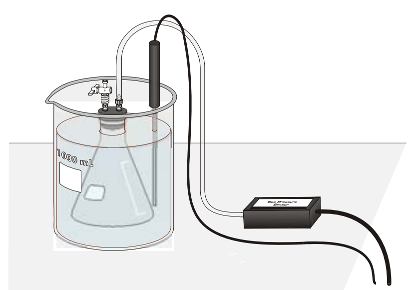

Figure 3

Procedure

1. Prepare four water baths. You may share these with another pair of students at your lab bench.

   a. Put about 800 mL of hot tap water into a l L beaker and place it on a hot plate. Turn the hot plate to a high setting.
   b. Put about 700 mL of cold tap water into a second 1 L beaker and add ice.

c. Put about 800 mL of room-temperature water into a third 1 L beaker.
d. Put about 800 mL of hot tap water into a fourth 1 L beaker.

2. a. Plug the gas pressure sensor into channel 1 and the temperature probe into channel 2 of the computer interface.

   b. Obtain a rubber-stopper assembly with a piece of heavy-wall plastic tubing connected to one of its two valves (see Figure 4). Attach the connector at the free end of the plastic tubing to the open stem of the gas pressure sensor with a clockwise turn. Leave its two-way valve on the rubber stopper open (lined up with the valve stem as shown in Figure 4) until Step 5.

   c. Insert the rubber-stopper assembly into a 125 mL Erlenmeyer flask. **Important:** Twist the stopper into the neck of the flask to ensure a tight fit.

   d. Close the 2-way valve above the rubber stopper—do this by turning the valve handle so it is perpendicular with the valve stem itself (as shown in Figure 3). The air sample to be studied is now confined in the flask.

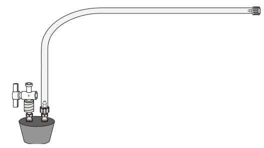

Figure 4

MAKE SURE YOUR SET UP IS AIR TIGHT!!!

3. Start Logger*Pro* and open the file "07 Pressure-Temperature" in the *Chemistry with Computers* folder.

4. Click ▶ Collect to begin data collection. This will allow you to collect data points in the table as you go.

5. Collect pressure *vs.* temperature data for your gas sample:

   a. Place the flask into the ice-water bath. Make sure the entire flask is covered (see Figure 3). Stir.
   b. Place the temperature probe into the ice-water bath.
   c. When the pressure and temperature readings displayed stabilize, click Keep. You have now saved the first pressure-temperature data pair.

6. Repeat the Step-5 procedure using the room-temperature bath.

Think about it: Has the measured pressure changed as you expected with increased temperature? If the pressure had stayed about the same, what do you think is wrong with the setup?

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7. Repeat the Step-5 procedure using the hot-water bath.

8. Use a ring stand and utility clamp to suspend the temperature probe in the boiling-water bath. To keep from burning your hand, hold the tubing of the flask using a glove or a cloth. After the temperature probe has been in the boiling water for a few seconds, place the flask into the boiling-water bath and repeat the Step-5 procedure. Remove the flask and the temperature probe after you have clicked Keep. **CAUTION:** *Do not burn yourself or the probe wires with the hot plate.*

9. Click ■ Stop when you have finished collecting data. Turn off the hot plate. Record the pressure and temperature values in your data table, or, if directed by your instructor, print a copy of the table.

10. Decide if your graph of pressure *vs.* temperature (K) represents a direct or inverse relationship:

    Based on the graph, we think there is a __________ relationship between the pressure and temperature of a gas.

    In Part 1, you learned how to make calculated columns and graphed them to see if there was a direct or inverse relationship. There is a different way to verify your prediction:

    a. Click the Curve Fit button, .
    b. Choose your mathematical relationship from the list at the lower left. If you think the relationship is direct, use Linear. If you think the relationship is inverse, use Power. Click [Try Fit].
    c. A best-fit curve will be displayed on the graph. If you made the correct choice, the curve should match up well with the points. If the curve does not match up well, try a different mathematical function and click [Try Fit] again. When the curve has a good fit with the data points, then click [OK].
    d. Autoscale both axes from zero by double-clicking in the center of the graph to view Graph Options. Click the Axis Options tab, and select Autoscale from 0 for both axes.

11. Record the data on the next page and print a copy of the graph of pressure *vs.* temperature (°C). The regression line should still be displayed on the graph. Enter your name(s) and the number of copies you want to print.

Report Sheets

Empirical Gas Laws (Parts 1 and 2) Name_________________________

Lab Partner_________________ Section _______

Data for Part 1

Create a data table to use for this experiment. You will record values on paper in case the computer loses your data. **Don't forget units.**

VOLUME ( )	PRESSURE ( )

Data for Part 2

Create a data table to use for this experiment. You will record values on paper in case the computer loses your data. **Don't forget units.**

TEMPERATURE ( )	PRESSURE ( )

Report Sheets

Follow-up Questions for Parts 1 and 2:

1. Prepare plots for Parts 1 and 2. You should have at least two linear and one non-linear plot to turn in. On linear graphs, obtain a best-fit line and equation for a line on the graph. Number all your graphs (Graph 1, 2, etc…) and include an appropriate **title** for each one. Make sure **axes labels include units**. Print a copy of the graphs for each person.

2. **Using specific data points on your graphs or best-fit lines**, explain approximately what happens to the pressure when:

a) The volume is halved

b) The temperature is halved

3) Based on the answers above,

a) Is pressure and volume directly or inversely proportional?

b) Is temperature and pressure directly or inversely proportional?

c) Suppose you obtain a nicely curved plot by graphing variables *x* and *y*. You assume this means *x* and *y* are inversely proportional. Describe another way to plot *x* and *y* to confirm they are inversely proportional (be specific).

Report Sheets

4) a) Write a verbal statement that correctly expresses the relationship between pressure and volume. Explain this relationship using the concept of molecular collisions.

b) Do the same for pressure and temperature. Use grammatically correct sentences.

5) a) Using your Pressure-Temperature graph (from Part 2), determine the pressure of air at 32°C by using the equation of the line you obtained. Show your work below.

_____________ kPa

b) Determine the pressure of air at 200°C by using the equation of the line you obtained. Show your work below.

_____________ kPa

c) Determine the value for **Absolute Zero in degrees Celsius** (Hint: What is the value of pressure at Absolute Zero?).

d) Calculate a % error by comparing your value (in the previous part) to the theoretical value of -273.15 °C.

$$\% \text{ error} = \frac{|(\text{experimental} - \text{theoretical})|}{\text{theoretical}} \times 100$$

Pre-Lab Assignment:
Gas Laws, Parts 1 and 2

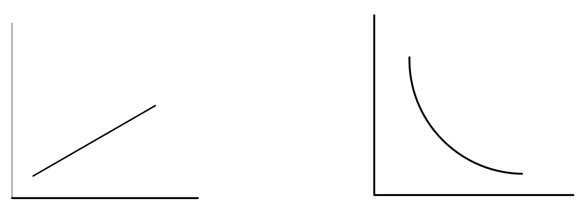
Name______________________
Section______

1) List three variables of gases that will be studied in Parts 1 and 2 of this experiment.

2) a - When the temperature of a gas in a container increases, do you expect the pressure to increase or decrease (assuming the volume of the container and number of gas molecules is constant)? Provide a brief molecular explanation.

b - When the volume of a gas increases, do you expect the pressure to increase or decrease (assuming the temperature and number of gas molecules is constant)? Provide a brief molecular explanation.

3) Label whether the variables most likely exhibit an "inversely proportional" relationship (one variable goes up while the other goes down) or "directly proportional" relationship (both variables increase or decrease at the same time).



4) Suppose you wish to study the effect of temperature on the volume of a gas by heating a gas in a cylinder and measuring the resulting changes in volume. What assumptions need to be made in order to study temperature and volume relationships?

5) For the pressure-temperature experiment (part 2), why is it important to use temperatures that are as spread out as possible?