Chem 30A   Thursday Oct. 29

Gas Laws

- Ideal Gas Law

- Combined Gas Law
    - Boyle's Law
    - Charle's Law
    - Avagadro's Law

- Dalton's Law of Partial Pressures

Ideal Gas Law

- Gas particles travel in straight line & unaffected by gravity

- Energy & direction traded in Collisions.

- Size of gas particle doesn't matter, treat as a point mass ⇒ has no volume, only mass.
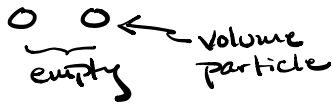
- Hotter something is the faster it is moving

Gases

Solid   liquid

Condensed Matter
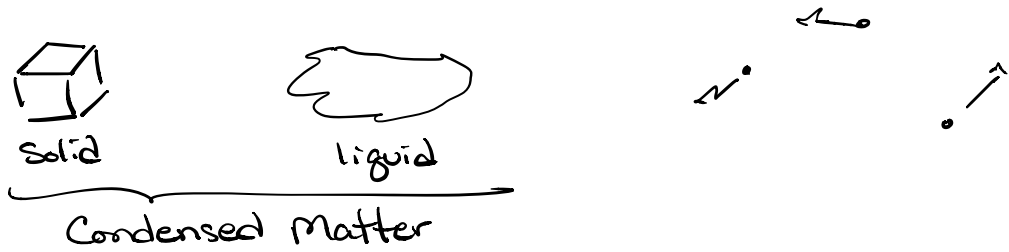
| 90 - 95% particles | 80 - 85% particles | 0.1% particles |
| 5 - 10% empty space | 15 - 20% empty space | 99.9% empty space |

empty   volume particle

Gases travel fast

O_2 @ 25°C   500 mph

10 x diameter between Collisions
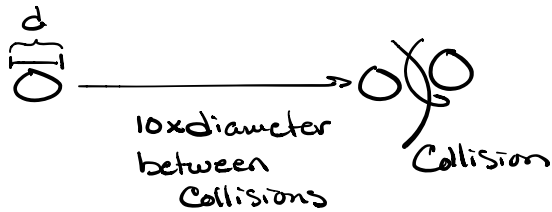
Collision

Energy is traded in Collisions

fast   Collision   Slow

Slows down ⇒ Colder

Speeds up ⇒ Hotter
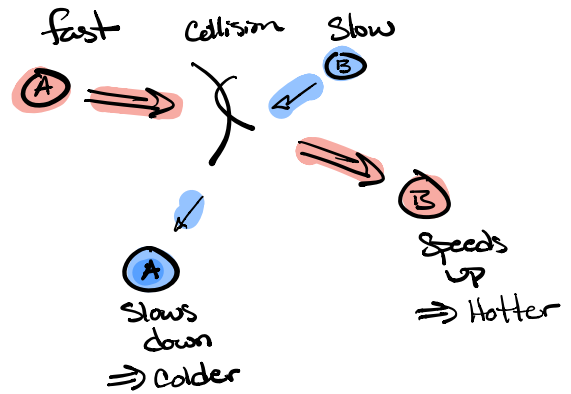
The Properties of Gasses

Property	Units
Volume	Liters (L)
Temperature	°C or K
⟹ Pressure	atmosphere (atm) or mmHg or torr
amount	moles

Pressure = force/area   force per unit area

Top of atmospher   1in × 1in   lbs/in²

pressure is less

Sea level   14.7 lbs/in²
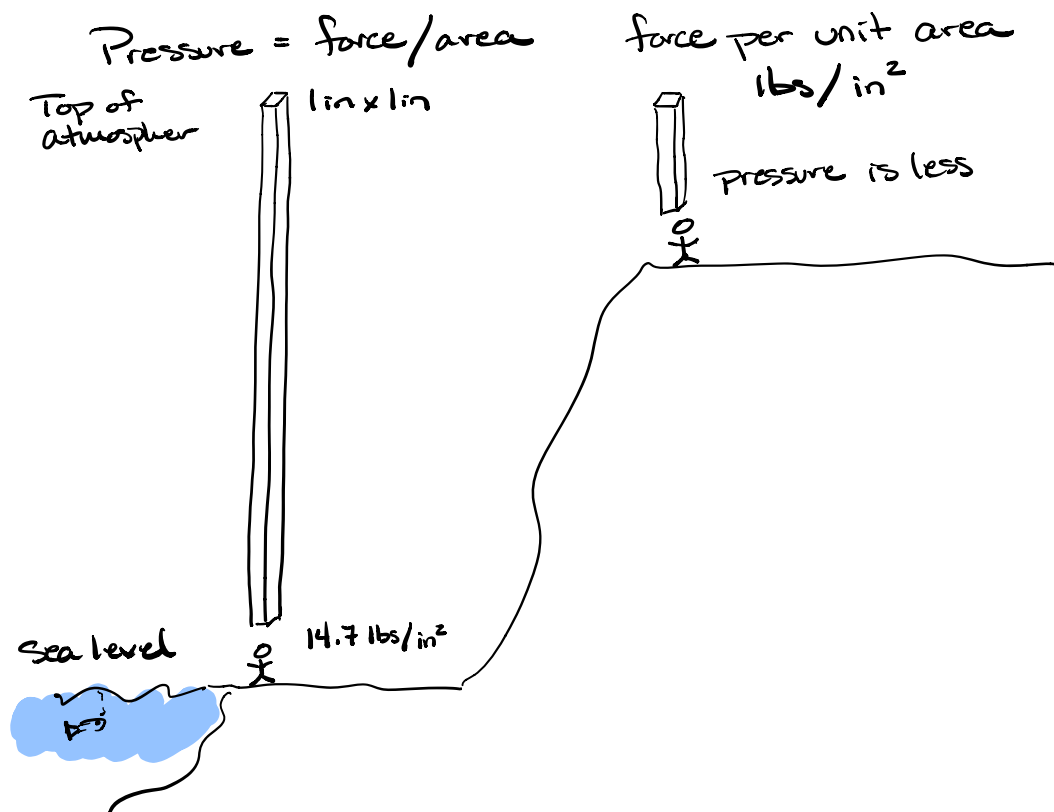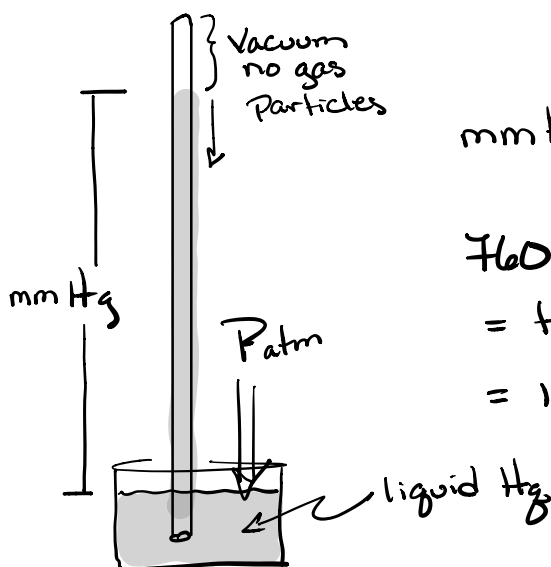
mm Hg = millimeters of Hg

760 mmHg = 1 atm
= to pressure at sea level
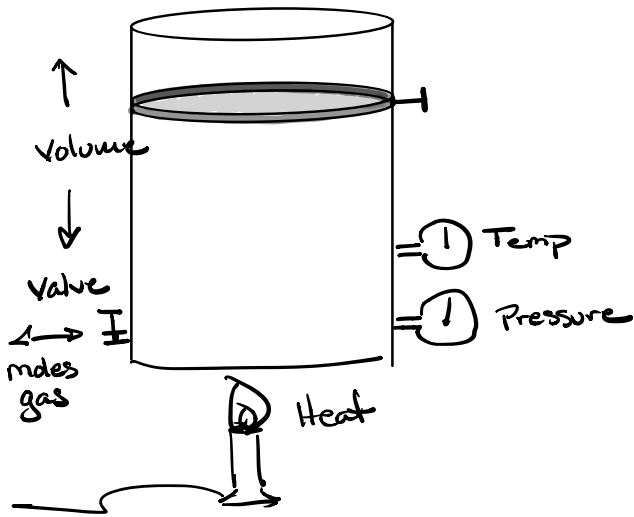= 14.7 lbs/in²

United States Barametric pressure
units of in Hg

$$760 \text{ mm Hg} \times \frac{1 \text{ cm}}{10 \text{ mm}} \times \frac{1 \text{ in}}{2.54 \text{ cm}} = 29.9 \text{ in Hg}$$

760 mmHg = 1 atm   Exact Conversion factor
                     Definition

760 torr = 1 atm

1 mm Hg = 1 torr

An investigation into
gas property relationships.
Look at two properties
while we hold the
other two constant.

Volume

Temp

Pressure

Valve

moles
gas

Heat

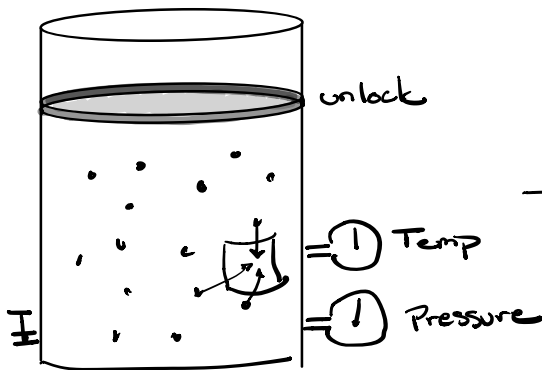## Boyle's Law Relationship

Pressure vs. Volume (hold temp & moles constant)

Result $V\downarrow$ $P\uparrow$ $P \propto \dfrac{1}{V}$ Inversely proportional

unlock

Temp

Pressure

Starting

Pressure = force/area
        = collisions/area·time

pushed very
slowly to
not change temp

unlock
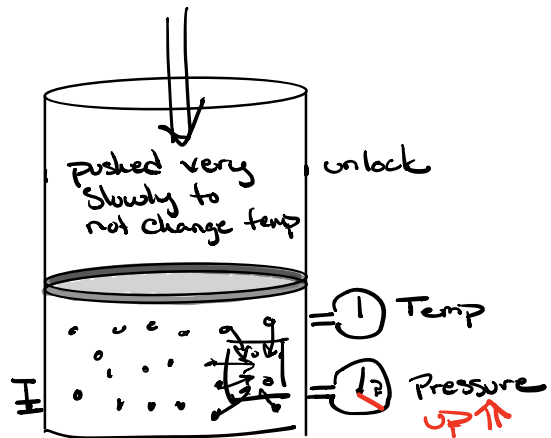
Temp

Pressure
UP

Ending

more collisions per area
more collisions per time
more pressure UP

Pressure vs Temp (volume & moles Constant)

Result $P\uparrow$ $T\uparrow$ $P \propto T$ Directly proportional

↑ proportional too
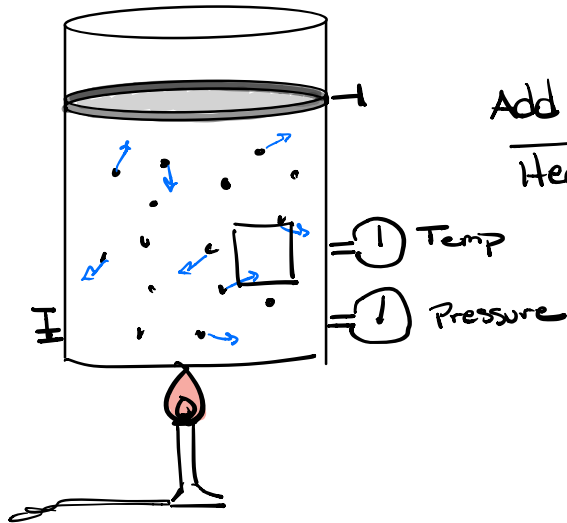
Add Heat →
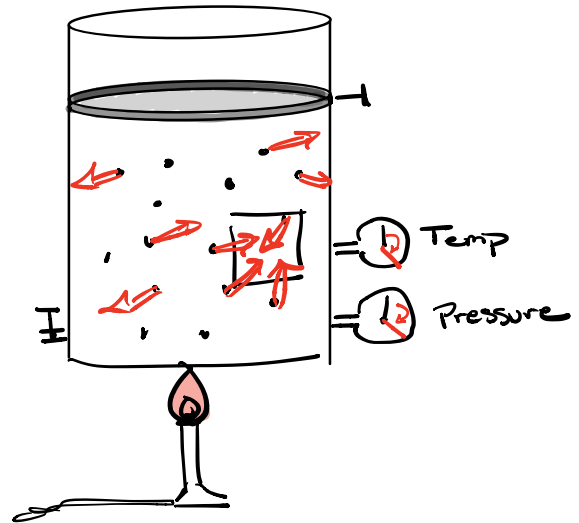
Temp

Pressure

$$P = \frac{Collisions}{Area \cdot time}$$

Particles moving slow
few Collisions in time
= low pressure

Temp

Pressure

- # of Collisions increase in time
- each Collision has more force
- Increase in Pressure

Pressure vs. Moles (Temp & Volume Const.)

Result ↑P   moles ↑   P ∝ moles Directly Proportional
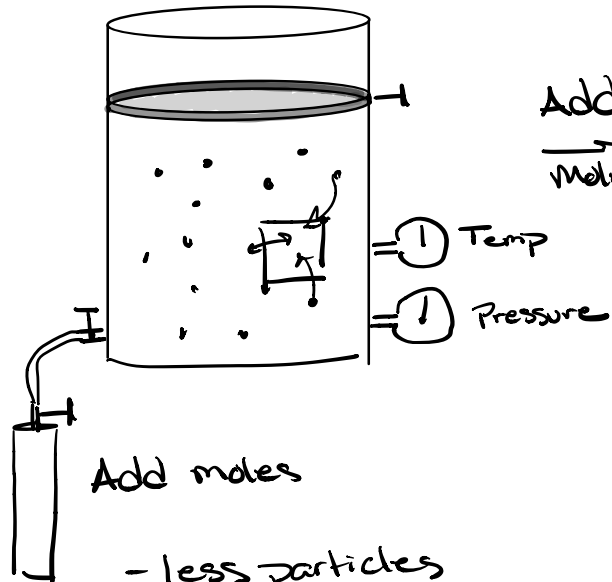
Add Moles

Add moles

- less particles
- Less Collisions per time
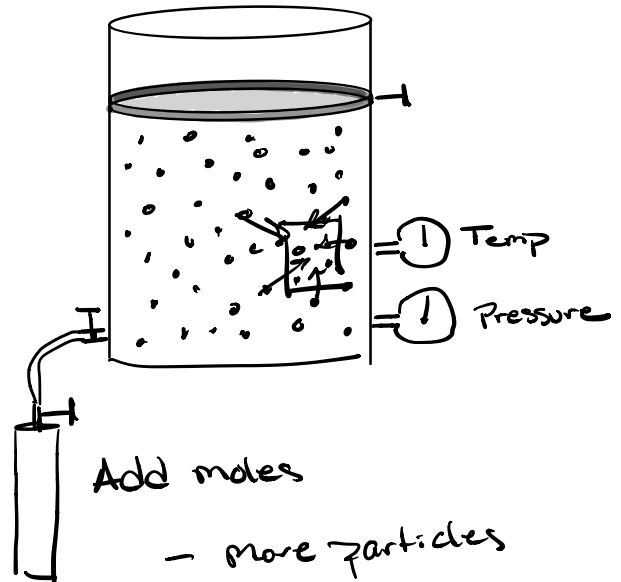
Add moles

- more particles
- more Collisions per time
- Higher pressure

$$P \propto \frac{1}{V}$$

$$P \propto T$$

$$P \propto n$$

$n = \text{moles}$

$$P \propto \frac{Tn}{V} \quad \text{Combined Relationship}$$

would like an equality $=$

$$P = \cancel{C} \frac{Tn}{V} + 0$$

proportionality Constant

$$y = mx + b \quad \text{Straight line formula}$$

Slope of line
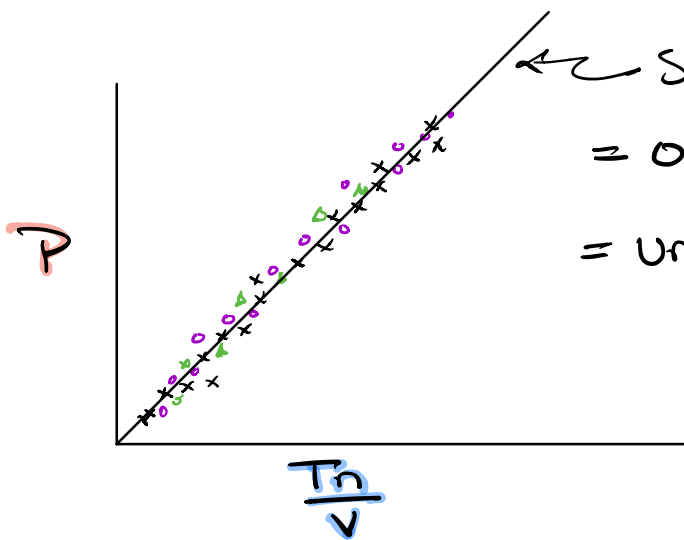
Slope of line

$$= 0.0821 \frac{L \cdot atm}{mole \cdot k}$$

$= \text{Universal Gas Constant}$

P

$\frac{Tn}{V}$

R is the variable assigned to that slope

$$R = 0.0821 \frac{L \cdot atm}{mol \cdot K}$$

$$P = R \frac{Tn}{V} \qquad \text{Ideal Gas Law}$$

$$y = m \, x \, + \, b$$

$$V \times P = \frac{RTn}{V} \times V$$

$$PV = nRT \qquad \text{Ideal Gas Law}$$

$$P = atm$$
$$V = L$$
$$n = moles$$
$$T = K$$

$$R = \frac{L \cdot atm}{mole \cdot K}$$

How to use the Ideal Gas Law
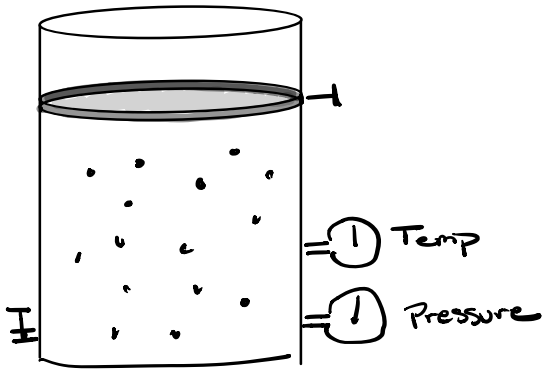
Volume = 2.5 L

moles = 3.6 mole N_2

Temperature = 25°C

$$\frac{+273}{298\ K}$$

Pressure = ?

$$PV = nRT$$

$$P = \frac{nRT}{V} = \frac{(3.6\ moles)(0.0821\ \frac{L\ atm}{mol\ K})(298\ K)}{2.5\ L}$$

$$P = 35.230752\ atm$$

$$\boxed{P = 35\ atm}$$

How to Solve PV = nRT Problems

- Parse problem & identify all variables & question

- make a list w/ units

  $P = ?$

  $V = 2.5 L$

  $n = 3.6$ moles

  $R = 0.0821 \frac{L \cdot atm}{mol \cdot K}$

  $T = 25°C$

- Convert any units not in the proper unit

Required	often given as
$T = K$	$T = °C$
$V = L$	$V = mL$
$n = $ moles	$n = $ grams of material
$P = $ atm	$P = $ mmHg or torr

- Solve equation for unknown

  $$\frac{P\cancel{V}}{\cancel{V}} = \frac{nRT}{V} \qquad \text{Solve for } P$$

  $$P = \frac{nRT}{V}$$

- Add in values & Calc answer

- Sigfigs & units

What is the temperature of a 1.5 L cylinder that contains 0.623 moles of nitrogen gas at a pressure of 723 mm Hg ?

$P = 723 \, mmHg \times \dfrac{1 \, atm}{760 \, mmHg} = 0.951315789 \, atm = 0.951 \, atm$

$n = 0.623 \, mol$

$T = ?$

$R = 0.0821 \, \dfrac{L \cdot atm}{mol \cdot K}$

$V = 1.5 \, L$

$\dfrac{PV}{nR} = \dfrac{\cancel{n}R T}{\cancel{n}\cancel{R}}$

$\dfrac{PV}{nR} = T$

$T = \dfrac{(0.951 \, atm)(1.5 \, L)}{(0.623 \, mol)(0.0821 \, \frac{L \cdot atm}{mol \cdot K})} = \dfrac{1}{\frac{1}{K}} = 1 \times \dfrac{K}{1} = K$

Calc

$0.951 \times 1.5 \div (0.623 \times 0.0821) = 27.889489973$

or

$0.951 \times 1.5 \div 0.623 \div 0.0821 = 27.889489973$

$\boxed{= 28 \, K}$

$$\frac{PV}{nT} = \frac{nRT}{nT} \qquad \text{Solve for } R$$

Condition 1 $\quad \dfrac{P_1 V_1}{n_1 T_1} = R$

Condition 2 $\quad \dfrac{P_2 V_2}{n_2 T_2} = R$

$$\dfrac{P_1 V_1}{n_1 T_1} = \dfrac{P_2 V_2}{n_2 T_2}$$

Combined Gas Law
used for changin
Conditions

$x = R$

$y = R$

$x = \cancel{R} = y$

$x = y$

Boyle's Law P vs V

hold T & moles
Constant

$$\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2}$$

$$\frac{P_1 V_1}{\cancel{n_1 T_1}} = \frac{P_2 V_2}{\cancel{n_1 T_1}}$$

$$\boxed{P_1 V_1 = P_2 V_2 \quad \text{Boyle's Law}}$$

Ideal Gas Law $PV = nRT$ | $R = 0.0821 \frac{L \cdot atm}{mol \cdot K}$

$P = atm$
$V = L$
$T = K$
$n = moles$

$760\ mmHg = 1\ atm$

Combined Gas Law

$$\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2}$$

Name:_____ Section Number:_____ Score:_____

Gas Law's: Boyle's Law: Pressure-Volume Relationship in Gases

The primary objective of this experiment is to determine the relationship between the pressure and volume of a confined gas. The gas we use will be air, and it will be confined in a syringe connected to a Gas Pressure Sensor (see Figure 1). When the volume of the syringe is changed by moving the piston, a change occurs in the pressure exerted by the confined gas. This pressure change will be monitored using a Gas Pressure Sensor. It is assumed that temperature will be constant throughout the experiment. Pressure and volume data pairs will be collected during this experiment and then analyzed. From the data and graph, you should be able to determine what kind of mathematical relationship exists between the pressure and volume of the confined gas. Historically, this relationship was first established by Robert Boyle in 1662 and has since been known as Boyle's law.

OBJECTIVES

In this experiment, you will

- Use a Gas Pressure Sensor and a gas syringe to measure the pressure of an air sample at several different volumes.
- Determine the relationship between pressure and volume of the gas.
- Describe the relationship between gas pressure and volume in a mathematical equation.
- Use the results to predict the pressure at other volumes.
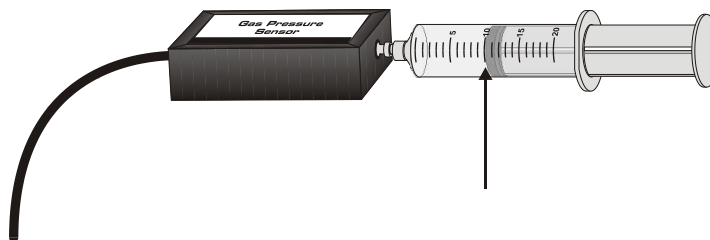
Figure 1

MATERIALS

LabQuest	Vernier Gas Pressure Sensor
LabQuest App	20 mL gas syringe

PROCEDURE

1. Prepare the Gas Pressure Sensor and an air sample for data collection.

   a. Connect the Gas Pressure Sensor to LabQuest and choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor.

   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 1) is positioned at the 10.0 mL mark.

    c. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.

2. Set up the data-collection mode.

    a. On the Meter screen, tap Mode. Change the mode to Events with Entry.

    b. Enter the Name (Volume) and Units (mL). Select OK.

3. To obtain the best data possible, you will need to correct the volume readings from the syringe. Look at the syringe; its scale reports its own internal volume. However, that volume is not the total volume of trapped air in your system since there is a little bit of space inside the pressure sensor.

    To account for the extra volume in the system, you will need to add 0.8 mL to your syringe readings. For example, with a 5.0 mL syringe volume, the total volume would be 5.8 mL. *It is this total volume that you will need for the analysis.*

4. You are now ready to collect pressure and volume data. It is easiest if one person takes care of the gas syringe and another enters volumes.

    a. Start data collection.

    b. Move the piston so the front edge of the inside black ring (see Figure 2) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the screen stabilizes.

    c. Tap Keep and enter **5.8**, the gas volume (in mL) on the screen. Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Select OK to store this pressure-volume data pair.
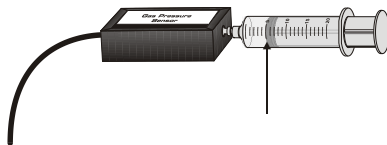

Figure 2

    d. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.

    e. Stop data collection.

5. When data collection is complete, a graph of pressure *vs.* volume will be displayed. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the pressure and volume values are displayed to the right of the graph. Record the pressure and volume data values in your data table.

6. Based on the graph of pressure *vs.* volume, decide what kind of mathematical relationship exists between these two variables, direct or inverse. To see if you made the right choice:

    a. Choose Curve Fit from the Analyze menu.

    b. Select Power as the Fit Equation. The curve fit statistics for these two data columns are displayed for the equation in the form

$$y = Ax^{\wedge}B$$

    where *x* is volume, *y* is pressure, *A* is a proportionality constant, and *B* is the exponent of *x* (volume) in this equation. **Note:** The relationship between pressure and volume can be determined from the value and sign of the exponent, *B*.

    c. If you have correctly determined the mathematical relationship, the regression line should very nearly *fit* the points on the graph (that is, pass through or near the plotted points).

    d. Select OK.

7. (optional) If directed by your instructor, proceed directly to the Extension that follows Processing the Data.

DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, k P/V (direct) or P•V (inverse)
5	110	
10	56	
12	42	
15	35	
17.5	30	
20	25	
40	??	

PROCESSING THE DATA

1. If the volume is *doubled* from 5.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer.

2. If the volume is *halved* from 20.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer.

3. If the volume is *tripled* from 5.0 mL to 15.0 mL, what does your data show happened to the pressure? Show the pressure values in your answer.

4. From your answers to the first three questions *and* the shape of the curve in the plot of pressure versus volume, do you think the relationship between the pressure and volume of a confined gas is direct or inverse? Explain your answer.

5. Based on your data, what would you expect the pressure to be if the volume of the syringe was increased to 40.0 mL. Explain or show work to support your answer.

6. Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL.

7. What experimental factors are assumed to be constant in this experiment?

8. One way to determine if a relationship is inverse or direct is to find a proportionality constant, k, from the data. **If this relationship is direct, $k = P/V$. If it is inverse, $k = P•V$.** Based on your answer to Question 4, choose one of these formulas and calculate k for the seven ordered pairs in your data table (divide or multiply the *P* and *V* values). Show the answers in the third column of the Data and Calculations table.

9. How *constant* were the values for *k* you obtained in Question 8? Good data may show some minor variation, but the values for *k* should be relatively constant.

10. Using *P*, *V*, and *k*, write an equation representing Boyle's law. Write a verbal statement that correctly expresses Boyle's law.

EXTENSION

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs. reciprocal of volume* (1/volume) may also be plotted. To do this using LabQuest:

    a. Tap the Table tab to display the data table.
    b. Choose New Calculated Column from the Table menu.
    c. Enter the Name (1/Volume) and Units (1/mL). Select the equation, A/X. Use Volume as the Column for X, and **1** as the value for A.
    d. Select OK.

2. Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of pressure *vs.* 1/volume:

    a. Choose Graph Options from the Graph menu.
    b. Select Autoscale from 0 and select OK.
    c. Choose Curve Fit from the Analyze menu.
    d. Select Linear as the Fit Equation. The linear-regression statistics for these two data columns are displayed in the form:

    $$y = mx + b$$

    where *x* is 1/volume, *y* is pressure, *m* is a proportionality constant, and *b* is the y-intercept.
    e. Select OK. If the relationship between P and V is an inverse relationship, the graph of pressure *vs.* 1/volume should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.

3. Draw a sketch of the two graphs:
    a. Pressure (y-axis) vs Volume (x-axis)   b. Pressure (y-axis) vs 1/Volume (x-axis)