The Ideal Gas Law

Objective:

Investigate the relationship between pressure, temperature, volume, and the amount of gas occupying an enclosed chamber. This experiment consists of three parts. In part one the relationship between pressure and volume will be measured. In part two the relationship between pressure and the amount of gas present in a chamber will be determined. Part three will illustrate the relationship between pressure and temperature. The results of these measurements will be used to derive the Ideal Gas Law.

Apparatus:

PASCO SE-8011 Gas Law Experimenter, Science Workshop 2.2 or higher, Science Workshop Computer Interface, CI-6532 Absolute Pressure Sensor, Stainless Steel Temperature Sensor, heat source and 3
rubber bands.

Theory:

The Ideal Gas Law describes the relationship between pressure, volume, the number of atoms or molecules in a gas, and the temperature of a gas. This law is an idealization because it assumes an "ideal" gas. An ideal gas consists of atoms or molecules that do not interact and that occupy zero volume. A real gas consists of atoms or molecules (or both) that have finite volume and interact by forces of attraction or repulsion due to the presence of charges. In many cases the behavior of real gases can be approximated quite well with the Ideal Gas Law.

The relationship between pressure and volume can be explained by the following theory. Gases exert force on the walls of their containers by means of continual collisions of the gas molecules with the surface. The force per unit area is termed pressure. If the volume of a container holding a gas sample is increased, the molecules may be expected to spend a larger portion of their time traveling through the interior. Therefore, they will strike the walls of the container less frequently, so the pressure should decrease. Decreasing the volume of the container should have the opposite effect on pressure.

This theory also explains why a gas container with more atoms or molecules will have a higher pressure than the same container with fewer atoms or molecules. Since molecules colliding with the walls of the container cause pressure, the more molecules there are, the more collisions there will be and thus a greater force per unit area will be present.

Molecules of a gas at a high temperature have higher kinetic energy than molecules of the same gas at a lower temperature. This explains why the molecules of a high temperature gas are moving at higher speeds than molecules of the same gas at a lower temperature. Molecules moving at high speed will exert more force on the walls of the container than the same molecules moving at lower speeds, thus a high temperature gas has a higher pressure than the same gas at a lower temperature.

The concepts of proportionality and inverse proportionality will be needed for this lab. If the variable *x* is proportional to *y* we write x α y. If the variable *x* is inversely proportional to *y* we write.

$$x \propto 1/y$$

The term "is proportional to" means there is a constant that makes the above expression equality x=cy, The term "is inversely proportional to" similarly implies.

$$x = b/y.$$

In this experiment you will measure the pressure, temperature, amount, and volume of air in a container. Since air is a real gas you will notice that its behavior is not exactly the same as an ideal gas, however, your results will illustrate quite well the relationships expressed by the Ideal Gas Law.

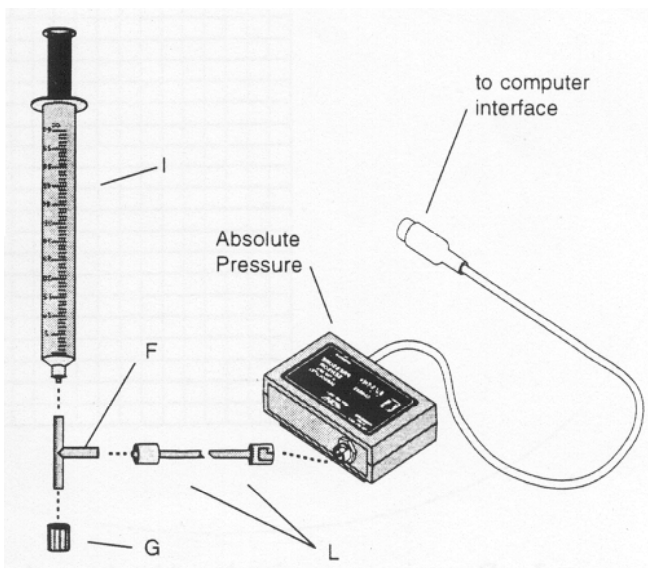
Part one: The relationship between pressure and volume

Purpose:

This experiment provides data needed to determine the relationship between volume and pressure, in a quantitative manner. Volume will be measured in cubic centimeters (cc) and pressure will be measured in thousands of Pascals (kPa). The results of this experiment, when combined with the results to experiments 2 and 3, lead to the Ideal Gas Law equation.

Procedure:

1. Make sure the syringe and fittings are dry inside and out. Connect the fittings as shown below:



2. In order to put 30 ml of air at ambient pressure in the syringe, complete the following steps:

a) Remove plug ***G*** and push the piston all the way in.
b) Pull the piston out to the 60 ml mark, and reinstall plug ***G***.
c) Disconnect ***L*** from the Absolute Pressure Sensor.
d) Push the syringe in to the 30 ml mark, and reconnect ***L*** to the Absolute Pressure Sensor.

3. Set up the Absolute Pressure Sensor to display absolute pressure in Pascals (kPa) as follows:

a) Insert the 8-pin DIN plug of the Absolute Pressure Sensor into the analog channel A jack of the computer interface.
b) In the Experiment Setup window of *Data Studio*, drag the analog plug icon to the analog channel A icon and select **Pressure Sensor (Absolute**).
c) Click okay, on the Digits icon to the analog channel A icon.

4. Begin monitoring the absolute pressure inside the syringe by holding down the "**Alt"** key and the "**M"** key simultaneously.

5. Have one lab partner record the volume of the syringe and the absolute pressure inside the syringe while the other lab partner moves the syringe to the following positions:

30 cc, 20 cc, 15 cc, 30 cc, 45 cc, 60 cc

Data:

P_0 = _______ (Absolute pressure when the volume of the syringe is 30 cc)
V_0 = __30 cc__

Pressure and Volume data

Pressure (Pn)	Volume (Vn)

Analysis:

Calculate the ratios Pn/Po and Vn/Vo

Pressure/P_0 (Pn/Po)	Volume/V_0 (Vn/Vo)

Summarize your data by completing the following sentences:

When the volume is two thirds as great as V_0 , the pressure is about ___________ as great as P_0.
When the volume is one half as great as V_0 , the pressure is about ___________ as great as P_0.
When the volume is three halves of V_0 , the pressure is about ___________ as great as P_0.
When the volume is twice as great as V_0 , the pressure is about ___________ as great as P_0.

These relationships suggest that Volume times Pressure is a constant. How does this theoretical prediction compare to the experimental results in the data table.

P_1 x V_1 = _______________
P_2 x V_2 =_______________
P_3 x V_3 =_______________
P_5 x V_5 =_______________
P_6 x V_6 =_______________

In words, we could say, "Pressure is ________________ to volume."

Part two: The relationship between pressure and N, the number of moles of gas

Purpose:

This experiment shows the relationship between the pressure and N, the number of moles of gas. One mole of gas contains Avogadro's number of molecules (6.022×10^{23}). The results of this experiment, together with those of parts 1 and 3, lead to the Ideal Gas Law equation.

Procedure:

1. Set up the apparatus as shown in the figure below.

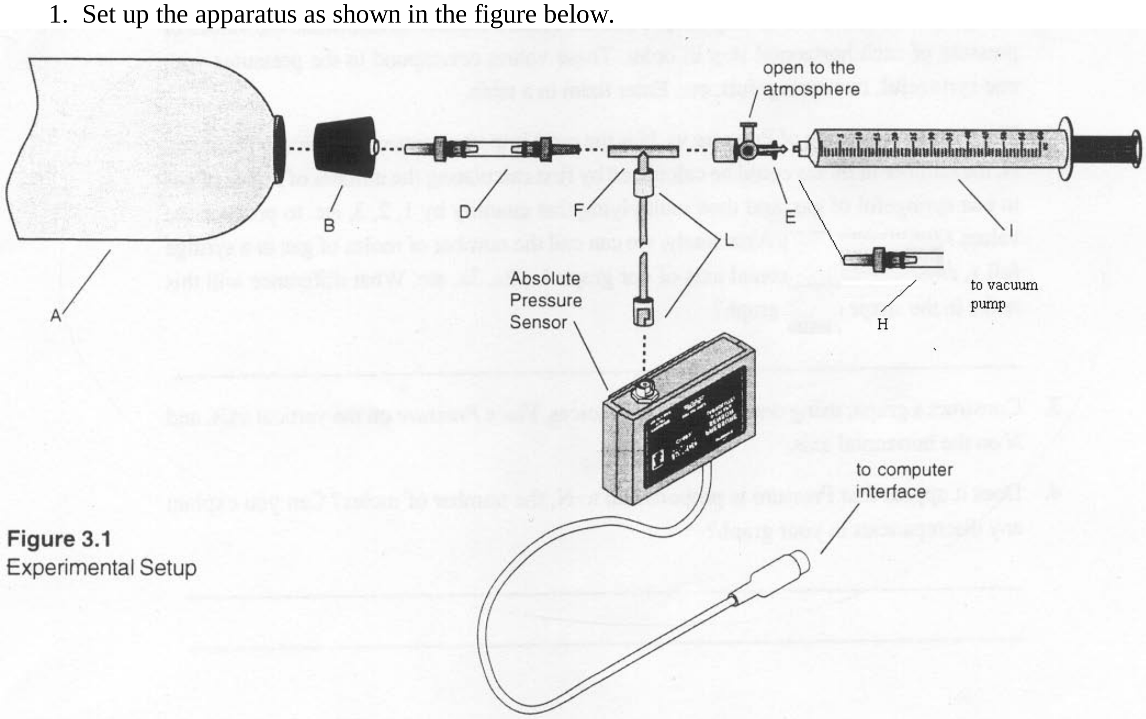


Figure 3.1
Experimental Setup

2. Press the "**Alt**" key and the "**M**" key simultaneously to display the canister pressure in the digital display. Evacuate the canister to 20 kPa either manually or with a vacuum pump by completing the following steps:

Manual evacuation:

a) Attach the syringe to ***E*** as shown in the figure.
b) Turn the handle of valve ***E*** toward the canister.
c) Push the syringe all the way in and turn the handle of valve ***E*** toward its side arm.
d) Pull the syringe all the way out to the 60 cc mark.

e) Turn the handle of valve ***E*** toward the canister.
f) If the pressure is not below 20 kPa go back to *step c*.

- ***Two people should be able to complete the above steps in 2 or 3 minutes.***

Evacuation with a vacuum pump:

a) Attach ***H*** to ***E*** and attach the vacuum pump to ***H*** as shown in the figure.
b) Turn the handle of valve ***E*** toward its side arm.
c) Start the vacuum pump.
d) Let the pump run until the pressure drops below 19 kPa.
e) Turn the handle of valve ***E*** toward the canister.
f) Turn off the vacuum pump and disconnect it from ***H***.
g) Attach the syringe to ***H***.

3. Add gas to the cylinder a "syringe full" at a time by completing the following steps until the pressure is just above 50 kPa:

a) Record the current pressure in the data table.
b) Pull the syringe all the way out to the 60 cc mark.
c) Turn the handle of ***E*** toward the side arm. One "syringe full" of air will enter the chamber.
d) Turn the handle of valve ***E*** toward the canister.
e) Wait 5 seconds and record the current pressure and number of "syringe full" of gas that have entered the canister. If the pressure is below 50 kPa, go to *step b*.

Data:

Pressure	Change in Pressure	Syringe fulls	Change in Syringe fulls
	---	N_0	---
		$N_0 + 1$	
		$N_0 + 2$	
		$N_0 + 3$	
		$N_0 + 4$	
		$N_0 + 5$	

Analysis:

1. To analyze the data we could calculate the number of moles of gas in one "syringe full" and then multiply that quantity by 1,2,3 etc. Alternately, we can call the number of moles of gas in a "syringe full" 1 unit.
2. Fill in the change in pressure and change in number of "syringe full" of gas in the data table.
3. Examine the data and notice that the pressure increases by nearly the same amount each time a "syringe full" of gas enters the chamber.
4. Assume that at zero pressure there are zero "syringes full" of gas in the canister. Extrapolate backwards and determine N_0.

5. In words, we can say, "Pressure is __________ to N, the number of Syringes full of gas."

Part three: The relationship between pressure and temperature

Purpose:

This experiment provides data needed to determine the mathematical relationship between pressure and temperature of a gas. Temperature will be measured in degrees Celsius and then converted to Kelvin by adding 273.16. The results of this experiment, when combined with the results to experiments 1 and 2, lead to the Ideal Gas Law equation.

Procedure:

1. Refer to the figure for part two. With the handle of valve ***E*** turned toward the canister, remove the syringe from ***E***. The canister should still have a pressure of just over 50 kPa.

2. Place three rubber bands around the canister. Place one at the neck and the other two around the body of the canister.

3. Affix a Temperature Sensor to the side of canister with two of the rubber bands.

4. Place the canister in the heat source and fill the heat source with water.

5. Connect the Temperature Sensor to the computer interface box as follows:

    a) Insert the 8-pin DIN plug of the Temperature Sensor into the analog channel B jack of the computer interface.
    b) In the Experiment Setup window of *Data Studio*, click the analog plug icon to the analog channel B icon and select **Temperature Sensor**.
    c) Drag the Digits icon to the analog channel B icon.

6. Press the "**Alt**" and "**M**" keys simultaneously to begin monitoring the pressure and temperature. ("**Alt**" and "**.**" halts monitoring.)
7. Plug the heat source into an AC outlet to begin heating the gas.
8. Record the pressure and temperature at 10 degree C intervals. At each interval unplug the heat source and wait for 30 seconds before taking the measurements. This will allow time for the gas to come to equilibrium. Continue until the temperature is above 80 degrees C.

Data:

Temperature Celsius	Temperature Kelvin	Pressure	Pressure/Temperature

Analysis:

1. Notice that for each row of data the pressure divided by the temperature in nearly the same.

2. If the pressure divided by the temperature of an ideal gas is equal to the same constant for all values of pressure and temperature then "Pressure is _____________ to temperature."

Deriving the Ideal Gas Law

1. Summarize the results of Experiment 1:

    Pressure is proportional to _____________.

    Summarize the results of Experiment 2:

    Pressure is proportional to _____________.

Summarize the results of Experiment 3:

Pressure is proportional to _____________.

2. A useful theorem is as follows:

If a is proportional to b, and
a is proportional to c, and
a is proportional to d, then
a is proportional to the product of b, c, and d.

Apply this theorem to the results of experiments 1-3:

Pressure is proportional to __________________________.

3. Use the definition of "is proportional to" to state your answer to question 2 as an equation. Use the symbol R to represent the constant of proportionality.

4. Show the algebraic steps necessary to express this equation in the form PV = NRT.