Gas Laws: Boyle's and Amonton's Laws

MCTC Chemistry *v.9.17*

Objective: The purpose of this experiment is confirm Boyle's and Amontons' Laws in the laboratory.

Prelab Questions: Read through this lab handout and answer the following questions before coming to lab. There will be a quiz at the beginning of lab over this handout and its contents.

1. Convert the pressure measurement 789 mmHg into torr <u>and</u> atmospheres with the correct number of significant figures.

2. What variables are considered "constant" in Boyle's Law calculations?

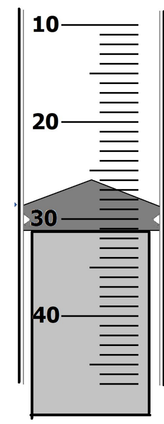
3. In the Boyle's Laws experiment you will be determining a value for the volume of the tube. Consider the tube to be 50. cm long with an inside diameter of 4.0 mm. Use the volume equation for a cylinder to determine the volume of the tube in mL. $Vol_{cylinder} = \pi r^2 h$

4. How is Charles's law different from Amanton's law? How are they alike?

5. A person guesses your age at 26 years. However, you are actually 33 years old. Calculate Δ%.

6. How many points will be used to calibrate the pressure sensor?

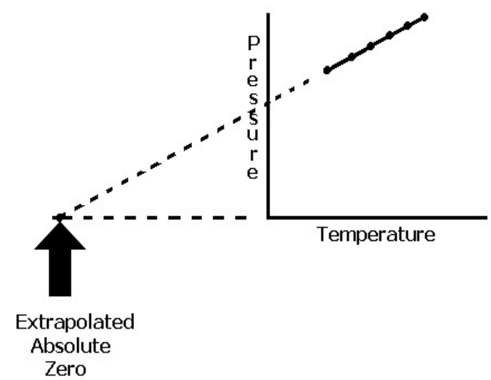
7. What is the correct reading for the syringe at right?



8. While heating the flask (Amonton's law) the hose becomes disconnected. What do you do?

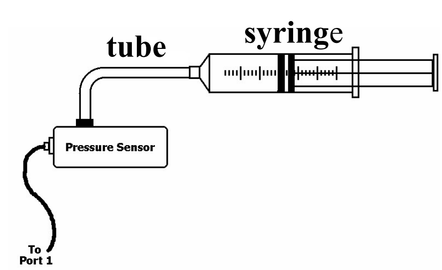
9. We'll be extrapolating a value for Absolute Zero in this experiment (figure at right). What part of the graph represents the data points actually measured?

10. In the Amonton's law experiment, how do we measure the temperature of the gas within the flask?



Boyle's Law

If one considers a constant amount of a gas (n=constant) and an unchanging gas temperature (T=constant), then Boyle's Law states that the pressure externally exerted on a gas is related to the volume occupied by the gas such that PV = k where k is a constant. If the pressure on a gas is varied then the volume will adjust to keep the product PV constant, as long as every variation is done with a constant n and T.



The apparatus used for this experiment is shown above. A syringe is connected via a tube to a pressure sensor, which is connected to a computer. The volume occupied by the gas is the sum of the syringe volume, $\mathbf{V_{syringe}}$ and the small, fixed volume of the tube that connects the pressure sensor to the syringe, $\mathbf{V_{tube}}$.

The total volume (V_{total}):

$$V_{total} = V_{tube} + V_{syringe} \qquad (1)$$

is used to calculate the Boyle's Law constant, k:

$$P \times V_{total} = k \qquad (2)$$

Failure to include V_{tube} in the calculation produces a Boyle's Law constant that isn't very constant at all!

The data you collect consists of nine different pressure-volume readings. The pressure measurement is obtained from the Logger Pro computer readout. The volume measurement, $V_{syringe}$, is obtained by determining the position of the syringe plunger against the graduated scale on the syringe barrel.

V_{tube} is determined mathematically using two different (P, $V_{syringe}$) experimental data points and the mathematics that follow. According to Boyle's law the product of **P** × V_{total} should be the same for any set of pressures and volumes so long as the number of moles of gas, n, and the temperature, T, do not change. This can also be stated as:

$$P_x \times V_{tot\ x} = P_y \times V_{tot\ y} \qquad (3)$$

The total volumes are the combined syringe- tube volumes:

$$V_{tot\ x} = V_{syringe\ 1} + V_{tube} \qquad (4)$$
$$V_{tot\ y} = V_{syringe\ 2} + V_{tube} \qquad (5)$$

Substituting equations 4 & 5 into equation (3) we obtain:

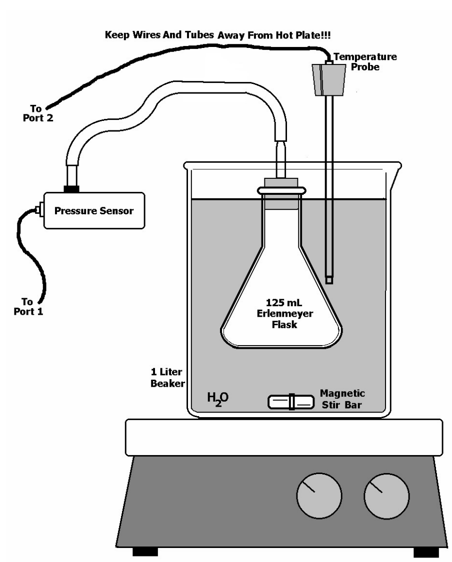
$$P_1 \times (V_{syringe\ 1} + V_{tube}) = P_2 \times (V_{syringe\ 2} + V_{tube}) \qquad (6)$$

Which can be solved for V_{tube}:

$$V_{tube} = \frac{(P_1 \times V_{syringe\ 1} - P_2 \times V_{syringe\ 2})}{P_2 - P_1} \qquad (7)$$

One obtains V_{tube} by substituting any two pressure-volume data points into the equation. This one value of V_{tube} is then added to each of the $V_{syringe}$ values before the respective P × V_{total} product is calculated.

Amontons' Law



Amontons' Law states that a pressure-temperature relationship exists for a fixed amount of gas in a fixed volume. At constant volume, the pressure exerted by a fixed amount of gas is directly proportional to the absolute temperature (i.e. Kelvin scale):

$$P = K \times T \qquad (8)$$

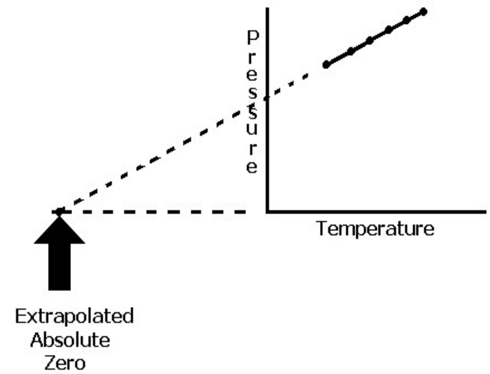
Here **K** is *a different constant* than the constant expressed in the Boyle's Law.

In this part of the experiment you will collect pressure & temperature data to test whether the quotient, P/T, is a constant.

The apparatus used to collect the pressure-temperature data points (right) consists of an Erlenmeyer flask immersed in a water bath whose temperature is **increased slowly** using a hot plate. A stopper in the top of the flask traps the gas inside the flask, fixing the volume and amount of gas. The pressure sensor is attached to the flask via a tube inserted into the stopper.

Different temperatures are obtained by ***slowly*** heating the Erlenmeyer flask indirectly with the water bath using a hot plate. A large magnetic stir bar is used to continuously stir the water bath guaranteeing a uniform temperature throughout. So long as the temperature doesn't change too fast, assuming the temperature of the gas is the same as the temperature of the surrounding water bath is valid. A temperature sensor is used to measure the temperature of the water bath (and flask).

Amontons' Law says a graph of pressure versus temperature for an ideal gas is a straight line (figure at right). The straight line can be extended or ***extrapolated*** to lower pressures to where the pressure is zero. At this point the lowest possible temperature, **absolute zero** (defined in the Kelvin system), can be read from the graph's horizontal axis. This temperature, **absolute zero**, is the theoretical temperature where all molecular motion stops. In reality, real gases condense or liquefy before reaching absolute zero.



In your data analysis, you will use M.S. Excel to graph your experimental pressure-temperature data points and perform the *trend line analysis* of the data to predict the value of absolute zero in the Celsius temperature system.

Delta Percent: Comparing data differences using percent calculations

Delta percent (Δ%) calculations are often used to compare experimental values to known values. The Δ% value is the difference between the two values expressed as a percentage. Δ% is expressed with either a + or – to indicate whether the experimental value is higher or lower than expected.

Delta percent is calculated as follows:

$$\Delta\% = \frac{(\text{Experimental value} - \text{Known value})}{(\text{Known value})} \times 100$$

For example, if someone guesses your age to be 27 years old when your actual age is 30, Δ% can be used to describe the error:

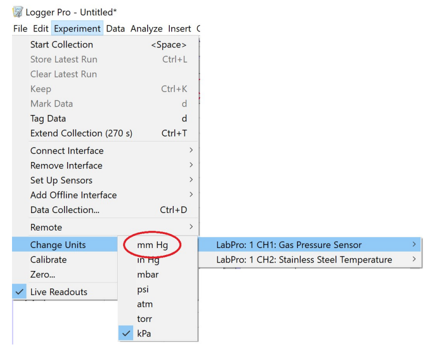
$$\Delta\% = \frac{(\text{Experimental value} - \text{Known value})}{(\text{known value})} \times 100 = \frac{(27 \text{ years} - 30 \text{ years})}{30 \text{ years}} \times 100$$

$$\Delta\% = -10\%$$

Notice that Δ% appears with a negative sign telling us that the "guess" was lower than the known value.

In the Boyle's Law experiment, you'll be calculating the P x V constant for several different trials. An average value for the constant will be calculated and considered the "known" value. Δ% values for each P x V trial will be determined comparing each to the average value.

Experiment: Calibration



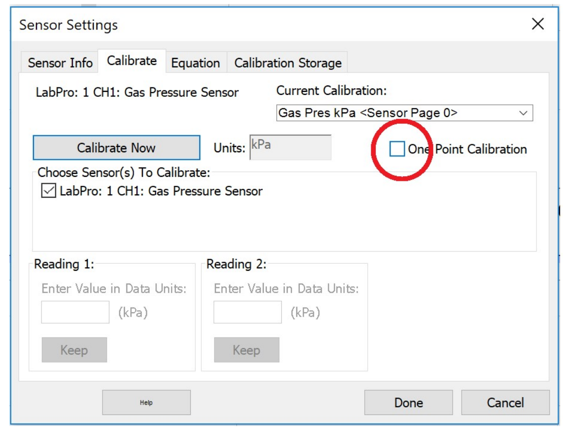
1. Attach the pressure sensor to CH 1 of the Vernier Interface.

2. Attach the stainless steel temperature sensor to CH 2.

3. Activate the Logger Pro software.

4. Set the pressure units to mm_{Hg} by clicking (Figure at right)

   Experiment -> Change Units -> LabPro Ch1: Gas Pressure Sensor -> mm Hg



5. <u>Disconnect</u> the pressure sensor hose. It must be open to the atmosphere.

6. Open up the calibration menu by clicking on Experiment -> Calibration -> Pressure sensor

7. De-select the One Point Calibration check box (figure at right). We'll be using a two point calibration

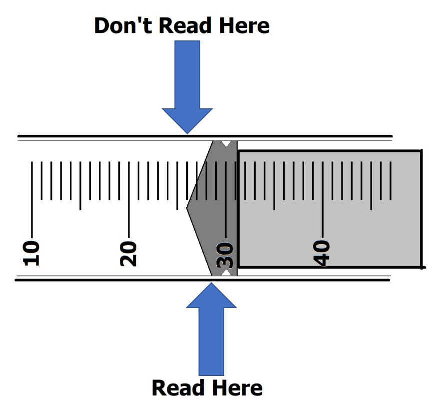
8. Click "Calibrate Now" and enter the current atmospheric pressure (mm_{Hg}) in the Reading 1 box.

9. Click "Keep"

10. Notify your instructor that you're ready for the second calibration point.

11. Verify the calibration is correct by reading atmospheric pressure and comparing it to the known value.

Experiment: Boyle's Law

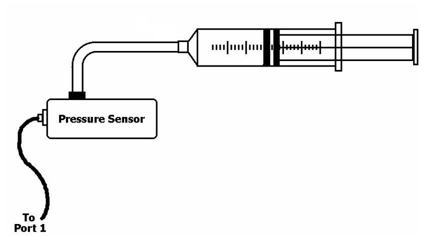


1. Position the plunger of the syringe at the 60 mL mark. Assemble the apparatus shown below. Push the clear plastic tube firmly on the end of the syringe. There must be NO LEAKS!

2. Record the pressure indicated by the LoggerPro display. This measurement should be paired with volume = 60 mL.

   The pressure display will fluctuate so record only those digits that are significant.

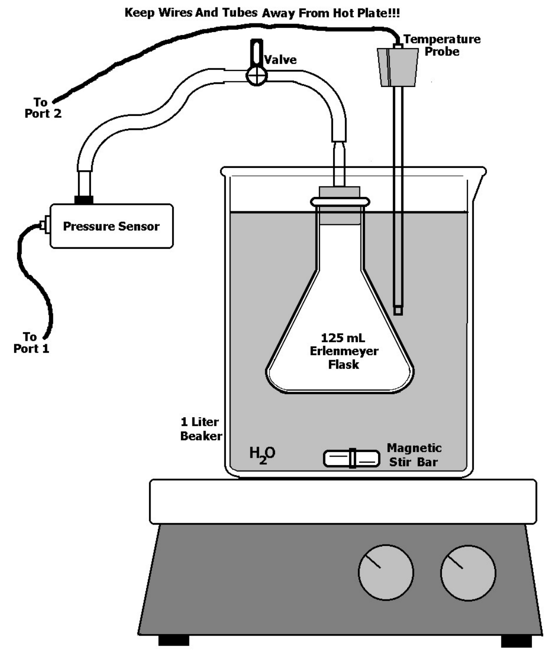
3. Push the plunger in to the 55.00 mL mark and again record the pressure on your data table.



4. Repeat the process above for each of the following nine volumes:
   a. 60.0 mL
   b. 55.0 mL
   c. 50.0 mL
   d. 45.0 mL
   e. 40.00 mL
   f. 35.0 mL
   g. 30.0 mL
   h. 25.0 mL
   i. 20.0 mL

Do not attempt volumes smaller than 20.00 mL as you may damage the syringe and pressure sensor!

Experiment: Amonton's Law



1. Assemble the apparatus at right.
    a. Hotplate: Off
    b. Stir Function: Off

2. Push the pressure sensor tube firmly on the glass tube sticking out of the 125 mL Erlenmeyer flask.

    If the tubing pops off during the experiment, you will have to start over from the beginning.

3. Use a utility clamp *around the topmost part of the flask* to support it and to keep it submerged in the water. (clamp not shown in figure)

4. Use the articulated arm (not shown in figure) to support the temperature probe.

    Position the tip of the temperature sensor halfway down the flask and as close to the flask as possible.

5. Keep wires and tubes away from the hot plate (they will melt)

6. Fill the 1 L beaker with enough COLD TAP water to cover the 125 mL flask as shown in the figure above.

7. The beaker will be almost completely full. (*All of the gas inside the flask must experience the same temperature provided by the water bath*).

8. Start the stir bar (500 – 600 rpm). Very vigorous stirring is required to keep such a large amount of water well mixed.

    We will assume the temperature of the water is the same as the gas temperature.

9. Before you begin heating, have the instructor check over your apparatus.

10. Set the hot plate temperature at 400°C.

11. As the water warms up, it expands and will overflow the beaker. Use the squeeze blub and pipette (right) to remove water as necessary.

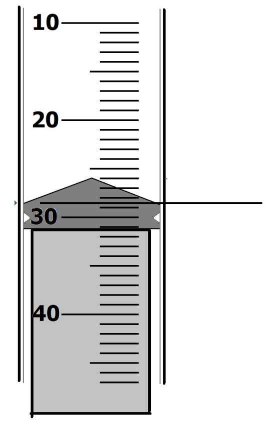
12. Record at least 30 pressure/temperature data points that are roughly evenly distributed between your start temperature and 80°C.

Prelab Questions: Answers

1. 789 mmHg = 789 torr = 1.04 atm

2. moles (n) and temperature (T)

3. $Vol_{tube} = \pi r^2 h = (3.1415)(0.4\ cm/2)^2 (50\ cm) = 6.3\ cm^3$ = 6.3 mL (typical value for tube volume)



4. Similar:

   Charles's and Amonton's laws have similar forms. Charles's law volume is proportional to temperature and Amanton's law pressure is proportional to temperature.

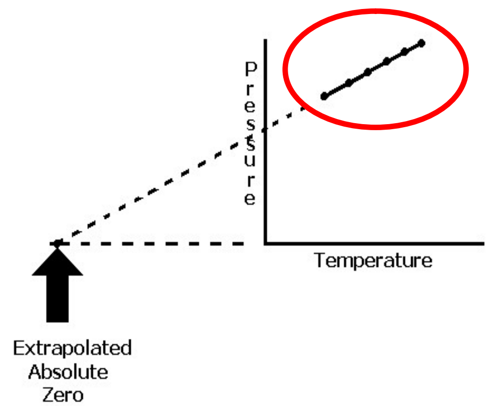
   Different:

   Charles's law assumes Pressure and moles are constant. Amonton's law assumes Volume and moles are constant.

5. – 21%

6. Two points. Atmospheric pressure and Atmospheric pressure + 250 $mm_{Hg.}$

7. 28.5 mL



8. Start over. Re-attach the hose. Fill the beaker with cold water and begin taking data again.

9. Measured points are circled in RED.

10. The temperature probe measures the temperature of the water near the walls of the flask. We'll assume the gas temperature is the same as the water.

C1151 Data Sheet
Gas Laws
Instructor Initials_____

Name___________________________
Date of Exp. _________________
Lab Section _________________

Your *<u>individual</u>* *experimental report (4 pages) will be due at the beginning of class next week.*

Data Table: (All entries must be in written in ink before you leave the lab).

***Atmospheric Pressure =** ____________ mm_{Hg}*

Data table: Boyle's Law

Trial #	Pressure (mm_{Hg})	Pressure (atm)	$V_{syringe}$ (mL)	**V_{tube} (mL)	V_{total} (mL)	$P \times V_{total} = K$ (atm*mL)	Δ%
1 *			60.0				
2			55.0				
3			50.0				
4			45.0				
5			40.0				
6			35.0				
7			30.0				
8			25.0				
9 *			20.0				
					$K_{average}$ =		

1. *** Calculate V_{tube} ONCE using Equation #7 and data from Trials 1 & 9.**
   This one V_{tube} value will be used in all $V_{total} = V_{syringe} + V_{tube}$ calculations.

2. Calculate $P \times V_{total}$ for each set of points and record the result with the correct S.F. in the data table.

3. Calculate an average value for K and report it also in the table

4. For each $P \times V$ "constant" calculate Δ%

Data table: Amonton's Law

Temp.	Pressure (mm_{Hg})	Temp.	Pressure (mm_{Hg})	Temp.	Pressure (mm_{Hg})	Temp.	Pressure (mm_{Hg})	Temp.	Pressure (mm_{Hg})

Boyle's Law:

1. Use your experimental Boyle's law result to calculate the gas pressure you would expect to measure when the syringe is at the 5 mL position in this experiment. (Show all work)

Amontons' Law: **Create a Pressure (mm_{Hg}) vs. temperature (°C) graph using M.S. Excel**

- The x-axis should range from -300°C to +100°C.
- The y-axis should range from 0 to 1200 mm_{Hg}.
- Extend (extrapolate) the trendline backwards far enough for it to cross the temperature axis.
- Perform a trendline analysis of the data and display the equation on the graph with 8 decimal place accuracy.

2. Is it necessary to know the volume of the apparatus in the Amonton's Law experiment? Why or Why not?

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3. Use your trendline equation to mathematically determine a value for absolute zero. (Show all work)

4. Compare your value of Absolute Zero (in °C) to the known value (°C) by calculating Δ%. (Show all work)

5. Use your trendline equation to determine the gas pressure at 200 K and 400 K. (notice the temperature units)
   How many times greater is the pressure at 400 K in comparison to 200 K?
   Is this what you'd expect?
   Why?

6. In this experiment we've extrapolated a value for absolute zero. Why is it impossible to perform an experiment where you would *interpolate* a value for absolute zero?

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